Training Workshop on Marine Resources Sampling, Data Collection & Interpretation for the South Asian Seas

Conducted in India

18 to 22 September 2009

Manual

Organised by

South Asian Seas Programme

South Asia Co-operative Environment Programme

in collaboration with

Ministry of Earth Sciences, Government of India and

United Nations Environment Programme

Partners - UN Division for Ocean Affairs and Law of the Sea
UNEP - GRID Arendal

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SACEP, Sri Lanka
September 2009

FOREWORD

The South Asian Seas Programme (SASP) has taken the initiative in organising a Training Workshop on Marine Resources Sampling, Data Collection & Interpretation for the South Asian Seas based on a recommendation of the Intergovernmental Meeting of Ministers of SASP, wherein Capacity Building has been identified as one of the four major activities. Some of the cross-cutting issues are Development of National Research, Monitoring and Assessment Capacity, including Training in Assessment and Early Warning; Support to National and Regional Institutions in Data Collection, Analysis and Monitoring of Environmental Trends; and Access to Scientific and Technological Information.

It is noted that the Bali Strategic Plan for Technology Support and Capacity Building, approved by Ministers in the Twenty-Third Session of the United Nations Environment Programme, Governing Council (UNEP-GC), capacity building was taken as a priority area and one of the thematic areas identified by Bali Plan of Action was Oceans and Seas and Coastal Areas, including Regional Seas and the Protection of the Marine Environment from Land-based Activities.

As a part of this workshop SACEP has complied a Manual which we feel is indeed timely and would be a bench mark document not only for this region but to all other Regional Seas Programmes. The themes covered in the Manual are Marine Pollution, Oil Spill & Mitigation Techniques, Near Shore Environment, Ocean - Data Collection, Presentation & Analysis, Policy & Management and the Status of Multilateral Environmental Agreements (MEAs) on Coastal and Marine Environment for SAS member countries.

We also wish to place on record, the contribution received from Government of India, in their capacity as the current Chairman of the South Asian Seas Programme in providing technical facilities to conduct this workshop which amounts around 70% of the total budget and UNEP's financial support to meet the cost of participation of the member country delegates and the technical support.

It is SACEP's wish that this Workshop will pave the way for future similar activities. We look for a positive outcome from this workshop and would endeavour implementation of the recommendations resulting from our effort.

Jacintha S. Tissera
Officiating Director General
South Asia Co-operative Environment Programme

ACKNOWLEDGEMENTS

The South Asian Seas Programme which is under the umbrella of South Asia Co-operative Environment Programme thank the Government of India and the United Nations Environment Programme (UNEP) for extending support to conduct this Training Workshop on '*Marine Resources Sampling and Data Collection & Interpretation for South Asian Seas'.* We express our sincere gratitude to Dr Shaliesh Nayak, Secretary to Government of India, Ministry of Earth Sciences (MoES), New Delhi for readily agreeing to provide the Ship, Laboratory Facilities and extending Technical and Administrative Support for this workshop.

Following individuals and organizations are acknowledged for their contribution to this Training Workshop.

Dr. Jacqueline Alder, Co-ordinator, Marine Ecosystems & Coastal Environment Branch (MECB), UNEP, Nairobi

Mr Serguei Tarassenko of United Nations Division for Ocean Affairs and the Law of the Sea (UNDOALOS), New York

Dr. Morten Sorenson of UNEP Global Resource Information Database (GRID) – Arendal

Dr. S. K. Das, Adviser, Ministry of Earth Sciences, Government of India

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Inspector General, SPS Basra,YSM, PTM, TM; Commander Indian Coast Guard Region (East) Chennai

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Mr. M. M. Subramanian, NCAOR Goa

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Master, Officers & Crew on board ORV Sagar Kanya

Staff of ICMAM Chennai, NCAOR Goa and INCOIS Hyderabad

Contributors to this Manual

SACEP Staff

MESSAGE

The marine environment experiences multiple uses by human ranging from traditional use for fishing and navigation to modern use for harnessing energy, minerals and waste disposal. These uses stress and in many cases adverse effects on marine ecosystem, especially the fishery resources. A thorough understanding of the physical, chemical, biological and geological processes prevalent in the marine environment reveal the causes of decline in fish production. For example the physical processes like currents, play a vital role in transporting the chemical elements present in the wastes disposed into the sea from its place of disposal to remote areas thus affecting a virgin area which is devoid of any source of waste generation and disposal. The high levels of chemical elements in the sea have several adverse effects like reproductive failures in fishes.

Understanding the marine processes is achieved through observation of wide range of parameters. Considering the vastness and hostile weather conditions in the sea, observation of oceanic parameters through ship based methods has always been remaining a challenge. The recent advancement of remote sensing techniques especially by sensors from satellites has given tremendous advantage of obtaining data on oceanic parameters on a higher frequency due to repetitive coverage of satellites over the world ocean.

The present training workshop on the Marine Resources Sampling, Data Collection and Interpretation for the South Asia Seas has included the unique feature of ship based techniques for ocean observations onboard the Oceanographic Research Vessel (ORV) Sagar Kanya, which is one of the ocean going research vessels of Ministry of Earth Sciences, Government of India. Further training organized at Integrated Coastal and Marine Area Management Project Directorate (ICMAM-PD), Chennai and Indian National Centre for Ocean Information Services (INCOIS), Hyderabad can signify the importance and need for collecting these data.

I am also glad to note that UNEP is financially supporting this programme and UNDOALOS and UNEP-GRID Arendal have also joined to conduct this training workshop. Further I appreciate the efforts taken by the South Asian Seas Programme / SACEP for organizing this workshop and all my colleagues who have participated to this task.

I hope that this training workshop will provide an opportunity to the participants to get familiarize themselves in the sampling and observation techniques using a wide range of equipment. I wish the training all success.

Dr. Shailesh Nayak
Secretary
Government of India
Ministry of Earth Sciences
'Mahasagar Bhavan', Block-12 C.G.O. Complex
Lodhi Road, New Delhi-110 003

Dear workshop participants

GRID Arendal is an official UNEP collaborating centre located in Arendal Norway. GRID Arendal has established a marine programme that focuses on the application of geoscientific information to provide knowledge, tools and the development of capacity to support the improved management of the oceans. The programme draws on the expertise developed through the UNEP Shelf Programme and its network of partners.

GRID Arendal fully supports the approach to the marine environment championed by the Regional Seas Programme – acknowledging the transboundary nature of many marine environmental and management issues and that we share the common ocean.

GRID Arendal hopes that this workshop in Chennai, addressing the important issues of marine resources and data collection, marks the beginning of a very fruitful relationship with the South Asian Seas. The South Asian Seas region combines unique marine habitats with rapidly expanding human use, so careful marine management is essential. It is an area where there is large capacity for the collection and interpretation of geoscientific and biophysical data and GRID Arendal looks forward to working with the South Asian Seas in finding ways to use this data to support ecosystem based management.

Best regards

Morten Sorensen
Head, Marine Programme
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CONTENTS

10. **O.R.V Sagar Kanya – Biological Research Activities**
Ganesh M Chandwale
National Centre for Antarctic & Ocean Research, Goa, India

11. **O.R.V. Sagar Kanya and Investigation on Physical Processes of Indian Ocean**
Jenson V. George, Nuncio Murukesh and N. Anilkumar
National Centre for Antarctic & Ocean Research, Goa, India

12. **Scientology and The Sea**
K.K. Gupta
Medical Officer, ORV Sagar Kanya

13. **O.R.V. Sagar Kanya" – An Introduction and Overview of Technical Management**
Praveen Kumar, Vice President (L&PS)
M/s Shipping Corporation of India Ltd., Mumbai, India.

14. **Manual Methods for Measuring Nutrients (PO_4-P, NO_2-N and NO_3-N)**
R.S.Robin and Sivaji Patra
Integrated Coastal and Marine Area Management Project Directorate Ministry of Earth Sciences Chennai, India

Theme IV : Ocean - Observation

15. **Potential Fishing Zone (PFZ) Advisories – Technology Perspective**
T. Srinivasa Kumar, M. Nagaraja Kumar, E. Padmaja, N Naga Swetha and Satish Shenoi
Indian National Centre for Ocean Information Services (INCOIS), Ministry of Earth Sciences, Hyderabad, India

16. **Ocean Modelling and observations**
M.Ravichandran
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17. **Ocean Data and Information System**
E. Pattabhi Rama Rao, T.V.S. Udaya Bhaskar and R. Venkata Shesu
Indian National Centre for Ocean Information Services (INCOIS)
Hyderabad India

Theme V : Policy and Management

18. **Geoscience as a Tool for Marine Management : The Application of Biophysical Data to Support Decision Making.**
Kristina Thygesen and Elaine Baker, UNEP/GRID Arendal

19. **Status of International Environmental Agreements on the coastal and marine environment By SAS member countries in South Asian Seas region**
R Venkatesan and Prasantha Dias Abeyegunawardene
South Asian Seas Programme, South Asia Co-operative Environment Programme
Colombo. Sri Lanka

CONTENTS

Theme V : Policy and Management

Schedule

<table>
<tr><td>Day 1</td><td>09.30 – 11 00 Hrs</td><td>11.15 – 12.45 Hrs</td><td>14.00 – 15.30 Hrs</td><td>15.30 - 17.00 Hrs</td></tr>
<tr><td>Friday
18.9.2009</td><td>Inauguration
SESSION 1
Theory Marine Pollution</td><td>SESSION 2
Theory : Oil Spill and Mitigation Techniques</td><td>SESSION 3
Theory
Near Shore Sampling</td><td>SESSION 4
Practical - Visit to laboratory
GIS Laboratory
Ecotoxicology Laboratory
Field Demonstration of Arc Pad & Real Time Kinematic GPS</td></tr>
<tr><td>Day 2</td><td>08.00 – 11 hrs</td><td>11 – 12 45 Hrs</td><td colspan="2">14.00 - 17.00 Hrs</td></tr>
<tr><td>Saturday
19.9.2009</td><td>Departure from Hotel
Boarding vessel at Chennai Port</td><td>Sailing
SESSION 5
Practical
On board display and demonstration of sampling survey and analytical instruments</td><td colspan="2">SESSION 6
On board demonstration
Physical oceanography - CTD sampling,
Meteorological observations
Seawater and sediment sample collection
Chemical oceanography
Laboratory analysis of Nutrients</td></tr>
<tr><td>Day 3</td><td colspan="2">0900 to 1200 hrs</td><td colspan="2">1400 – 1700 hrs</td></tr>
<tr><td>Sunday
20.9.2009</td><td colspan="2">SESSION 7
Ecosystem approach
UN DOALOS</td><td colspan="2">SESSION 8
Geophysical survey techniques in marine policy development and management
UN GRID Arendal</td></tr>
<tr><td>Day 4</td><td colspan="2">09.00 – 12. 00 Hrs</td><td>19.00 Hrs</td><td>20.00 Hrs</td></tr>
<tr><td>Monday
21.9.2009</td><td colspan="2">SESSION 9
Multilateral Environmental Agreements
GPA – Initiatives in South Asian Seas
UNEP
International Conventions
UNDOALOS
Status of International Environmental agreements in South Asian Seas region
SASP / SACEP
Sailing back to Chennai Port
Visit to Ship Navigation facility</td><td>Departure to Hyderabad from Chennai</td><td>Arrival Hyderabad
Stay at Hotel</td></tr>
</table>

Day 5	09.00 – 1700 Hrs INCOIS Hyderabad		
	10.00 -12.00 Hrs	14.00 – 16.00 Hrs	16.00 – 17.00 Hrs
Tuesday 22.9.2009	**SESSION 10** Theory Ocean Modelling Ocean State Forecast Ocean data management and Ground stations Potential Fishing Zone	**SESSION 11** Practical PFZ; OSF; IOGOOS; Ocean Information Bank having data sets such as :In-situ Data, Satellite Data, Historical Data Sets and Maps	Wrap up Feed Back from Participants Closing Ceremony
Wednesday 23.9.2009	DEPARTURE		

INTRODUCTION

Background and Rationale

The Inter-governmental Meeting of Ministers of the South Asian Seas Programme (SASP) had approved the South Asian Seas Action Plan and identified Capacity Building as one of the four major activities. Within this framework, SASP has identified Capacity Building in Marine Sciences as one of the important issue pertaining to this region. It is acknowledged that the mid-level managers working in the field of policy making and research relevant to SASP should be given an opportunity to understand the latest developments in the field of Marine Environmental Management at the National, Regional and Global level and also to provide platform for them to interact with each other.

The Bali Strategic Plan for Technology Support and Capacity Building approved by the Environment Ministers at the Twenty-Third Session of the United National Environment Programme, Governing Council (UNEP-GC) also noted that Capacity Building is to be taken as a priority area.

This is a joint effort of SACEP / SASP in collaboration with UNEP and the Ministry of Earth Sciences, Government of India. The programme funded by Government of India and UNEP.

Also United Nations Department of Ocean Affairs and the Law of the Sea (UNDOALOS) and UNEP - GRID Arendal are partners to this Training Workshop.

Objective

To conduct a training on board research vessel and in laboratory for middle managers working in Government Departments in SAS member countries; i.e. Bangladesh, India, Maldives, Pakistan and Sri Lanka, on Marine Resources, Sampling, Data Collection & Interpretation.

Expected Outcome

- Enhanced skills and knowledge from the hands-on experience and the lectures delivered by eminent resource persons from Regional Research Institutions and UN organizations on correlation and interpretation of data.

- Enabled the mid-level managers to define policies and programmes to effectively perform their duties in conservation and management of marine resources

- Strengthened collaboration and interaction among the participants that will contribute to develop and implement future regional activities

Methodology

The SAS member countries are represented by 2 participants from each country viz. Bangladesh, India, Maldives, Pakistan and Sri Lanka.

Resource Persons are from Ministry of Earth Sciences, Government of India, ICMAM PD Chennai, NCAOR Goa, INCOIS Hyderabad, UNEP Nairobi, UNEP-GRID Arendal Norway, UNDOALOS New York, Indian Coast Guard and SASP / SACEP Colombo Sri Lanka.

Training is divided into three components such as on board the ship and in laboratory in Chennai and Hyderabad for a period of 5 days. Marine Pollution, Near shore sampling and GIS techniques for the coastal data presentation are demonstrated at the Integrated Coastal and Marine Area Management -Project Directorate (ICMAM) Chennai India. The training workshop also covers practical demonstration in the field on board the research vessel Sagar Kanya which is co-ordinated by National Centre for Antarctic & Ocean Research, Goa, India. Finally visit to the Institute Indian National Centre for Ocean Information Services (INCOIS), Hyderabad India to understand the ocean data collection, interpretation and dissemination techniques.

The programme is organised in three stages

- Integrated Coastal and Marine Area Management- Project Directorate (ICMAM – PD), Chennai : 18 September 2009
- Sailing on board Sagar Kanya : 19 to 21 September 2009
- Indian National Centre for Ocean Information Services (INCOIS), Hyderabad : 22 September 2009

This is unique of its kind as training workshop comprises of field data collection and specialist lectures on international policies and regulations.

Manual:

It is decided that a manual on this training workshop will be very beneficial to participants and can be used as reference material for the SAS region. With support of resource persons the manuscripts were compiled and printed.

From the lecture notes, themes are divided as Marine Pollution, Near Shore Environment, Ocean - Data Collection, Ocean - Data Presentation & Analysis and Policy and Management. The status of Multilateral Environmental Agreements on Coastal and Marine Environment for SAS member countries is compiled and presented here. This is a long standing requirement, as these are co-ordinated by different ministries in the respective countries. All efforts are made in coordinating with various agencies to make this Manual a useful and Unique Reference Material for the Effective and Sustainable Management of Coastal and Marine Resources in the South Asian Seas Region.

R. Venkatesan
SASP Coordinator – South Asian Seas Programme
SACEP

MARINE POLLUTION

Marine pollution includes a range of threats including from land-based sources, oil spills, untreated sewage, heavy siltation, eutrophication (nutrient enrichment), invasive species, persistent organic pol-lutants (POP's), heavy metals from mine tailings and other sources, acidification, radioactive substances, marine litter, overfishing and destruction of coastal and marine habitats

UNEP

1.STATUS OF MARINE POLLUTION IN THE BAY OF BENGAL AND ARABIAN SEA BORDERING INDIA

Dr B.R. Subramanian
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India has a coastline of 7516 km. It has an Exclusive Economic Zone of 2.04 Million Sq. Km. Out of its 820 million population, nearly 25% live in the coastal areas. Many highly populated and industralised cities like Bombay, Madras, Calcutta, Cochin, Visakhapatnam are located along/near the coastal areas. There are 11 major ports and a number of minor ports handling shipping to various degrees of intensity. The coastline of the mainland fall under the divisions of 9 States and two Union Territories. The coastline of islands belong to Andaman, Nicobar and Lakshadweep (Laccadives) group of islands. The details of its population, area etc., are given in Table 1.

1. HYDROGRAPHIC FEATURES

In relation to the Equator, the Indian Ocean has an asymmetric shape largely due to the presence of the Asian continent. The result is that this ocean gets separated from the deep-reaching vertical convection areas of the northern hemisphere. Such an asymmetric configuration leads to a weak circulation and poor renewal at depths of the Northern Indian Ocean.

The Indian Ocean can, broadly speaking, be divided into three regions on the basis of their distinct circulation systems (i) the seasonally changing monsoon gyre; (ii) the south hemisphere subtropical anticyclonic gyre; and (iii) the Antarctic waters with the circumpolar current. The monsoon gyre, unique to the Indian Ocean, is separated from the subtropical anticylonic gyre by a front in the hydrochemical structure at about 10° S. Latitude.

The Indian Ocean, north of the Equator, comprising of the Arabian Sea, the Bay of Bengal, the Andaman and Laccadive Seas, in addition to the equatorial region, comes under the monsoon gyre. However, the hydrographical and hydrochemical characteristics are widely different in different parts of this gyre itself owing to the diverse meteorological and geographical factors characteristic of each area.

The Arabian Sea is bordered on the northern, eastern and western sides by the land masses of Asia and Africa. It is connected to the Gulf through the Gulf of Oman by a 50m deep sill at the Hormuz Strait. Similarly, a 125m deep sill at the Strait of Bab-el-Mandab separates the Red Sea from the Arabian Sea through the Gulf of Aden. The Arabian Sea is an area of negative water balance where evaporation exceeds precipitation and runoff. The excess of evaporation over precipitation is maximum (100- 150cm) off the Arabian coast and decreases steadily towards the southeast. A slight excess of precipitation over evaporation (<20cm) occurs annually off the southwest coast of India. The high rate of evaporation results in the formation of several high-salinity water masses. The Arabian Sea high salinity water, formed in the northwestern Arabian Sea, flows southward and can be traced as a tongue of high-salinity within the surface layer. The high salinity water in the Gulf, characterised by a sigma value of 26.6, flows through the Hormuz Strait and the Gulf of Oman into the Arabian Sea and maintains its density level at about 300m depth. This water mass flows south, mostly east of 63°E longitude, and loses its characteristics in the southern Arabian Sea. The Red Sea water enters the Arabian Sea through the Strait of Bal-el-Mandab and the Gulf of Aden along sigma 27.2 at the surface. This water mass is generally confined to south of about 17° N latitude.

Occasionally, the sub-surface high salinity water masses originating in the Gulf and the Red Sea form a thick layer which is vertically of almost uniform salinity, although the individual layers can still be recognized as weak salinity maxims. The wholelayer is called the North Indian high-salinity intermediate water. The deep and bottom waters are of circumpolar origin, probably transported by a deep western boundary current through a chain of basins. They are called the North Indian Deep Water and North Indian Bottom Water.

Surface circulation in the Arabian Sea undergoes biannual reversal associated with the southwest (SW) and northeast (NE) monsoons. The NE monsoon is weak in this region, but the SW monsoon is very intense. Strong winds blowing with the Somali and the Arabian coasts to the left cause intense upwelling off these coasts during the SW monsoon period. Moderate upwelling also occurs off the southwest coast of India, partly due to the cyclonic motion in the neighbourhood of the Maldives and the Laccadives.

In contrast to the Arabian Sea, the Bay of Bengal is a region of positive water balance. The average annual excess of precipitation is of the order of 70cm. The total annual river runoff in the Bay of Bengal has been estimated to be about 2.000 km^3. The high excess of precipitation over evaporation and the massive river runoff result in low surface salinities, especially in the northern Bay of Bengal. The salinity, lower at any level in the Bay of Bengal as compared to the Arabian Sea, increases steeply within the thermocline/ pycnocline and a weak salinity maximum may be observed at a depth of about 500m. The salinity thereafter decreases monotonously with depth. The SW monsoon current probably carries the North Indian high salinity intermediate water from the Arabian Sea and fills the Bay of Bengal at intermediate depths, resulting in the salinity maximum. The deep water is of circumpolar origin probably derived from the Central Indian basin.

As in the Arabian Sea, the surface circulation in the Bay of Bengal changes with the monsoon cycle. The NE monsoon is much more intense here as compared to the Arabian Sea. Induced by favourable currents and winds, moderate upwelling occurs along the coast of India during the SW monsoon, even though the runoff from the rivers may partially compensate for the offshore movement of surface waters.

2. COASTAL ECO-SYSTEMS

Coastal wet lands

Along the Indian coastline, the brackishwater areas including marshes, backwaters, mangroves, inter- and sub-tidal measures about 14,16,300 hectares. These areas act as feeding and nursery grounds for a variety of commercially important fish, prawn and crabs, media for inland transportation, fishing etc.

Mangroves

Along the Indian coast mangroves are found along the islands, major deltas, estuaries and backwaters of the east coast of India. They also exist along the oceanic island groups of the Andaman and Nicobar . The total mangrove area is estimated to be 6,81,976 hectares. While the mangroves along the west coast of India are dense, they are scattered and comparatively small in area along the West coast. Gangetic Sunderbans (418,888 ha), Andaman-Nicobar Islands (115,000 ha), Krishna, Kaveri and Godavari deltas and Mahanadi delta are some of the best mangrove formations of India. There are about 45 mangrove species along the Indian coast. The dominant genre are *Rhizophora, Avicennia, Bruquiera, Sonneratia, Canocarpus, Heretiera, Xylocarpus, Ceriops*, and *Exoecaria.* Mangrove forests mainly function as the most ideal spawning, breeding and nursery grounds for nearshore an estuarine organisms like fishes, crabs, prawns, molluscs, etc. Some of the common and economically important species are *Mugil cephelus, Hilsa ilisha, Lates calcarifer, Scylla seratta, Meretrix casta, Crassostrea grephoides and Penaeaus* spp.

Apart from the captive and culture fisheries, mangroves are also important as “Coastal Stabilizers” and “Shelter belt areas”. These formations protect the coasts and the landward areas from erosion and cyclonic destructions to some extent. Apart from these the mangrove forests of India have importance from a wildlife, recreation and education point of view. “Project Tiger” of Sunderbans and “Crocodile Sanctuary” in the Mahanadi delta are examples of such activities.

Coral reefs

Around India, coral reef formations are found in the Palk Bay, Gulf of Mannar, Gulf of Kutch, Central West coast of India, Lakshadweep atolls, and Andaman-Nicobar Islands. Both the coral atoll and the fringing coral reefs are of utmost significance in Indian waters. A few species of corals have recently been reported from the Malvan (Maharashtra) coast. 32 genera from Minicoy Islands, 34 genera from Palk Bay and Gulf of Mannar, 25 genera from Andaman Islands, 9 genera from Lakshadweep and 3 genera from Nicobar Islands have also been reported. 342 species belonging to 76 genera from the seas around India have been described.

Primary productivity studies of coral reefs in Indian waters indicated comparable rates with other reefs and marine ecosystems. Often the large benthic algal communities and extensive seagrass beds are equally important as the energy released from them is transferred to higher trophic levels by way of the detrital food chain.

3. ENVIRONMENTAL PROBLEMS

India is one of the highly populated countries in the world. The demographic pressure, rapid industrialisation and urbanisation in the coastal cities, and towns have added variety environmental problems, besides those are caused due to natural events. Details on population, reverine discharge etc., are given in **Table 1**. A brief account of these problems and remedial measures taken are outlined below:

Disposal of Domestic Sewage

Demographic pressure in the urban cities and towns have resulted in the production of enormous amounts of domestic waste materials. These materials reach the marine environment either directly or indirectly through rivers, creeks, bays, etc. The domestic sewage contributes to the largest amount of waste and it has been estimated that approximately 18,240 MLD (Million Litres per Day-as of 1994) reach the coastal environment of the country. Even though the quantity of these wastes vary from place to place, the chemical characteristics of these almost remain similar. The features of domestic sewage of Bombay is given in **Table 2.**

Domestic wastes are discharged mostly in untreated conditions due to the lack of treatment facilities in most of the cities and towns. It has been reported that only primary treatment facilities are available in cities and towns where the population is more than 100,000 and the capacity of the plants is not adequate for the treatment of the total waste generated in the cities and towns. For example, in Bombay, the treatment facilities are available only for 390 MLD as against 1600 MLD of domestic sewage which is generated. Due to such partial treatment, the chemical characteristics of the waste water retain almost their original features and cause damage to the environmental water quality.

Industrial Waste

India is one of largest industrialised nations in the world. Major industrial cities and towns of the country such as Surat, Bombay, Cochin, Madras, Visakhapatnam and Calcutta are situated on or near the coastline. The total quantity of wastes discharged by these industries is estimated to be 0.7×10^9 cu.m (as of 1994) Details of industries located in the coastal states are given in **Table 3.**

4. PROGRAMME FOR MONITORING MARINE POLLUTION

One of the basic requirements for controlling pollution is generation of data on levels of pollutants over a period of time so that a clear picture on the increase and decrease of pollution in correspondence with measures taken can be obtained. For this purpose systematic monitoring of levels of pollutants along the selected and appropriate regions of the country's coastline is essential. With this objective, a programme on Coastal Ocean Monitoring and Prediction Systems (**COMAPS**) is being operated since 1991 by the Department of Ocean Development in close co-operation with the Ministry of Environment and Forests. The main objective of the programme is to constantly assess the health of India marine environment and indicate areas that need immediate and long-term remedial action. Data on nearly 25 environmental parameters are being collected at 77 locations with the help of 11 R&D institutions in the 0 -25 km sector of the coastline of the country.

Objectives

- To establish a knowledge-base in the field of biogeochemical parameters in estuaries and in coastal, shelf and open seas.

- To operate an appropriately structured information system for ready dissemination of various data sets to users in government, industry, research and social institutions.

- To provide advisory and technical services to government, industry and public institutions aimed at evolving pollution containment measures.

- To detect radical changes in the biogeochemical regimes of the marine system and to alert government, public and social institutions, of their implications.

- To set standards for the measurement of various pollution parameters and to ensure compatibility between the data acquired and processed by various monitoring agencies.

Institutional arrangements

In order to achieve adequate coverage for monitoring of our coastal waters, DOD Centre/Units were established in the major laboratories in maritime States

Parameters and locations of monitoring marine pollution

The coastal waters from Kandla to Kanyakumari to Bangladesh border upto a distance of about 25km from the shoreline along the predetermined transects was monitored. These transects were selected on the basis of (a) location of industries (b) Ecologically Sensitive areas and (c) location of urban establishments and d) based on earlier base line survey. Accordingly 78 locations have been selected and the details of these locations are given below :

GUJARAT
Kandla, Poshitra, Vadinar, Okha, Dwarka, Porbandar, Veraval, Hazira

DIU, DAMAN

MAHARASHTRA
Trombay, Bassein, Mahim, Thane, Bombay Harbour, Versova, Ulhas creek, Murud, Thal, Ratnagiri, Reddy

GOA
Mandovi, Zuari, Marmagao*

KARNATAKA
Karwar*, Honawar, Mangalore*

KERALA
Kasargod, Cannanore, Calicut, Ponnani, Kochi*, Alleppey, Kayamkulam, Paravur, Quilon*, Veli*

TAMIL NADU
Kanyakumari, Koodankulam, Arumuganeri, Tuticorin, Vaiparu estuary, Gundaru estuary, Mandapam (Palk Strait), Mandapam (Gulf of Mannar), Uchipulli, Thondi, Nagapattinam, Cuddalore, Cooum, Madras Harbour, Ennore

PONDICHERRY Pondicherry**,** Karaikal, Yanam (Gautami - Godavari)

ANDHRA PRADESH
Krishnapatnam, Nizampatnam, Machilipatnam, Kakinada Bay, Visakhapatnam Harbour, Visakhapatnam Steel Plant, Kalingapatnam

ORISSA
Dhamra, Gopalpur, Paradip, Puri, Konark, Chandipur

WEST BENGAL
Saptamukhi, Digha, Sandheads, Diamond harbour, Haliday island, Dalhousie Point, Sunderbans, Indo-Bangladesh Border

ANDAMAN & NICOBAR ISLANDS
Port Blair

LAKSHADWEEP ISLANDS
Kavaratti

Parameters

A list of parameters on which data is being collected is presented below **:**

a) Water quality

Temperature, salinity, dissolved oxygen, pH suspended solids BOD, inorganic phosphate, nitrate, nitrite, ammonia, total phosphorous, total nitrogen, total organic carbon, petroleum hydrocarbons,pathogenic Vibro pathogenic Enterobacteriaceae (*E.Coli, Salmonella, Shigella, Proteus klebsiella, Vibrio cholera, Pseudomonas aerugenosa* and *Streptococcus faecalis*).

b) Sediment quality

Texture, organic carbon, phosphorous, cadmium, lead and mercury and pesticide residues (DDT, BHC and Endosulfan). Radioactivity levels through the assistance of Bhabha Atomic Research Centre, Bombay. Pathogenic Vibros, pathogenic Enterobacteriaceae (E.Coli, Salmonella, Shigella)

c) Biological characteristics

Primary productivity, chlorophyll a phaeophytin, phytoplankton cell count, total and major species of phytoplankton. Zooplankton standing crop. Experimental trawling for catch, total species and major species of fishes.

Selected organisms to be analysed for cadmium, lead and mercury and for pesticide residues (DDT, BHC, Endosulfan)

Intensively monitored as an area of concern/definite source of pollution

Coastal Research Vessels

The institutions involved in the Coastal Ocean Pollution Monitoring Programme (COMAPS) programme were collecting sea water , sediment and biological samples by engaging small trawlers. A few parameters like nitrate, phosphate, etc. will have to be analysed immediately after the collection of the samples. These fishing trawlers, have an endurance of less than 14 hours and have no space to keep instruments, and therefore, the samples collected were brought back to the shore to rush to the laboratory for analysis of the mandatory parameters. This is a time consuming and laborious procedure. Further, as the fishing trawlers are available in places where jetty facilities are available, collection of samples around 2 to 3 kms in places where jetty facilities are available, alone was possible.

In order to overcome the shortcomings, the DOD has acquired two Coastal Research Vessels namely **Sagar Purvi** and **Sagar Paschimi** in 1996. They are of 30 metres in length. These vessels facilitate collection of samples at all desired locations. Laboratory facilities along with analytical instruments are also built in for onboard analysis of mandatory parameters. Some of the analytical equipment kept on board the vessel, include Auto Analyser, Spectroflurometer, Spectrophotometer, etc. The vessels have modern satellite communication and navigational facilities.

OUTPUTS OF COMAPS PROGRAMME

STATUS OF MARINE POLLUTION

From the data generated the status of marine pollution in the country could be fairly understood and the details are as under:

Areas Of Clean Sea Water Quality

The sea approx. off 2 km all along our coastline except off Bombay and the locations not specified in the under mentioned categoriesis clean and conform to qualities of clean sea water.

As a result of the systematic monitoring of the coastal areas, health of our seas could be assessed and areas of low, medium and high concentrations of pollutants could be identified. The areas of high concentration of pollutants are being monitored intensively. Details of these locations are:

i) Areas of clean sea water quality:

The sea approx. beyond 2 Km along the coastline of India except off Bombay is clean and conform to quality of clean waters. In Bombay, the sea off 5 Km is clean. This is primarily due to the fact that the levels of dissolved oxygen and other parameters fulfilling the requirements of clean sea water.

ii) Areas of no concern:

In Vadinar and Kandla of Gujarat, Ratnagiri in Maharashtra, Mandavi and Zuari in Goa, Mangalore Port in Karnataka, Cannanore and Calicut in Kerala, Cuddalore in Tamil Nadu and the West Bengal coast, the concentrations of dissolved oxygen was fairly good and other toxic elements like ammonia, heavy metals in sediments and biota were slightly higher (about 15%) than the clean waters.

iii) Areas that need intensive monitoring

In Porbandar, Damanganga estuary, and Vapi industrial estate in Gujarat, Mangalore coast in Karnataka, Kochi backwaters, Quilon, Paravur in Kerala and Tuticorin and Arumuganeri in Tamil Nadu, Puri in Orissa the levels of dissolved oxygen were moderate to normal and however some of the elements like ammonia, pathogenic bacteria in sea water and heavy metals in sediments showed higher concentration (about 25%) than the normal values. Due to the definite source of pollutants and chances of increase in concentration are likely to be high, these areas need intensive monitoring.

iv) Areas of concern

In Veraval Port in Gujarat, Versova Creek, Mahim Bay and Thane Creek in Maharashtra, Veli in Kerala, Visakhapatnam Harbour and Kakinada Bay (canal) in Andhra Pradesh, the concentrations of dissolved oxygen were nil to low during low tide period and improved their levels only moderately (30-50%) during the high tide period. Further, the levels of toxic metals like cadmium and lead were high in sediments in some locations (like Thane creek) and pH was very low (Veli). If no control measures are exercised now, the areas will become regions of high concentrations of pollution in the another 5 to 6 years.

Levels of organochlorine pesticides like HCH and DDT were analysed in 32 species of marine fish collected at various locations along the east coast of India. The levels of both the chemicals were very much lower than those observed in the terrestrial animals and other food items. These levels are well below the limits (5 parts/billion is the safety limit) set by the Health authorities. This would indicate that the marine fish is not contaminated with the pesticide residues in the locations from which the samples were collected.

Several samples of fish species collected along the various locations along the West Coast also indicated that the DDT levels ranged from 0 to 1.7 parts per billion and HCH levels from .045 to 1 part per billion well below safety limits.

The results are being brought to the notice of the State Pollution Control Boards and they are being evaluated by a Steering Committee chaired by the Chairman, Central Pollution Control Board and represented by all the Coastal State Pollution Control Boards (CSPCB). In these meetings action taken by the CSPCBs are discussed at length.

5. ACTION TAKEN FOR REMEDIAL/CONTROL MEASURES

India has a wide range of laws and regulations governing the environment. These include: laws enacted by the Parliament, regulations issued by the Central and State Governments as well as an increasing body of judicial decisions affecting industrial activity that generate pollution. The major environmental acts are:

- The Water (Prevention and Control of Pollution) Act, 1974
- The Water (Prevention and Control of Pollution) Cess Act, 1977
- The Air (Prevention and Control of Pollution) Act, 1981
- The Environment (Protection) Act, 1986
- Public Liability Insurance Act, 1981
- Hazardous Waste (Management and Handling Rules), 1989
- Environment Audit Rules, 1992
- Environment Impact Assessment Notification, 1994

Policy Framework

The Government of India has formulated a comprehensive Policy Statement for Abatement of Pollution which envisages integration of environmental and economic aspects of development planning, lays stress on preventive aspects of pollution abatement and promotion of technological inputs to reduce industrial pollution.

The Policy aims at:

- Prevention of pollution at source,
- Encourage develop and apply the best available, practicable technical solutions,
- Ensure that the polluter pays for the pollution and control arrangements,
- Focus on the protection of heavily polluted areas and river stretches, and
- Involving the public in decision making

Promotional measures

Pursuant to the Policy Statement for Abatement of Pollution, several initiatives have been taken for promoting cleaner technologies of industrial production. These include: economic instruments, such as water cess, effluent charges, financial assistance by way of credit and loans at reduced rates of interest, establishment of a clean technology institutional network designed to promote the development, diffusion and transfer of technologies with environmental benefits for industrial sector, extension services for the identification of appropriate waste minimisation and abatement methods for small scale industries and organisation of waste minimisation circles, strengthening of standards, eco-labelling etc.

Industrial Zoning Atlas

A detailed exercise for preparation of zoning atlas for siting fo industries based on environmental considerations in various districts of the country has been taken up. So far, zoning atlas for 19 districts have been developed. 24 critically polluted areas have been identified and action plan for control and abatement of pollution have been prepared for 21 areas, out of which 12 are in coastal areas. Studies on effect of environmental pollution on health of surrounding population in these areas have also been taken up.

River Action Plans

River basin-wise surveys were conducted to identify the polluted stretches and their sources. Based on such surveys, Ganga Action plan and subsequently National River Action plan for all major rivers in the country have been launched.

Pre-Assessment

Environmental Impact Assessment for 29 categories of projects have been made mandatory. The proponent has to prepare a detailed a EIA report indicating the existing status, likely environmental impacts and proposed remedial measures. Public consultation and incorporation of their views regarding social and socio-economic aspects relating to the project are also mandatory. While approving the project, conditions for environmental safeguards are given to the proponent, which are periodically monitored and reported during the implementation of the Project.

Treatment of wastes and results

For the past three years the efforts to put up the sewage treatment plants in all the coastal states and towns were intensified and also the dispersal of the treated effluents in the deeper areas of the sea for better dilution and dispersal through pipelines have also been planned. Several treatment plants have been set up in Bombay city and similar such proposals are under consideration in Madras and Calcutta. The government has prepared an action plan for treatment of wastes that are being generated from the domestic sources. Assistance from the International funding agencies like World Bank have already been availed for setting up of waste treatment plants and for construction of deep sea outfalls for the Bombay city. Efforts are also on to avail more technological and financial assistance for other areas.

The enactment of Water Pollution Act in 1974 and Environment Protection Act, 1986, have helped in regulating the disposal of wastes from the industries. Now all the major industries treat their effluents and comply with the standards set for each type of industry. The impact could be seen in improvement of seawater quality in Bombay, Cochin, Madras, Visakhapatnam, etc. Rules and guidelines have been prepared relating to hazardous waste management and handling of hazardous substances which have been notified under the Environment (Protection) Act, 1986.

While the major industries treat their effluents, the problem always remains with the processing of waste generated by medium and small scale industries. To deal with such issues several measures have been taken. Common treatment plants for small and medium scale industries have been set up in the coastal states like Andhra Pradesh, Gujarat and Tamilnadu. In remaining states they are under construction. A scheme to promote adoption of waste minimisation technology for small and medium scale industries has also been taken up. About 15 waste minimisation circles in sectors of electro-plating, paper, textiles, dyeing and printing, hostels etc. have been established in various parts of the country including in the coastal states. These measures have resulted in reduction of pollution loads to the ambient water bodies to the extent of 15 to 30%. In addition to this, a National Cleaner Production Centre has been set up with the assistance of UNIDO. Capacity building and awareness creation in the areas of cleaner production in small and medium scale industries have been taken up. Environmental audit has been made mandatory for all polluting industries. Implementation of this scheme, resulted in smooth monitoring of industrial activities and also adoption of low waste technology and minimisation of consumption of resources. Fiscal incentives are provided for installation of pollution control equipment and also for shifting of industries from non-confirming areas. These include: depreciation of allowance at 100%, investment allowance, customs and exercise duty exemptions for pollution control/monitoring equipment etc.

Effect of coastal circulation and oceanic currents

The coastal circulation patterns and also the reversal of currents during the bi-monsoonal periods make the process of coastal circulation complicated even though it remains passive. Recent studies on the role of coastal physical processes in dispersing and diffusing the pollutants indicate that the wastes discharged into the sea are primarily diluted by the tidal action which is very prominent in Bombay and Gujarat coasts since the tidal amplitude in these regions is more than 6 metres. In other areas the tidal action does not play a major role in diluting the pollutants. All the studies have revealed that the wastes discharged into the sea, by and large, remain within the coastal region upto 1 km from the coast due to the effect of long shore and onshore-offshore currents. While wastes present in dissolved form get diluted and degraded, the particulate forms settle on the sediments and cause an accumulation of pollutants Lead, Cadmium and mercury in the sediments. In some areas the thickness of the contaminated sediments reach even upto 40 cms. It is hoped that future reduction in input of pollutants into the sea water due to treatment of wastes generated through domestic and industrial sources, the problem of accumulation of toxic metals in sediments would get solved. further accumulation of these metals on these sediments can be prevented, the question remains about the removal of the contaminated sediments from the coastal areas, particularly in Bombay.

Agricultural Waste

The pesticides are used in agriculture and public health. DDT which was used previously in agriculture as well as public health is now used in public health in a very limited and regulated manner. Low HCH formulations are used in agriculture. The pesticides used in present days mostly belong to organophosphorus, carbmate and synthetic pyrethroid groups. Since the latter group insecticides are bio-degradable and sparingly soluble in seawater, the problem of pesticide residues in marine fishes due to these pesticides does not occur. Due to the restricted usage of DDT and HCH, their levels in food fishes have also decreased significantly. For eg., samples of popular edible fish *Scomberomoru guttatus* collected over a period of two years from areas where agricultural wastes are drained into the sea showed only maximum values of 2.00 ng/g (wet wt.) in case of DDT and 0.04 ng/g (wet wt.) in case of HCH. Usage of pesticides are regulated under the Pesticides act.

Radioactive and thermal wastes

Although, power generation is mostly thermal in the India, nuclear power is also being generated. So far no serious harm has been reported from these sources, but fly ash from thermal power plants invariably creates environmental problems.

Radioactive wastes from nuclear power plants are normally disposed of according to strict international conventions. However, their heat generation poses several problems. Nuclear power plants normally release 50 per cent of their generated heat to the coastal marine environment. Localised damage to ambient flora and fauna appears to be unavoidable.

Degradation in specialised ecosystem

Mangroves

Mangroves in India have suffered from various biotic problems such as reclamation, deforestation and pollution. The abiotic problems like extreme climates resulting in cyclones and floods also pose a danger to mangroves. The Gangetic Sunderbans, Cochin backwaters, Bombay region and Gulf of Kutch are examples of indiscriminate exploitation, reclamation and pollution. Mangrove forests have been converted into agricultural land, fish farms, residential complexes and industrial units. The effect of insecticides and pesticides like Dimacron, Nuvan and Nuvacron was also found to be harmful to these plants although at a slow rate.

Control Measures

Mangroves have been declared as ecologically sensitive areas under the Environment Protection Act, 1986. All exploitation and developmental activities in these areas have been banned. Disposal of wastes from the adjoining industries and also carrying of wastes by pipelines through the mangrove areas have also been prohibited. A state-wise Mangrove Committee has been formed for effective management of the mangrove ecosystem.

Coral Reefs

It has been observed that dead as well as live coral beds are exploited for the carbide industry and for white cement. Large scale exploitation of corals in the Gulf of Kutch, has been checked to a great extent due to timely warning. A survey of the coral reefs in the Gulf of Mannar emphasized the need for conservation. Development of Tuticorin harbour and associated industrial activities as well as oil pollution, has resulted in large scale destruction of coral reefs around the islands of Tuticorin Andaman-Nicobar fringing reefs and Lakshadweep coral atolls are comparatively free from such problems. However, the recent data of Minicoy and Kavaratti atolls and Great Nicobar

Island indicate that there is a definite effect of oil pollution on corals of these areas. *Acanthester plancii,* a reef dwelling echinoderm, which feeds extensively on corals, is also responsible for destroying the corals in these two major groups of islands.

Apart from this, use of corals for ornamental and decorative purpose is yet another serious threat to this sensitive ecosystem. Local people of Lakshadweep also use corals for construction and white washing of houses and as mortar. Corals and mangroves occur together at some places in the Gulf and Andaman-Nicobar Islands. Of course mangroves grow mostly in the intertidal region while corals are found in somewhat deeper waters. However, extensive deforestation of mangroves in the Gulf of Kutch resulted in siltation on the coral reefs, which ultimately killed them.

Control Measures

Under the Environment Protection Act, 1986, mining of corals and coral sands have been banned. The coral reefs have been declared as special ecosystem for protection. Efforts for rejuvenation of corals are being taken on mission basis.

Table 1. Population and related data and some estimates of pollutants entering the sea around India (as of 2009)

Population	1.2 BILLON
Coastal population (19% of total)	228 million
Area of the country	3.287×10^6 km^2
Agricultural area	1.65×10^6 km^2
Exclusive Economic Zone	2.015×10^6 km^2
River runoff (annual mean)	1645 km^3
Rainfall per year (on land)	3.5×10^{12} m^3
Rainfall per year (on Bay of Bengal)	6.5×10^{12} m^3
Rainfall per year (on Arabian Sea)	6.1×10^{12} m^3
Domestic sewage added to the sea by coastal population per year (@ 60 l per head/day)	13.6×10^9 m^3
Industrial effluents added to the sea by coastal industries per year	0.6×10^9 m^3
Fertilizer used per year (@ 30.5 kg/ha yr^1)	13×10^6 tons
Pesticides used per year (@ 336 g/ha yr^1)	80000 tons
Synthetic detergents used per year	125000 tons
Oil transported across the Arabian Sea per year	550 MT

Table 2. Characteristics of the domestic waste water pollutants entering the marine environment of Bombay. Daily domestic waste water output at 1200 mid (approximate) (Source: Zingde 1985)

Parameter	ug/l	kg/day
Dissolved Solids	1450*	7.4**
Suspended Solids	245*	2.9**
BOD	258*	3.1**
Sulphate	75*	0.4**
Nitrogen	35*	0.9**
Phosphorus	6*	7200
Chloride	587*	7
Manganese	507*	608
Iron	2529	3035
Cobalt	30	36
Nickel	81	97
Copper	110	132
Zinc	251	301
Lead	11	13

* x one thousand ** x hundred thousand

Table 3. Details of some of the industrial complexes/industries, located along the coastal areas, are given below (as on 1995)

State	**No. of coastal industrial complexes/industries**
West Bengal	10 major industries
Orissa	3 " "
Tamil Nadu	17 " "
Pondicherry	4 " "
Kerala	20 " "
Karnataka	3 " "
Maharashtra	20 industrial complexes
Gujarat	15 industries and 2 industrial complexes

2 OIL SPILL MANAGEMENT IN MARINE ENVIRONMENT

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The bulk quantity of the world's oil is transported through sea. 70% 0f India's demand for crude oil is being imported through sea. Similarly South-East Asia, East Asia, Japan and China are heavily dependent on the import of oil from West Asia which passes through Indian Exclusive Economic Zone (EEZ). As a consequence, there is a constant risk of oil spills all along the ship routes, near oil handling facilities and ports. So far, 66 spills incidents reported in Indian water during last 20 years from (1988-2007), though most of them were minor quantity.

The threat for oil spill demands the preparedness to protect our all economical / ecological sensitive habitats and marine national parks along Indian coast such as Gulf of Kachchh, Mumbai, Malvan, Goa coast, Mangalore, Kerala coast, Gulf of Mannar, Kakinada, Haldia and Sundarbans etc. However, Gulf of Kachchh (GOK) is on top of the list due to its strategic proximity to Persian Gulf and it is an ecological rich habitat declared as Marine National Park and Marine National Sanctuary. GOK as the hub of oil handling agencies catering to its present capacity of about 78 MMT of crude out of total Indian import of 128 MT for 2007, and it is likely to increase upto 195 MMT by 2012. Any possible incidence of collision of oil tanker in the GOK is bound to result in extensive damage to fish, corals, mangroves, and other inter-tidal flora and fauna and the marine ecological system in the region.

The oil spill may occur at any time, any where in the open ocean along tanker route or near oil installations, but have threat to impacting the shoreline at any where depending on the action of currents, winds and tides conditions. Management of Oil spills in marine environment are challenging task to Oil Spill Coordinating Agencies and demands a quick and adequate response in order to reduce the environmental consequences. Proper understanding of the physical and chemical properties of crude oils and how they weather and behave on the sea surface is crucial for evoking / activating appropriate spill control and clean up procedures for managing oil spills in an optimal way.

Worldwide Operational Incidence of spills by cause, 1974-2007

OPERATIONS	< 7 tonnes	7-700 tonnes	> 700 tonnes	Total
Loading/ discharging	2823	333	30	3186
Bunkering	548	26	0	574
Other operations	1178	56	1	1235

Accidental Incidence of spills by cause, 1974-2007

ACCIDENTS	< 7 tonnes	7-700 tonnes	> 700 tonnes	Total
Collisions	175	300	98	573
Groundings	235	226	119	580
Hull failures	576	90	43	709
Fires & explosions	88	15	30	133
Other/Unknown	2186	150	25	2361
TOTAL	7809	1196	346	9351

Causes of oil spill

Spills usually happen due to bad weather (hurricanes, storms, and earthquakes), intentional acts of violence (like war, vandals, or dumping) and human mistakes. The main causes of oil spills are usually result of a combination of actions and circumstances, all of which contribute in varying degrees to the outcome and may be grouped into two categories like "Operational" and "Accidental". The worldwide information about spills from oil tankers indicates that most of operational spills(>91%) are involving small quantity < 7 tonnes due to routine operations such as loading, discharging and bunkering which normally occur in ports or at oil terminals. While accidental causes such as collisions and groundings generally give rise to much larger spills, with at least 84% of incidents involving quantities in excess of 700 tonnes being attributed to such factors.

Oil type and properties

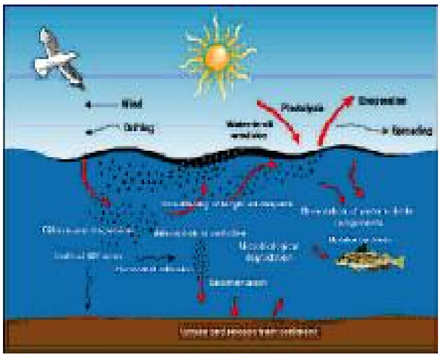
There is several hundreds type of crude oil depending upon their origin and their physical and chemical properties, whereas many refined products tend to have well-defined properties irrespective of the crude oil from which they are derived. Residual products such as intermediate and heavy fuel oils, which contain varying proportions of non refined components blended with lighter refined components, also vary considerably in their properties. The main physical properties which affect the behaviour and the persistence of an oil spilled at sea are specific gravity, distillation characteristics, viscosity and pour point. All are dependent on chemical composition (e.g. the amount of asphaltenes, resins and waxes which the oil contains).

Physical characteristics of three typical crude oils

Origin	Arabian Bonny	Light Merey	Super Light
	Saudi Arabia	Nigeria	Venezuela
Specific gravity °API	48.5	34.6	15.7
Specific gravity at 15°C	0.79	0.85	0.96
Wax content	12%	13%	10%
Asphaltenes	7%	No data	9%
Pour point	-29°C	12°C	-18°C

Fate of oil spill in the Marine environment

The transport and fate of oil spill in marine environment are governed by physical, chemical, and biological processes that depend on the oil properties, hydrodynamics, meteorological and environmental conditions. The processes include advection, turbulent diffusion, surface spreading, evaporation, dissolution, emulsification, hydrolysis, photo-oxidation, biodegradation, etc. When the oil spill occurs on the sea surface, it spreads to form a thin film called as oil slick. The movement of the oil slick is governed by advection due to current and turbulent diffusion due to wind action.



The composition of the oil and oil phases changes from the time of the spill. Light (low molecular weight) fractions evaporate, water-soluble components dissolve in the water column, and immiscible components become emulsified and dispersed in the water column as small droplets. The formation of an oil-in-water emulsion depends upon turbulence, but usually occurs within days to weeks after the initial spill. It forms thick pancakes on the water and intractable sticky masses if it comes ashore. After a long time this may disintegrate into lumps of tar. In some circumstances, the oil droplets may become attached to sediment particles in the water column and move towards seabed where oil gets buried leading to bacterial degradation, a much slower processes. Although the individual processes causing these changes act simultaneously, but their relative importance varies with time.

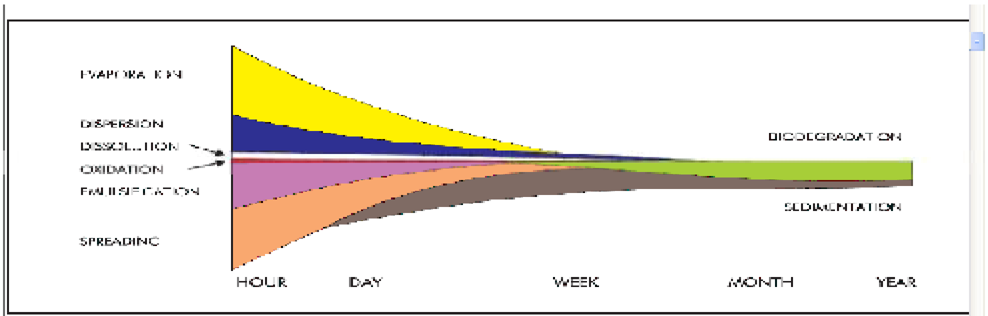
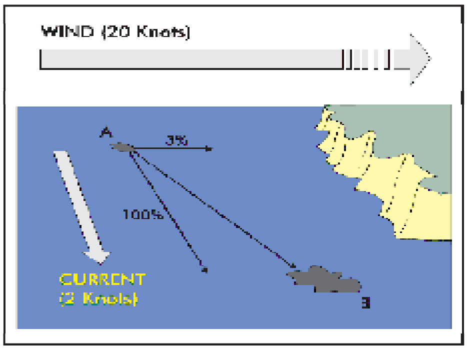


Figure 2. A schematic representation of the fate of a crude oil spill showing changes in the relative importance of weather processes with time - the width of each band indicates the importance of the process

Factors influencing oil movement, impact and recovery



Environmental factors

Oil Spill Modeling is a complex process, influenced by many factors, both human and non-human. The main factors affecting the fate of spilled out are :(i) Oil properties- surface tension, specific gravity, temperature; (ii) spreading; (iii) advection - waves, winds and current ; and (iv) weathering. Most general environmental factors affecting oil spill weathering are water and air temperature, sea state and wind speed. Type of release, solar radiation, air temperature, water characteristics, sediment load are also import to some extent. High temperatures and wind speeds increase evaporation, which decreases the toxicity of the remaining oil. Temperature also influences the rate of microbial degradation which is the ultimate fate of oil in the environment

The computer models are able to consider the temporal and spatial changed in these parameters for a given domain over a period. However, in the lack of information, Oil movement can be calculated by using approximately 3.5% of the wind velocity and at the surface current velocity.

Geographical factors

The geographical features of the coast along influence the impact and recovery processes. Though the, oil slicks may disperse in the open sea, the most damage occurs closed to shore in sheltered bays and inlets close, where oil becomes concentrated. On the shore, the fate and effects of oil vary with exposure to wave energy and shore type. On exposed rocky shores, effects tend to be minimal and recovery rates rapid. The most sheltered shores have high biological productivity and are the worst oil traps. If oil penetrates into the substratum, residence times are likely to be increased. Shores with sand, gravel or stones are porous, and oil penetrates relatively easily. If it weathers *in situ* to become more viscous, it may remain in the sediment for many years. In contrast, oil does not readily penetrate into firm waterlogged fine sand or mud. However, sheltered sand and mud shores

with high biological productivity provide oil pathways in the form of animal burrows and plant stems and roots. Oil penetration can kill the organisms that normally maintain these pathways, which then become filled with sediment; oil trapped within them degrades very slowly.

Estimating the volume of a spill

It is very difficult to get accurate information about oil quantity and type. Therefore, initially to run the model, the quantity of spilled oil can be computed by visual observing the thickness of the film of oil and its appearance on the surface of the water and estimating the surface area of the spill. Subsequently model can be updated using more precise information about oil quantity to generate the oil trajectry.

Oil Type	**Appearance**	**Approximate Thickness**	**Approximate Volume (m^3/km^2)**
Oil Sheen	Silver	>0.0001 mm	0.1
Oil Sheen	Iridescent (rainbow)	>0.0003 mm	0.3
Crude and Fuel Oil	Brown to Black	>0.1 mm	100
Water-in-oil Emulsions	Brown/Orange	>1 mm	1000

Application of Modelling and GIS in oil spill management

(a) OIL SPILL MODELLING

Oil Spill Modelling is a complex process, influenced by many factors, both human and nonhuman. The main factors affecting the fate of spilled out are :(i) Oil properties- surface tension, specific gravity, temperature; (ii) spreading; (iii) advection - waves, winds and current ; and (iv) weathering. Oil will move at approximately 3.5% of the wind velocity and at the surface current velocity. Computer models are able to make predictions about the trajectory and fate of spilled oil and to generate the likelihood of sensitive resources being threatened and associated time scales using required data. Modelling exercise provides clear idea about oil movement and will enhance the decisions concerning strategy development and the identification of necessary response capability. However, it is very essential the operator of these models understand their various limitations, such as the quality of information on water currents programmed into a model and the inherent difficulties in predicting some oil fate processes. Modelling is only a predictive tool and cannot readily replace the need to monitor a spill physically in the event of an actual incident. This can be effectively verified from aircraft or remote sensing or interpretation of visual observations of oil on water.

(b) GEOGRAPHIC INFORMATION SYSTEM

A GIS is useful in handling spatially referenced data which can hold information at any scale indeed, provided the data are correctly formatted, data from all sources can reside together, including satellite images, air photos and standard cartographic products. These advantages should only be exploited with careful use of the data, respecting issues of common data scales and data quality. The following information may be incorporated in the maps:

1. **Oil spill trajectory model Results**
   - Model results for various scenario showing bathymetry, circulation pattern, movement of oil, oil concentration and thickness, quantity of dispersed oil etc
2. **Ecological sensitive areas:**
   - *Coral reefs, Seagrass beds*, *Mangroves, Salt pans, Mudflats, beachs and nature* of shoreline, Wildlife protected areas and fishing activities,
   - Details of the areas of greatest sensitivity such as feeding and breeding areas , locations, which are important for threatened or endangered species, nearshore shallow water fishing areas, seaweed gathering; beaches with fishing activities

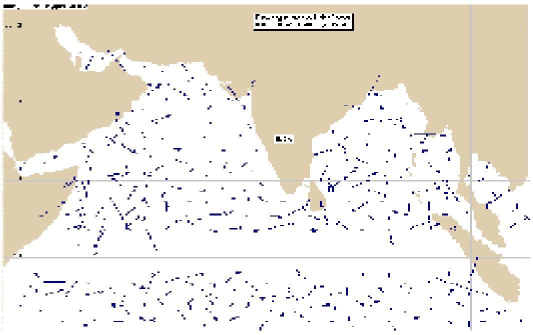
3. Socio-economic features -

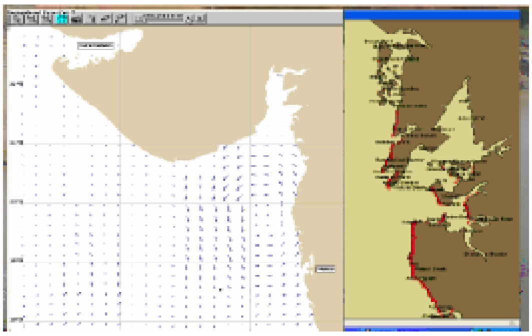
- Ports, harbours, jetties, SPMs and boat ramps;
- Industrial facilities, for example water intake system for power stations and desalination plants, coastal mining, and salt evaporation lagoons; recreational resources such as amenity beaches, bathing enclosures, water sport and game-fishing areas; and sites of cultural, historical or scenic significance, on or close to the shore.

7. A CASE STUDY

A few incidents of oil spills in the gulf have been reported in the past. The probability of incidents from tanker traffic, loading, unloading, and associated activities may increase in the years to come as the demand for petroleum and its products continues to rise. Since the oil spills cause extensive damage to fish, corals, mangroves, and other intertidal fauna, the threat due to the spills on the ecology of the gulf and consequent economic losses need to be addressed through scientific techniques to help manage these sensitive habitats from accidental oil spills. Tracking the movement of oil during the spills in Gulf of Kachchh is a fundamental requirement in oil spill contingency planning and prevention of marine resources and MNP & MS.

As per the Allocation of Business Rules 1961, Ministry of earth Sciences (MoES) is responsible for coordination and regulatory measures to prevention, conservation and protection of ocean. Accordingly, Ministry has taken up a R&D programme to understand the movement of oil in marine environment and identifying the resources at risk using two mathematical models of different level of complexity. First is very generic model, which is developed to predict the movement of oil and its fate in the Indian Ocean water. Other is habitat specific model for detailed trajectory and impact analysis on marine resources. The generic model uses GNOME (Generalized NOAA Oil Spill Modelling Environment) computer code for tracking of oil spills from offshore to coastal areas of India. The model works based on wind speed, wind velocity, sea current, etc with 60 to 18 km resolution. The model is capable to run in hindcast and forecast mode using diffusion, forecasted winds and forecasted regional currents for ocean state. The model also considers uncertainty parameter which can be decided based upon the data quality being used for the model.





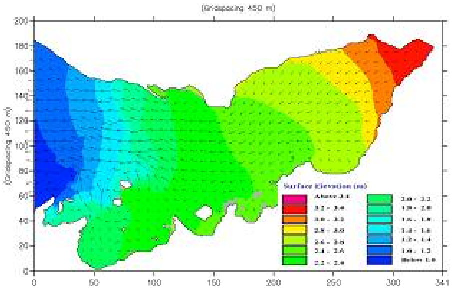
Once spilled oil reaches in the vicinity of Gulf of Kachchh region, the detailed habitat specific model simulates the detailed analysis of oil fate and trajectory using the bathymetry and local circulation pattern at 450 m spatial resolution. The oil spill trajectory models are linked to a GIS information system to provide the vital information about the extent and type of the resources likely affected.

Surface Elevation and circulation pattern in Gulf of Kachchh

Hydrodynamic and Oil Spill modelling

An integrated model was used to generate the oil trajectory in the gulf water and to track the path and fate of spilled oil under prevailing hydrodynamic and meteorological conditions for the entire Gulf covering Okha to Navlakhi. Tide and circulation patterns were generated and supplied for oil spill modelling. The circulation in the Gulf is mainly governed by tides and winds. The scientific validity of model for hydrodynamic and oil spill model results were demonstrated at various forums in India and published in international peer reviewed journal.

The oil spill module takes into account all important phenomena of an oil slick in an aquatic environment and computes the slick thickness and dynamics, and distribution of the oil in the water column and atmosphere, which are required for contingency planning and environmental impact assessment. The major forcing functions for trajectory analysis of an oil spill model are local wind conditions and circulation pattern, while chemical composition and properties of oil along with environmental parameters are the deciding factors for fate analysis.

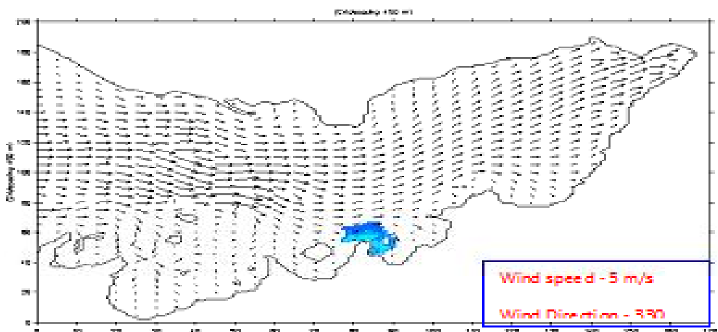


Surface Elevation and circulation pattern in Gulf of Kachchh

Past 30 years wind data at Jamnagar was used to determine the monthly meteorological scenarios in the gulf. Three wind scenarios, *i.e.,* no wind during calm period, a constant wind speed of 5 m/s blowing from 240º and 330º from north during pre-monsoon (March–May) and post-monsoon (September–November), respectively, were selected. These derived wind conditions were reconfirmed from synoptic field observations.

The spill results were evaluated for all three seasonal wind conditions, *i.e.,* calm, SW monsoon, and NE monsoon. Wind and water currents guide movement of oil parcels at the water surface. The currents play an important role in transportation of dispersed oil in the water column. The area covered by oil spill trajectories simulated under different wind conditions for the Gulf. The modeling results revealed that under the “no wind condition,” oil was moved as per the path of the streamlines of tidal flow. During flood tide, the oil moved in the Pathfinder creek toward the Vadinar jetty located on the southwest side. For the second scenario, when wind blows from 240º from the north, the oil moves toward the central channel (NE), and it would reach the northern coast near Kandla creek within 5 hours. While under the third condition, when wind blows from 330º north, the spilled oil would be transported toward the southern coast. The oil residues would hit the coast at Narara reef, located on the southeast side, in 12 h.

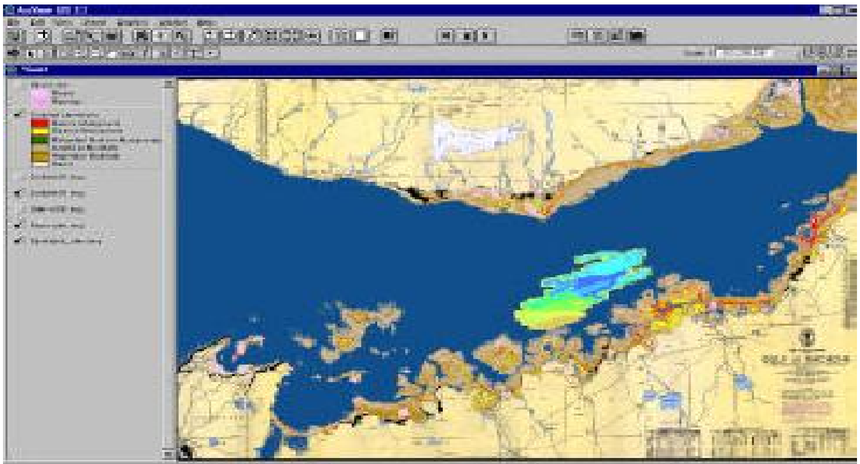
The oil mass balance calculation concluded that 40 % volume of spilled oil was lost due to evaporation and 5 % dispersed in the water column after 48 hours simulation. It was noticed that about 1% oil was vertically dispersed in first 12 hours, but it reached upto 5% at the end of 48 hour. This is due to increase in the oil density and degradation of oil due to emulsification. The left out oil (55%) was the threat to coastal and marine environment as either it would hit the coast or disperse in the water column in the long term.



Oil Spill Movement after 24 hours when Wind is blowing from 330^0 N

USE OF GIS IN ESTIMATION OF AREA OF RESOURCES AFFECTED

An operational GIS-based information system was used to predict the comprehensive movement and fate of spilled oil, to explore the possibility of different strategies in an interactive manner, to respond to an oil spill, and to quantify the impacts of oil spill on resources. To analyze the impact of an oil spill on marine organisms and resources, a model output was generated in terms of track of oil, oil thickness, area of dispersed and dissolved material, and these model outputs were converted into GIS compatible format. The results were then analyzed using Arc-View to identify the resources that were "hit" for a given scenario. The time exposition maps were prepared and overlaid on the resource map to quantify the resources at risk with time.



GISintegrated resource map for risk assessment

Resources exposed to oil (km2) after 48 h.

Resources	Calm-Scenario	SW Monsoon -Scenario	NW Monsoon - Scenario
Mud Flats	37.20	0.02	33.85
Sandy Flats	0.63	0.00	1.80
Mangroves	0.15	0.00	1.20
Coral Reefs	6.37	0.00	2.42
Seawater	148.25	258.15	81.36
Length of Shore (km)	54.30	2.00	34.40

Table 2. ***Total risks to marine organisms and ecosystems.***

Scenario	Area with TRR _ 1 (km^2)	Mean TRR
Calm	166	10
SW Monsoon	620	6
NW Monsoon	142	15

NATIONAL OIL SPILL DISSATER MANAGEMENT PLAN

The country has an Oil Spill management programme since 1980 to protect coastal and marine areas against oil spill damages. The Ministry of Home Affairs is the nodal ministry for crisis management in case of an oil spill disaster and Coast Guard is coordinating agency for combating oil spill pollution in Maritime zones of India in the event of oil spills. The important aspects include

R&D in oil spill detection, management, combating and legal aspects. The use of booms and skimmers to recover floating oil and dispersants to enhance natural dispersion are established methods of responding to oil spills. Response strategies to a spill are decided based upon the aerial /visual observation of oil, quantifying floating oil, assessment of potential threat, protecting Sensitive Resources, shoreline Clean-up etc.

The National Oil Spill Management programme of Government of India was reviewed in May 2005. The Ministry of Earth Sciences (MoES) has given additional responsibilities to provide scientific support in monitoring and detection of oil pollution / spills, predicting its movement towards Indian shores and assessment of extent of damage along with existing responsibility scientific monitoring of oil pollution through COMAPS programme.

INITIATIVES OF MOES

Though, the existing models provide an additional tool for efficient decision making, however, it is necessary to interprete the model results cautiously as each model has some "limitations". The models needs to be calibrated with real spill situations. Key data restrictions include:

- Ø The databases of oil types may not have an exact match for the specific oil spilled, but additional analysis work can allow a particular oil to be entered
- Ø Quality of tide and current data varies between regions and models

Therefore, Ministry has taken up a project on "Oil Spill Modelling" during XI plan period under COMAPS programme 18 priority areas to delop Oil Spill Models by collecting the experimental sea state data at Beaches of Dwarka, Mumbai, Dhanu, Entire coastline of Goa, Mangalore, Cochin, Neendakara, Vizhinjam, Kavaratti, Kanyakumari, Gulf of Mannar, Chennai, Pulicat, Kakinada, Visakhapatnam Paradip, Hooghly and Sundabans in West Bengal to understand the movement of oil in marine environment and identifying the resources at risk for selected locations during 11th pan period and to strengthen existing GIS based Oil spill tracking system. The major work involves:

- Ø Study of Sea state by collecting Oceanographic data at 18 locations along the coastline
- Ø Development of 18 habitat specific models for above locations
- Ø GIS database for providing all information about the sea state, resources, industry and oil related other attributes
- Ø R&D on to improve the predictability and reliably of the model

The advantages of the GIS based Oil Spill Tracking System are:

- Ø accurate spill prediction for both forecasting and hindcasting model,
- Ø rapid output of results regardless of spill geographic location,
- Ø ability to adjust inputs considering changing conditions and field observations,
- Ø use in remote field locations or effective transmission of model outputs to field operators,
- Ø Useful aid to meet a number of requirements for Oil spill responders and incident planners to take appropriate decisions to minimize the environmental and economical damage of the shoreline.

NEAR SHORE ENVIRONMENT

Shorelines are generally more or less in dynamic equilibrium. Their evolution due to changes in winds, waves, currents, and sediment transport, is rather seasonal, characterized by alternate erosion and accretion. Additional changes occur when perturbations are introduced by anthropogenic factors/activities. Shoreline change is a natural process of evolution of coastal areas. It may occur on different scales of time, from a single tidal event, to decades or centuries.

3. MONITORING OF SHORELINE CHANGES - TOOLS AND TECHNIQUES

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1. INTRODUCTION

Nearshore Zone, that extends from high water line on land side to depth of closure so called active depth (approximately 6m to 8m water depth varies with tide and wave) on sea side is dynamic and subjected to seasonal and annual changes due to various forcing functions such as wave, tide, current wind and sediment inputs. Often, the processes in this zone are not understood completely due to lack of proper monitoring. State Governments do monitor the shoreline changes but the result could not be used for shoreline management studies due to lack of complete information. The state Public Works Department of Tamilnadu is monitoring the shoreline under **Crest of the Berm** Project, where the position of berm is monitored periodically from 1975. Though, the above data forms a valuable information to a coastal engineer/scientist, still lot of gaps exits to interpret the data for Shoreline Management. The various processes operating in nearshore area have been discussed in the earlier papers. This paper discusses about the different monitoring techniques required to understand the processes in the nearshore zone and instruments used for the shoreline survey.

2. BEACH PROFILE MEASUREMENT

A beach profile is a two dimensional view of cross sectional transect measured perpendicular to the shoreline. Having an accurate time series of beach profile measurements is essential for deciphering shoreline erosion and accretion trends and tracking beach recovery after storms. The transect of beach profile runs from well behind the backshore upto a wading depth (depth of closure approximately 6 m to 8 m depending on prevailing hydrodynamic conditions). Beach profile surveys typically must include an inshore survey or “wading survey” which is performed by using standard land surveying techniques. A survey team member traverses the survey line holding a rod, stopping at appropriate intervals to allow an instrument operator to read and record the elevation. The type of instrument used by the operator may be simple as a level or as complex as an advanced electronic survey instrument. The wading survey continues seaward into the water until the rod holder can no longer stand steady with the survey rod. This land section of the profile is surveyed preferably at low tide so that the cross section extends as far seaward as possible. Traditional land surveyors may not be accustomed to or comfortable with entry into the water in the wading survey, but gathering of these data is indispensable for obtaining overlap with the offshore survey, discussed next. Understanding of surf zone waves, circulation (such as rip currents), and morphology (such as berms, scarps, steps, troughs and bars) is essential for obtaining accurate data, as well as for safety of the survey party.

2.1 Inshore Survey

Beach profiles are measured using the Emery technique, named after the person who applied this topographic measurement method to beach studies. It is simple and “low-tech” but accurate, which was used widely. The above technique can be slightly modified for speedy and accurate measurement of vertical position using dumpy level. The difference between emery technique and modified method is that dumpy level is used in place of two rods and siting level to measure vertical position. A step by step procedure to measure beach profile is given below.

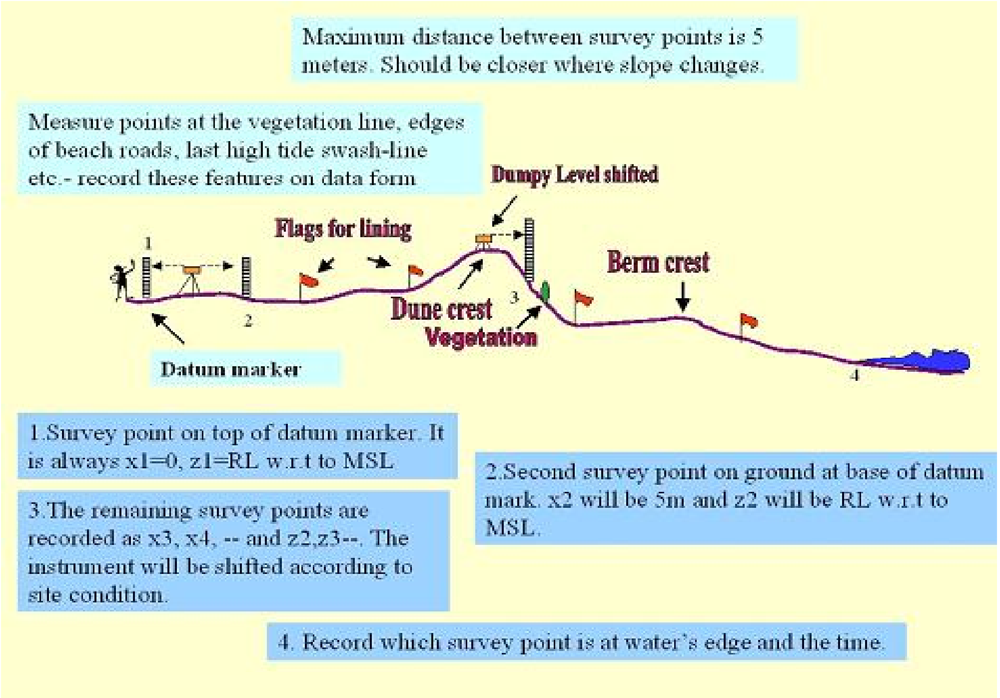


Fig. 1 - A typical sketch showing the beach profile measurement using Modified technique

Mark profile with stakes/flags - Flags will help the surveyors stay along a consistently oriented traverse. See the **Fig. 1** that illustrates this process.

a) One person goes to the fore dune crest or other point from which the entire profile is in view. Using a sighting compass, site back to the datum and move left or right until the correct azimuth is obtained (when sighting landward, the azimuth will actually be the reciprocal (180 degrees difference) of the value listed as the azimuth). Place a stake or flag at this location.

b) Standing on this point, have a team member with a stake or flag move about half way between you and the datum point. Line this person up so that they are on the profile (between you and the datum point). Have them place another stake or flag. The landward portion of the profile is now marked.

c) Still standing on the same point determined in (a), turn 180 degrees and, with the compass, site toward the water in the direction of the proper azimuth for the profile. Have a team member go to the wet/dry line (The wet/dry line is the landward most limit of sand wetted by ocean water, not rain). Direct the team member to move left or right until they are on the profile. Have them place a stake or flag at this point.

d) Now have the team member move towards you along the profile. Line them up on the profile. Have them place a stake or flag at the vegetation line (seaward extent of vegetation).

e) Place other flags along the profile at all bermcrests, the last high-tide swash line (often delineated by a line of debris or wet/dry boundary), edges of beach roads, and other features you want to be sure you measure during the profile survey.

Note - If one can view the entire profile from the water's edge, fewer stakes will be required. This will be the case when surveying a profile without a prominent foredune. The idea is to place markers so that at least 2 of them are visible behind or in front of the surveyors when conducting the topographic survey.

Conduct topographic survey (profile) - After marking the profile line, you are ready to measure distances and heights along the profile.

- Start at the datum point. The top of the first point is point #1 and is always x1=0, z1=0. Use your tape measure to measure z for point #2. The second point is the ground surface above or below the datum point. At this point, x is always 0, and z is the distance above or below the top of the datum point or w.r.t to MSL. The maximum distance between the rods should be about 5 meters. Shorter distances should be measured where there is a change in the slope of the ground or some other key feature such as the vegetation line. The procedure upto this stage is as per emery technique.

- Use dumpy level to measure the level at each point with respect to the datum along the profile. Record observations (vegetation, geomorphology and sediment) in the notes column. The sediment samples should be collected at three or four selected points along the profile. Record x and z where sediment samples are taken.

2.2 Sled Surveying Equipment

The method is needed to complete the beach profile survey in water deeper than wading depth, the offshore survey. The offshore survey is conducted by using a survey sled (the method recommended in this article) or by boat-mounted echo sounder. An echo sounder survey system consists of a vessel mounted depth sounder and positioning system. A survey sled system consists of a survey rod, or mast, mounted on a sled that rides along the sea bottom while being towed. The mast supports surveying reflectors, prisms, or gradations that allow the elevation of the sea bottom or beach to be read by a land-based surveying instrument. **Figure 2** shows a survey sled used on the Ennore coast by ICMAM-PD. In order to achieve accuracy as described above, a sled survey system is required which consists of a towable sled with mast, tow-boat or truck, and electronic distance meter/theodolite (total station) with data collector notebook computer.

Fig. 2 - Photograph showing the Sea Sled and Dumpy level used for beach profile

Electronic total stations, the most sophisticated survey instruments available, are normally used when beach profile data are collected along the full profile out to depth of closure. Less capable instruments generally will not have the range or accuracy for this application. High-quality instruments have a maximum range exceeding 4 km.

The sled and towing mechanism (truck, boat, winch, etc) must be designed to operate in a range of conditions that allow the work to be performed in a reasonable length of time and with safety. Typical conditions for operation of a sled system will include 1-2 knots of longshore current, individual waves with heights upto 2m for any possible wave period, and tow speeds up to 4 knots. A typical survey sled is a bottom-riding frame that supports a tall mast. Survey reflectors are affixed on top of the mast for siting and measurement by the total station. The sled is normally a pipe frame constructed of steel or aluminium with two runners. Lighter ballasted PVC sleds have been used in very calm sea conditions. The sled runners ride on the sea floor and a mast, attached to the frame and properly guyed to maintain support under tow, is visible above the water surface and waves during data collection. The mast must be designed to be stable under wave and current forces. Portable sleds, which can be disassembled for transport, typically weigh between 400 and 1000 lb depending on coastal wave conditions, before ballasting.

Under calm sea conditions, an inflatable boat with a small engine (50 hp) may provide adequate power and control for towing a survey sled. However, more capable vessels are commonly used with as much as 300 hp, especially in areas where occasional sea floor obstructions are present. In such cases, vessel maneuverability and power are important. Navigational control and experienced operators are critical for safe operation near the surf zone where breaking, refracting, and shoaling waves can easily capsize a boat.

3. BEACH SEDIMENT SAMPLES

Geologic setting and physical and biological processes control sediment grain size and type. Geologic setting refers to the geomorphology of the terrain and the type of sediment or rock on which the beach is formed. In some cases, a topographically low, eroding, muddy marsh may be the platform on which the beach is formed in others an earlier established sandy barrier island or a bedrock ledge may be the setting. Physical processes refer to the action of waves, tides, and wind as they move sediment on the beach. Biological processes are those associated with plants and animals. Plants and animals may be sediment producers for the beach, especially shell producing animals, but they also affect sediments by their burrowing and their baffling of wind and wave energy.

Grain size and type analyses of three sediment samples taken along the beach profile will typically reveal the different processes at work. Comparison of samples over time and among different beaches will provide additional insight to how beaches respond to varying conditions. At each location, you will take a core of sediment about 5 cm long that will represent conditions over some period of time. Given the frequency of your sampling (every 2 to 4 months), analyses on a core of sediment will provide more reliable data than just scraping the surface of the beach, which would often just represent the last few moments of deposition or erosion. Take one sand sample from the foredune, berm top, and beachface areas (**Fig.3**). Index the beach sediment samples such as Sample location: *foredune (FD), berm top (TB), or beachface (BF)*, Date (year/month/day) and time: *e.g. 1997/09/23 0830*, Sample number: *e.g. BEG08-BF-19970923-0830*

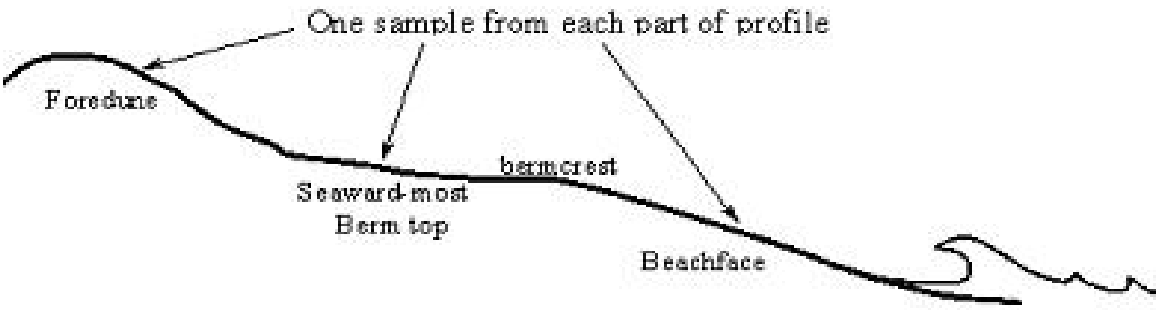


Fig. 3 - Location of beach samples to be collected along the beach profile

4. PROCESS MEASUREMENTS (LITTORAL ENVIRONMENTAL OBSERVATION)

Tracking the topography of the beach shows us how the beach changes, but measuring the wind and waves will help us to understand why the beach changes. The process measurements you make during your beach visits are just a snapshot of what is going on in terms of wind, waves, and currents. These measurements are also named as Littoral Environmental Observation (LEO). What is really pertinent to the state in which you find the beach, however, is what was happening for some period of time (hours to months) before your arrival. Unless you obtained process measurements every day, you will not be able to collect enough data to properly relate your measurements to your beach profiles. Fortunately there are many areas where instruments are acquiring hourly data on wind and waves.

Weather from IMD and current, and wave data from the National Data Buoy program of NIOT at nearest stations should also be collected. These stations, however, will not likely be at your beach profile location, but you can use the measurements you make to determine the differences in measurements between your location and the continuously operated stations. After you have enough simultaneous measurements, you will be able to “calibrate” the continuous data for your beach location. For example, if your wave height measurements are consistently higher than those obtained by an offshore gauge you will know to increase the wave height measurements at the offshore gauge before applying the data to your beach location. Similarly if the wind direction at a weather station is consistently more out of the north than at your location or the speed is higher, then you know how to correct these data for your location.

There is another reason to make careful measurements of the processes. This is simply to hone your powers of observation and to increase your appreciation of the physical processes shaping the beach environment. The techniques here are qualitative, therefore, 3 people will make estimates to provide more reliable data. Following are the methods to employ.

4.1 Wind Direction and Speed

- Go to a high point in the area of the beach profiles. The foredune crest (location 7, **Fig.4**) or on top of a seawall would do fine. Make sure you are not shielded from the wind in any direction.
- Face directly into the wind by feeling it on your face. Without moving your head, raise the sighting compass and determine the bearing pointing into the wind. Record this magnetic bearing.
- Face directly into the wind and hold the wind meter to the wind. Watch the meter for about 1 minute and determine the sustained wind speed. The sustained wind speed does not include sudden gusts or short calm periods of wind.
- Determine and record the highest wind gust speed during this time.

4.2 Wave Direction

- From the same point that you determined the wind direction and speed, now determine the direction from which the waves are coming.
- Look across the breaker zone and focus on the waves where they first break. Turn your head so that you are looking directly into the oncoming waves. Raise your sighting compass and determine the bearing directly into the waves. Record this magnetic bearing. When sighting on the breakers, you may find it helpful to align the horizontal edge of the compass so that it is parallel to the breaker line.
- It is important to focus on the waves where they first break offshore and not on the waves near the beach.
- Keep your wave direction measurement secret and pass the sighting compass to the second and then the third observer for their determinations.
- All observers should record their observation in the place that corresponds with their observer number as written on the top of the form.

4.3 Wave Breaking Height

- Move to the waterline and estimate the height of the breaking waves when they first break offshore (from location 8 in **Fig.4**). Moving to the waterline gives you a better perspective for estimating height. You will be nearly on the same level of the waves.
- Record your estimate in centimeters on the data form. Be sure to record in the location that corresponds with your observer number at the top of the data form.
- Keep your estimate secret and pass the form to the next observer.

4.4 Wave Period

- Focus on an imaginary point in the middle of the surf zone and count the waves passing this unmoving point for 10 seconds.
- As the crest of a wave passes your point count that as zero and start your stopwatch. The next wave is wave number one.
- When the 10th wave passes your point, stop the watch.
- Divide the number of seconds by 10 to get the wave period. Don't forget to convert minutes of time to seconds before you divide.
- Record your estimate in seconds on the data form. Be sure to record in the location that corresponds with your observer number at the top of the data form.
- Keep your estimate secret and pass the form to the next observer.

4.5 Surfzone Width

- While standing at the waterline, estimate the width of the surf zone. This is the distance from the waterline out to where the waves first break. Record your estimate in meters on the data form. As with the period and height measurements, be sure to record in the location that corresponds with your observer number at the top of the data form. You should also consider that most people tend to underestimate distances across water.
- Keep your estimate and cross checked with next observer.

4.6 Number of long-shore bars

- Estimate the number of apparent long-shore bars by counting the number of breaker lines or visible shallow zones oriented parallel to the beach. As with the period and height measurements, be sure to record in the location that corresponds with your observer number at the top of the data form.
- Keep your estimate and cross checked with next observer.

4.7 Wave breaker type

Waves break in different ways depending on the wavelength, wave height, and slope of the surf zone. When the crest of waves curl and suddenly collapse, they are said to be "plunging". These are the types of waves surfers crave. When the crest continuously breaks as the wave moves on shore, it is said to be spilling. Surging waves push up the shore and slosh onto the beach without an orderly breaking of the crest. Observe the outer most breakers and record the breaker type as plunging, spilling, or surging. Make sure you record the outer most breaker type. Along shorelines with nearshore bars, spilling type breakers will almost always be present inshore of the outer breakers so don't confuse these breakers with what is occurring where the waves first break. There is often a mixture of plunging and spilling types, but you must decide which is the dominant type and check only one on the form.

4.8 Long-shore current

The long-shore current is the movement of water along the shoreline and is caused by (1) waves approaching at an angle to the shoreline, (2) tidal currents, and (3) wind. You will measure the speed and direction of the current using a float that you throw into the surf zone.

a) You need a float that you can throw at least 30 m and that has a low profile to the wind when it is in the water. A low profile is important because our intention is to measure the water current, not the wind direction and speed. A rubber or hard plastic ball about the size of a baseball and that has some weight to it makes a good float. You also need a stopwatch.
b) Go to the water line and throw the float into the middle of the surf zone or as far as you can if you can not reach the mid surf zone.
c) Step back up the beach and, with your heel, mark a line in the sand at the position of the ball and start the stopwatch.
d) Walk along the beach following the ball as it moves along the shore. Do not take your eyes off the ball. When 50 seconds have passed, mark another line in the sand.
e) Record the distance from the waterline you initially threw the float. This is an important record because your results may vary with this distance.
f) Measure in meters the distance the ball moved along the beach.
g) Multiplying the distance by 2 gives the speed of the longshore current in centimeters per second. Record the speed and direction the float moved on the form.
h) Repeat (b) through (g) two more times.

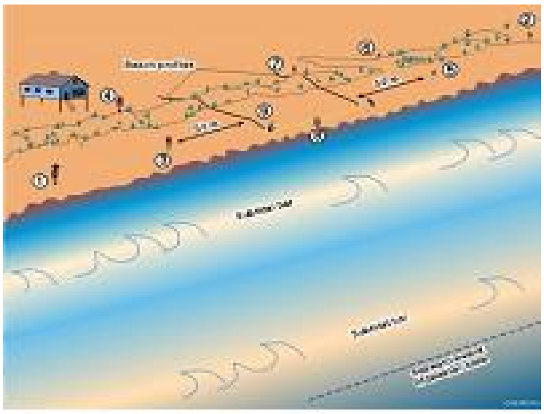


Fig. 4 – Sketch indicating the various features to be monitored for Shoreline Management

1. Survey at least 500 m of the shoreline with the GPS receiver.
2. Survey at least 500 m of the vegetation line with the GPS receiver.
3. Take photograph looking along the berm crest or wet/dry line.
4. Take photograph looking along the dune crest.
5. Take photograph looking along the berm crest or wet/dry line.
6. Take photograph looking along the dune crest.
7. Determine wave direction, and wind direction and speed from highest point on profile, count number of longshore bars, measure foredune crest orientation.
8. Estimate height of breaking waves, measure wave period and longshore current.
9. Measure beach cusps and berm crest or wet/dry line orientation.
10. Shoreline and process measurements.

5. GLOBAL POSITIONING SYSTEM (GPS) SURVEY OF THE SHORELINE AND VEGETATION LINE

Beach profiles provide detailed topographic information for analyzing morphology and sediment volume. These profiles, however, cross the shoreline and vegetation line at just one point. GPS surveys provide continuous data alongshore. Measured shorelines and vegetation lines from different times can be plotted on the same map for comparison. This is how the rate of shoreline change is typically determined along a coast.

The shoreline for the purpose of this study is defined as the wet/dry line. The wet/dry line is the landward most limit of sand wetted by ocean water (not rain). This roughly corresponds to the position of high tide on the beach and is identified by a tonal contrast. The vegetation line is the seaward extent of vegetation. The vegetation line is measured because it is an important legal and physical boundary. Often, houses and buildings must remain landward of the vegetation line. Vegetation is also required for the natural growth and maintenance of protective foredunes. On the otherhand,the crest of the berm can be defined as Shoreline. Monitoring of this line would indicate the seasonal and annual variation in shoreline.

The GPS receiver uses transmissions from satellites to determine latitude and longitude. A GPS receiver operating alone can determine positions accurate to about 3m. When a second receiver, however, is operated simultaneously and remains in a known location, data from it can be used to correct the position of another receiver in the area that is moving. This is called differential GPS, and it can provide accuracy of a few centimeters. Real-time KGPS/ DGPS receiver is receiving data from the satellites to calculate latitude and longitude while at the same time it is receiving data from a nearby receiver operated by the Ministry of shipping in case for DGPS and from the movable base station for Real Time Kinematic GPS. The detail of Base and Rover of Real Time Kinematic GPS is shown in **Fig 5**. The receiver uses the data from the Ministry of shipping or movable base to correct its computed position immediately or in other words in “real time.”

Fig.5 - Real time kinematic GPS for shoreline mapping

Before beginning the GPS survey, the profile location should be marked with flags. Flags should be placed on the vegetation line, the wet/dry line (shoreline) and crest of the berm along the profile. Keep the base station (Leica SR530) in a known location where you know the precise Latitude, Longitude and the height (MSL) values and make it on. Now the base GPS will start to send the signals to the rover. Make the rover GPS on and wait till it tracks the available satellites in that location. After receiving the sufficient signals from the satellites, with the help of signals from the base stations it calculates Latitude, longitude and altitude of the present location. All this data with the data and time will be automatically stored in the rover GPS receiver.

Differential GPS (DGPS) along with GIS software also can be used for the shoreline monitoring. For this walk along the wet/dry line or crest of the berm while the receiver (Leica GS5+) is automatically recording the data (**Fig.6**) and the GIS software (ARCPAD 6.0) in the pocket PC will convert this GPS data in to the map format. If the receiver is set correctly, you can see your path plotted on the screen.

Fig. 6 - Mapping of the Inlet or Berm using standalone GPS operates on GIS software

Because of the small variations in beach topography and the way waves rush up the beach, the wet/dry line/crest of the berm will have curves in it. It is not necessary to follow every curve. Instead, walk a relatively straight line that is an average of these curves. Do not stray from your line or you will have extraneous points in your recorded file. Do not stop for long periods of time or your GPS receiver may run out of memory.

When you reach the flag on the other end of the survey area, proceed along the beach profile without changing the receiver. Repeat the GPS survey along the coastline and profile line for the area considered.

6. BEACH ORIENTATION AND BEACH SHAPE

Shoreline and foredune orientation – These measurements are needed for an exercise illustrating the relationship between wave direction and height, shoreline orientation, and longshore current speed and direction. Disparity between the shoreline and foredune orientation may also indicate an ongoing “adjustment” of the shoreline. The vegetation line is a more stable feature than the shoreline and under static conditions it would be roughly parallel to the shoreline. Varying rates of shoreline advance or retreat alongshore, however, may cause the two lines not to be parallel.

Stand on the foredune crest along the profile line and sight along the crest to determine the orientation. Turn around and sight along the crest in the opposite direction. Record these values on the form. If there is no foredune, use the vegetation line and make sure you note this on the form. Stand on the shoreline (wet/dry line) and repeat the measurement you made standing on the foredune crest.

7. BEACH CUSPS

Beach cusps are rhythmic topographic features on the beach caused by the interaction of waves, nearshore bathymetry (slope and shape of the ocean bottom out to where the waves begine to shoal), and beach. They appear as a scalloped pattern, but their regularity, spacing, and relief (height difference between high and low areas) varies greatly over time. The high portions of the cusps are called “horns”, and the low areas are called “embayments”. The relief of a set of cusps is the height difference between the horns and embayments. The outline of the cusps usually forms an identifiable berm crest, but sometimes the relief of cusps is so subtle that a berm crest is not well defined. There are often two sets of cusps present. A high set that formed during a period of high water and possibly large waves and a newer lower set that may be actively forming during your observations. You will measure the wavelength (spacing) of the cusps and the relief. Count the number of cusp horns along one of the 100-m distances you set out for the GPS survey. It does not matter which direction you go from the profile. Counting over this distance will give you a more consistent measurement for comparison from one time to the next because the spacing of cusps is not always regular. Make this count for the lower and higher set of cusps if present. If cusps are not present, make note of this on the form by recording the number of cusps to be zero.

Use the Emery rods to estimate the relief (height difference between the horns and embayments). Pick a representative cusp for this measurement. There is no need to measure every cusp in the set. You may want to measure a few cusps and average the results.

8. ROLE OF REMOTE SENSING AND GIS

The importance of shoreline monitoring is dealt in earlier sections. After monitoring the data needs to be preserved and it should be made available to the coastal community. GIS and remote sensing are the two important tools to handle and retrieve the spatial data sets respectively. “Remote sensing is the science of deriving information about the earth’s land and water areas from images acquired at a distance. It usually relies upon measurement of electromagnetic energy reflected or emitted from the features of interest (Campbell 1987).” GIS is a useful tool for analysis, interpretation and presentation of data, which can be aptly applied for shoreline management. The conceptual design of GIS and relevant attributes for shoreline monitoring and management are discussed initially and the usefulness of GIS is detailed with a case of Chennai.

8.1 Design Using GIS

8.1.1 Potential operations supported by GIS

In addition to monitoring erosion, which is a main task in shoreline management, operations relevant to shoreline management that can be supported and improved by GIS technologies are discussed below:

Coastal Engineering

Planning of coastal structures such as breakwater/ Groin/ gabbion/jetty requires information about identified site and adjoining areas. The information on adjoining area would help in studying the structural influence on other areas. A survey has to be performed to provide topographic/bathymetric maps, for example, on a scale of 1:1,000 for structure design. Tidal water level (High tide line and Low Tide line) and storm surge data are necessary to determine height of the structure. In addition, geotechnical data such as the shear strength of soil are also needed. Design drawings can be generated using Auto CAD and linked to GIS. With all these data available in the digital form in a GIS environment, a computerized or partially computerized design procedure is anticipated, which will make the design process much more efficient and user friendly.

Inlet / Creek / Estuary Mouth Dredging

The local Government or agency often conducts inlet dredging to improve port access, navigation of fishing boats at both high and low tides and for related purposes based on approximate area. Though the current procedure does not envisage any guidelines for planning and implementation of dredging operation and disposal, it is essential for effective shoreline and environmental management. With the understanding of site and proper planning, the dredge spoil can be utilised for nourishment of vulnerable erosion sites. The boundaries of the area to be dredged are drawn on a 1:1 mile topographic map. A detailed bathymetric survey of the specified area is performed and a map of 1:2000 is produced. The design boundary of the dredging area is located based on the survey map. A post dredging survey is carried out to estimate the volume of the dredged material. Periodical surveys may be performed to monitor trends of sedimentary movement and predict future dredging sites and time. This operation may be improved by integrating numerical modeling techniques. If the bathymetric data are in digital form, and the survey data are supplied in digital form as well, the design procedure, volume estimation, and long-term trend analysis can be accomplished in a GIS environment. The monthly variations of inlet cross section indicates the amount of water exchanged between river and sea which is useful for assessing water quality variations inside the creek / estuary.

Coastal Project Implementation and Monitoring

Services such as project cost estimation, project budget justification, tenders and budget monitoring are part of project monitoring. When the design is completed and the contract has been awarded, the progress of the project is monitored by government. This is done by reviewing progress reports from contractors. In the monitoring work, important information needed is what has been done and what still has to be carried out.

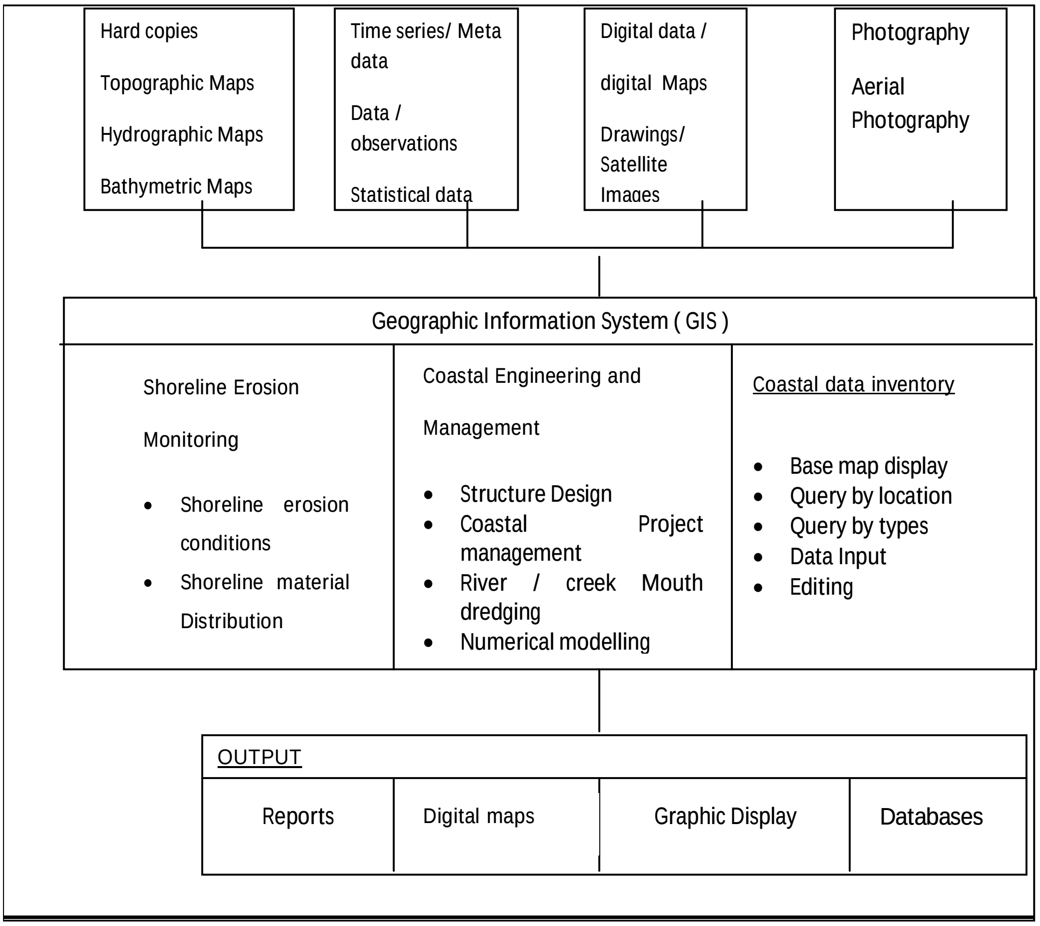
Numerical Modeling

Numerical modeling is a technique whereby the physical environment of the shoreline can be investigated using computer technology. In particular, it is suitable for studying the erosion process, shoreline changes, structure design and shoreline erosion prediction. Data needed for numerical modeling include shoreline, bathymetry, size of grain, waves and tides. More sophisticated numerical models consider the effects of wind as well. In an integrated system, if digital data are available, data for numerical modeling should be organized in GIS and provided to the modeling system. The result of the numerical modeling can then be displayed in the GIS environment. For example, shoreline changes caused by different input data sets can be overlaid and compared. The simulated shoreline can also be overlayed in GIS on other features such as land parcels and land use classes, so that effect of erosion particularly the type of land that will be affected can be easily assessed.

8.1.2 Function Design

Based on the analysis of the operations to be supported under shoreline management, three primary functions are identified:

A flow chart describing the functional design of shoreline management is shown below:



Under coastal erosion monitoring, shoreline erosion conditions are available along shoreline stretches at the regional/local level. The overall information to be provided for erosion monitoring consists of a base map of shoreline that is extracted from a digital map including shoreline with state and district boundaries. Different colours and patterns represent shoreline segments with different erosion categories. Information including location, length of shoreline affected, area or number of lots affected, protection measures, description of erosion categories, and a picture of a typical scene of this segment, is associated with each shoreline stretch. GIS data can be used to generate digital maps of shoreline material distribution, critical erosion sites, locations of existing erosion control structures, and land use.

Digital maps integrate spatial and non-spatial data and allow flexible queries. Specific information can be obtained by clicking the mouse on the segment one is interested in. The comprehensive integration of available data, the queries, and the analysis of the information across geo-referenced layers are efficiently used for erosion monitoring, analysis of erosion causes, and shoreline management.

Coastal Engineering

The coastal engineering subsystem covers functions related to additional operations discussed previously. In this GIS environment, basic data for coastal engineering design such as topographic data, bathymetric data, and locations associated with time series data are geo-referenced in an unique system, disregarding the effect of scale and projection. For example, a digital topographic/ hydrographic map can be overlaid with a cadastral map and an erosion condition map to find lots and parcels to be affected by coastal erosion. Design of a coastal structure may be accomplished on the screen, in an interactive mode. River mouth dredging can be planned more efficiently using GIS because this system provides an unique environment for interactively defining the dredging boundaries (locations to be dredged precisely) monitoring dredging progress, dredge disposal and representing post-dredging survey results.

Coastal engineering involves operations such as structure design, coastal zone management, coastal project monitoring, river/creek mouth dredging design, and modeling. Specific coastal engineering and modeling software packages are usually not provided by a commercial GIS software system, and, therefore, need to be integrated in the GIS environment. Some of the modules developed by Danish Hydraulic Institute for modelling can be integrated to GIS Arc View through a module called MIKE INFO Coast to represent all sorts of the data. Otherwise, simple public domain modules can be linked to GIS like Refraction-Diffraction program that shows wave energy concentration along the shoreline. However, generalization of these modules for other areas is a difficult task because the variables are site specific and needs expertise.

Coastal Data Inventory

The GIS is also a central coastal data inventory unit. If digital data are available from various sources will be directly stored in the database. For digital data, that are very large and not of spatial nature such as time series data, a metadata file may be stored instead of the actual data set itself. The metadata supply the information such as data collector, reference system, datum, date of collection, format for retrieving, storing site, availability and contact person. With this meta information, users would be able to have an overview of the data and know how to request. This is also beneficial to data collection planning.

8.1.3 Shoreline and Related data

To support the functions described above, various types of data are required. Because data acquisition and database generation are often the most expensive and important, existing data (both in digital or hard copy format) should be integrated into GIS. Considering the nature of this coastal GIS, the following data can be included in databases:

Shoreline history: Aerial photographs of the entire country's shoreline should be taken every five years in order to accumulate data for monitoring long-term shoreline changes (Stanley 1985, Li 1995). In areas with severely eroded shoreline segments, large-scale aerial photographs should be taken more frequently, i.e. every 1 to 3 years. Large-scale photographs may be used to calculate shoreline and periodical changes, as well as for other purposes such as coastal zone topographic mapping. Seasonal data on Beach profiling, crest of berm and erosion patterns should also be considered.

Bathymetric data: These data can be obtained from hardcopy nautical charts of 1:125,000 and 1:150,000. Charts of National Hydrographic Department (NHD) and some local authorities are valuable source for studying morphological changes.

Topographic data: Topographic maps of 1:50,000 maintained by the Survey of India can be used for interpretation of land use changes near coastline.

Attribute data: Attribute data, such as information on demographic trends, land use, geology, soil types, and quality of the environment, are necessary when planning for setbacks, to protect residential areas, CRZ limits to avoid environmental impacts, and for other purposes.

Multimedia data: These can be built using terrestrial and aerial photographs (which are invaluable when interpreting erosion status of shoreline segments over periods of time), line drawings, video clips, and results of simulation and animation. In the project described here, hardcopy photos are scanned into the system, and the scanned images are then associated with the features under observation. The multimedia data so created can be displayed via a hot link, by clicking the corresponding features.

Hydrodynamic and Meteorological data: Time series data, such as wave and wind data, water surface elevation data (tides) and daily river discharge data describe the processes affecting the shoreline and other coastal settings. A link between time series and spatial data opens a new way of comprehensive database management based on integrated coastal modeling. In most cases, time series data have the following characteristics: a) the position of a sensor can be treated as a constant, and b) the observation data are large in size and expand rapidly along with time.

Littoral Environment Observations (LEO) and Long term Wave Statistics: Short duration observations for wave, beach slope, longshore current, and water level information collected at LEO sites are compiled and made available for estimation of annual Littoral drift. Data from Wave rider buoy are considered and statistical analysis of 20-minute data records obtained by sampling at every 3 hours is kept in digital form for assessing long term wave climate.

8.1.4 External Design

At this stage, the complex physical phenomenon is simplified to accommodate the requirements of the database generating applications, as information from the dynamic processes is too rich to be all included in a database. The result of the external design is usually a description of existing spatial and attributable data. A list of data categories that should be included in the database is given in Li (1994 and 1995).

8.1.5 Conceptual Design

At this stage, a structure for organizing the data is constructed. Spatial objects are defined as entities and transferred to features in GIS. Attributes are associated with the entities. Associations/ relations are used to describe relationships between entities. To implement the relationship which also checks the consistency of the database. The result of the conceptual design is an Entity Relation (ER) model where erosion-related attributes are associated with stretches of a shoreline organized as a route using Arc Info's dynamic segmentation feature. The model incorporates demographic, land use and other information at the state, district, and parcel levels (Li, 1995). All the data defined in the data dictionary can be used in this model.

8.1.6 Logical Design

In this phase, the ER model is converted into tables, if it is decided that the relational database is to be applied. Usually, each entity or association/relation is converted into a table. However, some tables may be combined into one or split into a number of tables in order to conform to the consistency requirements of standard spatial relational databases. The following are examples of some major tables that can be created at this stage.

Point tables

City (City_ID, Name, Population, Distr_name, State-name…..)
Construct_site (Const_site_ID, Name, Type, Year, Drawing_file, Img_file, Design_file….)
LEO_XY (LEO_ID, X, Y, File_name…)
Airphoto_XY (Airphoto_ID, X, Y, Scale, Meta_name, Img_File…)

Arc tables

Intern_border (Intern_line_ID, Count_I, Count_r, Length…)
Shoreline (Shoreline_ID, From, To, Length, Erosion_categ, Material, Landuse, Distr_name…)

Polygon tables

State (State_ID, Name, Population….)
District (District_ID, Name, Population, State_name….)
Geology (Poly_ID, Geo_categ, Distr_nsme, State_name…)
Landuse (Poly_ID, Landuse, Distr_nsme, State_name…..)

The shoreline table is a line event table defining erosion categories of shoreline stretches in the dynamic segmentation system. One of its advantages is its flexibility in defining shoreline segments. For example, a change in erosion status of the shoreline within one region or state depends on the severity of the erosion. Also, the erosion status of the shoreline changes over time and it needs to be updated periodically.

In a dynamic segmentation model, the shoreline segments can be updated in a route system by setting the measurements (or attributes) of the distances between the origin of the route to the start and end points of the segments, respectively, without breaking arcs and defining nodes. LEO_XY and Airphoto_XY are two point-even tables linking LEO time-series observations and aerial photographs to the GIS. This provides an interface between the GIS and the vast amount of time series data and the images.

8.1.7 Interior Design

The first three database design phases are system independent. In the interior design, however, the functions and capabilities of the hardware and software have to be considered. The spatial data modeling was supported by dBase, ArcCAD (ESRI 1994) and ArcView. The tables that were implemented in the project were designed with the strength and limitations of the hardware and software systems used in mind. In ArcCAD, for instance, graphic data are all stored in an AutoCAD format as drawings. Specific geometric entities or groups could be organized as blocks and layers. The GIS data will be organized according to themes, which are similar to layers in ArcInfo. The graphic data of a theme could be from a drawing file or from an ArcInfo layer. Each theme is associated with a GIS data set where additional geometric data, attributes, and topological data are stored.

9. IMPLEMENTATION

The model described in the proposal is at implementation stage at ICMAM-PD and the some of the findings are indicated with illustrations generated in GIS Environment.

9.1 Erosion Monitoring

The Tamil Nadu State Public Works Department is observing monthly shoreline oscillations from 70's under the monitoring program **Crest of Berm**. The distance of the berm is measured from reference pillar located at a considerable distance from the water point. The trends of erosion / accretion along the Chennai coast interpreted from the above program is shown with background map of NHO chart in the **fig 7**. It indicates the overall pattern of erosion/accretion along the coast. The specific information about the particular site is available at that location which can be represented by polygon.

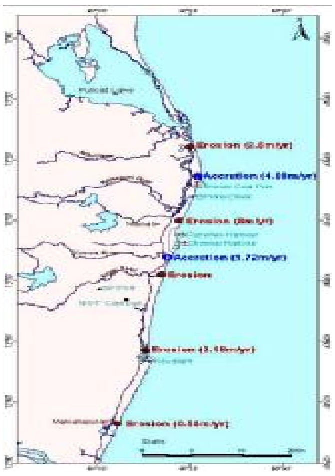


Fig. 7 - Trends of Erosion/ Accretion along Chennai

Fig 8. - Status of shoreline at Ennore

The above program can be further extended to cover beach profiles upto water depth of 7 m and +1.0 m on landside. ICMAM-PD has undertaken a field program in association with the Institute for Ocean Management, Anna University, to study the impact of satellite port on shoreline changes. The beach profile measurements are carried out with high precision equipment Real Time Global Positioning System (RTK). The details of beach plan forms were shown in **fig 8 and fig 9**, and the for different periods near Ennore are shown in **fig 10**. DTM of the shoreline can be generated if fine grid data is available along the coast which will be useful for prediction of extent of inundation during coastal flooding and amount of material lost during storm.

The synoptic overview provided by satellite remote sensing along with its capability of repeated coverage, enables to detect the changes in the shoreline. IRS –1D satellite launched by ISRO provides a spatial resolution of 5.6 m with temporal coverage of 24 days. In the present study, radiometrically corrected data was obtained from NRSA and processed for further analysis. It is a normal practice to undertake geometric rectification using Ground Control Points (GCP) derived from Survey of India (SOI) toposheets, which are available at the scale of 1:25000. As, the rectification based on toposheet is likely to generate error in the order of 30 meters and above, the image is corrected using predetermined GCP points, obtained from the field survey using RTKGPS, which is having an accuracy of sub-meter. The 1998 scene was registered to geographical coordinates using 1st order polynomial to transform the line and column location of pixels to their LAT/LONG locations derived from the map and RTKGPS data. The other images were registered to the Geo corrected 1998 scene. Among the different techniques available to enhance the quality of the image, spatial enhancement with convolution filtering is adopted for determining shoreline features. Image enhancement is the process of making an image more interpretable for a particular application (Faust, 1989). Enhancement makes important features of raw, remotely sensed data more interpretable to the human eye. Convolution filtering is the process of averaging small sets of pixels across an image and is used to change the spatial frequency characteristics of an image (Jensen, 1996). Remote sensing images from 1999 to 2003 are used to monitor the evolution of beach fill. **Fig 9** clearly brings out the configuration of shoreline before fill (1999), after fill (2000) and eroding fill (2003).

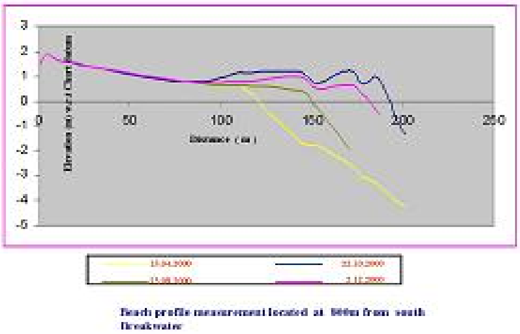


Fig 9. - Evolution of beach fill between 1999-2003

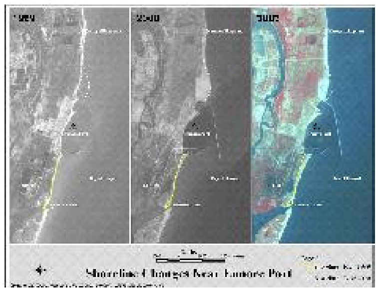


Fig 10 - Beach profiles south of Ennore Port (Cross section at typical transect located 800 m from breakwater)

9.2 Coastal Engineering

Coastal Engineering involves many operations such as structure design, river / creek mouth dredging and modeling. The importance of river / creek dredging and numerical modeling for prediction of morphological changes due to construction of Ennore port is explained through following examples.

9.2.1 Inlet/ Creek dredging

Due to construction of Ennore port, the beach south of port is accreting with rate of 10 m per anum. As a result of this accretion, Ennore creek that is 2.6 km from the south breakwater is experiencing siltation due to north born littoral drift. Tamilnadu state electricity board (TNSEB) resorted for continuous dredging by deploying two dredgers. The monthly rate of dredging is shown in **fig 11**. This clearly indicates that the littoral drift rate is low during NE monsoon (October to February). This information together with other coastal engineering data is useful for estimating littoral drift, identifying disposal site for dredging and for planning beach nourishment in the areas where sever erosion is taking place.

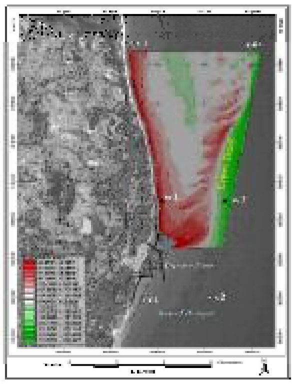


Fig 11. - Plot showing the dredging rate at Ennore Creek

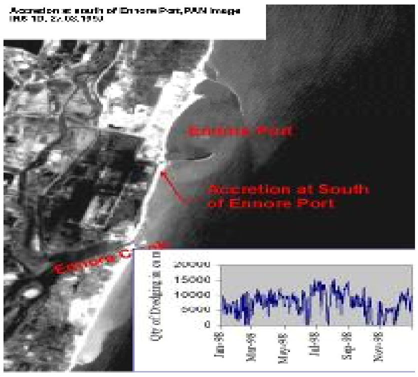


Fig 12. Shoals at Ennore

The coast north of Ennore port is protected by naturally formed shoals. These shoals extend upto length of 14 km with its width varying between 500 m to 1500 m. The configuration of shoals generated in GIS is shown in **fig 12**. The reason formation shoals can be attributed to difference in longshore sediment transport rate due to change in orientation of coast. Construction of satellite port is expected to alter the circulation and sediment transport pattern north port, thereby the shoals may experience erosion. The erosion of shoals will lead to increased wave attack on coast north of port resulting erosion.

9.3 Coastal data Inventory

The data on waves, tides, currents, beach profiles, bathymetry, dredging and sediment characteristics is useful for modelling and planning interventions. The data on above parameters can be stored with location under coastal project (MIKE INFO COAST, DHI).

References

1) Li, R., 1998, A Coastal GIS for Shoreline Monitoring and Management – Case study in Malaysia.
2) Pathic , J.,1984, An Introduction to Coastal Geomorphology, Arnold- Oxford University Press, p.259.

4. APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEM (GIS) IN INTEGRATED COASTAL AND MARINE AREA MANAGEMENT

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I. INTRODUCTION

The coastal zone comprising the coastal land of marine influence and the coastal water influence by hinterland activities, is one of the most dynamic areas supporting a variety of natural and human related activities. Management of the activities prevailing in the coastal zone like human settlement, industrial and port operations, recreation, fishing etc. is one of the most complicated and difficult tasks. Each activity fall into one or more sectors and operation of these activities do create impact on the other activities. These activities if planned in isolation and not implemented in consonance with other activities will lead to severe degradation of ecology of the coastal and marine areas. Further the coastal zone inhabits specialized ecosystem like mangroves, coral reefs, breeding and nesting grounds of endangered species like turtles, dugongs etc. If the coastal zone activities like construction of ports etc., are carried out without properly understanding the process that play a vital role on the impact of constructing manmade structures, it might affect the ecology of ambient ecosystem especially the coral reefs and mangroves, thereby causing the degradation/loss of these habitats. Therefore, a thorough understanding of the processes and other phenomena prevalent/operating along the coastal and marine ecosystem is extremely essential to minimize damage to the coastal ecosystem.

It is essential to use appropriate tools and techniques to understand the processes and phenomena that are operating in the coastal and marine environment. Several advancement in the development of these tools and techniques have taken place over the years which include development of modelling software to understand the role of coastal process in studying the impact of structure of ports and harbours, disposal of wastes in the sea and tools like Remote Sensing to have a glimpse of the latest status of coastal land and the Geographical Information System (GIS) to collate, display and analyze the data and present the information in an user friendly manner. Further, for effective use of these tools and techniques, the nature of the coastal zone, the ecosystem prevalent, the multiple use of coastal zone for several activities and their impact on coastal and marine environment are essential. The details of coastal ecosystem and coastal activities along the coast including their impact on the ecosystem are given below:

2. COASTAL ECO-SYSTEMS

India has a coastline of 7516 km. It has an Exclusive Economic Zone of 2.02 Million Sq. Km. Out of its 940 million population (as of 1999), nearly 20% live in the coastal areas. Many highly populated and industrialized cities like Mumbai, Chennai, Kolkata, Cochin, Visakhapatnam are located along/near the coastal areas. There are 12 major ports and a number of minor ports handling shipping to various degrees of intensity. The coastline of the mainland falls under the divisions of 9 States and two Union Territories. The coastline of islands of Andaman, Nicobar and Lakshadweep (Laccadives) group of islands constitute nearly 2000 km.

The details on various coastal ecosystems, environmental problems due to prevalence of various activities and management needed are given below:

Coastal wet lands

Along the Indian coastline, the brackishwater areas including marshes, backwaters, mangroves, inter- and sub-tidal measures about 14,16,300 hectares. These areas act as feeding and nursery grounds for a variety of commercially important fish, prawn and crabs, media for inland transportation, fishing etc.

Mangroves

Along the Indian coast mangroves are found along the islands, major deltas, estuaries and backwaters of the East Coast of India. They also exist along the oceanic island groups of the Andaman and Nicobar. The total mangrove area is estimated to be 6,81,976 hectares. While the mangroves along the West Coast of India are dense, they are scattered and comparatively small in area along the West Coast. Gangetic Sunderbans (418,888 ha), Andaman-Nicobar Islands (115,000 ha), Krishna, Kaveri and Godavari deltas and Mahanadi delta are some of the best mangrove formations of India.

There are about 45 mangrove species along the Indian coast. The dominant genera are *Rhizophora, Avicennia, Bruguiera, Sonneratia, Canocarpus, Heretiera, Xylocarpus, Ceriops* and *Excoecaria.*

Mangrove forests mainly function as the most ideal spawning, breeding and nursery grounds for nearshore estuarine organisms like fishes, crabs, prawns, molluscs, etc. Some of the common and economically important species are *Mugil cephalus, Hilsa ilisha, Lates calcarifer, Scylla serrata, Meretrix casta, Crassostrea grephoides* and *Penaeus* spp.

Apart from the captive and culture fisheries, mangroves are also important as “Coastal Stabilizers” and “Shelter belt areas”. These formations protect the coasts and the landward areas from erosion and cyclonic destructions to some extent. Apart from these, the mangrove forests of India have importance from a wildlife, recreation and education point of view. “Project Tiger” of Sundarbans and “Crocodile Sanctuary” in the Mahanadi delta are examples of such activities.

Coral reefs

Around India, coral reef formations are found in the Palk Bay, Gulf of Mannar, Gulf of Kutch, Central West Coast of India, Lakshadweep atolls, and Andaman-Nicobar Islands. Both the coral atoll and the fringing coral reefs are of utmost significance in Indian waters. A few species of corals have recently been reported from the Malvan (Maharashtra) coast. 32 genera from Minicoy Islands, 34 genera from Palk Bay and Gulf of Mannar, 25 genera from Andaman Islands, 9 genera from Lakshadweep and 3 genera from Nicobar Islands have also been reported. 342 species belonging to 76 genera from the seas around India have been described.

Primary productivity studies of coral reefs in Indian waters indicated comparable rates with other reefs and marine ecosystems. Often the large benthic algal communities and extensive seagrass beds are equally important as the energy released from them is transferred to higher tropic levels by way of the detrital food chain.

Marine National Parks, marine sanctuaries

On account of their high bio-diversity, the Gulf of Mannar and Wandoor (Andaman) have been declared as Marine National Parks and Malvan coast (Maharashtra), Gulf of Kutch, Jamnagar as Marine Sanctuaries. There are a number of other specialized ecosystems which exhibit a large variety of marine life and they include Chilka and Pulicat Lakes, Point Calimere, etc.

3. ACTIVITIES IN MARINE AREAS, ENVIRONMENTAL PROBLEMS THEIR IMPACT ON MARINE ENVIRONMENT

(i) Land-based activities causing pollution

(a) Disposal of Domestic Sewage

Demographic pressure in the urban cities and towns has resulted in the production of enormous amounts of domestic waste materials. These materials reach the marine environment either directly or indirectly through rivers, creeks, bays, etc. The domestic sewage contributes to the largest amount of waste and it has been estimated that approximately 21600 Million Litres per Day (Figures as on 2000) reach the coastal environment of the country. These wastes predominantly contain degradable organic matter, which utilize enormous amount of oxygen from seawater for its oxidation. The low oxygenated seawater leads to decrease of population of flora and fauna.

Domestic wastes are discharged mostly in untreated conditions due to the lack of treatment facilities in most of the cities and towns. It has been reported that only primary treatment facilities are available in cities and towns where the population is more than 100,000 and the capacity of the plants is not adequate for the treatment of the total waste generated in the city. As a result, the chemical characteristics of the wastewater retain almost their original features and cause damage to the environmental water quality.

Due to the disposal of wastes from the land into the sea, which is predominant at present in Bombay, Madras, Visakhapatnam, Calcutta and Mangalore, not only the ecology of the marine environment in these areas is disturbed but also its impact is likely to be carried to the other areas due to the prevalent pattern of coastal circulation. For e.g., the strong northerly drift during November to December prevalent along the Gujarat coast causes movement of water from the Gulf of Cambay moves up to Sutrapada. Since the Gulf of Cambay is one of the zones of high drainage of pollutants from the nearby estuaries, it is quite possible that the wastes discharged into the coastal waters are carried out to the northern region. It is well known that the Saurashtra coast is rich in fishery resources. Even though the pollution problem in the coastal waters of Gulf of Cambay is not very serious at present, considering the population explosion and rapid industrialization in that area, continuation of the dumping of pollutants in the Gulf of Cambay in the subsequent years might lead to pollution along the Sutrapada coast, affecting the fish production by way of mortality of juveniles which are sensitive to pollutants.

(b) Discharge of Industrial Waste

India is one of highly industrialized nations in the world. Major industrial cities and towns of the country such as Surat, Mumbai, Cochin, Chennai, Visakhapatnam and Kolkata are situated on or near the coastline. The total quantity of wastes discharged by these industries is estimated to be 0.67×10^9 cu.m (Figures as on 1994).

While the major industries discharge treated effluents into the sea, numerous small and medium scale industries discharge the untreated effluents into the adjoining wastewater canals, municipal drains, creeks, etc. The industrial effluents containing toxic metals like mercury, cadmium, Lead, Arsenic etc reach the human through edible fishes. The metals like mercury cause several muscular ailments in the human.

(ii) Other activities causing environmental problems:

(a) Developmental activities like construction of ports, breakwaters, etc.

The coastal engineering studies have revealed that the construction of breakwaters alter the sediment transport mechanism in the coastal areas, thereby causing erosion and accretion, depending on the direction of the littoral drift. The effect of accretion will be siltation in the areas where coral reefs are abundant. Such siltation completely covers the coral bed causing the mortality of coral polyps, ultimately leading to destruction of the coral environment. Erosion leads to loss of land which, probably, is used for coconut plantations, etc. Erosion in the mangrove areas leads to decrease in the density of mangroves. Erosion in the riverbed and the channel areas cause eutrophication in the coastal waters, etc.

(b) Impact of dredging of the ocean area for maintenance and deepening the navigation channels

Deepening of navigation channels for ensuring adequate draft to the vessels is one of the essential aspects in major ports. Before initiating the dredging, generally the port authorities conduct model studies to locate sites for disposal of the dredged sediments. These are mostly non-biological models and give solutions for dispersal of dredged sediments away from the dredged area so that there is no immediate accretion of sediments in the navigational channels. However, such models do not give any impact of dredged sediments on the marine life.

Studies conducted have revealed that in the mouth of estuaries and in the outer port limits where normally the dredging is done, the dispersed sediments increase the concentration of suspended matter in the ambient water which may cause mortality of filter feeders like clams. In fact, in most of the areas where the dumping of dredged sediments occur, the area is devoid of filter feeding animals. This leads to reduction in biodiversity in that area.

(iii) Sea-based activities causing environmental disturbances and pollution

(a) Offshore oil platforms:

The oil platform discharge operational wastes like mud slurry into the surrounding environment, which contain trace amount of oil also. The slurry, when introduced into the marine environment, causes mortality of the organisms in the ambient marine environment due to lowering of oxygen levels in the surrounding areas. This effect is significant in productive waters like the West Coast of India. A fair amount of primary production has been recorded in the West Coast of India, wherein the offshore platforms do operate. However, such disposal will cause insignificant impact on the deep offshore areas, particularly in oligotrophic waters.

(b) Navigation by ships, tankers, etc.:

The western part of the Indian Exclusive Economic Zone, i.e. Arabian Sea adjoining peninsular India, forms the main international tanker route for oil tankers originating from the Gulf. It has been estimated that some 434 million tonnes of crude oil is transported annually along this route, involving approximately 2500 laden tankers. The preferred route is through the 9^{o} channel between the Maldives and Lakshadweep Islands, during the Southwest monsoon (May to September), and north of Lakshadweep following the 200 metre depth curve west of Mangalore, at other times. Considering the large volume of oil transported and high rate of tanker movement, the probability of tanker accident is high. The last major accident in the area occurred in Jan., 1993 and a few tonnes of oil spilled in the Andaman Sea. During the southwest monsoon, oil spills occurring between 68° E and 76°E, will tend to drift towards the Lakshadweep Islands and Kerala coast. At other times oil spills could threaten the Lakshadweep between December and February and the Kerala coast during March and April. Any accidental spillage of oil along the tanker route will cause severe and in some cases irreparable damage to the marine ecosystem. Similar damage would be caused if accidents take place during the southwest monsoon seasons. In addition, offshore oil exploration and production activities, the transfer operations of oil at single buoy mooring stations, as well as in lightering operations and during bunkering operations in the major ports and at Single Point Mooring (SPM) in Gulf of Kutch, also cause spillage of oil particularly during accidents. Besides such oil transfer facilities in India, the lightering operations carried out in the rest of the South Asian countries may also be the additional sources of oil pollution to the Indian waters especially during accidents.

Impact of oil spill on the marine environment

The extent of damage caused by an oil spill depends upon the quantity of the oil spilled, type of oil involved in the spillage and the oceanographic and meteorological conditions prevailing in the location where the spill has occurred. Immediately after a spill, oil spreads on the sea surface at the rate of 3% of the prevailing wind speed. Having lower surface tension than seawater, oil will spread faster than the flow of water under it. The lighter fractions of oil, carbon numbers less than C_{12}, comprising around 40%, will evaporate during the 24 hours immediately after a spill. Photo oxidation by solar UV radiation will account for a maximum of 1% per day of the total volume spilled. The heavier fraction will be broken down by oil degrading bacteria, naturally occurring in seawater. The maximum possible rate for this is 2 $gm^{-2}d^{-1}$. A part of the oil will also be oxidized by the dissolved oxygen at the rate of 1 mg oil per 3 mg oxygen. Barely 1% of the spilled oil may get dispersed, suspended or dissolved in water. All these processes proceed quite fast in warm water. One can, therefore, optimistically presume, in warm tropical waters roughly half of the spilled oil will disappear during the first 24 hours after an oil spill. Of course, this amount will vary with the varying density and viscosity of the oil at its source. The surface phytoplankton gets completely decimated after a spill. Zooplankton population will also be affected because of the availability of excess oil as they can ingest and excrete oil. But this process has been observed to last 3 to 4 days only.

When the oil spills in large quantity, it temporarily affects the air-sea interaction, thus preventing the entry of oxygen from atmosphere. The first set of organisms to be affected are the primary producers like phytoplankton which is the basis of the marine food chain. The other free-swimming organisms such as fish larvae, fish, etc., also get affected. When they come in contact with the oil, the gill region of the fish get clogged by the oil, which affects the respiratory process in fish, leading to their death. However, this is uncommon among fast swimming fishes. In case the oil spill occurs in an enclosed area and if the spill remains undisturbed in the surface by winds and other oceanographic conditions, the underneath water becomes deoxygenated due to the absence of air-sea interaction. This deoxygenation apparently causes mass mortality of inhabiting organisms due to obvious reasons of lack of adequate levels of oxygen for respiration. Further, when the oil sinks during the course of time, it affects the benthic organisms such as clams, mussels, etc., as the tar particles get deposited in the mantle of these organisms which arrests their physiological activities including respiration. The operational discharges from ships and tankers do not cause any large-scale damage to planktonic organisms. However, if the traffic is more close to coral reef ecosystems, the thin film of oil formed on surface is likely to prevent air-sea interaction resulting into decrease of oxygen which will have an adverse impact on the survival of corals and other associated organisms.

Even though very few oil spill incidents had occurred in Indian waters, the damage caused to the marine environment on such occasions was alarming in one or two cases for e.g., when the American tanker “Transhuron”, carrying furnace oil, ran aground spilling about 5,000 tons of oil on the shores of one of the Lakshadweep group of islands, viz. Kilton Islands. Investigations revealed that mass mortality of corals, lobsters and crabs occurred. The recent incident of rupturing of ONGC pipeline resulted into deposition of tar residues of oil along 3 km in Murud beach giving unaesthetic appearance and also causing mortality of micro and meiofauna.

During the oil spill accidents, a layer of oil gets coated on the surface of the fish, which makes it as unacceptable for human consumption. The fishermen who happen to get only such kind of fish catches during the oil spill incidents are affected economically.

Other effects

Besides its deleterious impact on marine ecology and also socio-economy of fishermen, the oil spills do cause operational problems to several coastal industries like power plants, coastal refineries as well as shipping.

4. THE APPLICATION OR CONCEPT OF INTEGRATED COASTAL AND MARINE AREA MANAGEMENT (ICMAM) TO ADDRESS PROBLEMS IN THE COASTAL AREAS.

Due to complexity of activities prevalent along the coastal land and marine environment, an integrated management of these activities in a coordinated manner through appropriate planning exercises would provide a solution to minimize inter/ sectoral/cross sectoral activities. For e.g. construction of ports/ harbours/ breakwaters without considering the suitability of the site may lead to damage to surrounding ecosystem which may be a brackishwater lake or tourism beach or habitat for endangered species. Similarly disposing waste from domestic/industrial areas close to recreation facilities like beach resort or areas of ecto-tourism will affect the economy derived from the tourism and related activities. Adoption of ICMAM avoids such conflicting uses and other detrimental effects.

ICMAM can benefit a country or region through any or all of the following:

1. Facilitating sustainable economic growth based on natural resources.
2. Conserving natural habitats and species.
3. Controlling pollution and the alteration of shorelands and beachfronts.
4. Controlling watershed activities that adversely effect coastal zones.
5. Controlling excavation, mining and other alteration of coral reefs, water basins, and sea floors.
6. Rehabilitating degraded resources.
7. Providing a mechanism and tools for rational resource allocation.

To accomplish its objectives, ICMAM requires several national actions, including the following:

1. A policy commitment to support coastal resources management and environmental conservation.
2. Achieving an understanding on resources and environmental objectives among the various coastal stakeholders.
3. An effective coordination mechanism among government agencies
4. Initiation of a system for review of development projects, including environmental assessment.
5. Accumulation of technical information.
6. Design and development of effective planning and management programmes with the aid of scientific tools and techniques.

GIS as a scientific tool for Coastal and Marine Area Management

As said earlier, the scientific based management tools to analyze various coastal problems/issues are, Computer based modeling, Remote Sensing, GIS, etc. GIS is a powerful tool to assemble the data on various aspects of the coastal zone. It has the ability to handle much larger data bases and to integrate the Synthesize data from a much wider range or relevant criteria than might be achieved by manual methods. This indicates that more balanced and coordinated management strategies may be developed for considerably longer lengths of coast. The GIS is being extensively used in the following coastal and marine related applications, which mostly encompass the problems stated in, section 3.

1. Inventories of Resource Distribution, location of ports, recreation areas, water bodies, land use features, biological organisms etc.
2. Monitoring of shoreline due to seasonal accretion/erosional problems
3. Mapping of low lying areas for protection against floods and storm surges, natural resources (like corals, mangroves)
4. Monitoring the movement of the oil spills especially close to the ecologically sensitive areas like coral reefs, mangroves etc.
5. Display of model outputs especially on sea level changes, behaviour of wave parameters on coastal areas etc.
6. Understanding the relationship between resources and environment and other parameters that affect the resources. The overlay facility/function available in the GIS Software enables to make the study of such a relationship.

Several examples can be shown to demonstrate the application of GIS on the above aspect. They are:

(a) GIS in Inventories

Inventories on proportion of the mangrove areas and associated ecosystem and the infrastructure available can be used to display in the GIS, which help as a ready reference to various aspects of the habitat. The figure below (Fig.1) shows the distribution of mangrove areas in Coringa of Andhra Pradesh along with other details of location of villages, landuse, rivers, road network etc. Such an information reveal the nature of land use prevalent which might influence the mangrove ecosystem and other facilities available around the mangrove area, which may help in promoting the eco-tourism, fisheries, trade etc.

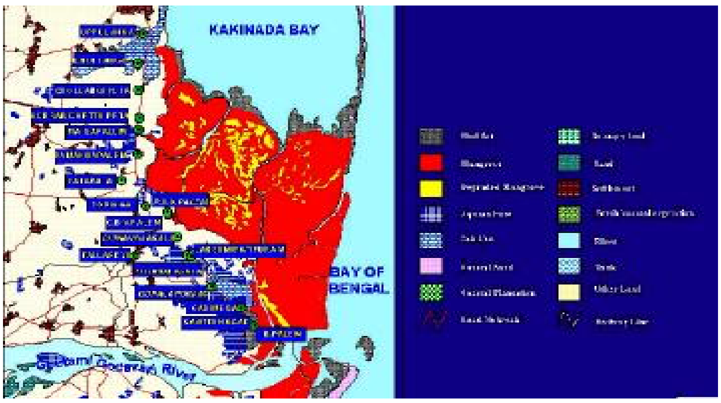


Fig. 1 Mangrove and adjoining areas of Coringa

(b) GIS for Land-use Management

The figure below (Fig. 2) indicates the type of land that are prevalent along the fast developing city like Chennai, which help planners to understand the type of land available for future expansion and also to maintain the sustainable utility of these resources in the long-term.

The figure below (Fig. 3a) pertains to land-use available along the East Coast road close to Chennai which have been attracting tourism industry. The area has rich underground aquifers, which is one of the major drinking water sources for the Chennai City. Fig. 3b indicates recharge potential of these areas. An overlay of recharging potential of soil of these land cover, indicate areas falling under different recharge categories (Fig. 3c). This helps in avoiding development of large concrete based tourism establishments in the highly rechargeable areas.

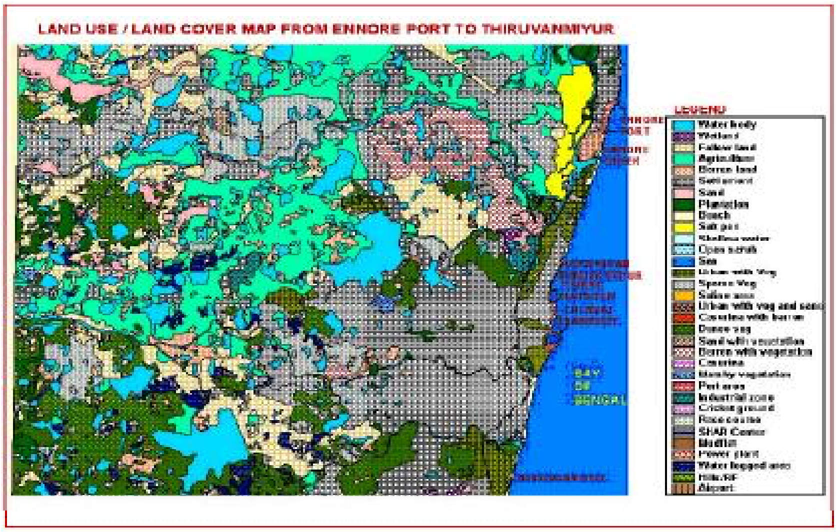


Fig. 2 Land use/Land cover of Chennai and Suburbs

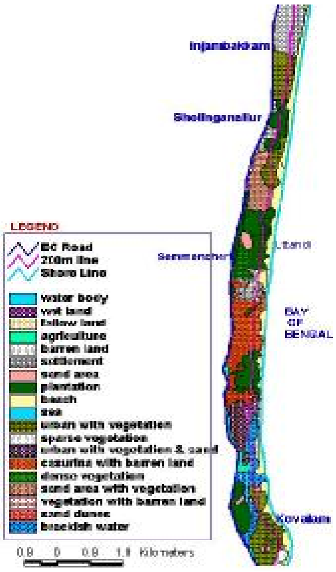


Fig. 3a Land-use/land cover along East Coast Road

Fig. 3b. Recharge potential

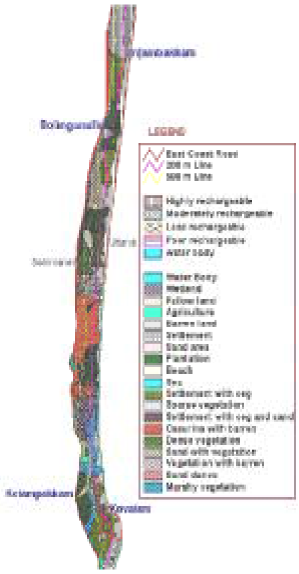


Fig. 3c Overlay of landuse map and water rechargeable areas from Injambakkam to Kovalam

(c) GIS in shoreline changes studies

GIS has been extremely useful in studying the shoreline changes particularly in areas where the seasonal reversal of littoral drift occur. This is prominent in the coastline especially where the near shore obstruction like breakwater of ports and harbours etc. exist. The figure below (Fig.4) shows the influence of breakwater on the shoreline changes, south of newly built Ennore Port (Chennai) causing accretion on the beach. The GIS software helps to measure accurately the extent of accretion and its exact location along the coast of the area. The displays shows extension shoreline within 500 m from the breakwater as 75 m in April 200, 147 m in Aug, 2000 and 128 m in October 2000. It also helps in the management of the shoreline changes by way of facilitating the display of model outputs over the existing shoreline which would enable the Coastal Engineer to understand the extent of utility of the model output.

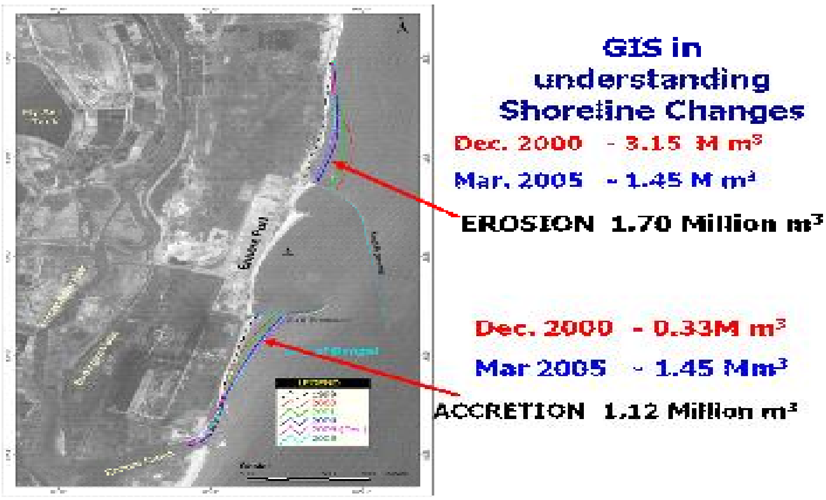


Fig. 4 Seasonal variation in shoreline changes at Ennore

(d) GIS in Mapping of natural resources and hazard areas

GIS is extensively used in mapping of natural resources like corals, mangroves, fishery resources, areas prone to inundation in the event of flood, cyclone etc. The figure given below indicates the extent of distribution of live corals of the Mandapam Group of Islands in the Gulf of Mannar. The overlay facility enables super imposing of depth contours.

around these islands. This enables the Resource Manager to understand the extent of distribution of live corals against the depth. Such an inventory-based mapping is very useful to exercise preservation, conservation and regulatory measures in the coral reef areas.

GIS is useful in understanding inundation of the extent of seawater into the coastal land area during cyclone and mapping of low-lying areas. The Nellore to Machalipatnam area along the Andhra coast is a low-lying area (Fig. 6a) and is prone to cyclonic effects. The map below (Fig. 6b) indicates the extent of inundation of during storm surges with a height of 3.1 m along the coastline of these areas. The inundated area was estimated to be about 1207 sq.km with varying distance from the coast. Such an output is helpful in planning several preventive and remedial measures, when such calamities occur.

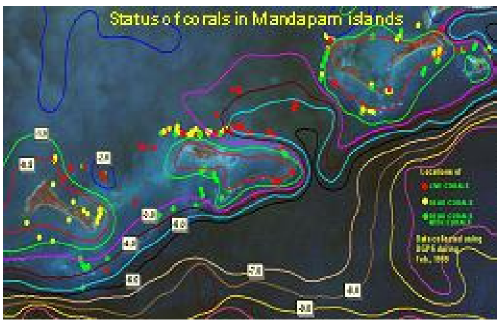


Fig. 5 Distribution of live corals around the Mandapam group of islands in Gulf of Mannar with depth contours

Fig. 6a Map indicating Nellore to Machalipatnam

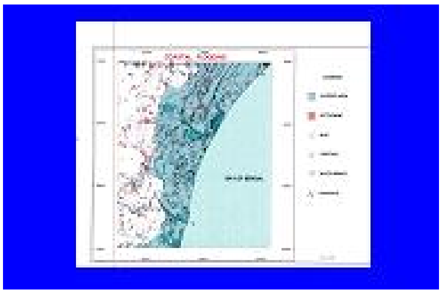


Fig. 6b Flooding of low lying areas in the event of storm and flooding

(e) GIS in studying effect of Oil spills

GIS is used extensively all over the world to understand the movement of the oil spills especially close to the ecologically sensitive areas like coral reefs and mangroves. This would clearly indicate the extent of the area that would be affect in the event of such spills. The figure below indicate the simulated oil spill in Gulf of Kutch (Fig. 7a) and their landing along the coastal areas including coral reefs and mangroves after a period of 96 hours (Fig. 7b). In this case, GIS is used an illustrative presentation tool of model output which was performed using the modelling software Mike 21.

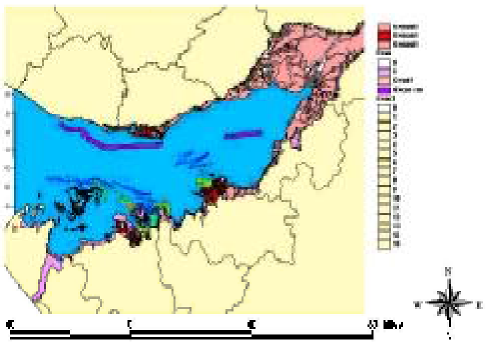


Fig. 7 A Output of oil spill models in GIS

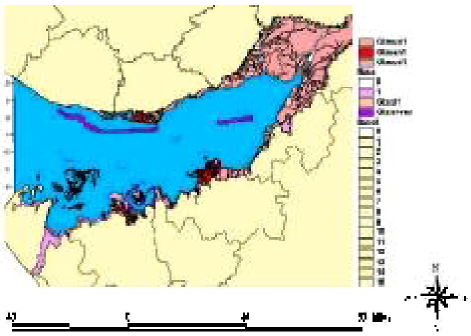


Fig. 7b   Showing spilled oil reaching close to coral reef areas after 96 hrs

Such an output is useful in taking preventive measures like deployment of oil containing devices like booms to protect these resources.

Data needs of GIS for Coastal Zone Management

The use of GIS in the coastal zone management including management of critical habitats demand extensive data generated through a database. Application of GIS depends on data from primary resources, which can be obtained by direct methods like field investigation on parameters such as tides, currents, water quality, and population of biological organisms of the area. In order to facilitate representation of the data, especially in a spatial manner, the secondary data such as maps, satellite/remote sensing data with reasonable accuracy in resolution are needed. There are several types of databases that can be used in GIS and some of these are:

1. Basic geodetic or planemetric data, which establish the geographic referencing system, caused such coastal entities/processes of interest may be placed.
2. Topographic data, which records locations and distribution of land and cultural factors (beaches, cliffs, dunes, roads, settlements, harbours etc.).
3. Qualitative and Quantitative data which provide further information about the properties of parameters such as grain size of sand/sediment on a beach morphodynamic indices, tidal range especially in ports population of organisms etc., of coastal entities and phenomena.
4. Time series data which allow temporal databases to be prepared and information to be gleaned about the variability of coastal entities, attributes and relationships in both space and time;
5. Metadata, which allow estimate of currency, history, ownership and reliability of information, desired from the system.

Difficulties in gathering data in coastal areas

The coastal and marine areas being complicated due to operation of several dynamic phenomena like waves, currents etc., cause severe operational difficulties in collecting the data required for understanding the role of these parameters, especially the role of coastal process on coastal structures, and waste disposal. Globally the data on marine related parameters are scarce. This become complicated by non-accessibility of the data collected by various agencies on physical parameters for strategic and commercial considerations. For e.g. large scale maps used by the Defence establishments are non-accessible to the civilian agencies which need these maps/data to study the impact of cyclones and floods on the inundation of sea water/flood water in the land areas especially to know the extent of the land infrastructure, settlements and other resources that will be affected during such occasions. This is true not only in developing countries but also in the developed nations.

The other difficulties experienced with respect to the need for data to be used in GIS is the coastal mapping, which is the basic necessity for all possible information/model outputs in GIS. Lack of adoption of standards in the scale of the maps that are used by several agencies, make the GIS applications more complicated.

Several research on use of data for GIS applications are still in progress. Even though considerable progress has been made to display the spatial data (mostly satellite based data), basic research need to be done into spatial – temporal reasoning. Once these problems solved, it will help in several operational applications of GIS, which would effectively help in the management of the coastal and marine areas.

Conclusion

The field of application of GIS for coastal management has proved its utility in its present capabilities which enables the Coastal Managers to use this tool for effective management of various phenomena like erosion, oil spill, resource inventory etc. The marine application of GIS is being challenging, demands greater R&D on application of this tool in the coming years.

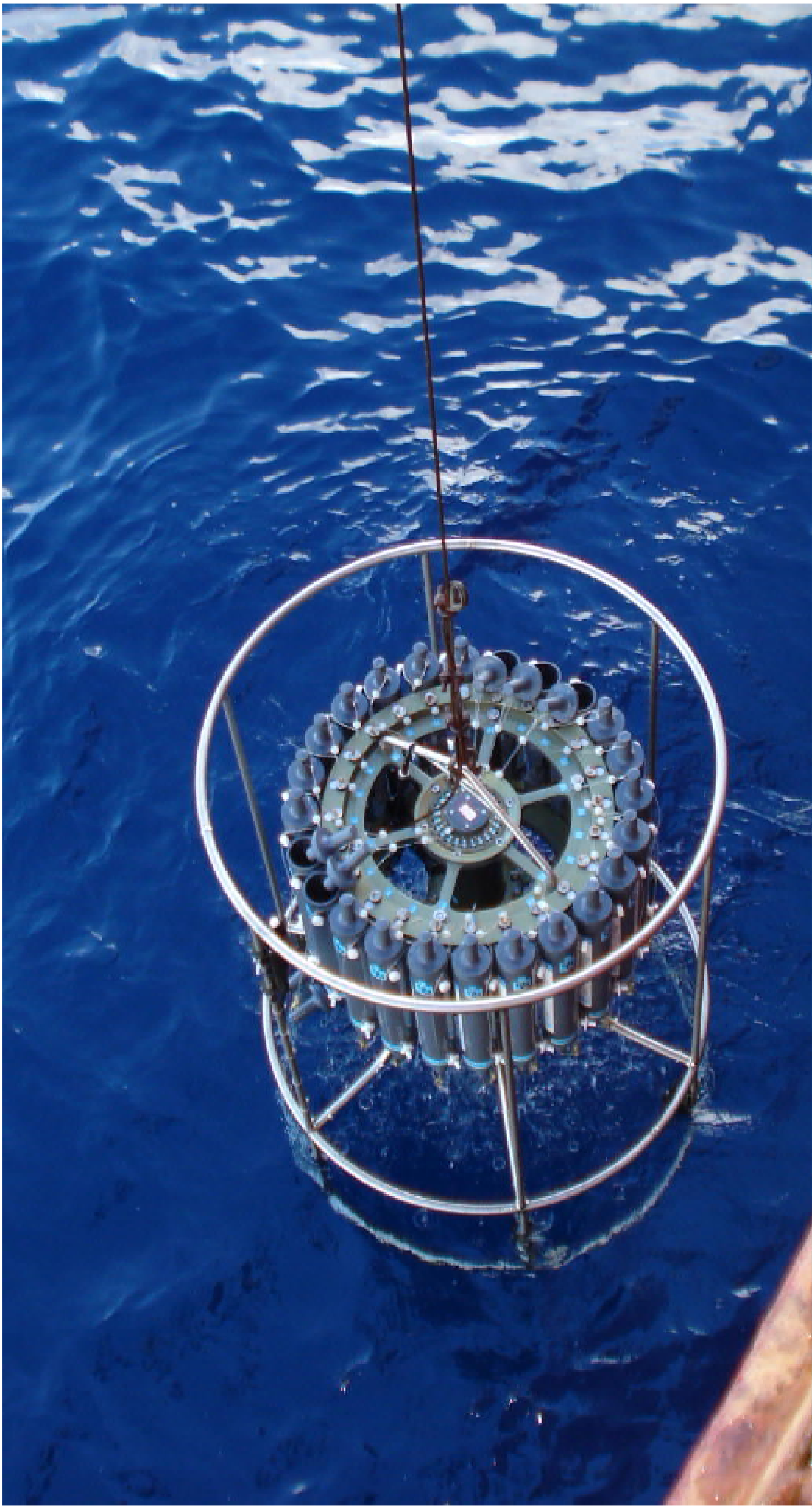
The use of GIS for coastal and marine applications is largely related coastal land environment except that of coral reef mapping. The present paper shows a few examples of application of GIS for Coastal Zone Management. Considering its utility for coastal management, there is an urgent need to develop methodology for a variety of marine applications including the 3D GIS. A few attempts have already been in this direction and further research is needed in the future.

References

1. GIS and Coastal Zone Management 2001, Association for Geographic Information
2. Resources Information System for Gulf of Mannar (India) 2001, ICMAM Project Directorate, Department of Ocean Development, Chennai, India
3. Dr. Latha, A forecasting model for Storm surges and estimation of coastal inundation along the East Coast of India; Vol. 2, 2000, NIOT, Chennai, India
4. Carrying Capacity of Tourism development along East Coast Road (Thiruvanmiyur to Cheyyur), 2000, ICMAM Project Directorate, Department of Ocean Development, Chennai, India

Recommended Reading:

1. Coastal Zone Management Hand Book; John R Clark; CRC Press; 1995
2. Environmental Modelling with GIS; Michael E Goodchild; Oxford University Press; 1993



OCEAN – DATA COLELCTION

The marine environment is facing a multiplicity of challenges. Some, such as the decline in fish stocks and land-based sources of pollution are persistent ones. Others, from the emergence of 'dead zones' and the impacts of climate change including acidification are rapidly emerging ones. Indeed experts now estimate that up to 40 per cent of the C02 entering the atmosphere is being cycled through the marine environment, thus playing a crucial role in moderating climate change. A systematic assessment process is long overdue. The oceans' play a vast role in countering climate change - they are our 'blue' forests.

Achim Steiner, UN Under-Secretary General UNEP Executive Director

5. A BRIEF INTRODUCTION OF SCIENTIFIC VESSEL O R V SAGAR KANYA

Rasik Ravindra and M.M. Subramaniam
National Centre for Antarctic & Ocean Research, Goa, India

Oceanographic Research vessel (ORV) ***Sagar Kanya***, a multidisciplinary ship was built in Germany under the joint efforts of Indian and German partners within the framework of Indo-German Economic Cooperation. Commissioned in the year 1983, the vessel is a versatile ocean observing platform equipped with technologically advanced scientific equipment and related facilities. The vessel has been built in conformity with highest class requirements of "Lloyd's Register of Shipping" and "Indian Register of Shipping". The vessel is fully automatic diesel-electric type equipped with fin stabilizers improving the behaviour of the ship in rough seas. In addition to the twin-screw propulsion two fin rudders and one bow thruster will give the vessel excellent maneuvering ability. As our endeavor to upgrade the vessel with state of art facility the ship was recently augmented with Dynamic Positioning (DP) System and retractable Azimuth thruster. This enables the vessel to be stationary at a place where the observations are being taken.

The vessel is capable of carrying out Geoscientific, Meteorological, Biological, Physical, Chemical Oceanographic and Atmospheric Research as major disciplines. It provides a stable platform that is capable of operating under all weather conditions including the Southern latitudes. The ship is provided with all facilities to perform its tasks with the greatest possible efficiency worldwide voyages up to 10,000 sea miles lasting 45 days and reaching up to 55 degree South latitudes. Its normal operation has been around the Indian sub-continent and deeper parts of the Indian Ocean region.

ORV Sagar Kanya has, through her excellent design features and wide range of onboard equipment, contributed in major way to the advancement of oceanography in India. The vessel had been the flagship of the country in all ocean related activities for over 25 years and has been utilized for atmospheric and ocean research in both national and international programs. The results of the studies have brought laurels to the nation.

The major oceanographic programs carried out onboard Sagar Kanya

- Identification and quantification of non-living resources particularly polymetallic nodules – the effort resulted in the International Sea Bed Authority (ISBA) allotting an exclusive mine site to India, the Central Indian Ocean Basin.
- Integrated geological & geophysical surveys in Exclusive Economic Zone (EEZ)
- Demonstrated the pivotal importance of an ocean going vessel in fostering oceanography in Indian Ocean region – carried out EEZ surveys for island nations like Mauritius and Seychelles.
- Offered services and training to the Caribbean in all aspects of marine sciences.
- Executed a long term bilateral program of more than a decade with Germany through sediment flux studies (Sediment trap moorings)
- World Ocean Circulation Experiment (WOCE)
- Joint Global Ocean Flux Study (JGOFS)
- Indian Ocean Experiment (INDOEX)
- Bay of Bengal Fan Studies (BENFAN)
- Bay of Bengal Monsoon Experiment (BOBMEX)
- Satellite Validation (IRS-P3 & P4)
- **Southern Ocean**: Vessel made her first expedition to sub-polar regions up to S.56^{o} under NCAOR leadership and collected multi-disciplinary data. Sediment sampling, plankton sampling (Palaeoclimate studies), other oceanographic data (temperature, salinity, current and surface met), underway bathymetric, gravity and sub-bottom profiling were carried out.

- A cruise was organized on war-footing as consequence of 26th December 2004 event off Sumatra to study the **after effects of tsunami** that devastated the Andaman & Nicobar Islands, eastern coasts of India and Sri Lanka.
- **Tsunami Buoys / Data Buoys deployments** carried out in Bay of Bengal / Arabian Sea and the Early Tsunami Warning System was devoted to nation by Former Honourable Union Minister Shri. Kapil Sibal.

Technology Demonstrations

Deep Sea Mining Demonstration: The Crawler was tested successfully at 451m water depth off Malwan Coast in Arabian Sea.
ROSUB and HANS trials successfully carried out by NIOT.
Hopper for laying Artificial Nodules in seabed were successfully carried out by NIOT.
In-situ Deep Sea Soil Tester trials at 5200m in CIO Basin.

- **Survey & Recovery of GSLV parts (NCAOR)**: The vessel was mobilized in very short time for the survey and recovery and successfully recovered vital parts for the failure analysis by ISRO.
- **River Channel Studies:** Carried out multidisciplinary data collection along the underwater river channels in Bay of Bengal.
- Under **BOBPS** programme of MoES, observations made for studying spatial and temporal variations in physical, chemical and biological properties and effect of various forcing in contributing to this variability in Bay of Bengal.
- **INRIDGE** Programme: Multidisciplinary data/samples were collected for plume identification in Central Indian Ridge and Carlsberg Ridge.
- **ARMEX**: Monsoon studies in Arabian Sea carried out successfully.
- Integrated Campaign for Aerosol, Gases & Radiation Budget (**ICARB**) under ISRO-GBP for observations over Bay of Bengal and Arabian Sea.
- **Bulk Sediment Sampling**: The vessel was used to collect record no. of core samples (500+ in nos) in just about 25 days time-span off Gujarat under MoU between NCAOR and ONGC.
- **CHATNI**: Multidisciplinary cruise under CHATNI programme is successfully carried out.
- Ocean observations in Equatorial Indian Ocean and other parts under **OOS** programme.
- Deployment of **ARGO** floats.
- **Indo-US-Oman joint oceanographic studies** in Arabian Sea and off Oman for studying physical, chemical, biological and geological processes.

Vessel parameters

Length over all	100.34 metres
Breadth over all	16.39 metres
Depth to main deck	9.80 metres
Draught	5.60 metres
Speed	14.25 knots
Engine Electric propulsion	(2x1230 KW)
Endurance:	45 days/10,000 nautical miles

Scientific Equipment onboard

- Single-beam Shallow and Deepsea Echosounders
- Multibeam Swath Bathymetric System
- Magnetometer
- Sub-bottom Profiler
- Side Scan Sonar

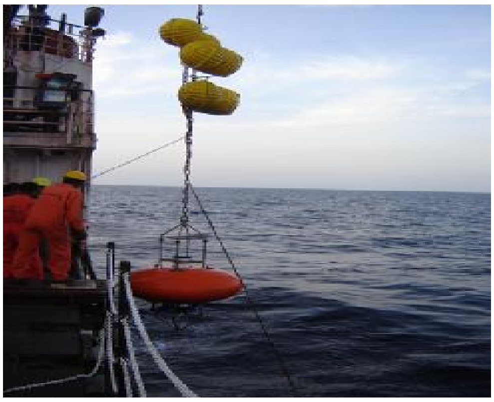
- Sea-bed Sampling including dredging rocks and seamounts, Coring for sediments and Grab Sampling
- Sub-sampling devices, rock mill, rock cutter, sample preservation in cold storage room, sediment sieving appliances etc.
- Acoustic Doppler Current Profiling System
- Continuous temperature and salinity measurement of sea water (Thermosalinography)
- Profiling of Sea-water Conductivity, Temperature, Depth (CTD) and online recording
- Wave measurements/recording instrument
- Sea Surface temperature measuring instrument
- Surface meteorology measurements by Automatic Weather Station.
- Bucket Thermometers
- Upper air atmospheric (pressure, temperature, humidity) by Radiosondes
- Dissolved Oxygen, Nutrients and Chlorophyll measurements in seawater.
- UV Chamber, Hot Air Ovens, Freezers, Autoclave, Clean work Bench etc.
- Multiple Plankton Nets for biological sampling
- Scores of water & biological samplers and nets
- Deepsea Mooring devices, acoustic releases and deck unit
- Weather facsimile Receiver.
- GPS and DGPS positioning.
- Dynamic Positioning
- HiPAP Acoustic Positioning
- Spacious deck for sampling operations with adequate deck gear like winches, cranes, gantries and well-equipped workshop
- CCTV system
- Local Area Network (LAN) facility
- Computers, Laser & Inkjet printers, Plotters and photocopier
- Voice, Fax, Telex, e-mail facilities through Terrestrial (RT) and Satellite systems.
- Accommodation for 31 scientists and 60 officers & crew including a medical officer (doctor), the laboratories and all living spaces centrally air-conditioned.

Sagar Kanya has been the first deep–sea multidisciplinary oceanographic research vessel of the country owned by Government of India, Ministry of Earth Sciences. Over fifty national laboratories, academic & research institutes, universities involved in ocean and allied science have benefited from this crucial national facility. The vessel is managed by the National Centre for Antarctic & Ocean Research (a constituent of Ministry of Earth Sciences), Goa. The operation and maintenance of the vessel is carried out by M/s Shipping Corporation of Indian Ltd. and the scientific equipment are maintained and operated by M/s. Norinco Pvt Ltd.

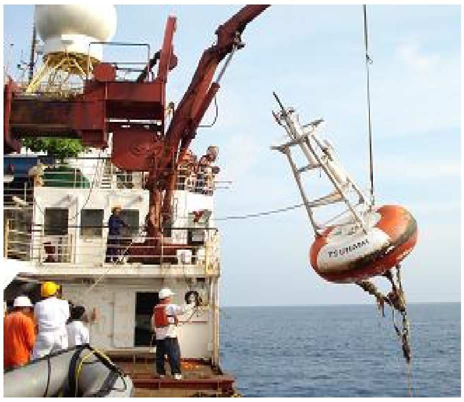
Sagar Kanya has completed 262 major cruises so far while advancing our understanding of the seas around us. The results had been documented / published in national and international journals of repute.

ORV SAGAR KANYA

Remotely Operable Submersible Testing from the vessel



ADCP Mooring in Arabian Sea



INCOIS buoy deployment during SK-251 in Bay of Bengal

ICARB-Winter Campaign in SK-254: Kytoon tethering for atmospheric studies

6. ORV SAGAR KANYA AND GEOLOGICAL OCEANOGRAPHY – CAPABILITIES AND ACHIEVEMENTS

M.M. Subramaniam
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Introduction

Since her inception in 1983, ORV Sagar Kanya had contributed immensely to the Geological Oceanographic research in India. There were several national-thrust programmes as well as international collaborative programmes successfully carried out with ORV Sagar Kanya playing key role as the ocean-going platform. Numerous leading researchers from National Institute of Oceanography, Geological Survey of India, National Centre for Antarctic & Ocean Research along with several other institutes and Universities explored the shallow and deep seabeds of seas surrounding India and elsewhere and came out with spectacular findings.

Onboard infrastructure for Geological Oceanography

ORV Sagar Kanya is provided with superlative infrastructure for carrying out geological sampling, sub-sampling and further onboard analyses. The working deck of 500 m^2 main deck with various geological sampling machineries like Deep Sea Winch with the 22 tonnes safe working load and the capacity to have 10000 metres 18mm wire rope, an A-frame at the aft-end with the a ramp, Jibboom on the starboard side, three cranes, a gallow winch on jibboom and CCTV system plays significant role in safe and able Geological sampling at sea. Two ample cargo-holds accommodate portable winches and heavy geological sampling devices.

Two wet labs, open to the main deck, are well-designed with ovens, freezers, sub-sampling station, rock saw, rock mill, sieves set with sieve shaker and agate mortars. Both freshwater and seawater supply is provided to these labs. There is a Core Store on the second deck where cores and seabed samples are stored in suitable lockers at a constant temperature of 4^{o}C and high humidity. This core store is directly connected by a lift from the main deck with which the samples could be shifted to core store with ease in minimum time.

Seabed sampling devices and others

The vessel is adequately augmented with seabed sampling gadgets like Hydraulic Piston Corer of 18m capability, Gravity Corers of 6m capability, Spade Corers, Grabs, Pipe and Chain Bag Dredges. The Dynamic Position System onboard Sagar Kanya ensures the precise position-keeping during the sampling operations. Geophysical instruments like Magnetometer, Sub-bottom profiler, Side Scan Sonar, Single-beam and Multibeam echosounders onboard are very critical for the Geologists for more meaningful interpretations. The existing Gravimeter and Seismic System are being upgraded.

Accomplishments

Several important national programmes were taken up onboard Sagar Kanya pertaining to Marine Geology and allied disciplines during the last 25 years of service of the vessel. Few major programmes are listed below:

- **Poly-Metallic Nodules (PMN):** Polymetallic nodules on the ocean floor are considered to be treasure-house of much needed metals. The potato-shaped, largely porous nodules, are found in abundance carpeting the sea floor of world Oceans. These nodules are of much economic importance because, besides manganese and iron, they contain nickel, copper, cobalt, lead, molybdenum, cadmium, vanadium and titanium of which cobalt, copper and manganese are considered to be of strategic importance. Survey confirmed that about 15 million sq. km. of the Indian Ocean have nodules of different size and quality. The nodules are found mostly at depths ranging from 3500m to 6000m. After a very intensive survey, India identified sites in the central Indian Ocean having nodules deposits. Pursuant to vigorous sailing and bathymetric survey, International Seabed Authority allocated to India an area of 1,50,000 square kilometer in the Central Indian Basin in 1987 and India became the first Pioneer investor for exploration of nodules from seabed. Intensive survey conducted to ascertain the extent of resources in the pioneer area using Sagar Kanya which has been equipped with multi-beam swath bathymetric system to generate high precision bathymetric maps on seabed topography. Besides, the cruises also generated baseline oceanographic data on physical, chemical, biological and environmental parameters. The baseline data is being used for comprehensive data is being used for comprehensive geostatistical evaluation of the resources of polymetallic nodules and their distribution in the pioneer area.

- Integrated geological & geophysical **surveys in Exclusive Economic Zone (EEZ)** of India. Besides, EEZ surveys for island nations like Mauritius and Seychelles were also carried out.

- **Palaeo-oceanographic Studies in the Bay of Bengal Fan (BENFAN):** The main objective of the program is to reconstruct the paleo-oceanography / paleo climate using the sediment cores in the Bay of Bengal. Bathymetric data collected in parts of Bay of Bengal in the Exclusive Economic Zone were analysed to identify areas of long core collection. Gravity core samples were also collected and taken up for analysis at the participating labs/ organizations.

- **Southern Ocean**: Vessel made her first expedition to sub-polar regions up to S.56^{o} and collected multi-disciplinary data including sediment sampling and geophysical data.

- A cruise was organized on war-footing as consequence of 26th December 2004 event off Sumatra to study the **after effects of tsunami** that devastated the Andaman & Nicobar Islands, eastern and western coasts of India and Sri Lanka.

- **INRIDGE** Programme: Multidisciplinary data/samples were collected for plume identification in Central Indian Ridge and Carlsberg Ridge.

- **Bulk Sediment Sampling**: The vessel was used to collect record no. of core samples (500+ in nos) in just about 25 days time-span off Gujarat under MoU between NCAOR and ONGC.

- **Indo-US-Oman joint oceanographic studies** in Arabian Sea and off Oman for studying physical, chemical, biological and geological processes.

7. MULTIBEAM SWATH BATHYMETRIC SYSTEMS ONBOARD ORV SAGAR KANYA

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The multi-beam systems onboard the vessel has served the requirements of many major scientific programmes.

Some of the progammes are specified below:

- Identification and quantification of non-living resources particularly polymetallic nodules – the effort resulted in the International Sea Bed Authority (ISBA) allotting an exclusive mine site to India in the Central Indian Ocean Basin.
- Seabed Mapping of the Exclusive Economic Zone of India.
- Integrated geological & geophysical surveys in the Exclusive Economic of India
- Indian Continental Shelf Programme.
- Swath mapping in Indian Ocean region – carried out EEZ surveys for island nations like Mauritius and Seychelles.
- Post-tsunami studies in the Andamans subduction zone.
- Seabed surveys for site selection for Deployment of Tsunami buoys.
- GSLV Salvage programme (The recovery of GSLV Subsystems from sea is second in Space History, after recovery of Ariane by Europeans Space Agency in 1996)**.**

ATLAS HYDROSWEEP DS System:

The ATLAS HYDROSWEEP Equipment belongs to the family of multi-beam bathymetric sweeping survey systems with a broad coverage of 90° perpendicular to the ship's longitudinal axis and is based on a sonar frequency of 15.5 kHz. In a single sweep, it covers 59 depth values and the coverage width is about double the vertical water depth, in case of flat sea-bottom. Beside swath bathymetric depth information, backscatter data for seabed classification and side scan data also can be acquired. The Hydrosweeo system was installed onboard ORV-Sagar Kanya in 1990 and was decommissioned in 2005.

The specifications and features of the system were as follows:

Make	ATLAS Hydrographic GmbH
No. of beams	59
Swath coverage	2 x Water Column
Frequency of operation	15.5 kHz
Technology	Cross Fan Calibration
Depth performance	Max. 11,000 m.
Acquisition software	ATLAS Hydromap Control
Data Processing software	Interface for third party software

One special feature of the ATLAS HYDROSWEEP Equipment is that the sound velocity measurements of the water column can be carried out using a special calibration technique called "Calibration Mode". In this mode, the 59 depth values are measured parallel to the ship's longitudinal axis and the transmitting and receiving functions of the system are swapped between the two hydroacoustic transducer arrays.

SEABEAM-3012 System:

SeaBeam 3012 Multibeam Echosounder, which is presently onboard ORV-Sagar Kanya was installed in 2005 and is being used to carry out extensive swath bathymetric surveys.

The specifications and features of the system were as follows:

Make	L3-Communications Elac-Nautik
No. of beams	201
Swath coverage	5 x Water Column
Frequency of operation	12 KHz
Technology	Full motion compensation (Sweptbeam technology)
Depth performance	Max. 11,000 m.
Acquisition software	Hydrostar
Data Processing software	Eiva NaviPac

The system is fully realtime-compensated for roll, pitch and yaw to guarantee complete coverage even during bad conditions. The implemented swept beam technology is superior to any other realtime motion compensation technology available in the market to date.

The SB3012 is a 12 kHz, 201 beam sonar system, with an effective 150° of swath. The system has a beam width of 1 degree at nadir and is capable of depths 200 meters to 11000 meters. The Windows NT-based SeaBeam 3012 offers a depth performance of 11000 meters with still 110° coverage resulting in seafloor coverage of 31 km. The SeaBeam Water Column Imaging (WCI) option logs water column data and displays real time images from the water column, both below and to the sides of the vessel.

8. GEOPHYSICAL INVESTIGATIONS ONBOARD SAGAR KANYA

John Kurian P
National Centre for Antarctic & Ocean Research, Goa, India

ORV Sagar Kanya, flagship vessel of the Ministry of Earth Sciences, Govt. of India has been very well utilized as a platform for collection of significant geophysical data from the offshore realms of India. Having equipped with different systems for acquisition of geophysical data including seismic, gravity, magnetic, bathymetry etc., ORV Sagar Kanya has served the Indian scientific community in acquisition of key geophysical information, thus enabling them in resolving many important geological and tectonic problems.

Understanding the geological and tectonic aspects of different structural elements in the Northern Indian Ocean is vital in understanding the overall evolutionary history of the Indian Ocean. Magnetic and gravity data offer important constraints in these perspectives and is considered as an important tool for understanding the crustal configuration, nature of the crust, paleo-geographic reconstruction, depth and extent of different geo-tectonic features etc. ORV Sagar Kanya, being equipped for the acquisition of magnetic and gravity data, is extensively used for gathering key geophysical information thus facilitating the Indian scientists in addressing geological and tectonic history of the Northern Indian Ocean in a better way. The areas covered by the vessel for geophysical acquisition include Western and Eastern Continental margins of India, Andaman fore arc and back arc basins, 85°E Ridge, Ninetyeast Ridge, Laxmi Ridge, Laccadive Ridge, Prathap Ridge, Carlsberg Ridge, Central Indian Ridge etc. and the different offshore basins surrounding the Indian continental margin. Some of the significant geophysical contributions include the identification of Mesozoic anomalies in the Bay of Bengal, records of magnetic quiet zone in the distal Bengal Fan, identification of seafloor spreading anomalies in the Laxmi Basin, Geophysical picture of the Laccadive Ridge and South-western continental margin of India apart from many other path-breaking geophysical findings.

The shallow seismic equipment of Sub-bottom profiler onboard Sagar Kanya offer 2D images of the shallow layers and enables to identify and characterize layers of sediment or rock under the seafloor. This information, coupled with bathymetric data from single and multi-beam echo-sounders, is vital in selection of proper sites for retrieval of sediment cores, being taken for sedimentological and paleo-climatic investigations. It also caters to the requirements of morphological studies, geotechnical studies, pipe-line laying etc. Sagar Kanya is also equipped with Side Scan Sonar, which can be used to image the ocean floor using the high-frequency sound pulses. The side scans sonar images are best suitable for identification of Shipwrecks, downed aircraft, lost anchors, dredges or other equipment lost at seafloor.

9. THE ROLE OF ORV SAGAR KANYA IN CHEMICAL OCEANOGRAPHIC MEASUREMENTS

Sharon Noronha and Zeena Jayan
National Centre for Antarctic & Ocean Research, Goa, India

Since its commissioning in 1983, Ocean Research Vessel (ORV) Sagar Kanya, a multidisciplinary deep sea research vessel has been serving our nation by being the platform for crucial scientific research in the high seas. Global and regional issues relating to phenomena such as global warming, CO2 and N2 fluxes, etc have been investigated after conducting major programmes such as JGOFS, BOBPS, INDOEX, LOICZ, and PESO, to name a few.

Apart from the above mentioned programmes, regular seasonal cruises are held to study the Biogeochemistry and Hydrodynamics of the Tropical Indian Ocean (an ongoing project by NCAOR). Field studies and measurements of much needed chemical parameters such Dissolved Oxygen (DO), CO2, Nitrous oxide, pH, nutrients and trace elements are carried out onboard. Some of the equipment available onboard such as Auto analyzer for nutrient estimation, pH meter and Dosimat for D.O. analysis facilitate these studies. Some of the chemical parameters measured in the JGOFS (Joint Global Ocean Flux Study) cruise were, D.O., nutrients, total CO2, ammonia, methane and carbon dioxide of surface air samples and nitrous oxide measurements of the water column. One of the major achievements of this study was that the central and eastern Arabian Sea could be a source for atmospheric carbon dioxide. A sequel to JGOFS was BOBPS. The Bay of Bengal Process Studies aimed to study the seasonal and inter annual variability in the overall CO2 air-sea exchange balance in the Bay of Bengal and also the role of remote forcing in the spatio-temporal variability of the water column in terms of nutrients and productivity. They found that contrary to conventional belief that, the Bay of Bengal maybe a sink for atmospheric carbon dioxide, the pCO2 and TCO2 measurements indicated that except in the northern Bay during summer and fall intermonsoon, the Bay of Bengal is a minor source of CO2 to the atmosphere. The INDOEX (Indian Ocean Experiment) aimed to study the aerosol and atmospheric chemistry characterization of aerosol pertinent to mineral, sea spray and sulfate (non sea salt and anthropogenic components). The Land Ocean Interaction in the Coastal Zone studied the sinking particulate matter and its dispersion in the coastal zone.

Physical, chemical, biological and atmospheric observations were carried out in the Pilot Expedition to Southern Ocean in 2004 onboard ORV Sagar Kanya.

Other scientific activities such as, amino acid dating bio marks of sediments in the Bay of Bengal, bio-geo-chemical cycling of elements and investigation of fluxes and processes and studies on methane rich gas charged sediments were also carried out onboard ORV Sagar Kanya.

10. ORV SAGAR KANYA – BIOLOGICAL RESEARCH ACTIVITIES

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National Centre for Antarctic & Ocean Research, Goa, India.

ORV Sagar Kanya is equipped with sampling gear, equipments, laboratories etc. designed exclusively for preliminary marine biological/microbiological sampling and data collection. Sea-water samples as well as flora and fauna can be collected from desirable depths by use of variety of equipments, for example – 1. Remotely operated multiple plankton net [MPN] sampler – this devise can be fitted with five nets, of required mesh size at a time and lowered to sea in a closed state. The nets can be sequentially opened and closed again by a remote control for collection of biological samples at desired water columns. The samples collected in the nets are gathered in a bucket fitted at the tail-end of the net 2. Rosette water sampler – this device can be fitted with CTD system [Conductivity Temperature Depth]. Water sampling bottles of various capacity such as 1.7 ltrs., 5 ltrs., 10 ltrs and 30 ltrs etc shall be attached with the system. The sampler can be lowered along with CTD in to water for sample collection. Each bottle on the sampler can be closed remotely at a desired depth. Various sensors for measuring dissolved oxygen, chlorophyll turbidity etc. can be fitted with the CTD system since these information are also useful for biological research and analysis work.

All of the above sampling and data is used for hoards of marine biological research fields like productivity analysis, density analysis and isolation of biological/microbiological specimens/samples etc. Further above information are vital for studies under various programmes / projects such as bio-prospecting and biotechnology of marine microorganisms, habitat ecology, controlled reproduction and conservation of marine organisms with food and medicinal value analyses and evaluation, mechanism and control of biofouling, phytoplankton and zooplankton variability under various environmental conditions, extent of concentration and effect of marine pollutants on marine life and productivity etc.

Data and samples collected are stored / preserved in an appropriate media and subsequently transported to laboratories on land at the end of each scientific expedition onboard Sagar Kanya for further processing and analysis.

11. O.R.V. SAGAR KANYA AND INVESTIGATION ON PHYSICAL PROCESSES OF INDIAN OCEAN

Jenson V. George, Nuncio Murukesh, N. Anilkumar
National Centre for Antarctic & Ocean Research, Goa, India

Seas around us plays major role in shaping its weather, climate and food security of the subcontinent. Studies carried onboard O.R.V. Sagar Kanya has been intended mainly to address these broad issues. A sizeable amount of time was spent in the North Indian Ocean mainly to address the evolution of circulation in association with the seasonally reversing monsoon winds. Numerous *In-situ* hydrographic as well as atmospheric datasets have been collected by using various instruments like Conductivity, Temperature Depth [CTD], Expendable Bathythermograph [XBT] and Automatic Weather Station [AWS] along with the vessel mounted Acoustic Doppler Current Profiler [ADCP] in a number of programs. The most important being the participation in WOCE-IGOOS hydrographic cruises.

Ocean-Atmosphere CO_2 fluxes received great attention during early 1990's. Major programs like Arabian Sea JGOFS and its sequel BOBPS in the Bay of Bengal addressed the issue of ocean-atmosphere CO_2 exchange. This resulted in new insight not only in terms of CO_2 fluxes alone but improved understanding of response of ocean to atmospheric forcing, bio-physical coupling and microbial loop.

Monsoon plays a key role in shaping the life of the subcontinent and O.R.V. Sagar Kanya continue to be a reliable platform to study monsoon. Programs like INDOEX, ARMEX and BOBMEX aimed at this resulted in new insight on air-sea interaction and monsoon physics. The phenomena like Arabian Sea warm pool, Lakshadweep heigh and low are explored in this connection and are studied using the hydrographic data collected during Sagar Kanya cruises. All these studies underlined that ocean play an active role in regulating monsoons. A number of cruises have been conducted to collect the sea truth data for validation of Indian satellites, studying harmful algal blooms and for obtaining CTD and XBT profiles to understand the hydrodynamics. Apart from this a number of drifting buoys and ARGO floats were deployed from Sagar Kanya as a part of international understanding. These floats gives information on a wide range of parameters viz, atmospheric pressure/temperature, sea surface temperature, Ocean surface winds, temperature salinity profiles with respect to depth. Besides, locating their positions gives a Lagrangian view of the Ocean circulation.

12. SCIENTOLOGY AND THE SEA

Dr. K.K. Gupta,
Medical Officer, ORV Sagar Kanya

I am fortunate to be associated with Scientology since the last 10 years. During this time, I became aware of Scientology's deep connection with sea-fearing and this inspired me to pursue a career in Merchant Navy as medical-officer. Scientology religion was founded by American philosopher L.Ron Hubbard in 1954. According to Wikipedia, this is the only major religion to appear in the 20^{th} Century.

L.Ron Hubbard was a naval officer in U.S. Navy and became USA's first casualty in Atlantic during World War 2. After the war, while recovering from severe injuries that left him crippled and partially blinded, he had remarkable insights that led him to write the book "Dianetics: The Modern Science of Mental Health" in 1949. This is the only book to have become a New York best-seller in two different decades- 1950s and 1980s.

As he further pursued his research, he eventually founded the Scientology religion in 1954. He said," For 2000 years, humanities have lagged behind while science has made progress. We have restored to humanities the exactitude of science."

In 1966 as the research continued, he took his entire work aboard a ship called Apollo. There he worked till his death in 1986.

He felt that sea provides a distraction-free environment which is conducive to high-level research that he was doing. In Scientology parlance, it can be said that sea is free from MEST Universe dramatizations. MEST is derived from first letters of matter, energy, space and time. Being on land, one is constantly bombarded with noise and vibrations. Any person on land who is thinking is emitting certain vibrations. Due to over-crowding and consequent vibration-overload on land, there is a constant "noise". The sea is relatively free from this kind of "noise".

In tribute to L. Ron Hubbard's high regard for sea, the elite Scientology organization entrusted with high-end technology is called the Sea Organization. The highest level training and auditing in Scientology is still delivered aboard a ship called Freewinds, which has its mother-port in Curacao in Netherland Antilles in West Indies. The highest land-based Scientology organization is Flag Land Base situated in Clearwater, Florida, USA. This is after the fact that during L.Ron Hubbard's time, there were several Scientology ships and the ship on which he happened to be present was called the Flag-ship—and he was addressed as Commodore as the person in-charge of a flotilla of ships.

L.Ron Hubbard's writings and lectures are inter-spersed with references to sea-fearing. In one of the writings, for example, he says the following while explaining how a different attitude is required on sea compared to land:

> "It requires, in actual fact, a considerable thought to go to the sea. It requires a "What is the consequence of…." A crew member walks by a bilge and notices a rag and says, "Well, ha, shouldn't be." A crew that picks up the rag and a crew that walks by- is the difference between seamen and landlubbers."

Today, the total research and discovery carried out by him runs into more than 100 thick volumes. He felt that without the sea, it would not have been possible. As he once said, "I have seen life upside down and I have seen it downside up and I know how it looks both ways and I can tell you that there is hope."

13. OCEAN RESEARCH VESSEL SAGAR KANYA" – AN INTRODUCTION AND OVERVIEW OF TECHNICAL MANAGEMENT

Capt. Praveen Kumar, Vice President (L&PS)
M/s Shipping Corporation of India Ltd., Mumbai, India.

Sagar Kanya is an ocean going dedicated scientific research vessel was built in March, 1983 at Schlichting- WERFT GMBH LUBECK TRAVENMUNDE (GERMANY). The vessel has overall length is 100.34m and breadth of 16.39m and capable of accommodating thirty one scientists. The vessel displaces 4855.3 MT on a summer draft of 5.6m.

Sagar Kanya is equipped with Diesel Electric Propulsion with twin screw/rudder designed to provde a speed of 14.25m knots with a power output of 1230 KW x 2 = 2460KW and bow thruster 1200 KWEL.M and engine output being 2 X 1230 KW. The cruising range of the vessel is forty five days and ten thousand nautical miles making her capable of taking the challenge of global research work on world wide scale. Sagar Kanya is equipped by most modern reverse osmosis plant for producing 35 MT fresh water per day against daily consumption of 22 MT of fresh water.

The technical features of Sagar Kanya are unique and typical as no other vessel in Indian Shipping has such matching features. The vessel is classed under Indian Register of Shipping and certified as + 100 A1 + LMC "Research vessel" – IRS +SVL +IY+HY.

Sagar Kanya had undergone a major refit in 2005 involving renewal of five auxiliary engines and fitment Dynamic Positioning system thus acquiring station keeping capability on the high seas.

Right from inception, ORV Sagar Kanya is managed by The Shipping Corporation of India Ltd. The national Carrier, "The Shipping Corporation of India" (SCI) is the largest Shipping Company in India with eighty two owned and fifty eight managed vessels under its flag. A team of technical professionals with more than one hundred years professional experience is devoted for management of Sagar Kanya on round the clock basis at Mumbai. Informatively, SCI has shore based technical manpower of around three thousand years professional experience that is what makes for SCI's technical core competence. SCI has a large support system on global basis comprising of more than seven hundred agents located world wide, this frame work ensures SCI's management presence all over the world on round the clock basis.

Additionally SCI has large technical manpower for the onboard management of fleet and around one thousand highly qualified personnel ashore to manage the fleet and carry out commercial operations. This unmatched management resource of SCI is unparalleled in the history of maritime Industry of India.

Sagar Kanya has completed more than twenty five years of service, which is beyond the economic life in the maritime parlance, may have to be replaced, so as to continue the good work of ocean research work to meet national objectives. Despite being at the end of economic life, Sagar Kanya continues to perform and successfully achieve the scientific cruise requirements till date. Sagar Kanya is a valuable national utility providing service in search of excellence in scientific endevours on high seas. It is a matter of great pride to be associated in the management of such a sophisticated vessel.

14. MANUAL METHODS FOR MEASURING NUTRIENTS (PO_4-P, NO_2-N and NO_3-N)

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Ministry of Earth Sciences Chennai, India

1. Sea Water Quality

Sea Water Quality is a term used to describe the physical, chemical, and biological characteristics of water and its general composition. These attributes affect water's ability to sustain life. Good water quality is essential for survival of animal life, fish farming, swimming, surfing etc. Water is the most important compound for all life processes. It forms the major constituent of the body tissues of all living organisms, without which the biochemical activities essential for the perpetration of life are not possible. Water is also able to dissolve and retain all the essential compounds useful for living organisms. However, excess or depletion of any of the organic and inorganic materials found in dissolved forms in water may affect normal life activities. Therefore, it is crucial to monitor the quality of water in time.

1.1. Why seawater quality is so important areas of concern?

Monitoring the water quality is for economic, environmental, and social importance. Water quality can be defined in terms of a water body's suitability for various uses such as water supply source, swimming and protection of aquatic life. It is affected by water abstractions, by pollution loads from human activities and by climate and weather. The pressure from human activities becomes so intense that water quality is impaired to the point that drinking water requires even more advanced and costly treatment or that aquatic plant and animal species in rivers, lakes, and seas are greatly reduced, then the sustainability of the water resource use is in question.

The marine environment is an important resource not only in terms of the biodiversity it supports but also as a resource for eco-tourism, industry, freshwater production, and recreation. Sea-based activities (yachting, water sports, diving, fishing, and fish farming) impact the marine environment, although land based developments and activities, (such as ship building and repairing, sewage disposal, desalination plants, landfills, industry, tourism infrastructure, and power stations) also generate significant impact on the sea.

Marine resources need to be used in such ways that doesn't impact the marine environment, otherwise ecosystems and habitats can be lost, and marine biodiversity can be diminished. The main cause of biodiversity loss in the marine environment is due to human activity: increased coastal and urban development, growing demand for food resources and commercial products, which indirectly favors for increased pollution. The quality of the marine environment has not only for economic impact but also for social and environmental impacts as it links to the quality of people's lives.

Marine environmental performance indicators should therefore be designed to measure and monitor human activities and their effects to marine environment.

1.2. Seawater Sampling

Collecting water sample is a tedious operation, which must be carried out with all possible care, since it will determine the analytical results and their interpretation. The sampling technique will wary with the origin of the water. There are many types of water samplers used by oceanographers and limnologists. An account on the Niskin water sampler used in the estuaries, near shore waters is given hereunder

1.2.1. Niskin sampler

The Niskin sampler is a development of the Nansen bottle patented by Shale Niskin in March 1966. Instead of a metal bottle sealed at one end, the ‘bottle’ is a tube, usually plastic to minimize contamination of the sample, and open to the water at both ends. Each end is equipped with a cap which is either spring-loaded or tensioned by an elastic rope. The action of the messenger weight is to trip both caps shut and seal the tube.

A reversing thermometer may also be carried on a frame fixed to the Niskin bottle. Since there is no rotation of the bottle to fix the temperature measurement, the thermometer has a separate spring-loaded rotating mechanism of its own tripped by the messenger weight.

A modern variation of the Niskin bottle uses actuated valves that may be either preset to trip at a specific depth detected by a pressure switch, or remotely controlled to do so via an electrical signal sent from the surface. This arrangement conveniently allows for a large number of Niskin bottles to be mounted together in a circular frame termed a *rosette*. As many as 36 bottles may be mounted on a single rosette.

Niskin sampler

CTD/Niskin rosette cast

1.3. Sample Preservation

It should be understood that the concentration of nutrients is bound to change with time, due to biological activity(microorganism present in the seawater). Therefore, there is no good substitute to analyse within the minutes of sampling. Where immediate analysis is not possible, methods recommended include freezing and poisoning with mercuric chloride, chloroform and pH control using sulphuric acid (pH control using acid is not recommended for Nitrate sample preservation)

Method of preservation are relatively limited and intended generally to

1. Retard biological action.
2. Retard hydrolysis of chemical compounds and complexes.
3. Reduce volatility of compounds.

Preservation method is generally limited to pH control, chemical addition (mercuric chloride), refrigeration and freezing. Among these methods refrigeration and freezing are the best preservation method.

1.4. Spectrophotometry

Spectrophotometry is the quantitative study of electromagnetic spectra. It is more specific than the general term electromagnetic spectroscopy in that spectrophotometry deals with visible light, near-ultraviolet, and near-infrared. Also, the term does not cover time-resolved spectroscopic techniques.

Spectrophotometry involves the use of a spectrophotometer, which is a photometer (a device for measuring light intensity) that can measure intensity as a function of the color, or more specifically, the wavelength of light. There are many kinds of spectrophotometers. Among the most important distinctions used to classify them are the wavelengths they work with, the measurement techniques they use, how they acquire a spectrum, and the sources of intensity variation they are designed to measure. Other important features of spectrophotometers include the spectral bandwidth and linear range.

Perhaps the most common application of spectrophotometers is the measurement of light absorption, but they can be designed to measure diffuse or specular reflectance. Strictly, even the emission half of a luminescence instrument is a kind of spectrophotometer.

1.4.1. Design

There are two major classes of spectrophotometers; single beam and double beam. A double beam spectrophotometer measures the ratio of the light intensity on two different light paths, and a single beam spectrophotometer measures the absolute light intensity. Although ratio measurements are easier, and generally more stable, single beam instruments have advantages; for instance, they can have a larger dynamic range, and they can be more compact.

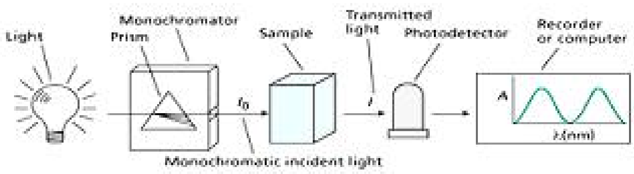
Historically, spectrophotometers use a monochromator to analyze the spectrum, but some spectrophotometers that use arrays of photosensors especially for infrared spectrophotometers. Other spectrophotometers use a Fourier transform technique to acquire the spectral information more quickly in a technique called Fourier Transform Infra Red.

The spectrophotometer measures quantitatively the fraction of light that passes through a given solution. In a spectrophotometer, a light from the lamp is guided through a monochromator, which picks light of one particular wavelength out of the continuous spectrum. This light passes through the sample that is being measured. After the sample, the intensity of the remaining light is measured with a photodiode or other light sensor, and the transmittance for this wavelength is calculated.

In short, the sequence of events in a spectrophotometer is as follows:

1. The light source shines through the sample.
2. The sample absorbs light.
3. The detector detects how much light the sample has absorbed.
4. The detector then converts how much light the sample absorbed into a number.
5. The numbers are either plotted straight away, or are transmitted to a computer to be further manipulated (e.g. curve smoothing, baseline correction)

Many spectrophotometers must be calibrated by a procedure known as “zeroing.” The absorbency of some standard substance is set as a baseline value, so the absorbencies of all other substances are recorded relative to the initial “zeroed” substance.



Schematic diagram of a spectrophotometer

The instrument consists of a light source, a monochromator that contains a wavelength selection device such as a prism, a sample holder, a photodetector, and a recorder or computer. The output wavelength of the monochromator can be changed by rotation of the prism; the graph of absorbance versus wavelength is called a spectrum.

1.4.2. Beer-Lambert Law

Beer's law states *that for a parallel beam of monochromatic radiation passing through homogeneous solutions of equal path-length the absorbance is proportional to the concentration.*
The law states that there is a logarithmic dependence between the transmission (or transmissivity)of light through a substance and the product of the absorption coefficient of the substance and the distance the light travels through the material (i.e. the path length). The absorption coefficient can, in turn, be written as a product of either a molar absorptivity of the absorber and the concentration of absorbing species in the material or an absorption cross section and the (number) density of absorbers, .

For liquids, these relations are usually written as;

Beer-Lambert's law

$$A(\lambda) = Log_{10}\left(\frac{I_{inc}(\lambda)}{I_{trans}(\lambda)}\right) = -Log_{10}(T(\lambda))$$

The measurement of **A(λ)** gives an absolute measurement of the transparency of the medium with respect to the wavelength.

PART I: NUTRIENTS IN SEAWATER

1.5. Nutrients in Seawater

1.5.1. Definition of nutrients

The term nutrient in seawater refers to silicate, phosphate, ammonium, nitrite, and nitrate.

1.5.2. Genesis of Phosphorous in seawater

The weathering of rock leads to liberation of phosphorous as soluble alkali phosphates and colloidal calcium phosphate, the bulk of which is carried to the sea. In addition, anthropogenic inputs of super phosphate as fertilizer and alkyl phosphate as detergents, lead to an increase in the content of phosphorous as detergents, lead to an increase in the content of phosphorous in the sea.

There are two forms of phosphorous in the sea inorganic and organic. Inorganic P exists as PO_4^{3-} ions and as HPO_4^{2-} ions. Condensed phosphate ions as $P_2O_7^{4-}$ exist in estuarine and coastal waters and play an important role in energy transformation process of the biological system. Organic P exists as Phospholipids, Phosphonucleotides resulting from decomposition and excretion of organism. Therefore, the determination of P in seawater involves two parts determination of inorganic phosphate-P and total phosphorous that includes all forms of P.

1.5.3. Genesis of various forms of nitrogen in seawater

Nitrogen in the atmosphere gets converted to nitrate on lightening and is carried by rain to the sea. Anthropogenic input of nitrate as fertilizer contributes to the presence of various forms of N in seawater. Nitrate is reduced to nitrite and further to ammonia, under anoxic conditions. It is the amino acid compounds, which are the synthetic blocks of proteins and of the cells of the biota. Thus NH_3, NH_4^+, NO_2^-, NO_3^- exist in seawater.

Nitrate is considered a micronutrient, controlling primary production in the euphotic surface layers. If there is sufficient light penetration into the seawater, the uptake by the primary producers is much faster than processes transporting nitrate into surface layers. Nitrite is an intermediate compound in the microbial reduction of nitrate or oxidation of ammonia. The natural levels of nitrite in seawater are very low (0.1 µmol/L). Upwelling lead to higher values of nitrite (1-2µmol/L). Pollution leads to very high values.

The concentration of ammonium nitrogen varies considerably. Nitrate is first reduced to ammonia before transformation to amino acids. Ammonia is also excreted directly by animals. In oxygenated unpolluted waters, NH3 and NH_4^+ together rarely exceed 5 µmol/L. However, in anoxic waters, the amount of ammonium can be as high as 100 µmol/L.

1.5.4. Determination of phosphate

The inorganic phosphate ions in seawater react with acidified molybdate reagent to yield phosphomolybadate complex, which is reduced to molybdenum blue. The colour is measured spectrophotometricly at 880 nm.

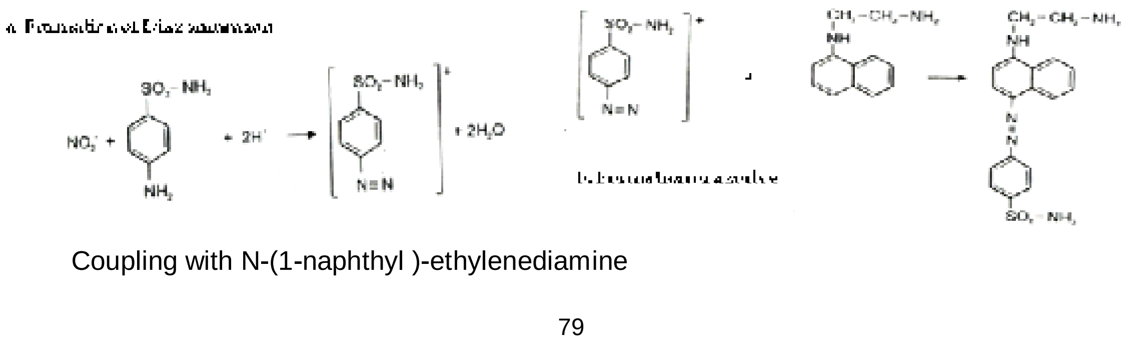
The mixed reagent is the combination of ammonium molybdate in sulphuric acid containing antimony in the bivalent state. The presence of antimony ions leads to a rapid reaction resulting in the formation of phospho antimony molybadate complex (P: Sb as 1:1), which yields a heteropoly blue complex on reduction. The reducing agent favored is ascorbic acid. The method is essentially based on the Murphy and Riley procedure. It has been demonstrated that acid/molybdenum ration is crucial, in determining the form of the reduced complex and in controlling the kinetics. To obtain a rapid color development and to suppress the interference of silicate, the final pH should be less than 1 and that the ratio of sulphuric acid to molybdate should be between 2 and 3, when the concentrations are given in normality and percentage respectively.

Sensitivity: - The molar absorptivity is around 22700 at 880nm. A sample of seawater having a phosphate concentration of 1.0 µmol/L gives an absorbance of around 0.227, using a 10cm cuvette. Therefore, the use of smaller path lengths, for measurements of phosphate, when the normal concentrations are 1.0µmol/L should be completely discouraged.

1.5.5. Determination of nitrite and nitrate

The method of nitrite determination depends on reaction with an aromatic amine, sulpanilamide, which is then coupled with n (1-naphthyl)-ethylene diamine dihydrochloride, to form an azo dye. The absorbance of the dye is measured spectrophotometrically at 540 nm. Basically this method is the same as the one suggested by Bendschneider and Robinson 1952.

The reaction leading to the formation of the azo dye can be formulated as follows.



Coupling with N-(1-naphthyl)-ethylenediamine

The nitrate is reduced to nitrite before its determination. The reduction is carried out by Cd reduction column. The conditions are so adjusted that the nitrate is quantitatively reduced to nitrite. The standard potentials are very close in both reactions.

$$NO_3^- + 3H^+ + 2e^- \longrightarrow HNO_2 + H_2O \quad (E_0 = 0.94\ V)$$

$$NO3- + 4H^+ + 3e^- \longrightarrow NO + 2H_2O \quad (E_0 = 0.97\ V)$$

However, in a neutral or alkaline solution, the standard potential is

$$NO3^- + H_2O + 2e^- \longrightarrow NO_2^- + 2OH^- \quad (E_0 = 0.015\ V)$$

Under these conditions, there is a possibility that cadmium ions formed during reduction is precipitated as the hydroxide and thus reducing the efficiency of the reduction column. Therefore, the solution should be buffered to prevent this efficiency loss. Seawater, of course has a limited buffering capacity, but this is not sufficient. Therefore ammonium chloride is added as a buffer and as a complexing agent for Cd^{2+} ions.

$$2NH_4^+ \longleftrightarrow 2NH_3^+ + 2H^+$$

$$Cd^{++} + 2NH_3 \longrightarrow [Cd\ (NH_3)2]^{++}$$

Thus the two H^+ formed neutralize the two OH^- irons formed, as in equation above. The Cd^{++} combines with ammonia to form the complex.
The efficiency of the reduction of nitrite should be maintained close to 100% by frequent standardization.

Sensitivity:- The molar absorptyvity of the azo dye formed from nitrite is 46,000 at 540nm.There for a sample of sea water having a nitrite nitrate concentration of 1.0 µmol/L at $(NO_3^- NO_2)N$ per liter should have an absorbance of 0.230, using a 5cm path length cell. For nitrite, which is normally present at sub microgram mol per litre, thus use of a 50mm path length is a must.

PART II: METHOD FOR THE DETERMINATION OF NUTRIENTS IN SEAWATER

2. INORGANIC REACTIVE PHOSPHATE (PO_4 – P)

2.1. Aim

To determine dissolved inorganic reactive Phosphate – Phosphorus in seawater.

2.1.1. Outline of the method

Phosphate in seawater is allowed to react with acid Ammonium molybdate, forming a Phosphomolybdate complex, which is reduced by Ascorbic acid, in presence of Antimomyl ions (to accelerate the reaction) to a blue coloured complex containing 1 : 1 atomic ratio of phosphate and antimonyl ions.The extinction of the blue colour is measured at 882 nm using 5 cm cell. To avoid interference by silicate the pH is kept below 1.

2.2. Reagents

1. ***Sulphuric acid (9.0 N):*** Add carefully 250 ml conc. H_2SO_4 to a 1 l volumetric flask containing 750 ml Milli Q (MQ) water and dilute to 1000 ml.

2. ***Ammonium molybdate solution:*** Dissolve 12.5 g Ammonium molybdate tetrahydrate (AR) in 125 ml MQ water. Store in a plastic or glass bottle.
3. ***Potassium antimonyl tatrate solution:*** Dissolve 0.5 g Potassium antimonyl tartrate (AR) in 20 ml MQ water. Store in a glass bottle.
4. ***Mixed reagent:*** Add slowly while stirring 125 ml Molybdate solution to 350 ml 9.0 N Sulphuric acid. Then add 20 ml Tartrate solution, mix by shaking. Reagent is stable for many months. Store in an amber glass bottle.
5. ***Ascorbic acid solution:*** Dissolve 10 g Ascorbic acid in 50 ml MQ water and add 50 ml 9.0 N Sulphuric acid. The reagent remains stable for at least a week and can be used as long as it remains colourless. Store in an amber coloured glass bottle, in a refrigerator.
6. ***Phosphate standard solution:*** Weigh accurately 0.1361 g of Potassium dihydrogen phosphate (AR) and dissolve in 100 ml MQ water containing 1 ml of 9.0 N sulphuric acid (prior to weighing, dry potassium dihydrogen phosphate in an oven at 110^0 C and cool in a desiccator). This solution contains 10 mmol/L PO_4^{-3} – P or 10,000 µmol /L PO_4^{-3} - P.

2.3. Apparatus

1. Spectrophotometer : With 5 cm path – length cell
2. Stoppered glass test tubes : With marking at 25 ml volume
3. Volumetric flasks : 100 ml
4. Measuring pipettes : 1ml, 2ml and 3ml

2.4. Procedure

1. ***Working Phosphate solution:*** Transfer 1 ml Phosphate standard solution to a 100 ml volumetric flask and dilute to the mark with MQ water. This solution contains 100 µmol PO_4^{-3} – P/L. Prepare the following standards of 0.5, 1.0, 2.0, 5.0, 10.0 µmol PO_4^{-3} – P/L concentrations from the stock solutions.

2. ***Calibration and blank:*** Measure out 25 ml of MQ water for blank determination. Measure out 25 ml working phosphate solutions in clean-stoppered glass test tubes. Add *0.5 ml of Ascorbic reagent* to each tube and mix well. Then add *0.5 ml of Mixed reagent*, mix and wait for 10 min to allow the development of blue complex. Measure the absorbance of blank A (b) and standard A (st) in a Spectrophotometer using 5 cm cells at *880 nm* using MQ water as reference.

3. ***Sample analysis:*** Measure out 25 ml of the sample in a glass tube and add the reagents in the same order as described above. Measure the absorbance A (s) of the sample in 5 cm cuvette at 880 nm.

2.5. Calculations

Calculate the factor F from the relation,

$$F = \frac{\text{Conc. of standard solution}}{A\,(st) - A\,(b)}$$

Where A (st) = Mean absorbance of standards
A (b) = Mean absorbance of blanks

Calculate the amount of Phosphate – Phosphorus present in the sample from the relation

$$PO_4^{-3}–P = F \times A\,(s) - A\,(b)$$

Where A (s) = Mean absorbance of sample
A (b) = Mean absorbance of blanks.

2.6. Results

Report the results up to two places of decimal and presented in **µmol l^{-1}**.

3. Nitrite – Nitrogen (NO_2 – N)

3.1. Aim

To determine Nitrite – Nitrogen in seawater.

3.1.2. Outline of the method

The Nitrite in seawater is diazotised with Sulphanilamide at pH 1.5 to 2.0 and then resulting diazo compound is coupled with N – (1– naphthyl) – Ethylene diamine to form a highly coloured azodye with absorption maxima at 540 nm.

3.2. Reagents

1. ***Sulphanilamide:*** Dissolve 2.5 g Sulphanilamide in 25 ml conc. HCl (AR) and make up to 250 ml with MQ water. Store in an amber coloured bottle.
2. ***N –(1–naphthyl) – Ethylene diamine dihydrochloride (NEDA):*** Dissolve 0.25 g of Amine in 250 ml MQ water. Store in an amber coloured glass bottle.
3. ***Nitrite stock solution:*** Anhydrous Sodium nitrite ($NaNO_2$) is dried at 110^0 C for some hours. Dissolve 0.069g of the dry salt in water and dilute to 100 ml. This solution contains 10 mmol/L NO_2 – N or 10,000 µmol /L NO_2 – N.

3.3 Apparatus

1. Stoppered glass test tubes : With marking at 25 ml
2. Spectrophotometer
3. Volumetric flasks : 100 ml,
4. Measuring pipettes: 1ml,2ml and 3ml

3.4. Procedure

1. ***Working Nitrite solution:*** 1 ml of stock solution is diluted to 100 ml. This solution contains 100 µmol NO_2 – N/L. Prepare the standards of 0.5, 1, 2, 3 and 4 µmol/L.

2. ***Calibration and blank:*** Measure 25 ml of the above diluted standard solution into clean test tubes and 25 ml of MQ water in another tube for blank. Add *0.5 ml of Sulphanilamide* and mix well. After 1 min reaction time, add *0.5 ml of NEDA* solution. Mix the sample once again and allow the reaction to proceed for 15 min. Measure the absorbance of blank A (b) and standards A (st) in 5 cm cuvette against MQ water as reference at *540 nm*.

3. ***Sample Analysis:*** Measure 25 ml of the sample in duplicate and add the reagents as described above and measure the absorbance A (s).

3.5. Calculations

Calculate the factor (F) from the relation

$$F = \frac{\text{Conc. of standard solution}}{A\ (st) - A\ (b)}$$

Where A (st) = Mean absorbance of the standards
A (b) = Mean absorbance of the blank

Calculate the concentration of the Nitrite from the relation

$$NO_2 - N \; \mathbf{\mu mol\ l^{-1}} = F \times A(s) - A(b)$$

Where A (s) = Mean absorbance of the sample
A (b) = Means absorbance of blanks

.

3.6. Results

Report the results up to two places of the decimal.

4. Nitrate – Nitrogen (NO_3 – N)

4.1. Aim

To determine Nitrate – Nitrite in the seawater.

4.2. Outline of the method

Nitrate in seawater is quantitatively reduced to nitrite by heterogeneous reduction involving Copper – cadmium granules. Nitrite thus produced is determined by diazotising with Sulphanilamide and coupling with N – (1– naphthyl) – Ethylene diamine through the column without change. Hence correction should be made for Nitrite present in the sample.

4.3. Rreagents

- **Ammonium chloride buffer**: Dissolve 10.0 g of ammonium chloride (AR) in 1000 ml MQ water. Store in a polyethylene bottle and the pH adjusted to 8.5 with ammonia.
- **Sulfanilamide solution (1%):** dissolve 1 g sulfanilamide in 10 ml conc. hydrochloric acid and make up to 100 ml with MQ water. Store in an amber coloured glass bottle.
- **N-(1-naphthyl) – ethylene diamine dihydrochloride (1%)**: Dissolve 0.1 g in 100 ml MQ water and store in an amber coloured glass bottle.
- **Cadmium metal filings:** 0.3 to 1.6mm (E Merck-Product No. 1.02001.0250)
- **Copper sulfate solution $CuSO_4.5H_2O$ (1%): D**issolve 2.5g of CuSO4.5H_2O in 250ml of MQ water.
- **Nitrate standard solution**: Dissolve 0.1011 g dry potassium nitrate (previously dried at 105°C to constant weight) in 100 ml distilled water. The stock solution contains 10mM or 10,000 µmol/L NO_3-N.

  From 10,000 µmol /L, 1ml in 100ml gives 100µmol /L.
  From 100 µmol /L, 5ml in 100ml gives 5µmol /L.
  From 100 µmol /L, 10ml in 100ml gives 10µmol /L.
  From 100 µmol /L, 15ml in 100ml gives 15µmol /L.

- **Nitrate Activator Solution**: Transfer 20ml of 100µmol/L to a 100ml of volumetric flask and make up to the mark. This solution contains 20 µmol/L

4.4. Preparation of Reduction column ***:*** The size of the Cd granules should be between 0.5 to 1.0 mm. E Merck grad Cd granules can be used for packing the column. Remove any iron particles from the filings with the help of magnet. Wash the filings with Acetone to remove oil and grease. Next wash them with HCl (2 N) and then with copious amounts of MQ water.

Place Cadmium filings (70 – 80 g) in a stoppered glass bottle (125 ml) and fill the bottle either with 2% Copper sulphate. Stopper the bottle taking care to see that no air bubbles are trapped in the bottle. Shake the bottle for 10 min and keep 15 min. Open the bottle and drain out the copper sulphate solution. Wash thoroughly with distilled water until the water drain out the is clear. Take care that cadmium metal does not come in contact with the air. Fill MQ water up to the rim of the bottle.

4.5.Packing the Reduction column:

- Place a plug of glass wool at the bottom end of the column and the column and the reservoir filled with MQ water.
- Transfer the copperised cadmium into the column reservoir. Allow the filings to fall freely into the column taking care that no air cavities are formed.
- After transferring the filings in the column, place another piece of glass wool on the top of the filings.
- The cadmium filings should be kept under water always to avoid getting dried.
- Adjust flow rate to 6-8 mL/min. Pass the buffer solution (pH 8.5) through the column. **(Fig.1)**

4.6.Activation of column

- Pass 50 ml of activator solution plus 50 ml of buffer through the column at a rate of 6-8 ml in 1 minute and discard the elute.
- Pass 50 ml MQ water plus 50 ml buffer through the column. Stop the elution, leaving the buffer water just above the filings in the column.

4.7.Procedure

1. Calibration and determination of blank for Nitrate + Nitrite analysis : Prepare the following standards from the stock solution i.e., 5, 10, 15 and 20 μmol NO_3–N/l concentration. Take 50 ml of this diluted nitrate standard solution plus 50 ml buffer in a 100 ml standard flask and pass through the column. Discard the first 50 ml and collect next portion of 25 ml eluate in the stoppered glass tubes for subsequent analysis. Add to each tube *1 ml of Sulphanilamide* and mix well. After 1 min reaction time,*1 ml of NEDA* solution is added, mix well and a reaction time of 15 min allowed. Measure the absorbance A (st) in 1 cm cuvette at *540 nm* against MQ water as reference within 1h.

2. Blank: Take 50 ml MQ water plus 50 ml buffer in a100 ml standard flask and pass through the column. Discarded the first 25 ml and collected next two portions of 25 ml in the stoppered glass tubes for determining the absorbance of blank A (b).

3. Sample analysis : Measure 50 ml of the sample plus 50 ml buffer in 100ml standard flask and pass through the column, rejected the first 50 ml and the next two portions preserved. Pass the sample through the column and proceed as before for the standards. Measure the absorbance A (NO_2+NO_3) in a 1 cm cuvette at 540 nm against MQ water as reference. Analyze the same sample for Nitrite and determine the concentration of nitrite in μmol/l

4.8. Calculations

Calculate the factor F for Nitrite from the formula

$$F = \frac{\text{Conc. of standard solution}}{A\text{ (st)} - A\text{ (b)}}$$

Where A (st) = Mean absorbance of standards
A (b) = Mean absorbance of blanks

Calculate the concentrations of Nitrate + Nitrite from the relation

$$C\,(NO_2+NO_3) = F \times [A\,(NO_3+NO_2) - A\,(b)]$$

Correct the value for Nitrate by using the relation

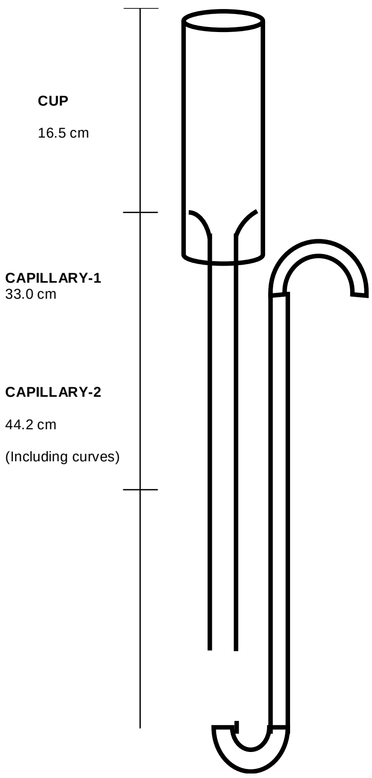
$C\,(NO_3)$ **µmol l^{-1}** $= C\,(NO_2+NO_3) - C\,(NO_2)$

where the (NO_2) was the concentration of nitrite in µmol/L determined earlier

4.9.Results

Report the results up to two places of decimal.

Fig.1 REDUCTION COLUMN



DIMENSIONS	Inner diameter
Cup	3.5 cm
Capillary-1	0.75 cm
Capillary-2	0.30 cm

PART III: BASIC CALCULATIONS IN WATER QUALITY ANLYSIS

5. Basic Calculations in water quality analysis

5.1. Introduction

In the metric system, the decimal scale is based upon multiples of 10 to measure units of volume, length and weight. The meter is the fundamental unit of the metric system because from this standard of linear measure that the other two metric units of weight and volume are derived. The details are given hereunder:

5.2. Metric system table

Weight		Volume	
1000 mg	1 g	1000 ml	1 L
1000 μg	1 mg	1000 μl	1 ml
1000 ng	1 μg	1000 nl	1 μl
1000 pg	1 ng	1000 pl	1 nl
1000 fg	1 pg	1000 fl	1 pl
1000 ag	1 fg	1000 al	1 fl

μg is otherwise called as gamma (χ) and μl as lambda (λ)

5.3. Solutions

It will be important to understand a few terms dealing with solutions, the definition of the terms are:

- **Solution** — a mixture consisting of a solute and a solvent
- **Solute** — component of a solution present in the lesser amount
- **Solvent** — component of a solution present in the greater amount
- **Concentration** — amount of a solute present in a solution per standard amount of solvent

5.3.1. Standard solution

In a volumetric analysis, a solution of a known strength is called a standard solution.

5.3.2. Normal solution

It may be defined as a solution which contains a gram equivalent weight of the substance in a liter of the solution.

5.4. Parts per million (ppm)

One ppm is equivalent to 1 milligram of substance in one liter of water (mg/l) or 1 milligram of substance in one kilogram of soil (mg/kg).

$$\text{ppm} = \frac{\text{grams of solute}}{\text{grams of solution}} \times 10^6$$

(1 part per 10^6 parts)

5.5. Parts per billion (ppb)

One ppb represents one microgram of chemical in 1 lit. of water (μg/l) or one microgram of the chemical in 1 kg. of soil (μg/kg)

$$\text{ppb} = \frac{\text{grams of solute}}{\text{grams of solution}} \times 10^9$$

5.6. Expression of strengths

Remember 1 in 1000;1 in 2000;1 in 3000, 1 ppm, 1ppb etc.
1 in 1000 means 1 gm of solid dissolved in 1000 ml i.e. 1 gm/1000 ml
If the solvent utilized is water, then it is 1 gm in 1000g because 1 ml of water weight is equal to 1 gm.
If it is a liquid diluted in another liquid, then it is 1 ml in 1000 ml

Basically 1 ml of water at 4^0C weighs 1 g. But at room temperature it may vary slightly.

5.7. Percentage solution

1 g or 1000 mg of a solid chemical dissolved in 100 ml is termed as 1% solution; i.e 1 ml contains 1000/100 = 10 mg of chemical in 1% solution.

5.8. Molar solution

Definition: One molecular weight gram of a substance dissolved in one liter of water is called as one Molar solution, and is expressed as M.

- One mill molar solution (1mM) – 1 mol. Wt. mg of a substance dissolved in 1 lit. of water.
- One nanomolar solution (1nM) – 1 mol.wt. µg of a substance dissolved in 1 lit. of water

Molarity (M) : This unit of concentration relates the moles of solute per liter of solution.

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{L solution}}$$

Molality (m): This unit of concentration relates the moles of solute per kilogram of solvent

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{kg solvent}}$$

Molar is weight/volume and Molal is weight/weight

If it is a liquid other than water, then for molal, we have to look for its specific gravity.

For example, sp.gr of Kerosene – 0.9 i.e. 1 ml of water = 1 g
1 ml of kerosene = 0.8g

Specific gravity is a comparison of the weight of a substance of a particular volume with the weight of water. To find out the sp.gr of a substance, divide its weight by the weight of an equal volume of water.

5.9. Molarity and Normality

How do you calculate 1 N of NaOH?
The question I am trying to figure out is Describe how to prepare a 1N and a 0.1 N solution of NaOH.

First of all, you need to understand what molarity and normality are.

Molarity refers to the number of molecules of a substance in a solution; a1M solution contains 1 mole (6.02 x 10^23 molecules or particles) of the substance in 1 liter of solution.

Normality refers to compounds that have multiple chemical functionalities, such as sulfuric acid, H_2SO_4: a 1M solution of H_2SO_4 will contain only one mole of H_2SO_4 in 1 liter of solution, but if you titrate the solution with base, you will find that it contains two moles of acid. This is because a single molecule of H_2SO_4 contains two acidic protons. Thus, a 1M solution of H_2SO_4 will be 2N.

Now, for your specific question: NaOH contains only one significant chemical functionality, which is the basic hydroxide, OH^-. So, for NaOH solutions, molarity and normality will be the same thing. So, a 1.0 N solution of NaOH in water is also a 1.0 M solution of NaOH in water, and a 0.1 N solution of NaOH in water is a 0.1 M solution of NaOH in water.

How do you make these? The first thing you need to know is the mass of a mole of NaOH. This is just its molecular weight: 40.0 g/mol. (That's what a molecular weight means: the mass in grams of one mole of the substance.)

So, to make a 1.0 M (= 1.0 N) solution of NaOH in water, you will want to weigh out 40.0 grams of NaOH, dissolve it in about 0.8 liters of water, and then add water to the solution to take the total volume up to exactly 1.0 liters. You would do the same thing to make a 0.1 M (= 0.1 N) solution: weigh out 0.1 mole of NaOH (= 4.0 g), dissolve it in water, and add enough water to make the total volume equal to exactly 1 liter.

If you don't want exactly on liter of these solutions, then you need to change the amounts by the same factor: if you need 0.5 liters of a 1.0 M solution, you use 0.5 moles of the substance and enough solvent to make the solution volume exactly 0.5 liters.

The 'Normality' of a solution is the 'Molarity' multiplied by the number of equivalents per mole (the number moles of hydroxide or hydronium ions per mole) for the molecule. For NaOH there is one equivalent per mole (one mole of hydroxide ions release per mole of NaOH dissolved in water) so the 'Normality' is the 'Molarity' times 1 eq / mole.

The 'Molarity' of a solution is the number of moles of solute in one liter of solution. To make a 1 N solution of NaOH would be the same as making a 1 Molar solution, (1 eq / mole) X (1 mole / liter). To make one liter of a 1 Molar solution, weigh out one mole of NaOH and slowly, with constant stirring and while monitoring the temperature of the solution (by touching the outside of the beaker), add it to about 750 ml of deionized water in a 1 liter beaker. (If the beaker gets warm to the touch, stop adding the NaOH and continue stirring until all the solid is dissolved and you are sure the solution is not overheating.) When all the NaOH has been added, bring the total volume up to 1.0 liter of solution by adding more deionized water.

To make a 0.1 N solution of NaOH you could follow the above procedure using 1/10 as much NaOH or you can dilute the above solution by a factor of 10. To do this, measure 100 ml of solution in a graduated cylinder. Slowly, and while stirring, add this to about 750 ml of deionized water in a 1 liter beaker.

(ALWAYS add the more concentrated solution to the less concentrated solution!) Again, monitor the temperature of the resulting solution. When all the solution from the graduated cylinder has been added, rinse the graduated cylinder several times with 10 or 20 ml of deionized water and finally, bring the total volume of the solution up to 1 liter.

For more accuracy you could use a 1 liter graduated cylinder instead of a beaker.
Smaller quantities of solution can be prepared by using the appropriate ratios of NaOH and total solution.

5.10. Solutions

PERCENT, MOLAR, NORMAL, SATURATED

We use reagents primarily in solution form. They are made up as percent solutions or molar or normal solutions. Rarely do you ever see molar solutions. All of these terms are just a means of naming the concentration of solutions.

5.10.1. Percent solution

There are three types of percent solutions. All are parts of solute per 100 total parts of solution.

Based on the following definitions you may calculate the concentration of a solution or calculate how to make up a specific concentration.

1 **% W/W -** Percent weight of solute in the total weight of the solution. Percent here is the number of grams of solute in 100 grams of solution.

Example:

A 100% (W/W) NaCl solution is made by weighing 100 g NaCl and dissolving in 100 g of solution.

2 **%** W/V **-** Percent weight of solution in the total volume of solution. Percent here is the number of grams of solute in 100 ml of solution. This is probably the least significant way of naming a solution, but the most common way of doing it. In fact, any percent solution not stipulated as W/W, W/V, or V/V is assumed to be % W/V.

Example:

A 4% (W/V) NaCl solution is 4 g of NaCl in 100 ml of solution.

3**% V/V -** Percent of volume of solute in the total volume of solution %V/V. Percent here is the number of milliliters of solute in 100 ml of solution.

Example:

A 10% (V/V) ethanol solution is 10 ml of ethanol in 100 ml of solution; unless otherwise stated, water is the solvent.

So now, here are some applications

1. What is the percent concentration of a solution that you made by taking 5.85 g of NaCl and diluting to 100 ml with H_2O?

5.85 g/100 ml = 5.85% W/V solution of NaCl

2. What is the percent concentration of a solution that you made by taking 40 g of $CaCl_2$ and diluting to 500 ml with H_2O?

You set up a proportion problem.

40 g /500 ml = Xg /100 ml

X = 8g

8g/100 ml = 8% (W/V) solution

OR

Another way to look at this is, 40 grams solute is what percent of the 500 ml solution? The 100 is used to convert to percent.

3. How would you make 250 ml of a 8.5% NaCl solution?

This works backwards from the others —
8.5%= 8.5 g /100 ml
Again, set up a proportion
8.5 g /100 ml= X / 250 ml
21.3 g = X

OR

an alternative method is to say what is 8.5% of 250 ml?
250 x 0.085 = 21.3
Therefore you would need to weigh out 21.3 g NaCl and dilute to 250 ml with H_2O.

4. How much (volume) 0.85% NaCl may be made from 2.55 g NaCl?

An 0.85% NaCl solution = 0.85 g/100 ml
Setting up a proportion again,
0.85 g /100 ml = 2.55 g/X
X = 300 ml
Therefore, 300 ml of 0.85% NaCl may be made from 2.55 g NaCl.

5.10.2. MOLAR SOLUTIONS (M)

The definition of molar solution is a solution that contains 1 mole of solute in each liter of solution. A mole is the number of gram molecular weights (gmw). Therefore, we can also say a 1M = 1 gMW solute/liter solution.
1M NaCl solution would be
Na = MW of 23
Cl = MW of 35.5
NaCl = MW of 58.5
1M = 58.5 g of NaCl in 1 liter of solution.

It may be made by weighing out 58.5 g of NaCl and qs to 1 liter with water. The qs stands for quality sufficient and is a term used to designate that the total volume must be 1 liter (or whatever is stated).

58.5 g NaCl qs 1 liter with H_2O
Examples of other solutions would be
1 M H_2SO_4 = 98 g/l
1 M H_3PO_4 = 98 g/l

Problems

Let's look at some problems as examples.
1. How would you make a liter of 4M $CaCl_2$? First find molecular weights.
Ca = 40 ; Cl_2 = 35.5 x 2 = 71
$CaCl_2$ = 111 (MW)
Then, 1M = 111 g/l ; 4M = 4 (111 g/l) ; = 444 g/l
Weigh out 444g $CaCl_2$ qs 1 liter with H_2O

2. How would you make 300 ml of a 0.5M NaOH solution?
First find molecular weights.
Na = 23 ;0 = 16 ; H = 1
NaOH = 40 (MW)

Then, 1M = 40 g/l ; 0.5M = 0.5 (40 g/l) ; = 20 g/l
But you only want 300 ml so . . .
20 /1000 ml = x /300 ml
6 g = x

Weigh out 6 g NaOH pellets qs. 300 ml with H_2O
3. You weighed out 58.5 g of NaCl and diluted it to 250 ml. What is the molarity of the solution?
Set up a proportion to find the equivalent in a liter.
58.5 g /250 ml = x / 1000 ml
x = 234 g /1000 ml = 234 g / 1l
Since 1M = 23 + 35.5 = 58.5 g/l
Set up another proportion.
x /234 g/l = 1 M /58.5 g/l
4 M = x

5.10.3. NORMAL SOLUTIONS:

The definition of a normal solution is a solution that contains 1 gram equivalent weight (gEW) per liter solution. An equivalent weight is equal to the molecular weight divided by the valence (replaceable H ions).
1N NaCl = 58.5 g/l
1N HCl = 36.5 g/l
1N H_2SO_4 = 49 g/l

Problems involving normality are worked the same as those involving molarity but the valence must be considered:
1N HCl the MW= **36.5** the EW = **36.5** and 1N would be **36.5** g/l
1N H_2SO_4 the MW = **98** the EW = **49** and 1N would be **49** g/l
1N H_3PO_4 the MW = **98** the EW = **32.7** and 1N would be **32.7** g/l

PROBLEMS:

1. You weigh out 80 g of NaOH pellets and dilute to 1 liter. What is the normality?
MW of NaOH = 40
EW = 40
1N = 40 g/l
80 g/l /40 g/l = **2N**
What is the molarity?
MW = 40
1M = 40 g/l
80 g/l /40 g/l = **2M**

2. You weighed out 222g of CaCl**2** and diluted to 1 liter. What is the normality?
EW = 111 /2 = 5.55
1N = 55.5 g/l
222 g/l /55.5 g/l = **4N**

What is the molarity?
1M = 111 g/l
222 g/l /111 g/l = **2M**

Then the **molarity times the valence equals the normality**.

5.11. Dilutions

The dilutions describe the ratio of the solute to the final volume of the diluted solution.

For example, to make a 1:10 dilution of a 1M NaCl solution, you would mix one "part" of the 1M solution with nine "parts" of solvent (probably water), for a total of ten "parts." Therefore, 1:10 dilution means 1 part + 9 parts of water (or other diluent).

5.12. Serial dilutions

Similarly for making up 10^{-1} M to 10^{-5} M solutions from a 1M stock solution.

- Pipette 10 ml of the 1M stock into a 100 ml volumetric flask and make up to the mark to give a 10^{-1} M solution.
- Now, pipette 10 ml of this 10^{-1} M soln. into another 100 ml flask and make up to the mark to give a 10^{-2} M solution.
- Pipette again, 10 ml of this 10^{-2} M solution. into yet another 100 ml flask and make up to mark to give a 10^{-3} M solution.
- Pipette a 10 ml of this 10^{-3} M solution. into another 100 ml flask and make up to mark to give a 10^{-4} M solution.
- And from this 10^{-4} M solution. pipette 10 ml into a 100 ml flask and make up to mark to give a final 10^{-5} M solution.

5.12.1. Dilution formula

Sometimes it is necessary to use one solution to make a specific amount of a more dilute solution. To do this, you can use the formula:

$V_1C_1 = V_2C_2$

where:
V_1 = volume of starting solution needed to make the new solution
C_1 = concentration of starting solution
V_2 = final volume of new solution
C_2 = final concentration of new solution

For example: Make 5ml of a 0.25M solution from 2.5ml of a 1M solution.

$V_1C_1 = V_2C_2$

(V_1) (1M) = (5mL) (0.25M)
V_1 = [(5ml) (0.25M)] / (1M)
V_1 = 1.25ml

So you will need to use 1.25ml of the 1M solution. Since you want the diluted solution to have a final volume of 5ml, you will need to add (V1-V2 = 5ml - 1.25ml) 3.75ml of diluent.
Sometimes it is necessary to dilute by a large factor so several serial dilutions are necessary.

5.12.2. Making Solutions

5.12.3. Solutions made using percentage by weight (w/v)

The number of grams in 100ml of solution is indicated by the percentage.

For example, a 1% solution has one gram of solid dissolved in 100ml of solvent. To make this type of solution properly, you should weight 1g and dissolve it in slightly less than 100ml. Once the solids have dissolved, you can bring the volume up to the final 100ml

5.12.4. Solutions made using percentage by volume (v/v)

In this case, the percentage indicates the volume of the full strength solution in 100ml of dilute solution.

6. WEIGHTS AND MEASUREMENTS

The Imperial System, established in 1824, was until the late 1960s, the main system of measurement used in the British Commonwealth. Virtually every country using the imperial system began a changeover to the metric system beginning in the late 1960s and 1970s. The metric system outlined here in the modern form of the metric system, referred to as the International Systems of Units. (System International d'Unites, or SI). The multiples and submultiples of the base and other units of the metric system are shown here for various types of measure, these are formed by applying established prefixes, which are the same whichever unit is used. Examples are milligram (mg), millimeter (mm), kilometer (km), kilowatt (kw) and Megawatt (MW). Only one multiplying prefix is applied at one time to a given unit. Thus, one thousandth of a milligram is referred to as a microgram and not as a millimilligram. Unit names take a plural 's' when associated with numbers greater than 1. Abbreviations, however, remain unaltered in the plural form and should be without a full stop. Thus, km is the correct abbreviation for kilometer and kilometers.

1.1. IMPERIAL SYSTEM

LENGTH

1 angstrom	=	0.0001 micron
1 inch	=	1000 milli inches
	=	2.54 centimeters
1 foot	=	12 inches
	=	0.3048 meter
1 micron	=	0.001 millimeter
1 yard	=	3 feet
	=	0.91 meter
1 rod	=	5.5 yards
	=	25 links
1 furlong	=	220 yards
	=	40 rods
1 mile	=	5280 feet
	=	1760 yards
	=	8 furlongs
1 league	=	3 miles
1 chain	=	100 links
	=	66 feet
	=	22 yards
	=	4 rods

LENGTH (Nautical)

1 fathom	=	6 feet
	=	1.83 meters
1 cable length	=	100fathoms(approx)
1 nautical mile	=	6080.2 feet
	=	1.85 kilometers
	=	1.15 statute miles
	=	10 cable length
1 statute mile	=	2580 feet
	=	1.6 kilometers
	=	0.87 nautical miles

AVOIRDUPOIS WEIGHT

1 ounce	=	437.5 grains
	=	16 drams
1 pound	=	7000 grains
	=	256 drams
	=	16 ounces
	=	453.6 grams
1 stone	=	14 pounds
1 quarter	=	28 pounds
	=	2 stones
1 cental	=	100 pounds
1 cwt	=	112 pounds
	=	4 quarters
1 ton	=	35840 ounces
	=	2240 pounds
	=	20 cwts
1 long ton (UK)	=	1.016 Mg
1 short ton (US)	=	0.907 Mg

CAPACITY

1fluid ounce	=	8 fluid drachms
1 gill	=	5 fi ounces
1 pint	=	20 fi ounces
	=	4 gills
1 quart	=	40 fi ounces
	=	2 pints
1 gallon	=	160 fi ounces
	=	8 pints
	=	4 quarts
	=	4.55 dm^3
	=	4.55 liters
1 peck	=	2 gallons
1 bushel	=	4 pecks

AREA

1 sq foot	=	144 sq ins
1 sq yard	=	9 sq feet
1 sq rod	=	30.25 sq yds
1 sq chain	=	484 sq yard
1 sq acre	=	4840 sq yds
1 acre	=	160 sq rods
1 sq mile	=	640 acres
1 sq centimeter	=	0.155 sq inches
1 sq meter	=	10.8 sq feet
1 sq kilometer	=	247.1 acres
	=	0.386 sq statute mile
	=	0.292sq.nauticalmile
1 rod	=	1210 sq yds

	=	8 gallons
1 quarter	=	64 gallons

VOLUME

1 cu foot	=	1728 cu ins
1 cu yard	=	46656 cu ins
	=	27 cu feet
1 cu meter	=	1000 liters
1 milliliter	=	0.001 liter
	=	1 cubic centimeter
1 liter	=	1000 cubic centimeter
	=	1.06 liquid quarts
1 gallon	=	4.55 cubic decameter
	=	4.55 liters
1 cubic meter	=	1000 liters

CONCENTRATION

M	=	gram molecular Weight per liter (or molecular concentration)
µg-atoms/l	=	mg-atoms/m^3µM
µg/l	=	mg/m^3

ppm (parts per million)	= mg/l
ppb(parts per billion)	= µg/l
µg/l ÷atomic wt	= µg-atoms/l
µg/l÷molecular wt	= µMµmol/l

1.1. THE METRIC MEASUREMENT

PREFIX NAME	PREFIX SYMBOL	DESCRIPTION	
Atto	a	10^{-18}	one million million millionth
Femto	f	10^{-15}	onethousand million millionth
Pico	p	10^{-12}	one million millionth
Nano	n	10^{-9}	one thousand millionth
Micro	m	10^{-6}	one millionth
Milli	m	10^{-3}	one thousand
Centi	c	10^{-2}	one hundred
Deci	d	10^{-1}	one tenth
Deca	da	10^{1}	ten
Hecto	h	10^{2}	one hundred
Kilo	k	10^{3}	one thousand
Myria	my	10^{4}	ten thousand
Mega	M	10^{5}	one million
Giga	G	10^{9}	one thousand million
Tera	T	10^{12}	one million million
Peta	P	10^{15}	one thousand million million
Exa	E	10^{18}	one million million million

6.3.MASS

1 microgram	=	1000 nanograms
1 milligram	=	1000 micrograms
1 metric carat	=	200 milligrams
1 gram	=	1000 milligrams
	=	5 metric carats
1 metric ounce	=	25 grams
1 hectogram	=	100 grams
1 kilogram	=	1000 grams
1 quintal	=	100 kilograms
1 megagram	=	1000 kilograms
	=	10 quintals
1 tonne	=	10 quintals

6.4.VOLUME & CAPACITY

1 cu centimeter	=	1000 cu millimeters
1 cu decimeter	=	1000 cu centimeters
1 cu meter	=	1000 cu decimeters
1 cu decameter	=	1000 cu meters
1 cu hectometer	=	1000 cu decameters
1 cu kilometer	=	1000 cu hectometers
1 milliliter	=	1000 microliters
1 cu centimeter	=	1000 microliters
1 centiliter	=	10 milliliters
1 deciliter	=	10 centiliters
1 liter	=	1000 milliliters
	=	100 centiliters
1 hectoliter	=	100 liters
1 kilolitre	=	1000 liters
	=	10 hectoliters
1 cu meter	=	1000 liters

6.5.METRIC STANDARD ABBREVIATIONS

A	=	ampere	Å	=	angstrom	a	=	are
bar	=	bar	C	=	coulomb	^{0}C	=	Celsius
cc	=	cubic centimeter	cg	=	centigram	cl	=	centiliter
cm	=	centimeter	cm^2	=	square centimeter	cm^2/s	=	square centimeter per second
cm^3	=	cubic centimeter	CM	=	metric carat	cN	=	centinewton
cP	=	centipoises	cSt	=	centistokes	daa	=	dekare
dag	=	dekagram	dal	=	dekaliter	dam	=	decameter
dam^2	=	square decameter	dam^3	=	cubic decameter	dyn	=	dyne
EHz	=	exahetrz	F	=	farad	g	=	gram
GHz	=	gigahertz	GJ	=	gigajoule	GΩ	=	gigohm
GPa	=	gigapascal	GW	=	gigawatt	h	=	hour
H	=	henry	ha	=	hectare	hbar	=	hectobar
Hg	=	hectogram	hl	=	hectoliter	hm	=	hectometer
hm^2	=	square hectometere	hm^3	=	cubic hectometer	hpz	=	hectopieze
Hz	=	hertz	J	=	joule	kA	=	kiloampere

Kbar	=	kilobar	kC	=	kilocoulomb	kg	=	kilogram
Kgf	=	Kilogram –force	kgf m	=	kilogram–force meter	kHz	=	kilohertz
kJ	=	kilojoule	kl	=	kiloliter	km	=	kilometer
km^2	=	square kilometer	km^3	=	cubic kilometer	km/h	=	kilometer per hour
km/s	=	kilometer per second	kN	=	kilonewton	KΩ	=	kilohm
Kp	=	kilopound	kPa	=	kilopascal	ks	=	kilosecond
kS	=	kiloseimens	kV	=	kilovolt	kW	=	kilowatt
kW h	=	kilowatt hour	L or l	=	liter	M	=	meter
M/s	=	meter per second	m^2	=	square meter	m^2/s	=	square meter per second
M^3	=	cubic meter	mA	=	milliampere	mbar	=	millibar
mC	=	millicoulomb	MC	=	Megacoulomb	mg	=	milligram
Mg	=	megagram	mH	=	Millihenry	MHz	=	megahertz
MJ	=	megajoule	ml	=	Milliliter	Mm	=	megameter
Mm	=	millimeter	mm^2	=	square millimeter	mN	=	millinewton
MN	=	meganewton	mΩ	=	milliohm	MΩ	=	megaohm
mPa	=	millipascal	MPa	=	megapascal	mPa/s	=	millipascal second
Ms	=	millisecond	m/s	=	meter per second	mS	=	milliseimens
mT	=	millitesia	mV	=	millivolt	MV	=	megavolt
mW	=	milliwatt	MW	=	megawatt	mA	=	microampere
Mbar	=	microbar	mC	=	microcoulomb	mF	=	microfarad
Mg	=	microgram	mH	=	microhenry	ml	=	microliter
Mm	=	micrometer	mN	=	micronewton	mΩ	=	microhm
mPa	=	micropascal	ms	=	microsecond	mS	=	microseimens
mT	=	microtesia	mV	=	microvolt	mW	=	microwatt
N	=	newton	nA	=	nanoampere	mC	=	nanocoulomb
Ng	=	nanogram	nH	=	nanohenry	mm	=	nanometer
Ns	=	nanosecond	nT	=	nanotesia	XΩ	=	ohm
P	=	pong	P	=	poise	pA	=	picoampere
Pa	=	pascal	Pa/s	=	pascal second	pC	=	picocoulomb
pF	=	picofarad	pH	=	picohenry	pHz	=	picohertz
Pm	=	picometer	pz	=	poize	q	=	qunital
S	=	second	S	=	seimens	sn	=	sthane
St	=	stokes	t	=	tonne	T	=	tesia
THz	=	terahertz	TJ	=	terajoule	TW	=	terawatt
V	=	volt	W	=	watt			

6.6.METRIC CONVERSION

Use of double conversion tables :

The bold figures in the central columns of each table can be read as either the metric or the imperial measure. For example, 1 pound * 0.453592 kilogram, or 1 kilogram * 2.204622 pounds. To determine the equivalent for ten (10), hundred (100), thousand (1000), etc., units move the decimal point one place to the right for each zero (0). For example, 10 pounds = 4.53592 kilograms, 100 pounds = 45.3592 kilograms, 1000 pounds = 453.592 kilograms. In the same way, the equivalent conversion for 0.1, 0.01, 0.001, etc., can be obtained by moving the decimal point one place to the left for each decimal place in the unit to be converted. For example, 0.1 pound = 0.0453592 kilogram, 0.01 pound = 0.00453592 kilogram. Thus, the conversion for 120.5 pounds can be obtained from the table by adding together the conversion for 100 pounds and that for 20 pounds and of 0.5 pound. This equals to 45.3592 kilogram plus 9.0718 kilogram plus 0.2268 kilogram or 54.6578 kilograms. However, the rounding is not always accurate for the last decimal place after making this calculation.

6.7.CONVERSION FORMULAE

MASS

To convert	Multiply by
Grains into milligrams………..…………	64.79891
Grains into metric carats……………..…………	0.323995
Grains into grams…………….…………..	0.064799
Pennyweights into grams…………………………..	1.555174
Drams into grams…………….…………	1.77185
Ounces into grams…………….…………..	28.349523
Ounces troy into grams…………….…………..	31.103477
Ounces troy into metric carats……………..…………	155.5174
Ounces into kilograms…………………..	0.0283495
Pounds into kilograms…………………..	0.4535924
Stones into kilograms…………………..	6.3502932
Hundredweights into kilograms..…………………	50.802345
Tons into kilograms………...	1016.0469
Tons into metric tons……..	1.01604
Tahils into grams…………….…………	37.799
Kati into kilograms…………	0.060479

VOLUME & CAPACITY

To convert	Multiply by
Cubic inches into cubic centimeters…………………..	16.387064
Cubic inches into cubic .liters.	0.016387
Cubic feet into cubic meters...	0.0283168
Cubic feet into liters…………..……………	28.316847
Pints into liters…………..……………	0.5682613
Quarts into liters……………..…………	1.1365225
Cubic yards into cubic meters………………………	0.7645549
Gallons into liters……………...…………	4.54609
Gallons into cubic meters………………………	0.0045461
Fluid ounces into cubic centimeters…………………	28.413063

AREA

To convert	Multiply by
Square inches into square millimeters………………	645.16
Square inches into square centimeters……………...	6.4516
Square feet into square centimeters……………...	929.0304
Square feet into square meters……………………	0.092903
Square yards into square meters……………………	0.836123
Square yards into ares.………………………	0.0083613
Acres into square meters……………………	4046.8564
Acres into ares…………..…………	40.468564
Acres into hectares………..…………	0.4046858
Square miles into hectares………..…………	258.9988
Square miles into square kilometers……..………...	2.589988

7.0. Quality Assurance in Chemical Analysis

Measurements should be comprehensible, Precise, accurate and interpretable

7.1. Steps in test procedures (part of QA)

- Sampling
- Sample conservation
- Sample transportation
- Sample storage
- Sample preparation/processing
- Measurement
- Data evaluation
- Test report

7.2. Implementation of QA

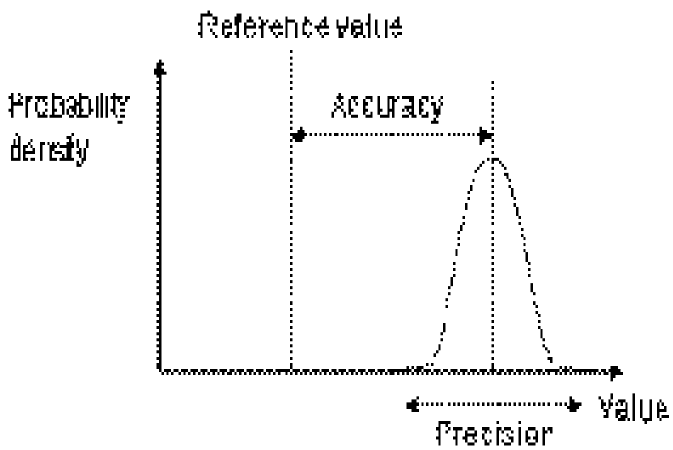
- Optimization of personnel
- Optimization of equipment/instrument
- Choice of suitable test procedures for the problem
- Determination of the parameters for the test procedures used
- Carrying out internal QA procedures
- Participation in external QA procedures
- Evaluation and documentation of QA procedures used

7.3. Calibration, why?

- Parameter – physical attribute, concentration or amount to be measured
- There is no “absolute” scale in nature
- Measurement (Quantification) is a human invention
- Any device used for measurement has to be calibrated
- You cannot achieve a reliability of measurement better than the reliability of the measuring device

7.4. Accuracy and precision

In the fields of science engineering and statistics, **accuracy** is the degree of closeness of a measured or calculated quantity to its actual (true) value. Accuracy is closely related to **precision**, also called reproducibility or repeatability, the degree to which further measurements or calculations show the same or similar results.



Accuracy indicates proximity to the true value, precision to the repeatability or reproducibility of the measurement

The results of calculations or a measurement can be accurate but not precise, precise but not accurate, neither, or both. A measurement system or computational method is called *valid* if it is both *accurate* and *precise*. The related terms are *bias* (non-random or directed effects caused by a factor or factors unrelated by the independent variable) and *error* (random variability), respectively.

7.5. Accuracy versus precision; the target analogy

High **accuracy**, but low **precision**

High **precision**, but low **accuracy**

7.6. Quantifying accuracy and precision

Ideally a measurement device is both accurate and precise, with measurements all close to and tightly clustered around the known value. The accuracy and precision of a measurement process is usually established by repeatedly measuring some traceable reference standard. Such standards are defined in the International System of Units and maintained by national standards organizations such as the National Institute of Standards and Technology.

REFERENCE

Grasshoff, K., Ehrhardt, M., Kremling, K., 1999.Methods of Sea water analysis, 3rd edition, Verlag Chemie, Weinheim, Germany.

OCEAN – OBSERVATION

Required to establish and sustain ocean data gathering, analysis and predictive systems for the marine environment, accessible to everybody, providing safer and more efficient ocean operations, improved safety and risk management in the marine environment and coastal seas, as well as an improved scientific and information basis for marine and ocean policy development. Ocean observation has economic benefits because the data are used to derive products, such as forecasts, that are used by decision makers to make choices that affect economic well-being.

15. POTENTIAL FISHING ZONE (PFZ) ADVISORIES – TECHNOLOGY PERSPECTIVE

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About 7 million people living along the Indian coastline, spanning more than 8100 km, are dependent on fishing for their livelihood. Locating and catching fish is, however, becoming more challenging as fish stocks dwindle and move further offshore, thus increasing the search time, cost and effort. A reliable and timely forecast on the potential zones of fish aggregation will benefit the fishing community to reduce the time and effort spent in searching the fishing grounds, thus improving their socio-economic status. The concerted efforts of scientists from Earth Sciences, space and fishery science in collaboration with the coastal states have resulted in a unique service of Potential Fishing Zone (PFZ) advisories.

Evolution of the PFZ Mission

The Ministry of Earth Sciences (MoES), earlier known as the Department of Ocean Development (DOD), initiated Marine Satellite Information Services (MARSIS) programme in June 1990, to address some aspects of remote sensing applications for coastal region and oceans. The major accomplishments of MARSIS programme was successful demonstration of generation and experimental dissemination of Potential Fishing Zone (PFZ) information to the end users.

PFZ forecast was started during 1989-90 at NRSA using only NOAA-AVHRR derived Sea Surface Temperature (SST) data. Indian National Centre for Ocean Information Services (INCOIS), in the year 1999, has taken up this in mission mode to generate and disseminate PFZ advisories to entire coastal fishery community. The launch of the IRS-P4 (Oceansat-1) has enriched the PFZ Advisories. An integrated approach was developed using IRS-P4-OCM derived Chlorophyll concentrations and AVHRR derived SST for locating the PFZ. And the Integrated PFZ forecast technique was transferred to INCOIS by the Space Applications Centre (SAC) in the year 2000. Over the years, the technology for generation of PFZ information has undergone changes considerably in light of results from continuous validation experiments. The Mission of the PFZ Advisory services is shown below as Fig 1.

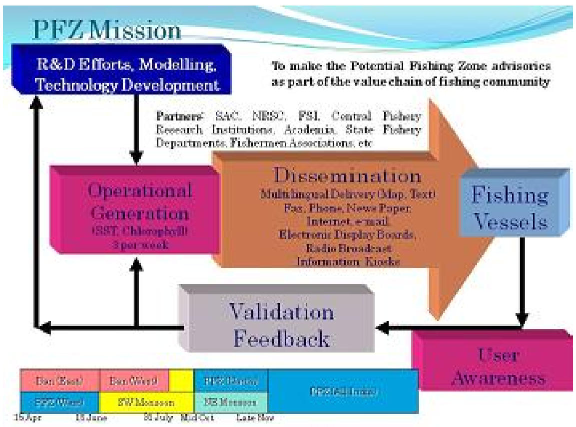

Fig 1: Mission of PFZ Advisory Services

Methodology for Generation of PFZ Advisories

It is well known that the adaptation of fish to the surrounding marine environment is controlled by various physico-chemical and biological factors. Fishes are known to react to changes in the surrounding environmental conditions and migrate to areas where favorable environmental conditions in terms of seawater temperature, salinity, dissolved oxygen levels etc., exist. Availability of food is an important factor which control their occurrence, abundance and migrations in the sea. Sea Surface Temperature (SST) is the most easily observed environmental parameter and is quite often correlated with the availability of fish, especially pelagic fish. Many pelagic species are known to concentrate at current boundaries especially in areas with sharp horizontal temperature gradients. Usually, chlorophyll and SST images are expected to reveal common gradients due to inverse correlation between these two parameters. *(Solanki, et al, 2005).*

Monitoring the above mentioned parameters in space and time is time-consuming and prohibitively expensive and a real time picture of any one of these parameters or a combination of the above becomes almost impossible. Indirect methods of monitoring selected parameters such as SST and phytoplankton pigments (Chlorophyll-a) at sea surface from satellites is found very ideal as it provides high repetivity and large special coverage. The methodology discussed on integration of Chlorophyll and SST images (Shown in Fig 2 below) by *Dwivedi & co-workers* has been adopted.

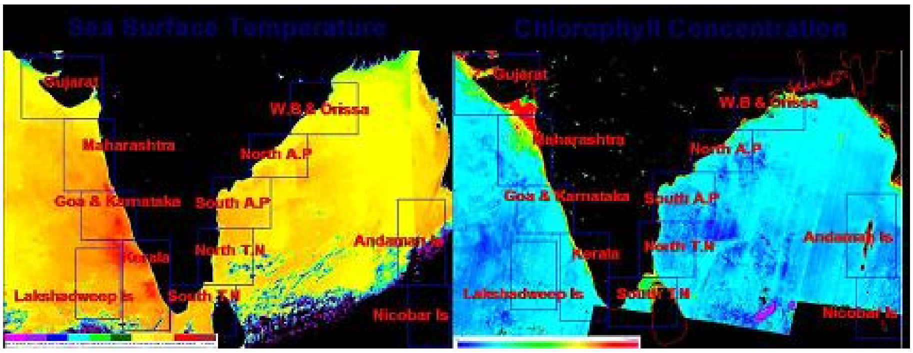

Fig 2: SST and Chlorophyll Images overlaid with 12 PFZ Sectors

Integrated PFZ (IPFZ) Advisories are generated using SST and Chlorophyll Imagery derived from NOAA-AVHRR (USA) and IRS P4-OCM (India) data. The features such as oceanic fronts, meandering patterns, eddies, rings, up-welling areas (Table 1) are identified from these satellite images in near real time and translated as advisories in terms of latitude, longitude and depth of the shelf at such locations as well as angle, direction and distance from the landing centres/light houses. These IPFZ advisories prepared in English, Hindi and other local languages (Gujarati, Marathi, Kannada, Malayalam, Tamil, Telugu, Oriya and Bengali) and local measurement units are disseminated thrice a week, i.e. every Monday, Wednesday and Friday through various dissemination modes.

Table 1: Relevance of oceanographic features to fishery resource
(Source: H.U. Solanki, et al, 2003)

Sl. No.	Feature Type	Definition/ Morphology description	Relevance to fishery resource
1.	Oceanic Fronts (colour and thermal)	Fronts are the boundaries between two water masses with different properties They can be easily detected as breaks in the ocean colour (chlorophyll concentration) or SST of water masses on an image.	High chlorophyll is indicator of biomass production. Hence, resource sustained for longer period. The chances of development of local eco system are greater, which enables benthos exploration. Higher SST gradient is an indicator of upwelled water from deeper layer. Hence, the water with greater nutrient concentration would be available in euphotic zone, which enables enhanced production. Restrict movement in species that prefer particulate temperature ranges.
2.	Mushroom shaped features	The feature appears mushroom shaped on an image.	Form an enclosed pocket. Periphery is important. Sometimes rings form inside the feature, which may be productive. Form due to wind driven current.
3.	Coastal Upwelling	Easily detected in thermal imagery. Appear as different bands of thermal gradients in the images.	Indicates the nutrient rich water transported from bottom to surface. Form in different phases like initiation phase, stabilization phase and maturation phase. Initiation phase should be avoided for fishing due to low oxygen water. In the maturation phase a well developed ecosystem forms, should be exploited.
4.	Meandering pattern of features	A turn or winding of current that may be detached from the main stream. Easily detected through the curvatures in the image.	They cover a large area. So, even if feature shift the potential area may not shift totally. This also helps in delayed fishing. Large concentrations of phytoplankton are available as compared to linear features. An enclosed pocket is formed, hence confining the resources. Sometimes rings are formed, which are productive and important for resource exploration.
5.	Eddies	A current of water often on the side of the main current, especially one moving in a circle. Easy to monitor in space and time.	Rotating water masses cause deep mixing hence nutrient enrichment occurs leading to high production. Persistence for relatively longer duration. The visual predictors like tunas prefer periphery of eddies and streamers.
6.	Rings	Rings of derivative of meanders and eddies. Easy to identify on an image.	Rings are productive and already localised developed eco systems. These features ensure secondary and tertiary production.
7.	Plume front	Plumes form mostly in the coast area near river mouths as well as at discharge points of effluent.	Coastward side should be avoided because of the turbidity; generally fish avoid turbid water due to visibility and blocking of gills. Seaward side may be explored for resources. Sediment images may be checked before suggesting the PFZs.
8.	Shelf Break Front	Formed due to bathymetry at shelf and slope depth gradient.	If it is a high depth gradient it will appear many times at same location. Persist for longer periods. Supporting ecosystem. Not suitable for bottom trawling.
9.	Diverging fronts	Water flows in a different direction from the centre due to diverging current.	The process enriches the nutrient supply, which supports the enhanced production.
10.	Converging fronts	Two or more fronts converge at one point.	Causes mechanical aggregation of resources and plankton, centre may be more productive. Can be used for resource exploration.

Generation of PFZ Maps

In the beginning of this technique, Sea Surface Temperature (SST) images were converted into Negative Films and the films were optically zoomed using Optical Zoom Transferoscope to fit onto the National Hydrographic Base Maps. The features were delineated on the base map using these analog techniques and the same maps were used for the end use. With the advent of the digital techniques available, INCOIS has started creating digital database for coastline, bathymetry, major landing centres, light houses along the coastal states. The new base maps have been created using the digital techniques which are a combination of overlaid coastline, bathymetry contours, landing centres and light houses.

SST and Chlorophyll parameters have been retrieved from AVHRR and IRS P4 OCM using the remote sensing and image processing techniques. SST has been obtained by the use of MCSST algorithm and Chlorophyll with the use of Bio-Optical Algorithms like OC2. These retrieved parameters have been subjected for various image processing techniques for image enhancement, restoration, geometric correction, filtering, etc. From these SST and Chlorophyll images, the PFZ Interpretation keys were identified on-screen the image and were overlaid onto the base maps.

For easy understanding of the fishermen community, these PFZ Maps were translated into multi-lingual PFZ Text information which provides information about the PFZ Location viz. Bearing Angle, Distance from the coast, Depth at the location and latitude & longitude information.

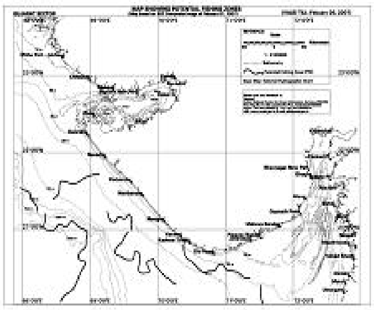

Fig 3: PFZ Map Image and PFZ Text Sheet

Dissemination of IPFZ Advisories

These multi-lingual IPFZ advisories are being generated and disseminated during the non-ban and non-monsoon period to the entire fishermen community situated all over the entire coast of India and Islands under 12 sectors, viz. Gujarat, Maharashtra, Goa & Karnataka, Kerala, South Tamilnadu, North Tamilnadu, South Andhra Pradesh, North Andhra Pradesh, Orissa & West Bengal, Andaman Islands, Nicobar Islands and Lakshadweep Islands. To improve the coverage, advances in Information and Communication Technology have been adapted.

PFZ Advisories were disseminated in 90's using the traditional ways by using Telephone and/ or Fax. In the beginning of the 20's, PFZ Advisories were also disseminated using the Internet/ website and email as mode of communication. Later, with the state of art of technology available, INCOIS has designed and installed Electronic Display Boards (EDB) at major fishing harbours which have made significant impact in the delivery chain. These EDB's have undergone to various changes and leading towards the new Generation of EDB's which facilitates dissemination of satellite pictures, animations, short-films, ocean state information, disaster information and Disaster warning and alert system in addition to the normal text information.

Validation Experiments

Primary Objectives

- Ø To collect concurrent and quantitative feedback on the total catch (species-wise) obtained in the notified and non-notified areas from the fishing boats operating in the region in a common format. Also an analysis should be made on the reliability of forecast.

Secondary Objectives

- Ø Data Collection on Oceanographic/Biological Parameters
  - o Physical Oceanographic data could be obtained from alternate sources viz. by coordinating the cruises of other research vessels in the area, etc.
  - o Length Frequency Analysis
  - o Gut Content Analysis to study the food and feeding habits as well as Prey-Predator relationships.

Methodology adopted for validation of PFZ Advisories:

- Ø To conduct validation exercises by hiring a commercial fishing vessel, in order to obtain concurrent and quantitative feedback on the total catch (species-wise) obtained in the notified and non-notified areas. A representative could be sent onboard the hired vessel.
- Ø Collect feedback data in a common feedback format (Annexure I) for carrying out further quantitative and qualitative analysis.
- Ø To carry out downstream dissemination of PFZ advisories to the fisher-folk on a regular basis and to increase the awareness among the fishing community by conducting group discussions/ awareness campaigns.
- Ø Estimation of the benefits of PFZ advisories by means of calculating the reduction in searching time, saving of fuel and CPUE and generation of Reports

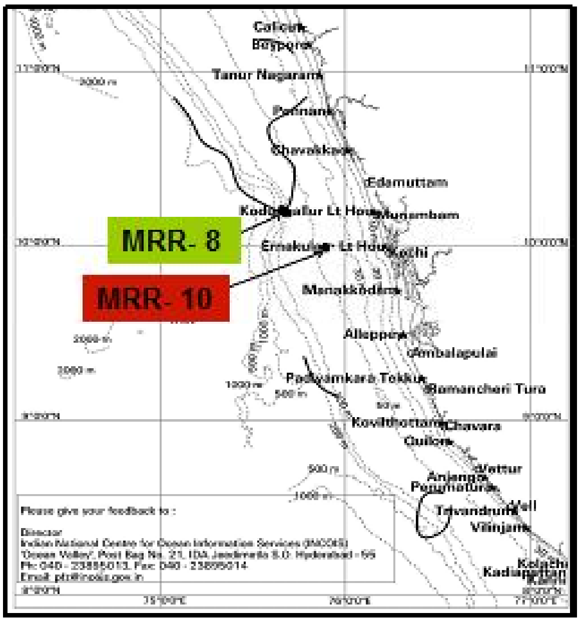

Fig 4: SST based PFZ Forecast issued on December 15, 2006

Table 2: Quantitative Results of the Simultaneous fishing operations made Using Fig 6

Date of Fishing: December 16, 2006

Details (Experiment in Kerala)	**PFZ**	**Non PFZ**
Name of the Boat	MRR-8	MRR-10
Type of Boat	Mech. Ring Seine	Mech. Ring Seine
Duration of Total Trip	9 Hrs 30 Min	7 Hrs 15 Min
Number of fishing hours	01	01
Number of Hauls	01	01
Number of Fishermen Engaged	37	36
Total Catch (Kgs)	7200	1800
Major Species Caught	Carangids	Carangids
Approximate cost of total catch (Rs) (@ 50 Rs /Kg)	3, 60, 000	90, 000
Total Expenditure in Fishing Operation (Rs)	77, 600 (Fuel: 5, 400) (Wage:72, 000)	21, 440 (Fuel: 3, 240) (Wage:9, 000)
Net Profit	2, 82, 400	68, 560

Results of IPFZ Advisories

1. PFZ advisories generated from satellite retrieved SST and Chlorophyll were found more beneficial to artisanal, motorised and small mechanised sector fishermen engaged in pelagic fishing activities such as ring seining, gill netting etc., thereby reducing the searching time which in turn result in the saving of valuable fuel oil and also human effort.
2. Reduction in searching time was found to be 60-70% for oil sardine shoals in ring seining with 30-40% reduction reported for mackerel, anchovy, tuna and carangid shoals in ring seining operations.
3. From the quantitative results of the fishing operations done by identical vessels simultaneously within and outside PFZ area, it was concluded that the average income received by vessels operated in the PFZ areas were considerably higher than vessels operated in non PFZ areas. Fishing expenses were also comparatively less for vessels which operated within PFZ.
4. The catch within the PFZ area gave more CPUE and net profit compared to the results of operations in the non PFZ areas.
5. In PFZ Areas, commercially importance species are more abundant and supports richer fishes compared to the non-PFZ Areas.
6. Fishing operations undertaken on or closer to dates on which related SST/chlorophyll imageries have been received yielded positive results. When the gap increases the yield within PFZ is likely to come down unless the features remain more or less in the same location as revealed by the succeeding satellite imagery.
7. The Gut content analysis of Rastregiller and Decapterus species revealed predominant presence of Copepod. Crustacean larvae and other small fishes were also seen in the Rastregiller where as some small fishes were seen in Decapterus species.

References:

1. Solanki, et al, IJRS Vol. 26, No. 10, 20 May 2005, 2029–2034
2. Dwivedi, et al, IJMS Vol. 34(4), December 2005, pp.430-440
3. H.U. Solanki, R.M. Dwivedi, S. R. Nayak, et al, IJRS, 2003, VOL. 24, NO. 18, 3691–3699

17. OCEAN OBSERVATION AND MODELING FOR REALIZING OPERATIONAL OCEANOGRAPHY

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1.0 Introduction

The sea contains 96% of the Earth's water - the atmosphere holds .001% and the other 4% is mostly ice. The budget of water and heat are closely linked since evaporation requires a large amount of heat and precipitation releases it. Hence, for example, the Indian Ocean stores heat that is transferred to the atmosphere and then released by monsoon rainfall. The circulation and transport of heat in the Indian Ocean is unique in many ways, compared to the Pacific and the Atlantic. The Asian landmass blocks the ocean in the North so that currents cannot carry tropical heat to higher latitude as the Atlantic and Pacific do. Also, this is the only ocean wherein the heat and mass are transported from/to Pacific via Indonesian throughflow. The mass and heat transport are highly variable in time. Till the recently it was generally perceived that the influence of the Indian Ocean on climate variability limits to the monsoons. But this view changed recently, particularly since 1997, with new evidence indicating the important climatic role of Indian Ocean sea surface temperature (SST) on the Indian Ocean as well on the other parts of the globe. Hence Indian Ocean plays a unique role in the variation of regional and global climate systems. The societal and economic impacts of these climate variations affect the lives of nearly two-thirds of the world's population. The benefit to be derived from describing, understanding and predicting the coupled ocean-atmosphere behaviour in this region is potentially huge, but limited at the present time by a lack of observational data on the ocean. The international oceanographic and meteorological community recognized the imperative need for enhancing ocean predictability and well designed and sustained operational ocean observations to enable this. The natural sequel to this recognition was mounting of a number of national efforts, with some of them sponsored and coordinated internationally, with significant components of ocean sciences, ocean observations, operational oceanography and marine meteorology.

Ocean observation systems consists of (a) in-situ measurements (using sensors mounted on ships, buoys, moorings, coastal stations) to capture changes in time and depth at specific points or tracks and (b) remote sensing systems (satellites, aircraft, radar, etc) to capture the spatial and temporal variations, synoptically, as ramified at the surface and sub-surface. The high variability of the Asian monsoon brings frequent floods and droughts in the region. To understand this variability, it is necessary to understand the behavior of ocean-atmosphere system as a single entity. Compared to the Atlantic and Pacific Oceans, the Indian Ocean lacks systematic observations that are essential for the understanding of oceanic processes and their impact on the variability of Asian monsoon. Hence, sustained, systematic, basin-scale observations measuring key Ocean and atmospheric variables are required for improving our understanding of the ocean-atmosphere system and to enhance the predictive capability.

The major science issues to be considered while planning the ocean observations in the Indian Ocean are the following:

i) Seasonal and intra-seasonal monsoon variability
ii) Indian Ocean circulation and pathways of heat and salt
iii) Indian Ocean dipole and El-Nino Southern Oscillation
iv) Warming trends in the Indian Ocean
v) Shallow overturning cells also known as cross equatorial cells
vi) Deep meridional overturning cells
vii) Indonesian throughflow
viii) Bio-geo-chemical cycling

In addition, the planned observations should also encompass the oceanic parameters required for the fisheries (maps of SST, mixed layer depth, chlorophyll, etc.), safe navigation (waves, tides, currents, etc.) and protection of marine environment.

2. Integrated Ocean Observing System

The key oceanographic parameters required for the climate studies are sea surface temperature, sea surface salinity, surface wind vectors, sea level, surface flux of heat and mass, sea ice, surface waves, surface carbon flux, upper ocean temperature and salinity profiles and ocean currents. No single system shall be able to observe all the parameters. Hence an integrated observing system comprising mooring arrays (subsurface temperature, salinity and currents), Argo floats (sub surface temperature, salinity, dissolved oxygen (in few cases), moored buoys (sea surface temperature, surface winds, atmospheric fluxes, precipitation, etc.), drifting buoys (air pressure, sea surface temperature), sea level stations on coast and deep sea, expendable bathythermographs (XBT) along ship routes, has been implemented partly. These in-situ observation systems capture changes in time at several depth levels at specific locations or tracks.

Satellite remote sensing systems provide the spatial and temporal variations, synoptically, as ramified at the surface. An intelligent fusion, analysis and synthesis of these observations enable us to generate the necessary information on the physical, chemical, biological and geological state of the ocean at larger spatial and temporal scales. Availability of such information, in near-real-time in most cases, is essential for spatial analysis, decision support systems and for forcing models that lead to climate predictability both at short and long time scales. India has made significant progress in ocean observing systems, with a mix of in-situ platforms and satellite systems and concomitant capability in retrieval of data, use of models, generation of value-added services and advisories in specific areas.
However, considering the stupendous nature of the task, it is not be possible for a single nation to sustain such an observing system. The natural sequel to this recognition was mounting of a number of national efforts, with some of them sponsored and coordinated internationally, with significant components of ocean sciences, ocean observations, operational oceanography and marine meteorology.

2.1. Tide Gauge Network

Survey of India has a long history of over 125 years (since 1877) of maintaining tidal data generated from the tide gauge network along the Indian Coast and Islands. The importance of sea level information, whether historical, real-time, or as forecasts, on all energy-, space-, and time-scales, is very widely understood. The most reliable external information on the stability of the sea-surface height measurement was afforded by the global tide-gauge network. Unnikrishnan and Shankar (2007) estimated the sea level rise in the North Indian coast between between 1.06–1.75 mm yr^{-1}, with a regional average of 1.29 mm yr^{-1} and these estimate is consistent with global sea level rise estimates reported by IPCC. The real time data are useful for calibrating the satellite altimeters as well as for the identification and forecasts of tsunami events. After 2004 Indian Ocean Tsunami, India established 36 automated tide gauges to receive real time measurements of sea level changes for the purposes of tsunami warning(Fig. 1).

2.2. Drifting buoy

The drifting buoy, attached with a 7 m long holey-sock drogue, was designed to track the mean current in the top 15 m water column. It uses the Argos satellite tracking system for location and data transmission. A dimensionally-stable drogue, designed to perform well under adverse conditions guides the buoy to follow the ocean currents rather than the sea surface winds and waves. The drifters deployed by India are shown in Fig. 1.

The drifting buoy provides the resultant current arising from Ekman and geostrophic apart from the measurement of sea surface atmospheric pressure and sea surface temperature. The key application of surface drifter data is reduction of the bias error in satellite SST measurements, mapping large scale surface currents and identifying their role in heat transports and the generation of SST patterns and variability. These data are also used for improving the surface current climatology (Shenoi et.al ,1999) and to trace the seasonal pathways of freshwater plumes (Sengupta, et.al, 2006).

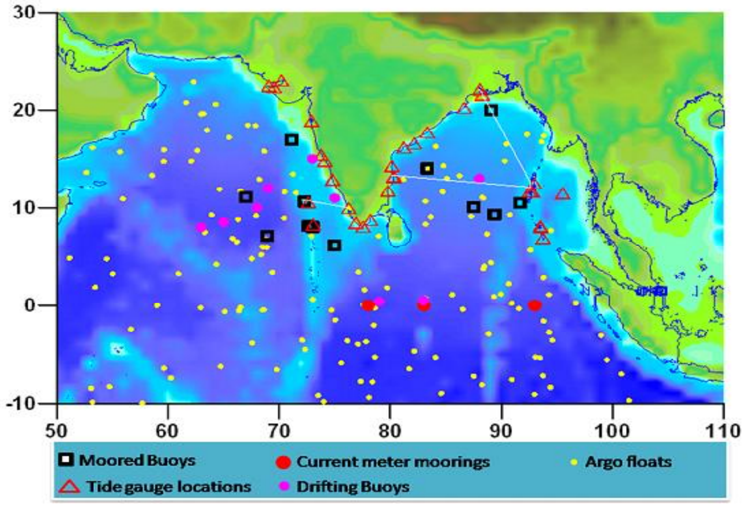

Figure 1 Locations of moored buoys, current meter moorings, Argo floats, Tide gauge stations and drifting buoys established and maintained by Ministry of Earth Sciences, India. White line in the figure shows the high density XBT line.

2.3. Current meter mooring

India has deployed three current meter moorings along the equator (Fig. 1), measuring the currents simultaneously at different levels since March 2002 in the Eastern Equatorial Indian Ocean (EEIO) (76^0 E, 83^0 E and 93^0 E). An additional mooring at equator, 64°E will be deployed soon. These moorings have been providing direct current measurements in the equatorial Indian Ocean to document the seasonal and inter-annual variability of currents in the water column and also the impact of El Nino Southern Oscillation and Indian Dipole mode events on the upper ocean currents variability. These direct current measurements when supplemented with the upper ocean measurements of temperature, salinity and Lowered acoustic Doppler current meter (LADCP) currents would lead to a comprehensive understanding of the dynamics of the equatorial as well as the northern Indian Ocean.

Conductivity, Temperature and Depths (CTD) measure temperature and salinity at the top of the mooring and the other closer to the bottom. Further the measurements of temperature, salinity and currents below the thermocline would enhance our understanding of the variability in the water mass structure of the EEIO and the impact of the 'Meridional Overturning'. The data on currents would also be used to validate the Ocean General Circulation Model (OGCM) simulations. The long-term measurements of currents at the equator, 93°E mooring location in the eastern equatorial Indian Ocean revealed the presence of high frequency intraseasonal variability of period 10-20 day period (biweekly) in the meridional currents (Murty et al., 2002). The zonal velocity is dominantly the low frequency semi-annual variation with superimposed intraseasonal variability (~40-60 day period). The observed currents are compared with the simulations from an Ocean General Circulation Model (OGCM) and shows a good comparison of 10-20 day biweekly period both from observations and model simulations (Sengupta et al., 2004).

In addition, the data from these moorings are essential to monitor the heat and mass transports and budget them regularly. Thus the time series stations for the marine meteorological, surface-ocean and sub-surface parameters are paramount importance to understand the temporal variability of the climate

2.4. Expandable bathy thermograph (XBT) observations

XBT operations are relatively easy, can be operated even when the ship is steaming at its full speed and even in rough weather conditions. In addition, these are cost effective. XBT measurements have been continuing since 1990. XBT provides upper ocean temperature profiles up to a depth of 760 m along the selected shipping lanes in the seas around India at bimonthly intervals. It explores the linkages between upper ocean heat content variability and Indian monsoon / cyclone activity. Further, since 2003, new XBT lines are being operated in the Kochi-Kavarati route in the Lakshadweep Sea to understand the southeastern Arabian Sea warm pool dynamics. These long term measurements will help in understanding the evolving state of the upper ocean thermal structure in the North Indian Ocean. The data from the XBT transects in the Bay of Bengal collected during 1990 to 2009 shows interannual variations both at the surface and sub-surface. Both surface and sub-surface temperature anomaly shows a warming trend in the Bay of Bengal (Gopalakrishna, 2009, Personal communication). Also, these data are useful to understand the interannual variability of thermal inversions (Gopalakrisha et al, 2009) and anomalous upwelling during the monsoon season (Gopalakrishan, et al, 2008).

2.5. Moored data buoy

Real time monitoring of meteorological and oceanographic parameters over the Indian seas for oceanographic research including monitoring short and long-term climatic changes is important. A number of in-situ observation platforms to acquire ocean parameters on a real time basis from the seas around India have been established in 1999. The data from these moored buoys helped to understand the dynamics of coastal currents and upper ocean thermo-haline structure in addition to the data on surface atmospheric parameters like air temperature, wind speed and direction, atmospheric pressure, short wave flux, humidity etc. The in-situ data obtained from moored buoys and the validated satellite data are useful for the assimilation in ocean models for better representation of ocean structure in the North Indian Ocean (past, present and future state of ocean at different temporal and spatial resolutions). The moored buoy observing system covers coasts, shelves, slopes and the blue-water regions of the whole Bay of Bengal and the Eastern Arabian Sea. The buoy provides real time information about the air temperature, air pressure, winds, waves, currents, sea surface temperature, salinity, etc once in 3 hours. Efforts have been initiated to establish a long-term mooring in the northern Bay of Bengal (BoB) to monitor sub surface temperature, currents and salinity profile including marine meteorological parameters. This BoB observatory shall help in validating models of regional climate variation and change. Premkumar et.al (1999), Sengupta and Ravichandran (2001), Bhat etal (2001), Rajesh et.al (2005) and Joseph et.al (2005) demonstrated the usefulness of the buoy data and stressed the importance of the long term measurements for climate in general and monsoons in particular.

2.6. Argo profiling floats

The Argo "Oceanographic radiosonde" is a revolutionary concept that enhances the real time capability for the measurement of temperature and salinity through the upper 2000 m. Following the geostrophic principles, it contributes to the global description of the variability of the upper ocean thermo-haline structure and circulation on seasonal and inter-annual time scales. Under a unique, internationally coordinated efforts, a global array of about 3000 floats at a spatial resolution of 3^0x3^0 grids have been established in 2002. The data from these floats have helped to study the state of the upper ocean and the patterns of ocean climate variability, including heat and freshwater storage and transport.

The combination of *Argo* and satellite altimetry has enabled a new generation of applications. Global maps of sea level, on time scales of weeks to several years, have been interpreted with full knowledge of the upper ocean stratification. Global Ocean and climate models can be initialized, tested and constrained with a level of information hitherto not available. The drift estimates from such an array would in addition provide useful estimates of deep pressure fields (reference level). Applications of Argo data are numerous and varied, including initialization of ENSO forecast models, initialization of short-range ocean forecasts, routine production of high-quality global ocean analyses, and studies of predictability on inter-annual and decadal time scales. Total sea level from altimeter, upper ocean steric height from Argo array, and ocean mass variations from GRACE gravity mission will help in closing the sea level budget ((Leuliette, and Miller, 2009).

India has deployed 172 floats in the Indian Ocean and 91 floats are active. The data provide information of the subsurface mean ocean conditions in several data-sparse regions. Though Argo observations are intended for studying seasonal to climate time scale phenomena, there are many new insights has come out by different authors in shorter time scales in the Indian Ocean region.

Ravichandran et.al, 2004 have demonstrated the usefulness of these observations for different applications. Contrary to the general belief that a stronger Indian summer monsoon causes larger summer cooling and leaves behind a cooler Arabian Sea, Vinayachandran (2004) find that the Arabian Sea was warmer during 2003 summer (normal monsoon) than during 2002 (weak monsoon). Also, these observations enabled to understand the upper ocean variability of Arabian sea, temporal variability of the core-depth of Arabian Sea High Salinity Water mass (ASHSW) and the causative effect of the same was brought out by Sudheer and Freeland (2005), buoyancy flux variations and its role in air sea interaction (Anitha et.al, 2008), identifying the Observed low-salinity plume off Gulf of Khambhat, India, during post-monsoon period, mixed layer variability of western Arabian Sea (Bhaskar et al, 2006), and seasonal variability of the observed barrier layer (Thadathil, etal 2008). The importance of upper ocean temperature and salinity during cyclone has brought out by McPhaden et.al (2009a).

Argo profiles reveal a pronounced up-westward propagation of subsurface warming in the southern tropical Indian Ocean associated with Rossby waves traveling on the sloping thermocline (Chowdary et.al 2009). Using Argo and satellite observations, Vinayachandran and Saji (2008) found intense cooling of the sea surface at intraseasonal time scales in the southern tropical Indian Ocean during austral summer. Argo data sets provided an opportunity to explore the usefulness of the coupled assimilation for seasonal forecasts on the passage of intra seasonal waves over the subsurface global oceans (Krishnamurty eta al, 2006). The results suggest that the inclusion of subsurface ARGO profiler data sets can be useful for prediction of the intraseasonal waves in the atmosphere/ oceans and hold the promise for the improved seasonal outlook projections for the active and break monsoon.

3. IndOOS

CLIVAR (Climate Variability panel) and IOGOOS (Global ocean observing system for Indian Ocean) have identified the need for an observing system in the Indian Ocean. The Panel consolidates the activity and resources of many operational and research agencies in the Indian Ocean rim-nations, and in partner-nations outside the region. Implementing a basin wide system is too large for any one nation or agency. Agreement to use the available resources in a coordinated and cost-effective way is an essential part of achieving the full implementation. The basin wide system thus conceptualized and implemented in the Indian Ocean consists of observation platforms based on satellites as well as in situ. While the satellite provide the observations of oceanic surface properties, the *in situ* observations provide the complementary subsurface information on the vertical structure of ocean.

Indian Ocean Observing system (IndOOS) is a multi-platform long-term observing system, which consists of Argo floats, surface drifting buoys, tide gauges, a surface moored buoy arrays, current meter arrays, VOS based XBT/XCTD sections, and satellite measurements (International CLIVAR Project Office, 2006). The ***R***esearch Moored ***A***rray for African-Asian-Australian ***M***onsoon ***A***nalysis and Prediction (RAMA), a moored buoy network to address the outstanding scientific questions related to Indian Ocean variability and the monsoon is described in McPhaden et.al (2009b). The resources for IndOOS come from diverse national and international bodies. The system is designed to provide high-frequency, near real-time climate-related observations, serving the needs of the intra-seasonal, inter-annual and even decadal time-scale climate studies and climate services in many national meteorological agencies.

Oceanic variability associated with climate has a very large range of time- and space-scales, so we have to recognize that no individual type of measurement can provide all of the necessary data. For example, a fully implemented Argo array as presently planned cannot resolve the eddy variability in the ocean, but combined with satellite altimetry it can. Similarly the Argo array cannot resolve the upper ocean dynamics of intraseasonal variability in the ocean. However, it is expected that the combination of a basin scale mooring array, Argo floats and satellite observations will resolve enough of the variability to make progress in understanding and predicting these phenomena.

Some of the *in situ* measurements like tide gauges, XBT's, surface drifters, Argo floats and few moored buoys existed in the Indian Ocean as part of GOOS and GCOS.prior to the formation Indoos.

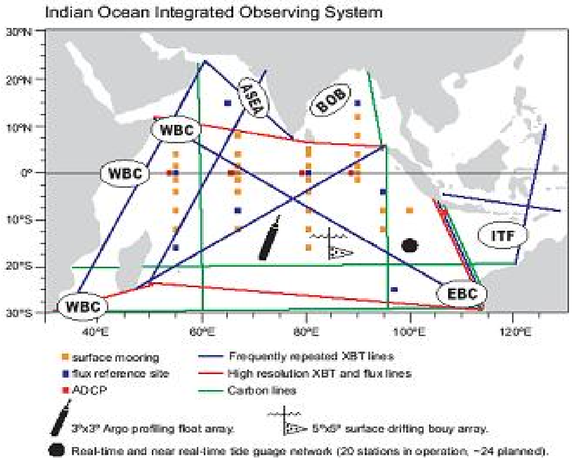

Figure 2. Indian Ocean Integrated Observing System

4. Ocean modeling – towards realizing operational Oceanography

India has mounted large number of in-situ observation platforms to monitor the ocean for the variety of applications including climate parameters. Apart from the above in-situ observations, there are large numbers of satellites system provides data and provide the synoptic picture of different variables. Effective utilization of these data is paramount importance to understand the climate variability and future prediction. While many of the observing elements are already in place, several are still in the planning stage. It is impossible to measure different oceanic parameters for different temporal and spatial scales to understand the dynamics and thermodynamics of the ocean. Hence we need to use modeling tools to map the heat and mass transport between the oceans at different temporal scales. The most significant challenge lies in use of state of the art computers to produce advanced numerical models that can assimilate and integrate data from both oceans based and space based measuring systems and accurately simulate the behavior of the oceans to improve our understanding and prediction of weather and climate.

Global climate modelling is one of the grand challenges of computational science, and ocean modelling plays an important role in both understanding the current climatic conditions and predicting the future climate change. Three-dimensional time-dependent ocean general circulation models (OGCMs) require a large amount of memory and processing time to run realistic simulations. Recent advances in computing hardware have dramatically propelled the prospect of studying the global climate. The significant computational resources of massively parallel supercomputers promise to make such studies feasible. In addition to using advanced hardware, designing and implementing a well-optimized parallel ocean code will significantly improve the computational performance and reduce the total time to complete these studies.

Operational oceanography has lagged far behind atmospheric modelling because of two major complications. First, oceanic space and time scales are much different than those of the atmosphere. Ocean eddies are typically 100 km in diameter, which makes them 20 to 30 times smaller than comparable atmospheric highs and lows. As a result, approximately four orders of magnitude more computer time and three orders of magnitude more computer memory are required. Second, unlike the meteorological radiosonde network that provides initial conditions from the surface to near the top of the atmosphere, there are few observations below the ocean surface at the synoptic time scale. Thus, effective oceanic data assimilative techniques are limited to surface satellite observations, which were not available until the 1990s. One advantage ocean prediction enjoys is that forecast skill for many ocean features, including ocean eddies and the meandering of ocean currents and fronts, is longer than the 10 to 14 day limit for atmospheric pressure systems.

Climate models are computationally intensive because of lots of stuff to calculate, but this computational burden has other causes. Fundamental cause is that interesting climate change simulations are century scale. Time steps are limited by stability criterion to minute scale (A lot of minutes in a century). High resolution Ocean model (1/12º) has 608 million grid cells needs 60 Gbyte storage with 40 x 1015 floating point operations/model year and produces a 20 Gbyte data set every 3 model days. A comparative climate model with ocean, atmosphere and land sub-models needs about twice the resources. For research, climate modelers need up to 32 runs, each of 200 years. Oceanographers have a similar requirement of approximately 2.6 x 10^{20} Floating point operations, ie., approximately 3 months of a 100 Tflop computer.

INCOIS is striving to understand the ocean dynamics and thermodynamics of Indian Ocean using models for prediction of future oceanic conditions (intra seasonal, seasonal, annual, decadal, etc.,). In order to achieve this, the following four modules are aimed during the near few years.

1. Ocean Modelling with Data Assimilation for providing description of past, present & future state of Ocean at appropriate spatial & temporal resolutions.

   The plan is to (a) assemble long-term climatic data sets to describe past states and time-series showing trends and changes (Hindcast), (b) provide a description of the present state of the sea, including marine living resources with optimal accuracy (Nowcast) and (c) develop efficient data assimilation technique in the model to provide a description of the future condition of the sea as far ahead as possible (Forecast)

2. Contribute to Weather/Monsoon/Climate forecast by providing forcing for Atmospheric Models

   Daily, monthly and seasonal thermo-haline field from Ocean model will help in forcing atmospheric model in order to predict weather, monsoon and climate. Hourly fields for a specific domain required for forcing meso-scale model for predicting cyclone intensity and track, and decadal thermohaline fields will help for long term monitoring of climate and its change.

3. Understanding the variability of Ocean & Marine environment

   Observing system will ever be so intensive that a mere contouring of the data would present a usable product for most customers, since every user tends to need very local site-specific information. By assimilating new data into numerical models, whenever possible and generating products based on the diagnostics and predictions of the models, Numerical model will deliver high quality information whilst keeping observation costs within practical limits.

   The data acquired from ocean observations will be used in a wide range of ocean models to summarize the best quantitative understanding of different processes operating in the oceans and their interactions. Since the models are the most concise and complete representation about state of knowledge on ocean processes, they will serve as a link between observations and advance its ability to predict future ocean conditions

4. Simulation experiment to optimize the observation system

   Modeling is required to understand where and what frequency the sensors and platforms are required to deploy to capture better spatial and temporal sampling to resolve scientific objective. This simulation experiments will also help in cost-benefit analysis for limited observations for optimal ways in a realistic budget. Though the ocean will always be under sampled, Models containing a proper representation of the ocean with assimilating data can supplement and extend observational data that are necessarily limited in space or time.

References:

Anitha, G. M. Ravichandran, R. Sayanna, 2008 : Surface buoyancy flux in the Bay of Bengal and Arabian Sea. Annales Geophysicae, 26 (3), 395-400.

Bhaskar, TVSU, Swain, D., Ravichandran, M., 2006: Inferring mixed-layer depth variability from Argo observations in the western Indian Ocean. Journal of Marine Research 64(3): 393-406.

Bhat G. S., S. Gadgil, P. V. Hareesh Kumar, S. R. Kalsi, P. Madhusoodanan, V. S. N. Murty, C. V. K. Prasada Rao, V. Ramesh Babu, L. V. G. Rao, R. R. Rao, M. Ravichandran, K. G. Reddy, P. Sanjeeva Rao, D. Sengupta, D. R. Sikka, J. Swain and P. N. Vinayachandran (2001): BOBMEX - The Bay of Bengal Monsoon Experiment. Bull. Am. Met. Soc., 82, 10, 2217-2243.

Chowdary J. S., C. Gnanaseelan, S.P. Xie, 2009: Westward propagation of barrier layer formation in the 2006-07 Rossby wave event over the tropical southwest Indian Ocean. Geophysical Research Letters, 36, L04607

CLIVAR–GOOS Indian Ocean Panel and others**,** Understanding the role of the Indian Ocean in the climate system – Implementation plan for the sustained observations, Jan 2006, WCRP Informal Report No. 5/2006 *ICPO Publication Series No. 100, GOOS Report no. 152*

Gopalakrishna, V. V., Z. Johnson, G. Salgaonkar, K. Nisha, C. K.Rajan, and R. R. Rao, 2005: Observed variability of sea surface salinity and thermal inversions in the Lakshadweep Sea during contrast monsoons. Geophys. Res. Lett., 32, L18605, doi:10.1029/2005GL023280.

Gopalakrishna, V. V., and Coauthors, 2008: Observed anomalous upwelling in the Lakshadweep Sea during the summer monsoon season of 2005. J. Geophys. Res., 113, C05001, doi:10.1029/2007JC004240.

Joseph, Sudheer; Freeland, Howard J., 2005, Salinity variability in the Arabian Sea, Geophysical Research Letters, Volume 32, Issue 9, 200432(9),L0960710.1029/2005GL022972.

Jossia Joseph K, M. Harikrishnan, G. Rajesh and K. Premkumar (2005): Moored Buoy Observations in Arabian Sea Warm Pool. Mausam Vol. 56(1), pp161-168.

Leuliette, E. W., and L. Miller (2009), Closing the sea level rise budget with altimetry, Argo, and GRACE, *Geophys. Res. Lett.*, 36, L04608, doi:10.1029/2008GL036010.

Krishnamurti, T.N., A. Chakraborty, R. Krishnamurti, et al, 2007: Passage of intraseasonal waves in the subsurface oceans. Geophysical Research Letters 34 (14): Art. No. L14712.

McPhaden, G. Meyers, M. J., K. Ando, Y. Masumoto, V. S. N. Murty, M. Ravichandran, F. Syamsudin, J. Vialard, W. Yu, L. Wu, 2009: RAMA: Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction. Bull. Am. Meteor. Soc., in press.

McPhaden, M., J., G. R. Foltz, V. S. N. Murty, M. Ravichandran, G. A. Vecchi, J. Vialard, J. D.. Wiggert and L. Tu, 2009: Ocean-Atmosphere Interactions During Cyclone Nargis, *EOS*, Vol. 90, No. 7, 17 February 2009.

Murty, V. S. N., A. Suryanarayana, M. Sarma, V. Tilvi, V. Fernando, G. Nampoothiri, A. Sardar, D. Gracias, and S. Khalap (2002), First results of Indian current meter moorings along the equator: Vertical current structure variability at equator, 93 E during February-December 2000, 1, pp. 25–28, Proc. 6th Pan Ocean Remote Sensing Conference, PORSEC 2002, Bali,Indonesia.

Premkumar, K., M. Ravichandran, S.R. Kalsi, D. Sengupta, S. Gadgil (1999): First results from a new observational system over the Indian Seas. Current Science, 78, 323.

Rao A. D., M. Joshi, M. Ravichandran, 2009: Observed low-salinity plume off Gulf of Khambhat, India, during post-monsoon period. Geophysical Research Letters, 36, L03605.

Rajesh, G., K. Jossia Joseph, M. Harikrishnan, K. Premkumar (2005): Observations on extreme Meteorological and Oceanographic parameters in Indian Seas. Current Science, Vol 88 (8), pp 1279-1282.

Ravichandran M.,Vinayachandran, P.N., Joseph, S., Radhakrishnan, K., 2004. Results from the first Argo float deployed by India. Current Science, 86(5), 651-659

Sengupta, D., and M. Ravichandran (2001): Oscillations of Bay of Bengal sea surface temperature during the 1998 summer monsoon. Geophysical Research Letters, 28, 10, 2033-2036.

Sengupta, D., G. N. Bharath Raj, and S. S. C. Shenoi (2006), Surface freshwater from Bay of Bengal runoff and Indonesian Throughflow in the tropical Indian Ocean, *Geophys. Res. Lett.*, 33, L22609, doi:10.1029/2006GL027573.

Sengupta, D., R. Senan, V. S. N. Murty and V. Fernando (2004): A biweekly in the equatorial Indian Ocean. *J. Geophysical Research*, 109, C10003, 10.1029/2004JC002329

Shankar, D., Shetye, S.R., 1999. Are interdecadal sea level changes along the Indian coast influenced by variability of monsoon rainfall? J. Geophys. Res. 104, 26031-26041.

Shenoi, S.S.C, P. K. Saji and A.M. Almeida, Near surface circulation and kinetic energy in the tropical Indian Ocean derived from lagrangian drifters, *Journal of Marine Research, 57,* 885–907, 1999

Thadathil, P., P. Thoppil, R.R. Rao, et al, 2008: Seasonal Variability of the Observed Barrier Layer in the Arabian Sea. Journal of Physical Oceanography, 3, 624-638.

Unnikrishnan, A.S. and Shankar D. (2007) Are sea-level-rise trends along the coasts of north Indian Ocean coasts consistent with global estimates? Global and Planetary Change, 57, 301-307.

Vinayachandran, P.N., 2004. Summer cooling of the Arabian Sea during contrasting monsoons. Gephysical Research Letters, 31, L13306,doi:10.1029/2004GL019961.

Vinayachandran, P.N. & N.H. Saji, 2008: Mechanisms of South Indian Ocean intraseasonal cooling. Geophysical Research Letters, 35, 23, L23607.

17. OCEAN DATA AND INFORMATION SYSTEM

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1. INTRODUCTION

The Indian National Centre for Ocean Information (INCOIS) has been playing a key role in the Indian Ocean by providing ocean data, information and advisory services to society, industry, government and scientific community through sustained ocean observations and constant improvements through systematic and focused research in ocean data, information management and ocean modelling.

The observations from the oceans are the backbone for any kind of operational services (potential fishing zone advisory services, ocean state forecast, storm surges, cyclones, monsoon variability, tsunami etc.), research and development including validation of satellite sensors and parameterizing key processes for models and verifying model simulations. In order to provide a variety of operational services, a network of in-situ ocean observing systems particularly the cutting edge technology such as Argo floats and other observational platforms, viz. drifting buoys, XBT surveys, current meter mooring array, moored buoys, tide gauges, bottom pressure recorders, coastal radars were established in the Indian Ocean. The data received from these observing systems is vital for developing robust ocean and coastal forecasting system.

INCOIS, being the central repository for marine data in the country, receives voluminous oceanographic data in real time, from the network of in-situ and remote sensing observing systems. In addition, a large amount of historical data has been obtained from the web and other sources for various in-house studies and modelling activities. Availability of ocean data in real-time is essential for spatial analysis and decision support system to provide ocean information and advisory services and forcing models that lead to climate predictability, both short-term and long-term. Further, with the vast amount of data available, Ocean models could be fruitfully utilized to undertake need based user projects for coastal and offshore applications.

Apart from serving as a national repository of marine data, the INCOIS has been designated as the National Oceanographic Data Centre (NODC) by the International Oceanographic Data and Information Exchange (IODE) Programme of Intergovernmental Oceanographic Commission (IOC). Further, as part of the International Argo Programme, INCOIS serves as the National and Regional Argo Data Centre for India and the Indian Ocean, respectively.

The objectives of the data centre at national and regional levels are acquisition, processing, quality control, inventory, archival and dissemination of data and data products in accordance with national responsibilities and also responsible for international data exchange. Finally, exploitation of the advancements in the web and geospatial technology for providing data and information services in real-time forms crucial part in the ocean data and information system.

2. Ocean data and information system

The Ocean Data and Information System (ODIS) is a one stop shop for providing data and information on physical, chemical and biological parameters of ocean and coasts on various spatial and temporal domains that is vital for both research and operational oceanography. It is an end-to-end ocean data management system, developed by exploiting the advances in the field of information and communication technology that brought revolutionary changes in data acquisition, processing, analysis and data availability at a click away. ODIS is fed by voluminous (~5 Tb per year) and highly heterogeneous oceanographic data in real time, acquired from the Ocean Observing Systems (both in-situ and remote sensing) established in the Indian Ocean. The ODIS is also supported by the data received from both the in-situ platforms and satellites, Global Telecommunication System (GTS), projects/experiments, data from other sources and the data exclusively retrieved for the Indian Ocean from historical data sets.

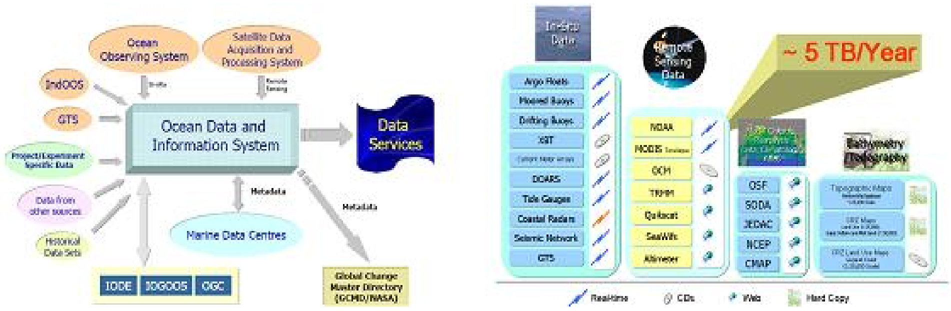

Figure 1. Elements of the Ocean Data and Information System and the Data Flow

Strong organizational arrangements are in place with all the agencies involved in ocean observational programmes to ensure the real-time data flow to ODIS. We plan to strengthen the system with the data generated from a chain of designated Marine Data Centres, academia, etc. by networking and enabling them on the INCOIS web-site with appropriate access privileges. Further, we have active collaboration with IODE, Indian Ocean Global Ocean Observation System (IOGOOS) and Open Geospatial Consortium (OGC) programmes on data and information management related activities. The total estimated data flow from both the in-situ and remote sensing satellites is estimated about 5 Tb per year.

Platform/Instrument	**Parameters**
Argo Floats	Temperature and Salinity Profiles up to 2000 m
Moored Buoys	Air Pressure, Air Temperature, Wind Speed and Direction, Water Temperature, Significant Wave Height, Wave Direction, Current Speed and Direction
Drifting Buoy	Sea Surface Temperature, Air Temperature, Barometric Pressure, Sea Surface Currents
Current Meter Data from the Equatorial Current Meter Mooring Arrays	Current vector
Tide Gauges	Sea Level
Bottom Pressure Recorders	Water Column Height
XBT Observations	Temperature Profiles up to 760 m

Table 1. In-situ Ocean Observing System and the parameters measured

A sophisticated communication system was deployed to receive data from the in-situ platforms in real-time. The in-situ platforms and the parameters measured are listed in the Table 1.

The Satellite Data Acquisition and Processing System (SDAPS) was setup to receive remote sensing data in real time from NOAA (17 and 18), Terra and Aqua Satellites to meet the operational data requirements of Potential Fishing Zone advisory services and Indian Argo Project.

Sensor/Satellite	Parameters
AVHRR- NOAA (17 and 18)	Sea Surface Temperature
MODIS - Terra and Aqua	SST and Chlorophyll(Other atmospheric and ocean parameters are generated on request)

Table 2. Remote sensing data received from the satellites in real-time at SDAPS

The data received from various observing systems in real-time at different communication systems are assembled and standardized. The metadata was generated using the Marine Environmental Data Inventory Software developed by the IOC (MEDI, 2002) for the Moored Buoy, Drifting Buoy, Current Meter Mooring and XBT data sets. The metadata for the Argo floats are generated as per the guidelines of the Argo Programme.

The data go through the quality control procedures for each of the observing system separately as per the internationally adopted quality control procedures and standards (NDBC, 2003; Hansen and Poulain, 1996). The quality controlled data then loaded to the data base for providing web-based data services.

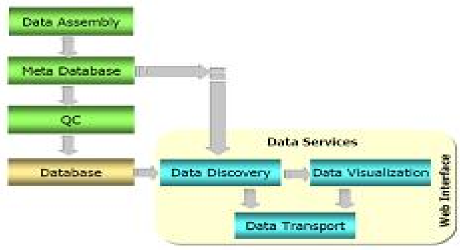

Figure 2. Data management flow chart

The data received from the Moored Buoys, Drifting Buoys are published on the web after the real-time quality control checks. The data from the Tide Gauges, Bottom Pressure Recorders and Seismic Stations are being used internally at Tsunami Early Warning Centre for its operational activities. The data sets from the XBT surveys and Current Meter Mooring Array are received in delayed mode and go through the same process before publishing on the web. The entire process of reception, data processing, quality control, loading in to the database, web publishing and also dissemination to the users for their operational activities was fully automated. The Argo data after the QC are made available to the scientific community on the web-site with in 24 hours of the acquisition. The interactive web-interface for accessing and downloading the Argo float data is discussed in the next chapter. Web-interfaces were developed for data discovery, visualisation and transport of other data sets.

In addition to the data sets discussed above, large amount of data generated from various national and international experiments, model outputs, reanalysis data sets and historical data sets extracted exclusively for the Indian Ocean region as listed in the Table 3 are available with us. These data sets are also being organised in to the database to build a comprehensive India Ocean Database.

Data sets	Parameters	Period
Simple Oceanographic Data Assimilation	Currents, Temperature, Salinity	1955-2001
Joint Environmental Data Analysis Centre	Temperature Profiles	1955-2004
National Centre for Environmental Prediction	Surface meteorology, Surface fluxes	1950-2005
CMAP	Rainfall	1979-2006
Altimeter	Sea Surface Height Anomaly	1996-2007
TMI	Sea Surface Temperature, Rainfall, Wind Speed	1997-2007
Quickscat	Wind Vector	1998-2007
SeaWifs	Chlorophyll	1997-2005

Table 3. Other data holdings

The main challenge in developing ODIS is managing highly heterogeneous and voluminous data from a suite of in-situ platforms and remote sensing satellites, developing open standards and addressing the interoperability issues for exchange of data. To meet these objectives and data demands from wide spectrum of users, it is necessary to harmonize the data in standard formats, apply quality control procedures, generate meta data and database, while adopting international standards for seamless exchange of data and implementation of data warehousing and mining concepts for providing web-based data services.

3. WEB-based Data services

The advent of internet technology facilitates the user with easy and faster access to the availability of information at a mouse-click and the Geographical Information System (GIS) provides the capability for storing and managing large amounts of spatial data. A Web-GIS system combines the potential of both internet and GIS technologies enabling the users to access the geospatial information and data via web-browsers without purchasing expensive, proprietary GIS software. Data and map services are being implemented using Web-GIS. The growing number of research publications and implementation of many common GIS software have proven the potential and increased utility of Web-GIS (Dragicevic, 2004; Markstorm et al, 2002; Tsou 2004).

The web-based ocean data, information and advisory services viz. Potential Fishing Zone Mission, Ocean State Forecast, Indian Argo Project were developed at INCOIS with Web-GIS technology. The web-based multilingual on-line data and information delivery system with Web-GIS capability enables the users to query, analyze, visualize and download ocean data, information and advisories for their regions of interest. The system allows integration of large amount of data from different sources and management.

Argo Float Data

Argo is a global array of free-drifting profiling floats that enable continuous monitoring of the temperature, salinity, and velocity of the upper ocean up to 2000 m depth, with all data being relayed and made publicly available within hours after collection. As part of the International Argo Programme in the Indian Ocean, 168 floats were deployed by India and 817 floats were deployed by various other countries.

The web-interface with Web-GIS features display the distribution and status of Argo floats deployed by different countries in the Indian Ocean. The Web-GIS features also allow the users to see the float information, selection of float by id and country, query with desired time, depth and parameters, and download required data in ASCII format. It also provides tools for measuring distance among the floats, selection of floats in group. The GIS layers include active floats, inactive floats, total floats and trajectory of the floats. Regional Coordination of Argo float deployment in the Indian Ocean is done through web-interface.

The Argo value added data products available on INCOIS Website are listed below.

Float-wise data products: Water Plot of Temperature, Water Plot of Salinity, Temperature vs. Salinity Plot, Time Series Surface Temperature, Time Series Surface Salinity, Time Series Surface Pressure, Time Series Bottom Pressure, Float Trajectory.

Monthly data products: Temperature, Salinity and Geostrophic Currents data products are available at 0, 75, 100, 200, 500, 1000m depths, Mixed Layer Depth, Isothermal Layer Depth, Depth of 20° Isotherm, Depth of 26° Isotherm, Heat Content, Dynamic Height, Sea Surface Height Anomaly.

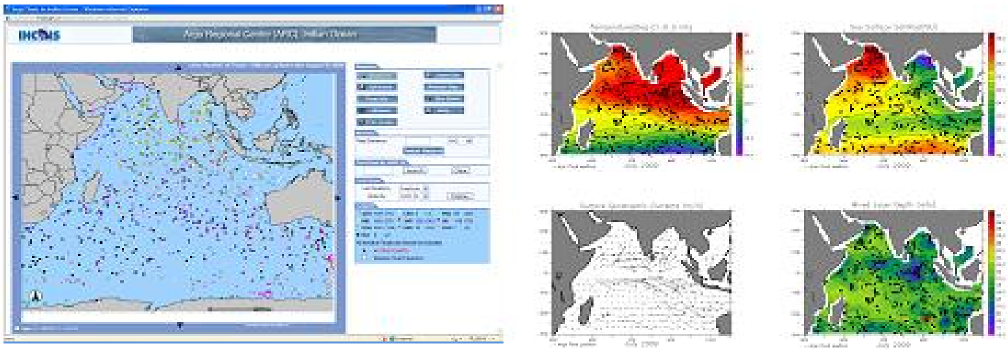

Figure 3. Interactive Web-GIS page displaying distribution and status of Argo floats and Argo data products

In-situ data from various observing system and remote sensing data products are made available on INCOIS web-site. Users can query, query, analyze, visualize and download ocean data for their regions of interest.

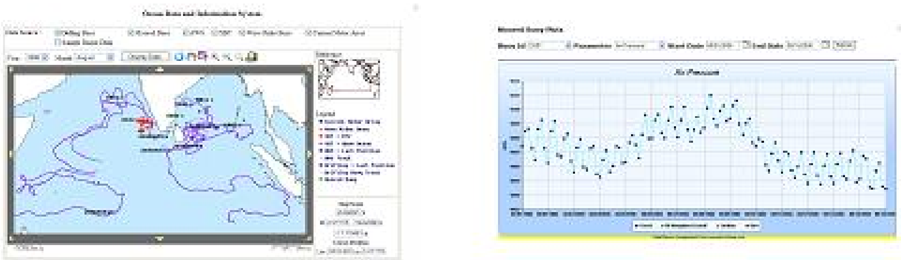

Figure 4. In-situ Data and Visualisation

Figure. 5. Remote Sensing data products from AVHRR (NOAA) and MODIS (Aqua & Terra) are published on INCOIS web-site

4. OPEN STANDARDS and interoperability

Open standards and interoperability are being widely used for the land based GIS applications and now gaining wider acceptance in marine community. The recent international projects in ocean sciences deals with compliance with open standards and interoperability for exchange of the data.

INCOIS joined the Ocean Science Interoperability (Ocean IE) Project evolved by the Open Geospatial Consortium (OGC) (http://www.opengeospatial.org/projects/initiatives/oceansie), in its early stages to play a major role in developing open standards and addressing the interoperability issues. These developments certainly facilitate enormous potential for sharing oceanographic and meteorological data with common standards for providing web-based and location based services.

Live Access Server: The Live Access Server (LAS), a highly configurable web server designed to provide flexible access to geo-referenced scientific data (http://ferret.pmel.noaa.gov/ Ferret/LAS/). LAS use the Open-source Project for a Network Data Access Protocol (OpenDAP) and Distributed Ocean Data System (DODS) technology. The LAS allows the user to download and visualize data using a simple graphical user interface.

LAS enable the data provider to (i) unify access to multiple types of data in a single interface, (ii) create thematic data servers from distributed data sources, (iii) offer derived products on the fly (iv) remedy metadata inadequacies (poorly self-describing data), (v) offer unique products (e.g. visualization styles specialized for the data).

LAS enable the Web user to visualize data with on-the-fly graphics, request custom subsets of variables in a choice of file formats, access background reference material about the data (metadata) and compare variables from distributed locations.

The LAS was implemented at INCOIS to serve the gridded data products in net common data format (netCDF) that is widely used by the oceanographic community. The LAS at INCOIS serves the ocean scientific community with the data following data sets:

- ARGO Data Products: Temperature and Salinity at 20 levels – 10 Days and Monthly.
- Quickscat Daily Data Products: Meridional wind stress component, Wind stress curl, Wind stress magnitude, Zonal wind stress component.
- Quickscat Monthly Data Products: Meridional wind speed component, Wind speed module, Zonal wind speed component.
- Sea Surface Height Anomaly: 10 Day Composite.
- TMI 3 Day Composite Data Product: Sea Surface Temperature
- TMI Monthly Data Products: Atmospheric Water Vapour, Cloud Liquid Water, Rain Rate, Sea Surface Temperature, Surface Wind Speed using 11 Ghz channel, Surface Wind Speed using 37 Ghz channel.
- Levitus Climatology: Temperature and Salinity at 18 levels.

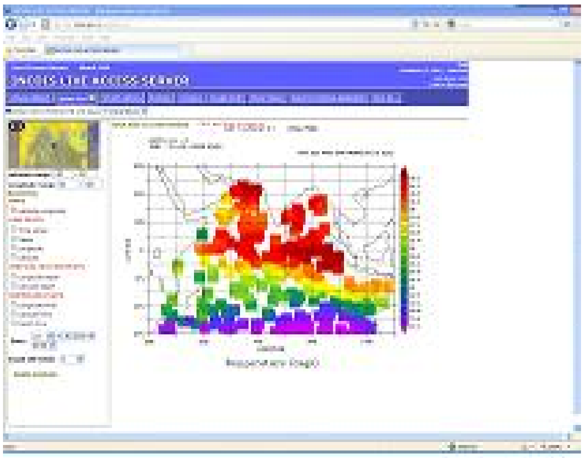

Figure 6. Gridded data products on INCOIS Live Access Server

The LAS is emerging as a promising web application for providing oceanographic data and addressing open standards and interoperability issues.

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The authors wish to thank Dr. Shailesh Nayak, Secretary, Ministry of Earth Sciences and Dr. S.S.C. Shenoi, Director, INCOIS, and colleagues at INCOIS for their support in development of the Ocean Data and Information System. Also, authors acknowledge the support of Dr. M. Ravichandran, Head-MOG, Shri. B.V. Satyanarayana, Head-CWG, Dr. T. Srinivasa Kumar, Head-ASG and Dr. T.M. Balakrishnan Nair, Head-ISG in providing and web-based data services. The support of colleagues in Data and Information Management Group, INCOIS is highly acknowledged.

REFERENCES

Dragicevic, S., 2004. The potential of Web-based GIS. *Journal of Geographical Systems,* 6 (2), pp. 79–81.

Hansen, D.V., and Marie Poulain, P., 1996. Quality control and interpolation of WOCE/TOGA drifter data. *Journal of Atmospheric and Oceanic Technology*, 13, pp. 900-909.

Live Access Server, http://ferret.pmel.noaa.gov/Ferret/LAS/.

Markstrom, S.L., McCabe, G., and David, O., 2002. Web-based distribution of geo-scientific models. Computers and Geosciences, 28, pp. 577–581.

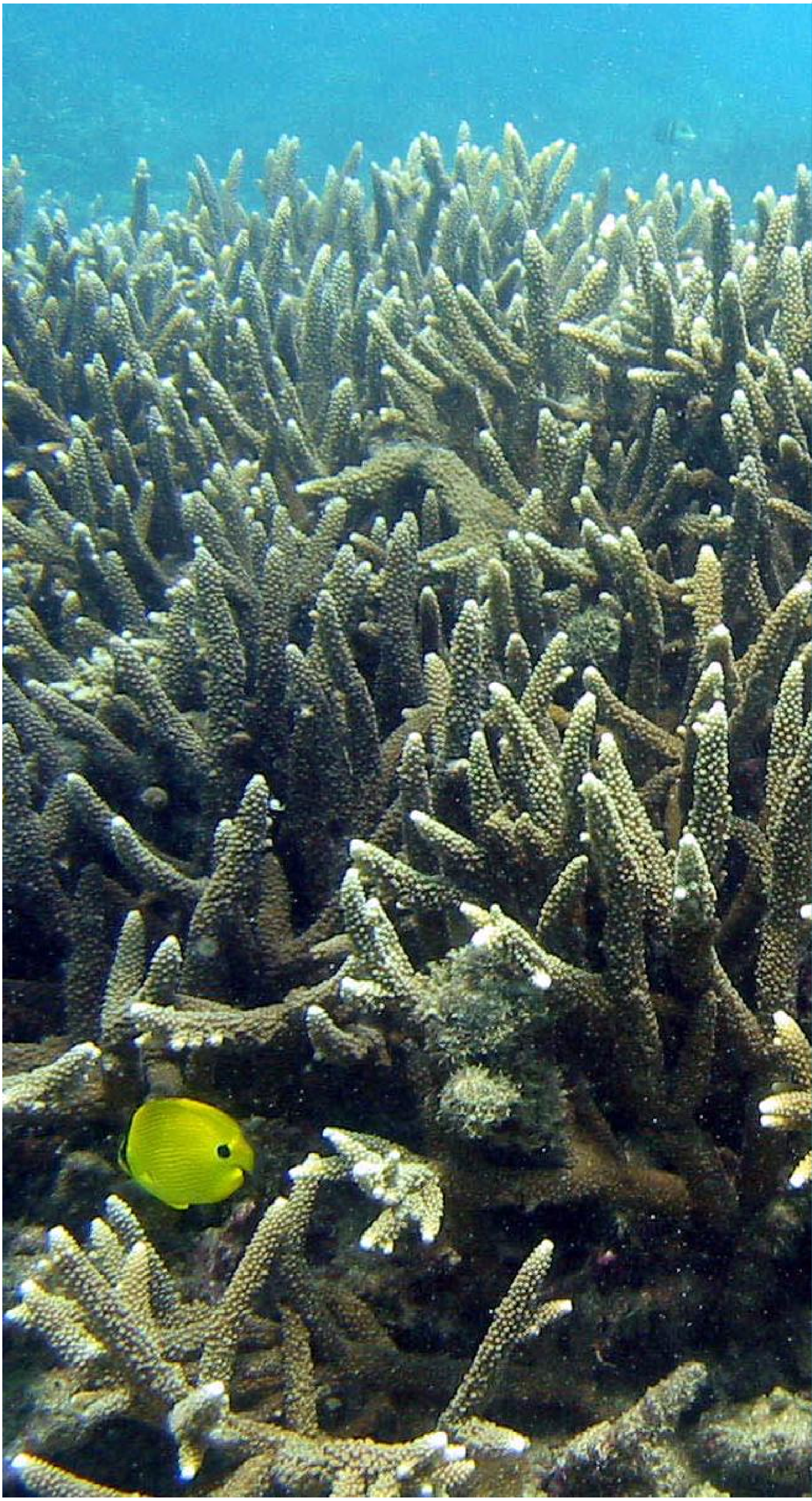
MEDI: The IOC Metadata System. Software User Manual, *IOC User Manual, UNESCO 2002.*

Nayak, S., Kumar, T. S., and Kumar, M.N., 2007. Satellite-based fishery service in India. *The Full Picture*. Group on Earth Observations, Geneva, Switzerland, pp. 256-257.

NDBC Technical Document 03-02, 2003. Handbook of Automated Data Quality Control Checks and Procedures of the National Data Buoy Center.

OGC Ocean Science Interoperability Experiment, http://www.opengeospatial.org/projects/initiatives/oceansie.

Tsou, M. H., 2004. Integrative Web-based GIS and image processing tools for environmental monitoring and natural resource management. *Journal of Geographical Systems,* 6(2), pp. 155–174.



POLICY AND MANAGEMENT

The protection of marine and coastal environments is now an important task globally. The environmental health and well–being of our oceans and seas has assumed a prominence in recent decades, attributed largely to growing scientific knowledge and understanding; the gradual demystification of the oceans and seas; increased and diversified uses of the water masses; the actual and potential environmental risks of use; and geopolitical realities

Among the major responses to the environmental problems of marine and coastal areas is the establishment and development of appropriate legal and institutional mechanisms at the international, regional and national levels

18. **GEOSCIENCE AS A TOOL FOR MARINE MANAGEMENT**: THE APPLICATION OF BIOPHYSICAL DATA TO SUPPORT DECISION MAKING

Kristina Thygesen and Elaine Baker
UNEP/GRID Arendal

Background – the UNEP Shelf Programme

The UNEP Shelf Programme was established to assist developing States to comply with article 76 of the United Nations Convention on the Law of the Sea (UNCLOS). Article 76 sets out the definition of the continental shelf and the criteria by which a coastal State may establish its outer limits – this is the continental shelf beyond 200 M (Figure 1). Determining the outer limits requires analysis of the depth and shape of the seafloor, and in some cases the thickness of the underlying sediment.

Figure 1. Light blue **à** EEZ; dark blue **à** area of Outer Continental Shelf - from submissions currently lodged with the UNDOALOS); purple **à** Outer Continental Shelf - from preliminary information documents submitted to UNDOALOS. From Continental Shelf Ltd, UNEP/GRID-Arendal, in press.

The UNEP Shelf programme has been compiling geoscientific data (the "one stop data shop" – OSDS, Figure 2) that can be used by states to determine seafloor morphology and the depth of continental margin sediments. The data inventory is viewable on the web at http://www.continentalshelf.org/onestopdatashop.aspx. For many developing states, putting together a submission for the outer continental shelf beyond 200 M, has resulted in the first compilation of national seabed data, a valuable resource that can be used for the development of marine management plans. Securing the outer limits of the continental shelf provides States with a legal regime within which to manage the environment and resources. The continental shelf however, is only one of a number of zones that constitute the marine jurisdiction of a coastal state (Figure 3). Under UNCLOS all member States have the obligation to protect and preserve the marine environment. In particular, a coastal States' sovereign rights to exploit resources in their national jurisdiction, must be exercised consistent with their duty to protect and preserve the marine environment.

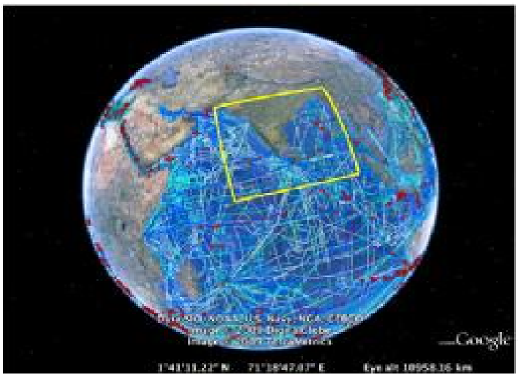


Figure 2. The OSDS showing some of the data tracklines in the data inventory, displayed on Google Earth.

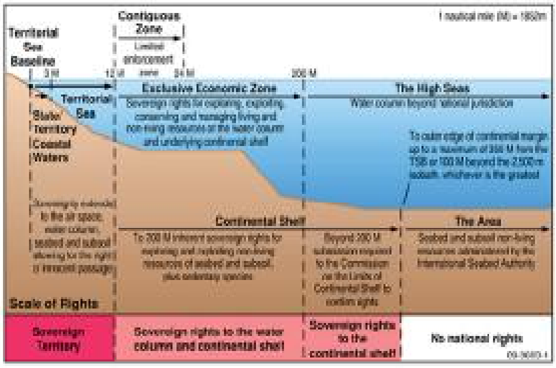


Figure 3. Maritime zones and rights under the 1982 United Nations Convention on the Law of the Sea (UNCLOS) from Symonds et al 2009

States that ratified the United Nations Convention on Biodiversity (CBD), are bound by its articles and associations. Article 8 of the Convention requires parties to establish marine protected areas (MPAs) for the conservation and sustainable use of threatened species, habitats, living marine resources and ecological processes. To protect biodiversity MPAs must be arranged in a network to maximise the protection of ecosystems; ecosystem processes and ecosystem linkages or connectivity. As illustrated in Figure 4, the progress towards both the CBD and the WPC (World Parks Congress) targets for the establishment MPAs lags well behind the stated goals.

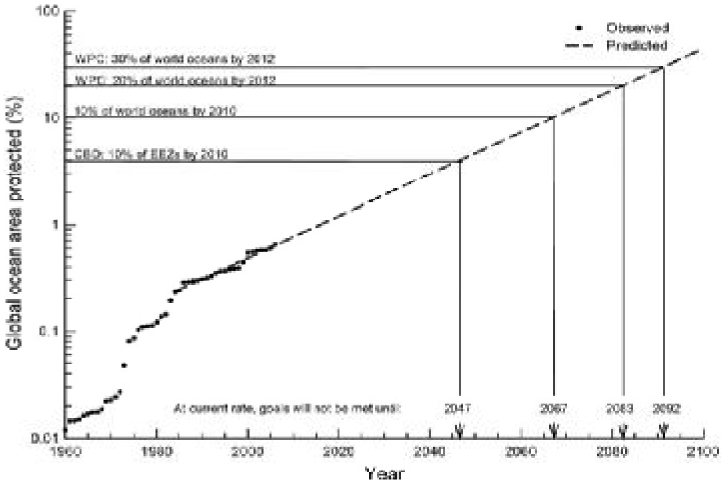


Figure 4. Projection of the annual rate of increase (4.6%) of global marine area protected between 1984 and 2006 and into the future, in relation to attainment of marine protection targets adopted by the Convention on Biological Diversity (CBD) and the World Parks Congress (WPC). From Woods et al 2008.

Marine and coastal habitats may be protected individually or through national or regional systems of marine protected areas. Part of an MPAs success depends on the delineation and classification of the target area. Geoscience information can be used to provide crucial supporting information to characterize habitats and bioregions in order to inform managers of the diversity of major ecosystems which may be represented in MPAs.

Conserving benthic marine biodiversity

Managers need information to help them make decisions about human activities that affect the oceans (e.g. Figure 5). Ecosystem based management requires planning and management to be based on ecosystem boundaries, rather than political or jurisdictional boundaries. However our knowledge of marine diversity and the distribution of marine biota is generally extremely patchy (biological surveys uncover new species during every expedition). The lack of biological data is a serious impediment to the management of the marine environment, however the use of physical datasets can provide an alternative to the species–based approach to conservation. These datasets include the morphology of the seafloor, water depth and sediment properties to name a few.

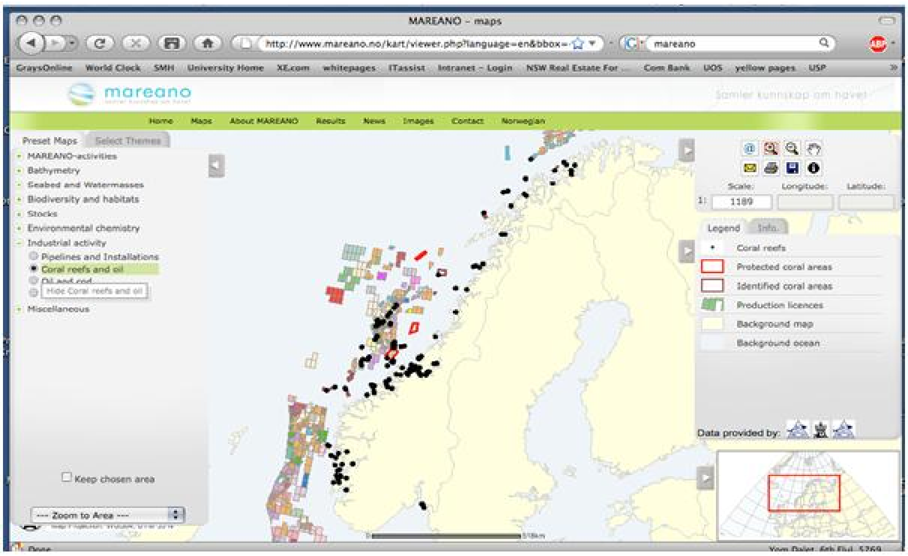


Figure. 5. Page from the Norwegian seabed mapping programme Mareano website, showing coral reefs (black dots) and oil production leases off the coast of Norway (http://www.mareano.no).

Habitat mapping

> "Only a small proportion of the seabed can be observed or sampled and the complete coverage of habitats is inferred from the association between the physical habitat data and the seabed samples so the final maps predict the distribution of seabed habitats. The physical habitat factors act as a proxy for the biological habitat data" (MESH Guide to habitat mapping http://www.searchmesh.net/).

Physical properties can be measured much more quickly and over greater areas than biological data, providing a rapid assessment of marine ecosystems. Presently there are about 14 different marine benthic habitat schemes available for use in characterizing deepwater and coastal (subtidal) habitat types: ten developed for the United States, two for Europe, one for Canada, and one for Australia (Greene et al, 2008).

To take one example that relies heavily on geoscientific data, the habitat mapping scheme used in Australia is based on the national bioregionalisation (Department of Environment and Heritage, 2005; http://www.environment.gov.au/). It includes two parts, the benthic and the pelagic regionalisation. The benthic (sea floor) component covers 80% of Australia's Exclusive Economic Zone (EEZ). Existing seabed bathymetry was used to produce a geomorphic features map of the EEZ - water depth affects temperature, light, nutrients, energy regimes, and seabed sediment conditions—key drivers of marine biota, especially benthic biota. A total of 21 geomorphic feature types were defined using a bathymetric model of the EEZ. Geomorphic features provide an important predictor of species assemblages at a large scale. For example, on the slope different species live on low-gradient terraces compared to those on the steep-walled submarine canyons.

The geomorphic features map was combined with data on demersal fish, sponges and sediments, and oceanographic data to define bioregions, producing a suite of unique bioregions. Additional data layers were added to make “seascapes” – which are used as a surrogate for species diversity and distribution (Table 1 and Figure 6). This work resulted in geomorphic, bioregionalisation, and seascape mapping on a regional scale.

Dataset		Data type	Product
Bathymetry (m)	*	Continuous interpolated data	Seascapes
Gravel (>2 mm) content (%)	*		
Mud (<0.63 μm) content (%)	*		
Seabed disturbance ((Nm^{-2})$^{1.5}$)	*		
Slope (°)	*		
Seabed temperature (°C)	*		
Primary productivity (g Carbon m^{-2} a^{-1})	*		
Geomorphology	*	Categorical data	Focal variety analysis

Table 1. Data sets used in seascape analysis in the Australian region (Heap 2006)

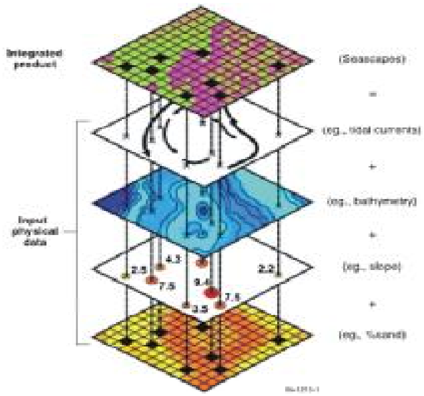


Figure 6. Seascapes represent a combination of different physical data that have an identifiable and consistent relationship with marine biota (Heap 2006).

The scale of the management issue determines the mapping scale and the type of information required. The broad scale of bioregionalisation for example, is perhaps best suited to broad issues. It is considered a “bottom up” scheme as it is underpinned by the geological substrate, in comparison to a “top down” classification, which might for example, be tied to the distribution of a vulnerable species in a local area. In some cases knowing the geomorphology of the habitat will provide adequate information, but in other cases it may not be detailed enough to provide the level of classification required. In these cases combinations of biotic and physical data can be used to subdivide broad areas that would be classified as a single habitat using geomorphology alone.

Greene et al (2008) described the critical elements for habitat mapping using geophysical techniques as including at least the following:

- **Depth**, which in turn can be related to temperature, photic and non-photic zone, and physiography (scale dependent)
- **Substrate,** which relates to refugia, foraging areas, reproduction/nesting places and anchoring surface for sessile organisms
- **Geomorphology**, which relates to features such as canyons, rocky banks, reefs (scale dependent)
- **Slope**, which relates to relief and steepness of the seafloor
- **Complexity**, which relates to the ruggedness or rugosity of the seafloor
- **Currents**, which affect the provision of nutrients, can play a role in the distribution of sediment and the disturbance of habitat
- **Biology,** in terms of the synergy between geology and biology where encrusting and sessile organisms can attach to hard substrate and infauna can burrow or bury into soft substrate. Organisms can themselves form biological substrate under appropriate conditions.

As we increase the number and range of human activities in the ocean, there is an increasing need for spatially delineated benthic environments. Ecosystem based management requires that we understand what lives where. On land we have seen the collapse of ecosystems and major species loss. Geoscience is being used more and more in marine management. It has been demonstrated that geomorphic features can be mapped easily and fairly cheaply and the resulting maps can be used to characterise seafloor environments - which translate to broad scale seafloor habitats. As noted by Heap and Harris (2008) geomorphology can be used to identify regions within national jurisdiction that are distinctive or unique. When geomorphic maps are combined with other physical and biological data sets to create seascapes, they can be used to map marine biodiversity and distribution.

Lingcod, Sitka Pinnacles, Alaska – Alaska Department of Fish and Game groundfish project

References

Cogan, C. B., Todd, B. J., Lawton, P, and Noji, T. T. 2009. Role of marine habitat mapping in ecosystem-based management. ICES Journal of Marine Science, 66: 000-000

Greene, H. G., O'Connell, V., Brylinsky, C. K., and Reynolds, J. R. 2008. Marine Benthic Habitat Classification: What's Best for Alaska? J.R. Reynolds and H.G. Greene (eds.): 169-184.

Heap, A. 2006. Classifying Australia's seascapes for marine conservation: Geoscience data predicts seabed biodiversity. AUSGEO news, issue 84.

Heap, A.D. and Harris, P.T. 2008. Geomorphology of the Australian margin and adjacent sea floor. Australian Journal of Earth Science 55 (4), 555-584.

Post, A. 2006. Mapping marine diversity: Habitats are keys to conservation management. AUSGEO news, issue 84.

Symonds P., Alcock, M. and French, C. 2009. Setting Australia's limits: Understanding Australia's marine jurisdiction. AUSGEO news, issue 93.

Wood, L.J., Fish, L., Laughren, J. and Pauly, D. 2008. Assessing progress towards global marine protection targets: shortfalls in information and action. Oryx 42(3), 1–12.

UNEP/GRID-Arendal. Continental Shelf Limited in press.

19. STATUS OF INTERNATIONAL ENVIRONMENTAL AGREEMENTS ON THE COASTAL AND MARINE ENVIRONMENT BY MEMBER COUNTRIES IN THE SOUTH ASIAN SEAS REGION

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ABSTRACT

This paper focuses on outlining the global regime for protection of the marine and coastal environment as contained in the primary global and regional instruments and an effort has been made to compile the International Conventions / Treaties / Protocols signed, ratified or accessed by the South Asian Seas (SAS) member countries. Many International agreements aiming at the protection of the ocean and coastal marine environment have been negotiated providing the legal basis for co-operation among the states on this subject. Collectively these Agreements form a substantial and coherent regime for protection of the marine environment including, pollution from sea-based activities; pollution from land-based activities; and sustainable use and protection of living marine resources.

1. INTRODUCTION

Nations felt fortunate if their national boundaries were marked by bodies of water. Knowing that water is not the natural habitat of humans, the nations, particularly with marine boundaries, felt a sense of security because traversing the expanse of oceans would have been a daunting task. However, with the progress of civilization, floating vessels appeared on the watery expanses and advances in marine navigation and engineering transformed the vessels from wind dependent sailboats to steam propelled ships. This, in turn, changed the role of oceans from the daunting barriers to the routes of marine trade. Today, although the nations with expansive marine coast and harbours can be considered fortunate in that they have easy access to global trade, they have also become the recipients of marine pollution caused by marine traffic. Added to this, the implications of climate change for each coastal state vary significantly, so each state requires independent assessment.

With the assistance of the United Nations Environment Programme (UNEP) in the development and implementation of the International Environmental Instruments, States have begun to confront the worsening state of the marine environment. The South Asian Seas Programme Action Plan for the Protection and Management of the South Asian Seas Region was adopted at a Meeting of Plenipotentiaries in New Delhi, India on 24 March 1995. National legislations and regulations for the protection and development of marine and coastal resources should be harmonised whenever international uniformity is required to meet the obligations of such legislation.

The ratification and implementation of existing international agreements concerning the prevention and control of marine pollution and the protection of marine resources should be encouraged. The International Environmental Agreements (IEA) Database developed by Ronald B. Mitchell under the IEA Database Project, 2002 - 2009 which was funded by National Science Foundation, USA and University of Oregon lists of over 900 multilaterals, 1500 bilaterals, and 250 environmental agreements between governments and international organisations.

Hence, there is a need to develop an exclusive South Asian Seas data base on International Marine Environmental Agreements. The objective is to compile and give this information to SAS member countries and also this data base seeks to provide negotiators, treaty secretariats, scholars, students, and interested citizens with a reliable list of all historic and current International treaties.

2. ROLE OF UN

United Nations Environment Programme

The roots of the United Nations Environment Programme are found in the United Nations Conference on the Human Environment held in Stockholm. 5 - 16 June 1972. The decision to concentrate on ocean and coastal marine environments was also an outgrowth of the Stockholm Conference. The Stockholm Conference in 1972 on the Human Environment was the spiritual father of the United Nations Environment Programme. The Conference underlined the "vital importance" for humanity of the seas and all the living organisms, which the oceans support. UNEP in its very First Governing Council Sessions in 1973 set the "Health of the Oceans" as one of its priority concerns. Even today this remains as one of its major concerns. Among other activities, UNEP developed the Regional Seas Programme in 1974 which concentrates on assessing and addressing marine environment problems.

Before 1972: The majority of environmental conventions related to the conservation of wildlife. A pioneering convention in conservation terms was the 1968 African Convention on Conservation of Nature and Natural Resources, Algiers. Also notable and considerably more successful is the Ramsar Convention on Wetlands of International Importance, especially as Waterfowl Habitat, which establishes a network of protected wetland areas in the territories of member states

After 1972: The years between 1972 and 1992 witnessed an astonishing increase in the number and variety of international environmental law instruments. Much of this activity is directly attributable to the Stockholm Conference. The United Nations Environment Programme (UNEP) was directly responsible for the sponsoring of a number of key global environmental treaties. This period saw the conclusion of a number of nature conservation treaties both at a global and regional level. At the global level, particularly noteworthy are the 1972 UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage, the 1973 Washington Convention on International Trade in Endangered Species (CITES), the 1979 Bonn Convention on the Animals and the 1985 Vienna Convention for the Protection of the Ozone Layer. At the regional level a large number of treaties also came into force.

United Nations Conference on Environment and Development (UNCED)

Twenty years after the Stockholm Conference, a second major global environmental conference was held in Rio de Janeiro, 1992. The United Nations Conference on Environment and Development (UNCED) reviewed progress since the Stockholm Conference and adopted Agenda 21 as the blueprint for global change into the next century. Sustainable development was endorsed as the overall objective. UNCED reinvigorated the environmental movement both inside and out of the United Nations system and Agenda 21 has become the touch stone for action.

The Chapter 17 of Agenda 21 focuses on protection of the oceans, all kinds of seas, including enclosed and semi-enclosed seas, and coastal areas and the protection, rational use and development of their living resources. The following programme areas were selected for concentration:

- Integrated Management and Sustainable Development of Coastal Areas, including Exclusive Economic Zones.
- Marine Environmental Protection.
- Sustainable Use and Conservation of Marine Living Resources of the High Seas;
- Sustainable Use and Conservation of Marine Living Resources under National Jurisdiction;
- Addressing Critical Uncertainties for the Management of Marine Environment and Climate Change;
- Strengthening International, including Regional, Co-operation and Co-ordination; and
- Sustainable Development of Small Island Developing States.

The outcome of the Earth Summit at Rio led to three very important Conventions that include the Climate Change Convention (UNFCCC), the Biodiversity Convention (CBD) and the Convention to Combat Desertification (UNCCD). Later in 1997, the Climate Change Convention was supplemented by the Kyoto Protocol. The Cartagena Protocol on Biosafety to the Convention on Biological Diversity came into force in 2000.

There are many different legal instruments which address marine environmental protection and prescribe environmental standards to be applied. These instruments are a critical part of the overall marine environment protection regime. The principle conventions dealing with the protection of the marine environment are:

- 1969 *Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Damage*
- 1969 *International Convention on Civil Liability for Oil Pollution Damage;*
- 1971 *Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage*
- 1972 *International Convention on the Prevention of Marine Pollution from Dumping of Wastes and Other Matter;*
- 1973 / 78 *International Convention for the Prevention of Pollution by Ships (MARPOL);*
- 1982 *United Nations Convention on the Law of the Sea (UNCLOS)*
- 1990 *International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC); various Regional Seas Conventions and Protocols*

It should be noted that these instruments operate alongside other international laws which also generally assist with the protection of the marine environment, for example specialised instruments on safety at sea such as the *1972 Convention on the International Regulations for Preventing Collisions at Sea.*

Various other environment conventions have a tangential effect on the marine and coastal environment. These include the *United Nations Convention on Climate Change (UNFCCC), the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal* (Basel), the *Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer* (Ozone Convention and Montreal Protocol), *the Convention on Wetlands of International Importance Especially as Waterfowl Habitat* (Ramsar), *the Convention on the Conservation of Migratory Species of Wild Animals* (CMS), and various Agreements under that Convention, the *Convention on Conservation of Antarctic Marine Living Resources* and various Action Plans under the Regional Seas Programme including the *Action Plan for the South Asian Seas.*

Finally, there are various "soft law" instruments that complete the marine and coastal environmental protection regime. These include the *1995 Global Programme of Action for Protection of the Marine Environment from Land-based Activities (GPA), Global Programme of Action for Marine Mammals and the International Coral Reef Initiative.*

United Nations Division for Ocean Affairs and the Law of the Sea (UNDOALOS)

UNDOALOS provides support to the organisations of the United Nations system to facilitate consistency with the Convention of the instruments and programmes in their respective areas of competence. Further provides States and intergovernmental organizations a range of legal and technical services, such as information, advice and assistance as well as conducting research and preparing studies, relating to the United Nations Convention on the Law of the Sea (UNCLOS), the Agreement relating to the implementation of Part XI of UNCLOS and the Agreement for the implementation of UNCLOS relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN Fish Stocks Agreement) with a view to promoting a better understanding of UNCLOS and the implementing Agreements, their wider acceptance, uniform and consistent application and effective implementation.

International Maritime Organization (IMO)

The International Maritime Organization (IMO) came into existence in 1958. Prior to its formation, several important international conventions had already been developed, such as

- The International Convention for the Safety of Life at Sea of 1948,
- The International Convention for the Prevention of Pollution of the Sea by Oil of 1954 and
- Treaties dealing with load lines and the prevention of collisions at sea.

Now IMO is responsible for nearly 50 international conventions and agreements and has adopted numerous protocols and amendments. Contracting Parties have obligations to make notifications on various matters to the IMO. Then IMO convenes consultative meetings of the parties to review the implementation of the Convention, adopt amendments, promote regional co-operation, etc. Periodic reviews and amendments of the Convention are made through the regular Consultative Meetings. The Convention was amended in 1978. Under a tacit amendment procedure, amendments to the annexes take effect for all parties within a certain time, unless they object within 100 days. Under this procedure, the annexes have been amended several times
.
IMO Conventions The majority of conventions adopted under the auspices of IMO or for which the Organisation is otherwise responsible, fall into three main categories.

- The first group is concerned with maritime safety;
- The second with the prevention of marine pollution; and
- The third with liability and compensation, especially in relation to damage caused by pollution. Outside these major groupings are a number of other conventions dealing with facilitation, tonnage measurement, unlawful acts against shipping and salvage etc.,

Adopting Convention: IMO has six main bodies concerned with the adoption or implementation of conventions. The Assembly and Council are the main organs and the committees involved are the Maritime Safety Committee, Marine Environment Protection Committee, Legal Committee and the Facilitation Committee. Developments in shipping and other related industries are discussed by Member States in these bodies, and the need for a new convention or amendments to existing conventions can be raised in any of them.

- Step 1 Normally the suggestion is first made in one of the committees, since these meet more frequently than the main organs
- Step 2 If agreement is reached in the committee, the proposal goes to the Council and, as necessary, to the Assembly
- Step 3 If the Assembly or the Council, as the case may be, gives the authorization to proceed with the work, the committee concerned considers the matter in greater detail and ultimately draws up a draft instrument. In some cases the subject may be referred to a specialised sub-committee for detailed consideration.
- Step 4 Work in the committees and sub-committees is undertaken by the representatives of Member States of the Organisation. The views and advice of intergovernmental and international non-governmental organisations which have a working relationship with IMO are also welcomed in these bodies. For example SASP/SACEP is a member of committee on BLG 13 sub committee to formulate guidelines for the Biofouling - Invasive Alien Species
- Step 5 The draft Convention which is agreed upon is reported to the Council and Assembly with a recommendation that a conference be convened to consider the draft for formal adoption.

- Step 6 Invitations to attend such a conference are sent to all Member States of IMO and also to all States which are members of the United Nations or any of its specialised agencies. These Conferences are therefore truly global conferences open to all Governments who would normally participate in a United Nations Conference. Before the Conference opens, the draft Convention is circulated to the invited Governments and organisations for their comments. The draft Convention, together with the comments thereon from Governments and interested organisations is then closely examined by the Conference and necessary changes are made in order to produce a draft acceptable to all or the majority of the Governments present.
- Step 7 The Convention thus agreed upon is then adopted by the Conference and deposited with the Secretary-General who sends copies to Governments
- Step 8 The convention is opened for signature by States, usually for a period of 12 months. Signatories may ratify or accept the Convention while non-signatories may accede.
- Step 9 The drafting and adoption of a convention in IMO can take several years to complete although in some cases, where a quick response is required to deal with an emergency situation, Governments have been willing to accelerate this process considerably.

Fisheries and Agriculture Organization (FAO)

When FAO was founded in 1945, five countries from the Asia-Pacific Region were signatories to FAO's Charter – Australia, China, India, New Zealand and the Philippines and at present all the 5 SAS member countries are signatories.

Fish Stocks Agreement: In the early 1990s a consensus among states developed that the general provisions requiring co-operation between states in the conservation and management of high seas fisheries resources (Art. 117-120) needed strengthening. This lead to the 1995 Agreement for the implementation of the provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks (UN 1995), also known as the United Nations Fish Stocks Agreement.

FAO Code of Conduct for Responsible Fishing: A number of other multilateral agreements further elaborate the evolving set of rules for the governance of fisheries. The Code of Conduct for Responsible Fishing (1995) *inter alia* spells out flag state responsibilities for the activities of fishing vessels flying its flag and seeks to advance management measures, by agreement among states, that improve the optimal and sustainable use of fisheries resources. The Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas (Resolution 15/93) similarly builds on flag state responsibility for fishing vessels flying its flag (Art. III) and operating on the high seas.

Other significant agreements: Other important agreements which have significant implications for the management of fisheries resources are the 1992 Biological Diversity Convention, the 1982 Convention on the Conservation of Antarctic Marine Living Resources, and the 1972 World Heritage Convention. A range of other global and regional treaties exist which, in some cases, have a direct bearing on the governance of the fisheries sector.

3. INTERNATIONAL ENVIRONMENTAL AGREEMENTS – SAS REGION

In the present study the International Environmental Agreements relevant to coastal and marine environment in the South Asian Seas region are categorised into ocean, marine biodiversity, marine pollution, fisheries, safety and intervention, civil liability and fund conventions and are presented here

3.1 OCEAN

United Nations Convention on the Law of the Sea *1982*

In 1973, the Third UN Conference on the Law of the Sea was convened. The deliberations lasted for nine years, and resulted in the 1982 Convention on the Law of the Sea. The 1982 Convention was intended to provide a global constitution for the oceans. It entered into force on 16 November 1994. The 1982 Convention is of critical importance because it is increasingly regarded as a constitutional document, which sets out the basic legal framework for the oceans. It is a major law-making treaty, which has significance for all states, whether or not they are parties to it. All of the global conventions covering specific areas, such as the IMO and UNEP Conventions, are generally read subject to the 1982 Convention.

Subsequent documents of fundamental importance, such as Chapter 17 of Agenda 21, are also read so as to be consistent with the 1982 Convention. The 1982 Convention is the strongest comprehensive global environmental treaty in existence. It established for the first time a comprehensive legal framework for the protection and preservation of the marine environment. It is significant because it represents the first attempt to set out in a global convention a general framework and structure for a legal regime which establishes the obligations, responsibilities and powers of states in matters of marine environmental protection. Part XII of the 1982 Convention (articles 192 to 237) sets out state's obligations with respect to the marine environment generally and also their obligations with respect to the major sources of marine pollution.

General Provisions: Prior to the 1982 Convention states had the *right* to pass legislation to protect and preserve the environment, but no clear *duty* to do so. The 1982 Convention represents a major change because in ***Article 192*** it places an affirmative obligation on states to take action to preserve and protect the marine environment. ***Article 193*** recognizes that although states have a sovereign right to exploit their natural resources, they must do so pursuant to their environmental policies and *in accordance with their duty to protect and preserve the marine environment.* To this extent, the provision recognises that the sovereign right of states to exploit their natural resources is subject to their obligations to protect and preserve the marine environment. ***Article 194*** provides that states shall take all measures consistent with the Convention to prevent, reduce and control pollution of the marine environment from any source. It provides that states must use the best practicable means at their disposal and in accordance with their capabilities. Nevertheless, states are obliged to take all measures necessary to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other states and their environment.

Global and Regional Co-operation*:* Section 2 of Part 12 is also significant because it specifically provides that states have an obligation to co-operate on a global basis, or as appropriate, on a regional basis. ***Article 197*** provides that States shall co-operate directly or through competent international organisations, in formulating and elaborating international rules, standards and recommended practices and procedures for the protection and preservation of the marine environment. Such co-operation must take into account regional features.

Monitoring and Environmental Assessment*:* The most significant provision of the 1982 Convention relating to environmental impact assessments is ***Article 206*****.** It provides that when states have reasonable grounds for believing that planned activities under their jurisdiction or control may cause substantial pollution of or significant and harmful changes to the environment, they shall, as far as practicable, assess the potential effects of such activities on the marine environment.

Pollution from the various sources*:* The 1982 Convention represents an important advance over the prior law because it addresses all of the sources of marine pollution. It contains detailed provisions on vessel source pollution, and also places a specific obligation on states to pass laws to regulate ocean dumping. Specific obligations are also set out for other sources of pollution, such as pollution from sea-bed activities, pollution from the atmosphere and pollution from land based activities.

UNCLOS covers virtually every conceivable use and benefit of the oceans including shipping, fishing and seabed mining. It also establishes a regime for dispute resolution, dividing the resources of the seabed, the limits of innocent passage, and coastal and flag state jurisdiction.

3.2 MARINE BIODIVERSITY

The Conventions discussed here deal with biodiversity and marine biodiversity is also part of it. In addition, other global Conventions, including CBD, CMS, UNFCCC and CITES, directly or indirectly affect the protection of living marine resources. These Conventions are dealt here to merely point out how these various instruments assist in the protection of living marine resources.

CBD: The CBD is intended to promote the conservation of biological diversity, the sustainable use of its components and the equitable sharing of the benefits arising out of the use of genetic resources. At the Second Conference of the Parties to the Convention held in Jakarta in late 1995, the Parties decided to request the Subsidiary Body on Science, Technology and Technological Advice to the Convention to establish a three year panel on marine/coastal biological diversity to examine in particular, protected areas, sustainable use, integrated management, introduction of alien species and mariculture.

CMS: CMS provides a framework by which Parties may act to conserve migratory species and their habitat by adopting strict protection measures for migratory species that have been categorised as endangered, concluding agreements for the conservation and management of migratory species or their separate populations that have an unfavourable conservation status or would benefit from international co-operation and undertake joint research or management activities.

CITES : The objective of CITES is to ensure that international trade in species threatened with extinction is prohibited except in special circumstances, and that trade in species whose survival might be threatened by such trade is controlled and monitored to ensure the trade is sustainable. To this end, CITES establishes a world-wide system of controls on international trade in threatened animals and plants and articles derived from them. All such trade must be authorised by government issued permits or certificates. This would include, for example, trade in sea tortoise shell.

3.3 MARINE POLLUTION

Marine pollution is defined as: the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea impairment of quality for use of sea water and reduction of amenities.

The position prior to World War II: Under the rules of customary international law governing the oceans, the principle of *freedom of use* was the prevailing norm. The resources of the oceans were regarded as inexhaustible. The oceans were also viewed as ideal dumping grounds which were so vast that they were not capable of being polluted through the activities of man. The potential for ships to pollute the marine environment was recognised as early as the 1920's, and a conference was convened in Washington in 1926 to draw up a draft convention on pollution from ships. However, it was only after World War II that the international community began to realise that international action may be required to regulate pollution of the marine environment.

Oil Pollution Convention, 1954: The 1954 International Convention on the Prevention of Pollution of the Sea by Oil was the first international convention to attempt to prevent pollution of the sea by oil from tankers. It prohibited the discharge of oil or oil mixture by tankers within prohibited zones. It originally applied to all sea-going ships over 500 tons or more, but was amended in 1962 to cover tankers of 150 tons or over. Amendments were made to the 1954 Oil Pollution Convention in 1969. It was amended to provide for more stringent requirements for operational discharges which were consistent with the “load-on-top system’ of operating which had been adopted by oil tankers. In 1971 the Convention was amended to impose new standards on the construction of oil tankers. This convention has been superceded by the 1973/78 MARPOL Convention, which will be discussed later in this paper.

Geneva Convention on the High Seas, 1958: The 1958 Geneva Convention on the High Seas contained only two provisions relating to marine pollution. Article 24 recognised the potential harmful effects of oil pollution from ships and from off-shore oil exploration and exploitation.

IMO International Maritime Dangerous Goods Code: This code was introduced by a resolution of the IMO Assembly in 1965. It classifies dangerous goods and sets out detailed requirements as to marking, labelling, packaging and documentation. It has been updated on a regular basis in response to developments in the shipping and chemical industries. It is widely observed and the IMO has recommended that states adopt it as the basis for national legislation. It supplements several IMO conventions, and is essential for their effective implementation. The IMDG Code is regularly amended. Amendments made in 1994 were so extensive that the entire 2500 page Code has been reprinted.

3.4 INTERVENTION, CIVIL LIABILITY AND FUND CONVENTIONS

The *Torrey Canyon* disaster in 1967, in which a Liberian tanker carrying over 119,00 tons of crude oil, caused considerable pollution damage along the coasts of France and the United Kingdom. This prompted two international conventions in 1969 to deal with the problem of oil spills from maritime casualties - the Intervention Convention and the Civil Liability Convention. These two conventions were supplemented by the 1971 Fund Convention.

Intervention Convention, 1969: The Convention Relating to the Intervention on the High Seas in Cases of Oil Pollution Casualties was adopted in Brussels on 29 November 1969. It entered into force on 6 May 1975. This treaty gives coastal states special powers to take self-help measures beyond the limits of their territorial sea following a maritime casualty involving oil pollution from ships which may reasonably be expected to result in major harmful consequences. Coastal states may take such measures as may be necessary to prevent, mitigate or eliminate grave and imminent danger to their coastline or related interests from pollution or threat of pollution of the sea by oil. A Protocol adopted in 1973 extends the Convention to substances other than oil. The 1973 Protocol entered into force on 30 March 1983.

Civil Liability Convention, 1969: The 1969 International Convention on Civil Liability for Oil Pollution Damage was also adopted in Brussels in 1969. It entered into force on 19 June 1975. The 1969 Civil Liability Convention creates a scheme of liability for oil pollution damage caused by oil tankers. The Convention provides that the ship owner is strictly liable for oil pollution damage, without any need to prove negligence or fault except in certain circumstances, such as war and insurrection. They allow persons who suffer damage from oil pollution to have recourse directly against the owner of the vessel, without involving states. Under the 1969 Convention the owner’s liability is limited according to a formula related to the tonnage of the ship and the overall total, unless the incident occurred as a result of his actual fault. The 1969 Convention was amended by a Protocol in 1976, which entered into force on 8 April 1981.

Fund Convention, 1971: The 1971 Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (1971 Fund Convention) was adopted in Brussels in 1971. It entered into force on 16 October 1978. The purpose of the 1971 Fund Convention is to establish a fund to provide additional compensation so that within the limits of the Fund's total liability, the victims are fully and adequately compensated. The fund is established from a levy on oil importers, who are mainly the oil companies whose cargoes the vessels are likely to be carrying. The Fund Convention thus provides a form of security for claimants who have suffered pollution damage. However, the Fund established by the Convention is not available in certain exceptional circumstances, including where the claimant cannot prove that the damage resulted from an incident involving one or more ships.

London Convention, 1972: The proposals at the Stockholm Conference led to the adoption in the following year of the 1972 Convention on the Prevention of Marine Pollution by the Dumping of Wastes and other Matter (London Convention). The Convention entered into force on 30 August 1975. The purpose of the London Convention is to regulate the dumping of wastes at sea. It regulates the deliberate disposal at sea of certain substances, including oily wastes, dredging and land-generated wastes. It does not govern oil pollution caused by operational discharges from the normal operation of ships. Nor does it govern pollution caused by maritime casualties. Under the London Convention contracting parties pledge themselves to take all practicable steps to prevent the pollution of the sea by the dumping of waste and other matter that is liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea.

Two provisions are of special interest to less developed countries. First the obligation to take individual measures is according to their scientific, technical and economic capabilities. Second, parties are obliged to promote support for other parties who require training of personnel, supply of equipment, and facilities for research and monitoring and disposal and treatment of waste.

The London Convention contains a 'black list' of Annex I substances that may not be dumped at sea; a 'grey list' of Annex II substances that may be dumped subject to a special permit. Annex III contains criteria for determining whether other substances may be dumped at sea, pursuant to a general permit. Beginning in 1991, the Contracting Parties to the London Convention began to adopt what might be described as a 'precautionary approach' to ocean dumping. Under this approach, "appropriate preventive measures are taken where there is reason to believe that substances or energy introduced in the marine environment are likely to cause harm even where there is no conclusive evidence to prove a causal relation between outputs and their effects. The effect of the new amendments to the annexes has led to a complete ban on the dumping of radioactive waste, to a phase out of the dumping of industrial waste and to a ban on the incineration of waste at sea. The London Convention is supplemented by regional agreements in many parts of the world.

MARPOL Convention, 1973/78: The Stockholm Conference was an impetus for the adoption of the 1973 Convention for the Prevention of Pollution from Ships (1973 MARPOL Convention) in the following year. The 1973 MARPOL Convention replaced the 1954 Convention. The 1954 Convention had not been particularly successful. Not all flag states were parties to it, and the enforcement record of flag states which were parties was weak. The initial 1973 text was adopted by the IMO in 1973. Before it received a sufficient number of ratifications to enter into force, it was substantially amended by a protocol in 1978 to facilitate its entry into force. The Convention, as amended by the 1978 Protocol, entered into force on 2 October 1983. The object of the Convention is to prevent the pollution of the marine environment by the operational discharge of oil and other harmful substances and to minimise the accidental discharge of such substances. States parties are obliged to apply the provisions of the convention to ships flying their flag and to ships within their jurisdiction. The Convention has had a major impact on the construction of tankers, and in practice, all tankers built after 1975 have been built to meet MARPOL requirements. In practice, the vast majority of ships today conform to MARPOL standards.

Amendments adopted in 1992 and which entered into force in 1995 impose new standards to improve the safety of tankers. All new tankers ordered after July 1993 of 5,000 dwt and above must be fitted with double bottoms and double hulls. In addition, the construction requirements for tankers of 25 years of age or above (those built prior to 1970) were amended to require the mandatory fitting of double hulls or an equivalent design. In addition, the 1992 amendments provided for an enhanced system of inspection for oil tankers aged five years and above. The effect of these amendments is likely to be that aging tankers which were constructed prior to the MARPOL Convention will be either upgraded to modem standards or scrapped.

Implementation of the Convention is based in part upon the right of inspection by port states. Parties are obliged to co-operate in the detection of violations and the enforcement of the provisions of the convention. Ships in the port or offshore terminals of any party to the convention are required to hold certificates issued pursuant to the Convention, and are subject to inspection by the port state to verify the certificate. If any ship in port does not carry a valid certificate, or if there are clear grounds for believing that the condition of the ship or its equipment does not correspond substantially with the particulars of its certificate, a more detailed inspection is required. In such case, the Party carrying out the inspection is obliged to take such steps as will ensure that the ship shall not sail until it can proceed to sea without presenting an unreasonable threat of harm to the environment. The MARPOL Convention relies mainly on technical measures to limit oil discharges, including standards for the construction of new oil tankers. Discharges of small quantities of oil are permitted, but only when the vessels are enroute and more than 50 miles from land. The Convention allows that certain areas can be designated as 'special areas' where all discharges are prohibited. The Convention is not con fined to oil pollution. It also regulates other types of pollution caused by the operation of ships, including the bulk carriage of noxious liquids and garbage. The Convention contains annexes which contain regulations governing different types of pollutants. The annexes are:

Annex I	Oil Discharges
Annex II	Noxious Liquid Substance Discharges
Annex III	Harmful Substances in Packaged Form and Containers
Annex IV	Sewage Discharges
Annex V	Garbage Discharges
Annex VI	Air Pollution

All of the annexes are in force except Annex IV on Sewage Discharges. All parties are bound by Annexes 1 and II. States parties to the MARPOL Convention are obligated to supply reception facilities. However, the record of port States in supplying such facilities has been not been good in some parts of the world because of financial constraints. Another problem for implementation by port States is the cost of administering a system of inspection and enforcement, including the training of the necessary personnel. It has also been observed that there has been lack of effective implementation of the Convention by many flag states. Among the reasons cited for this are a lack of trained and experienced personnel to carry out the inspections, especially the need to train and retain qualified and experienced surveyors. It is generally believed that the participation costs for developing countries will be reduced if there is co-operation on a regional basis in implementing the Convention.

Under Article 17 of the Convention, States parties are obligated to promote, in consultation with the IMO and with assistance and co-operation from UNEP, support for Parties requesting assistance for the training of scientific and technical personnel and the supply of necessary equipment and facilities for reception and monitoring. Another benefit of regional co-operation is the standardisation of rules and procedures.

Convention on Oil Preparedness, Response and Co-operation, 1990: In 1990, following the *Exxon Valdez* disaster off the coast of Alaska, the IMO adopted a global instrument entitled the Convention on Oil Pollution Preparedness, Response and Co-operation which sets out general obligations for co-operation and assistance to deal with major oil pollution incidents. Its purpose is to help Governments combat major oil pollution incidents. It entered into force on 13 May 1995, one year after being accepted by 15 states. The Convention is intended to encourage the establishment of oil pollution emergency plans on ships and offshore installations, and at ports and oil handling facilities. It also is intended to encourage the establishment of national and regional contingency plans, and a framework for international co-operation. Amendments to the 1973/78 MARPOL Convention were adopted in 1991 in response to this Convention.

HNS Convention, 1996: The International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea (HNS) was prepared by the legal committee of the IMO and adopted at a diplomatic conference in May, 1996. The HNS Convention establishes a system for compensation and liability covering in principle all kinds of hazardous and noxious substances. The HNS Convention introduces strict liability for the ship owner, with higher upper limits than are available under existing general limitation regimes. It also introduces a system of compulsory insurance and insurance certificates. The ship owner's liability is supplemented by a HNS Fund, which is financed by cargo interests. Contributions to the HNS Fund will be levied on persons within the territory of contracting Parties who receive a certain minimum quantity of HNS cargo during a calendar year. The HNS Convention goes further in its scope than the oil pollution compensation regime in that it covers not only pollution damage but also the risks of fire and explosion.

Protocol to London Convention, 1996: A Protocol to the Convention on the Prevention of Marine Pollution by the Dumping of Wastes and Other Matter, 1972, was adopted at a conference held at IMO headquarters in London in November, 1996. The Protocol will enter into force 30 days after ratification by 26 countries, 15 of whom must be Contracting Parties to the 1972 treaty. The Protocol represents a major change of approach to the question of how to regulate the use of the sea as a depository for waste materials. One is to introduce the "precautionary approach". This requires that "appropriate preventative measures are taken when there is reason to believe that wastes or other matter introduced into the marine environment are likely to cause harm even when there is no conclusive evidence to prove a causal relation between inputs and their effects." *The Protocol also provides that "the polluter should, in principle, bear the cost of pollution" and it emphasizes that Contracting Parties should ensure that the Protocol should not simply result in pollution being transferred from one part of the environment to another.*

The 1972 Convention permits dumping to be carried out provided certain conditions are met. The severity of these conditions varies according to the danger to the environment presented by the materials themselves and there is a "black list" containing materials which may not be dumped at all. The Protocol is much more restrictive. It states (in Article 4) that Contracting Parties "shall prohibit the dumping of any wastes or other matter with the exception of those listed in Annex 1.

These materials include:

- Dredged material
- Sewage sludge
- Fish waste, or material resulting from industrial fish processing operations
- Vessels and platforms or other man-made structures at sea
- Inter inorganic geological material
- Organic material of natural origin

- Bulky items primarily comprising iron, steel, concrete and similar unharmful materials for which the concern is physical impact and limited to those circumstances, where such wastes are generated at locations, such as small islands with isolated communities, having no practicable access to disposal options other than dumping.

The only exceptions to this are contained in Article 8 which permits dumping to be carried out "in cases of force major caused by stress of weather, or in any case which constitutes a danger to human life or a real threat to vessels.."

Incineration of wastes at sea was permitted under the 1972 Convention, but this practice has since been ended and it is specifically prohibited by article 5 of the Protocol. Incineration at sea of industrial waste and sewage sludge had already been prohibited under amendments to the London Convention adopted in 1993. In recent years concern has been expressed at the practice of exporting wastes which cannot be dumped at sea under the 1972 Convention to non-Contracting Parties.

IMO Conventions on Maritime Safety: Other IMO conventions and instruments, although technically dealing with maritime safety, are also relevant to prevention of pollution of the marine environment. The most important of these are: (a) 1974 Convention on Safety of Life at Sea (SOLAS); (b) 1972 International Regulations for Preventing Collisions at Sea (COLREGS); and (c) 1978 Standards of Training, Certification, and Watch-keeping.

UNEP Instruments Relating to Marine Pollution

In the 1980s the following international instruments of relevance to the marine environment were promulgated by UNEP: (1) 1982 Guidelines Concerning the Environment Related to Offshore Mining and Drilling Within the Limits of National Jurisdiction; and (2) 1985 Montreal Guidelines for the Protection of the Marine Environment from Land-based Sources; and (3) 1989 UNEP Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the EEZ. In addition, an important UNEP convention adopted in 1989, the Basel Convention on the Control of the Transboundary Movement of Hazardous Wastes and their Disposal, represented the first global attempt to regulate the transboundary movement of hazardous waste.

Montreal Guidelines on Land-based Marine Pollution, 1985: No global treaty exists for the control of land-based sources of marine pollution. Regional agreements exist in several areas, but not in this region. In 1985 UNEP adopted a non-binding instrument known as the Montreal Guidelines for the Protection of the Marine Environment against Pollution from Land-based Sources. These guidelines offer a checklist for national legislation, as well as for the development of global, regional or sub regional agreements. The guidelines call for the negotiation of internationally agreed rules and standards. The annexes give guidance on control strategies and the classification of substances. The Basel Convention is not directly on marine pollution. However, it is related to other marine pollution conventions in the sense that it forms an integral part of a regime governing the movement of hazardous waste. The 1972 London Convention controls the dumping of such wastes in the oceans, the 1973/78 MARPOL Convention regulates the manner of storing and packing such substances during transit on the oceans, and the Basel Convention regulates their transboundary movement to other states, including the transit of such substances through other states. It has been recognized that there is a need to study whether all of the provisions of the Basel Convention, the 1972/78 MARPOL Convention and the 1972 London Convention are compatible. There is also a need for states to understand that the three conventions complement one another and that there may be gaps or lacunae in their laws if they do not ratify and implement all three conventions. Therefore, there is a need for states to ensure that the domestic legislation implementing the three conventions are consistent with one another.

Global Programme of Action on Land-based Activities, 1995: The major weakness of the efforts of the international community has been the failure to deal effectively with marine pollution caused by land-based activities, which accounts for nearly 70% of all marine pollution. In 1995 an attempt was made to deal with this complex problem. An Inter-governmental Conference to Adopt a Global Programme for the Protection of the Marine Environment from Land-based Activities was held in Washington, D.C. from 23 October to 3 November, 1995.

3.5 FISHERIES

The fisheries management is organised in four layers: Global, Regional, National, and Local.

Global: UN Convention on the Laws of the Sea (UNCLOS) regulates the fishing behaviour of member countries with specific written regulatory details in the FAO code of conduct for responsible fisheries (FAO-CC), along with its historical predecessors, as summarized in the table below.

Mid-1970s	Creation of EEZ
1982	United Nations Convention on the Law of the Sea (EEZ regime emerged)
1993	1993 agreement to promote compliance with international conservation and management measures by fishing vessels on the high seas (compliance agreement)
1995	United Nations fish stocks agreement (entered into force in 2001) FAO code of conduct for responsible fisheries
2001	International plan of action to prevent, deter and eliminate illegal, unreported and unregulated fishing (IPOA -IUU)

Fisheries advisory and technical agreements are: the constitution of the FAO agreement to constitute the international centre for living aquatic resources management as an international organization. The International fisheries management agreements which SAS countries either signatories / ratified/ agreed are: Convention on the Conservation of Antarctic Marine Living Resources and Agreement for the establishment of the Indian Ocean Tuna Commission

Among the Global Agreements on the Conduct of Fishing Operations, there is no agreement in this category in SAS region. Among the labour and welfare agreements below given are relevant to this region: ILO convention on work in fishing, ILO Convention concerning fishermen's articles of agreement, ILO Convention concerning the medical examination of fishermen, ILO Convention concerning accommodation on board fishing vessels ; and ILO Convention concerning fishermen's certificates of competency

The more specific maritime safety instruments by the International Maritime Organization are the International Convention for the Safety of Fishing Vessels and International Convention on Standards of Training, Certification and Watch keeping for fishing vessel personnel (STCW -F)

The global agreements on marine mammals and marine biodiversity are: International Convention for the Regulation of Whaling (Management); Convention for the Conservation of Antarctic Seals (Management) and Agreement on the International Dolphin Conservation Programme (Agreement). The International Trade Agreements related to fisheries are World Trade Organization Agreements (WTO) and Convention for International Trade in Endangered Species (CITES).

Finally there are non-binding global instruments such as United Nations Driftnet Resolutions, UNCED Agenda 21 and declaration of principles, FAO code of conduct for responsible fisheries, International plan of action for the management of fishing capacity, International plan of action for the conservation and management of Sharks, International plan of action for reducing incidental catch of seabirds in long line fisheries, International Plan of Action to prevent, deter and eliminate illegal, unreported and unregulated Fishing and World Summit on Sustainable Development. Plan of implementation and declaration

Regional: The Regional Fisheries Bodies implement the regulations complementary to global rules. At the national level, each nation has its own fishing program and more often than not, local fisheries management influences how the upper levels of national and regional management operate. Regional fisheries agreements provide fertile ground to test arguments about the influence of political determinants on international institution building.

National: Today, global regulation continues to depend on voluntary national implementation. The global fisheries regime, like other international co-operation regimes, relies heavily on national level implementation. States are expected to improve their monitoring, control and surveillance systems, establish mandatory licensing regimes and strengthen legal frameworks. The vessel registration is the easiest method; states rarely monitor by-catch and discard

4. REGIONAL AGREEMENTS

One of the difficulties which exist with global instruments addressing environmental issues is that many of them are unable to deal with region specific problems. Regional agreements can be effectively concluded and implemented precisely because of the need to protection a commonly shared resource. This is the case with protection of regional seas, including the South Asia Seas.

The regional agreements have been extraordinarily effective in engaging governments in protecting the environment. Unlike the global environmental conventions, these regional conventions are comprehensive, covering issues ranging from chemical wastes and coastal development to the conservation of marine animals and ecosystems. Their limited geographic focus enables them to channel the energies of a wide range of interest groups on solving what are, after all, a series of interlinked problems. With attention turning to global conventions in recent years, many people are unaware of the effective regional instruments that are already in place.

As has been recognised through the Regional Seas Programme, co-operation at the regional level can be crucial for success in arresting marine degradation. This is particularly so where a number of countries share the same marine and coastal area, such as in enclosed or semi-enclosed seas. Regional co-operation can strengthen regional and national capacity, provide an avenue for harmonising and adjusting measures to fit particular environmental and socio-economic circumstances and support more efficient and cost-effective implementation of the programmes of action. States are encouraged to participate in regional and sub-regional arrangements. Effective functioning of such arrangements might include: strengthening regional information networks; inviting multilateral financing agencies, particularly regional development banks, to cooperate in and support action plans; and encouraging collaboration between national and regional focal points and economic groupings, other relevant and international organisations, development banks and regional rivers authorities in the development and implementation of action plans.

Action Plan: The substantive aspects of any regional programme are outlined in an action plan which is formally adopted by an Intergovernmental Meeting of the Governments of a particular region before the programme enters into its operational phase. In the preparatory phase leading to the adoption of the Action Plan, Governments are consulted through a series of meetings and missions about the scope and substance of an action plan suitable for their region. In addition, with co-operation of appropriate global and regional organizations, a review of the specific environmental problems of the region are prepared in order to assist the governments in identifying the most urgent problems in the region and the corresponding priorities to be assigned to the various activities outlined in the action plan. It is designed to link assessment of the quality of the marine environment and the causes of its deterioration with activities for the management and development of the marine and coastal environment. The Action Plans promote the parallel development of regional legal agreements and of action-oriented programme activities

4.1 REGIONAL SEAS PROGRAMME

The Regional Seas Programme was initiated by UNEP in 1974. At present, in accordance with the relevant decisions of UNEP's Governing Council, the Regional Seas Programme covers 13 areas and 140 countries where regional action plans are operative or are under development. These include the Mediterranean Area (1975); the Kuwait Action Plan (1978); the West and Central African Region (1981); the Wider Caribbean Region (1981); the East Asian Seas Region (1981), the Southeast Pacific Region (1981). The Red Sea and Gulf of Aden Region (1982). The South Pacific Region (1982); the Eastern African Region (1985); the South Asian Seas Region (1995); the Black Sea Region (Framework Action Plan adopted in 1993) the Northwest Pacific Region (1994) and the Southwest Atlantic Region.

It is essential to bear in mind that all components of a regional programme are interdependent. Assessment activities identify the problems that need priority attention in the region. Legal agreements are negotiated to strengthen co-operation among States in managing the identified problems. They also provide an important tool for national policy makers to implement national control activities. Management activities, aimed at controlling existing environmental problems and preventing the development of new ones, are one of the means by which States fulfil their treaty obligations. Co-ordinated assessment activities then continue to assist governments by providing scientific information by which to judge whether the legal agreements and management policies are effective.

4.2 SOUTH ASIAN SEAS REGION

The **South Asian Seas** (SAS) Region includes parts of the Bay of Bengal and the Arabian Sea in the Northern Indian Ocean, as well as the seas bordering Bangladesh, India, Maldives, Pakistan and Sri Lanka. Bangladesh, India, and Pakistan are parts of the Indian subcontinent, while the island of Sri Lanka shares a part of the continental shelf with India. Maldives is constituted of coral atolls.

Broad Marine Ecology

The South Asian Seas Region can be categorised into two distinct geographical groups. While Maldives and Sri Lanka are island nations, Bangladesh, India and Pakistan are situated on the Asian mainland. India has two groups of islands in the Arabian Sea and Bay of Bengal, whose problems are similar to that of Maldives and Sri Lanka. The northern Indian Ocean with its adjoining seas, Bay of Bengal and Arabian Sea form the common marine boundary for the five South Asian nations. Located in the tropical monsoon belt, the region is strongly affected by monsoons, and is vulnerable to storm surges, cyclones, and tsunamis. The unique monsoonal circulation introduces marked seasonality in oceanographic and biogeochemical processes. South Asia's coastal countries (Bangladesh, India, the Maldives, Pakistan and Sri Lanka) account for less than 2 percent of the world's total coastline. Yet the low elevation coastal zones of these countries, with an area of about 160,000 km^2, contain 135 million people – 22.5 percent of the global population living in such zones. The coastal zones also contain about 40 percent of the economic activities in the region and most of its critical economic infrastructure.

Marine Biodiversity: South Asia's coastal regions are extraordinarily rich in ecological diversity. More than 8 percent of the world's mangrove areas are in South Asia. The Sundarban delta is the world's largest continuous stretch of mangroves as well as the coral reefs of the Maldives, India, and Sri Lanka, and the dryland mangroves of Pakistan-support thousands of floral and faunal species. This ecological richness, however, has been subjected to great pressure through over extraction of recourses, enhanced pollution, and physical alterations in coastal ecosystems. Mangroves have been exploited for timber, fuel wood, and other purposes. For about 200 years, large mangrove areas have been cleared for agricultural activities and for shrimp farming, particularly in India and Pakistan.

Marine Ecosystem: Mangroves, coastal wetlands, and other coastal habitats also have been severely affected by discharges of untreated industrial and domestic sewage, freshwater interceptions for irrigation, and dredging and re-suspension of contaminated silts. Oil pollution also increasingly threatens coral reefs, often located in areas where large-scale petroleum industries, tourism, and fishing industries flourish. Most of the shallow water coral reef habitats of Sri Lanka, the Maldives, and India have been severely damaged as a result of bleaching. The northern Indian Ocean is one of the 10 hotspots of the world's threatened coral reef areas. The mangrove ecosystem supports important coastal fisheries and provides direct sustenance to coastal communities from timber and other products. It is also endowed with rich biodiversity and wildlife. The numerous estuaries and backwaters found along the coasts provide a range of environmental conditions, serving as breeding grounds for commercially important fish and supporting high biological diversity. Most coastal regions (especially the west coast of India) are very productive, supporting rich fisheries.

Coastal Developments: Major economic activities are concentrated in coastal areas. These include ports and harbours, fisheries and aquaculture, tourism, and rapidly expanding industrial activities. Agriculture forms a major part of the overall economic activity. In some areas, mining is also important, and although the production of oil and natural gas is limited, a significant volume of crude oil is transported by tankers through the region. Further offshore explorations and exploitation in Arabian Sea and Bay of Bengal is being implemented in deeper waters for Oil & Gas and Methane Gas hydrates and exploration of polymetallic nodules in the Indian Ocean

Climate Change: Countries most severely to be affected are located in South Asia and highlight a hidden challenge for coping with climate change. The island nation Maldives an exotic equatorial paradise is to be affected by virtue of its low height from mean sea level. Bangladesh, where Sea level rise is expected to impact over 13 million people with a 16% loss of national rice production In South Asian countries, a substantial reduction in crop yields from rain fed agriculture could occur. Additionally, dramatic changes in the land use patterns in South Asia compound this problem. The mangrove forests of the Sundarbans of Bangladesh, the largest continuous mangrove area in the world, which provides habitat for a large range of wildlife including Bengal tigers, Indian otters, spotted deer, estuarine crocodiles and marine lizards, could be destroyed by a 1m rise in sea level. In addition, loss of mangrove communities will result in major socio-economic impacts, due to effects on fisheries and other resource industries (e.g. woodcutting) that rely on the Sundarbans.

ACTION PLAN FOR THE SOUTH ASIAN SEAS

The Action Plan for the Protection and Management of the Marine and Coastal Environment of the South Asian Seas was adopted at a Meeting of Plenipotentiaries at New Delhi, India on 24 March 1995. The Action Plan applies to the marine and related coastal environment, including international waters adjacent to Bangladesh, India, Maldives, Pakistan and Sri Lanka.

The objective of the Action Plan is to protect and manage the marine environment and related coastal ecosystems of the region, including the promotion of sustainable development and sound management of regional marine and coastal resources. As with the other Action Plans, this Action Plan addresses the five components of Environmental Assessment, Environmental Management, Environmental Legislation, and Institutional and Financial Arrangements and adds a sixth: supporting measures.

In preparing for the development and implementation of the Action Plan, UNEP assisted with the compilation of national reports on environmental problems of the marine and coastal areas for each of the countries involved, which included a description of existing national legislation addressing this issue. In the area of environmental legislation, the Action Plan recommends that

a) National Legislation and regulations be reviewed and expanded, updated or strengthened as necessary,

b) National Legislation related to marine and coastal resources be effectively enforced;

c) National Legislation be harmonised where international uniformity is required;

d) An up to date compilation of national laws be maintained; and

e) International Agreements related to Protection of the Marine and Coastal Environment should be ratified and implemented.

International Marine Environmental instruments for SAS region: There are 173 Multilateral Environmental Instruments related to SAS countries and out of which 61 agreements, 92 Amendments and 20 Protocols are categorized in this study. Ocean category has 11 International Instruments relevant to SAS region. Under the Marine Pollution there are 78 international instruments and one regional instrument on oil and chemical pollution by SAS member countries is finalised and will be signed by member countries soon. Fisheries, has totally 8 international and regional instruments are listed in Fisheries.

Regional Oil and Chemical Pollution Contingency Plan for South Asia: The South Asian Seas Programme / South Asia Co-operative Environment Programme (SACEP) and the International Maritime Organization had undertaken a jointly funded project to assist the region in Developing a South Asian Regional Oil Spill Contingency Plan in 1989. A draft Regional Oil Spill Contingency Plan and other background documents were reviewed by a Meeting of Senior Officials held in Colombo Sri Lanka 14th to 16th December 1999. The Final Plan was then submitted to a “High Level Meeting” which approved it on the 6th December 2000 prior to its formal acceptance by the Government of Bangladesh, India, Maldives, Pakistan and Sri Lanka. The 4th IMM, held in Jaipur India in May 2008, had requested SACEP to finalise the Regional Plan and MoU as a matter of high priority. SACEP Secretariat is circulating final agreed Regional Plan and MoU for the signing by Ministers of member countries.

Fisheries: The International Environmental Agreements (IEA) database, lists seventy-three multilateral fisheries agreements. Out of which 11 multilateral global and regional instruments are relevant to SAS region. In the South Asian Seas region, Asia-Pacific Fishery Commission, Indian Ocean Tuna Commission and Bay of Bengal Programme – Inter Governmental Organisation are regional advisory bodies co-ordinating with SAS member countries. The Agreement for the establishment of the Asia-Pacific Fishery Commission was concluded under the aegis of FAO. It was drawn up by the Governments concerned at Baguio, Philippines in February 1948 and approved by the FAO Conference at its Fourth Session on 26 February 1948. The Agreement entered into force on 9 November 1948 and was amended in 1958, 1961, 1977, 1994 and 1996. The 1977 amendment changed the name of the title from Indo-Pacific Fisheries Council to Indo-Pacific Fishery Commission. The 1994 amendments included the change of the title to Asia-Pacific Fishery Commission. The scope of the 1997 amendment was to reinforce and update the terms of reference of the Commission. In 1999, the functions of the former Indian Ocean Fishery Commission (IOFC) in the Bay of Bengal were merged into APFIC (approved by FAO Council Resolution 1/116). The Commission carries out its functions and responsibilities in the Asia Pacific Area. In 1999, the functions of the former Indian Ocean Fishery Commission (IOFC) in the Bay of Bengal were merged into APFIC. The BOBP-IGO Agreement was formally signed by the Governments of Bangladesh, India and Sri Lanka at Chennai on 26 April 2003 and by the Government of Maldives at Chennai on 21 May 2003 (BOBP-IGO Agreement). The fisheries trade and marketing agreement is on agreement for the establishment of the intergovernmental organization for marketing information and technical advisory services for fishery products in the Asia and pacific region. There is also a voluntary regional instrument called memorandum of understanding (MoU) on the conservation and management of marine turtles and their habitats of the Indian Ocean and South-East Asia

Reference

1. Alder, Jackie, Gail Lugten, Robert Kay, and Bridget Ferriss. 2001. "Compliance with International Fisheries Instruments in the North Atlantic." In *Fisheries impacts on North Atlantic ecosystems: evaluations and policy exploration*, eds. Tony Pitcher, Ussif Rashid Sumaila, and Daniel Pauly. Vancouver: Fisheries Centre, University of British Columbia, 55-80.
2. AUSTLII (University of Technology Sydney and University of New South Wales Faculties of Law). 2003. *Australian Treaties Library*. http://www.austlii.edu.au/au/other/dfat/. Accessed on: 1 May 2003.
3. Australian Maritime Safety Authority. 2003. *IMO conventions and their entry into force dates*. http://imo.amsa.gov.au/public/a-conventions-eif.html. Accessed on: 1 May 2003.
4. Basel Convention on the Control of Transboundary Movements of Hazardous Wastes @ http://www.basel.int/index.html
5. Brown Weiss, Edith, Daniel Barstow Magraw, and Paul C. Szasz. 1999. *International environmental law: basic instruments and references, 1992-1999*. Ardsley, NY: Transnational Publishers.
6. Centre for Environmental Cooperation for NFTA @ www.cec.org
7. Convention on Biological diversity @ http://www.biodiv.org/
8. Convention on Climate Change @ http://unfccc.int/
9. Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) @ http://www.cites.org/eng/disc/what.shtml
10. Convention on Migratory Species @ http://www.wcmc.org.uk/cms/
11. Convention on Wetlands of International Importance (especially as Waterfowl Habitat) @ http://www.ramsar.org/
12. Convention Regional Seas @ http://www.unep.ch/seas/
13. Convention to Combat Desertification. website @ http://www.unccd.int/main.php
14. Conventions on Ozone Layer protection The Convention for the Protection of the Ozone Layer The Montreal Protocol on Substances that deplete the Ozone Layer @ http://www.unep.org/ozone/aboutsec.shtml
15. ECOLEX. 2002. *Multilateral treaties*. http://www.ecolex.org/. Accessed on: 06 June 2002.
16. Embree, C. 1988. "Multilateral environmental treaties, conventions and agreements: implementation and compliance in Canada." Course paper submitted to Professor W. Found, Faculty of Environmental Studies, York University, Canada.
17. FAOLEX. 2002. *FAOLEX database*. http://faolex.fao.org/faolex/index.htm. Accessed on: 5 November 2002.
18. Fletcher School of Law and Diplomacy. 2002. *Multilaterals Project: multilateral conventions - chronological listing*. http://fletcher.tufts.edu/multi/chrono.html. Accessed on: 06 June 2002.
19. Hedley, Chris. 2002. *Oceanlaw's Internet Guide to International Fisheries Law*. http://www.oceanlaw.net/. Accessed on: 30 September 2002.
20. International Environmental Conventions: http://iea.uoregon.edu/page.php?query=static&file=sources.htm
21. International Maritime Law Institute. 2002. *International Maritime Law Treaties and Legislative Instruments*. http://www.imli.org/ (follow the Legal Documents link). Accessed on: 5 August 2001.
22. International Maritime Organization. 2002. *Complete list of conventions*. http://www.imo.org/Conventions/mainframe.asp?topic_id=260. Accessed on: 30 June 2002.
23. Kenyon, Todd. 2002. *Admiralty and Maritime Law Guide, International Conventions*. http://www.admiraltylawguide.com/interconv.html. Accessed on: 20 October 2002.
24. Molitor, Michael, ed. 1991. *International Environmental Law: Primary Materials*. Boston, MA: Kluwer Law and Taxation Publishers.

25. Northern American Free Trade Agreement (NAFTA) and Free Trade Agreement of America FTAA. (environmental relating issues and institutional system)

26. Rotterdam Convention on voluntary Prior Informed Consent procedure about hazardous import and export @ http://www.pic.int/index.html
27. *Survey of International Agreements* http://www.yoto98.noaa.gov/yoto/meeting/intl_agr_316.html. Accessed on: 30 September 2002.
28. The Convention Concerning the Protection of the World Cultural and Natural Heritage (the World Heritage Convention) @ http://whc.unesco.org/nwhc/pages/sites/main.htm
29. The Multilateral Environmental Agreements Bulletin (MEA Bulletin) http://www.iisd.ca/email/mea-l.htm
30. United Kingdom Foreign and Commonwealth Office, Treaty Section. 1998. *List of current international agreements for which the Government of the United Kingdom is depositary*. http://www.fco.gov.uk/servlet/Front?pagename=OpenMarket/Xcelerate/ShowPage&c=Page&cid=1007029396014. Accessed on: 1 May 2003.
31. United Nations Convention on the Law of the Sea. http://www.un.org/Depts/los/index.htm United Nations Division for Ocean Affairs and the Law of the Sea Office of Legal Affairs. 2001. *Major international instruments relating to the marine environment (status as of 15 October 1996)*. http://www.un.org/Depts/los/. Accessed on: 13 August 2002 (apparently no longer available online).
32. United Nations Environment Programme. 1996. *Register of international treaties and other agreements in the field of the environment*. Nairobi, Kenya: United Nations Environment Program.
33. United Nations Food and Agriculture Organization. 2002. *Directory of FAO Statutory Bodies and Panels of Experts as of August 2000*. http://www.fao.org/docrep/X8075e/X8075e00.htm. Accessed on: 30 September 2002.
34. United Nations, Food and Agriculture Organization Legal Office. 2003. *Treaties deposited with FAO*. http://www.fao.org/Legal/treaties/treaty-e.htm. Accessed on: 1 May 2003.
35. United Nations, Food and Agriculture Organization, Development Law Service, FAO Legal Office,. 1997. *Treaties concerning the non-navigational uses of international watercourses: Africa*. Rome: United Nations, Food and Agriculture Organization.
36. United Nations. 2001. *Multilateral treaties deposited with the Secretary-General, Part I, Chapter XXVII*. http://untreaty.un.org/ENGLISH/bible/englishinternetbible/introduction.asp . Accessed on: 30 May 2001.
37. United Nations. 2003. *United Nations treaty collection*. http://untreaty.un.org/. Accessed on: 25 April 2001.
38. United States National Oceanic and Atmospheric Administration. 1998. *1998 Year of the Ocean:*

Important Terminologies used in International Conventions

Geographical reach : The Conventions all have an article which defines the geographical reach of the convention. Inland waters are generally excluded from the Convention, the exception being the *Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region,* which specifically includes "related inland waters". This is changing, however, considering the concern over marine pollution from land based activities. All States with jurisdiction over a part of a drainage basin into a coastal area may have to be involved in activities to address this concern.

Specific issues : Each convention then goes on to address specific issues of concern in the region. These may include pollution from land-based activities; airborne pollution; pollution from seabed activities; pollution from vessels; specially protected areas and protection of wild flora and fauna; co-operation in combating pollution in cases of emergency; pollution caused by dumping from ships and aircraft; and erosion of the coastal area. The Conventions also generally provide for environmental impact assessment, scientific and technical co-operation, technical and other assistance, and liability and compensation. Also established under each Convention are the necessary institutional arrangements for assisting with the implementation of the Convention, authorising an organisation to carry out the functions of Secretariat for the Convention.

Protocol : Each of the Conventions has at least one Protocol, setting out in greater detail specific duties outlined in the Convention. In fact, each of the Conventions has a protocol for co-operation to address environmental emergencies, generally specifically oil spills. The protocols deal with the same geographic region outlined in the conventions and spell out the relationship between the Convention and the Protocol. Generally the Rules of Procedure and financial rules of the Convention apply to the protocols. The parties to the convention are generally also required to become a party to at least one protocol at the same time. Sometimes this is automatic. Conversely, no State may be a party to a protocol without also being a party to the convention.

Signature, Ratification, Acceptance, Approval and Accession

The terms Signature, Ratification, Acceptance, Approval and Accession refer to some of the methods by which a State can express its consent to be bound by a treaty. The Vienna Convention on the Law of Treaties is the basis for these terms **(**Source : IMO web site http://www.imo.org)

Signature: Consent may be expressed by signature by the states where the treaty provides that signature shall have that effect; it is otherwise established that the negotiating States were agreed that signature should have that effect; the intention of the State to give that effect to signature appears from the full powers of its representatives or was expressed during the negotiations

Signature subject to ratification, acceptance or approval : A State may also sign a treaty "subject to ratification, acceptance or approval". In such a situation, signature does not signify the consent of a State to be bound by the treaty, although it does oblige the State to refrain from acts which would defeat the object and purpose of the treaty until such time as it has made its intention clear not to become a party to the treaty. Most multilateral treaties contain a clause providing that a State may express its consent to be bound by the instrument by signature subject to ratification. In such a situation, signature alone will not suffice to bind the State, but must be followed up by the deposit of an instrument of ratification with the depositary of the treaty.

This option of expressing consent to be bound by signature subject to ratification, acceptance or approval originated in an era when international communications were not instantaneous, as they are today. It was a means of ensuring that a State representative did not exceed their powers or instructions with regard to the making of a particular treaty. The words "acceptance" and "approval" basically mean the same as ratification, but they are less formal and non-technical and might be preferred by some States which might have constitutional difficulties with the term ratification. Many States nowadays choose this option, especially in relation to multinational treaties, as it provides them with an opportunity to ensure that any necessary legislation is enacted and other constitutional requirements fulfilled before entering into treaty commitments. The terms for consent to be expressed by signature subject to acceptance or approval are very similar to ratification in their effect.

Accession : Most multinational treaties are open for signature for a specified period of time. Accession is the method used by a State to become a party to a treaty which it did not sign whilst the treaty was open for signature. Technically, accession requires the State in question to deposit an instrument of accession with the depositary.

Amendment : Technology and techniques in the shipping industry change very rapidly these days. As a result, not only are new conventions required but existing ones need to be kept up to date. For example, the International Convention for the Safety of Life at Sea (SOLAS), 1960 was amended six times after it entered into force in 1965 - in 1966, 1967, 1968, 1969, 1971 and 1973. In 1974 a completely new Convention was adopted incorporating all these amendments (and other minor changes) and has itself been modified on numerous occasions.

Tacit Acceptance : In early conventions, amendments came into force only after a percentage of Contracting States, usually two thirds, had accepted them. This percentage requirement in practice led to long delays in bringing amendments into force. To remedy the situation a new amendment procedure was devised in IMO. Instead of requiring that an amendment shall enter into force after being accepted by, for example, two thirds of the Parties, the "tacit acceptance" procedure provides that an amendment shall enter into force at a particular time unless before that date, objections to the amendment are received from a specified number of Parties.

Entry into Force : The adoption of a convention marks the conclusion of only the first stage of a long process. Before the convention comes into force - that is, before it becomes binding upon Governments which have ratified it - it has to be accepted formally by individual Governments. When the appropriate conditions have been fulfilled, the convention enters into force for the States which have accepted - generally after a period of grace intended to enable all the States to take the necessary measures for implementation. It is therefore essential that these should, upon entry into force, be applicable to as many of the maritime states as possible. Accepting a convention does not merely involve the deposit of a formal instrument. A Government's acceptance of a convention necessarily places on it the obligation to take the measures required by the convention. Often national law has to be enacted or changed to enforce the provisions of the Convention; in some cases, special facilities may have to be provided; an inspectorate may have to be appointed or trained to carry out functions under the Convention; and adequate notice must be given to ship owners, shipbuilders and other interested parties so they make take account of the provisions of the Convention in their future acts and plans.

Enforcement : The enforcement of IMO conventions depends upon the Governments of Member Parties. Contracting Governments enforce the provisions of IMO conventions as far as their own ships are concerned and also set the penalties for infringements, where these are applicable. They may also have certain limited powers in respect of the ships to other Governments.

Module I: Introduction to an Ecosystem Approach

Module Plan

1. Introduction
2. Basic concepts
   - 2.1 Ecosystem approach
   - 2.2 Ecosystems
   - 2.3 Ecosystem health
3. The necessity of adopting an ecosystem approach
   - 3.1 Traditional approaches and ecosystem appraches
   - 3.2 Direct and indirect benefits of an ecosystem approaches
4. Ecosystem approaches
   - 4.1 Ecosystem approaches that focus on marine ecosystems
   - 4.2 Ecosystem approaches that focus on fisheries
5. Ecosystem approaches in international law and policy instruments
   - 5.1 Global instruments on the application of an ecosystem approach
   - 5.2 Other relevant international and regional instruments

1. Introduction

The international community has come to recognize the need to effectively manage human activities that have an effect on the marine environment and its ecosystems in order to promote the sustainable development of oceans and seas and their resources. This issue was highlighted at the 2002 World Summit on Sustainable Development (WSSD), where States committed to promote the sustainable development of marine ecosystems. More specifically, States encouraged the application of the ecosystem approach by 2010, and, promoted integrated, multisectoral, coastal and ocean management at the national level.[1]

The General Assembly has also emphasized the importance of applying an ecosystem to the management of ocean-related activities, including by integrating ecosystem approaches into fisheries conservation and management.[2] In 2005, the General Assembly requested the seventh meeting of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea[3] to focus its discussions on the topic, "ecosystem approaches and oceans". Following its discussions on the subject, the meeting agreed that continued environmental degradation in many parts of the world and increasing competing demands required an urgent response and the setting of priorities for management interventions aimed at conserving ecosystem integrity.[4] It was further recognized that ecosystem approaches to oceans management should be focused on managing human activities in order to maintain and, where needed, restore ecosystem health to sustain goods and environmental services, provide social and economic benefits for food security, sustain livelihoods in support of international development goals, including those contained in the United Nations Millennium Declaration, and conserve marine biodiversity.[5] Significantly, the meeting also reached an agreement on the elements relating to ecosystem approaches and oceans, including the proposed elements of an ecosystem approach, means to achieve implementation of an ecosystem approach, and requirements for improved application of an ecosystem approach (see Module IV).

[1] Plan of Implementation of the World Summit on Sustainable Development, Part IV, paras 30-37, in Chapter 1 (2) of the Report of the World Summit on Sustainable Development, Johannesburg, South Africa, 26 August- 4 September 2002, available at: http://documents.un.org.

[2] See, for example, General Assembly resolution 62/177, preamble and para. 5

[3] Report on the work of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea at its seventh meeting, para. 3, 17 July 2006, available at: http://documents.un.org.

[4] *Ibid*, para. 3.

[5] *Ibid*, para 4

The General Assembly welcomed the report on the work of the seventh meeting of the Consultative Process and invited States to consider the agreed consensual elements.[6] In this respect, the General Assembly recalled that States should be guided in the application of ecosystem approaches by a number of existing instruments, in particular the 1982 United Nations Convention on the Law of the Sea (UNCLOS) and its Implementing Agreements, and encouraged States to cooperate and coordinate their efforts and take all measures, in conformity with international law, to address impacts on marine ecosystems in areas within and beyond national jurisdiction, taking into account the integrity of the ecosystems concerned.[7]

Other international fora and organizations have also promoted the application of an ecosystem approach, including the Conference of the Parties (COP) to the Convention on Biological Diversity (CBD), the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP) and the United Nations Development Programme (UNDP). In order to restore and improve ecosystems, the Global Environment Facility (GEF) considered it "an urgent need" to adopt "management systems embracing comprehensive and cross-sectoral approaches" and highly recommended "integrated ecosystem management" as "a particularly useful system".[8]

It has thus been recognized by the international community that the protection of marine ecosystems is essential for sustainable development. A number of ecosystem approaches have been developed to achieve this goal, however, successful development and implementation requires a sound understanding and appropriate handling of a number of multidimensional issues relating to science, law and politics. This manual will consider these issues in detail and provide participants with the tools and skills necessary for the effective implementation of an ecosystem approach in their national context. More specifically, Module I will discuss basic concepts relating to an ecosystem approach, the origin and evolution of ecosystem approaches and their relation to international law and policy instruments, different approaches to ecosystems, and the direct and indirect benefits of an ecosystem approach. The Annex to Module I outlines the international governance framework for an ecosystem approach. Development and implementation of an ecosystem approach, including principles and guidance, international practice, and challenges, will be discussed in Module IV.[9]

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[6] General Assembly resolution 61/222 of 20 December 2006.

[7] *Ibid.*

[8] Global Environment Facility, *Operational Programme # 12: Integrated Ecosystem Management*, April 20, 2000, available at: http://www.gefweb.org/Operational_Policies/Operational_Programs/OP_12_English.pdf

[9] For additional background information, also see Report of the Secretary General A/61/63, section X, available at: http://www.un.org/Depts/los/general_assembly/general_assembly_reports.htm

2. Basic concepts

2.1 Ecosystem approach

The term "ecosystem approach" was first coined in the early 1980s and it was further developed in the context of the CBD in the 1990s.[10] It has been recognized, however, that there is no universally agreed definition of the term, and it has been interpreted differently in different contexts.[11] A number of associated terms are in use, including "ecosystem-based approach", "ecosystem management approach", "ecosystem-based approach to management", and "ecosystem process-oriented approach" (also see Section 4 below).[12] However, these similar or overlapping terms all refer to a comprehensive, science-based approach to the conservation and management of natural resources.

Among the various definitions of an ecosystem approach,[13] the one given by the Fifth Meeting of the COP to the CBD is representative. The meeting interpreted an ecosystem approach, consistent with the definition of "ecosystem" provided in article 2 of the CBD, as a strategy for the integrated management of natural resources that equitably promotes both conservation and utilization. An ecosystem approach focuses on levels of biological organization, which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans are an integral component of ecosystems. It takes adaptive measures to deal with the complex and dynamic nature of ecosystems, and adopts the precautionary principle. It does not preclude other existing

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[10] Joint Nature Conservation Committee of the UK, The Eco-System based Approach, available at: www.jncc.gov.uk p. 2518

[11] Consultative Process, *supra* note 3, para. 6; see also Nordic Council of Ministers, *Workshop on the Ecosystem Approach to the Management and Protection of the North Sea*, Oslo, Norway, June 15-17, 1998, p. 41; Envirosphere Consultants Limits, "Ecosystem: In Review of Terms and Definitions Relevant to Ocean and Marine Resources Management under the Oceans Act", *Report to Fisheries and Oceans Canada, Marine Ecosystems Conservation Branch*, Ottawa, 1999, pp. 1 and 4

[12] Other related terms include: bioregional approach; bioregional planning; ecoregion-based conservation; watershed management approach; holistic, intersectoral and interactive approach; ecosystem approach that integrate the conservation of biological diversity and the sustainable use of biological resources; ecosystem approach that integrate the conservation and sustainable use of biological diversity as well as socio-economic considerations; and precautionary ecosystem management approach

[13] For example, see NOAA's definition of an ecosystem approach: "An ecosystem approach to management (EAM) is one that provides a comprehensive framework for living resource decision making. In contrast to individual species or single issue management, EAM considers a wider range of relevant ecological, environmental, and human factors bearing on societal choices regarding resource use"; Murawski, S., "Top 10 Myths Concerning Ecosystem Approaches to Ocean Resource Management," presented at the Panel "Demystifying Ecosystem Approaches and Oceans", *United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea*, 12 June, 2006, available at: http://www.un.org/Depts/los/index.htm

conservation and management approaches, such as single-species conservation, protected areas, biosphere reserves, etc., rather, it may integrate all these approaches as a holistic system.[14]

Box 1: Elements of an Ecosystem Approach

The ecosystem approach incorporates three important considerations:

1. Management of living components is considered alongside economic and social considerations at the ecosystem level of organization; the focus is not simply on managing species and habitats;
2. If management of land, water, and living resources in equitable ways is to be sustainable, it must be integrated and work within the natural limits and utilize the natural functioning of ecosystems;
3. Ecosystem management is a social process. There are many interested communities, which must be involved through the development of efficient and effective structures and processes for decision-making and management.

CBD COP Decision VII/11, Annex I.

2.2 Ecosystems

In order to understand the meaning of "ecosystem approaches" it is important to understand the concept of "ecosystem". The term "ecosystem" was introduced by Alfred George Tansley in 1935,[15] though the idea itself has a much longer history.[16] Tansley defined an ecosystem as a biotic assemblage and its associated physical environment in a specific space.[17] Since then, this definition has remained a fundamental concept in ecology.[18]

[14] Secretariat of the Convention on Biological Diversity, From Policy to Implementation: "Decisions from the Fifth Meeting of the Conference of the Parties to the Convention on Biological Diversity, Nairobi, Kenya, 15-16 May 2000", *Montreal: Secretariat of the Convention on Biological Diversity* 36, available at: http://www.biodiv.org/decisions/default.asp?lg=0&m=cop-05&d=06; See also CBD COP Decision VII/11, Annex I. "Refinement and Elaboration of the Ecosystem Approach, Based on Assessment of Experience of Parties in Implementation, (A) Further Guidance on the Implementation of the Ecosystem Approach Principles", available at: http://www.biodiv.org/decisions/default.aspx?m=COP-7&id=7748& lg=0; Patlis, J., "Biodiversity, Ecosystems, and Endangered Species," *in* W. J. Snape (ed), *Biodiversity and the Law*, Washington, D. C. and Covelo, California: Island Press, 1996, pp. 46-47.

Article 2 of the CBD provides: "Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."

[15] Tansley, A G., "The Use and Abuse of Vegetational Concepts and Terms," *Ecology* 16, 1935, pp. 284-307

[16] Major, J., "Historical Development of the Ecosystem Concept", *in* V.G.M. Dyne (ed), *The Ecosystem Concept in Natural Resource Management* 9, New York and London, Academic Press, 1969; Christensen, N.L., *et al.* "The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management," *Ecological Applications* 6, 1996, p. 670

[17] A G. Tansley, *supra* note 15, p. 299

Although the term "ecosystem" has been variously defined by numerous successors, including some international legal instruments, the basic connotations embraced in Tansley's definition have never been altered. For example, article 1(3) of the 1980 Convention on the Conservation of the Antarctic Marine Living Resources (CCAMLR)[19] provides that "the Antarctic marine ecosystem means the complex of relationships of Antarctic marine living resources with each other and with their physical environment." Article 2 of the CBD defines an ecosystem as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit."

The key features of an ecosystem can be summarized in five points: (1) an ecosystem exists in a space with boundaries that may or may not be explicitly delineated; ecosystems are distinguishable from each other based on their biophysical attributes and their locations; (2) an ecosystem includes both living organisms and their abiotic environment, including pools of organic and inorganic materials; (3) the organisms interact with each other, and interact with the physical environment through fluxes of energy, organic and inorganic materials amongst the pools; these fluxes are mediated and functionally controlled by species' behaviour and environmental forces; (4) an ecosystem is dynamic[20] - its structure and function change with time;[21] and (5) an ecosystem exhibits emergent properties that are characteristic of its type, and which are invariant within the domain of existence.[22]

2.3 Ecosystem health

The health of ecosystems is not only essential to the environment, but also important to the existence and development of human society.[23] Ecosystems are life-support systems and critical to the survival and welfare of human beings.[24] Conversely, as components of

[18] Golley, F.B., "A History of the Ecosystem Concept in Ecology – More than the Sum of the Parts", Yale University Press, New Haven and London, 1993, p. 9

[19] Convention on the Conservation of Antarctic Marine Living Resources, 1980 reprinted in 19 *International Legal Materials* 841, 1980

[20] Nordic Council of Ministers, *supra* note 11, at p. 45; see also Consultative Process, *supra* note 3, p. 13

[21] Likens, G., "An Ecosystem Approach: Its Use and Abuse", *Ecology Institute*, Oldendorf/Luhe, Germany, 1992, p. 10

[22] O'Neill, R.V., *et al*, "A Hierarchical Concept of Ecosystems", Princeton University Press, 1986, pp. 68-69; Hatcher, B.G., "Coral Reef Ecosystems: How Much Greater Is the Whole than the Sum of the Parts?", *Coral Reefs* 16, 1997, p. S83

[23] For more discussion on ecosystem service and the relation between ecosystem health and human health, see, for example, Costanza, R. and S.E. Jorgensen (eds), "Understanding and Solving Environmental Problems in the 21st Century: Toward a New, Integrated Hard Problem Science", Oxford, UK, Elsevier Science, 2002, pp. 101-138 and 167-219

[24] See Global Environment Facility, *supra* note 8

ecosystems, humans and their interactions have profound effects on the structure and function of ecosystems. All over the world, ecosystems are increasingly affected by human-induced impacts, which often have profound effects on human habitats, human health and socio-economic development.

Ecosystem health has long been a major concern in environmental protection and has become an important concept in understanding ecosystems. Ecologically, ecosystem "health" is defined in terms of "activity", "organization" and "resilience" (also see Module II, Section 6). These components of ecosystem health are embraced in the concept of "sustainability", which means that the system is active, maintains its organization and is resilient to stress over time.[25] By contrast, an unhealthy system is one that is not sustainable and will eventually cease to exist. Many guidelines and measures have been suggested for assessing ecosystem health.[26]

In a broader context, ecosystem health can also reflect prevailing social and economic conditions. A healthy ecosystem could thus be described as one where the environment; the economy, and the community are all viable.[27]

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[25] Haskell, B.D., *et al*, "What Is Ecosystem Health and Why Should We Worry about It?" *in Ecosystem Health: New Goals for Environmental Management*, Washington, D. C., Island Press, 1992, pp. 8-9; Costanza, R. and M. Mageau, "What is A Healthy Ecosystem?" *in* H. Kumpf, K. Steidinger and K. Sherman (eds.), "The Gulf of Mexico Large Marine Ecosystem: Assessment, Sustainability, and Management", Blackwell Science, England, 1999, pp. 386-393. For other definitions of ecosystem health, see Angermeier, P.L. and J.R. Karr, "Biological Integrity versus Biological Diversity as Policy Directives: Protecting Biotic Resources," *Bioscience* 44, 1994, pp. 690-697; Sparks, R.E., "Need for Ecosystem Management of Large Rivers and Their Flood Plains," *Bioscience* 45 (3), 1995, pp. 169-182.

[26] For example, see Schaeffer, D.J., E.E. Herricks and H.W. Kerster, "Ecosystem Health: Measuring Ecosystem Health," *Environmental Management* 12, 1988, pp. 445-455: 1. Health should not depend on criteria based on the presence, absence, or condition of a single species. 2. Health should not depend on a census or even inventory of large numbers of species. 3. Health should reflect our knowledge of normal succession or expected sequential changes that occur naturally in ecosystems. 4. While the optimal health measures should be single-valued (monotonic) and vary in a systematic and discernible manner, ecosystem health does not have to be measured as a single number. Single numbers compress a large number of dimensions (one for each type of items) to a point that geometrically has zero dimensions. 5. Health measures should have a defined range. 6. Health criteria should be responsive to change in data values but should not show discontinuities even when values change over several decades. 7. Health measures should have known statistical properties, if these are relevant. 8. Criteria for health assessment must be related and hierarchically appropriate for use in ecosystems. 9. Health measures should be dimensionless or share a common dimension. 10. Health measures should be insensitive to the number of observations, given some minimum number of observations; also see R. Costanza and M. Mageau, *supra* note 25, pp. 393-402.

[27] Hancock, T., "Towards Healthy and Sustainable Communities: Health, Environment and the Economy at the Local Level," *Third Colloquium on Environmental Health*, Quebec, November 22, 1990. An interim working definition of a healthy ecosystem was offered by the first meeting of experts on the Jakarta Mandate on Marine and Coastal Biological Diversity: "one whose parameters do not vary outside predetermined limits from a predetermined level within a given period of time", and "a harmful effect was defined as one that violates the conditions for a healthy ecosystem", Jakarta, Indonesia, 7-10 March, 1997, available at: http://darwin.bio.uci.edu/~sustain/bio65/indonesia/jak_man.html

Box 2: Case Study: Coral Reef Phase Shifts in Jamaica

Jamaica's 795 km long coastline has diverse ecosystems, including bays, beaches, rocky shores, estuaries, wetlands, cays, seagrass beds and coral reefs. Its shallow-water marine ecosystems suffer from combined stresses of overfishing, disease, hurricanes/storms, sedimentation and pollution, etc. Due to the difficult economic situation in Jamaica, fishing is one of the few job opportunities for the fast-growing coastal population. With 240,000 people earning a living from its coastline, Jamaica's waters are severely overfished. Today the local fishery supplies only a third of local demand. Huge growth in the tourism industry has generated some alternative employment opportunities but not enough to reduce fishing pressure. Mass tourism has also brought swelling populations and unmanaged development to the coastal zone.

Adverse impacts on the marine ecosystem are most clearly illustrated in the phase shift of coral reefs. Dramatic phase-shifts of dominant species have resulted in reefs normally dominated by corals losing coral cover and being dominated by macroalgal species. From 1977 to 1993, live coral cover declined from 52 percent to 3 percent, and fleshy algae cover increased from 4 percent to 92 percent. The phase shift demonstrates how human and natural disturbances may interact, and how an unhealthy marine ecosystem may affect the coastal community.

Jamaica has made efforts to protect and restore its marine ecosystem. Measures taken include establishing strategic partnerships, an integrated system of parks and marine protected areas, integrated coastal zone management, watershed management, sewage treatment interventions, an alternative income programme, zoning and fisheries management, monitoring, education, volunteer and enforcement programmes.

Vierros, M., "Seas at the Millennium: An Environmental Evaluation: 1. Regional chapters: Europe, The Americas and West Africa", *in* C.R.C. Sheppard (ed.), Jamaica, 2000, pp. 559-574; Burke, L. *et al.*, "Reefs at Risk in the Caribbean", 2004, available at: http://reefsatrisk.wri.org/casestudy_text.cfm?ContentID=3348.

Summary of key ideas

(a) The term ecosystem approach has been variously defined in different settings and there exists no consensus on its exact meaning A number of associated terms are in use, but all refer to a comprehensive, science-based approach to the conservation and management of natural resources

(b) The COP of the CBD described an ecosystem approach as a strategy for the integrated management of natural resources that equitably promotes both conservation and utilization.

(c) An ecosystem is a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit

(d) The health of ecosystems is not only essential to the environment, but important to the existence and development of human society Ecosystems are life-support systems and critical to the survival and welfare of human beings

Questions for discussion

(a) What are the key features of an ecosystem?

(b) Why is ecosystem health so important?

(c) How do humans interact with ecosystems and how does this affect ecosystem functioning?

3. The necessity of adopting an ecosystem approach

3.1 Traditional approaches and ecosystem approaches

Traditional methods of marine resource management are usually based on species-specific, sectoral and zonal approaches, and have typically ignored the integrity of the ecosystem and the interaction between ecosystem components. These management systems have often not achieved desired outcomes, have resulted in a patchwork of legislation, policies, programmes and management plans at the local, national and international levels, and have not prevented a deterioration of ecosystem health. Marine ecosystems in different parts of the oceans and seas now suffer degradation and deterioration to a greater or less extent.[28]

Sectoral management can often be characterized by overlapping management areas and conflicts of functions and interests between different agencies, local authorities, organizations, and other concerned stakeholders. This often leads to conflict between conservation and development, contradiction of plans, duplication of work, and lack of communication and cooperation between various parties. Sectoral management also often ignores the interplay between different users and uses of coastal and ocean resources, and their common effect on marine ecosystems. Stakeholders often act in their own interests and deflect problems to other users.

For example, one of the major shortcomings of the single-species approach in the context of fishing is that it fails to take into account the fact that fishing activity not only impacts the target stock, but also impacts the ecosystem as well. By-catch is inevitable with unselective fishing methods and can include endangered or threatened species such as sharks, seabirds and turtles, or benthic organisms, such as corals. Unwanted or uneconomical by-catch may simply be discarded. The single-species approach also fails to take into account

[28] WSSD "Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Biodiversity Synthesis", Chapter 17 of Agenda 21, World Resources Institute, Washington, D.C., 2005, which is available at: http://www.millenniumassessment.org/documents/document.354.aspx.pdf.

the fact that, in addition to fishing activity, target stocks are affected by factors such as changes in abundance of predators and prey, loss of habitat, marine pollution and climatic changes.[29]

The traditional zonal approach to management involves dividing sea areas into zones within which States exercise different jurisdiction and adopt different management systems. The major deficiency of this approach is that political boundaries are usually not consistent with ecosystem boundaries. This discrepancy is exemplified in the conflicting interests in these zones, including between coastal and high seas interests and between development and conservation interests. It has also led to the failure and inefficiency of marine resource conservation in many sea areas, and the consequent decline and deterioration of the marine environment and resources.[30]

Reflections on the deficiencies of sectoral and zonal approaches resulted in the conceptualization of integrated coastal management (ICM) in Chapter 17 of Agenda 21, which was adopted at the United Nations Conference on Environment and Development (UNCED). ICM aims at overcoming "the fragmentation inherent in both the sectoral management approach and the splits in jurisdiction among levels of government at the land-water interface."[31] It involves comprehensive planning and regulation of human activities towards a complex set of interacting objectives and aims at minimizing user conflicts while ensuring long-term sustainability. It also recognizes the need to protect the ecosystem, taking into account the effects of multiple uses and acknowledges the limitations of the sectoral approaches and the linkages between inland, coastal and ocean uses.[32]

Both ICM and ecosystem approaches have the goal of sustainable development of the marine and coastal environment and its resources. The contents of these concepts overlap and the principles, rules and measures adopted are generally identical. The major difference is that ecosystem approaches can be applied anywhere in the oceans, whereas ICM is specific to coastal areas. Ecosystem approaches also place more emphasis on the integrity of the marine ecosystem, and the management scope may be broader in case of a large marine ecosystem (see Section 5 below) so as to cover the entire ecosystem concerned.

[29] FAO "Putting into Practice the Ecosystem Approach to Fisheries", 2005, p. 3, which is available at: ftp://ftp.fao.org/docrep/fao/008/a0191e/a0191e00.pdf.

[30] In response to deficiencies in the zonal approach to marine environmental protection in regional seas, UNEP launched the Regional Seas Programme, in which marine environmental protection is geography-based, with an attempt to attract full participation of all concerned littoral States. But such a regional approach has not proved to be as effective as expected. In some regions, some of the coastal States have not joined the regional arrangements or relevant agreements, which undermines the effectiveness of the regional mechanisms *in* H. Wang, "Ecosystem Management and Its Application to Large Marine Ecosystems: Science, Law, and Politics", *Ocean Development & International Law* 35 (1), 2004, p. 60.

[31] Cicin-Sain, B. and R.W. Knecht, "Integrated Coastal and Ocean Management: Concepts and Practices", Island Press, Washington D.C., 1998, p. 39.

[32] Garcia, S.M., *et al*, "The ecosystem approach to fisheries: Issues, terminology, principles, institutional foundations, implementation and outlook", *FAO Fisheries Technical Paper* 443, 2003, p. 7.

Regarding the relationship between these approaches, the Third Global Conference on Oceans, Coasts, and Islands concluded that both "adopt a holistic, integrated approach covering both environmental and socio-economic dimensions, and are basically similar; however, the scale of operation and level of management intervention might vary with respect to geographical scale."[33] In this sense, the "ecosystem approach is an evolution of integrated coastal and ocean management, with a greater emphasis on ecosystem goals and objectives and their outcomes. Moving to an ecosystem approach should be considered an evolutionary step in integrated management and action, not a break with the past."[34] It is thus important in developing an ecosystem approach to build on existing institutions and resources.

Box 3: Traditional Approaches vs. Ecosystem Approaches

Traditional approaches focus on managing ecosystem parts:

1. Individual species;
2. Narrow perspective and scale;
3. Humans activities evaluated for individual activities;
4. Resource management by sectors;
5. Scientific monitoring programmes focused narrowly;
6. Single use and purpose observations.

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Ecosystem approaches focus on ecosystem relationships, processes, and tradeoffs:

1. Multiple species, interactions between species and habitats;
2. Broad perspective and scale;
3. Humans integral to ecosystem;
4. Integrated resource management;
5. Adaptive management based on scientific monitoring;
6. Shared and standardized observations

NOAA, "Ecosystem Management of Interrelated River Basins, Estuaries, and Coastal Seas", 2006.

[33] Reports from the Third Global Conference on Oceans, Coasts, and Islands, "The Ecosystem Approach to Integrated Ocean and Coastal Management", UNESCO, Paris, January 23-28, 2006. p. 3, available at: www.globaloceans.org

[34] *Ibid.*, p. 2

3.2 Direct and indirect benefits of an ecosystem approach

In an ecosystem approach, the assessment and management of the marine environment and resources are addressed from multiple perspectives, involving natural science, technology, socio-economics, law, and politics. The components of a marine ecosystem are protected and managed in a holistic, integrated manner, and the relations and interactions among components of an ecosystem are comprehensively taken into consideration. This multispecies and multi-sectoral approach makes up for the deficiencies of the traditional single-species and sectoral approach, which protects the target species of exploitation without taking into account dependent and associated species, or their environment. In fact, the major impetus in the evolution from traditional approaches to ecosystem approaches has been science; in particular, further scientific understanding of marine ecosystems. In other words, it has become clear that the interconnected and complex nature of marine ecosystems requires an ecosystem approach.

It has been suggested that the goal of an ecosystem approach is to restore and sustain the functions of ecosystems, based on their health, productivity and biological diversity, and the overall quality of life, through management systems that are fully integrated with social and economic goals, for the benefit of current and future generations.[35] In relation to fisheries, the goal of an ecosystem approach to fisheries is to plan, develop and manage fisheries in a manner that addresses the multiplicity of societal needs and desires, without jeopardizing the options for future generations to benefit from a full range of goods and services provided by marine ecosystems.[36]

An ecosystem approach thus focuses on the maintenance of biological diversity and ecosystem complexity, aimed at the long-term sustainability of the ecosystem. "Healthy, intact, resilient marine ecosystems have a greater capacity to provide the full range of benefits".[37] In the short term, an ecosystem approach may cause economic loss due to limitations being placed on the exploitation of resources for the sake of long-term sustainability. However, such short-term consequences must be balanced against future

[35] The Ramsar Convention on Wetlands, Strategic approaches to freshwater management: Background paper – The ecosystem approach.

[36] Report of the Expert Consultation on Ecosystem-based Fisheries Management, Reykjavik, 16-19 September 2002.

[37] McLeod, K.L., *et al*, "Scientific Consensus Statement on Marine Ecosystem-Based Management", *Communication Partnership for Science and the Sea*, 2005, available at: http://compassonline.org/?q=EBM

benefits in the form of sustainable ecosystems and their associated communities.[38] "History has demonstrated that overexploitation of resources resulting in diminished diversity often has both ecological and economic long-term opportunity costs that far exceed the short-term benefits."[39]

An ecosystem approach also allows for marine-related sectors to work in partnership in the protection and management of the marine environment from a multi-sectoral perspective. Coordination of efforts of various agencies helps to reduce duplication of work, reconciles conflicts among management entities with different mandates, and maximizes limited resources. The spatial scale of the assessment and management of an ecosystem approach may also extend across maritime boundaries and jurisdictions to encompass an entire ecosystem, and thus allows for the possible harmonization of measures in the interest of the integrity of the marine ecosystem. Since an ecosystem approach may also deal with marine environmental and resource issues "across" various global, regional and sub-regional marine-related instruments applicable to the marine ecosystem concerned, it also permits the implementation of these instruments in an integrated and harmonized manner.[40] The need for States and relevant organizations to cooperate and coordinate at all levels in this respect is essential.

Indirect benefits of the health and sustainability of ecosystems are also much more likely to result from an ecosystem approach since such an approach attaches more importance to the integrity and balance of the ecosystems. Indirect benefits, such as the health of ecosystems, cultural heritage and spiritual benefits, derive from the conservation and protection of ecosystems and are hard to measure in monetary terms. In contrast, direct benefits with economic value generate from the extractive uses of ecosystem components, such as fishing and exploitation of oil and gas. While traditional societal goals have emphasized these direct benefits, an ecosystem approach broadens these goals to include the indirect benefits of health and sustainability.[41]

[38] The Ecosystem-based Fishery Management -A Report to Congress by the Ecosystem Principles Advisory Panel, as mandated by the Sustainable Fisheries Act amendments to the Magnuson-Stevens Fishery Conservation and Management Act 1996, available at: http://www.nmfs.noaa.gov/sfa/EPAPrpt.pdf.

[39] N.L. Christensen, *et al*, *supra* note 16.

[40] H. Wang, *supra* note 30, p. 280.

[41] NOAA, "Marine Fisheries Advisory Committee by the Ecosystem Approach Task Force", *Strategic Guidance for Implementing an Ecosystem-based Approach to Fisheries Management*, May 2003, p. 6, available at: http://www.nmfs.noaa.gov/ocs/mafac/meetings/2003_05/mafac_rev_5th_7Finalwref.pdf.

Box 4: Learning About the Ecosystem Approach to the Management of Small Islands: Some Experiences from New Zealand

A case study submitted to the Secretariat of the CBD

New Zealand's 600 small islands contribute enormously to sustaining and restoring the indigenous biodiversity of the country. Many species and ecological communities once characteristic of the mainland are now confined to islands.

An ecosystem approach can be applied at different scales across the range of islands and in the context of an overall biodiversity management strategy for the country. The 600 small islands range from those that are maintained as uninhabited and pristine, to those that are the subject of intensive restoration and are often key sites for the recovery of threatened species, to those where community objectives, including ecotourism and sustainable traditional harvest, take precedence. Some of the management activities, such as the absolute protection of sub-antarctic Snares Islands or restoration of Campbell Island, are government initiatives, whereas other island programmes (e.g., Mana and Tiritiri Matangi), are collaborations between community and government. The success of these projects has led to significant growth in the number of community and private island restoration programmes, a number of which are in partnership with or initiated by Māori, such as Ohinau Island. While some island protection and restoration is aimed at minimising and mitigating human impact, other projects are designed around community knowledge and aspirations and provide opportunities for people to interact with biodiversity.

The national island strategy provides objectives, procedures, best-practice and standards. The management of New Zealand islands has evolved from simple pest eradication and translocation of threatened species, to the planned restoration of the key ecosystem drivers (e.g., seabirds), as illustrated by Mana Island and the Mercury Islands. This involves removal and minimisation of threats, the establishment of targets and measures and the step-wise addition of missing components of the system.

While much of the reported New Zealand experience centres around the protection and recovery of endemic species and biological communities, the story is not complete without acknowledging the traditional ownership, harvest and management of island resources by Iwi Māori, notably the Rakiura tribes. Their ownership, management and long-term traditional harvest of titi or muttonbirds (*Puffinus griseus*) is the subject of collaborative research on sustainability, co-funded by the government and managed by the Rakiura Titi Islands Committee and undertaken jointly by the Committee and the University of Otago. This initiative and recent work on co-management of marine resources illustrate some of the challenges and benefits of acknowledging and incorporating traditional ownership and knowledge into a shared vision.

A case study by R. Hay and E. Wright, New Zealand Department of Conservation submitted to the Secretariat of the CBD, available at: http://www.cbd.int.

Summary of key ideas

(a) Traditional methods of marine resource management are usually based on species-specific, sectoral and zonal approaches, which often fail to taken into account the integrity of the ecosystem and the interaction between ecosystem components, and therefore have often not achieved desired outcomes.

(b) Sectoral management can often be characterized by overlapping management areas and conflicts of functions and interests between different agencies, local authorities, organizations, and other concerned stakeholders.

(c) ICM aims at overcoming the fragmentation inherent in both the sectoral management approach and the splits in jurisdiction among levels of government at the land-water interface. It involves comprehensive planning and regulation of human activities towards a complex set of interacting objectives and aims at minimizing user conflicts while ensuring long-term sustainability.

(d) Ecosystem approaches are based on the idea that more holistic, integrated and adaptive management approaches, based on scientific information, will maintain ecosystems in the sustainable condition necessary to achieve desired economic and social benefits

(e) In an ecosystem approach, the assessment and management of the marine environment and resources are addressed from multiple perspectives, involving natural science, technology, socio-economics, law, and politics. The components of a marine ecosystem are protected and managed in a holistic, integrated manner, and the relations and interactions among components of an ecosystem are comprehensively taken into consideration.

Questions for discussion

(a) What are the shortcomings or deficiencies of traditional approaches to management and how are these overcome by ICM and an ecosystem approach?

(b) How would you characterize ecosystem approaches as an evolution from traditional approaches to management? What has caused this evolution?

(c) What are the direct and indirect benefits of an ecosystem approach?

(d) What are the general goals of an ecosystem approach?

4. Ecosystem approaches

4.1 Ecosystem approaches that focus on marine ecosystems

As noted above, there is no single internationally agreed definition of "ecosystem approach" and the term has been interpreted differently in different contexts. The related terms that are in use, including an "ecosystem-based approach", "ecosystem management approach", "ecosystem management approach", "integrated ecosystem management", and "ecosystem considerations", all refer to a comprehensive, science-based approach to the conservation and management of natural resources.[42]

As there are various terms in use, so also definitions and explanations of the same term can be different. The result is a range of approaches that differ in their ability to incorporate ecosystem information and in the degree to which management orientation is focused on maintaining the sustainability of the ecosystem.[43] For example, the "ecosystem considerations" approach does not make the claim that the ecosystem is the prime focus in decision-making and ecosystem information is simply considered as part of the basis for management.[44] In contrast, "ecosystem-based management" (EBM) calls for an integrated, comprehensive, approach to the management of all human activities in a marine ecosystem.[45] There are also various definitions of the term "ecosystem-based management",[46] and in some literature, the terms "ecosystem management" and "ecosystem-based management" are used interchangeably. In addition, there is little agreement on "the new terminology, conceptual categories, and classifications" used to discuss EBM.[47]

Along with its various explanations, the terms EBM and ecosystem management are expressed in different phrases, such as "integrated ecosystem management", and "total ecosystem management" In this respect, the term "management" might generally be defined as the regulation of human activities and resources to achieve certain objectives.[48]

[42] H Wang, *supra* note 30, pp. 41-74.

[43] Christie, P., *et al*, "Assessing the Feasibility of Ecosystem-based Fisheries Management in Tropical Contexts", *Marine Policy* 31, 2007, p 241.

[44] *Ibid*, p. 240

[45] *Ibid.*

[46] For a list of selected definitions of ecosystem management, see N L. Christensen, *et al*, *supra* note 16

[47] Cortner, H.J, *et al*, "Institutional Barriers and Incentives for Ecosystem Management", Gen Tech. Rep. PNW-GTR-354, Portland, Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1996, p. 35

[48] Alexander, L.M , "Management of Large Marine Ecosystem: A Law of the Sea-Based Governance Regime," *in* H Kumpf, K Sreidinger and K Sherman (eds), "The Gulf of Mexico Large Marine Ecosystem: Assessment, Sustainability, and Management", Malden, Blackwell Science, 1999 "Management" has also been defined as, "a continuous, interactive, adaptive, participatory process comprised of a set of related tasks, all of which must be carried out to achieve a desired set

On the other hand, "ocean management" means the coordination of various uses of the oceans and the protection of the marine environment.[49] It has also been defined as "the process by which specific resources or areas are controlled to achieve desired objectives."[50]

The Committee on the Scientific Basis for Ecosystem Management of the Ecological Society of America defined the term "ecosystem management" as management based on the "best understanding of the ecological interactions and processes necessary to sustain ecosystem structure and function."[51] It defined "ecosystem-based management" as a systemic process aimed at the sustainable use of natural resources largely through the integration of economic, ecological, social, and technological elements, and the protection of ecosystems in the utilization of natural resources.[52] It is understood that decision-making in the process of EBM takes into account all major components of the affected ecosystems, including the adjacent ecosystems.

Box 5: What is Ecosystem-based Management?

Ecosystem-based management is an integrated approach to management that considers the entire ecosystem and the cumulative impacts of different sectors. More specifically, ecosystem-based management:

- emphasizes the protection of ecosystem structure, functioning, and key processes;
- is place-based in focusing on a specific ecosystem and the range of activities affecting it;
- explicitly accounts for the interconnectedness within systems, recognizing the importance of interactions between many target species or key services and other non-target species;
- acknowledges interconnectedness among systems, such as between air, land and sea; and
- integrates ecological, social, economic, and institutional perspectives, recognizing their strong interdependences.

McLeod, K.L., *et al.*, "Scientific Consensus Statement on Marine Ecosystem-Based Management", *Communication Partnership for Science and the Sea*, 2005, available at: http://compassonline.org/?q=EBM.

of goals and objectives, however those goals and objectives are established and specified.", "ICM Basics: What is Management?", available at: www.globaloceans.org

[49] Juda, L. and R.H. Burroughs, "The Prospects for Comprehensive Ocean Management," *Marine Policy* 14 (1), 1990, pp. 23-35.

[50] Cicin-Sain, B. and R.W. Knecht, "The Future of U.S. Ocean Policy: Choices for the New Century", Island Press, Washington D.C., 2000, p. 14

[51] N.L. Christensen, *et al*, *supra* note 16, pp. 668-669

[52] *Ibid*, p. 19

In this context, it is scientifically more accurate to speak of "ecosystem-based management" or "an ecosystem approach to management" as opposed to "ecosystem management". The term "ecosystem management" implies controlling and managing an entire ecosystem as such, which is beyond the ability of humans. In fact, humans cannot control ocean currents or most animals within a marine ecosystem. As such, EBM focuses on managing human activities, rather than deliberately manipulating or managing entire ecosystems.[53] An "ecosystem approach to management" is defined as "management that is adaptive, specified geographically, takes into account ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse social objectives."[54] In fisheries management, an ecosystem approach to management intends to maintain a holistic perspective on fisheries as well as other aspects of marine management.[55]

4.2 Ecosystem approaches that focus on fisheries

In the context of marine ecosystems, "ecosystems-based management" and "ecosystem-based fisheries management" (EBFM) are different, but complementary approaches. As discussed above (see Section 3.1), managing individual sectors, such as fishing, is necessary but not sufficient to ensure the continued productivity and resilience of a marine ecosystem. "Individual human activities should be managed in a fashion that considers the impacts of the sector on the entire ecosystem as well as on other sectors. The longer-term, integrated, cumulative impacts of all relevant sectors on an ecosystem must be evaluated, with a mechanism for adjusting impacts of individual sectors."[56]

In this respect, EBM calls for an integrated comprehensive approach to management of all human activities affecting oceans and seas, instead of focusing on fisheries.[57] In contrast, EBFM is defined as "fishery management actions aimed at conserving the structure and function of marine ecosystems, in addition to conserving the fishery resource."[58] It emphasizes an improved understanding and management of stock interactions, stock-prey

[53] K.L. McLeod, *et al*, *supra* note 37.

[54] NOAA, "Internal Ecosystem Research and Science Task Team, Framework for an External Review of NOAA's Ecosystem Research and Science Enterprise", which is available at: www.sab.noaa.gov/Doc/Ext_Rev_of_NOAAs_Ecosystem_Research_and_Science_Enterprise_Framework.pdf

[55] P. Christie, *et al*, *supra* note 43

[56] *Ibid*

[57] *Ibid*

[58] Ecosystem-based Fishery Management, *supra* note 38, p. 39

relationships, and habitat protection. A set of policies and principles is required to reduce and eliminate impacts of fisheries on the ecosystem, including the control of overfishing and reduction of by-catch.

The purpose of an "ecosystem approach to fisheries" (EAF) is "to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems."[59] EAF differs from the EBFM approach by balancing socio-economic needs with ecological function. It focuses on fishery management to make decisions while taking into account other ecosystem components.[60]

Although there are relative discrepancies between various terms concerning ecosystems approaches to fisheries and marine ecosystems, it is clear that individual management activities such as fisheries management should be integrated with, rather than isolated from, the holistic management of the entire marine ecosystem. In the international context, CCAMLR provides a good example of implementation of EBFM. In the developing State context, the Fisheries Improved for Sustainable Harvest (FISH) project in the Philippines is in the early stages of EBFM (see Box 6).[61]

Box 6: EBFM Case Study: The FISH Project

The FISH Project (Fisheries for Improved Sustainable Harvest) is a seven-year effort focused on strengthening the capability of local and national institutions to manage coastal resources and marine fish stocks in the Philippines. FISH has adopted an EBFM framework and aims at a 10% increase in fish stocks in four target areas by 2010.

As detailed below, a combination of growth, control and maintenance mechanisms are implemented in close coordination with fishers, local government units, national government agencies and other key stakeholders:

1. Growth mechanisms - to enhance fisheries production and marine ecosystem integrity.
    - Encourage environment-friendly economic development and revenue-generating mechanisms such as marine ecotourism, user-fee system and appropriate aquaculture.

[59] FAO, *supra* note 29, pp. 3-4.

[60] P. Christie, *et al*, *supra* note 43.

[61] *Ibid.*

2. Control mechanisms - to allocate access to fisheries and coastal resources.

   - Identify restrictions on fishing gear, fish size limits, fishing areas and seasons to achieve sustainable fishing based on the results of the baseline assessment, critical threats analysis, and stakeholder planning;
   - Register fishers and issue licenses for fishing vessels and gear (municipal and commercial) based on estimated sustained yield of fish stocks;
   - Establish a licensing system supported by legislation for commercial fishing vessels to operate in areas where sustainable yields of fish stocks can be expected and regulated; and
   - Train coastal law enforcement units to enforce fisheries and other coastal resource-related laws.

3. Maintenance mechanisms - to improve institutional capacity for fisheries and coastal resource management.

   - Develop ecosystem-based fisheries management programmes to address critical threats to fisheries and other coastal resources;
   - Cluster local government units into viable fisheries and coastal resource management units in association with interagency and multisectoral collaborative mechanisms for planning, implementation and enforcement;
   - Assist stakeholders integrate population and reproductive health programmes in fisheries management;
   - Identify appropriate and efficient market-based incentives for compliance and investments in sustainable fisheries; and
   - Promote public-private partnerships for fisheries management.

FISH is unique for the Philippines and other tropical countries in the following ways:

- The definition of project target areas was informed by ecological criteria (fisheries boundaries that represent ecosystem function) rather than based mainly on political boundaries.
- The project is working with groups of municipal and provincial government agencies whose jurisdictions cover the fisheries ecosystem of concern.
- The project's planning process encourages municipal governments to look beyond their boundaries and commit to an EBFM plan as opposed to only municipal government plans.
- Ecosystem response to management interventions will be measured throughout the project with specific and ambitious goals of 10% increase in biomass of selected fisheries in focal sites of the larger project target areas.

Christie, P., *et al.*, "Assessing the Feasibility of Ecosystem-based Fisheries Management in Tropical Contexts", *Marine Policy* 31, 2007, pp. 239-250; One Ocean - The Philippines' Coastal and Fisheries Management Information Center, available at: http://www.oneocean.org.

Despite the various concepts and definitions related to an ecosystem approach that focuses on marine ecosystems or on fisheries, and discrepancies in meanings, there is largely no difference between the terms with regard to their general criteria of sustainability, ecological health, and inclusion of humans in the ecosystems as well as other specific criteria.[62]

Summary of key ideas

(a) There are a number of terms in use that describe an ecosystem approach and definitions and explanations of the same term can also be different. The result is a range of ecosystem approaches that differ in their ability to incorporate ecosystem information and the degree to which management orientation is focused on maintaining the sustainability of the ecosystem.

(b) Ecosystem-based fisheries management aims at conserving the structure and function of marine ecosystems, in addition to conserving fishery resources. It emphasizes an improved understanding and management of stock interactions, stock-prey relationships, and habitat protection, and requires policies and principles to reduce and eliminate impacts of fisheries on the ecosystem, including the control of overfishing and reduction of by-catch.

(c) Despite differences in the various conceptions and definitions of ecosystem approaches, these ecosystem approaches emphasize sustainability, ecological health, and inclusion of humans in the ecosystems.

Questions for discussion

(a) What are the key elements of ecosystem-based management?

(b) Describe examples of ecosystem approaches to marine ecosystems and fisheries?

(c) What is the main difference between the various concepts of an ecosystem approach?

(d) What ecosystem approaches have been adopted in your region(s)?

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[62] For this reason, some scholars have advocated the use of only one term, such as "ecosystem-based management". See, for example, Arkema1, K., *et al*, "Marine Ecosystem-based Management: from Characterization to Implementation", *Front Ecological Environment* 4 (10), 2006, pp. 525-528. This manual will use more general terminology, such as "an ecosystem approach".

5. Ecosystem approaches in international law and policy instruments

5.1 Global instruments on the application of an ecosystem approach

The origin of the movement towards an ecosystem approach is said to have been a proposal of the International Council for the Exploration of the Sea (ICES) at its first meeting in 1901. This initiative was the consequence of an awareness of the limitation of marine resources and the adverse impacts of over-exploitation. Since the mid-1970s, ICES has been giving increasing prominence to a multi-species approach to the management of marine living resources,[63] and the approach has evolved into a broader concept of ecosystem approaches.[64]

The movement towards an ecosystem approach has been gradually promoted worldwide. Since the 1980s, the concept has also been incorporated into a series of international legal instruments, as described below. For a description of the international governance framework for an ecosystem approach, see the Annex to Module I.

CCAMLR

The first global convention to adopt an ecosystem approach was CCAMLR.[65] The impetus behind this Convention was the concern in the 1970s over the large-scale krill fishery and its harmful impact on the whole Antarctic marine ecosystem. Since krill forms the basis of the Antarctic food chain, its exploitation threatened to jeopardize other dependent and associated marine living resources in the area.[66] In view of the importance of the integrity of the Antarctic ecosystem,[67] the objective of CCAMLR is to conserve the Antarctic marine living resources,[68] which are defined as "the populations of fin fish, molluscs, crustaceans and all other species of living organisms, including birds, found south of the Antarctic Convergence".[69]

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[63] Sherman, K. and L.M. Alexander (eds.), "Introduction to Part One: Case Studies of Perturbations in Large Marine Ecosystems", *Biomass Yields and Geography of Large Marine Ecosystems*, Colorado and London: Westview Press, 1989, p. 3.

[64] See, for example, the ICES Strategic Plan, February 2002, which is available at: http://www.ices.dk/iceswork/strategic%20plan-final.pdf

[65] Convention on the Conservation of Antarctic Marine Living Resources, *supra* note 19.

[66] Gulland, J.A., "The Antarctic Treaty System as a Resource Management Mechanism," *in* G. Triggs (ed.), "The Antarctic Treaty: Law, Environment and Resources", Cambridge University Press, 1987, p. 120.

[67] CCAMLR Scientific Committee, Ecosystem Approach, preamble, available at: http://www.ccamlr.org/pu/e/sc/eco-app-intro.htm

[68] CCAMLR, article 2 (1).

[69] *Ibid*, article 1 (2).

The ecosystem approach to marine living resources conservation in CCAMLR is defined primarily in sub-paragraphs (b) and (c) of article 2(3) of the Convention.[70] First, sub-paragraph (b) requires the maintenance of the ecological relationships between all the organisms concerned in the Antarctic ecosystem. The conservation measures, therefore, focus not only on the harvested species, but also involve the dependent and related populations. For example, while regulating fishing for target species, such as krill, consideration needs to be given to the impact of fishing on these populations; however the impact on dependent or associated species who feed on krill, such as whales and penguins, also needs to be taken into account. In other words, dependent or associated species should be protected from the adverse impacts of harvesting the target species. This multi-species approach differs from the traditional single-species approach under which only the target species is considered when setting catch limits.[71]

Second, sub-paragraph (c) provides that the Antarctic marine ecosystem is to be preserved from irreversible changes and reflects the so-called precautionary principle. It means that any risk or threats of long-term adverse effects on the Antarctic marine ecosystem must be prevented or minimized without delay, even if sufficient and solid scientific evidence for such effects is not available.[72] The precautionary principle plays an important role in the ecosystem approach of CCAMLR.[73] One important aspect of this approach to the preservation of the whole Antarctic ecosystem is to set a "conservative (i.e. precautionary) krill catch limit" to take account of the needs of associated species and to preserve the ecological sustainability of all the species concerned.[74]

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[70] Article 2 (3) states:

"Any harvesting and associated activities in the area to which this Convention applies shall be conducted in accordance with the provisions of this Convention and with the following principles of conservation: (a) prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual increment; (b) maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in sub-paragraph (a) above; and (c) prevention of changes or minimisation of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes, with the aim of making possible the sustained conservation of Antarctic marine living resources."

[71] Lyster, S., "International Wildlife Law: An Analysis of International Treaties Concerning with the Conservation of Wildlife", Cambridge, University Press, 1994, p. 158.

[72] Principle 15 of the 1992 Rio Declaration which provides for the precautionary approach states:

"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

[73] For a discussion on the linkages between the precautionary principle and ecosystem management, see Kaye, S.M., "International Fisheries Management", The Hague, London, Boston, Kluwer International, 2001, pp. 273-274.

[74] CCAMLR, *supra* note 67

The ecosystem approach in CCAMLR is further reflected in its geographic scope of application: the whole Antarctic area within the Antarctic Convergence, which is the natural ecological boundary of the Antarctic ecosystem.[75] Furthermore, regarding stocks or stocks of associated species, which occur both within the CCAMLR Convention Area and in its adjacent marine areas, CCAMLR provides for the harmonizing of conservation measures adopted in respect of such stocks.[76] Lastly, CCAMLR provides mechanisms and measures to implement its ecosystem approach to the conservation of the Antarctic marine ecosystem.[77]

In short, CCAMLR's ecosystem approach is innovative and has been recognized as setting the benchmark for a new international regime for the conservation of marine living resources.

United Nations Convention on the Law of the Sea

UNCLOS provides the legal framework for the implementation of an ecosystem approach with respect to all activities conducted in marine areas. Although UNCLOS does not explicitly provide for an ecosystems approach, its objectives and relevant provisions are supportive of such an approach, as described below.[78]

[75] Article 1 (1) of CCAMLR reads:

> "This Convention applies to the Antarctic marine living resources of the area south of 60° south latitude and to the Antarctic marine living resources of the area between that latitude and the Antarctic Convergence which form part of the Antarctic marine ecosystem."

The Antarctic Convergence is where warmer sub-Antarctic waters flowing south meet the colder Antarctic waters in an upwelling zone of considerable biological productivity, forming a natural biological frontier which separates distinct marine communities on either side. Its coverage extends beyond the boundary of the Antarctic Treaty area at 60° South latitude and includes an important area between the Convergence and 60° South latitude where many of the known concentrations of krill are situated. Baird, R., "Fishing and the Southern Ocean: The Development of Fisheries and the Role of CCAMLR in their Management", *University of Tasmania Law Review* 16 (2), 1997, p. 168; Mitchell, B. and J. Thinker, "Antarctic and Its Resources", London, Earthscan, 1980, p. 67.

[76] See CCAMLR, article 11.

[77] See particularly articles 7, 9, 10, 11, 14, 15, 24 of CCAMLR.

[78] L.M. Alexander, *supra* note 48, pp. 512-513; Birnie, P., "Are Twentieth-Century Marine Conservation Conventions Adaptable to Twenty-first Century Goals and Principles? Part I", *The International Journal of Marine and Coastal Law* 12 (3), 1997, pp. 307-339; Orrego Vicuña, F., "The Changing International Law of High Seas Fisheries", Cambridge University Press, 1999, p. 289; Miles, E.L. "The Approaches of UNCLOS III & Agenda 21- A Synthesis", *in* M.K. Atmadja, T.A. Mensah and B.H. Oxman (eds.), "Sustainable Development and Preservation of the Oceans: The Challenges of UNCLOS and Agenda 21", The Law of the Sea Institute, William S. Richardson School of Law, University of Hawaii, 1997, pp. 18 and 27-28; Kimball, L.A., "United Nations Convention on the Law of the Sea: A Framework for Marine Conservation," *in* IUCN, *The Law of the Sea: Priorities and Responsibilities in Implementing the Convention*, Part I, Gland, Switzerland: IUCN, 1995, pp. 77 and 103; Hayashi, M., "The 1995 UN Fish Stocks Agreement and the Law of the Sea," *in* D. Vidas and W. Østreng (eds.), "Order for the Oceans at the Turn of the Century", *Kluwer Law International*, The Hague, London, Boston, 1999, pp. 48-49; Hey, E., "The Regime for the Exploitation of Transboundary Marine Fisheries Resources: The United Nations Law

First, an ecosystem approach coincides with the spirit and objectives of UNCLOS. As stated in the preamble, one of the objectives of UNCLOS is to promote the equitable and efficient utilization of marine resources, the conservation of marine living resources, and the study, protection and preservation of the marine environment.[79] Moreover, UNCLOS recognizes that "the problems of ocean space are closely interrelated and need to be considered as a whole."[80] These provisions support the view that an integrated ecosystem approach is the optimum manner to deal with complex issues of ocean management.

Second, a number of provisions of UNCLOS are relevant and embrace attributes of an ecosystem approach, including articles 61, 63, 64, 66, 67, 118, 119, 123, 145, 192, 194 (1) (5) and 211 (6), as highlighted below.

(a) UNCLOS not only recognizes the interrelation between harvested species and associated species, but also the ecological integrity and geographical interrelation of transboundary stocks.[81] The general principles concerning marine living resources require States to adopt conservation and management measures based on the best scientific evidence available and designed to maintain or restore harvested species at levels that can produce maximum sustainable yield, as qualified by relevant environmental and economic factors. According to articles 61 (3) (4) and 119 (1) of UNCLOS, when determining allowable catch and establishing conservation measures for living resources in exclusive economic zones (EEZs) and high seas, respectively, the interdependence of stocks and the effects on dependent and associated species are to be taken into account with a view to maintaining or restoring populations of such species above levels at which their reproduction may become seriously threatened. Articles 63, 64, 66, and 67 recognize the ecological and geographic integrity of certain stocks as well as the interrelation of conservation and management measures between EEZs and the high seas, and require relevant States to cooperate to varying degrees in the conservation and management of such stocks. In the case of highly migratory species, article 64 provides for international cooperative arrangements for conservation and optimum utilization to apply to the

of the Sea Convention Cooperation between States", Martinus Nijhoff Publishers, Dordrecht, Boston, London, 1989, p. 54

[79] UNCLOS, preamble, par. 4.

[80] For example, the Jamaica-Colombia Joint Regime Area. For other examples of maritime joint management /development zones, see Mann Borgese, E.M., "The Oceanic Circle: Governing the Seas as A Global Resource", United Nations, University Press, Tokyo, New York, Paris, 1998, p. 133

[81] Committee on the Environment, Regional Planning and Local Authorities, Parliamentary Assembly, Council of Europe, *The Oceans: State of the Marine Environment and New Trends in International Law of the Sea*, Report Doc. 8177, 1998

entire migratory range of the stocks. Article 64 is "in fact dealing with such resources in terms of ecosystem approaches".[82]

(b) Socio-economic factors are also to be considered in the conservation and management of marine living resources under UNCLOS. For example, articles 61 (3) and 119 (1) (a) provide that economic factors, including the economic needs of coastal communities and the special requirements of developing countries, are to be taken into account when determining allowable catch and establishing conservation and management measures.

(c) UNCLOS contains specific provisions on the protection of rare or fragile ecosystems and, more generally, of the ecological balance of the marine environment. Basic principles on the protection and preservation of the marine environment require States to protect all areas of the oceans from all sources of degradation, as well as to adopt special measures for rare or fragile ecosystems and the habitats of depleted, threatened or endangered species and other forms of marine life, as provided in article 194 (5). Pursuant to article 211(6), where international rules and standards are inadequate, special measures may be applied by the coastal State, as approved by International Maritime Organization (IMO), for the prevention of pollution from vessels in a clearly defined area of the EEZ recognized for its oceanographical and ecological conditions. Article 145 also expressly requires the protection of "the ecological balance of the marine environment" from harmful effects of activities in the Area, defined in article 1 as the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction.[83]

(d) UNCLOS also contains other provisions to facilitate an ecosystem approach, including the general obligation of States to protect and preserve the marine environment;[84] international coordination and cooperation in the conservation and management of marine living resources;[85] and the utilization of the best scientific evidence available.[86]

[82] F. Orrego Vicuña, *supra* note 78, p. 43

[83] See also Annex of the 1994 Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea, paras. 5 and 7, Section 1.

[84] UNCLOS, article 192

[85] See, for example, articles 61(2) (5), 63, 64, 66, 67, 118, 123, 194, and 197 of UNCLOS. The requirement of article 123 for the coordination and cooperation of States bordering enclosed or semi-enclosed seas in the conservation and management of living resources in these seas is particularly important because some Large Marine Ecosystems are defined as such seas. See L. M. Alexander, *supra* note 48

[86] See, for example, UNCLOS, article 61(2).

More elaborate ecosystem approaches gradually evolved after UNCLOS. Some instruments, especially Agenda 21 and the CBD, more specifically envisage an ecosystem approach. The concept was developed further by the 1995 United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, also known as the United Nations Fish Stocks Agreement (UNFSA), and the 1995 FAO Code of Conduct for Responsible Fisheries (see below).[87] Since the adoption of UNCLOS, a number of new concepts and principles have also emerged, including Large Marine Ecosystems (LMEs) and ecosystem-based management, many of which were incorporated into later instruments, including UNFSA.

With respect to fisheries, UNFSA's detailed regime governing straddling fish stocks and highly migratory species was negotiated and approved on the basis of principles and concepts embraced in UNCLOS, including the provisions supporting an ecosystem approach.[88] The approach provided in Part V of UNCLOS with respect to fisheries management[89] "is deliberately partially ecosystemic in nature (i.e., target species must be treated in conjunction with associated and dependent species)."[90] "All necessary components of a changed fisheries management paradigm"[91] can thus be found within UNCLOS.[92]

Agenda 21

The 1992 Declaration of the United Nations Conference on Environment and Development, known as the Rio Declaration, is well-recognized as a milestone in the development of international environmental law. It not only reaffirmed the 1972 Declaration of the United Nations Conference on the Human Environment (Stockholm Declaration), but also introduced new principles,[93] including an ecosystem approach.

[87] Code of Conduct for Responsible Fishing, available at: www.fao.org/fi agreem/codecond/ficonde.asp.

[88] *Ibid*, p. 43. See also Tahindro, A., "Comments in Light of the Adoption of the 1995 Agreement for the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks", *Ocean Development and International Law* 28, 1997, pp. 6-7.

[89] Regarding the relationship between the UNFSA and UNCLOS, article 4 of the UNFSA provides: "Nothing in this Agreement shall prejudice the rights, jurisdiction and duties of States under the Convention. This Agreement shall be interpreted and applied in the context of and in a manner consistent with the Convention."

[90] E.L. Miles, *supra* note 78, p. 18.

[91] P. Birnie, *supra* note 78, pp. 313-314.

[92] Also see E.L. Miles, *supra* note 78, p. 28.

[93] Examples of such new principles related to environmental protection include, among others, the principle of

In its preamble, the Rio Declaration recognizes "the integral and interdependent nature of the Earth", and calls on States to "protect the integrity of the global environmental and developmental system". Principle 7 requires States to "cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem." Moreover, the theme of the Declaration -- the principle of sustainable development[94] -- establishes a policy basis for an ecosystem approach. As noted above, the precautionary approach[95] is also very supportive of ecosystem approaches.

UNCED gave particular weight to ecological awareness and to the ecosystem as a unit of ocean management[96] and the holistic approach to both marine and terrestrial ecosystems is firmly endorsed by Agenda 21, which was adopted at UNCED.[97] The preamble to Agenda 21 emphasizes that "the continuing deterioration of the ecosystems" is one of the major issues with which humanity is confronted, and "better protected and managed ecosystems" cannot be achieved without integration of environment and development as well as international cooperation.

Following upon UNCLOS, Agenda 21 highlighted that the marine environment, including the oceans and all seas and adjacent coastal areas, forms an integrated whole and presents opportunities for sustainable development. Agenda 21 confirmed that UNCLOS provides an international basis for the protection and sustainable development of the marine and coastal environment and its resources, and emphasized that this demanded "new approaches to marine and coastal area management and development, at the national, subregional, regional and global levels, approaches that are integrated in content and are

sustainable development (Principle 3), the principle of common but differentiated responsibilities (Principle 7), public participation (Principle 10), the precautionary approach (Principle 15), the polluter pays principle (Principle 16), environmental impact assessment (Principle 17), and a vital role for indigenous people and women in environmental management (Principles 20 and 22), etc.

[94] The meaning of sustainable development is expressed in Principle 3 of the Rio Declaration: "The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations."

[95] Principle 15 of the 1992 Rio Declaration which provides for the precautionary approach reads:

> "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage lack of full scientific certainty shal not be used as a reason for postponing cost-effective measures to prevent environment degradation."

[96] Johnston, D.M., "UNCLOS III and UNCED: A Collision of Mind-Set?", *in* L.K. Kriwoken, *et al.* (eds.), "Ocean Law and Policy in the Post-UNCED Era: Australian and Canadian Perspectives", *Kluwer Law International*, London, The Hague, Boston, 1996, p. 13.

[97] Freestone, D., "The Conservation of Marine Ecosystem under International Law," *in* M. Bowman and C. Redgwell (eds.), "International Law and the Conservation of Biological Diversity", *Kluwer Law International*, London, The Hague, Boston, 1996, p. 94. See also Juda, L., "Rio Plus Ten: The Evolution of International Marine Fisheries Governance", *Ocean Development and International Law* 33, 2002, pp. 111-112.

precautionary and anticipatory in ambit".[98] These principles, as well as the programme areas[99] laid out in Chapter 17 of Agenda 21 on oceans and seas, promote an ecosystem approach. While UNCED rejected the idea of including the LME concept in Agenda 21, ecosystem approaches were included in Chapter 17 and the cross-sectoral, interdisciplinary, and regional elements were endorsed.[100]

The principles adopted at UNCED are by no means merely political statements. They are important "soft law" statements of an ecosystem approach and have been incorporated in legally binding international instruments, such as the CBD and the UNFSA.

Convention on Biological Diversity and the Jakarta Mandate and Programme of Work on Marine and Coastal Biological Diversity

The CBD deals with biological diversity, including marine ecosystems[101] and is the only legally binding global instrument that covers all ecosystems.[102] It adopts a holistic, multispecies approach to the conservation of biological diversity and the sustainable use of its components, which differs from the traditional, single-species approach.[103] It provides that the conservation of ecosystems is fundamental to the conservation of biological diversity,[104] and sets out a framework adopting an ecosystem approach to biodiversity conservation and sustainable use, as described below.[105] The ecosystem approach has been adopted as the primary framework for action under the CBD[106]

[98] Paragraph 1 of Chapter 17 of Agenda 21

[99] The seven programme areas laid out in Chapter 17 of Agenda 21 are: a) integrated management and sustainable development of coastal areas, including exclusive economic zones; b) marine environmental protection; c) sustainable use and conservation of marine living resources of the high seas; d) sustainable use and conservation of marine living resources under national jurisdiction; e) addressing critical uncertainties for the management of the marine environment and climate change; f) strengthening international, including regional, cooperation and coordination; and g) sustainable development of small islands.

[100] Laughlin, T.L., "Chapter 17 of Agenda 21: Implementing Data and Information Aspects," *Marine Policy* 17 (6), 1993

[101] See article 2 of the CBD, *supra* note 14

[102] Goote, M.M., "Convention on Biological Diversity: The Jakarta Mandate on Marine and Coastal Biological Diversity," *International Journal of Marine and Coastal Law* 12 (3), 1997, p. 378.

[103] See Biodiversity Law and Policy in Canada: Review and Recommendations, *Canadian Institute for Environmental Law and Policy*, Toronto, 1996, p. 27

[104] See paragraph 10 of the preamble of the CBD.

[105] See Secretariat of the Convention on Biological Diversity, *supra* note 14, p. 35. COP Decision V/6, is available at: http://www.biodiv.org/decisions/default.asp?lg=0&m=cop-05&d=06. It has been indicated that the ecosystem approach forms the underlying philosophy of CBD, *see* Johnston, S., "The Convention on Biological Diversity: The Next Phase", *Review of European Community and International Environmental Law* 6 (3), 1997, p. 219. See also Matz, N., "The Interaction between the Convention on Biological Diversity and the UN Convention on the Law of the Sea", *in* P. Ehlers, *et al.* (eds.), "Marine Issues: From A Scientific, Political and Legal Perspective", *Kluwer Law International*, The Hague, London, New York,

Two out of the three core objectives of the CBD are most directly related to ecosystem protection – the conservation of biological diversity and the sustainable use of its components.[107] The third objective – equitable sharing of benefits arising from the utilization of genetic resources – is also important for an ecosystem approach, as noted in decision V/6 of the CBD COP. The decision provides that the application of the ecosystem approach will help to reach a balance among the three objectives of the CBD.

The jurisdictional scope of the CBD covers both areas within and beyond the limits of national jurisdiction in consideration of the integrity of ecosystems and the effects of human activities on biodiversity.[108] Accordingly, the CBD requires international cooperation beyond areas of national jurisdiction and on other matters of mutual interest.[109] Moreover, the CBD provides a set of measures for the conservation of ecosystems and biodiversity,[110] such as general measures for conservation and sustainable use, in-situ and ex-situ conservation, and monitoring. In particular, articles 8 (d) and (f) specifically refer to the protection and restoration of ecosystems. The establishment of protected areas, one of the means of supporting the implementation of ecosystem approaches, is also envisaged in article 8.

In terms of implementation,[111] article 22 of the CBD states that, with respect to the marine environment, the CBD is to be implemented "consistently with the rights and obligations of States under the law of the sea".[112] While the reference to the law of the sea was intended to refer to UNCLOS, there are a number of other legal instruments which, together, form the corpus of the law of the sea[113] including, in regards to the conservation

2002, pp 207-210

[106] Decision II/8 of the Conference of the Parties to the CBD.

[107] CBD, Article 1

[108] CBD, Article 4

[109] CBD, Article 5

[110] See especially articles 6 through 10 of the CBD.

[111] De Fontaubert, A.C., D.R. Downes and T.S. Agardy, "Biodiversity in the Seas: Implementing the Convention on Biological Diversity in Marine and Coastal Habitat", Gland, Switzedland and Cambridge: IUCN, 1996

[112] Article 22 of the CBD provides:

"(1) The provisions of the Convention shall not affect the rights and obligations of any contracting Party deriving from any existing international agreement, except where the exercise of those rights and obligations would cause a serious damage or threat to biological diversity.

(2) Contracting Parties shall implement this Convention with respect to the marine environment consistently with the rights and obligations of States under the law of the sea."

[113] Joyner, C.C., "Biodiversity in Marine Environment: Resource Implications for the Law of the Sea", *Vanderbilt Journal of Transnational Law* 28, 1995, p. 650; Rengifo, A., "Protection of marine biodiversity: A new generation of fisheries agreements", *Review of European Community and International Environmental Law* 6 (3), 1997, p. 318; Australia's Ocean Policy, Background Paper 2, available at: http://www.environment.gov.au/coasts/oceans-policy/policy-publications.html.

and management of marine resources, UNFSA and the Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas (the FAO Compliance Agreement).[114]

The marine environment has been on the agenda of the COP and the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) of the CBD since September 1995. In this respect, the COP and the SBSTTA have developed a series of recommendations and decisions on the implementation of the CBD, among which the Jakarta Mandate on Marine and Coastal Biodiversity is significant.[115] Adopted by the Second Meeting of the COP in November 1995, the Mandate is a Ministerial Statement on the Implementation of the CBD, referring to a new global consensus on the importance of marine and coastal biodiversity. The Mandate also highlighted the importance of collaboration between relevant instruments and organizations.[116]

In 1998, COP adopted a programme of work on marine and coastal biological diversity to assist in the implementation of the CBD and the Jakarta Mandate at the national, regional and global levels.[117] The programme focused on five priority themes: implementation of integrated marine and coastal area management (IMCAM); sustainable use of marine and coastal living resources; marine and coastal protected areas (MCPAs); mariculture; and invasive alien species. In addition, several basic principles and approaches were acknowledged, including the ecosystem approach, the precautionary approach, the importance of science, and the related knowledge of local and indigenous communities. The special circumstances of small island developing States (SIDS) were also recognized.

The COP to the CBD has also adopted a series of decisions on the ecosystem approach, as well as on marine and coastal biological diversity, including development of a description of, and principles and guidance to, the ecosystem approach under the CBD (see Module IV).[118] A recent review of the ecosystem approach by the CBD COP highlighted that "one-size-fits-all" solutions for the ecosystem approach are neither feasible nor desirable and that learning from the experiences of those currently applying an ecosystem approach, or "learning by doing",

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[114] The FAO Compliance Agreement, *International Legal Materials* 33, 1994, p. 968

[115] CBD COP decision II/10, available at: http://www.biodiv.org/decisions/default.asp?lg=0&dec=II/10

[116] *Ibid*, paras 11-13

[117] The CBD programme of work on marine and coastal biodiversity was established in COP decision IV/5 and updated in decision VII/5. Other relevant COP decisions include II/11 (now retired), V/3, VIII/21 and VIII/22

[118] See, for example, CBD COP decisions V/3, V/6, VII/11, and VIII/22, which are available at: http://www.biodiv.org/convention/cops.shtml

is a priority for broader implementation.[119] Towards this end, the CBD has been collecting case studies from around the world relating to ecosystem approaches.[120]

The United Nations Fish Stocks Agreement

Agenda 21 called on States to convene an international conference to address the problems regarding high seas management of straddling fish stocks and highly migratory fish stocks.[121] The result of this process was the 1995 UNFSA,[122] which explicitly adopted an ecosystem approach to the conservation and management of marine living resources.[123]

The starting point of the UNFSA regime is "the biological unity of the stocks concerned".[124] The Agreement applies to the conservation and management of straddling fish stocks and highly migratory fish stocks beyond areas of national jurisdiction. However, the measures provided in articles 6 and 7 also apply to the fish stocks concerned within areas under national jurisdiction.[125] Furthermore, coastal States are required to apply, *mutatis mutandis*, the general principles enumerated in article 5 in areas under national jurisdiction.[126]

The underlying philosophy of the conservation and management measures set forth in UNFSA is the unity and the health of marine ecosystems. In this respect, the preamble of UNFSA points out that the States Parties are "conscious of the need to avoid adverse impacts on the marine environment, preserve biodiversity, maintain the integrity of marine ecosystems and minimize the risk of long-term or irreversible effects of fishing operations".

More specifically, UNFSA adopts a series of objectives and principles relating to the protection of marine ecosystems. These principles include, for example, ensuring the long-term sustainability of fish stocks and promoting the objective of their optimum utilization;[127] maintaining or restoring stocks at levels capable of producing the maximum sustainable yield, taking into account fishing patterns and the interdependence of stocks;[128]

[119] See COP decision IX/7, "Ecosystem approach", available at: http://www.biodiv.org/convention/cops.shtml

[120] See the Ecosystem Approach Sourcebook, available at: http://www.cbd.int/ecosystem/sourcebook

[121] Paragraph 49 of Chapter 17 of Agenda 21

[122] UNFSA, *International Legal Materials* 34, 1995, p. 1542.

[123] See, particularly, the preamble and articles 5, 7, 8 of UNFSA. For some discussion on this point, see, for example, F. Orrego Vicuña, *supra* note 78; and A. Tahindro, *supra* note 88

[124] F. Orrego Vicuña, *supra* note 78, p. 176

[125] UNFSA, article 3 (1).

[126] UNFSA, article 3 (2).

[127] UNFSA, article 5 (a)

[128] UNFSA, article 5 (b).

applying the precautionary approach;[129] assessing the impacts of fishing, other human activities and environmental factors on target stocks, associated or dependent stocks, and species belonging to the same ecosystem;[130] maintaining or restoring populations of such species above levels at which their reproduction may become seriously threatened;[131] minimizing pollution, waste, discards, catch by lost or abandoned gear, catch of non-target species, and impacts on associated or dependent species, in particular endangered species;[132] protecting biodiversity in the marine environment;[133] and taking measures to prevent or eliminate overfishing and excess fishing capacity and to ensure that levels of fishing effort do not exceed those commensurate with the sustainable use of fishery resources.[134]

These principles include those established in UNCLOS, as well as the principles developed in the post-UNCLOS era and, therefore, reflect the new concepts of conservation and management, including an ecosystem approach. As provided in UNFSA, wide application of the precautionary approach to the conservation, management and sustainable use of fish stocks[135] will also play an important role in the preservation and protection of marine ecosystems. These principles also highlight the interconnectedness of ecosystem approaches and the precautionary approach, and the importance of precaution in the successful implementation of an ecosystem approach.

UNFSA also requires compatibility of conservation and management measures in the high seas and in areas under national jurisdiction.[136] The purpose of these provisions is to ensure conservation and management of transboundary fish stocks in their entirety.[137] To this end, coastal States and States fishing on the high seas have a duty to cooperate in achieving compatible measures. In determining compatible conservation and management measures, certain ecological elements are to be taken into account, namely: the biological unity and other biological characteristics of the stocks and the relationships between the distribution of the stocks, the fisheries and the geographical particularities of the region

[129] UNFSA, article 5 (c). The detailed provisions on the precautionary approach are contained in article 6 and Annex II of the UNFSA. For more information on this point, see for example, FAO "Precautionary Approach to Fisheries", *FAO Fisheries Technical Paper*, No. 350, Rome, 1995

[130] UNFSA, article 5 (d).

[131] UNFSA, article 5 (e)

[132] UNFSA, article 5 (f)

[133] UNFSA, article 5 (g)

[134] UNFSA, article 5 (h)

[135] UNFSA, article 6 (1).

[136] UNFSA, articles 7 and 16

[137] UNFSA, article 7(2)

concerned, including the extent to which the stocks occur and are fished in areas under national jurisdiction;[138] the respective dependence of the coastal States and the States fishing on the high seas on the stocks concerned;[139] and the harmful impact on the living marine resources as a whole.[140] With respect to highly migratory fish stocks, UNFSA emphasizes that the States concerned shall cooperate with a view to ensuring conservation and management of such stocks throughout the relevant region, both within and beyond areas under national jurisdiction.[141]

The mechanisms outlined above make UNFSA an important international instrument in promoting the adoption of an ecosystem approach to the conservation and management of marine living resources.[142]

The FAO Code of Conduct for Responsible Fisheries

The 1995 FAO Code of Conduct for Responsible Fisheries is a global, non-legally-binding instrument, which sets out principles and international standards of behaviour for responsible fishing practices with a view to ensuring the effective conservation, management and sustainable use of living aquatic resources, with due respect for the ecosystem and biodiversity.[143] The thrust of the Code is sustainable utilization of fisheries resources in harmony with the environment, with wide adoption of an ecosystem approach to various fisheries activities and the conservation of the living aquatic resources and their environment.

In terms of the application of an ecosystem approach to fisheries resources and the marine environment, the Code is an important, comprehensive international soft law instrument.[144] More specifically, the Code sets out a series of general principles which are directly related to, or supportive of, an ecosystem approach. The first principle of the Code

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[138] UNFSA, article 7(2) (d).

[139] UNFSA, article 7(2) (e).

[140] UNFSA, article 7(2) (f).

[141] UNFSA, article 7(1) (b).

[142] See, for example, Juda, L., "The 1995 United Nations Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks: A Critique", *Ocean Development and International Law* 28, 1997, p. 160. For an in-depth analysis of some shortcomings of the UNFSA, see Burke, W.T., "Compatibility and Protection in the 1995 Straddling Stock Agreement", *in* H.N. Scherber (ed.), *Law of the Sea: The Common Heritage and Emerging Challenges*, The Hague, London, Boston, Martinus Nijhoff Publishers, 2000, pp. 105-126.

[143] Although the Code is a non- binding instrument, some of its contents are based on relevant rules of international law, including those reflected in UNCLOS.

[144] For a discussion on the influence of the Code on the application of ecosystem approach to marine fisheries management, see, for example, L. Juda, *supra* note 97, pp. 116-118.

makes it clear that the right to fish carries with it the obligation to conserve aquatic ecosystems.[145] The Code also broadly endorses ecosystem principles, such as: protection and rehabilitation of fisheries habitats in marine and fresh water ecosystems;[146] recognition of the transboundary nature of many aquatic ecosystems;[147] international cooperation in conservation and protection of living aquatic resources throughout their range of distribution, taking into account the need for compatible measures in areas within and beyond national jurisdiction;[148] further development and application of selective and environmentally safe fishing gear and practices in order to maintain biodiversity and to conserve aquatic ecosystems;[149] and the application of the precautionary principle.[150] It also provides that "management measures should not only ensure the conservation of target species but also of species belonging to the same ecosystem or associated with or dependent upon the target species".[151]

In addition, the Code provides guidelines for the application of these principles in various fisheries-related activities, including fisheries management,[152] fishing operations,[153] aquaculture development,[154] and integration of fisheries into coastal area management.[155]

The Johannesburg Plan of Implementation of the World Summit on Sustainable Development

At the 2002 World Summit on Sustainable Development States committed, among others, to promote the sustainable development of marine ecosystems. In this respect, the Johannesburg Plan of Implementation, adopted at the WSSD, highlighted the issues on which actions were most urgently needed, in particular:

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145 Code of Conduct for Responsible Fishing, *supra* note 87, article 6(1)

146 *Ibid*, article 6(8)

147 *Ibid*, article 6(4)

148 *Ibid*, article 6(12)

149 *Ibid*, article 6(6)

150 *Ibid*, article 6(5)

151 *Ibid*, article 6(2)

152 See, for example, article 7 of the Code

153 See, for example, articles 8(5), 8(7), 8(8), etc of the Code

154 See, for example, article 9 of the Code

155 See, for example, article 10 of the Code For a list of specific provisions related to the conservation of living aquatic ecosystems in the Code, see Garcia, S.M and I De Lerva Moreno, "Global Overview of Marine Fisheries", a paper presented at Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem, Reykjavik, Iceland, 1-4 October, 2001, pp. 17-18, available at: ftp://ftp.fao.org/fi/document/reykjavik/default.htm

(a) Encouraging the application by 2010 of the ecosystem approach;

(b) Promoting integrated, multidisciplinary and multisectoral coastal and ocean management at the national level and encouraging and assisting coastal States in developing ocean policies and mechanisms on integrated coastal management;

(c) Maintaining or restoring fish stocks to levels that can produce the maximum sustainable yield, with the aim of achieving these goals for depleted stocks on an urgent basis and where possible not later than 2015;

(d) Developing and implementing national, regional and international plans of action to prevent, deter and eliminate illegal, unreported and unregulated fishing (IUU fishing);

(e) Developing and facilitating the use of diverse approaches and tools, including the ecosystem approach, the elimination of destructive fishing practices, the establishment of marine protected areas consistent with international law and based on scientific information, including representative networks by 2012 and time/area closures for the protection of nursery grounds and periods, proper coastal land use and watershed planning and the integration of marine and coastal areas management into key sectors;

(f) Establishing a regular process under the United Nations for global reporting and assessment of the state of the marine environment, including socio-economic aspects, both current and foreseeable, building on existing regional assessments;

(g) Promoting sustainable patterns of production and consumption, applying inter alia the polluter-pays principle;

(h) Supporting sustainable development of aquaculture;

(i) Maintaining the productivity and biodiversity of important and vulnerable marine and coastal areas, including in areas within and beyond national jurisdiction;

(j) Developing national, regional and international programmes for halting the loss of marine biodiversity, including in coral reefs and wetlands.[156]

The WSSD also highlighted the need to provide assistance to developing countries in coordinating policies and programmes at the regional and sub-regional levels aimed at the conservation and sustainable management of fishery resources and implementation of ICM plans, including through the development of infrastructure.[157]

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[156] Plan of Implementation of the World Summit on Sustainable Development, *supra* note 1.

[157] Reports from the Third Global Conference on Oceans, Coasts, and Islands, *supra* note 33, p. 1.

5.2 Other relevant global and regional instruments

The above-mentioned instruments are the major global instruments relating to the application of an ecosystem approach to the conservation and management of marine resources. Other global instruments of relevance to the protection and preservation of the marine environment, include the 1971 Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat; the 1972 Stockholm Declaration on the Human Environment;[158] the 1973 Washington Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES);[159] the 1979 Bonn Convention on the Conservation of Migratory Species of Wild Animals (CMS);[160] the 1982 World Charter for Nature;[161] the 1991 UNEP Guidelines on Shared Resources;[162] and the 1995 Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities.[163]

Several instruments and activities in the context of the IMO also contribute to the implementation of an ecosystem approach, including the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78); the International Convention on the Control of Harmful Anti-fouling Systems on Ships; and the International Convention for the Control and Management of Ships Ballast Water and Sediments. IMO Guidelines also provide for the identification and designation of Particularly Sensitive Sea Areas (PSSAs), where additional protective measures can be applied to protect vulnerable ecosystems.[164]

A number of international instruments also endorse an ecosystem approach in the context of fisheries management, including: the 1992 Cancun Declaration on Responsible Fishing;[165] the 1995 Rome Consensus on Fisheries;[166] the 1995 Kyoto Declaration and Plan of Action;[167] the 1996 Rome Declaration on World Food Security and the World Food

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[158] The 1972 Stockholm Declaration, *International Legal Materials* 11, 1972, p. 1416

[159] CITES, *International Legal Materials* 12, 1973, p. 1085

[160] The Bonn Convention on the Conservation of Migratory Species of Wild Animals, *International Legal Materials* 19, 1980, p. 15

[161] The World Charter for Nature, A/RES/37/7, 1982

[162] UNEP, The Guidelines on Shared Natural Resources, *Environmental Law Guidelines and Principles* 2, 1991

[163] The Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities, available at: http://www.gpa.unep.org/documents/about-GPA-docs.htm

[164] Consultative Process, *supra* note 3, para. 38

[165] The Cancun Declaration on Responsible Fishing, 1992, available at: http://www.oceanlaw.net/texts/cancun.htm

[166] The Rome Consensus on Fisheries, 1995, available at: http://www.intfish.net/treaties/rome.htm

[167] The Kyoto Declaration and Plan of Action, 1995, are available at: http://www.oceanlaw.net/texts/kyoto2.htm

Summit Plan of Action;[168] the 2001 Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem,[169] the 2003 Guidelines on an Ecosystem Approach to Fisheries, FAO Technical Guidelines for Responsible Fisheries, No. 4,[170] and the United Nations General Assembly resolutions on Large-scale pelagic driftnet fishing.[171] As discussed above (see Section 1), the General Assembly also adopts annual resolutions on oceans and the law of the sea and on sustainable fisheries and, in this context, has emphasized the importance of apply an ecosystem to the management of ocean-related activities, including by integrating ecosystem approaches into fisheries conservation and management.[172]

At the regional level, the concept of ecosystem approaches has been adopted by many regional organizations, including instruments emanating from the LME Projects (see Box 7 below)[173] and the constitutive documents of regional fisheries bodies.[174] The UNEP Regional Seas Programmes, as well as other regional agreements and instruments,[175] including the 2005 Bali Plan of Action adopted by Asia-Pacific Economic Cooperation (APEC),[176] are also relevant to the application of an ecosystem approach.

[168] The Rome Declaration on World Food Security and the World Food Summit Plan of Action, 1996

[169] The Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem, 2001

[170] FAO, The ecosystem approach to fisheries, FAO Technical Guidelines for Responsible Fisheries, No. 4, Suppl. 2, 2003: http://www.fao.org/fi/eims_search/advanced_s_result.asp?series=116&lang=en&sortorder=5&form_c=AND. See also Turrell, W. R., "The Policy Basis of the "Ecosystem Approach to Fisheries Management", available at: http://www.eurogoos.org/publications/PolicyDrivers.pdf

[171] United Nations General Assembly resolutions on Large-scale pelagic driftnet fishing, available at: http://www.un.org/Depts/los/general_assembly/general_assembly_resolutions.htm

[172] See, for example, General Assembly resolution 62/177, preamble and para. 5.

[173] See, for example, the *BCLME Strategic Action Programme* (SGA) and the *BCLME Transboundary Diagnostic Analysis* (TDA), and Strategic Action Programme for the South China Sea (Draft Version 3, February 24, 1999)

[174] Besides the above-mentioned CCAMLR, other regional fisheries bodies such as the International Council for the Exploitation of the Sea (ICES), the North Pacific Marine Science Organization (PICES), South East Atlantic Fisheries Organisation (SEAFO), and the Western and Central Pacific Fisheries Commission (WCPFC) have an ecosystem approach mandate. Some other RFBs which have incorporated an ecosystem approach into their work are the International Commission for the Conservation of Atlantic Tuna (ICCAT), the North-West Atlantic Fisheries Organization (NAFO), the North-east Atlantic Fisheries Commission (NEAFC), the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), the North Atlantic Salmon Conservation Organization (NASCO), the General Council for the Mediterranean (GFCM), the Inter-American Tropical Tuna Commission (IATTC), the International Pacific Halibut Commission (IPHC), the International Whaling Commission (IWC), and the North Pacific Anadromous Fish Commission (NPAFC). See UNEP, "Ecosystem-based Management of Fisheries: Opportunities and Challenges for Coordination between Marine Regional Fisheries Bodies and Regional Seas Conventions", *Regional Seas Reports and Studies* 175, Nairobi, 2001, pp. 9 and 18-22. For more information on RFBs, available at: http://www.fao.org/fi/body/rfb/index.htm

[175] For example, the 1990 Protocol Concerning Specially Protected Areas and Wildlife (the SPAW Protocol) to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (the Cartagena Convention); and the 1986 Convention for the Protection of the Natural Resources and Environment of the South Pacific Region

[176] Bali Plan of Action, Part I (b), available at: http://www.apec.org.

Box 7: Case study: The Modular Approach to Large Marine Ecosystems Management

The concept of Large Marine Ecosystems emerged in the 1980s and recently has become a focal topic in international ocean governance. LMEs were defined by Sherman and Alexander as "regions of ocean space encompassing coastal areas from river basins and estuaries on out to the seaward boundary of continental shelves and the seaward boundary of coastal current systems. They are relatively large regions on the order of 200,000 km^2 or larger, characterized by distinct bathymetry, hydrography, productivity, and trophically dependent populations." Sixty-four LMEs have been identified around the world.

LMEs have great social, economic and environmental significance and are a focal area of various sea uses and competing interests, since most maritime activities take place in these areas. Conflicting interests over the use and protection of LMEs exist not only between domestic stakeholders, but between neighbouring States, and between coastal States and States with high seas interests. As a result, LMEs are particularly vulnerable to over-exploitation and pollution, and suffer from degradation and deterioration.

LMEs are highly complex in terms of ocean management because of transboundary elements and the involvement of various sectors and stakeholders. LMEs normally cover the territorial waters and EEZs of coastal States, and in case of the habitats of some straddling stocks and highly migratory species, the high seas beyond 200 nautical miles. Crossing several maritime zones, an LME normally encompasses many component ecosystems and relates to other interconnected ecosystems.

To be effective, the boundaries of LME management need to correspond with the natural boundaries of an LME. LME management not only must take into account the populations of exploited organisms, but also unexploited species that may be dependent and associated, their habitats and even the socio-economic development of the area concerned. A holistic approach is thus needed to encompass the entire ecosystem as an integrated management unit, and to conserve and manage entire communities of organisms and their habitats as a whole.

The concept of LME management reflects a large scale and holistic approach to assessment and control of marine natural resources. The sixteen current LME projects use five linked modules to monitor, assess and manage marine ecosystems: productivity and carrying capacity; fish and fisheries; pollution and ecosystem health; socio-economic conditions; and pertinent governance regimes. These modules cover all the major aspects of the protection and management of an LME, representing a paradigm shift from a sectoral, species-specific approach to a holistic, ecosystem approach to the assessment and management of the marine environment and resources.

Wang, H., "Ecosystem Management and Its Application to Large Marine Ecosystems: Science, Law, and Politics; An Evaluation of the Modular Approach to the Assessment and Management of Large Marine Ecosystems", *Ocean Development and International Law*, No. 1 and No. 3, vol. 35, 2004.

Summary of key ideas

(a) The origin of the movement towards an ecosystem approach to natural resources dates back to the early 1900s, and the concept has been gradually incorporated into a series of international legal instruments since the early 1980s. Ecosystem approaches to ocean management have now been well-established in a series of international policy documents and legally binding instruments.

(b) UNCLOS provides the legal framework for the implementation of an ecosystem approach to all activities conducted in the oceans and seas. Although UNCLOS does not explicitly provide for an ecosystem approach, its objectives and relevant provisions are supportive of such an approach.

(c) At the WSSD, States committed to promote the sustainable development of marine ecosystems and encouraged the application of the ecosystem approach by 2010.

(d) The concept of an ecosystem approach has been adopted at the regional level by many regional organizations, including in the context of the LME Projects, and by some regional fisheries bodies and regional seas programmes.

(e) The concept of LME management reflects a large scale and holistic approach to assessment and control of marine natural resources. LMEs are highly complex because of transboundary elements and the involvement of various sectors and stakeholders. They normally cross several maritime zones, encompass many component ecosystems, and relate to other interconnected ecosystems.

Questions for discussion

(a) Describe provisions in UNCLOS and UNFSA that provide for an ecosystem approach. What other instruments are relevant to the adoption of an ecosystem approach.

(b) What deadlines were established by the WSSD that are relevant to the implementation of an ecosystem approach?

(c) Describe political and legal challenges that may arise from the identification and establishment of an LME?

(d) What legal and policy instruments have been adopted in your region(s) that are relevant to an ecosystem approach?

Annex I

International governance framework for an ecosystem approach

As awareness of the need for ecosystem approaches to the management of ocean-related activities has been increasing, the international institutional framework set up to regulate and manage ocean-related activities has also evolved.

There are different layers of institutional frameworks – global, regional and national – addressing the implementation of an ecosystem approach. It is important to note that the work relating to ecosystem approaches undertaken by most international institutions involves the on-going adoption of decisions and programmes by their relevant governing bodies. These bodies usually meet on a periodic basis, in light of new information, understanding, and needs. These developments need to be constantly monitored to appreciate policy evolution. Collectively, they have contributed significantly to the development of new approaches to ocean management, including the move toward ecosystem approaches.

Decisions and programmes adopted by international institutions are increasingly based on the best scientific information available. Scientific advisory bodies are therefore an important part of the international institutional framework. ICES is an example of a regional scientific organization that coordinates and promotes marine research in the North Atlantic, gathers information about the marine ecosystem in order to fill gaps in existing knowledge and to provide scientific advice to regional policy-making organizations, such as the North-East Atlantic Fisheries Commission (NEAFC); the North Atlantic Salmon Conservation Organization (NASCO); and the Commission of the European Union (EC). International partnerships for scientific research are also providing important scientific information that can be used as the basis for policy decisions. For example, the Census of Marine Life - a global network of researchers in more than 80 nations – is engaged in a 10-year scientific initiative to assess and explain the diversity, distribution, and abundance of life in the oceans. The world's first comprehensive Census of Marine Life will be released in 2010.

Global institutional framework

An array of global organizations currently deal with oceans governance issues, including the United Nations General Assembly, FAO, IMO, UNEP, UNESCO/Intergovernmental Oceanographic Commission (IOC), as well as the bodies created by UNCLOS, i.e. the International Tribunal for the Law of the Sea, the International Seabed Authority, the Commission on the Limits of the Continental Shelf and the Meeting of States Parties. These organizations address various issues, including the conservation and management of marine living resources, mining activities beyond national jurisdiction, the protection and preservation of the marine environment, maritime safety and marine science.

The *United Nations General Assembly*, in its annual resolutions on oceans and the law of the sea and on sustainable fisheries, performs an annual review and evaluation of the implementation of

UNCLOS and other developments relating to ocean affairs and the law of the sea. The General Assembly has adopted a number of resolutions of relevance to ecosystem approaches, the most recent of which are resolutions 61/222 and 62/215. In 1999, the General Assembly established the Consultative Process in order to facilitate its annual review, by considering the report of the Secretary-General on oceans and the law of the sea and by suggesting particular issues to be considered by it, with an emphasis on identifying areas where coordination and cooperation at the intergovernmental and inter-agency levels should be enhanced. In 2004, by resolution 59/24, the General Assembly also established an Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction. Informal Consultations of States Parties to the United Nations Fish Stocks Agreement have been held annually since 2002 to consider, among other things, the implementation of the Agreement and preparations for the Review Conference convened pursuant to article 36 of the Agreement.

The *Division for Ocean Affairs and the Law of the Sea* of the Office of Legal Affairs of the United Nations performs the duties of the Secretary-General under UNCLOS, acts as Secretariat of UNCLOS and the UNFSA, assists the General Assembly in its annual review and evaluation of the implementation of UNCLOS and other developments relating to ocean affairs and the law of the sea, and substantively services the meetings of the bodies established by the General Assembly, as well as the Meeting of States Parties and the Commission on the Limits of the Continental Shelf.

The following institutions have been established pursuant to UNCLOS:

The *International Seabed Authority* (ISA) was established to organize and control activities relating to mineral resources in the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction (the Area). All States Parties to UNCLOS are ipso facto members of the ISA.

The *International Tribunal for the Law of the Sea* (ITLOS) is an independent judicial body established by the Convention as one of the mechanisms available to States to adjudicate disputes arising out of the interpretation and application of the Convention. Pursuant to the provisions of its Statute, the Tribunal has formed a number of chambers, including the Chamber for Marine Environment Disputes.

The *Commission on the Limits of the Continental Shelf* (CLCS) was created to facilitate the implementation of UNCLOS in respect of the establishment of the outer limits of the continental shelf beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured. The Commission makes recommendations to coastal States on matters related to the establishment of those limits.

UNCLOS also provides, in article 319, that the Secretary-General of the United Nations "shall convene necessary *Meetings of States Parties* in accordance with this Convention". As of 2008, there have been 18 Meetings of the States Parties to the Convention, as well as two special Meetings held on 2 September 2003, and 30 January 2008. The Meetings have dealt primarily with elections of the members of ITLOS and of the CLCS, as well as with budgetary and administrative matters:

UNCLOS also identifies on a number of competent international organizations to achieve its objectives. These include:

The *Food and Agriculture Organization of the United Nations*, through its Committee on Fisheries (COFI), reviews the FAO programmes of work in the field of fisheries and aquaculture and their implementation, conducts periodic general reviews of fishery and aquaculture problems of an international character, and appraises such problems and their possible solutions with a view to concerted action by States, FAO, inter-governmental bodies and civil society. The Committee also reviews specific matters relating to fisheries and aquaculture referred to it by the Council or the Director-General of FAO, or placed by the Committee on its agenda at the request of Members, or the United Nations General Assembly.

The *International Maritime Organization* encourages and facilitates the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships. Although safety was and remains IMO's most important issue, a considerable part of its work relates to the prevention and control of pollution from ships and a number of conventions have been adopted in the IMO context to that effect.

The *United Nations Environment Programme* addresses ocean issues through a number of its bodies. The Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA) Coordination Office assists in the implementation of the duty of States to preserve and protect the marine environment from land-based activities by assisting States in taking action at the national, regional or global level through a number of capacity building and technical programmes. UNEP also administers the secretariats of various biodiversity-related conventions (e.g., CBD and the CMS). The governing bodies of those conventions usually meet once every 2-3 years, and have, over the years, adopted a number of decisions of relevance to marine ecosystems.

UNESCO, through its *Intergovernmental Oceanographic Commission*, is active in the areas of marine scientific research and transfer of marine technology. The work of IOC has focused on promoting marine scientific investigations and related ocean services, with a view to learning more about the nature and resources of the oceans.

A number of other organizations outside the United Nations system also play an important role in the development of international ocean policies and the implementation of an ecosystem approach - for example, the International Union for the Conservation of Nature (IUCN) and several non-governmental organizations.

Regional institutional framework

A number of *regional environmental bodies* address issues ranging from chemical wastes and coastal development, to the conservation of marine living resources and ecosystems. The Regional Seas Programme of UNEP was launched in 1974 to address the accelerating degradation of the world's oceans and coastal areas through the sustainable management and use of the marine and coastal environment, by engaging neighbouring countries in comprehensive and specific actions to protect their shared marine environment. Regional Seas programmes established under the auspices of UNEP are: the Black Sea Region, Caribbean Region, Eastern Africa Region, East Asian Seas, Mediterranean Region, North-East Pacific Region, North-West Pacific Region, Pacific Region, Red Sea and Gulf of Aden, ROPME Sea Area, South Asian Seas, South-East Pacific Region, and Western Africa Region. Six of these programmes are also directly administered by UNEP. Five partner programmes, established for the Antarctic, Arctic, Baltic Sea, Caspian Sea and North-East Atlantic Regions, are also members of the Regional Seas family. The Regional Seas programmes generally focus on management of marine ecosystems, and are thus important for implementing an ecosystem approach regionally. Some of the relevant organizations in these regions, such as CCAMLR, the Baltic Marine Environment Protection Commission (HELCOM), and the Commission for the Protection of the Marine Environment of the North-east Atlantic (OSPAR), have explicitly committed themselves to the implementation of an ecosystem approach. *Regional fisheries management organizations and arrangements* (RFMO/As) are recognized as the primary mechanism for international cooperation at the regional level in conserving and managing fishery resources in accordance with their respective mandates. Many RFMO/As have incorporated provisions of UNFSA in their constitutive agreements, or have adopted measures in practice to implement the Agreement. It is important to note that not all areas of the oceans are covered by RFMO/As and most of these organizations do not manage all fish species located in their areas of competence.

Regional arrangements also include *Large Marine Ecosystems*, which are relatively large regions characterized by distinct bathymetry, hydrography, productivity, and populations depending on the same food chain. The LME approach provides an interdisciplinary framework for utilizing ecologically defined LMEs on the basis of a common strategy for assessing, recovering, managing, and sustaining marine resources and their environments. There are currently sixteen LME projects underway in Africa, Asia, Eastern Europe, and South America, which are primarily supported by the Global Environment Facility, the World Bank, UNDP, UNEP, FAO, the United Nations Industrial Development Organization (UNIDO), the IOC of UNESCO, and IUCN. These LMEs are used as assessment and management units for the marine environment and its resources, and scientific, technical and financial assistance is provided to the developing countries concerned, with the goal of improving the long-term sustainability of the global marine environment and its resources.

Module II: The Science of Ecosystem Approaches

Module Plan

1. Introduction

The concept of an "ecosystem" can be difficult to apply in practice. On the one hand, it can be overwhelming because it is impossible to know everything about an ecosystem before a decision is made. On the other hand, it can be trivial because managers and policy-makers need to be guided on where to focus their efforts and not simply told that every single component or process of an ecosystem could affect the success of their programme. For an ecosystem approach to be useful it is necessary to find middle ground and help managers and policy makers allocate resources and focus deliberations on their priorities.

This Module will review the scientific definitions of ecosystems on various scales (vertical and horizontal), including ecosystem composition and diversity, and the complex processes and interactions within and between ecosystems, including critical functions of ecosystems. It will also develop the scientific considerations that are important for managers and policy makers within an ecosystem approach. Module IV will consider ecosystem objectives, monitoring and the role of marine scientific research in the development and implementation of ecosystem approaches.

It is important to understand that these modules will not provide a simple recipe for the right ecosystem foundations for all policy and management choices, since no such recipe exists. However it will prepare policy makers and managers to ask the right questions of those providing such information about an ecosystem, so that important considerations can be identified early in the process of developing an ecosystem approach to a given area.

2. Science definitions of ecosystems

2.1 Diversity of definitions

As discussed in Module I, there is no single universally accepted definition of an "ecosystem approach" to ocean-related activities. Likewise, there is no single universally accepted definition of what constitutes an "ecosystem".

Definitions of "ecosystem" have been provided by international agencies, national marine agencies, and scientific experts (see Box 8). Although these definitions are not identical, there are important similarities in the definitions used by various agencies and States. In all cases, these definitions highlight that in adopting an ecosystem approach, consideration needs to be given to ocean physics, chemistry, and biology.

Box 8: Examples of Definitions of an Ecosystem

UNEP: "A dynamic complex of plant, animal, and micro-organism communities and their non living environment interacting as a functional unit. ... We can define ecosystems (of) any size so long as organisms, physical environment, and interactions can exist within it...[It can] therefore be as small as a patch of soil supporting plants and microbes; or as large as the entire biosphere of the Earth. This definition stresses the importance of place and the hierarchical scaling of the biosphere".

http://www.unep-wcmc.org/habitats/freshwater/definition.htm.

FAO: "A spatio-temporal system of the biosphere, including its living components (plants, animals, micro-organisms) and the non-living components of their environment, with their relationships, as determined by past and present environmental forcing functions and interactions amongst biota".

http://www.safmc.net/Portals/0/EMHome/MafacReportEcoMgmt.pdf.

CBD: a "dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit".

US - NOAA: "a geographically specified system of organisms (including humans), their environment, and the processes that control their dynamics".

http://ecosystems.noaa.gov/docs/EGT_Oceans_2005_Paper_070105.docb.

Canada: Center for Marine Biodiversity: "An ecosystem consists of all living and non-living things in an area. Ecosystems include a unique combination of animals, plants, microorganism and physical characteristics that define the location".

http://www.biodiv.org/doc/world/ca/ca-nr-me-en.doc.

"The sum total of biological populations and abiotic factors present in a region and their relationships to each other. No ecosystem is a closed system; hence the precise meaning of the term varies according to the scale of the region to which it is applied."

Cooke, J.G., "Glossary of technical terms", *in* R.M. May (ed.) "Exploitation of Marine Communities", Springer-Verlag, 1984.

"A spatio-temporal component of the bioshpere, determined by past and present environmental forcing functions and interactions amongst biota".

McGlade, J.M., "Ecosystem analysis and the governance of natural resources", *in* J. M. McGlade (ed.), "Advances in Theoretical Ecology", Blackwell Scientific Publications, 1999, pp. 308-336.

In considering management in an ecosystem context, it is thus important to first understand the **ocean physics, chemistry and biology** of an ecosystem. The relationship within and between the physical, chemical and biological components of an ecosystem are illustrated below (see Figure 1), and will be discussed further (see Section 3 below).

Ocean physics

Ocean physics has components that only change on very long time scales, such as the physical structure of the seafloor and coastlines. However, ecosystem characteristics are strongly influenced by the topographic or bathymetric features of the area – how deep and how irregular the seabed – and the "grain size" of the substrate of the seafloor – rocky, gravel, sand, mud.[177] Ocean physics also has important dynamic properties, both the heat content (temperature) and the energy in the movement of the ocean waters expressed through currents, tides, upwelling and regular wave action.[178] Many of these dynamic properties are also strongly affected by climate change and natural processes such as the El Niño – Southern Oscillation cycles.

Generally speaking, management cannot "manage" the dynamic properties of ocean physics. Currents and tides cannot be increased or decreased readily to help achieve management goals. However, an ecosystem approach to management and policy must consider the dynamic properties of local and regional ocean physics in planning. For example, these properties largely determine how oil spills and land-based runoff will be transported and distributed in coastal and offshore areas, and strongly influence traditional and commercial shipping and transportation routes.[179] They are also strongly influential on the biological productivity of the ecosystem on every scale; particularly at larger scales, as considered below.[180]

Managers and policy makers have more direct concerns regarding the static properties of ocean physics. Many human activities can alter or damage the structure of the seafloor, for example, through impacts of fishing gears, oil and gas development, activities associated with building port facilities, or maintaining shipping corridors, or dumping at sea. The type of seafloor substrate can also be altered through these activities, as well as land-based activities, which cause substantial runoff and sedimentation. These impacts to the seafloor may result in substantial changes to the biological communities and productivity supported by the area, on many scales, particularly more local ones.[181]

[177] Berman, M.S., K. Sherman and C. Melrose, "Measuring the Productivity of Large Marine Ecosystems, an Introduction", *Transactions American Geophysical Union* 87, No. 36, suppl., 2006

[178] Bakun, A., "Patterns in the Ocean: Ocean Processes and Marine Population Dynamics", *California Sea Grant*, 1996, p. 323; Hsieh, C. H., *et al*, "Distinguishing random environmental fluctuations from ecological catastrophes for the North Pacific", *Ocean Nature* 435, 2005, pp. 336-340

[179] Wang, S.D., Y.M. Shen and Y.H. Zheng, "Two-dimensional numerical simulation for transport and fate of oil spills in seas", *Ocean Engineering* 32, 2005, pp. 1556-1571

[180] Harrison, P.J. and T.R. Parsons (eds.), "Fisheries Oceanography: An Integrated Approach to Fisheries Ecology and Management", Blackwell Science, 2000, p. 359

[181] Barnes, P.W. and J.P. Thomas, "Benthic Habitats and Effects of Fishing", *American Fisheries Society Symposium* 41, 2005, p. 890

Ocean chemistry

thus closely follow these patters, particularly because ocean nutrient levels are In adopting an ecosystem approach, serious attention also needs to be given to ocean chemistry, and to human activities that are likely to alter the chemistry of the ocean. In this respect, important ecosystem features of ocean chemistry include salinity and concentrations of dissolved oxygen and nutrients, such as nitrogen, phosphorus, carbon, and even rarer elements, such as iron. Natural nutrient levels and oxygen concentrations vary widely in the sea, both seasonally and on many geographic scales, from basin-wide to local.[182] The dynamics of biological communities are generally adapted to these natural patterns of variation and their geographical distributions one of the key determinants of ocean productivity.[183]

At various times seasonal productivity of marine ecosystems is limited by inadequate nutrients. On occasion, management has attempted to augment productivity through fertilizing local areas with nutrients in limited supply.[184] Sometimes these experiments have worked, but they can also have unexpected consequences more serious than the original limited productivity, such as prompting blooms of undesirable or even toxic plankton, or creating large areas of oxygen levels too low to support many species of fish and invertebrates. These natural patterns of productivity need to be taken into consideration in aspects such as the timing of human activities seasonally, and in the overall level of activities which remove nutrients and production from systems.

In addition to the natural chemical features of ocean ecosystems, an ecosystem approach also requires consideration of chemicals introduced into an area by human activities. Some introductions alter the levels of naturally occurring chemicals, such as land-based run-off that increases levels of nutrients or diminishes oxygen levels in coastal waters, while other introductions involve new chemicals to marine ecosystems. Pollutants such as hydrocarbons from oil spills or heavy metals from industrial waste can have many effects on marine ecosystems.[185] They can alter the species composition of the biological communities by killing or reducing the productivity of species that are not tolerant to the chemical, and reduce the overall biological diversity of the communities if only a few species are tolerant

182 Longhurst, A., "Ecological Geography of the Sea", Academic Press, 1998

183 Williams, P.J le B., D.N Thomas and C.S. Reynolds (eds.), "Phytoplankton Productivity: Carbon Assimilation in Marine and Freshwater Ecosystems", Blackwell Science, 2002

184 Coale, K., *et al*, "A massive phytoplankton bloom induced by an ecosystem-scale iron fertilization experiment in the equatorial Pacific Ocean", *Nature* 383, 1996, pp. 495-501

185 Koelmans, A.A., *et al*, "Integrated modelling of eutrophication and organic contaminant fate & effects in aquatic ecosystems", *A review Water Research*, vol 35, 2001, pp. 3517-3536; Shahidul-Islam, M.D. and M. Tanaka, "Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis", *Marine pollution bulletin* 48, 2004, pp. 624-649.

of the pollutant.[186] Even when pollution levels are not high enough to cause direct mortality of marine species, the concentrations of many toxins can accumulate as they pass up the food web through predation, making the predatory fish dangerous for human consumption.[187]

Box 9: Philippines coastal resources and threats from coastal run-off

The Philippine Islands have a coastline of nearly 40,000 km and in 2000 nearly 2,500 inhabitants per km of coastline. The coastline supports extensive coral reefs, sea-grass beds and mangrove forests, which in turn support an exceptionally rich biodiversity. These resources are extremely important to the Philippine economy and coastal livelihoods. For example the mangrove forests are estimated to provide more that $600 per hectare in sustainable fish and wood production, and the coral reefs provide the economy over $1 billion per year in fishery, tourism, and coastal protection values.

The main pressures on these valuable coastal ecosystems are agriculture and forestry practices plus development of urban centers, tourism infrastructure, and industrial facilities. Past unsustainable forest practices and poor agricultural land management has resulted in extensive soil erosion in some areas, in turn leading to smothering of marine organisms in the reefs and sea-grass beds, reduction in light penetration, and changes in both nutrient and oxygen levels. In areas where agricultural runoff to the sea is not managed, these problems are increased by fertilizers, pesticides, animal wastes, and decaying plant material all further altering the nutrient regimes and reducing oxygen levels. The agriculture sector alone was estimated to produce over 800,000 tonnes of organic pollution in the early 2000s. These far exceed the capacity of the coastal ecosystems to adapt and assimilate the inputs, and productivity of the most heavily impacted coastal areas is declining, with loss of fish production, tourism opportunities and aesthetic and biodiversity values. Industrial and urban waste disposal are having effects that can be even more serious in local areas.

The Philippine government is instituting major initiatives to address agriculture practices that reduce runoff of all agricultural by-products. These initiatives involve communities extensively in adapting local practices. Because clean-up of severely impacted areas has proved costly and difficult, the emphasis is on prevention of undesirable run-off, rather than trying to correct the undesirable consequences of unsustainable practices. These efforts have highlighted the tight links between land-based practices and marine ecosystem health, and interconnectedness of all the components of the coastal ecosystems.

Available at: http://www.oneocean.org/download/990118/intros.pdf.

[186] Grall, J and L. Chauvaud, "Marine eutrophication and benthos: the need for new approaches and concepts", *Global Change Biology* 8, 2002, pp. 813-830

[187] Fleming, L.E., *et al*, "Emerging public health risks in the marine environment", *Marine Pollution Bulletin* 53, 2006, pp. 10-12

Ocean biology

As discussed in more detail below (see Ecosystem Composition and Biodiversity), the biological features of an ecosystem are also important in adopting an ecosystem approach, and include all the plants and animals in the area, whether they are permanent residents or only present seasonally. Plants include both phytoplankton, which constitute the basis for aquatic food webs, and macroalgae, which can be both an important food source for grazers and shelter for invertebrates and vertebrates trying to avoid predators. The animals range from very small zooplankton grazers on the smallest algae up to great whales, and include many diverse kinds of invertebrates, elasmobranches (sharks, skates, and rays), fishes, seabirds, and marine mammals.

2.2 The relevance of differences in definitions to management and policy

The major differences in the definitions of what is an "ecosystem" lie in the emphasis given to the physical, chemical, biological, and human components of the ecosystem, and to their interactions.[188] Many of the differences reflect the varying importance of the different types of features of an ecosystem at different spatial scales, in different parts of the planet, and sometimes even among areas with different histories of human activities. Such differences are important to those trying to apply an ecosystem approach in policy or management. They do not make one definition of an ecosystem more or less "right" than another definition. However, in any specific application, some definitions of an ecosystem are more useful to managers and policy makers than other definitions.

In this respect, the problems faced by managers and policy makers can influence what definition of "ecosystem" will be most useful. For example, a manager working on the scale of an individual lagoon or a coastal area of a few tens of kilometers in length will probably find that definitions stressing the structure of the seabed (bottom substrate, plants and animals that create physical structure such as corals and sponges, etc.) will correspond to the considerations important to their work.[189]

[188] Some differences may reflect disciplinary biases, as it is natural for experts to give special importance to the parts of the ecosystem on which their own work is already focused. Consequently, it is always valuable for policy makers and managers to know the backgrounds and interests of their science advisors, and to get a wide a range of professional and community advice on the status and trends of their ecosystem components.

[189] Hall, S., D. Raffaelli and S. Thrush, "Patchiness and disturbance in shallow water benthic assemblages", *in* P. Giller, A. Hildrew and D. Raffaelli (eds.), "Aquatic ecology- scale, pattern and process", Blackwell Science, 1994, pp. 333-375; Hewitt, J.E., *et al*, "Mapping of Marine Soft-Sediment Communities: Integrated Sampling for Ecological Interpretation", *Ecological Applications* 14, 2004, pp. 1203-1216

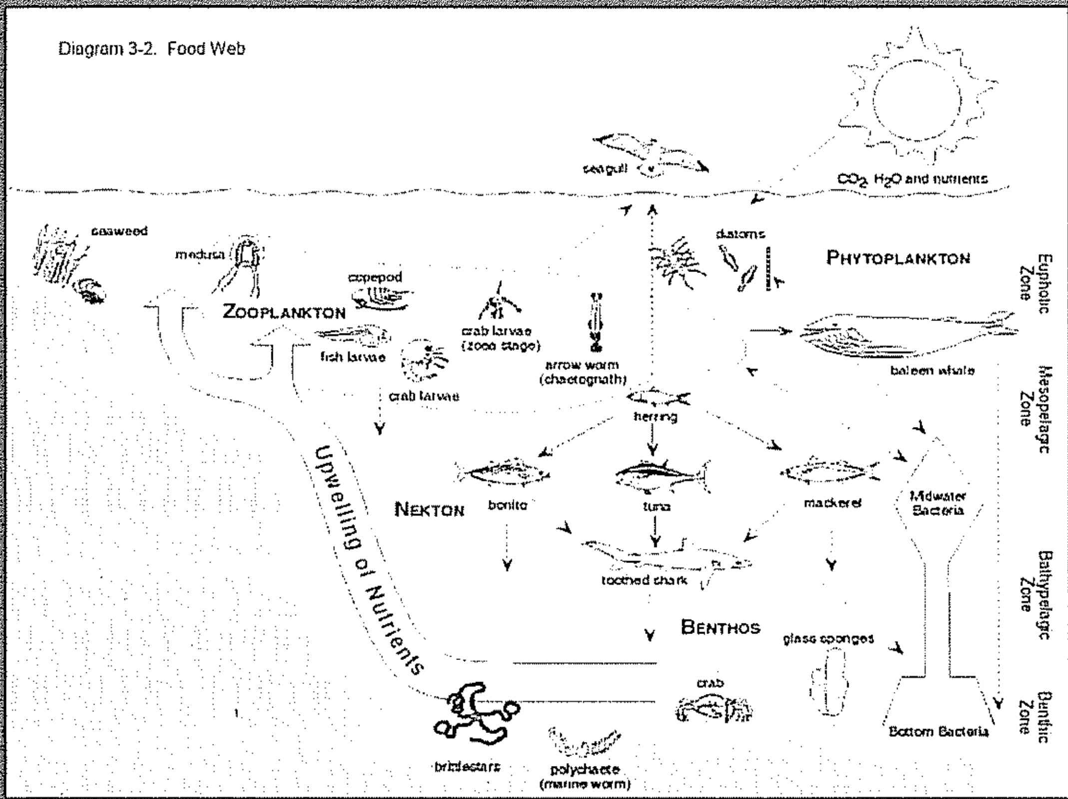

Figure 1: Interaction of Various Ecosystem Components
Available at: http://www.marine.usf.edu/pjocean/packets/f99/f99u2le3.pdf.

In contrast, a manager working on the scale of a major gulf or oceanic basin will find that definitions focusing on details of the seafloor are less helpful because the management decisions will be on much larger scales than specific seabed structures.

In the case of a manager working on a system dominated by an eastern oceanic boundary current, such as the Humboldt Current, the Benguela Current (see Box 10) or the Canary Current, variation in those currents exert strong influence on the productivity of the corresponding marine ecosystems.[190]

[190] Fiedler, P.C., "Environmental change in the eastern tropical Pacific Ocean: review of ENSO and decadal variability", *Marine Ecology Progress Series* 244, 2002, pp. 265-283; Shannon, L.J., *et al*, "Trophic flows in the southern Benguela during the 1980s and 1990s", *Journal of Marine Systems* 39, 2003, pp. 83-116

Box 10: A Coastal Upwelling System – the Benguela Current

Marine ecosystems to the west of most coastal land-masses at mid-latitudes are characterized by strong oceanographic processes and biological communities with many similarities. The system to the west of southern Africa, from southern Angola to South Africa, referred to as the Benguela Current system, has been studied by a coordinated project over the past two decades.

In this system, there is very strong seasonal and interannual variation in the abundance and productivity of most of the species in the food web. Winds and the strong, south-flowing ocean current combine to produce significant spring *upwelling* (rising to the surface of nutrient-rich cool, deep waters) in at least 8 locations along the coast. This water, in turn, produces a very strong seasonal burst in primary productivity. Year-to-year variation in the strength and timing of the winds and physical oceanographic events can be reflected or even amplified in year-to-year variation in the timing and magnitude of the pulse in primary productivity. Depending on the timing of the spring bloom, the types of zooplankton grazers that would benefit most could also change from year to year, with some conditions favouring large zooplankton like large *calenoid copepods* and *euphausiids*, and other conditions favouring small zooplankton like *cyclopoid* and small calenoid copepods.

Key fish species in the Benguela Current system include sardines and anchovies, which are the main predators on zooplankton, and the main forage fish species for the top predators in the systems. Anchovies feed on larger zooplankton than do sardines, so that oceanographic-driven changes in primary productivity can be transferred directly to changes in the relative abundance and productivity of sardines and anchovies. The migration patterns and spawning places and times are all adapted to these seasonal and geographic patterns of changing productivity and oceanographic conditions. Moreover, the major fish predators, such as Cape hake, and seabirds also are affected by the relative abundance of sardine and anchovy. The oil-rich anchovy generally provide greater benefits to the predator community, such that their year-to-year productivity – both growth and production of young - can also be driven by the basic oceanographic processes.

In such systems, managers and policy-makers need to remain informed about oceanographic conditions and the status of the main grazing communities. For example, South Africa monitors the zooplankton community monthly, to get early information on changes that may affect the fish populations supporting fisheries. The fisheries management objectives and approaches also need to be responsive to changes in oceanographic conditions, ensuring that the exploitation rate is appropriate for the productivity. Because of the effects of oceanographic conditions on these systems, long-term objectives of keeping populations of both sardines and anchovy at any fixed level would probably not be attainable.

Payne, A.B., K.A. Mann and K.H. Hilborn (eds.), 'Benguela Trophic Functioning", *South African Journal of Marine Science* 12, 1992, pp. 1108; Moloney, C.L., *et al*, "Contributions of the Benguela ecology program to pelagic fisheries management", *South Africa African Journal of Marine Science* 26, 2004, pp. 37-52.

Correspondingly, these managers and policy makers may find that definitions of ecosystems that give emphasis to the oceanic physical and chemical properties are quite relevant to their work, whereas the same definition may have less utility to a manager working in a sheltered coral reef (see Box 11).

Box 11: Coral reef ecosystems

Coral reef ecosystems are widespread in the world's oceans. Long considered a key ecosystem type in the shallow and warm seas of lower latitudes, there has been growing interest in deep-sea and cold-water corals, and their associated biota.

Shallow water coral reef ecosystems differ in many details of community composition, but have many similarities in the ecosystem processes. At the most fundamental level, they are characterized by the limestone/calcium-carbonate structural foundation built up usually over many centuries. Compared to many other types of marine ecosystem, coral reef systems tend to be relatively self-contained. Productivity is largely (but not exclusively) determined by local conditions of nutrients, temperature, and light penetration. Because of the more internal cycling of nutrients, biomass, and detritus, nutrient limitation often plays less of a role in coral reef system dynamics than it does in more open systems. Much of the local production remained within the species in the reef system. There are grazers on macroalgae as well as phytoplankton, and biomass is passed through the food web by grazing planktivores, predation, and recycling of detritus in the local area of the reef, although eventually as much as 75% of production eventually may be exported out of the reef. When reefs are located in the path of strong oceanographic currents they have some capacity to strip nutrients and biomass from the passing water column, and smooth over oscillations in its nutrient levels.

In addition to these features of comparatively (but not absolutely) stable productivity at lower trophic levels, coral reefs are also generally characterized by a complex three-dimensional structure provided by the reef itself. This three dimensional structure and stable production tends to result in fish and invertebrate communities with many species. Often no single species is numerically dominant at any trophic role, with niches sometimes partitioned quite finely among species with feeding strategies that can be highly specialized.

The species rich communities with many linkages among predators, prey and competitors make it hard to monitor and model the dynamics of the community with precision. Extractive use of the ecosystem, such fishing, may harvest many different species, with managers severely challenged to match catch levels of the various species to their different productivities. Without cautious management the large species in these systems can be depleted quickly. This can lead to substantial changes in the composition and processes in the rest of the system as top-down control is diminished. Managers also have to be highly risk averse relative to the structure provided by the reef itself. Without the complex three-dimensional structure, both the interactions between predators and prey (that depend on hiding places for both ambush and escape), and the basic bottom-up productivity of the system can be seriously altered.

Hatcher, B.C., "Coral reefs, How much greater are the parts than the whole", *Coral Reefs* 16, 1997, pp. S77-S91.

The emergent message from these considerations is that no matter which definition is chosen, an ecosystem includes all the living things in the area, the physical and chemical properties of the seafloor and water column, all their inter-linkages, and all the ways that they interact with humans using the area.

These things all matter, but they do not matter equally. One fundamental responsibility of a manager or policy maker is to determine which features are the key ones to consider for their jurisdictions. This task has several dimensions, including spatial scale, seasonality, and biological diversity and species composition.

Spatial scale

As discussed above, if management and policy are being applied on very local spatial scales, choices will be strongly influenced by information that may be available about the seafloor communities and habitats. Such information will contribute to development of policies and management programmes that ensure the sensitive and vulnerable habitats and communities are protected from harm, and allow human activities to occur in the places where they will be productive and sustainable.[191] If management and policy is on large spatial scales, the spatial considerations will be on much larger ecosystem features: overall depth and bathymetry, major oceanographic features such as upwelling zones, currents and gyres, and shelf breaks.

Where detailed information on the biological communities on the seabed is available, this may be important to decisions on where human activities should occur. More typically, however, little information on seafloor communities and fine-scale features is available, and the management decisions themselves are likely to be large-scale decisions with very little local spatial resolution. It is typically the case that spatial components of management on large scales will be based on the distributions of biological communities in the water column: fish, seabirds, and sea mammals rather than benthos.[192]

Seasonality

Another dimension in the consideration of an ecosystem approach is seasonality. Managers of terrestrial systems routinely take account of seasonal weather and climate patterns because ecosystems and human uses of them are dynamically linked to major seasonal

[191] P.W. Barnes and J.P. Thomas, *supra* note 181.

[192] Kareiva, P. and U. Wennergren, "Connecting landscape patterns to ecosystem and population processes", *Nature* 373, 1995, pp. 299-302; Leslie, H.M., "A Synthesis of Marine Conservation Planning Approaches", *Conservation Biology* 19, 2005, pp. 1701-1713.

weather patterns in rainfall, temperature, and even day length. To varying degrees, the seas are also seasonal, depending on latitude, depth, position in the major ocean basins and other factors. For example, "spring blooms" in productivity are tied to wind-driven "up-welling" of nutrient-rich deeper waters in coastal areas,[193] and the timing of migrations and reproduction of many mobile species that take advantage of seasonal periods of high food abundance.[194]

Human harvesting of marine and coastal resources has long been adapted to such seasonality, where it occurs. However, an ecosystem approach to the management of human activities that are not inherently extractive still needs to consider seasonal variations of the ecosystem in which the activity is occurring. Activities that may have little impact on the ecosystem in some seasons may cause substantial disturbances to animals in seasons when the animals are densely aggregated, and engaged in crucial activities, such as breeding, spawning, rearing young, or feeding intensively.

Biological diversity and species composition

Another relevant ecosystem dimension is the biological diversity and species composition of the ecosystem. The scientific community has debated the link between biological diversity and ecosystem stability without achieving consensus,[195] although recent findings by the Census of Marine Life certainly highlight the importance of biological diversity for ecosystem function in the deep sea.[196] This issue is discussed more fully below (see Section 3). However, it would be impossible for management and policy to be tasked with attempting to keep every species at some particular "natural" abundance, and every relationship between species at some particular rate. All natural communities and their component species vary in abundance, and usually distribution, on multiple temporal scales.[197]

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[193] Miller, C.B., "Biological Oceanography", Blackwell Science, 2004

[194] Jones, M.B., *et al* (eds.), "Migrations and Dispersal of Marine Organisms: Proceedings of the 37th European Marine Biology Symposium", Reykjavik, Iceland, 5-9 August 2002, Kluwer Academic Publishers, 2003, p. 262

[195] Pimm, S.L., "The complexity and stability of ecosystems", *Nature* 307, 1984, pp. 321-325

[196] Global Forum on Oceans, Coasts and Islands, Report from the Strategic Planning Workshop on Global Oceans Issues in Marine Areas Beyond National Jurisdiction in the Context of Climate Change, Nice, France, January 23-25, 2008, available at: www.globaloceans.org.

[197] Rice, J.C., "Implications of variability on many time scales for scientific advice on sustainable management of living marine resources", *Progress in Oceanography* 49, 2001, pp. 189-211 ; Finney, B.P., *et al*, "Fisheries productivity in the northeastern Pacific Ocean over the past 2200 years", *Nature* 416, 2002, pp. 729-73

In this respect, an ecosystem approach to policy and management is not tasked with attempting to "freeze" the ecosystem components into any specific configuration; rather, it is tasked with taking due account of the natural patterns of variation in the biological components of the ecosystems in which management is occurring. Managers and policy makers should ensure that human uses of the ecosystem are responsive to natural changes expected in the ecosystem, neither amplifying the natural variation to levels that are unstable nor creating human dependencies on particular species that will not be sustainable during normal periods of low availability of the species.

Summary of key ideas

(a) Various definitions of "ecosystem" highlight that in adopting an ecosystem approach consideration must be given to ocean physics, chemistry, and biology.

(b) Differences in the definitions of an "ecosystem" are in the emphasis given to the physical, chemical, biological, and human components of the ecosystem, and to their interactions.

(c) Any useful definition of an "ecosystem" will include all the features and inter-relationships of an area, and the humans who live near and interact with the physics, chemistry and biology of an area.

(d) It is the fundamental responsibility of managers and policy makers to determine the key features of an ecosystem that need to be considered in their jurisdiction. This task has dimensions involving spatial scale, seasonality, and biological diversity and species composition.

Questions for discussion

(a) What is the relevance of ocean physics, chemistry and biology in ecosystem approaches to policy and management?

(b) Why are different definitions of ecosystems applicable in different contexts?

(c) How can spatial scale, seasonality and biological diversity assist managers in determining which features of an ecosystem are most relevant in their area?

3. Biological ecosystem composition

As outlined above, the biological components of an ecosystem include the primary producers, grazers and from one to three or four levels of predators.

3.1 Primary producers

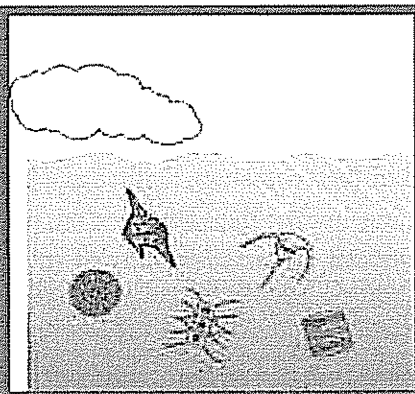

Figure 2: Primary Producers of the Ocean

www.bigelow.org/edhab/fitting_algae.html

Primary producers may be single-cell algae in the water column or marine plants attached to the seafloor. As the base of the food web and foundation of productivity for all the animals in the system, the primary producers are crucial to ecosystem processes, and their conservation and protection may be an important consideration in management.[198] Nutrient concentrations are an important driver of primary production, which means that an ecosystem approach requires ensuring that human activities do not greatly alter nutrient levels in the productive zone. Such alterations can be the consequence of land-based runoff or pollution as well as waste disposal at sea, which are important considerations in an ecosystem approach.[199] Primary production also requires light, so siltation can also be an important consideration.[200] When marine plants (often referred to as macro-algae) are an important part of a marine ecosystem, ecosystem approaches also require ensuring that human activities do not cause unsustainable rates of disturbance of these plants where they are attached to the seabed or floating freely. Such protection is particularly important because these plants do not just represent food for grazers but they also provide cover and shelter for fish and invertebrates, especially for larval and juvenile fish.[201]

3.2 Grazers or "secondary consumers"

Ecosystem grazers include both zooplankton and fish. Most phytoplankton consumption is by small zooplankton, whereas macro-algae can be eaten by small zooplankton, many types of invertebrates and even some species of fish. In some coastal ecosystems grazing on macroalgae by larger invertebrates and fish is a very important component of dynamic

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[198] Cushing, D., "Population Production and Regulation in the Sea", Cambridge University Press, 1995, p. 354

[199] Hedges, J.I., R.G. Kiel and R. Benner, "What happens to terrestrial organic matter in the ocean?", *Organic Geochemistry* 27, 1997, pp. 195-212

[200] Lundin, C.G. and O. Linden, "Coastal ecosystems: Attempts to manage a threatened resource", *Ambio* 22, 1993, pp. 468-473

[201] Gratwicke, B. and M.R. Speight, "The relationship between fish species richness, abundance and habitat complexity in a range of shallow tropical marine habitats", *J. Fish Biol.* 66m, 2005, pp. 650-667; Romanuk, T.N. and C.D. Levings, "Relationships between fish and supralittoral vegetation in near shore marine habitats", *Aquatic Conservation: Marine and Freshwater Ecosystems* 16, 2006, pp. 115-132.

ecosystem interactions.[202] Away from the near-coastal areas, however, zooplankton grazers are the key ecosystem component at the secondary consumption level. In most jurisdictions these zooplankton are rarely used directly by humans, so they rarely are a direct consideration in policy and management. However, as the key pathway by which production is transferred up the food chain to fish and larger invertebrates, management needs to be responsive to major changes in zooplankton abundance and species composition. Such changes can occur seasonally and from year to year in ecosystems which experience strong forcing by physical ocean conditions such as currents and temperature.[203] Occasionally, zooplankton is used directly by humans, such as the krill fisheries in some Antarctic waters and other oceanic areas. As explained later in this Module, it is particularly important that management of such fisheries is highly risk averse (i.e., precautionary) and takes an ecosystem approach. Over-harvesting of secondary consumers can have widespread consequences for many marine predators that depend on the zooplankton for food.

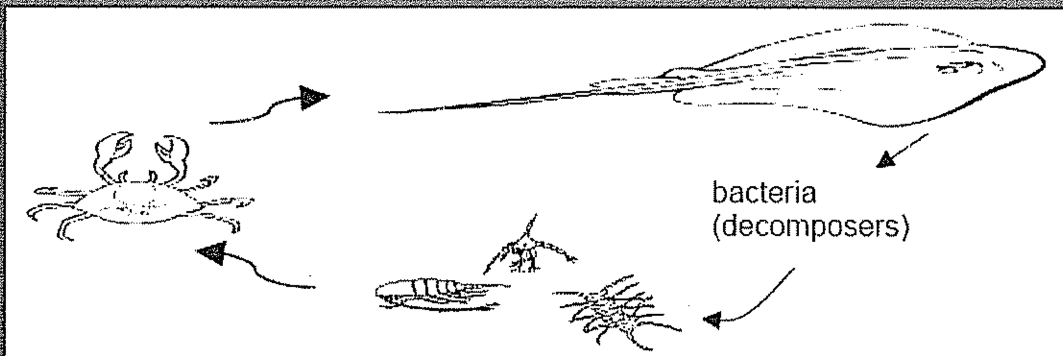

Figure 3: A simple marine food chain

The ray is the top consumer, the crab being the secondary consumer and the phytoplanktons are the primary producers.

Available at: http://www.marine.usf.edu/pjocean/packets/f99/f99u2le3.pdf.

[202] Mann, K D., "Ecology of Coastal Waters with Implications for Management", Blackwell Science, 2000.

[203] Hansen, P.J., P.K. Bjornsen and B.W. Hansen, "Zooplankton grazing and growth: scaling within the 2-2000m body size range", *Limnology and Oceanography* 42, 1997, pp. 687-704

In recent years, evidence has shown that there is a second pathway that primary production may take in marine ecosystems, from phytoplankton to microbial organisms where the production is cycled until it settles out in the detritus on the seafloor. This pathway is important because such energy is less available to the fish and larger invertebrates that graze on zooplankton.[204] Scientists do not yet understand fully the reasons why production may switch from the pathway of zooplankton, to fish and invertebrates, to the pathway of the "microbial loop", however, when it occurs it can result in major reductions in fish and invertebrates available for harvest. This illustrates another reason why ecosystem approaches try to maintain the species composition of the community, because such alterations in ecosystem composition and energy flows seem particularly hard to reverse, once they have occurred.

3.3 Marine fish and invertebrates

The diversity of marine fish and larger invertebrates is great, and new species continue to be found even in relatively well studied areas.[205] As a rule of thumb, highly productive systems have a greater biomass of fish and invertebrates, as well as more species.[206] In ecosystems characterized by stable physical oceanography, the species composition of the area may also be quite stable over time, including the relative abundances of the various species. In ecosystems where the physical processes are highly dynamic, either seasonally or among years, species composition and relative abundances of the fishes and invertebrates usually will also fluctuate greatly.[207]

Ecologists frequently differentiate the benthic, demersal, and pelagic components of the fish and larger invertebrate communities. This partitioning is partly a convenience for organizing information and conducting research. However, it does reflect that ecological relationships are often closest among species in the same component, although as explained below (see Section 3)), these components are always inter-linked.[208] The partitioning is often useful for managers and policy makers as well as for ecologists; because many managed

[204] D. Cushing, *supra* note 198; Miralto, B., *et al*, "The insidious effect of diatoms on copepod reproduction", *Nature* 402, 1999, pp. 173-176; Calbet, A. and M.R. Landry, "Meso-zooplankton influences on the microbial food web: direct and indirect trophic interactions in the oligotrophic open ocean", *Limnology and Oceanography* 44, 1999, pp. 1370-1380.

[205] Available at: http://www.coml.org.

[206] *Ibid.*; Ormond, R.F.G., J.D. Gage and M.V. Angel (eds.), "Marine Biodiversity: Patterns and Processes", Cambridge University Press, 1998

[207] Stachowicz, J.J., *et al*, "Biodiversity, invasion resistance, and marine ecosystem function: Reconciling pattern and process", *Ecology* 83, 2002, pp. 2575-2590; Snelgrove, P.V.R. and C.R. Smith, "A riot of species in an environmental calm: the paradox of the species-rich deep-sea floor", *Oceanography and marine biology: an annual review* 40, 2002, pp. 311-342.

[208] Kaiser, M.J., *et al*, "Marine Ecology: Processes, Systems and Impacts", Oxford University Press, 2005

human activities have their direct impacts, or draw their benefits directly from one of the three components. Thus the partitioning of the biological community into benthic (seabed), demersal (near the seafloor), and pelagic (up in the water column) components can be useful for both planning and for communication.

Benthic community

Where the seabed substrates are soft, such as sand and mud, a very diverse community of burrowing invertebrates and fishes may build up high biomasses. The burrowing "in-fauna" is often largely invertebrates, including many types of worms, shellfish, and others.[209] Both hard and soft seabed substrates can support diverse communities of benthic invertebrates attached to the seafloor but extending up into the water column. The emergent community can include many types of invertebrates, both sessile, such as corals, sponges, sea pens, bivalves, etc. and mobile species such as crustaceans, mollucs, etc.[210]

A number of fishes also are commonly part of both the burrowing and the emergent parts of the benthic community. Many of the fish and invertebrates can be important to commercial and subsistence fisheries, such as the shellfish, crabs, octopus, etc. Both of these benthic communities may be highly stable over time, or may be regularly diminished or even largely eliminated through wave actions, storms, etc.

Ecosystems characterized by regular natural disturbances of their benthic communities are often comprised of species that recolonize areas readily; whereas areas where natural disturbances are rare are likely to have more species with low ability to disperse and slow rates of population increase when they are introduced into an area.[211]

The benthic community is particularly important to management and policy for three reasons:

- Many types of human activities contact and alter the seafloor directly, and all of these will impact this community directly as well. In some cases the impact on the seabed is essential to conducting the activity, such as when fishing for burrowing shellfish. In other cases, the impacts are accidental but nonetheless can be serious, such as when

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[209] *Ibid.*; Waldbusser, G.G., *et al*, "The effects of infaunal biodiversity on biogeochemistry of coastal marine sediments", *Limnology and Oceanography* 49, 2004, pp. 1482-1492.

[210] Bradshaw, C., P. Collins and A.R. Brand, "To what extent does upright sessile epifauna affect benthic biodiversity and community composition?", *Marine biology* 143, 2003, pp. 783-791.; P.W. Barnes and J.P. Thomas, *supra* note 181; M.J. Kaiser *et al*, *supra* note 208

[211] Bolan, S.G., T.F. Fernandes and M. Huxham, "Diversity, biomass, and ecosystem processes in the marine benthos", *Ecological Monographs* 72, 2002, pp. 599-615; Rice, J.C. (ed.), "Ecosystem Effects of Fishing: Impacts, Metrics, and Management Strategies", *ICES Cooperative Research Report* 272, 2005a, p. 177.

benthic communities are smothered by dumping or sediments from seashore construction. The impacts of multiple or repeated human activities are also often cumulative. The consequences of a repeated chronic stress, or a number of different activities occurring in the same area, may pose a threat to the benthic community that warrants management action, even if impacts of individual activities are considered to be small. Hence, impacts on the benthic community will be a consideration in management of many human activities, not just those few that are actually intended to make use of the benthic community.[212]

- The severity of the impacts and the time at which it takes the community to recover will depend on both the nature of the impact and the natural patterns of disturbance of the benthic community. Good management and sound policies will have to take account of both the natural disturbance patterns of an area and the history of human use of the area. If the area is protected from natural disturbances by depth or natural protective barriers, and has not been used by humans intensively in the past, even relatively modest levels of disturbance may have major ecological consequences from which recovery will take many years.[213]
- The benthic community includes the natural detritus of the ecosystem. Everything that dies and sinks out of the water column without being eaten ends up on the seabed, so the benthic community is necessary to recycling energy and nutrients in marine ecosystems.[214] The importance of this will be discussed below (see Section 3), but in terms of implications for management, serious disturbances of benthic communities can have particularly widespread consequences for ecosystem functioning.

Demersal Community

Many species of fishes and some invertebrates comprise the demersal community. In high latitude and low productivity ecosystems there may be relatively few species in this community, but there may be many demersal species in an area that is highly productive, if the physical and chemical environment is fairly stable, or if the seafloor and benthic community has a complex three dimensional structure.[215]

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[212] Lindeboom, H. and S.J. de Groot, "The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems", 1998; ICES Report of the Advisory Committee on the Marine Environment, *Cooperative Research Report* 241, 2000

[213] Huston, A.H., "Biological Diversity: The coexistence of species on changing landscapes", Cambridge University Press, 1994; P.W. Barnes and J.P. Thomas, *supra* note 181.

[214] M.J. Kaiser *et al*, *supra* note 208; del Giorgio, P.A. and P.J. le B. Williams (eds), "Respiration in Aquatic Ecosystems", Oxford University Press, 2005.

[215] Gray, J.S., "Gradients in marine biodiversity", *in* R. F. G. Ormond, J. D. Gage and M. V. Angel (eds.) *Marine Biodiversity: Patterns and Processes*, Cambridge University Press, 1998, pp. 16-29

In ecosystems where productivity is highly seasonal, many important species in the benthic community may be migratory, sometimes over larger distances. Also demersal communities with many species are likely to contain species with very different life histories.[216] Some are fairly short-lived with most of the population comprising new recruits each year and maturation after only a few years or sometimes even a few months. Other species can be long-lived with very low rates of annual recruitment and may require two or three decades to mature. Demersal species may have very regular rates of annual recruitment, but often recruitment levels vary greatly from year to year, particularly in ecosystems where environmental conditions are highly variable over time. Individuals of some demersal species like cod and hake produce millions of eggs annually, but other species, such as skates and rays, usually produce only a few eggs. In many demersal species the larval and juvenile stages of fish and invertebrates may require different habitats and have different diets than the adult stages, and the various life history stages are sometimes found in completely different locations.

The key management and policy consideration is that the demersal fish community usually includes many of the species that support directed fisheries in an area.[217] The diversity of life history strategies that can be found in the demersal fish community makes it impossible to provide general guidelines on how management can ensure the fisheries are sustainable. Rather, this underscores the need for sustainable management to take account of the biological properties of the key species being exploited. This is often difficult in practice because the demersal community in most ecosystems contains a number of different species, with a range of life histories.

If the species are harvested together by unselective gears there is a tendency for exploitation rates to be set for the most productive and abundant species in the system. This can result in serious overexploitation of the species in the community with lower productivities – low annual rates of recruitment and older ages of maturation.[218] Where recruitment is highly variable from year to year, the exploitation rate for the species has to be

[216] Charnov, E.L. and J.F. Gillooly, "Size and Temperature in the Evolution of Fish Life Histories", *Integrative and Comparative Biology* 44, 2004, pp. 494-497

[217] D. Cushing, *supra* note 198

[218] Stokes, T.K., R. Law and J.J. McGlade (eds), "The Exploitation of Evolving Resources", Springer Verlag, Berlin, vol 99, 1993, p. 354

adjusted to track the changing productivity of the population.[219] This poses many management challenges, particularly when a species experiences a period of high recruitment, and attracts substantial interest from harvesters. When recruitment returns to average or low rates it may be hard to reduce or redirect the fishing effort that has built up, resulting in rapid depletion of the population at a time when it is unproductive and recovery is particularly difficult.[220]

Even if managers and policy makers are dealing with issues other than the directed fisheries, there still may be important considerations with respect to the demersal fish community. Because this community is closely associated with the seafloor and benthos, decisions affecting the well-being of the benthic community may have effects on demersal community stability and productivity as well. This is particularly the case when larval and juvenile fish make use of the three-dimensional structure of the seafloor and benthic community for shelter or feeding, which often occurs.

Pelagic Community

The fish species in the pelagic community often form dense schools, and are often highly migratory seasonally and mobile over short time periods. They can reach very high abundances, but abundance and productivity can both vary greatly between years and in many ecosystems, also on decadal and longer time periods.[221] Pelagic invertebrates are less commonly major components of the exploited pelagic community, but some species of squid, for example, show similar adaptations.

Small pelagic species such as sardines, anchovies, squid and herring can be important as food for other predators, whereas large pelagic species such as tunas and billfish can be dominant predators.[222] Because of their schooling and migratory patterns, and the tendency to occasionally reach high abundances, the role of pelagic species in local ecosystem dynamics can be important, but is hard to predict. Moreover, the migratory nature of many pelagic species means that ecosystem approaches to management of activities dependant on these populations will usually have to be on relatively large spatial scales, or else involve a cooperative effort among many jurisdictions. There are also some large pelagic sharks, and as

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219 *Ibid.*

220 Horwood, J., C. O'Brien and C. Darby, "North Sea cod recovery?", *ICES Journal of Marine Science* 63, 2006, pp. 961-968.

221 Schwartzlose, R.A., *et al*, "World-wide large-scale fluctuations of sardine and anchovy populations", *South African Journal of Marine Science* 21, 1999, pp. 289-347.

222 Cury, P., *et al*, "Small pelagics in upwelling systems: patterns of interactions and structural changes in 'wasp-waist' ecosystems", *ICES Journal of Marine Science* 57, 2000, pp. 603-618.

with demersal sharks, skates and rays, their life histories mean that they can sustain only low exploitation rates.[223]

The considerations for management and policy for this community are similar to those for demersal species. However, populations of pelagic species often vary even more than demersal species on decadal scales, and environmental conditions play a major role in these variations. There is an even greater risk that periodically managers will have to react to rapidly declining abundance of a species that support important fisheries.[224] The important role of many of these species in marine food webs also means that management failures often have serious, wide-spread and lasting consequences for many other parts of the ecosystems and for human uses of them. The position of many of the large and migratory pelagic species as top predators in the ecosystem also means that they can accumulate high levels of toxic chemicals if their prey is exposed to contaminants. These chemicals can pose health risks to humans eating the fish, and thus may pose challenges to managers and policy makers, even in jurisdictions far removed from the sources of pollution.

3.4 Seabirds, marine mammals, and sea turtles

All marine ecosystems support populations of marine birds, turtles, and mammals. Compared to fish and most invertebrates, all of these species have very low productivities and old ages of maturity, with many species producing a single young per year and some not even breeding every year.[225] This means that harvests of these species, if undertaken, need to be managed carefully at very low exploitation rates. Many, but not all, of these species are top predators feeding on fish or large invertebrates; however, some of the largest whales in the sea eat exclusively small zooplankton,[226] while turtles feed on seagrasses and/or invertebrates, such as sponges and jellyfish. Generally these higher vertebrates require reliable food supplies for survival and reproduction. Although many species are highly migratory on seasonal time scales, their breeding biology often ties them to very specific sites for key parts of the year. Thus, local prey availability at key breeding or foraging sites may matter at least as much as overall prey availability.

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[223] Musick, J.A., "Ecology and conservation of long-lived marine animals", 1999, pp. 1-10

[224] Rice, J.C., Evaluating fishery impacts using metrics of community structure in C. Hollingsworth (ed) *Ecosystem Effects of Fishing*, 2000, ICES Journal of Marine Science 57; Beamish, R.J., G.A. McFarlane and J.A. King, "Regimes and the history of the major fisheries off Canada's west coast Progress in Oceanography", 2004, pp. 355-385

[225] Croxall, J.P. (ed.), "Seabirds Feeding Ecology and Role in Marine Systems", Cambridge University Press, 1987; Hoetzel, A.R. (ed.), "Marine Mammal Biology", Blackwell Science, 2002b.

[226] Innes, S., *et al*, "Feeding rates of seals and whales", *Journal of Animal Ecology* 56, 1987, pp. 115-130; Tamura, T., "Regional assessments of prey consumption and competition by marine cetaceans in the world", *in* M. Sinclair and G. Valdimarsson, (eds.), "Responsible Fisheries in the Marine Ecosystem", FAO, 2003, pp. 143-170

The specific sites used for breeding, courtship, and other seasonal life history activities also usually require a high degree of protection. The protection is necessary when individuals are at the site for whatever life history activity is undertaken there, because populations are particularly vulnerable when they are aggregated. However, the habitat factors needed for the life history activity need protection even when the individuals are not present in the area, so the area will be suitable for the life history activity, when the proper season for each activity arrives.

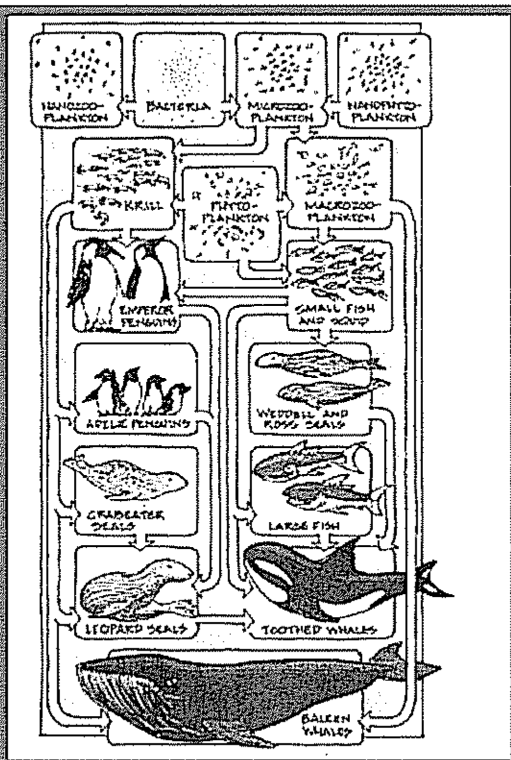

Figure 4: Biological ecosystem components: how it all comes together (food web)

http://www.gma.org/surfing/human/foodweb.gif

In terms of management and policy, these species are sometimes used for food, but almost none have been marketed commercially for several decades. However, populations of many species were severely depleted from historic over-harvesting or bycatches, or because their traditional habitats or migration routes have been greatly altered through human activities, including the release of exotic predators on many breeding colonies. With low inherent productivities, many of these species are recovering slowly, if at all, from their depleted abundances.[227]

Where legal mechanisms exist to protect species at risk of extinction, sea birds, sea mammals and sea turtles often are protected. Managers and policy makers often have to give high priority to protecting such species from harm, such as bycatch in fisheries or disturbance of their breeding sites. Even for abundant species of seabirds and marine mammals, species of fish and invertebrates on which they depend need to be managed to

[227] Perry, S.L., D.P. DeMaster and G.K. Silber, "The great whales: History and status of six species listed as endangered under the US Endangered Species Act of 1973", *Marine Fisheries Review* 61, 1999, pp. 1-74; IWC Report of the subcommittee on the Comprehensive Assessment of Other Whale Stocks, Annex G, *Journal of Cetacean Research and Management* 2, 2000, pp. 167-208.

allow ample food for their needs, often on relatively local spatial scales. All these species are air-breathing, as well, so they are frequently found on the surface of the water. This makes them highly vulnerable to oil spills, which is another consideration in routing of sea traffic. Many species also undergo major migrations, often in large groups, increasing even more their vulnerability to oil spills, boat strikes, or other disturbances by shipping at these times. When major migration routes are shared by several species, some jurisdictions will implement special management measures to protect the species along the migration corridor, as well the features that make the migration route important to the species. There is an on-going debate among scientists about the effects of noise in the ocean particularly on marine mammals. Although the issue is not yet resolved, it is certainly another consideration in management.[228]

3.5 Biological diversity

The concept of biological diversity is fundamental to an ecosystem approach. It stresses that an ecosystem is much more than just a list of species and the habitats in which they live.[229]

Biological Diversity of a System

The number of species of each general biological type that are present and the relative abundance of the different species are the cornerstones on which ecosystem relationships and ecosystems processes are built. Together, these factors – how many species are present (i.e., the "species richness" of an area), and how abundance varies among the species (i.e., the "evenness" of the abundance of the species), plus the genetic diversity within each population – constitute the biological diversity of the system. Some definitions of biological diversity (e.g., in article 2 of the CBD) also encompass ecosystem diversity in addition to species and genetic diversity.[230]

Ecosystems differ in these components of biological diversity, reflecting in part historic patterns of arrival of species in an area and adaptations of species to the physical and chemical features of the ecosystem and their variability, as well as the co-adaptations of the species to the presence of other species.

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[228] Richardson, W.J., *et al*, "Marine Mammals and Noise", Academic Press, 1995; Gordon, J., *et al*, "A Review of the Effects of Seismic Surveys on Marine Mammals", *Marine Technology Society Journal* 37, 2004, pp. 16-34

[229] R.F.G. Ormond, J.D. Gage and M.V. Angel (eds.), *supra* note 206; Duffy, J.E. and J.J. Stachowicz, "Why biodiversity is important to oceanography: potential roles of genetic, species, and trophic diversity in pelagic ecosystem processes", *Marine Ecology Progress Series* 311, 2006

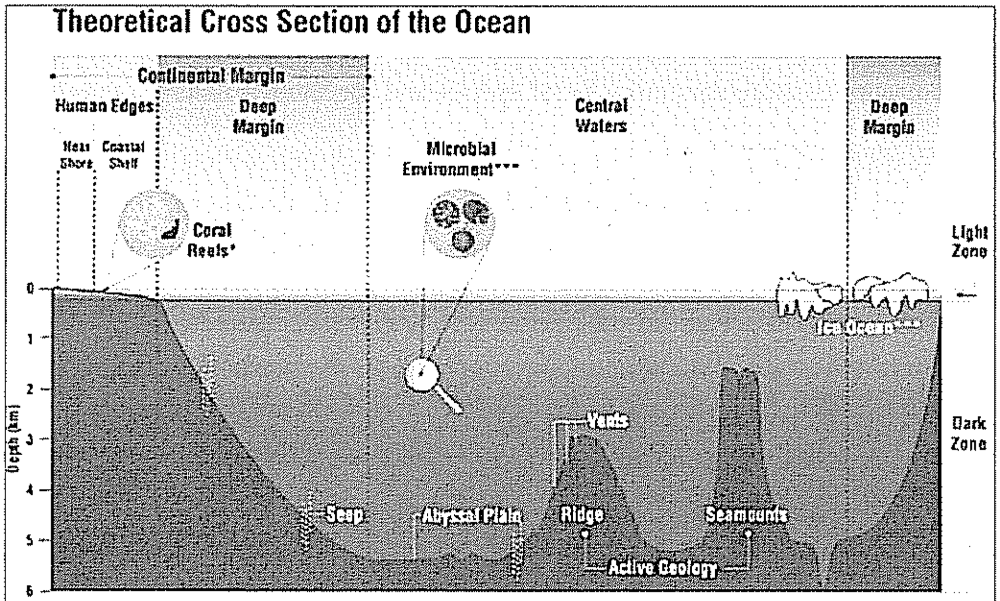
[230] According to article 2 of the CBD, "Biological diversity" means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

Box 12: The Census of Marine Life

The Census of Marine Life is a global network of researchers in more than 80 nations engaged in a 10-year scientific initiative to assess and explain the diversity, distribution, and abundance of life in the oceans. The world's first comprehensive Census of Marine Life-past, present, and future-will be released in 2010.

Seventeen projects conduct the research and analysis on six ocean realms that will be reported in the first Census of Marine Life in October 2010. The Scientific Committee on Oceanic Research Working Group monitors new technologies for observing marine life and recommends when cutting-edge marine technologies are mature enough to be used routinely in Census field projects.

Six Ocean Realms: To successfully undertake a task as massive as a global census of marine life, the oceans were divided into six realms (with respective sub-zones as necessary), with Census field projects developing efficient approaches for the exploration of each.



* Coral reefs are found in the warm waters of the Atlantic, Pacific, and Indian oceans

** Microbial environment encompasses the entire world ocean.

*** Ice oceans occur at both poles.

These realms were intended to encompass all major ocean systems and taxa, but were also selected to take advantage of the best available technologies. In all Realms, the Census seeks to representatively document diversity, in near surface waters it is tackling distribution, and along the human edges it is demonstrating best practices to estimate abundance. However, recognizing that over 95% of the more than 14 million geographic species records in OBIS are from less than 100 meter depths, it is clear that a quantitative census of all Realms was 'unknowable' in even such an ambitious ten-year program.

Available at: http://www.coml.org/aboutcoml.htm.

Determinants and consequences of biological diversity

Scientists have been studying the determinants and consequences of biological diversity for several decades.[231] Some important generalizations have emerged, as outlined below:

- **Productivity** – systems that are more productive also tend to be more diverse.
- **Structural complexity** – systems which have greater complexity of seafloor topography and/or marine plants and animals that provide three-dimensional habitat structure are more diverse than systems with less structural complexity.
- **Disturbance** – systems with a moderate rate of disturbance are more diverse than systems that are either very rarely disturbed or systems that experience frequent disturbances. It should be noted that:

  (a) the "disturbance" can involve impacts of human activities, but they can also involve natural disturbances, such as frequent scouring of shallow coastal seabed by storms and strong wave action;

  (b) in practice, there are no operational guidelines for what constitutes "moderate" or "frequent" disturbances and these are relative and comparative terms; and

  (c) the species composition and diversity of ecosystems can adapt to both very low and very high rates of disturbance: all are "ecosystems", but the life histories of species characteristic of areas of infrequent disturbances will be very different from those of areas with high rates of natural disturbance (the former will recover very slowly from major disruptions whereas the latter can often recover relatively quickly).

Like all generalizations, there are numerous exceptions to these patterns. However, where there is limited information about the communities that are actually present in an area, the generalizations present a reasonable basis on which to commence dialogue about policy and management. The dialogue should take account of the need for the **application of precaution** in the face of the uncertainties about the ecological communities (See Module 4).

Despite decades of scientific study, all issues concerning biodiversity have not been resolved. Debate still continues about the inter-relationship of diversity and stability of a community.[232] Interpretations of models and field studies have shown that highly diverse communities are more stable than less diverse communities for two reasons:

- Firstly, the greater diversity provides more linkages among species; and

[231] Pimm, S.L., "The Balance of Nature?", Chicago University Press, 1991; Covich, A.P., *et al*, "The Role of Biodiversity in the Functioning of Freshwater and Marine Benthic Ecosystems", *Bioscience* 54, 2004, pp. 767-775.

[232] S.L. Pimm, *Ibid.*; Schlaepfer, F. and B. Schmid, "Ecosystem effects of biodiversity: A classification of hypotheses and exploration of empirical results", *Ecological Applications* 9, 1999, pp. 893-912.

- Secondly, the greater number of linkages often buffers the system as a whole, damping major perturbations.

However, similar studies also have been interpreted as showing more diverse communities are less stable, in the sense that in a highly diverse community, external actions (human activities or environmental changes) are very likely to alter something in the community, and if the original community is highly diverse then once disturbed, there is a very low likelihood that it will return to exactly the same state as it was in before it was disturbed.

These debates are very interesting to the experts who have them, but often provide little help to managers and policy makers. Whether an ecosystem is highly diverse or relatively simple, it will change over time. Tasking managers and policy makers to allow human uses of marine ecosystems, while preventing any changes to them, will only guarantee that managers and policy-makers fail on both counts.

Ecosystem approach in the management context

An ecosystem approach is intended to guide managers and policy makers in choices which allow benefits to be taken from the seas while ensuring that the inevitable changes that are caused do not amplify in magnitude as they spread along the linkages in the ecosystem, and do not change even the most directly affected components of the ecosystem so much that recovery is unlikely.[233]

Summary of key ideas

(a) The biological components of the ecosystem include the primary producers, grazers and from one to three or four levels of predators.

(b) Some important generalizations have emerged from the study of the determinants and consequences of biological diversity: systems that are more productive also tend to be more diverse; systems that have greater complexity are more diverse than systems with less structural complexity; systems with a moderate rate of disturbance are more diverse than systems that are either very rarely disturbed or systems that experience frequent disturbances.

(c) The major ecosystem components share similar features, however, each grouping contains many different kinds of species and ecosystem-specific information is necessary to determine policy and management options that are appropriate for each specific ecosystem. In any given system, certain characteristics are likely to be the dominant considerations for managers and policy makers.

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[233] FAO Fisheries Department, "The ecosystem approach to fisheries", *Technical Guidelines for Responsible Fisheries* 4, suppl 2, 2003, p. 112.; Belfiore, S., *et al*, "A Handbook for Measuring the Progress and Outcomes of Integrated Coastal Ocean Management", *IOC Manuals and Guidelines* 46, ICAM Dossier 2, Paris, UNESCO, 2006.

Questions for discussion

(a) What important generalizations have emerged from the study of the determinants and consequences of biological diversity?

(b) What are the biological components of any given ecosystem?

4. Ecosystem processes and interactions

Ecosystems are more than the individual parts occurring in a specific place. The parts interact dynamically, including both interactions among species and individuals in an ecosystem, and the interactions of individuals and populations with the changing physical and chemical environment in which they live. The healthy functioning of these interactions is essential to the many services ecosystems provide for human societies and economies.[234] Unfortunately, the interactions are too numerous and too complex to measure and understand them all, and account for all of them in management. However, the types of interactions can be grouped into a small number of ecosystem **processes**. Understanding ecosystem processes provides a basis for managing human activities in the ecosystem in ways that do not jeopardize the structure and function of the ecosystem.[235]

Various scientific disciplines study and interpret these interactions and processes in different ways, depending on how the disciples conduct their work. Ecosystem experts may focus on nutrients and energy flows, and explain and model the ecosystem dynamics using physical and chemical terms and equations.[236] Alternatively, they may focus on individuals and populations, and explain and model ecosystem dynamics using terms and equations for physiological processes, life histories of plants and animals, and behaviours.[237] These two approaches are not fundamentally different in what they try to do or in the concepts underlying ecosystem processes. Neither way of looking at ecosystem processes is inherently more right or wrong than the other, nor is one any more useful to management and policy than the other. However, a number of aspects of individual applications may affect how easy it is to undertake either approach to understanding ecosystem dynamics, and apply the results to management and decision-making. Accordingly, it is necessary for managers and policy makers to be familiar with both approaches to the problem of representing and understanding ecosystem processes, and work effectively with information generated from each type of approach.

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[234] Costanza, R., "Thinking Broadly About Costs and Benefits in Ecological Management", *Integrated Environmental Assessment and Management* 2, 2006, pp. 166-173

[235] Pikitch, E.K., *et al*, "Ecosystem-Based Fishery Management", *Science* 305, 2004, pp. 346-347

[236] Ulanowicz, R., "Ecology the Ascendant Perspective", Columbia University Press, New York, 1997; Brown, J.H., *et al*, "Toward a metabolic theory of ecology", *Ecology* 85, 2004, pp. 1771-1789

[237] Koen-Alonso, M. and P. Yodzis, "Multispecies modelling of some components of the marine community of northern and central Patagonia, Argentina", *Canadian Journal of Fisheries and Aquatic Sciences* 62, 2005, pp. 1490-1512.

4.1 Nutrient and energetic approaches

As on land, life in the oceans usually begins with the basic process of **photosynthesis**, which requires sunlight and basic nutrients such as carbon, nitrogen, phosphorus, and many other elements and chemical compounds. The rates of production of organic carbon, amino acids, etc by algae (the chemical basis for the whole ecosystem) can be measured directly, or modeled from information about the nutrient concentrations in the sea, day length and light penetration, water temperature, and sometimes other basic features of the ecosystem.[238]

In marine ecosystems energy can enter the higher trophic levels through two other pathways. One is from the detritus (dead organic matter) on the seafloor and ammonia produced as waste by living organisms, which is called **regeneration** of energy/organic materials.[239] This organic matter on the seafloor may come from decomposed matter from aquatic plants and animals that have settled to the seabed, or from land-based runoff into coastal areas. Many benthic species depend on detritus as their primary source of food, and some bacteria use ammonia directly, providing a second pathway for organic carbon, energy and nutrient to be passed into the ecosystem.[240]

In recent decades, a third specialized core process for basic production in marine ecosystems has been found. In a few areas, such as hydrothermal vents on the sides of tectonically active undersea spreading ridges, hot, chemically-rich, waters are released from inside the earth's crust. In these areas, a number of specialized ecosystems have been found (see Box 13). These systems depend on **thermo-chemical processes** rather than photosynthesis as the basic source of energy and nutrients for their function.[241] The species in these ecosystems often are unique, with specialized adaptations in all their physiological processes. These highly specialized ecosystems that do not depend on the process of photosynthesis have not, to this point, been exploited by any major commercial or artisinal fisheries. However, they are important locales for scientific research; there is substantial interest in bioprospecting in these ecosystems; and there may be potential for eco-tourism. At present it is their unique biodiversity properties that make these areas most relevant to management and policy, because there is wide consensus that these unique ecosystems should be disturbed as little as possible by human activities.

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[238] R. Ulanowicz, *supra* note 236; C.B. Miller, *supra* note 193

[239] Legendre, L. and R. Rivkin, "Cycling of biogenic carbon in oceans: regulation by food-web control nodes", *Ocean Biogeochemistry, a New Paradigm* 1, 2000, pp. 85-86

[240] P.A. del Giorgio and P.J. leB. Williams (eds.), *supra* note 214

[241] Tunnicliffe, V.J., A.G. McArthur and D. McHugh, "A biogeographical perspective on deep-sea hydrothermal vent fauna", *Advances in Marine Biology* 34, 1998, pp. 353-442; Van Dover, C.L., "The Ecology of Deep-Sea Hydrothermal Vents", Princeton University Press, 2000

Box 13: Hydrothermal Vent Ecosystems

The discovery of diverse and productive biotic communities around deep-sea hydrothermal vents in the last half of the 20th Century was in sharp contrast to the view of the deep-sea as cold, unproductive, and poor in species diversity and biomass. These systems were found not to depend on carbon sinking from the sea's upper surface of primary productivity, but on micro-organisms like bacteria that used chemosynthesis rather than photosynthesis as a basis for primary production. There are at least four different kinds of micro-organisms that capture nutrients and form the basis for deep-sea food webs, such that there are many ecological niches in these communities, even at the level of the primary producers and fixers of energy in the biotic system.

Where hydrothermal systems support high production of micro-organisms, large and diverse communities of filter-feeding organisms have also evolved. Some of the species in these communities are highly specialized species from large and familiar families and orders of marine organisms, such as many species of tube-worms that are related to the common polychaete worms of shelf and coastal communities, and highly specialized bivalve molluscs, sometimes with obligatory symbiotic chemo-synthetic bacteria housed in their shells. However the thermal vent species may be adapted not just to feeding on the vent micro-organisms, but may have evolved tolerances to temperatures of 800 C or more, and to concentrations of hydrogen-sulfides and heavy metals so high that they may be lethal to benthos in coastal waters.

Mobile predators and grazers on the micro-organisms have also evolved in many hydrothermal vent communities. Some are related to known families and orders of marine invertebrates from coastal and shelf seas, such as shrimp and isopods.

Although some of the species found in these hydrothermal vent communities are related to known shelf and coast species, some are phyla, classes and orders not previously known to science – or known only from other extreme environments. These unique higher classification units underscore the unique biodiversity and community structure of these deep-sea hydrothermal vent communities. The values of these highly specialized organisms to knowledge are only beginning to be explored. Although potentially the source of new biochemical products for human use in health and possibly other fields, they are also a rich source of information on how marine ecosystems work, how communities co-evolve, and possibly even on the origins of life. Hence, there is growing interest in the scientific and conservation communities to ensure that these systems are effectively protected from all destructive human practices, whether targeted at these communities directly, or only affecting them indirectly.

Van Dover, C. L., "The Ecology of Deep-Sea Hydrothermal Vents", Princeton University Press, 2000.

Jeanthon, C., "Molecular ecology of hydrothermal vent microbial communities", Kluvier Academic Publishers, 2000.

There are other aspects of these processes that are important for policy and management. First of all, management and policy need to be sensitive to major changes in nutrient levels in ecosystems, because these may affect the productivity of the entire ecosystem. As described above (see Section 2), there are natural patterns of seasonal change in nutrients, inter-annually, and sometimes on other time scales. Human activities on land (for example, agricultural run-off) and in the sea (for example, open-pen aquaculture) may also alter nutrient levels in the sea, at least on local scales, sometimes by greater amounts than occur from natural variation in nutrient levels.[242] Because photosynthesis rate is also sensitive to light intensity, and under some circumstances, temperature, changes in water clarity due to human activities may affect the rate of these basic ecosystem processes. Photosynthesis produces oxygen in the sea, just as plants do on land, whereas regenerating organic energy from detritus does not. In fact, bacteria require oxygen in the process of decomposition of biological matter on the seafloor, so this process uses oxygen, rather than produces it. Hence, the balance of energy in a marine ecosystem from photosynthesis as opposed to detritus has many implications for the rest of the ecosystem that requires oxygen as well as energy from these processes.[243]

Ecosystem dynamics generally have adapted to natural variation in these features on many time scales. However, management and policy makers have to be vigilant to adapt the rate and pattern of harvesting of ecosystem components to changing productivity. Likewise, policy makers and managers need to remain aware of land-based and marine-based human activities that introduce new chemicals or alter the typical levels of characteristic nutrients and sediments. They should work to keep levels of introduced nutrients within historic ranges of the concentrations of the chemicals and sediments, and to react to changes appropriately when major changes are detected. It may often be the case that historic ranges of nutrients and chemicals are poorly known, or that systems have adapted to rates of nutrient inputs from external (often land-based) sources that differ from historical rates. In such cases, a more realistic management objective may be to keep further perturbations from elevating the rates of nutrient input to even more extreme levels, where consequences for the ecosystem are unknown.

Once energy is fixed (transformed) in ways that the other organisms in the ecosystem can use it, energetic approaches focus on the other processes that determine *how* it is used.

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[242] J.I. Hedges, R.G. Kiel and R. Benner, *supra* note 199; Lohrer, A.M., *et al*, "Terrestrially derived sediment: response of marine macrobenthic communities to thin terrigenous deposits", *Marine Ecology Progress Series* 273, 2004, pp. 121-138

[243] A. Longhurst, *supra* note 182; Levin, L.A. and R.J.A. Atkinson, "Oxygen minimum zone benthos: adaptation and community response to hypoxia", *Oceanography and Marine Biology Annual Review* 41, 2003, pp. 1-15; P.A. del Giorgio and P.J. leB Williams (eds.), *supra* note 214

One such key process is called **transport**. Oceans are dynamic, and the algae and bacteria responsible for photosynthesis and regeneration are so small that wind and storm-induced turbulence, tides, and currents, on many scales, may transport them great distances. These same physical processes can be responsible for the processes of **concentration** or **dispersal** and **retention** of the production. These physical processes in the sea have major implications for determining *where* in the sea there will be relatively dense or sparse concentrations of all animals and relatively rich or limited biodiversity.[244]

Models of the physical oceanography for many marine areas have been developed, on scales from local coastal embayments to full ocean basins. Where there is sufficient information to model ocean physics (that is, just the movement of water described by its characteristic temperature, salinity, etc.) these models often are very effective at explaining the movements, concentrations and dispersions of the basic organic production of the ecosystem as well.[245]

Managers and policy makers rarely attempt to manage ocean transport and concentration processes, particularly on scales above a few hundreds of meters. However, information on these processes is essential for effective spatial management of human activities in the sea. This information makes a fundamental contribution both to knowing where to achieve the greatest biodiversity benefits from protection of a given amount of area, and to knowing where to focus human activities to obtain the greatest sustainable benefits from the ecosystem with the least cost, effort, and minimal "footprint" on the ecosystem.

In an energetics framework, once organic energy is produced through photosynthesis or regeneration of nutrients, it is passed to the rest of the ecosystem through the processes of **grazing** and **consumption**.[246] The rate and magnitude of these processes are fundamental to the ecosystem structure and function, and the sustainable uses that can be made of the ecosystem.[247] The processes have a major role in determining how much biomass can exist at the higher trophic levels in the ecosystem, the rates at which biomass and energy naturally "turn over" in the ecosystem, and the rates at which human uses can sustainably remove biomass or energy from the ecosystem.

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[244] A. Bakun, *supra* note 178

[245] Agnostini, V.N. and A. Bakun, "Ocean triads in the Mediterranean Sea: physical mechanisms potentially structuring reproductive habitat suitability (with example application to European anchovy Engraulis encrasicolus)", *Fisheries Oceanography* 11, 2002, pp. 129-142.

[246] Grazing is a term usually applied to eating primary producers, whereas consumption can involve any animal eating another animal or plant.

[247] Banse, K., "Zooplankton: pivotal role in the control of ocean production", *ICES Journal of Marine Science* 52, 1995, pp. 265-277; K.D. Mann, *supra* note 202; C.B. Miller, *supra* note 193

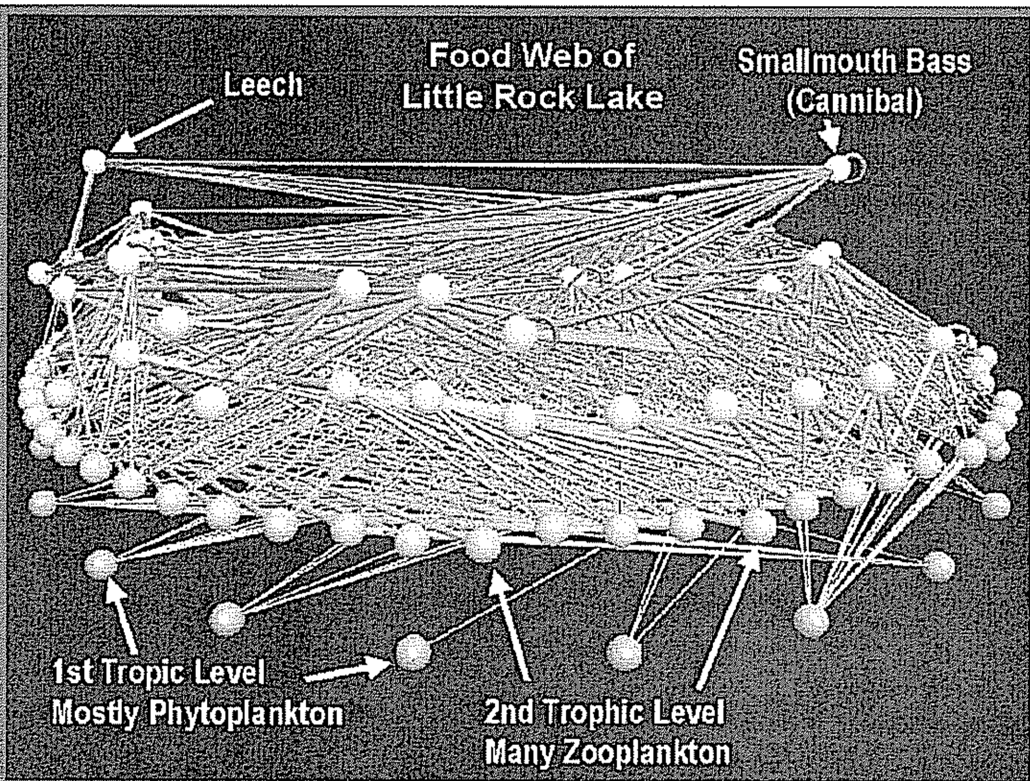

Figure 5: Complex interrelationships:
Model of trophic relationships between species within a marine food web

Available at: http://userwww.sfsu.edu/%7Ewebhead/lrl.html.

The other key process involved in the movement of energy and biomass in these energetics approaches is the **ecological efficiency** with which energy is used within each level.[248] Animals require energy to live, so not all of the energy they consume from their prey is available to either consumers that eat them, or to decomposers that will recycle their nutrients when they have expired and settled to the sea floor. The process of **respiration** is usually how energetics experts account for the energy used by organisms in performing their own life history functions, and thus not available to other consumers. The difference

[248] R. Ulanowicz, *supra* note 236; J.H. Brown *et al*, *supra* note 236.

between the energy taken in through grazing or consumption and lost through respiration is captured by the process of growth, which in energetics models may be either **growth** of the population or of the size of the individuals.

Scientists have devoted significant effort to developing models of these processes, and determining the key factors that affect the rate at which these processes proceed. One key consideration is the relative densities of the consumer and of the organisms they are consuming (both a grazer consuming algae or some higher predator consuming some prey). This relative abundance matters on the spatial scale and determines the rate of productivity and availability of food supply (prey) for the consumer (predator). This scale can be on small scales (centimeters) for grazers on phytoplankton, as well as larger scales of the concentration and retention mechanisms in the sea. This scale can be very large (hundreds to thousands of kilometers) when the consumers are large and highly mobile.[249]

If the density of the food supply is so low that consumers have trouble meeting their basic needs for respiration, then the system is food-limited or controlled from the "bottom-up". If the density of consumers is so low that they cannot eat the biomass of their food supply as fast as it is produced, then the dynamics of system are considered to be driven from the "top-down".[250]

Processes like consumption, respiration and growth are interconnected and occur at varying ecological rates. However, these rates are affected by more than just the densities of the consumer and the food supply. These rates are affected by the size of the organisms, with smaller organisms losing proportionately more energy to respiration than large ones, (i.e. being less "ecologically efficient").[251]

These ecological processes have many implications for managers and policy makers. Management and policy need to be responsive to natural variations in space and on time scales from diurnal to decadal, with regard to changing relative abundances of consumers

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[249] Schneider, D.C., "Quantitative Ecology: Spatial and Temporal Scaling", Academic Press, 1994; Fulton, E.A., A.D.M. Smith and C.R. Johnson, "Mortality and predation in ecosystem models: is it important how these are expressed?", *Ecological Modelling* 169, 2003, pp. 157-178

[250] Rice 2000, *supra* note 224; Hunt, G.L. and S. McKinnell, "Interplay between top-down, bottom-up, and wasp-waist control in marine ecosystems", *Progress in Oceanography* 68, 2006, pp. 115-124

[251] von Bertalanffy, L., "Quantitative laws in metabolism and growth", *Quarterly Review of Biology* 32, 1957, pp. 217-231; de Roos, A.M., L. Persson and E. McCauley, "The influence of size-dependent life history traits on the structure and dynamics of populations and communities", *Ecol. Lett.* 6, 2003, pp. 473-487

and their food. Management and policy need to ensure human activities do not greatly alter these ratios of consumers and their food supply in either direction. The consequences of switching systems from being driven from the top-down to the bottom-up can be very difficult to reverse.[252] Managers and policy makers need to take into account the composition of the biological community that they are managing. Any human activity that greatly increases the mortality rate in the ecosystem, including but not exclusively harvesting, usually results in a higher proportion of small organisms in the ecosystem. Animals need time to grow and with higher mortality rates it is harder to live long, with two consequences. Short-lived species that mature at small sizes become more common than long-lived animals that grow to larger sizes before maturing. In addition, the populations of long-lived animals become comprised of a higher proportion of small and immature individuals, as few survive to maturity. The increase in proportion of small organisms in the oceans will, all other things being equal, mean that more of the production will be lost through respiration, and less will be available for use by other organisms in the ecosystem and by humans taking benefits from the marine ecosystem.

4.2 Individual and population-based approaches

When considering primary **productivity**, the organism and community-focused approach is similar to the energetics-based approach. In both approaches, it is nutrient levels, and physical and chemical oceanographic conditions, that drive the dynamic changes in productivity. The major distinction in the models is likely to be calculations of density of plankton, or their abundance, rather than simply grams of carbon or some other chemical. These models also sometimes draw distinction among different types of plankton, such as diatoms (plankton with silicon skeletons that sink when they die) and dino-flagellates (plankton with no hard shell, and sometimes some mobility in the water column).[253]

[252] FAO 2003, *supra* note 233

[253] Sakshaug, E., *et al*, "Parameters of photosynthesis: definitions, theory and interpretation of results", *Journal of Plankton Research* 19, 1997, pp. 1637-1670; Cowles, T.J., D.J. Desiderio and M.E. Carr, "Small-scale plankton structure: persistence and trophic consequences", *Oceanography* 11, 1998, pp. 4-9; C.B. Miller, *supra* note 193.

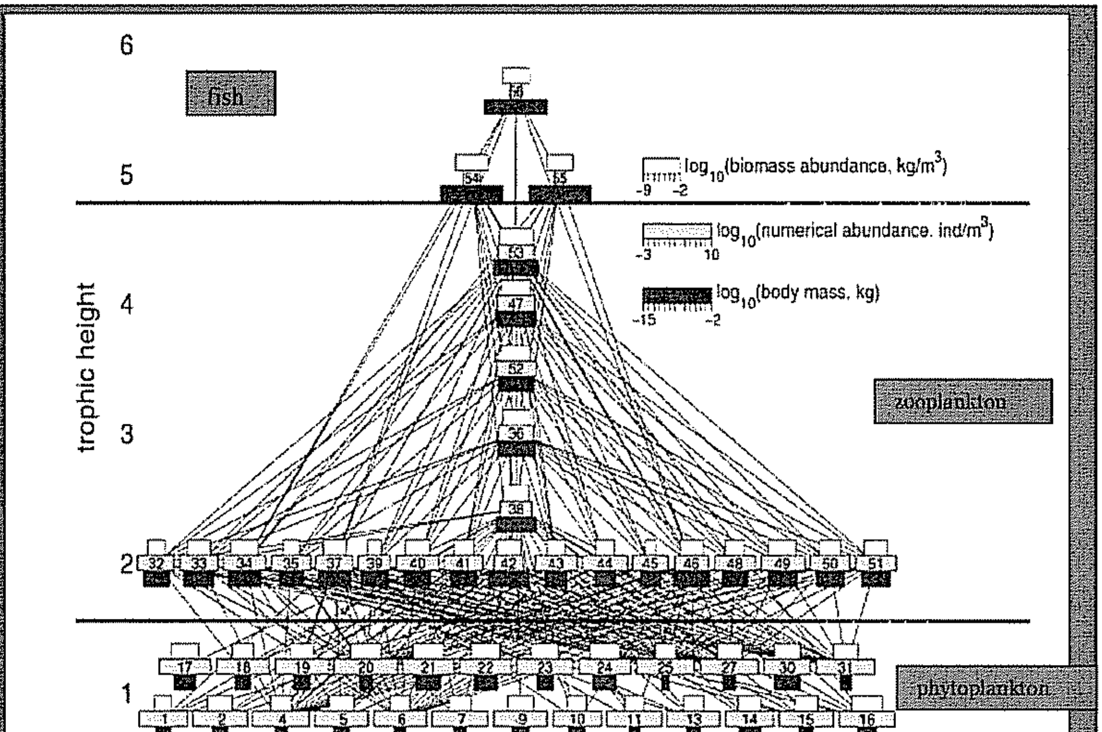

Fig. 1 The food web of Tuesday Lake in 1984. The width of the black, gray, and white horizontal bars shows the log_{10} body mass (kg), log_{10} numerical abundance (individuals per m^3), and log_{10} biomass abundance (kg/m^3), respectively, of each biological species. Species numbers are identified in ref. 5. The vertical positions of the species show trophic height. Basal species have a trophic height of 1, but to allow for wider, nonoverlapping bars the vertical positions of the basal species have been adjusted around 1. The horizontal position is arbitrary. Isolated species are omitted. Species with a trophic height of 1 are phytoplankton, those with trophic height >4.5 are fish, and those with intermediate trophic heights are zooplankton.

Figure 6: Simple "food pyramid" illustrating feeding relations between trophic levels and respective population characteristics at each level

Adapted from Cohen, J., T. Jonsson and S. Carpenter, "Ecological community description using the food web, species abundance, and body size", PNAS, 18 Feb 2003, vol. 100(4), pp. 1781-1786.

The management and policy considerations also are similar in the two approaches. One issue of growing importance in this type of approach is the relative abundance of diatoms and dino-flagellates in the production. These types of phytoplankton may have different fates in the food web, and different roles in how climate variation and climate change may affect and be affected by the ocean.

The physical oceanographic processes of **transport, retention, concentration,** and **dispersion** receive similar consideration in both approaches as well. The implications for management and policy, in terms of responsiveness to natural changes and in terms of place-based approaches to management, are much the same.

The major difference between the approaches is found in how the larger organisms in the ecosystem are studied, understood, explained, and managed. **Grazing** is commonly used in referring to zooplankton feeding on phytoplankton. However, feeding processes among the zooplankton, larger invertebrates, fish, and higher marine vertebrates are expressed as predator-prey interactions or **predation**. These can be studied and modeled on scales from the predatory behaviour of individual organisms to dynamic linkages between the biomass or abundance of large functional groups, such as "zooplankton", "forage species" and "top predators". In all cases, however, the models attempt to link the status of the predator to the status of the prey, and *vice versa*.[254]

Whereas predation is the pathway that allows individuals or populations to gain energy, within each individual, population, or trophic category, other life history processes are also considered as part of ecosystem dynamics. These include explicit representation of the processes of:

- **somatic growth**: increases in body size;
- **respiration**: the energy needed to live and move;
- **maturation**: at least to sexual maturity, and sometimes passage across multiple immature life history stages;
- **reproduction**: producing eggs or young;
- **recruitment**: receiving new individuals to the population; and
- **natural mortality**: death from non-human causes, or, when predation mortality is estimated directly, death from causes other than being eaten or killed by human activities.

In addition, in multispecies settings, additional processes become important, such as:

- **competition**: the impact that the presence of other species has on the resources available to one species; and
- **habitat selection**: the ability of an individual or population to find places where the resources needed for the other life history processes will be available.

[254] Hollowed, A.B., *et al.* "Are multispecies models an improvement on single species models for measuring fishing impacts on marine ecosystems?", *ICES Journal of Marine Science* 57, 2000, pp. 707-719; Steffansson, G., "Multi-species and ecosystem models in a management context", *in* M. Sinclair and G. Valdimarsson (eds.), "Responsible Fisheries in the Marine Ecosystem", FAO, 2003, pp. 171-188; E.A. Fulton, A.D.M. Smith and C.R. Johnson, *supra* note 249.

Approaches to modeling and understanding ecosystem dynamics do not always explicitly include consideration of all of these processes. Minimally, there should be representations of growth, reproduction, and mortality in a single-species population model, and predation in multi-species and ecosystem models. Models can be very simple or very complex, but usually include density-dependent relationships in at least one process: possibly the relationships between predators and their prey, the foraging behaviour of individual predators, the production of progeny by adults, or in several of those places at once.[255] The effects of changing the state of the physical and chemical environment can also be represented by linking environmental features directly to the life history processes that the environment is considered to affect.[256] For example, growth rates of individuals or populations can be linked directly to water temperature, maturation rate to the availability of food, and mortality rates to the quality of the habitat.

These individual and population-based approaches look attractive to many managers and policy makers, because they can represent exactly the parts of the ecosystem that are being used (for example, when harvesting a population that is also a key food supply), or being altered by a human activity (for example, coastal development that affects the quality of habitat for fish). However, the more detail that is desired in an ecosystem model for support of management or policy, the more that has to be known about the system being modeled.

This link between the information desired for management, the complexity necessary for the ecosystem representation (as a conceptual or computer model), and the information needed on the system being managed, has major implications for monitoring, as discussed below. It also has major implications for modeling as well. There is a growing tendency to seek models that are not "data – hungry". This can be attempted through aggregating groups of species or populations that are thought to act the same way, and that respond the same way to changes in the physical or chemical environment. In this case, it is only necessary to specify the dynamic behaviour of the aggregate, and not all its pieces.

Such simplifications are always necessary when knowledge is being used to support policy and management. However, those doing the work and those using the results should always keep in mind that the products can be made to look much more "scientifically rich"

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[255] Hilborn, R. and C.J. Walters, "Quantitative fisheries stock assessment: choice, dynamics and uncertainty", Chapman and Hall, New York, 1992; D. Cushing, *supra* note 198; G. Steffansson, *Ibid.*

[256] Schrum, C., I. Alekseeva and M. St. John, "Development of a coupled physical-biological ecosystem model ECOSMO Part I: Model description and validation for the North Sea", *Journal of Marine Systems* 61, 2006, pp. 79-99; see also: http://www.ecofoci.noaa.gov.

than they really are. If the groupings of "like species" in these ecosystem models are large, it will not be true that all the species in the grouping will respond the same way to changes in their food supply, the abundance of their predators, and their physical environment. Moreover, often the linkages between the species or groups in these ecosystem models are based on relatively little study, or study under a narrower range of conditions than the range of conditions under which they will be used. In these circumstances, the support provided to policy and management by these ecosystem studies and models may be unreliable, even though the outputs look scientifically impressive.

There are several important implications for management in this respect. First of all, managers and policy experts can get all the support from these types of models that they can get from energetics-based models. Sometimes the questions must be asked in different ways, but both paths can eventually lead to the necessary support. The choice of which approach to take may be partly a matter of taste or availability of expertise. However, the preferred choice also reflects to some extent what is being managed. If the human activities being managed are expected to have major impacts on nutrient levels, water clarity, or local physical mixing or turbulence (for example, land-based run-off, causeways, harbour developments) then energetic approaches address these considerations directly. When the activities being managed affect populations directly (for example, harvesting increasing mortality, or activities preventing easy access to places important for some life history activities) then population and community-based approaches may be the more useful. Likewise, when clients of management or policy are particularly interested in biodiversity or specific populations, approaches which focus on populations and communities often facilitate dialogue.

A great deal of data and knowledge of an ecosystem is needed if complete population and community models are to be developed in support of management and policy. However, even simple models can shed substantial light on which processes are critical functions (see Section 5 below), and on some of the consequences of major human perturbations to these systems. Simple models can use general knowledge of animal life histories matched to the most general patterns of major community properties, to explore management scenarios and system responses.[257]

Perhaps more importantly, population and community-based support for policy and management can also make extensive use of **community and traditional knowledge,** because residents of coastal areas and users of marine resources are likely to experience

[257] Pope, J.G., *et al*, "Modelling an exploited marine fish community with 15 parameters – results from a charmingly simple size-based model", *ICES Journal of Marine Science* 63, 2006, pp. 1029-1044

those systems through the status of their populations and communities.[258] This knowledge can be especially important because, as mentioned earlier, very often when science experts are asked to develop dynamic conceptual or computer models for a population or community, they have relatively little data with which to determine how relationships should be represented in the models. Even when they have such data, the management or policy question may ask how the ecosystem would respond under conditions, quite different from those where and when the data were collected. In these cases, experiential knowledge may be invaluable in helping to provide useful process-based insights into how the ecosystem would respond to the management or policy options that are being considered.

Summary of key ideas

(a) Ecosystems are more than the individual parts occurring in a specific place. The parts interact dynamically, including both interactions among species and individuals in an ecosystem, and the interactions of individuals and populations with the changing physical and chemical environment in which they live. The healthy functioning of these interactions is essential to the many services ecosystems provide for human societies and economies.

(b) The types of interactions in an ecosystem can be grouped into a small number of ecosystem processes. Understanding these processes provides a basis for managing human activities in the ecosystem in ways that do not jeopardize the structure and function of the ecosystem.

(c) Ecosystem experts may focus on nutrients and energy flows, and explain and model the ecosystem dynamics using physical and chemical terms and equations. Alternatively, they may focus on individuals and populations, and explain and model ecosystem dynamics using terms and equations for physiological processes, life histories of plants and animals, and behaviours.

(d) Ecological processes have many implications for managers and policy makers. Management and policy need to be responsive to natural variations in space and on time scales from diurnal to decadal, with regard to changing relative abundances of consumers and their food. Management and policy need to ensure human activities do not greatly alter these ratios of consumers and their food supply in either direction. Managers and policy makers need to take into account the composition of the biological community that they are managing.

[258] Berkes, F., J Colding and C Folke, "Rediscovery of traditional ecological knowledge as adaptive management", *Ecological Applications* 10, 2000, pp. 1251-1262; Grey, T.S (ed.), "Participation in Fisheries Governance", Kluvier- Springer, 2005.

Questions for discussion

(a) What are the differences between the nutrient and energetic and the individual and population-based approaches to explaining ecosystem dynamics?

(b) What are the respective advantages and disadvantages of these two approaches?

5. Critical functions

Every place and species in an ecosystem has some role in ecosystem structure and function; every place and species in the system may make some contribution, directly or indirectly, to the goods and services enjoyed from marine ecosystems. The preceding sections have explained why each major ecosystem component and process *may* be important to management and policy. However, given the huge number of components and processes (all the species and all their linkages) in an ecosystem, it is impossible for managers and policy makers to consider them all in each action that they take. Sustainable use is fundamentally about choices, and in an ecosystem approach, some of the choices are about which ecosystem components to treat as priorities.

From the biological and ecological perspective, those choices should be based on which components and which processes are *critical* to regulating ecosystem structure and function.[259] Even though all species and all places may make some contribution to maintaining ecosystem structure and function, their contributions are not equal. Rather, usually only a few of the species and processes in a complex ecosystem determine the rate at which system dynamics and species interactions occur in the ecosystem. These species are considered to **regulate** the critical functions in the system.

A process or species is considered to "regulate" ecosystem structure and function if the rate at which the processes occur in the ecosystem, or the well-being and productivity of the populations in it, are strongly influenced by the specific process or species.[260] "Strongly influenced", in turn, does not mean that every change in the status of the species or process that "regulates" system dynamics is matched by changes in many other parts of the ecosystem. However, it does mean that effects of any major alterations in the regulatory species or process can be expected to spread to many other species or processes, to expand widely in space – often beyond the site where the alteration was caused, and to persist in time.[261]

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[259] Rice, J C., *et al*, "Guidance on the application of the ecosystem approach to management of human activities in the European marine environment", *ICES Cooperative Research Report* 273, 2005, p. 22

[260] D. Cushing, *supra* note 198; A B. Hollowed *et al*, *supra* note 254

[261] Yodzis, P., "Must top predators be culled for the sake of fisheries?", *Trends in Ecology and Evolution* 16, 2001, p. 78-84

How can these critical functions be identified in any single case? Unfortunately, there is no recipe book that ensures that the critical functions in any system can be identified readily. Nonetheless, there are a number of questions which managers and policy makers can pose to their advisors on ecosystem approaches, and use as a basis for discussion with those considered to have experiential knowledge of the ecosystem. The answers to the questions and the inclusive dialogue can often help to identify the critical functions in any system.

- Are there **major physical or chemical drivers** that are known to vary greatly seasonally or among years, which affect the productivity and species composition of the ecosystem? Examples would include strong upwelling areas, areas dominated by strong tides, or areas where El Niño may produce strong changes in water temperature. In these cases primary productivity and temperature sensitivity of growth and maturation may be critical ecosystem functions.

- Is the **structural complexity** of the seafloor and benthic community important for habitat selection and protection from predation by fish and invertebrates? Examples would include slope edges, seamounts or coral reefs. In such cases habitat selection, predation, and recruitment of the species living in association with the structural habitat features may have critical ecosystem functions.

- Is the system often characterized as having surplus **nutrients** and/or low **oxygen levels**? Examples would include areas that frequently experience eutrophication. If so, productivity and respiration are likely to have critical functions in those systems.
  Are there **particular species of prey** that, when abundant, are the major food supply for many different predators in the ecosystem? Examples could be capelin in northern Boreal systems, or copepods or euphasiids in many mid-latitude systems. If so, then predation is a critical function and the ecosystem is likely to be regulated from the "bottom up", particularly if recruitment to the key feed species is strongly affected by water temperature, salinity, etc.

- Are there **particular species of predator** that, when abundant, remove major fractions of the prey base? An example is the reduction in prey around breeding sites for colonial seabirds. If so, predation is a critical function in the ecosystem and the ecosystem is likely to be regulated from the "top-down", particularly if the top predators are long-lived in comparison to the normal lifespan of their prey.

There are two additional key considerations regarding critical functions and food-web relationships. First, in even a moderately species-rich ecosystem, there are a very large number of connections between each species of prey and all the species that may prey on it, and between each predator and all the species on which it may prey. Hence, foodwebs of adequately studied marine ecosystems are always a tangle of linkages that are too inter-connected to be readily amenable to measurement.[262] Many studies have shown that the complexity of linkages is important to maintaining many higher-orders but vital ecosystem functions, such as resilience to stress and recovery from perturbations.[263] These numerous linkages can be particularly important when they are partly "compartmentalized"; that is partitioned in space in the larger ecosystem, such as having many interactions among the benthic species as predators and prey, and numerous interactions among pelagic predators and prey, but comparatively few linkages between those "compartments" of the ecosystem.[264] A small subset of all these linkages are often the ones which dominate the flow of biomass and energy through the ecosystem, and **regulate** the dynamic properties of the ecosystem. That does not make these **strong linkages** easy to identify without a lot of information, but it makes them very important to consider in management and policy.[265]

Second, even when no single species of predator may regulate ecosystem structure and function from the top down, it is possible that top-down predation pressure is still a critical function in the ecosystem. These circumstances can arise because predation in the sea is very often size-based more than it is species-based. For example, in a given area the diets of two large demersal species – perhaps two species of flatfish – of the same length may be much more similar to each other, than the diets of 10 cm and 70 cm fish within either species. This size-based view of predation is attracting substantial attention because fish size is relatively readily monitored in the sea and in catches, size-based models capture many important ecosystem dynamics at least as well as species-based models, and reasonable guidance to management and policy can often flow as readily from size-based ecological studies as from species-based studies.[266]

Once they have been identified, these critical functions have a number of roles in management:

[262] Yodzis, P., "Food webs and perturbation experiments: theory and practice", *in* G.A. Polis and K.O. Winemiller (eds.), "Food webs: integration of patterns and dynamics", Chapman and Hall, 1996, pp. 192-200

[263] Brookes, J.D., *et al*, "Multiple interception pathways for resource utilization and increased ecosystem resilience", *Hydrobiologica* 555, 2005, pp. 135-146.

[264] McCann, K.S., J.B. Rasmussen and J. Umbanhowar, "The dynamics of spatially coupled food webs", *Ecology Letters* 8, 2005, pp. 513-523

[265] Berlow, E.L., *et al*, "Quantifying variation in the strengths of species interactions", *Ecology* 80, 1999, pp. 2206-2224; Berlow, E.L., *et al*, "Interaction strengths in food webs: issues and opportunities", *Journal of Animal Ecology* 73, 2004, pp. 585-598

[266] Bianchi, G.L., *et al*, "Impact of fishing on size composition and diversity of demersal fish communities", *ICES Journal of Marine Science* 57, 2000, pp. 558-571; J.G. Pope, *et al*, *supra* note 257

First of all, managers and policy makers should consider if the critical ecosystem functions are already altered substantially, relative to what is known of their historic states. If so, the system may already be highly stressed and this has two implications for policy and management.

- The system may not be able to absorb substantial additional pressure to these critical functions, without consequences that are serious and difficult to reverse.
- It may be unwise to consider current conditions as a baseline state from which to judge the effectiveness of management and policy actions

If critical functions are already stressed to some extent in an ecosystem, it may not be co-evolved to function well in it its present state.[267] Rather, the current structure and function of the ecosystem may be in transition to adapt to the recent stresses, and no amount of management can maintain it in a transient state. Unfortunately, only in very knowledge-rich areas can it be possible to reconstruct what less stressed, and possibly more sustainable, states the ecosystem may have been in historically, and even more rarely can predictions be made about the structural and functional properties the system will have when the transient changes have passed through the linkages. These conditions make wise management very challenging.

If the critical functions of the ecosystem do not currently seem stressed, managers and policy makers can address two important considerations:

- For an activity being managed, which critical functions will the activity affect most directly and to what extent. Identifying those critical points of interaction between human activities and critical ecosystem functions can help identify risks associated with the activity by allowing the best assessments possible with the information available of the potential direct and indirect ecosystem consequences of an activity. Identifying the critical points also helps to focus monitoring on the ecosystem properties most likely to reflect any impacts that the activity may be having on the ecosystem and the activity proceeds.[268]
- For the activity being managed consider if different options perturb the critical functions by lesser or greater amounts.[269] The goal is to seek options which allow the

[267] Jackson, J.B.C., *et al*, "Historical overfishing and the recent collapse of coastal ecosystems", *Science* 293, 2001, pp. 629-638.

[268] Mills, L.S., M.E. Soulé and D.F. Doak, "The keystone-species concept in ecology and conservation", *BioScience* 43, 1993, pp. 219-224; Helleman, S. (ed.), "A Handbook for Measuring the Progress and Outcomes of Integrated Coastal and Ocean Management", *IOC Manuals and Guidelines* 46, ICAM Dossier 2, UNESCO, Paris, 2006.

[269] Sainsbury, K. and U.R. Sumaila, "Incorporating ecosystem objectives into management of sustainable marine fisheries, including 'best practice' reference points and use of marine protected areas", *in* M. Sinclair and G. Valdimarsson (eds.), "Responsible Fisheries in the Marine Ecosystem", FAO, 2003, pp 343-362.

desired social and economic benefits of the activity to be obtained, but ensure that critical ecosystem functions do not suffer harm that is serious or difficult to reverse.

A final point on critical ecosystem functions and ecosystem disturbances by human activities needs mention. Human stresses can alter ecosystem components or processes to the point where new features become "critical functions". If the consequences of human pressures make something become consistently in short supply (or occasionally abnormally abundant) in the ecosystem, the availability of that component or rate of that process may regulate the dynamics of a much larger part of the ecosystem. For example, excessive nutrient enrichment of a coastal area may lead to increased accumulation of decomposing algae and plankton on the seafloor. The oxygen used in the decomposition may leave the deep waters depleted of oxygen for long periods, with seriously detrimental consequences for the reproduction of many fish and larger invertebrates. Oxygen concentration eventually becomes a property that regulates the system dynamics, although prior to the nutrient enrichment oxygen levels were almost always sufficient, and other factors regulated system dynamics. Thus, although even naturally functioning ecosystems often have critical functions which regulate their dynamics, unsustainable human uses can accentuate how critical those functions are, or may create new critical functions.

Summary of key ideas

(a) Given the huge number of components and processes in an ecosystem, it is impossible for managers and policy makers to consider them all in each action that they take. Sustainable use is fundamentally about choices, and in an ecosystem approach, some of the choices are about which ecosystem components to treat as priorities.

(b) From the biological and ecological perspective, management choices should be based on which components and which processes are critical to regulating ecosystem structure and function. Usually only a few of the species and processes in a complex ecosystem determine the rate at which system dynamics and species interactions occur in the ecosystem. These species are considered to regulate the critical functions in the system.

(c) There is no recipe book that ensures that the critical functions in any system can be identified readily. Nonetheless, there are number of questions that managers and policy makers can pose to advisors on ecosystem approaches, and use as a basis for discussion with those considered to have experiential knowledge of the ecosystem.

(d) Human stresses can alter ecosystem components or processes to the point where new features become critical functions. If the consequences of human pressures make something become consistently in short supply, or occasionally abnormally abundant, in the ecosystem, the availability of that component or rate of that process may regulate the dynamics of a much larger part of the ecosystem.

Questions for discussion

(a) What are some of the questions that can be used to identify the critical functions in any given ecosystem?

(b) What roles do critical functions play in management?

6. Ecosystem health

Despite the pervasiveness of its use, the concept of "ecosystem health" is no easier to define in concrete and practical ways than is the concept of an "ecosystem approach".[270] In a general sense the concept is straightforward. The health of the ecosystem is the aggregate consequence of all the ecosystem components and processes being within their historical ranges of natural variation, and all critical functions not being disrupted by either human or environmental stress.[271] Interpreted this way, the concept of ecosystem health makes two important contributions to an ecosystem approach.

First, it focuses attention on the inherent natural variability of ecosystems, and the limits to that variability. In human health there is no single height or weight that is considered "normal". Nonetheless there are *relationships* between height and weight that are considered "normal". For any given height, there is a range of weights that are considered "healthy" and there are weights that are considered "*un*healthy" – either too low or two high. Moreover, for any given individual there is a weight that is characteristic, but that weight changes at least slightly on daily, monthly, and seasonal cycles. Some other common features of human health can vary even more within healthy individuals. Pulse rate, for example, varies greatly with level of activity, and it is considered "good health" both to have it reduce substantially during periods of rest, and be elevated regularly by planned exercise. Nonetheless, pulse rate is often one of the first things checked in emergency medicine to see if it lies outside the normal range of variation.

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[270] Costanza, R., "Towards an operational definition of ecosystem health", *World Meeting Number* 911 0080, AAAS 91 Annual Meeting, Washington, D. C., 14-19 Feb 1991

[271] Hewitt, J.E., M.J. Anderson and S.F. Thrush, "Assessing and monitoring ecological community health in marine systems", *Ecological Applications* 15, 2005, pp. 942-953; Pantus, F.J and W.C. Dennison, "Quantifying and Evaluating Ecosystem health: A Case Study from Moreton Bay, Australia", *Environmental Management* 36, 2005, pp. 757-771

These ideals have useful analogies in applying the concept of "ecosystem health". First of all, ecosystem health, like human health, is an integrative concept – it reflects some overall status and resilience of the whole system, not any specific part of it.[272] There is no globally "right" productivity for an ecosystem, nor a "right" biodiversity, degree of top-down or bottom-up control, or environmental forcing. Nonetheless, the many structural and functional features of an ecosystem are inter-related, and with a modest amount of information about some of them, reasonable expectations can be developed for others. To the extent that the status of the key structural and functional properties of a given ecosystem can be assessed at a given time, there is no expectation that it has to be kept in exactly that state to be "healthy". Moreover, different ecosystems can be expected to vary by different amounts, within their ranges of "healthy" status. At the same time, beyond the natural variation characteristic of a given system, there are states that it could be driven into by pressures from natural forces or human uses which would not be considered "healthy". How far these "unhealthy" states deviate from the "normal" condition in structural or functional properties is also a case-specific property of ecosystems, although it is related to the intrinsic amount of variation characteristic of a system. Perhaps the most important analogies between the concepts of ecosystem health and human health are in the "diagnosis" of health. Maintaining good health requires regular check-ups (assessments), sound "lifestyles" (sustainable uses), and above all a willingness to take action when there are indications that the system is moving towards an unhealthy state, not waiting until the patient (ecosystem) is in critical condition before taking remedial actions.

This concept of the assessment or "diagnosis" of ecosystem health brings in the second contribution that the concept makes to an ecosystem approach to policy and management. Although a complete assessment of a patient is needed to be relatively certain that every aspect of the patient's mental and physical health is good, such assessments are costly and usually unnecessary. Rather, routine check-ups are recommended where a suite of indicators of health are assessed. These indicators should be relatively easy and cost-effective to measure. The indicators are compared to standards for a coarse evaluation of whether each indicator is within the natural range of variation of the population and, where possible, the individual standards are calibrated in advance to the specific patient. It is important that the assessment indicators should reliably indicate if and where more complex and costly follow-up tests are justified.[273]

[272] J.E. Hewitt, M.J. Anderson and S.F. Thrush, *supra* note 271.

[273] Burger, J. and M. Gochfeld, "On developing bio-bindicators for human and ecological health", *Environmental Monitoring and Assessment* 66, 2001, pp. 23-46; Rice, J.C., "Environmental Health Indicators", *Ocean and Coastal Management* 46, 2003, pp. 235-259.

It is also important that when follow-up actions appear warranted based on the coarse assessment actions are already taken on the risk that appears to be present. It is not a coincidence that the application of precaution (see Module IV, Section 6) is a shared concept in protecting human health and ecosystem health. The most costly and invasive health measures may only be taken when the more detailed results are available. However, actions are recommended to cease at least the unhealthy practices as an interim measure, rather than awaiting a high level of certainty about potential harm before trying to improve health. These are all routine practices of good health care for populations, and they are good practices to maintain ecosystem "health" as well.[274]

Summary of key ideas

(a) The health of the ecosystem is the aggregate consequence of all the ecosystem components and processes being within their historical ranges of natural variation, and all critical functions not being disrupted by either human or environmental stress.

(b) Ecosystem health is an integrative concept. It reflects some overall status and resilience of the whole system, not any specific part of it.

(c) There is no globally "right" productivity for an ecosystem, nor a "right" biodiversity, degree of top-down or bottom-up control, or environmental forcing. Nonetheless the many structural and functional features of an ecosystem are inter-related, and with a modest amount of information about some of them, reasonable expectations can be developed for others.

7. Ecosystem integrity

Ecosystem integrity is another abstract and general concept, but is important to an ecosystem approach.[275] As the concept of ecosystem health applies to an aggregate state of the components and processes, ecosystem integrity applies to features that the ecosystem itself has when it is in a healthy state.

Ecosystem resilience

When ecosystems are healthy they show **resilience** to disturbances.[276] For example, suppose an environmental or human pressure changed some components or processes in an

[274] Simon, T.P., "Biological Response Signatures: Indicator Patterns Using Aquatic Signatures", CRC Press, 2003.

[275] Dayton, P.K., "The Importance of the Natural Sciences to Conservation", *American Naturalist* 162, 2003, pp. 1-13

[276] Gundersen, L.H. and L. Pritchard (eds.), "Resilience and the behaviour of Large-Scale Systems", Island Press, 2002; Hughes, T.P., *et al*, "New paradigms for supporting resilience of marine ecosystems", *Trends in Ecology and Evolution* 20, 2005, pp. 380-386

ecosystem, such as increased mortality on a key predator (over-harvesting) or changed rates of nutrient input to a system (land-based pollution), if the resilience of the ecosystem is intact, when the pressure is released, the ecosystem tends to return in the direction from which it was perturbed. It may not return to *exactly* the state that it was in previously, but major perturbations are corrected to more typical states. If resilience is lost, perturbations may actually be amplified rather than buffered as they spread in time or space, or to linked components and processes

Resilience is a concept that can be applied to social and economic systems that use ecosystems, as well as the ecosystems themselves. If the resilience of marine ecosystems is diminished through unsustainable uses, the resilience of dependent communities and industries is likely to be diminished as well. Moreover, some social scientists argue that the effects are reciprocal. If marine ecosystems are the basis for social or economic systems that are not resilient to normal variation in the ecosystem, then those uses may increase the stress on the ecosystem when natural variation has already placed the ecosystem at an atypical state. Thus social and economic systems of low resilience may diminish the resilience of ecological systems as well.

A major source of ecosystem resilience comes from feedback processes inherent in many ecosystem processes and relationships between species.[277] The importance of density-dependence in some ecosystem processes has been noted, and these contribute the necessary feedback to buffer ecosystems from perturbations. For example, if a human pressure increased mortality on a key predator, the density of that predator in the ecosystem would decline. If prey were unaffected directly by the pressure causing increased mortality on the predator, the remaining individuals of the predator species would find more food per individual. The result would appear as density dependence in the predation process. With better food per individuals, they might grow faster and mature sooner, or produce more eggs per individual. The result would appear as density dependence in recruitment to the predator. These sources of density dependent feedback have been the basis for commercial fisheries for centuries.[278]

Ecosystem Integrity

Ecosystem integrity refers to the degree to which all these processes which maintain ecosystem structure and functioning are working to keep returning the system to "healthy" conditions, as the system is perturbed by environmental variation and human uses.[279] As long

[277] del Monte-Luna, P., *et al*, "The carrying capacity of ecosystems", *Global Ecology and Biogeography* 13, 2004, pp. 485-495; M.J. Kaiser *et al*, *supra* note 208

[278] R. Hilborn and C.J. Walters, *supra* note 255; D. Cushing, *supra* note 198

[279] J.J. Stachowicz *et al*, *supra* note 207; J.E. Duffy and J.J. Stachowicz, *supra* note 229

as the individual pressures do not move the feedback processes outside their ability to compensate over time, the **integrity** of the ecosystem is intact.

It is the nature of density dependent feedback that within the tolerances of the compensating processes the effects of perturbations are buffered, and the system does not appear to suffer lasting or major changes in response to the pressures to which it is exposed. However, once the system tolerances are exceeded for even a few of the compensating processes, the ecosystem can quickly suffer harm that is serious and difficult to reverse – that is, the ecosystem integrity has been reduced or even lost.[280] Unfortunately, the incremental increase in a pressure that alters ecosystem integrity may appear small compared to the gradual increase in the pressure that has occurred without appearing to reduce ecosystem integrity at all. This can occur because strong density dependent processes are designed to work effectively until further compensation is not possible, and then they break down rapidly.

Similarly, ecosystem integrity can be harmed by cumulative effects of multiple pressures.[281] Past experience may have indicated that the ecosystem processes could compensate for the stress caused by each pressure as it was applied individually. However, sometimes the same components or processes were involved in compensation for several pressures. When they are later applied cumulatively, the combined stressors do exceed the density dependent (and any other) compensation mechanisms, and again ecosystem integrity is compromised. Alternatively, in a healthy ecosystem there may be many components and linkages among them that contribute to the resilience of an ecosystem to perturbations. As individual components and linkages are weakened or removed, many of the losses individually appear to have negligible impact on ecosystem structure and function. However, at some point the simplified system loses its ability to buffer and compensate for perturbations, and again an incrementally small pressure can result in large and lasting harm.

These types of major consequences of minor incremental pressures indicate why the integrity of the ecosystem as a whole is an important consideration in management and policy. They also highlight the importance of integrated management in an ecosystem approach, so cumulative effects receive due consideration.[282] They also highlight that conservation of biodiversity is a cornerstone of protecting ecosystem integrity, because it is

[280] Myers, R.A., K.G. Bowen and N.J. Barrowman, "The maximum reproductive rate of fish at low population sizes", *Canadian Journal of Fisheries and Aquatic Sciences* 56, 1999, pp. 2404-2419; Goodwin, N.B., *et al*, "Life history correlates of density-dependent recruitment in fisheries", *Canadian Journal of Fisheries and Aquatic Sciences* 63, 2006, pp. 494-509

[281] Preston, B.L. and J. Shackelford, "Multiple stressor effects on benthic biodiversity of Chesapeake Bay: implications for ecological risk assessment", *Ecotoxicology* 11, 2002, pp. 85-99; Jorgensen, S.E., R. Costanza and F.L. Xu (eds.), "Ecological Indicators for Assessment of Ecosystem Health", CRC Press, 2005

[282] B.L. Preston and J. Shackleford, *Ibid.*; T.P. Simon, *supra* note 274

often the multiplicity of components, processes and their linkages that give ecosystems their resilience and are vital to maintaining ecosystem integrity.[283] Finally, they are a caution with regard to reliance on adaptive management to react to changes in ecosystems as they are detected. Adaptive management assumes that each increment in a pressure can be addressed by a comparable increment in an appropriate management measure.[284] When ecosystem integrity is under pressure, this may be a dangerous assumption.

Summary of key ideas

(a) Ecosystem integrity refers to the degree to which the processes that maintain ecosystem structure and functioning are working to return the system to "healthy" conditions as the system is perturbed by environmental variation and human uses. As long as these individual pressures do not move the feedback processes outside their ability to compensate over time, the integrity of the ecosystem remains intact.

(b) Ecosystem integrity applies to features that the ecosystem itself has when it is in a healthy state. However, once the system tolerances are exceeded for even a few of the compensating processes, the ecosystem can quickly suffer harm that is serious and difficult to reverse. In other words, the ecosystem integrity has been reduced, or lost.

(c) A major source of ecosystem resilience comes from feedback processes inherent in many ecosystem processes and relationships between species.

(d) Conservation of biodiversity is a cornerstone of protecting ecosystem integrity, because it is often the multiplicity of components, processes and their linkages that give ecosystems their resilience and are vital to maintaining ecosystem integrity.

[283] Elmqvist, T., *et al*, "Response diversity, ecosystem change, and resilience", *Frontiers in Ecology and Environment* 1, 2003, pp. 488-494; Loreau, M., *et al*, "Biodiversity and Ecosystem Functioning; Synthesis and Perspectives", Oxford University Press, 2004.

[284] Charles A.B., "Sustainable fishery systems", *Blackwell Science*, 2001, p. 370; Olsson, P., C. Folke and F. Berkes, "Adaptive co-management for building resilience in social-ecological systems", *Environmental Management* 34, 2004, pp. 75-90

Legal regime for marine scientific research

2. The 1982 United Nations Convention on the Law of the Sea substantially extended national jurisdiction offshore and increased the rights and obligations of coastal States in the marine environment and in the exploitation of its resources. The Convention also places a legal obligation on States to apply sound principles of resource management within the exclusive economic zone, and it establishes the régime for the conduct of marine scientific research in that zone and on the continental shelf. The right to exploit the resources of the exclusive economic zone implies a responsibility for proper management concomitant with the duty not to inflict damage on the interests of other States. However, it is evident that proper management requires a knowledge base and a national scientific and political infrastructure to identify and provide viable solutions to any existing or potential problems.

3. The recognition that the ocean is a resource capable of making a growing and substantial contribution to sustainable economic development and also the recognition of the need to understand its role in the total global system have placed new and increased demands on marine science. At the same time, increased interest in coastal and shelf processes has been parallelled by a growing need to understand the holistic behaviour of the total global ocean system, particularly the way in which it acts as a control on climate variability through circulation and heat exchange.

4. As the Secretary-General indicated in his report to the Assembly at its forty-third session, "ensuring sustainable development in the future utilization of marine resources and environment will require special attention" (ibid., para. 72). The report emphasizes that "far from being a mature science, oceanography is still in the process of discovery and the chief source of new understanding comes from new observations, not from theory. Global prediction models must be verified in any event against observations of the state of the ocean, such as sea level, temperature and salinity, and must be compared with measured fluxes of heat, water, particles and gases between the atmosphere, the ocean and the ocean floor. The ocean sciences are thus entering an intensive data-gathering phase that will last through to the late 1990s and perhaps beyond" (ibid., para. 73).

5. The increasing world population places an ever growing pressure on land-based resources. The demand for marine products and ocean services will increase in parallel and strengthen the need for marine research. There is now widespread concern that man's activities may be adversely affecting the earth's environment and the sustainability of its resource base. The ocean plays a dominant role in maintaining the life-supporting system on earth through its interaction with the atmosphere, although the details of that role have yet to be fully understood. Concern over the environment and its changes is likely to shape the future of marine programmes in research and services at all levels, that is, local, regional and global.

6. It will come as no surprise that the major issues identified in this report as requiring concerted action by States and international co-ordination by organisations concerned are predominantly environmental issues, including the conservation of the living resources of the oceans. They include the following:

(a) Creation of national and regional marine scientific research capabilities to adequately provide sound scientific bases for development and management of marine resources, living and non-living;

(b) Research and monitoring of marine pollution;

(c) Global climate research programmes and associated large-scale oceanographic experiments to observe and understand air-sea interaction, the impact of the ocean on climate, and vice-versa;

(d) Coastal dynamics and sea-level rise;

(e) Development of global ocean observing systems to support marine scientific research and ocean uses.

7. Marine science is like any other science in that it relies on observation and tested hypotheses. However, marine scientists face a variety of time and space scales. The question of scales is important because in order to understand the global system, the determination must be made of those scales upon which the physical, chemical and biological processes interact with the global system. There is a need to study processes at intermediate and smaller scales in the individual disciplines of physics, chemistry and biology just as there is a growing need to study the large-scale questions. While the full value of a research project may not be immediately apparent, it is inherent in the nature of scientific research that an offshoot may have greater significance than the intended goals of the project. Large-scale projects are of special importance to the international community in that they call for collaboration among institutions and States. However, they are costly and logistically difficult to carry out but they benefit from and are dependent on international co-operation and planning.

8. For the successful implementation of such small or large-scale projects, it is important to ensure that international co-operation and co-ordination is pursued at the bilateral, regional and global levels as appropriate. Furthermore there also must be a legal framework within which this co-operation and co-ordination can develop.

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II. THE NEW LEGAL REGIME FOR MARINE SCIENTIFIC RESEARCH

9. The United Nations Convention on the Law of the Sea lays down a comprehensive global régime under which States are required to conduct marine scientific research and co-operate in such research. The Convention devotes an entire part (part XIII, consisting of 28 articles) to the question of marine scientific research. Several other parts contain special provisions concerning marine scientific research as it relates to different jurisdictional zones or specific subject matters. Part XII, concerning the protection and preservation of the marine environment, and part XIV, dealing with the development and transfer of marine technology, are the most important in this respect. Indeed, part XIII is so closely linked to those two parts that the three parts should be read together for all practical purposes. Of the 320 articles of the Convention, about 100 deal with the exploration, exploitation, conservation and management of the resources of the sea, the training of personnel in those fields, and the application of science in the protection and preservation of the marine environment. These provisions form the global legal régime for marine scientific research in a wider sense, and provide the basis for relevant bilateral, regional or other international agreements for the promotion of scientific investigation of the ocean and its resources.

10. The following sections demonstrate that the international community is now facing a growing challenge of better husbanding the oceans and their resources and that this requires the universal strengthening of marine scientific research in all its fields. Since problems and phenomena of ocean space are mostly interrelated and respect no national boundaries, all scientific research issues identified need to be tackled through the joint efforts of States, often together with relevant international organizations. What is most needed now, therefore, is the closer co-operation and co-ordination among States and international organizations in further promoting and facilitating the conduct of such research, disseminating the knowledge, information and data obtained, and developing human resources urgently needed in many countries.

A. General principles

11. The Convention confirms the right of all States and competent international organizations to conduct marine scientific research (art. 238) and lays down a fundamental principle that such research shall be conducted exclusively for peaceful purposes (art. 240). Another general principle recurring throughout the Convention is the duty of States to co-operate in marine scientific research; indeed the régime for marine scientific research is designed to promote international co-operation. 2/

B. General duty to co-operate

12. The Convention clearly enunciates the fundamental duty of all States and competent international organizations to promote and facilitate the development and conduct of marine scientific research in accordance with its provisions (art. 239). Then follows the general duty of States and competent international

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organizations to promote international co-operation in marine scientific research for peaceful purposes (art. 242, para. 1). They are furthermore obliged to co-operate to create favourable conditions for the conduct of such research and to integrate the efforts of scientists in the study of the marine environment (art. 243).

13. The call for international co-operation is particularly stressed in the case of States bordering enclosed or semi-enclosed seas, which are urged to co-operate with each other in exercising their rights and performing their duties, and are further obliged to endeavour to co-ordinate their scientific research policies and undertake where appropriate joint programmes of scientific research in the area (art. 123).

14. States are under a duty to promote international co-operation in scientific research on the sea-bed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction, by participating in international programmes and encouraging co-operation in such research by personnel of different countries and of the International Sea-Bed Authority (art. 143, para. 3).

15. On the basis of that fundamental duty to co-operate, the Convention provides for more specific obligations of States and international organizations. These focus on the following three subjects: (a) the consent régime; (b) the dissemination of information, data and knowledge; and (c) training, education and transfer of technology.

16. In addition, there is a fundamental duty found in part XIV of the Convention to assist the efforts of developing countries to acquire technology and scientific knowledge. The Third United Nations Conference on the Law of the Sea, sharing this sentiment, adopted, together with the Convention, a resolution on development of national marine science, technology and ocean service infrastructures. 3/

C. The consent régime

17. Recognizing the value to coastal States of detailed information on the marine environment and its resources, the Convention provides a legal framework for the acquisition of scientific knowledge in the exclusive economic zone and on the continental shelf. Under the Convention, marine scientific research in the exclusive economic zone and on the continental shelf shall be conducted with the consent of the coastal State (art. 246, para. 2). The Convention establishes detailed rules and procedures for such research activities on the basis of this requirement. 4/

18. Under the consent régime coastal States must, in normal circumstances, grant their consent. They may however at their discretion withhold their consent to the conduct of a marine scientific research project in the exclusive economic zone and on the continental shelf if the project is of direct significance for the exploration and exploitation of natural resources, whether living or non-living; involves drilling in the continental shelf, the use of explosives or the introduction of harmful substances into the marine environment; involves the

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construction, operation or use of artificial islands, installations and structures referred to in the Convention; or contains inaccurate information or if the researching State or international organization has outstanding obligations to the coastal State from a prior research project (art. 246, para. 5).

19. That qualified consent requires a coastal State to have an adequate understanding of the scientific nature of each research project. The Convention stipulates that the coastal State shall establish rules and procedures ensuring that consent is not delayed or unreasonably denied, which further underlines the need for a coastal State to reach the level of scientific knowledge necessary for a sound and objective assessment of the characteristics of the research project.

20. The Convention also provides that researching States or competent international organizations may proceed with a marine scientific research project six months after the date the required information relating to the project was provided to the coastal State, unless within four months of the receipt of the communication containing such information the coastal State has informed the State or organization wishing to conduct the research that it was withholding its consent or that the information given does not conform to evident facts or that supplementary information is required (art. 252).

21. There is a special provision (art. 247) in the consent régime for projects undertaken by or under the auspices of international organizations. In cases where an international organization to which a coastal State belongs or with which it has an agreement plans to carry out a research project either directly or under its auspices, the coastal State is deemed to have authorized the project if it approved the undertaking of the project when the decision was made by the organization or is willing to participate in it and has not expressed an objection within four months of notification by the organization. That procedure would be of great use, particularly, in facilitating research projects on a global scale.

D. Dissemination of information, data and knowledge

22. The publication and dissemination of information on research programmes and their objectives as well as knowledge resulting from marine scientific research are another form of the obligation to co-operate. For that purpose, States are obliged to promote actively the flow of scientific data and information and the transfer of such knowledge, especially to developing States (art. 244).

23. This is particularly true in the implementation of the provisions dealing with proper conservation and management of living resources of the oceans in order to avoid over-exploitation and to maintain or restore populations of harvested species at levels which can produce maximum sustainable yield. The Convention provides for the promotion of international co-operation in acquiring scientific data and exchange of information on the conservation of such living resources (art. 61).

24. In the exclusive economic zone and on the high seas, States are required to contribute and exchange, on a regular basis, available scientific information regarding catch and fishing effort statistics and other data relevant to the conservation of fish stocks. This should be done through competent international organizations, with the participation of all States concerned (arts. 61 and 119).

25. The Convention imposes additional duties on States concerning the need to co-operate or co-ordinate their measures for the conservation, development and management of certain specified fish stocks or species in the exclusive economic zone or on the high seas. The general obligation for the exchange of relevant information and data in connection with those stocks and species contained in article 61 applies to such stocks and species. The specific stocks mentioned are those straddling two or more exclusive economic zones or the exclusive economic zone and the high seas (art. 63) and anadromous stocks (art. 66). Other species mentioned are the highly migratory species listed in annex I of the Convention and catadromous species (art. 67). In addition, special provisions are made with regard to co-operation in the conservation of marine mammals (arts. 65 and 120).

26. A similar obligation is found with respect to marine pollution. States are obliged to co-operate in order to promote scientific research and encourage the exchange of information and data on marine pollution (art. 200). States are required to endeavour to study, by recognized scientific methods, the risks and effects of marine pollution and to publish the results obtained or otherwise make them available to all States (arts. 204 and 205). A coastal State is also required to provide other States with a reasonable opportunity to obtain from it, or with its co-operation, information necessary to prevent and control damage as well as to the health and safety of persons and to the marine environment (art. 242, para. 2).

E. Training, education and transfer of technology

27. The general emphasis that the Convention places on the needs of developing States is particularly articulated in the development of marine science and technology. States are obliged to co-operate in order actively to promote the development and transfer of marine science and marine technology on fair and reasonable terms and conditions. The need to promote the development of scientific and technological capacity of States is highlighted in the fields of resource conservation and development, ocean research and the protection and preservation of the marine environment (art. 266).

28. In addition to existing arrangements, the Convention calls for expanded and new programmes for facilitating marine scientific research, the transfer of marine technology and appropriate international funding for ocean research and development (art. 270). States are also required to promote the establishment, particularly in developing coastal States, of national and regional marine scientific and technological research centres and the strengthening of existing centres (arts. 275 and 276).

29. More specifically, upon request by a coastal State, States and international organizations, undertaking research in the exclusive economic zone or on the continental shelf, must provide it with an assessment of the data, samples and research results or provide assistance in their assessment or interpretation (art. 249, para. 1 (d)).

30. In the area of protection and preservation of the marine environment, States are obliged to promote programmes of scientific, educational and technical assistance to developing States, including the training of scientific personnel and developing facilities for research, monitoring and educational programmes (art. 202).

31. Finally, States parties to the Convention are required to promote international co-operation in marine scientific research in the Area by ensuring that programmes are developed for the benefit of developing States with a view, inter alia, to strengthening their research capabilities (art. 143).