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Monitoring and indicators of the coastal and estuarine environment – a literature review.

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1 INTRODUCTION

This literature review of monitoring and indicators of the coastal and estuarine environment is part of the Ministry for the Environment's National Environmental Indicators Programme.

The coastal and estuarine environment is monitored at several levels in most countries, from the local authorities, NGOs and interest groups to state and/or regional government and national government. International agencies such as the IUCN and OECD also undertake monitoring, usually by assessing the data and information provided by individual nations.

For this report a literature review was undertaken of monitoring projects and schemes and indicators used by agencies at the national and state or provincial level as this was considered comparable to the national set of environmental indicators that are being developed by the New Zealand Ministry for the Environment.

All available sources of literature were used including material available, World Wide Web, CAB Abstracts, Current Contents and personal international contacts. The relevant literature is summarised in Appendix 1 and the key points are noted below in Sections 2 and 3.

2 KEY POINTS OF INDICATORS AND MONITORING BY INTERNATIONAL AGENCIES

The **OECD** (1985) discusses indicators for coastal and estuarine issues including land-based pollution, oil pollution, dumping and incineration of wastes at sea, state of the environment and fisheries and aquaculture resources. They point out the preference for using biological indicators and sediment for state of the environment monitoring rather than water quality indicators while a number of countries use all three approaches. Catch data is used to monitor fish stocks.

The **IUCN** World Congress on Biodiversity last year stressed the need to review the use of indicators for assessing marine and coastal biodiversity and to develop new indicators and methodologies for this purpose. They also stressed the need for a classification of types of marine and coastal ecosystems to assist in monitoring and assessment.

Ballast water has become an international problem with loss of local biodiversity, degradation of habitat and loss of fisheries productivity. Developing effective solutions needs a concerted effort both internationally and nationally.

3 KEY POINTS OF COASTAL AND ESTUARINE INDICATORS AND MONITORING IN ENGLISH SPEAKING COUNTRIES

3.1 United States of America

The USEPA (1996) has provided a national set of environmental indicators for water quality of which 11 are relevant to the coast and estuaries. They are developed from specific objectives and are based on the Pressure, State, Response system. They are listed below as:

Objective I: To conserve and enhance public health

Indicator - Shellfish growing water classification - percentage of estuarine and coastal shellfish growing waters approved for harvest for human consumption.

Objective II: To conserve and enhance aquatic ecosystems

Indicator - Biological integrity - percentage of rivers and estuaries with healthy aquatic communities.

Indicator - Species at risk - percentage of aquatic and wetland species currently at risk of extinction.

Indicator - wetland acreage - rate of wetland loss.

Objective III: To support uses designated by the states and tribes in their water quality standards

Indicator - Designated uses in state and tribal water quality standards

- Fish and shellfish consumption designated use
- Recreation designated use
- Aquatic life designated use

Objective IV: To conserve and improve ambient conditions

Indicator - Selected coastal surface water pollutants in shellfish (oysters and mussels)

Indicator - Estuarine eutrophic conditions (chlorophyll-a, nitrogen, anoxia, submerged aquatic vegetation)

Indicator - Contaminated sediments - percentage of sites with sediment contamination that might pose a risk to humans and aquatic life.

Objective V: Reduce or prevent pollutant loadings and other stressors

Indicator - Selected point source loadings to surface water

Indicator - Nonpoint source loadings to surface water

Indicator - Marine debris - trends and sources of debris monitored in the marine environment

Other USEPA programmes and the USA Department of Commerce are developing regional indicators related to multiple resource assessment and fisheries respectively. The monitoring is very much issue related i.e. related to contaminants in water and seafoods, biomarkers, restoration projects etc. The North East Fisheries Centre is, however, also looking at indices of the state and health of the Northeast Shelf ecosystem which include water quality parameters, primary productivity, zooplankton, fish, marine mammals and birds, pollution and algal blooms.

University research is issue-based focussing on estuarine and marine contamination, eutrophication, hydrodynamic changes, introduction of non-indigenous species etc. However, concern is shifting to a more ecosystem perspective with the response of ecosystems to various pressures now being addressed.

3.2 Canada

Environment Canada produced a national set of environmental indicators in 1991 based on three goals for sustainable development: ecosystem integrity, human health and well-being, and natural resource sustainability. An issues approach is taken using the Pressure-State-Response model. Indicators are:

Marine environmental quality indicators:

- Municipal discharges to coastal waters: Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD)
- Pulp and paper mill discharges to coastal waters: TSS and BOD
- Volume of significant marine spills (exceeding one tonne spilled material)
- Area closed to shellfish harvesting
- Contaminant levels in seabird eggs: PCBs
- Contaminant levels in seabird eggs: Dioxins and furans

Fisheries indicators:

- Total commercial fish catches in Canadian waters off the Atlantic coast

Since 1991, additional indicators have been developed based on particular issues: the West coast herring fishery, pollutants in British Columbia's marine environment, and persistent organochlorines in the environment. In 1995, a marine ecosystem approach was presented at a workshop (Smiley, 1995) where a framework based on ecosystem structure and function in relation to environmental issues was presented. Valued Environmental Components (VECs) were used to define the ecological or societal feature or environmental component. Indicators are evaluated against a series of criteria. Wells and Rolston (1991) assessed how losses in marine environmental quality affected VECs.

National sediment quality guidelines are being developed by staff within Environment Canada, National Oceanic and Atmospheric Administration (Washington), and Florida Department of Environmental Protection based on the effects of a range of chemicals on benthic fish and invertebrates (Long *et al.*, 1995). The method will also be used for developing informal sediment quality guidelines for Florida.

3.3 United Kingdom

The National Monitoring Programme (P Matthiessen pers. comm.) uses chemical analyses, bioassays and benthic community analysis when surveying estuarine and coastal waters for human impacts. Sediment bioassays, biomarker tests and extraction techniques are used.

The Environment Agency General Quality Assessment schemes have developed components to quantify geographic differences and monitor trends in estuaries and coastal waters based on nutrient concentrations and aesthetic quality (Nixon *et al.*, 1996). For estuaries a basic chemical assessment based on concentrations of dissolved oxygen and ammonia was also developed. The National Rivers Authority is now in a position to implement these components.

For coastal waters, another component was based on sediment quality but these needs further research. Similarly, the feasibility of using macrobenthic community structure in estuaries and coastal waters was studied but also needs further work.

3.4 Australia

National indicators for State of the Environment Reporting are defined using the Pressure-State-Response system.

For marine and estuarine ecosystems, State and Pressure indicators were proposed at a workshop for different types of marine and estuarine ecosystems and species (Department of the Environment, Sport and Territories 1996). The indicators represent a wide coverage of these systems. There was some discussion at the workshop for developing good monitoring programmes, a system for assessing the health of estuaries, and a fine scale bioregional classification.

The State of Victoria has proposed a comparable list of state indicators for coastal and marine environments using "Valued Environmental Attributes" (Colman *et al.*, 1991). Unlike the proposed national indicators, these included aesthetic and cultural components. A set of Process/Activity indicators were also recommended comparable to Pressure indicators.

South Australia has an Environment Protection Policy 1994 with water quality guidelines to establish limits on pollution for people with environmental authorisations. These are in accordance with the Australian National Water Quality Guidelines. The Policy also has ten Schedules that set out water quality criteria for a variety of water uses.

3.5 South Africa

An Estuarine Health Index has been proposed by scientists in South Africa involving a classification of estuaries and an assessment of impact by considering biological health (using fish fauna), water quality and aesthetic condition (using floodplain landuse, appearance of floodplain surrounds, and degree of naturalness of channel margins) (Ramm *et al.*, ??). Each of the three components were given equal rating for the combined index value with a strong weighting on aesthetic condition.

4 RELEVANCE OF OVERSEAS INDICATORS TO NEW ZEALAND

4.1 Focus

The literature review reveals that coastal and estuarine indicators are still being developed throughout the English speaking world. With the exception of the indicators developed by the USEPA and Environment Canada, all other indicators are "proposed". Although no one entire "model" is applicable to New Zealand conditions, several countries are developing some very useful concepts that are applicable to this country.

Monitoring in the USA, Canada and UK tends to be focussed on pollution and the nature of the pollutants. The environmental effects and hence indicators of these pollutants are developed from this perspective rather than taking an ecosystem based approach where changes in the ecosystem from "natural" or "pristine" are the focus of attention. For example, estuaries are monitored to determine the concentrations of pollutants and the accumulation of pollutants in the sediments and benthic fauna, rather than to compare the ecology of the impacted site with that of a "healthy" site.

However, there seems to be a growing consensus of opinion that biological indicators provide an integrated "picture" of change in the marine and estuarine environment which measurements of water and sediment quality alone cannot provide.

4.2 Geographical Classification

Some type of geographical classification of estuaries and coastal regions is needed to define indicators precisely enough to be useful. Smiley (1995) incorporates a geographical classification in developing indicators of the state of the marine environment for Canada. Literature from South Africa and Australia refers to a need for classifying coastal and estuarine ecosystems. The UK is planning to use the General Quality Assessment schemes for estuaries and coastal waters (Nixon *et al.*, 1996) to provide an objective method for classification. A geographical classification will be important for New Zealand estuaries as each one tends to be unique and changes over time due to inputs from land and sea will not necessarily be consistent between estuaries.

4.3 Sediment Quality

Sediment quality is recognised as an important indicator by the USA, Canada, UK and Australia. This is related to the fact that pollutants tend to accumulate in sediments posing a risk to human and aquatic life. In New Zealand, large quantities of sediment are discharged from rivers to estuaries and the coastal zone. Contaminants from industry, municipal discharges, pesticide use and agriculture are now threatening aquatic ecosystems through sediment contamination/accumulation and a system for monitoring sediments and benthic fauna may need to be in place in certain areas. However, monitoring of sediment movement and coastal erosion and accretion is perhaps more important generally in the New Zealand coastal zone.

4.4 Objectives

Indicators must be developed on the basis of sound objectives like those developed for the USA national set (USEPA 1996) with objectives such as (a) "to conserve and enhance public health" and (b) "to conserve and enhance aquatic ecosystems". For New Zealand, the indicators for the first objective might be:

- Proportion of estuaries or the coastal zone receiving untreated domestic and/or industrial waste;
- Proportion of estuaries or coastal waters with harvesting closures based on health reasons;
- Proportion of estuaries with health related restrictions on contact recreation.

For the second objective, indicators might be:

- Number of areas of "critical" estuarine or coastal habitat under protection;
- Proportion of estuarine wetland margins managed for wetland habitat or biodiversity;
- Changes to status of indigenous species (rare, endangered, threatened) associated with estuaries or the coastal zone.

Other indicators for the coastal environment including estuaries have been suggested by Ward (1993).

4.5 Valued Environmental Components (VECs)

The Australian State of Victoria (Colman *et al.*, 1991) and Environment Canada (Smiley, 1995; Wells and Rolston, 1991) refer to the use of "Valued Environmental Components/ Attributes" (VECs) to define the valued features or components that need to be considered. VECs were defined by Clark (1986) as "attributes of the environment that some party to the assessment believes to be important". Ward (1990) discussed VECs for New Zealand State of the Environment Reporting after the Ministry for the Environment (1990) identified them as the link between science and the lay perceptions of the environment. The important part of these VECs is that they take into account not only environmental attributes but also aesthetic and societal values which includes cultural values. The UK and South Africa also use aesthetic quality as an important component, rated equally with water quality and biological components.

The process of incorporating VECs into a set of national environmental indicators needs careful consideration. International agencies such as the OECD recognise the difficulty in developing indicators for a sustainable environment to balance the role of science and the community (Smith 1997). The USEPA is trying to integrate community goals into their indicators programme (Smith 1997).

Further development of VECs for New Zealand would seem to be an important part of determining critical coastal and estuarine parameters to be monitored. Livesey (1988) suggested three world views held by New Zealanders in relation to the environment: the anthropocentric view, the minimal impact view, and the view in which people recognise a *wairua* or spirit embodied within the natural world. These views indicate the range of values held by New Zealanders. Wide discussion and consultation would be needed to identify the community environmental concerns. A particular instance of this might be to assess the VECs for the Marlborough Sounds where the potential for conflicting values is high. After initial identification of the VECs, periodic feedback through public participation should allow resources to be monitored and managed for their values to the community.

Cultural issues specifically (rather than as part of VECs) are recognised in the coastal region by the USA and Australia. In Canada, traditional involvement of native peoples tends not to be with the coastal environment (G Daborn pers. comm.) in contrast to New Zealand where the reverse seems to be true and must be given due consideration in any indicator development.

4.6 Criteria

Criteria need to be established for selecting VECs and for selecting indicators. Criteria for selecting VECs need to be based on environmental values as well as social and aesthetic values. Smiley (1995) used the criteria of rarity, fragility, ecological importance, scientific value, societal value and aesthetic value for selecting VECs but how these criteria are defined or weighted is unknown at present (reference requested). To eliminate the problem of individual preferences, in South Africa, Ramm *et al* (??). used the pristine state as the baseline for aesthetic health of an estuary. This was the same state as used as the basis for biological health of estuaries.

Criteria to select indicators are used internationally (Smiley, 1996, for example). In New Zealand, criteria were used to evaluate the proposed freshwater indicators (Ward and Pyle, 1997) and similar criteria could be extended for use in estuaries and the coast. Smith (1997) suggests a social filter to make sure that the indicators are socially and culturally applicable. However, if VECs are considered in the development of the indicators, these aspects would have been taken into account and an additional filter may not be needed.

4.7 Indices

The development and weighting of indices needs to be determined after indicator development. In the South African Estuarine Health Index, Ramm *et al.* (??) gave equal weighting to biological health, aesthetic health and water quality. Water quality itself was an index determined by suitability for aquatic life (35%), suitability for human contact (30%), and trophic status (35%).

5 CONCLUSIONS

From the literature review, the following need to be considered for New Zealand:

5.1 Pressures

Pressures on the coastal environment come from both sea and land sources and both need to be taken into account.

Sea sources include:

- Over-fishing
- Water pollution - oil, sewage, garbage
- Ballast water - exotic organisms
- Coastal erosion/accretion -sediment movement

Land sources include:

- Aquaculture
- Industry - toxics
- Municipal waste - sewage
- Catchment use - sediments, nutrients

5.2 Values

The values that New Zealanders feel are important in relation to estuaries and the coastal environment need to be identified. Workshops to which interest groups and individuals are invited to discuss community values and concerns need to be integrated into the development of indicators.

Examples of VECs might be:

- Water should be safe for swimming and shellfish collection and consumption;
- Water should be pleasant to look at: no rubbish, oil slicks, scums, acceptable colour, no marine farming, no marina or port development, etc;
- Water should be suitable for a variety of plants and animals to inhabit - so suitable for bird life, recreational and commercial fishing where applicable.

5.3 Objectives

Broad objectives need to be set for indicators of estuaries and the coast that reflect the particular values that are appropriate for New Zealand such as healthy ecosystems which in turn affect recreational and commercial uses, social, cultural and aesthetic values.

Examples of objectives might be:

- to maintain water suitable for contact recreation and shellfish gathering
- to maintain water that is aesthetically pleasing on a local and landscape scale in designated areas
- to maintain a healthy aquatic ecosystem

5.4 Environmental Components

From these objectives, environmental components need to be identified such as:

- Water quality parameters
- Sediment quantity and quality
- Biota
- Aesthetics
- Social and cultural issues

5.5 Indicators

Indicators need to be developed from each of these components. Some will be similar for more than one component. For example, indicators of healthy biota will be related to indicators of water quality, sediment quality and cultural values.

Indicators may be *either*

- Direct measures of the above components, for example:
  - nutrients
  - bacteria levels (faecal coliforms)
  - biodiversity and numbers of benthic fauna, shellfish, fish
  - bird numbers/behaviour
  - sediment accretion in estuarine areas

or indicators may be the

- Suitability of an area for desired uses, for example:
  - proportion of area of critical habitat protected
  - percentage of area closed to shellfish harvest or swimming for health reasons
  - proportion of estuary, harbour or coastline receiving untreated sewage

5.6 Geographic Classification

The need for a geographic classification system needs to be investigated so that types of marine and estuarine environments can be grouped if necessary. However, the uniqueness of each estuary and the way it changes over time from land and sea pressures needs to be recognised.

5.7 Reference Sites

Some system of reference sites needs to be developed against which to compare the system under study. For example, a pristine or less impacted estuary or harbour or stretch of coast of similar type could be used as a baseline for comparison with the impacted site.

5.8 Final Comment

The international literature provides a range of systems for monitoring and developing indicators of estuaries and the coastal environment. Many of these systems are still in the development phase, but they provide New Zealand with a range of approaches to consider and apply to national indicator development.

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APPENDIX I:

Literature Summary

APPENDIX I: LITERATURE SUMMARY

1 INTERNATIONAL AGENCIES AND ISSUES

1.1 Organisation for Economic Co-operation and Development (OECD)

1.1.1 The State of the Environment (1985) OECD, Paris

Coastal and estuarine issues:

a) Pollution from land-based sources

b) Oil pollution

c) Dumping and incineration of waste at sea

d) The state of the environment

"In most cases sea water quality does not seem to be a valid indicator of the state of the marine environment, and preference seems to be given to measurements based on living organisms or on sediment" except when:

- Human health risks involve measurement of micro-organisms (this is sometimes included in water quality monitoring);

Bioaccumulation of potentially toxic substances in sedentary living organisms not only reveals past history of contamination but also enables the impact of pollution control policy pursued on land to be investigated.

A number of countries have set up systems to monitor quality of water, living organisms and sediment:

- "water quality" monitors micro-organisms, nutritive substances (that may speed algal growth), traces of heavy metals, pesticides (DDT) and polychlorinated biphenyls (PCBs).
- "living organisms" frequently uses mussels eg USEPA's Mussel Watch Programme uses the physiological characteristics of mussels with regard to bioaccumulation of micro-pollutants as a way of monitoring the changing quality of the marine environment.

There is a general lack of systematic monitoring of the marine environment and available data is limited.

e) Fishing and Aquaculture Resources of the Marine Environment

Catch data is used to assess fish stocks. Over fishing is not the only cause of decline of marine species; pollution from industries and towns affect fish nurseries which are usually situated close to the shore and near estuaries and wetlands; they are thus very vulnerable to possible changes in the environment caused by land-based pollution or changes in the shoreline.

Aquaculture is developing at a rapid rate (5% per year in 1985). The quality of the marine environment has a substantial bearing on which species can be cultivated and on the diseases to which they are prone. Some shellfish can tolerate a wide range of pollutants and microbes but the permanent presence of these in the water leads to a build-up in the soft tissues of these animals and can cause diseases and epidemics among consumers.

1.1.2 Environmental Indicators: A Preliminary Set (1991), OECD, Paris

In this list of a preliminary set of indicators, there are no estuarine and coastal indicators. Only marine fish catches (tonnes/year for member countries) are mentioned.

1.2 IUCN World Congress Biodiversity Forum (Montreal 1996)

1.2.1 Marine and Coastal Biodiversity Workshop

The Jakarta Mandate identified five themes for consideration: integrated coastal area management, marine protected species, alien species, mariculture, and conservation and sustainable use of living marine resources. The participants of this workshop identified a number of research gaps in current work on Marine Protected Areas that need to be filled for more effective conservation and sustainable use of marine and coastal biodiversity.

a) Assessment and Indicators

Work should not be impeded by the lack of full scientific information and will incorporate explicitly the precautionary approach. Emphasis should go towards applying what is already known to better manage marine biodiversity resources.

A review of the use of indicators for assessing marine and coastal biodiversity is required including a compilation and assessment of existing indicators which directly or indirectly monitor changes in biodiversity. New indicators and methodologies need to be developed which combine scientific research with traditional knowledge.

b) Regional co-operation

c) Ecosystem management approach and ecosystem classification

There is a need for global and regional systems for classifying marine and coastal ecosystems in order to assist in assessment and monitoring. These systems should be compatible with existing terrestrial systems; be capable of incorporating threats such as climate change, pollution, increased human population and destructive fishing practices; and include the needs of stakeholders including indigenous people.

1.3 Ballast Water Problems

1.3.1 Royal Society of New Zealand
Barbara Haydon (1995): National Symposium on Ballast Water Problems

Developing effective solutions requires concerted effort by people with a wide range of skills and backgrounds.

Almost all major and most minor phyla of organisms have been shown to survive voyages in ballast tanks and many arrive at deballasting ports in vast quantities. Not all those that survive will go on to establish and breed. This depends on the organisms' attributes as an invader, the attributes of the native ecological community to resist invasion, and the physical environment in to which the exotic invader is introduced.

Well known examples are:
- Asian clam in California
- European zebra mussel to the Great Lakes and associated waterways in Canada and the USA
- Northern Pacific seastar in Tasmania and Japan
- Toxic dinoflagellates in New Zealand and Australia

1.3.2 Scripps Institution of Oceanography, University of California, San Diego
Introduction of Nonindigenous Species

In some coastal environments, nonindigenous species have been introduced by human activities and have established populations that have major ecological consequences. Transport of organisms in the ballast water of ships is a major and growing source of introductions of nonindigenous species. Consequences to coastal ecosystems include loss of biodiversity by elimination of indigenous species, alteration of trophic dynamics, degradation of habitats, and diminution of fisheries productivity.

2 COUNTRIES

2.1 United States of America

2.1.1 United States Environmental Protection Agency (USEPA)

The USEPA is developing an Environmental Monitoring and Assessment Programme (EMAP) to determine the current status and trends in the condition of the USA national and regional ecological resources for environmental protection and management. The EMAP's monitoring activities are co-ordinated by seven Co-ordination Groups: Quality Assurance, Indicators, Information Management, Design and Statistics, Assessment and Reporting, Landscape Characterisation, and Methods. The activities will operate over decades to collect data from seven Resource groups: Rangelends, Agroecosystems, Forests, Inland Surface Waters, the Great Lakes, Estuaries, and Landscapes. EMAP data will enable policy makers, scientists, and the public to evaluate the success of current policies and programmes and to identify emerging problems before they become widespread and irreversible (USEPA 1995).

Environmental Indicators of Water Quality in the United States, June 1996 Office of Water. EPA 841-R-96-002.

The USEPA Office of Water produced the first report on national environmental indicators for water in 1996. The report covered water quality indicators for freshwater, groundwater, wetlands, estuaries and coastal waters. The indicators were developed initially using the Pressure-State-Response system with most indicators being in the State category. This designation was dropped in the final report because of difficulties with this categorisation for some indicators.

The indicators are determined from specific objectives. Those related to coastal and estuarine waters are elaborated below.

Objective I: To conserve and enhance public health

Indicator #6 - Shellfish growing water classification - percentage of estuarine and coastal shellfish growing waters approved for harvest for human consumption.

> Shellfish growing waters are classified by individual states using the guidelines in National Shellfish Sanitation Program manuals produced by the Interstate Shellfish Sanitation Commission (ISSC). Every five years the National Oceanic and Atmospheric Administration (NOAA), in co-operation with the EPA and ISSC, produces the National Shellfish Register of Classified Estuarine Waters which reports the classification of all coastal and estuarine shellfish growing waters. The waters are classified as one of the following:
>
> - *approved* for harvest at all times

- *conditionally approved* for harvest at certain times depending on environmental conditions
- *restricted* harvesting is allowed if the shellfish undergo a cleansing or purification process
- *conditionally restricted* harvesting is allowed at certain times depending on environmental conditions and whether the shellfish undergo a cleansing or purification process
- *prohibited* harvesting at all times

Objective II: To conserve and enhance aquatic ecosystems

Indicator #7 - Biological integrity - percentage of rivers and estuaries with healthy aquatic communities.

Assessment of a waterbody for healthy biological communities is a complex process where the extent of biological integrity in a monitored site is compared with a reference site that exhibits the desired characteristics. Fish, macroinvertebrates and plants including algae can be used to measure biological integrity. It is recommended that two of these three assemblages be monitored to make an accurate assessment. Assessing water bodies for biological integrity is important because it takes account of the cumulative effects of a variety of pressures/stressors.

Indicator #8 - Species at risk - percentage of aquatic and wetland species currently at risk of extinction.

In assessing biological integrity and diversity, the absence of expected species and the expected population size can be determined. National lists of plant and animal species at risk or endangered are available.

Indicator #9 - Wetland acreage - rate of wetland loss.

It is estimated that 80% of the USA coastal fisheries and one third of the endangered species depend on wetlands for spawning, nursery areas, and food sources. Wetlands are home to millions of waterfowl and other birds, mammals, reptiles, and plants so protecting their quantity and quality is important for health and diversity of aquatic species.

Objective III: To support uses designated by the states and tribes in their water quality standards

Indicator #10 - Designated uses in state and tribal water quality standards.

b) Fish and shellfish consumption designated use
States and tribes report to EPA on the quality of fish and shellfish for consumption.

c) Recreation designated use
States and tribes also report to EPA on how many of their rivers, lakes and estuaries support recreational uses, especially for swimming and boating.

d) Aquatic life designated use
States and tribes also provide EPA with information on whether their rivers, lakes and estuaries can support their designated use for healthy aquatic communities.

Objective IV: To conserve and improve ambient conditions

Indicator #13 - Selected coastal surface water pollutants in shellfish (oysters and mussels).

NOAA collects data on the concentration and effect of persistent pollutants in USA coastal waters. This indicator shows the average concentration levels of six pollutants in shellfish for about 140 locations around the coastline. Shellfish filter water during feeding and tend to accumulate pollutants. The six pollutants are the toxic chemicals of greatest concern on fish and other organisms in USA estuaries: copper, mercury, lead, DDT pesticides, polychlorinated biphenyls (PCBs) industrial chemicals, and carcinogenic polycyclic aromatic hydrocarbons (PAHs).

Indicator #14 - Estuarine eutrophic conditions.

This indicator shows changes in specific constituents related to water quality that together can be used to assess the extent of eutrophication of an estuary and therefore its health and condition. Parameters monitored include chlorophyll-a, nitrogen, other nutrients, dissolved oxygen, and spatial cover of seagrasses or submerged aquatic vegetation. NOAA's National Estuarine Inventory contains 129 estuaries and 16 eutrophication-related parameters are monitored by over 400 estuarine scientists. This indicator also uses data from the EPA's National Estuary Program where 28 estuaries are monitored around the country by state and local managers. Together the NOAA and EPA activities will provide a comprehensive information base.

Indicator #15 - Contaminated sediments - percentage of sites with sediment contamination that might pose a risk to humans and aquatic life.

Some types of chemicals in water tend to bind to particles and collect in the sediment where they often persist longer than in water because they may degrade more slowly. At high concentrations, pollutants in sediments may be released back into the water. They may also accumulate in bottom dwelling organisms, in fish and shellfish and may move up the food chain and become hazardous to humans. This indicator shows the percent of measurements of contaminated sediments that indicate potential risk to ecological and human health by chemical or chemical group. The chemicals include heavy metals, pesticides, PCBs and PAHs. The levels of concern are based on field surveys, laboratory toxicity tests and studies on the behaviour of chemicals in the environment and in living fish tissue.

Objective V: Reduce or prevent pollutant loadings and other stressors

Indicator #16 - Selected point source loadings to surface water.

The major point sources of pollution are sewage treatment plants, industrial facilities, and "wet weather" sources such as combined sewer overflows, sanitary sewer overflows, and storm water sewers. Many pollutants have been identified as of particular concern. EPA and other agencies have identified a group of toxic and conventional pollutants to track as indicators of progress toward reducing point source pollution in surface waters. For example, biochemical oxygen demand (BOD) and lead could be two indicators used. High BOD indicates that there will be low levels of oxygen available for fish and other aquatic life and also possible bacterial contamination from sewage. Information about these pollutants is contained in the EPA's Permit Compliance System.

Indicator #17 - Nonpoint source sediment loadings to surface water.

Nonpoint source pollution is difficult to measure and highly variable due to climatic factors. It is the greatest source of water quality degradation in many areas, particularly from cropland, livestock, urban runoff and storm sewers. National figures can only be estimated in the absence of direct national measures. This indicator shows the amount of erosion (in million tons of sediment erosion) from agricultural cropland that is often associated with the delivery of sediment, nutrients and pesticides to receiving waters. Other national measures of nonpoint source loadings are being considered.

Indicator #18 - Marine debris - trends and sources of debris monitored in the marine environment.

Marine debris includes rubbish left on the beach, discarded from boats, carried by inland waters to the coast, or conveyed by overflowing sewer or stormwater systems. As an indicator, marine debris (measured in millions of pounds of debris collected during an annual event) can be used:

- as an early warning of possible risk to human health,
- as a risk to wildlife by entanglement or ingestion,
- to place limits on coastal recreation and fishing,
- to assess the effectiveness of programmes of control or prevention,
- to ascertain the aesthetic value of a coastal area and the economy it supports,
- to assess ambient conditions,
- as a risk to human health through entanglement, injury or exposure to medical waste.

USEPA Environmental Monitoring and Assessment Program (EMAP)

Mid-Atlantic Integrated Assessment (MAIA) Project
MAIA Geographic Reference Database (web site)

EMAP and EPA Region III are planning a comprehensive multiple resource assessment in the Mid-Atlantic Region that includes:

- the development and testing of cross-resource indicators of ecological condition and stress;
- characterisation of the condition of ecological resources including estuaries and landscapes; and
- assessment involving diagnostic analysis of associations between condition and stressors.

The results will provide insight into ecosystem and watershed management approaches for resource and environmental protection at different spatial scales.

2.1.2 Centre for Ecological Health Research

University of California, Davis (web site) Funded by USEPA

A goal of the Centre is to understand how multiple stresses affect biological processes in aquatic and terrestrial systems. Research over the next 5 to 10 years should provide:

- improved indicators of ecological change from multiple stressors; and
- techniques to predict and manage at least population level changes in impacted species

2.1.3 US Dept of Commerce/National Oceanic and Atmospheric Administration (NOAA) - from web page

Northwest Fisheries Science Centre: Environmental Conservation Division (EDA) (March 1994)

The EDA conducts nation-wide research to define the nature and extent of chemical pollution in the marine environment, its effect on the health of living marine resources, including protected species, and its implications for the safety and quality of seafood products. A range of scientific disciplines are used and the approach is three-pronged: field and laboratory research, environmental monitoring, and development of new technologies for detecting contaminant-related bioeffects and for measuring toxic chemicals in seafood products.

Areas briefly discussed:

- Development of biomarkers of contaminant-induced effects.
- Research on chemical contaminants in seafood.
- Understanding the effects of contaminants on marine ecosystems.
- Damage assessment, restoration and monitoring (environmental catastrophes, restoration projects, and monitoring programmes to document the status of and change in concentrations of chemical contaminants in sediment, bottomfish, associated pathological conditions and other bioeffects in over 120 sites nation-wide to allow assessment of trends of quality of estuarine and coastal waters).
- Research on protected species (to assess exposure to and effects of estuarine contamination on outmigrant juvenile salmon; to develop a national database on chemical contaminants in marine mammals - more than 10 species have been analysed for chlorinated hydrocarbons as well as for toxic metals).

North East Fisheries Science Centre
Northeast continental shelf ecosystem (web site)
Health of the Ecosystem

Evidence of potential human health problems, stresses on different components of the coastal ecosystem, and warning signs of environmental degradation often result in emergency management responses:

- closure of shellfish beds due to pathogens or biotoxins;
- closure of recreational beaches due to bacterial abundance in water and soil;
- closure of recreational facilities due to accumulation of garbage, medical wastes, or other floatables on beaches;
- issuance of advisories concerning high concentrations of pollutants in the fish, sediment, and other parts of the coastal environment;
- notifications regarding closure of public access to resources or amenities, fish kills, putrefaction of organics, and loss of valued wildlife and fishery resources due to chronic pollution or an accidental event.

Indices being developed to measure the changing states and health of the Northeast Shelf Ecosystem include:

- biodiversity
- stability
- yield
- productivity
- resilience

Time-series monitoring of key ecosystem parameters provides the data from which to derive the ecosystem indices. The choice of ecosystem parameters is related to resources at risk from over exploitation of species protected by legislative authority (marine mammals), and other key biological and physical components at the lower end of the food chain (plankton, nutrients, hydrography).

Parameters used in ecosystem indexing include:

- zooplankton composition
- zooplankton biomass
- water column structure
- photosynthetically active radiation (PAR)
- water transparency
- chlorophyll-a
- nitrate
- nitrite
- primary productivity
- pollution

- marine mammal biomass
- marine mammal composition
- runoff
- windstress
- seabird community structure
- seabird counts
- finfish species composition
- finfish biomass
- domoic acid
- saxitoxin
- paralytic shellfish poisoning (PSP)

These ecological parameters incorporate the behaviour of individuals and responses of populations and communities to perturbations including their interactions with the physical and chemical environment. The selected parameters are used to measure the changing state and "health" of the Northeast Shelf Ecosystem. Based on recent analyses, it is clear that significant changes have occurred in the system's biodiversity as defined by dominance shifts the fish community in both biomass and associated economic yields of the ecosystem. However, the stability and resilience of the zooplankton and physical patterns of the system remain essentially unchanged for the past 80 years.

Other recent changes observed include the increasing frequency and extent of harmful blooms of planktonic algae. Elevated levels of nutrients, possibly from human sources including wastewater in estuaries and nearshore coastal areas, have been suggested as possible causes for the blooms.

2.1.4 Texas A & M University Marine Mammal Research Program (January 1993) (web site)

Long term monitoring of population condition indices, utilising bioelectrical impedance and ultrasound technologies to document seasonal and inter-annual trends in body fat reserves as an index of environmental quality.

Long-term assessments of environmental quality using marine mammals as highly visible indicators of ecosystem status. Arguments provided for using marine mammals as indicators.

2.1.5 Virginia Institute of Marine Science

Martha Rhodes research interests (web site)
Research on public health issues related to estuarine microbiology:

- evaluation of alternate indicators of faecal pollution (to faecal coliforms) in estuarine environments
- evaluation and modification of enumeration methods for these alternate indicators

Howard Kator research interests (web site)

Research on the ecology of authochthonous bacteria and viruses in estuarine waters, especially indicators of faecal contamination:

- examination of the validity of selected micro-organisms or chemicals as indicators of sewage or faecal contamination
- evaluation of their methods of detection
- establishment of their applicability for regulatory use in the context of classifying waters for harvesting of molluscan shellfish or recreational use.

2.1.6 Rhode Island Coastal Resources Management Council

Imperial MT, Hennessey TM An ecosystem-based approach to managing estuaries - an assessment of the National Estuary Program. Coastal Management 24(2):115-139 (1996) (Current Contents)

Some of the strengths and weaknesses of this approach are identified.

(Reference to come)

2.1.7 Scripps Institution of Oceanography, University of California, San Diego

Major Coastal Environmental Issues (web site)

Issues that are characterised by their wide geographic scope and that address the problems of sustainable use of resources, reversibility of effects, and anthropogenically mediated deterioration of coastal ecosystems:

- **Eutrophication**

Inputs of nutrients to coastal areas from waste treatment facilities, non point sources in watersheds and the atmosphere are increasing world wide eg loading of nitrate and total nitrogen with increase in use of chemical fertilisers. Excessive nutrients lead to harmful or noxious algal blooms, shifts in food chains, increased sedimentation of organic particles and ultimately depletion of dissolved oxygen, particularly in bottom waters.

Changes in the biotic composition of planktonic and benthic communities as a result of nutrient enrichment and death of organisms from lack of oxygen could have important effects on biogeochemical cycles, living resources, and biodiversity.

Eutrophication has increased in many coastal regions around the world as a result of increasing inputs of nutrients from agriculture, municipal wastewater and atmospheric deposition of fossil fuel combustion products.

A key factor necessary for understanding eutrophication is the ability to detect subtle interannual changes in water quality and its effect on ecosystem structure and function. This requires long-term monitoring and research programmes.

- **Habitat modification**

Physical modifications of habitats by either natural forces or human influence pose serious threats to coastal ecosystem integrity and these modifications are often difficult to reverse. Such modification may result from filling of intertidal or subtidal habitat; loss of tidal wetlands; submerged aquatic vegetation or coral reefs due too a decline in water quality or changes in sedimentation; or from changes in the hydrodynamics of coastal systems. While some of these modifications are reversible over time if the offending conditions are ameliorated (eg re-vegetation by submerged aquatic vegetation or restoration of salinity conditions) the likelihood of recovery for many modified habitats is uncertain.

- **Hydrologic and hydrodynamic disruption**

Changes in water circulation to and within coastal ecosystems have created poorly understood but perhaps important consequences in some coastal systems. The hydrology of watersheds draining to the coast have been significantly altered as a result of landscape changes, channelisation and damming, consumptive water uses, and diversion to other drainage basins. Reduction in freshwater flow as a result of increased use or diversion have caused problems in coastal areas of the USA. Conversely, increased freshwater flow or higher peak flows can result because of the increase in impervious surfaces, deforestation, and channelisation of flows within flood plains.

Hydrological changes can affect not only salinity patterns and circulation within coastal systems but also the delivery of nutrients, toxicants, and sediment to the coast.

Geomorphological modifications of shallow coastal systems may significantly affect the hydrodynamics of the coastal regime, affecting the influence of the coastal ocean on estuaries as well as the movement of materials from rivers to the sea. Such modifications may result from dredging of navigation channels, shoreline development and filling, shoreline protection (breakwaters, groins), and channelisation of tidal wetlands.

- **Exploitation of Resources**

By-catch issues.

Environmental effects of exploitation of non-living resources including development of oil and gas resources, and recovery of sand, gravel and other minerals.

- **Toxic Effects**

- **Introduction of Nonindigenous Species**

In some coastal environments, nonindigenous species have been introduced by human activities and have established populations that have major ecological consequences. Transport of organisms in the ballast water of ships is a major and growing source of introductions of nonindigenous species. Consequences to coastal ecosystems include loss of biodiversity by elimination of indigenous species, alteration of trophic dynamics, degradation of habitats, and diminution of fisheries productivity.

- **Global Climate Change and Variability**

Global sea level rise could accelerate from a variety of factors, rising by as much as 3-10m. Local sea level changes (from subsidence in coastal areas due to freshwater withdrawal, erosion, movements of Earth's crust, and thermal expansion of seawater) could add to global effects. Results could be significant shoreline inundation, overstepping barrier islands, loss of intertidal wetlands, and increased salination of coastal embayments.

Potential effects of global climate change are discussed.

- **Shoreline erosion and hazardous storms**

Beaches buffer coastal lands and habitats from assault by the ocean, providing the most effective means of preventing coastal erosion and habitat destruction. Changes in land use can affect the supply of sediment to beaches (via rivers and streams) and consequently shoreline erosion.

Shoreline erosion is also influenced by coastal processes resulting in offshore and alongshore transport of sediments. Changing patterns in coastal storm climate can change the direction of sediment transport by altering the intensity and direction of the waves incident to a beach.

- **Pathogens and toxins affecting human health**

This can occur in coastal waters or from the consumption of undercooked or raw seafood harvested from those waters. Coastal population growth has resulted in the increasing flux of pathogens to coastal waters, primarily from sewage outfalls. There are two health issues:

i) induction of illness through exposures of recreational swimmers, divers, and boaters to pathogens
ii) consumption of undercooked or raw seafoods that have accumulated pathogens or toxin-bearing algae.

Faecal coliform testing has provided a significant level of protection, although illness and an occasional death still result from human pathogens in coastal waters.

In the case of toxic phytoplankton, state or local monitoring occurs on a local basis.

The Ecosystem Perspective

The emerging and widespread environmental threats discussed above pose new challenges to environmental policy, management, and science, requiring different approaches than those used for the past coastal problems such as point-source discharges of industrial and municipal effluents, coastal land use, direct habitat destruction, and oil spills. These issues have not been eliminated although some of their effects are relatively well understood and significant advances have been made in their management in several countries. Concern is shifting from issues amenable to single factor risk assessment to approaches involving multiple-stressor risk assessments and indirect cascading and scale effects on living resources. Understanding such coastal problems requires approaches that focus on ecosystems, populations of organisms and communities of species. There is now greater concern about the response of ecosystems to the effects of exploitation of resources, nutrient enrichment, and the indirect effects of human activities on coastal habitats.

2.1.8 University of Maine

Environmental impact of salmon net-pen culture on marine benthic communities in Maine. RH Findlay and L Watling (1995): Estuaries 18 (1A): 145-179.

Measured:
- increased carbon flux to the benthos caused by the net-pen.
- effects of elevated flux on sediment biogeochemistry and microbial and macrobenthic communities.

Results:
- Carbon flux to benthos increased 1-6-fold at edge of net-pen with little or no increase 10 m from the pen.
- Sediment organic matter showed a complex pattern of change over time.
- Beneath the pen, microbial and microfaunal communities were shifted towards those commonly associated with organic enrichment. When abundant, most epibenthic organisms were more numerous near the pen than in adjacent ambient areas.

Results suggest that net pen aquaculture can alter the benthic ecosystem in Maine coastal waters but that the effects are spatially limited.

2.2 Canada

2.2.1 Environment Canada

Web site

Environment Canada's indicator development is guided by three goals for *sustainable development*:

- assuring ecosystem integrity
- assuring human health and well-being
- assuring natural resource sustainability

Population, lifestyle and consumption patterns influence the attainment of these three goals.

An "issues" approach and stress-condition-response model have been adopted.

Environment Canada State of the Environment Reporting 1991 A report on Canada's progress towards a national set of environmental indicators

Marine environmental quality indicators:

- Municipal discharges to coastal waters: Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD)
- Pulp and paper mill discharges to coastal waters: TSS and BOD
- Volume of significant marine spills (exceeding one tonne spilled material)
- Area closed to shellfish harvesting
- Contaminant levels in seabird eggs: PCBs
- Contaminant levels in seabird eggs: Dioxins and furans

Fisheries indicators:

- Total commercial fish catches in Canadian waters off the Atlantic coast

Environment Canada SOE Bulletin No. 94-5, 1994 Sustaining Marine Resources: Pacific herring fish stocks

Issue context:

A highly valued marine resource, internationally, provides employment for thousands of Canadians and a way of life for numerous coastal communities and contributes millions of dollars to the national economy. Pacific herring is a regional indicator of marine resource sustainability carrying national significance.

Indicators:

- Abundance (spawning biomass) of Pacific herring stocks
- Commercial catch of Pacific herring
- Economic value of Pacific herring

Environment Canada SOE Bulletin No 93-1 Environmental Indicator Bulletin: Toxic contaminants in the environment - persistent organochlorines

Issue context:

These organochlorines (by-products of industrial processes and produced by incomplete combustion and during forest fires) can take decades or even centuries to break down naturally. Because of this persistence and their high solubility in fat, they tend to accumulate in some animals and then pass through the food chains to reach very high concentrations in the tissues of predators at the top of the food chain.

Indicators:

- Contaminant levels in double-crested cormorant eggs: DDE and PCBs
- Contaminant levels in double-crested cormorant eggs: Dioxins (PCDDs) and furans (PCDFs)

Environment Canada SOE Fact Sheet No 89-2 Pollutants in British Columbia's Marine Environment

Pollution: sources and effects

"Indicators":

- Number of permits issued by government of BC authorising the on-going discharge of wastes to the sea (sewage, food and other, pulp and paper and forest products, oil, gas, chemical, and mining)
- Area closed to shellfish harvesting in BC due to faecal contamination (municipal discharge, urban runoff, septic seepage, boat discharge, agriculture, hinterland)
- BOD (biochemical oxygen demand) and TSS (total suspended solids) provide measures of adverse effects of effluent discharged daily from coastal pulp mills.
- Amount of material dumped annually under ocean dumping legislation
- Number of marine spills over 1 tonne
- Mean mercury levels in crab meat
- Maximum trace metal concentrations in sediments at contaminated and reference sites
- Organic contaminants in Great Blue Heron eggs

B J Smiley: Selecting indicators for State-of-the-Marine Environment: A conceptual framework, an operational procedure and a contaminants example. Paper presented at Marine Ecosystem Network Workshop, Nanaimo, BC, 1995

Basic questions at the heart of State of the Environment reporting:

- What is happening?
- Why is it happening?
- Why is it significant or important?
- What is being done about it?

A conceptual framework is presented based on an ecosystem Structure and Function concept where environmental issues are evaluated through a series of inter-relationships on the Stress-Condition-Response continuum.

Structure of a marine ecosystem refers to the components that indicate that change has occurred, eg trophic composition, population abundance, size composition, age structure. The Function refers to the Processes that can lead to change eg nutrient recycling, bioaccumulation, reproduction.

Link hypotheses describe the relationships between an action(s) (Stress) and their effects (Response) in the environment.

The framework consists of an hierarchical, ecological and geographical classification which allows the identification of the relevant marine eco-units within Canada. This fosters an ecological approach to selecting indicators.

Operational procedure:

1. *Generate the Issue Hypothesis*

   Using Valued Ecosystem Components (VEC) to define the valued ecological or societal feature or environmental component. Criteria used for selecting VECs:

   - Rarity
   - Fragility
   - Ecological importance
   - Scientific value
   - Societal value
   - Aesthetic value

2. *Understand and refine the framework*

3. *Draw and validate the links*

4. *Select the indicators*

   Criteria used to select indicators:

   - Data reliability
     - timeliness (data provided within time frame consistent with decision-making requirements)
     - cost-effectiveness (easy and relatively inexpensive to measure)
     - coverage (spatial and temporal)
     - data adequacy (accurate and precise)
     - data availability (from literature and on-going programmes)

   - Issue relevance
     - scientific validity (scientifically defensible)
     - representativeness (indicator conveys understanding of the whole ecosystem)
     - responsive to change (early warning and forecasts)

   - Usefulness to decision-makers
     - understandable
     - relevant
     - target threshold (tied to stated targets, thresholds or tolerance limits)
     - potential for comparison (by other institutions or jurisdictions)

Indicators are evaluated against these criteria.

The data's precision and accuracy are very critical in choosing an ideal indicator, especially for geographical and temporal trends.

(Full report requested)

Environment Canada's State of the Environment in the Atlantic region 1994

The marine ecosystem is under stress from the impacts of human activities. Some stresses come from relatively large-scale point sources such as municipal and industrial effluents, ocean dumping, mining and associated industries or form oil and hazardous chemical spills. Other stresses from numerous diffuse non-point sources such as agricultural and urban runoff. Contaminants are listed.

Additional stresses are placed on the biota of the marine ecosystem from activities such as the commercial harvesting of groundfish, pelagic fish and shellfish, and from such activities as disposal of persistent marine litter and the accidental or intentional discharge of oil from ships. Ghost fishing by untended or lost fishing gear is also a problem.

Coastal development and physical changes such as infilling and dredging and construction of dams, causeways, wharves and dykes have also altered the marine ecosystem in certain areas.

Many chemicals and other substances from industrial activities can accumulate in marine biota.

Health of our oceans: a status report on Canadian Marine Environmental Quality. **Environment Canada 1991** Edited by PG Wells and SJ Rolston.

National and international perspectives:

Pacific, Atlantic and Arctic Regions are dealt with separately. Each is divided into: pollution sources (dredging, mining, pulp and paper etc), specific substances, geographic areas of concern, and assessment.

Assessment of Pacific Region:

This section assesses the implications for valued ecosystem components of losses in marine environmental quality. Most valuable fisheries are listed as salmon, herring, groundfish, and shellfish in that order. Marine mammals and seabirds are important aesthetically, culturally and ecologically and for tourism.

For salmon: dissolved oxygen and toxicity are two causes of habitat loss due to pollution

For benthic organisms: smothering of bottom habitats, toxic conditions in sediments, bioaccumulation are three identified threats

For shellfish: paralytic shellfish poisoning occurs regularly along the Pacific coast resulting in occasional harvesting closures

Atlantic coast:

Many stresses due to conflicting uses and combined pressures of a rural and an urban society dependent largely on the region's natural resources. A number of indicators and trend information show that marine quality is degraded in many places. Other indicators such as the abundance of marine wildlife, largely undisturbed beaches, aquatic life even in heavily used harbours and inlets, are signs that natural systems are still functioning and can recover from many abuses if that stops. Continued strong programmes of conservation and protection, guidelines and objectives for marine environmental quality, status and trends monitoring, comprehensive coastal management programmes and supportive research are required.

Environment Canada, National Oceanic & Atmospheric Administration, Florida Department of Environmental Protection

Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. ED Long, DD Macdonald, SL Smith, FD Calder (1995): Environmental Management 19 (1):81-97.

The method is being used as a basis for developing **national sediment quality guidelines for Canada** and **informal sediment quality guidelines for Florida**.

Based on an evaluation of existing data, three ranges in chemical concentrations were determined for 28 chemicals or chemical classes. These were defined by two guideline values: the lower 10 percentile and the 50 percentile of the effects data distribution. The incidence of biological effects was quantified for each of these ranges as an estimate of the accuracy of the guidelines. A range of benthic fish and invertebrates were used.

2.2.2 Dalhousie University, Nova Scotia

A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthis communities. J Grant, A Hatcher, DB Scott, P Pocklington, CT Schafer, GV Winters (1995): Estuaries 18 (1A): 124-144.

Sedimentation rates were higher under mussel culture lines than an adjacent reference site due to deposition of mussel faeces and pseaudofaeces. There was greater anaerobic metabolism at the mussel site but sulphite was absent from the upper sediments. Sediment oxygen demand showed little change between sites but maximum rates of ammonium release at the mussel site were twice the highest rates at the reference site. Abundance of benthic macrofauna was higher at the reference site but biomass was generally lower. In general, the impact of aquaculture on the benthos appeared to be minor.

2.3 United Kingdom

UK National Monitoring Programme (1994) (P Matthiessen, MAFF Fisheries Laboratory, Burnham-on-Crouch, UK pers. comm.)

This programme employs a mixture of chemical analysis, bioassays and benthic community analysis to survey estuarine and coastal waters for possible pollution and other anthropogenic impacts.

The official bioassay species is the oyster embryo which is used both for waters and sediment elucidates. A suite of whole sediment bioassays plus a range of biomarker tests and extraction techniques are routinely employed.

A widespread survey has been undertaken over the last five years to identify "hot spots", mainly in estuaries.

(Reference ordered to come by mail)

Plymouth Marine Laboratory and MAFF Fisheries Laboratory, Burnham-on-Crouch
Scope for growth and contaminant levels in North Sea mussels Mytilus edulis
(Widdows J, Donkin P, Brinsley MD, Evans SV, Salkeld PN, Franklin A, Law RL, Waldock MJ 1995 Marine Ecology Progress Series 127:131-148)

To date, North Sea monitoring programmes have focussed primarily on concentrations of chemical contaminants accumulated in biota and on the compositions of benthic communities. These need to be complemented by more sublethal biological effects measurements and ones that have the potential to identify the causes of any observed deleterious effects. The combined measurements of the stress response "scope for growth" and chemical contaminants in the tissues of mussels were able to detect, quantify and identify some of the major toxicants causing the pollution effects. "Scope for growth" is a physiological response and one of the most sensitive measures of pollution induced stress. It provides an instantaneous measure of the energy status of an animal.

The study demonstrated that the scope for growth technique can be adapted and applied to assess environmental quality and pollution impact over a wide geographic area such as the North Sea coastline.

Coastal and Estuarine Research, Department of Geography, University of London (web site)

Focus on:

- fundamental research on coastal and esturaine processes and landforms
- scientific bases for sustainable management of coasts and estuaries
- environmental monitoring

Interlinked research projects with overall objective of sustainable defence against estuarine flooding. Focus is on environmental dynamics of estuaries in SE England.

Port Erin Marine Laboratory, Isle of Man, Plymouth Marine Laboratory, and Leverhulme Unit, Marine Biological Association

From the individual to the community and beyond: water quality, stress indicators and key species in coastal ecosystems. Hawkins SJ Proud SV, Spence SK Southward AJ in Water quality and stress indicators in marine and freshwater systems: linking levels of organisation (individuals, populations, communities): invited papers from a conference by Freshwater Biological Association September 1993.

Population level bioindicators are rare in coastal ecosystems particularly on rocky shores although they are cheap and easy to use. At the community level rocky shores are too variable to monitor subtle effects but are useful for monitoring recovery from catastrophic events. Offshore or intertidal soft bottom communities are better for showing community level effects probably because impacts from organic matter or toxins end up in the sediments thereby affecting the benthic fauna.

Direct Toxicity Assessment National Centre, Environment Agency, Worthing, UK
Development and testing of General Quality Assessment Schemes. SC Nixon, S J Clarke, AJ Dobbs and M Everard, 1996, London, HMSO.

The National Rivers Authority (NRA) has identified a requirement for General Quality Assessment (GQA) schemes so that geographic differences can be quantified and trends of water quality in rivers, canals, estuaries and coastal waters in England and Wales can be monitored. The GQA will enable cost-effective water quality management and control and assessment of the effect of actions.

The main goal of the programme was to develop robust schemes that would provide overall assessment using different aspects of aquatic environmental quality. Consistent and quantitative comparisons of quality could then be made geographically and over time. Assessments could then be made by the NRA as to the sites of poor quality followed by appropriate management measures and monitoring of their effectiveness.

The components considered for inclusion in the GOA schemes for estuaries and coastal waters are:

a) **Nutrients** where *soluble reactive phosphorus* and *total inorganic nitrogen* were measured with median levels corrected for salinity differences.

b) **Aesthetic quality** where eight measures (*sewage derived litter, gross litter, general litter, faeces of non-human origin, oil, foam, colour, and unattached seaweed*) provided a semi-quantitative comparison of worst-case measured levels based on public perception.

c) **Sediment quality** where *metals, pesticides and other synthetic organic substances* are measured. Mercury, cadmium, chromium, copper, zinc, lead, nickel, arsenic and 11 organic substances were selected including lindane, dieldrin and PCBs. (Toxic substances can accumulate and persist in sediments so improvements in discharges may not lead to immediate or even rapid improvements in biological quality. Substances can be reintroduced into the water column from the sediment either by re-suspension or desorption processes.) Further development and testing are required before implementation is possible but four basic options were identified for the development of this GQA component by the NRA:

- Gross levels are compared across England and Wales
- Correction or normalisation techniques to take into account the variability of particle sizes within sediment samples and the tendency for metal and synthetic organic substances to associate with finer clay mineral and organic matter fractions of sediment.
- Correction or normalisation techniques to account for background levels so that an indication of contamination from human activities can be determined by taking natural metal levels from the measured levels.
- Relating gross measured levels to potential biological effects by, for example, basing class values on predetermined biological effects levels or sediment quality standards (UK has no generally accepted sediment quality standards but UK MAFF, Canada, USEPA, the Netherlands and OECD have developed methods for generating sediment quality guidelines and the resulting values are widely used for various management applications).

d) **Biological quality** where the *benthic invertebrate community* is assessed using pollution stress related measures derived from multivariate techniques. Very limited comparable data is available and further development and testing are required before implementation.

In addition for estuaries:

e) **Basic chemistry** where *DO* and *total ammonia* are measured. They are related to probabilities of biological effects in relation to concentrations, duration and frequency of exposure to those concentrations. These have been tested on continuously recorded DO data from three estuaries with spot samples from routine NRA monitoring. Tidal surveys were commissioned for this study.

The scheme is to be used to provide an objective method of classifying estuaries and coastal waters. Different approaches were evaluated in developing these components ranging from basing the classifications on measured determinand concentrations alone, to relating differences in class to potential effects on aquatic life. The development of all components was based on reviews of the water quality impacts and on detailed statistical examination and analysis of available data, which were mostly obtained from routing NRA monitoring surveys. The components were tested in this project.

At present there are no national sediment quality guidelines or standards for UK tidal waters although guidelines are applied locally by MAFF in the regulation of sludge/dredging waste grounds

The NRA are now in a position to implement the nutrient and aesthetic components for rivers, canals, estuaries and coastal waters, and also the basic chemical scheme for estuaries. Further research into the sediment and biological quality components for estuaries and coastal waters is still required.

2.4 Australia

State of the Environment Australia 1996. Proceedings of a workshop on: Key Environmental Indicators for Estuaries and the Sea in State of the Environment Reporting. Department of the Environment, Sport and Territories.

Environmental indicators for national State of the Environment reporting are not indicators of sustainability. Sustainability indicators must include social and economic as well as environmental considerations. Environmental indicators are viewed as a necessary but not sufficient tool for measuring progress toward sustainability.

The following indicators were proposed at the workshop using the Pressure-State-Response system.

State indicators identified were:

Beaches

- area of beach type
- gross movement of shoreline based on vegetation line along the backshore

- beach biota (key indicator species)

Sand dunes
- dune type by standard classification
- area of Holocene dunes
- species composition of vegetation

Estuaries and coastal lagoons
- estuary type by standard classification
- health of estuary (based on assessment of indicators for other elements, eg water quality, seagrasses, water exchange regime)

Gulfs and bays
- health (based on assessment of indicators for other elements)

Islands and cays
- type by standard classification
- physical area
- species diversity
- vesting (tenure)

Deep ocean
- flora and fauna coverage of sea mounts

Coral reefs
- reef type by standard classification
- areal extent
- health (based on assessment of indicators for other elements)

Saltmarshes, mangroves and seagrasses
- area by bioregion
- species composition
- productivity
- exotic species invasions

Microflora
- sea surface chlorophyll
- density reported frequency of blooms

Fish
- status of exploited stocks (recruitment index, breeding stock index, age structure, ratio of actual to expected catch)
- catch rates and species composition of bycatch

Introduced species

- proportion of exotic species by number/ area/relative abundance per region
- effect on native flora and fauna

Seafood quality

- percentage of samples exceeding Maximum Residue Levels by species

Nutrients

- nitrogen species (concentration)

Pressure indicators were identified for each ecosystem or species according to:

- population - where relevant
- habitat destruction and modification - such as % land cleared or shoreline modified
- hydrological modification - such as channel dredging or coastal engineering works
- tourism and recreation - such as boat use, fuel sold, ramp and fishing surveys
- stormwater discharge
- nutrients
- suspended solids
- pesticides, herbicides and industrial chemicals - pesticide use, National Pollutant Inventory
- metals
- pathogens
- litter
- fishing
- mining

Ecosystems and species listed for these pressure indicators were:

- estuaries and coastal lagoons
- saltmarshes
- mangroves
- seagrasses
- macroalgae
- microflora
- fish
- reptiles
- seabirds
- mammals
- seafood quality
- nutrients (estuaries)

Other pressure indicators were suggested for:

- introduced species
  - tonnage of ballast water discharged into ports, % discharged ballast water of "foreign" origin, hull cleaning (time since last cleaned), number of introduced species.
  - aquaculture use of exotic feeds, imports of foreign stocks, number of approvals.
  - habitat modification eg scallop dredging.

- beaches - indicator identified: area of unvegetated dunes
- deep ocean
- shipping - indicators: shipping quantity and lanes
- aquaculture - indicators suggested:

  number of aquaculture units (by species and abundance)
  area (by species and abundance)
  intensity (stocking index)
  farm production
  area of alienation (on-shore and off-shore)
  food input (conversion ratio)
  sediment quality
  frequency of disease outbreaks, fish kills, algal blooms
  escapes including genetic consequences

The workshop also identified further research and development needs. These included:

- testing the pressure-state-response model
- designing intelligent monitoring programmes to test cause-effect models using comparisons of "least disturbed" sites with impacted sites
- extending monitoring programmes for other systems, such as rivers, to estuaries and the sea; RIVPACS (River Invertebrate Prediction and Classification System) as a tool for comparative assessment of ecological health was specifically noted.
- developing a system for assessing the health of estuaries based on a range of simple indicators of specific biophysical aspects of estuaries
- developing a fine scale bioregional classification
- developing monitoring requirements for most key indicators

Indicators for monitoring Victoria's coastal and marine environments: Consultants report to the Commissioner for the Environment 1991. R Colman, D Gwyther, M Keough, G Quinn, J Smith, Victorian Institute of Marine Sciences.

The focus of this report is on detection of underlying trends of long-term change in the marine and coastal environment in a number of (defined) "Valued Environmental Attributes" and on ability to discern trends from "noise" in the data.

The set of 33 key indicators that were defined for the Valued Environmental Attributes are as follows:

Water quality:
- dissolved oxygen
- nutrients
- total organic carbon (TOC) and particulate organic carbon (POC)
- chlorophyll-a

- total phytoplankton count
- total toxic algal count
- bioaccumulative organisms

Marine Biota:

- extent and health of seagrass meadows
- extent of intertidal algal beds
- shorebirds
- introduced species of plants and animals
- intertidal animal populations
- commercial fish

Seabed sediment quality:

- sediment characteristics
- sediments analysed for nutrient content, TOC, POC, hydrocarbon content, heavy metal content (bioavailable and total), organics/biocide content

Coastal morphologies - all open coast and embayments:

- high water mark
- extent of sand beaches
- boundary of foredune vegetation
- extent of mangroves and saltmarshes
- age composition and condition of mangrove forests

Estuaries (includes Gippsland lakes):

- modification to salinity regime
- modification to estuarine morphology
- community structure and condition of estuary, estuary foreshore vegetation
- marine wetlands
- area of inundation
- period of inundation
- salinity of wetland waters
- community structure and condition of wetland vegetation

Foreshore vegetation:

- extent, community structure and condition of foreshore vegetation

Aesthetic:

- area of degraded shoreline (analyses of aerial and oblique photography)
- area of degraded shoreline (direct observation and reporting)
- proportion of developed/undeveloped coastline
- sensitive locations with visible development
- number of coastal planning controls on development

Cultural:

- number of significant cultural sites and their level of degradation

A parallel approach is to monitor concurrently *process and activity indicators* to separate these from the effects of human activities. These indicators of process and activity are summarised below.

Processes - basic environmental variables:
Nine indicators all monitored to the appropriate Standards:

- air temp
- water temp
- salinity of waters
- turbidity of waters and suspended solid content
- solar radiation
- wind speed and direction
- barometric pressure
- sea level
- wave climate

Human activity indicators for marine and coastal environments:
Ten indicators obtained through surveys and analyses of records and local authority planning and building approval data:

- area of land or seabed utilised or reclaimed for coastal facilities
- extent of capital dredging works
- volume of commercial shipping
- occupancy rates of marinas and swing moorings
- number of boats registered
- quality of antifouling paint applied to small craft
- volume of dredge spoil removed and its destination
- recreation pressure
- extent and distribution of developments in coastal catchments
- summaries of the number and extent of coastal and recreational facilities constructed

South Australia: Environment Protection (Marine) Policy 1994 (Web site)

Water Quality Guidelines for Estuarine and Marine Waters of South Australia were established in August 1992. ANZECC released the Australian Water Quality Guidelines for Fresh and Marine Waters in November 1992. The relevant parts of these guidelines were incorporated into the South Australian Guidelines for Licensing Discharges to the Marine Environment released by the EPA in November 1993. The guidelines were based on water quality criteria which set out the minimum quality required for particular beneficial uses of water. Each beneficial use has qualitative and quantitative criteria that are required to support the beneficial use.

The water quality guidelines in this policy are used to establish limits on pollution for persons holding environmental authorisations. The criteria are listed as acceptable concentrations of toxicants for marine and estuarine waters and are grouped as metals, pesticides, other organics, and miscellaneous. Indicators for nutrients in the National Guidelines are cited for phosphate, nitrate-nitrogen, ammonium-nitrogen and chlorophyll-a with limits for both estuaries and coastal waters.

An Action Priority table deals with water-borne pollutants and their human and ecological impact, source, areas in South Australia most affected and probable spread. Pollutants listed are:

- *nutrients and other organic wastes* that cause algal growth and red tides
- *faecal waste* that restricts recreation and seafood consumption but may promote filter feeders
- *particulates and turbidity* that affect aesthetics, swimming accidents, smothering substrate and changing species composition
- *exotic pests and diseases* that may foul hulls, cause algal blooms, compete directly or reduce advantage of local species
- *heavy metals* that contaminate seafoods, reduce fish numbers, and reduce marine organism numbers
- *litter* that restricts recreation, causes accidents, kills birds and mammals
- *other chemicals* (pesticides, consumer and household products) that contaminate seafoods, affect recreational exposure, and kill marine organisms
- *process waste* that has aesthetic effects, contaminates seafood, affects recreational exposure, and may affect behaviour of organisms
- *chemical spill/overspray* (from pest control) that kills fish that may be taken/consumed, and kills marine organisms
- *hydrocarbons* (oil) that foul structures and beaches, may taint seafoods, have a probable metabolic effect on organisms, and kill birds
- *bitterns* (salt fields) affect aesthetics, and probably affects organisms
- *thermal* that restricts recreation but boosts fish growth, excludes some species, and facilitates exotic species

The Environment Protection Act 1993 empowers the Authority to impose conditions in an environmental authorisation in relation to an environmental protection policy and to require the authorisation holder to monitor the environmental effects of an activity.

A series of 10 Schedules set out water quality criteria for a variety of water uses:

- *Schedule 1 Water quality criteria for recreational or scientific uses including national parks and similar aquatic reserves.* Indicator criteria are given for colour and clarity, dissolved oxygen, pH, suspended particulate matter, temperature change and levels of toxicants permitted.

- *Schedule 2 Water quality criteria for recreational waters - primary contact.* Biological indicator criteria: faecal coliform, blue-green algae, pathogenic protozoans; also pH, light penetration, aesthetic quality, dangerous objects, temperature, toxic substances.

- *Schedule 3 Water quality criteria for recreational waters - secondary contact* includes biological faecal coliform, and pH.

- *Schedule 4 Water quality criteria for recreational waters - passive recreation in non-pristine waters e.g. aquatic scenery.* Indicator criteria are given for abiotic considerations: odours, taints, colours, floatable matter and settleable matter; and biotic considerations: plant growth nutrients and wildlife.

- *Schedule 5 Water quality criteria for the maintenance of water-associated wildlife.* Indicator criteria are dissolved oxygen, pH, buffering capacity, salinity, light penetration, settleable substances, plant growth-nutrients, oil, chlorinated hydrocarbons, polychlorinated biphenyls, mercury, and other toxicants.

- *Schedule 6 Water quality criteria for the maintenance of marine aquatic ecosystems - Level I protection.* Indicator criteria are dissolved oxygen, pH, salinity-marine, salinity-estuarine, suspended solids, turbidity and colour, settleable solids, temperature, nutrients, toxicants, toxicant mixture.

- *Schedule 7 Water quality criteria for the maintenance of marine aquatic ecosystems - Level II protection.* Indicator criteria are dissolved oxygen, pH, salinity-marine, salinity-estuarine, suspended solids, turbidity and colour, settleable solids, temperature, nutrients, toxicants, toxicant mixture.

- *Schedule 8 Water quality criteria for shellfish culture and harvesting. 1 Criteria for the protection of shellfish growing areas.* Indicator criteria are organic tin (from antifoulants) and Schedule 6 indicator criteria.

- *Schedule 9 Water quality criteria for shellfish culture and harvesting. II Criteria for the protection of human consumers.* Indicator criteria in approved growing area: total coliforms and faecal coliforms. For restricted growing areas the following criteria apply plus post-harvest treatment: total coliforms and faecal coliforms at higher numbers, biotoxin levels must not exceed specified amount for harvesting, algae, nutrients, tainting substances.

- *Schedule 10 Water quality criteria to minimise effects of fish farming on the surrounding environment.* All requirements of the Fisheries (Exotic Fish, Fish Farming, and fish Diseases) Regulations should be met. In addition the Aquaculture Committee recommend the following indicator criteria: pH, oxygen, sediment. The SA Health

Commission monitors chemical residues and bacterial levels within oyster farming. Waters contiguous with leases should better criteria in Schedule 7 and approach Schedule 6.

Ferguson CM Coote BG Ashbolt NJ Stevenson IM Relationships between indicators, pathogens and water quality in an estuarine system. Water Research 30(9):2045-2054. 1966. (Current contents)

Water and sediment samples examined for a range of indicator and pathogenic micro-organisms for six sites in an urban estuary, Sydney, Australia. Water quality was affected by rainfall and sewage overflows which were associated with significant increases in faecal coliforms and other pathogens. In sediments, only faecal coliform concentrations were significantly increased by rainfall, although sewage overflow again resulted in increased concentrations of faecal coliforms and other pathogens.

Kirkman H. Baseline and monitoring methods for seagrass meadows. Journal of Environmental Management 47(2):191-201. 1996 (Current contents)

Seagrass meadows are one of the most vulnerable habitats of coastal and estuarine waters in Australia. Methods to measure health and abundance:

- Aerial surveys and remote sensing for gross scale inventory gathering
- Permanent transects can detect changes at a much smaller scale
- Biomass, density and productivity measurements all indicate the "health" of seagrass meadows

Liberal Party of Australia: Coalition Policies, Canberra (web site)
Saving our Natural Heritage
Cleaning up our Water and Coastline

A key indicator of the environmental health of the Murray-Darling Basin is the flows of the Murray River near where it enters the sea. Changes in flow volumes and patterns have produced:

- increased salinity in the river
- less frequent flooding and reduced floodplain inundation adversely affecting dissipation and riparian habitats
- a reduction in the area of wetlands
- more frequent and severe algal blooms
- a significant decline in native fish populations
- river environments that favour species such as European carp

Coasts often face major problems of erosion, pollution and inadequate management.

- *Ocean outfalls* discharge partially treated sewage at locations around the country
- Coalition will fund reduction in pollution inputs to the sewerage system
- improved design of outfalls

- progressively raise treatment standards
- develop significant water use efficiency and effluent reuse projects

Stormwater pollution impacts on bay and coastal water quality including threats to beaches and popular recreational and environmentally sensitive coastal areas.

Marine research into treatment of ballast water is needed to avoid introduction of noxious marine species.

Oil spills: additional control equipment in Cairns to help protect the Great Barrier Reef.

Exclusive Economic Zone: in consultation with major stakeholders, a comprehensive and integrated Oceans Policy is needed including future sustainable use of the marine environment, protection of representative marine systems and the development of effective marine management strategies.

Review of the effects of non-point source loading on coastal ecosystems AJ Gabric, P F Bell. 1993. Aust J Mar Freshwater Res 44: 261-83.

In areas subject to runoff and soil erosion, most of the nutrient load is transported in particulate form. Loads of nutrients discharged from cropping lands are typically an order of magnitude greater than those discharged from pristine forested areas. Nutrient export from pasture lands, fertilised or not, is also significantly greater than from pristine areas. The importance of the particulate fraction in the nutrient load necessitates effective control of soil erosion.

Having entered the coastal environment, nutrient compounds undergo a variety of biological, chemical and physical processes that tend to prevent their export to the ocean. Thus the coastal zone residence time for these terrigenous nutrients tends to be quite long. The flux of new nutrients (eg from rivers) must not exceed the assimilative capacity of the coastal ecosystem if eutrophication is to be avoided.

2.5 South Africa

The Estuarine Health Index: a new approach to scientific information transfer. Ramm, Cooper, Harrison and Singh, CSIR, Durban (Date?), Chapter 19, pp271-280.

This study is concerned with:

- classifying estuaries into different types
- assessing the degree to which estuaries have been impacted by considering three aspects of their health: biological, water quality, aesthetic condition

Sixty-two estuaries were studied on the east coast between Tugela and Mtamvuna.

Geomorphological classification

The morphology of Natal river mouths can be defined by:

- size and shape of the initial basin
- type and volume of sediment supplied to it, dependent on:
  - catchment size
  - catchment geology
  - river mouth geology
  - coastal topography

Biological health

Fish were used to generate an index of biological health of estuaries because better records of fish fauna exist than of macroinvertebrates. A reference list of fish species was developed representative of each physical group of estuaries. Exotic species and all stenohaline inshore marine species were removed from the list. Also those species that were considered rare or uncommon were removed. A Community Degradation Index measured the degree of similarity between the potential community and the actual community. A Biological Health Index was developed as:

$$BHI = 10(J)[Ln (P)/Ln (P_{max})]$$

where J = the number of species in the system + the number of species in the reference community; P = the potential species richness of each reference community; and P_{max} = the maximum potential species richness from all the reference communities. The index ranges from 0 to 10 (totally impacted to totally un-impacted)

Water quality

Index incorporates seven widely used chemical measures of water quality that reflect the water's suitability for aquatic life, suitability for human contact and its eutrophication potential:

- Suitability for aquatic life: dissolved oxygen (essential to aquatic faunal metabolism)
  oxygen absorbed (measure of organic loading)
  unionised ammonia (toxicity to aquatic fauna)
- Suitability for human contact: *E. coli*
- Trophic status: nitrate- nitrogen (aquatic plant growth stimulant)
  ortho-phosphate (aquatic plant growth stimulant)
  chlorophyll-a (indicator of algal growth)

For the water quality index, aquatic life was weighted at 35%, trophic status was weighted at 35%, and human contact at 30% (since only one variable was used)

Aesthetic health

The ideal state of estuarine area taken as pristine before any human intervention. Measurement of aesthetic health started from a perfect score of 10 from which amounts were deducted according to their relative impact.

Parameters considered that accommodate most of the aesthetic impact of an estuary were:

- floodplain landuse
- appearance of floodplain surrounds
- degree to which channel margins were natural

Also considered were persistent odours, water turbidity, presence of exotic vegetation, oil sheen, mouth stabilisation, presence of bridges, and degree of visual impact of multi-unit, single unit and industrial buildings.

The composite estuarine health index

The biological, water quality and aesthetic components were combined into a single value with equal rating to each parameter.