Global
Ocean
Observing
System

Intergovernmental Oceanographic Commission

The Final Design Plan for the HOTO Module of GOOS

GOOS Report No. 99
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FOREWORD

This present report is the final Report of the Health of the Ocean Panel of GOOS and provides a strategic design plan for HOTO elements in GOOS. It incorporates past activities of the Panel and supersedes any past reports. This present report adds a stronger link to human health, a more detailed discussion of data management and modelling an overview of the HOTO Pilot Project RAMP (Rapid Assessment of Marine Pollution) and a detailed discussion of future Pilot Projects for an implementation plan.

The HOTO Panel is to be merged with the GOOS Coastal Panel and the Living Marine Resources Panel. The scope of HOTO monitoring is more regional than that of ocean climate monitoring. In climate modelling, there are obvious requirements for inter-comparable data on global scales where most HOTO threats are regional. The value of the international GOOS HOTO Programme will be found through comparing trends in difference regions and in seeking common causal agents.

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EXECUTIVE SUMMARY

Pollution in the marine environment has become an issue of great concern, especially to coastal states. The oceans cannot provide an infinite sink for anthropogenic wastes but little attention has been given to evaluating the limits of capacity of coastal areas for waste assimilation. Consequently, instances of fisheries closures, spoiled beaches, destroyed coral reefs and wildlife habitat, toxic blooms and lost coastal ecological communities are widespread, with a corresponding determination of cost benefit. Recent concerns about connectivity of ocean health issues and the relationship to human disease highlight an important area for study.

In crude terms, about 80% of contamination reaching the oceans stems from land-based sources through the pathways of atmospheric, direct transport discharges, rivers and run-off. The problem is amplified by the fact that contamination largely occurs in the relatively fragile coastal zone. Ocean disposal of wastes and the discharges from marine shipping and offshore activities and natural sources make up the remaining 20% This situation was recognized as a major issue by UNCED in Agenda 21, Chapter 17.

The Health of the Oceans (HOTO) Module of the Global Ocean Observing Systems (GOOS) is intended to provide a basis for determining prevailing conditions and trends in the marine environment in relation to the effects of anthropogenic activities, particularly those resulting in the release of contaminants to the environment. Its primary objective is to provide information on the nature and extent of adverse effects, including increased risks, on human health, marine resources, natural change and ocean health. Data collection, biological-monitoring and biological effects assessment will be carried out on both global and regional scales using commonly agreed standards and methodologies. Areas of initial emphasis are: (i) The development of a set of reliable, relatively easily applicable ecological distress indices of the health of the marine environment; (ii) Monitoring concentrations and trends of contaminant loading in coastal zones in relation to community responses; (iii) Development of methodologies for the evaluation of assimilative capacities of coastal zones for contaminant introductions; and (iv) Reclamation of available data/information on contaminant levels/community responses at regional and national levels as baseline information for HOTO monitoring activities.

The term "Health of the Oceans" is operationally defined for the purposes of the HOTO Module of GOOS as a reflection of the condition of the marine environment from the perspective of adverse effects caused by anthropogenic activities, in particular the mobilization of contaminants and the release of human pathogens. Such condition refers to the contemporary status of the ocean and the prognosis for improvement or deterioration in its quality.

The Panel first identified a number of issues that, in global terms, are of contemporary concern in respect to the current health of the oceans. These include: climate change; endangered species; biodiversity; human health; tourism; and eutrophication. All of these issues are reflected in UNCED Agenda 21 and relate collectively to the following classes of contaminants or analytes chosen for attention within the HOTO Module:

Aquatic Toxins Nutrients	Petroleum Hydrocarbons (Oil)
Artificial Radionuclides	Pharmaceuticals
Dissolved Oxygen	Phytoplankton Abundance/Diversity
Herbicides/Pesticides/Biocides	Suspended Particulate Matter
Human Pathogens	Synthetic Organics/POPs
Litter/Plastics	Polycyclic Aromatic Hydrocarbons (PAHs)
Metals and Organometals	

The measurement of contaminant loads and pathogens cannot however alone, provide comprehensive quality criteria. Accordingly, the HOTO Module of GOOS must balance information on levels and trends in contamination with information on associated biological effects in order to permit global and regional assessments of pollution (i.e., adverse effects on the marine environment, its resources and amenities). Indices will have to be identified at different levels of biological structure: sub-organismal; individual; population; community and ecosystem. The Panel focused its

strategy to develop early warning methodologies in order to help developing and developed states to better manage their marine resources. The Rapid Assessment of Marine Pollution (RAMP) was adopted as a Pilot Project.

The Panel identified the range of anthropogenic activities that significantly mobilize the contaminants in the classes of concern listed above, these include: Aquaculture, Forestry/Logging, Coastal Development, Marine Transportation, Industrial Discharge, Sea Dumping, Agricultural Practices, Mineral Extraction Processes and Municipal and Urban Waste Discharge. There are also physical disturbances caused by these practices that have a direct effect on the marine environment and these must also be taken into account in the development of the HOTO Module. However, many of the physical disturbances have been outlined by the Coastal GOOS panel.

The Panel further examined the factors that bear on the selection of time and space scales for HOTO measurements. The first category of these involves managerial considerations that reflect the requirements of customers for interpretative practical products from the HOTO module. The second category includes scientific considerations relating to the scales of change following changes in the locations and rates of the introduction of substances and of physical disturbances of the marine environment. The third category involves considerations relating to the scales of natural variability in the marine environment for substances that are derived from both natural and anthropogenic sources.

The Panel evaluated the major data-reporting requirement for the HOTO Module. It based its evaluation on the assumption that all data, whether derived from research projects, regional monitoring activities, fisheries research or classified military activities, needs to be made readily available. Past and present data management practices need to be changed for the HOTO Module to have the required impact.

GOOS will foster and exploit the development of new technology to increase the cost efficiency of marine observations and improve the users' ability to access quality data and new technology. The Panel identified various needs for new technology and noted that these technologies must not only apply to chemical and physical measurements but also to biological ones extending, for example, to devices to improve the determination of the community structure of ecosystems as an important element of this module.

A major commitment needs to be made by all countries to implement effectively GOOS. Governments must be encouraged to:

- Make existing data available;
- Distribute data products;
- Facilitate data exchange;
- Develop data networks;
- Support the collection of satellite and *in situ* data;
- Support data collection by volunteer ships and data buoys; and
- Encourage person-to-person networking.

Lastly, the Panel identified a protocol for developing Pilot Projects for assessing ocean health and suggested a format of how a region could commence such a project. A draft paper written on HOTO implementation for Canada is a model for an approach other regions could use in designing a pilot programme (Annex III). The Panel has also included a component of ocean and human health for the Caribbean as an example.

1. BACKGROUND

At the present time there are unprecedented pressures on natural resources. Sustainable development of these resources is hindered by an inability to detect emerging environmental problems at an early stage when remedial measures can still be effective. Nowhere is this inadequacy so pronounced as in the marine environment. Global energy cycles and the biological processes upon which all life depend are critically influenced by the ocean. Knowledge of the ocean and humanity's impact on it is only now beginning to reveal the complexity and interdependence of all aspects of the system. Improved knowledge and predictive capabilities are required for more effective and sustained development of the marine environment to reap associated economic benefits and to preserve marine resources.

The two conventions signed at the United Nations Conference on Environment and Development (UNCED), The Framework Convention on Climate Change and The Convention on Biological Diversity, and the recommendations of Agenda 21, Chapter 17, require the establishment of an adequate observing system to help develop understanding and to monitor change. Many of the processes which control the variability and change of global climate are themselves controlled by processes in the ocean. Public perceptions of risk are only eased when governments are seen to be keeping the environment, including the ocean, under close observation. If the UNCED goals of global sustainable development and integrated oceans management are to be achieved, a much more integrated data management system and an ecological distress detection programme must be developed and implemented globally.

The major oceanographic processes that regulate the ocean's role in determining how the Earth System functions have variabilities over decadal time scales. These time scales exceed the anticipated lifetimes of the various global research programmes that have been, and are being, implemented to study ocean circulation (e.g., WOCE, TOGA, GODAE), chemical fluxes (e.g., JGOFS), land/ocean interactions (e.g., LOICZ), and the dynamics of ecosystems (e.g., GLOBEC, GEOHAB). These long term variations are associated with, *inter alia,* issues of climate change, the state of health of the ocean, biological diversity, human health protection, coastal zone management and their socio-economic impacts. Thus, it is essential that, as the coordinated research endeavours presently investigating the role of the ocean in the Earth System draw to a close, the relevant variables continue to be measured. To do this, continuing systematic, long term, interdisciplinary, global observations of marine physical, chemical and biological conditions are required, analogous to those under the World Weather Watch, operating under the auspices of the World Meteorological Organisation (WMO). Although there are some regional assessments of ocean health such as NOAA Status and Trends in the US, MEDPOL in the Mediterranean, CARIPOL in the Caribbean and the work of the Helsinki Commission there needs to be a commitment to sustained assessment programmes. In addition, with continuing interest in the relationship between humans and the ocean it is essential that there be co-ordinated programmes between ocean health and human health.

The purpose of this document is to finalize the strategy for and present a scientific and technical design of the Health of the Ocean (HOTO) Module of the Global Ocean Observing System (GOOS).

2. THE CONCEPT OF THE GLOBAL OCEAN OBSERVING SYSTEM (GOOS)

The objective of the GOOS is to ensure the establishment of a permanent system of global and systematic observations adequate for forecasting climate variability and change; for assessing the health or state of the marine environment and its resources, including the coastal zone; and for supporting an improved decision-making and management process, which takes into account potential natural and man-made changes in the environment and their effects on human health and marine resources. GOOS will provide a mechanism and infrastructure for data and information to be made available on various time scales to participating nations. As a result, individual national observing capabilities will be strengthened.

GOOS is an internationally coordinated system for systematic operational data collection (measurements), data analysis, exchange of data and data products, technology development and transfer. GOOS will use a globally coordinated, scientifically based strategy to allow for monitoring and subsequent prediction of environmental changes globally, regionally and nationally. Data will be generated by repeat sampling and remote sensing using sea-surface and sub-surface instrumentation in the open sea and coastal regions worldwide, including enclosed and semi-enclosed areas. Major physical, chemical and biological variables need to be identified that can be used to provide an integrated assessment of the current health of the oceans and early warning of deterioration.

GOOS has been established by Member States and implemented through nationally owned and operated facilities and services. Coordination is provided by the IOC in cooperation with WMO, UNEP and ICSU. GOOS is based on the principle that all countries should participate and that participants should make certain commitments, according to their capabilities, so that all countries can both contribute and benefit. The GOOS will be developed from operational and scientific data gathering systems and activities already in place, such as in the first instance, IGOSS, IODE and GLOSS, and in the latter, JGOFS, WOCE and TOGA as well as regional monitoring programmes such as AMAP, CARIPOL, etc.

Observations should be:

- Long term/sustained: Measurements once begun should continue into the indefinite future and should focus on the time-varying changes in the ocean. The time-series stations in the Atlantic off Bermuda (BATS) and in the Pacific off Hawaii (HOT) are examples of open ocean long term measurement programmes, CALCOFI off the coast of California provides an example of a long time-series in the near coastal environment. It is essential to make sure that commitments are made to continue measurement programmes once started;

- Systematic: Measurements should be made in a rational fashion, with the spatial and temporal sampling frequencies, as well as the precision and accuracy, tuned to address the specific deliverables of GOOS;

- Relevant to the global system: Measurements should be made either to address ocean variables important to the issues underlying the objectives of GOOS, or to provide data needed to initialize and validate models that describe and predict these variables from seasonal to decadal time scales and beyond. In the specific case of HOTO the strategic design calls for regional programmes which will contribute to a global overview;

- Cost effective: Efforts should be made to maximize the return on available resources (financial as well as human) by applying observational methods that are economical and efficient. This is especially relevant for the developing areas of the world. This emphasis on providing better tools for environmental assessment in developing nations is one of the major objectives of HOTO;

- Routine and pragmatic: The observations should be considered as part of the normal workload, with routine data acquisition, processing, archiving, quality control, and the dissemination of products to be carried out on a regular basis.

Originally the sponsors agreed that GOOS will comprise the following five “application modules”, whose objectives may overlap and which will share some of the same data (e.g., the data and information generated from all modules will contribute to the needs of Coastal Zone Management and Development), but which will have individually distinct purposes:

- Climate, Monitoring, Assessment and Prediction, including seasonal and interannual variability;

- Monitoring and Assessment of Living Marine Resources (LMR);

- Monitoring of the Coastal Zone Environment and its Changes (C-GOOS);
- Assessment and Prediction of the Health of the Ocean (HOTO); and
- Marine Meteorological and Oceanographic Services.

In the year 2000, after initial development, the first four of these panels have merged into two, a Climate Panel (OOPC) and a Coastal Ocean Observations Panel (COOP). All of the previous work of HOTO, LMR and C-GOOS will now reside in COOP.

3. PURPOSES AND BENEFITS OF THE HOTO MODULE

The objectives of the HOTO Module of GOOS are to provide a basis for the assessment of the state and trends in the marine environment regarding the effects of anthropogenic activities, including, *inter alia,* increased risks to human health, harm to marine resources, alterations of natural change and general ocean health.

Two principles were endorsed at UNCED: marine resources should be used sustainably; and a precautionary approach should be adopted for the prevention of adverse effects of anthropogenic activities on the environment. The adoption of a precautionary approach is primarily a managerial issue since, in the conventions where it has been adopted, decisions can be made on the basis of circumstantial evidence.

However, there are elements of precaution that have commonly been applied in the formulation of scientific responses to management questions such as the adoption of conservative approaches that take account of scientific uncertainties. A good example of such conservatism was the procedure used for the definition of radioactive wastes unsuitable for dumping at sea under the London Convention (1972).

Some other aspects of precaution have been inadequately applied by the scientific community in dealing with management questions that have been insufficiently specific. For example, the assumption that there are no effects of a given contaminant on a marine organism may be due to the inability of the sampling design to detect change with the given design. The inclusion of such considerations is essential to the application of a precautionary approach.

The terms of reference for the HOTO Panel were modified from the original Strategic Plan in 1996 in Singapore. HOTO is responsible for:

Ensuring continued updating of the Strategic Plan for HOTO to adequately reflect scientific understanding and technical capability arising from relevant research and development by:

- Maintaining liaison with research and monitoring activities to ensure that assessments and predictions of the health of the oceans are based on sound and contemporary scientific knowledge; and
- Developing interactions with other scientific and technical bodies and programmes relevant to the development of GOOS (i.e., ICES, PICES, Euro-GOOS, LOICZ, etc.);
- Analyzing further environmental health criteria or indices that can provide early warning of change in marine environmental quality and threats to human health;
- Co-coordinating with other GOOS Modules to ensure compatible strategic and scientific development of all GOOS Modules;

- Identifying the requirements, nature and availability of models that can facilitate the proper development of HOTO products and/or allow prognostic prediction of potential/future conditions relating to the health of the oceans;

- Identifying the scientific components of training, mutual assistance and capacity building, to undertake regional assessments;

- Examining the content of existing operational systems, both national and international, that deal with the health of the oceans with a view to advancing GOOS; and

- Defining HOTO products and socio-economic benefits relevant to the requirement of specific users and describing the procedures leading from the base variable measurements, through scientifically valid interpretation, to the preparation of such products and benefits.

Central to the objectives and terms of reference of the HOTO Module and Panel is a definition of the term "Health of the Oceans" and identification of environmental health criteria, or biological indices, that can provide early warning of change in the quality of the marine environment and relationships to human health.

The term "Health of the Oceans" is operationally defined for the purposes of the HOTO Module of GOOS as a reflection of the condition of the marine environment from the perspective of adverse effects caused by anthropogenic activities, in particular, changes in biodiversity, genetic loss, habitat loss and alteration in ecosystem structure and processes. Such condition refers to the contemporary state of the ocean, prevailing trends and the prognosis for improvement or deterioration in its quality. The definition of human health is the state of being bodily and mentally vigorous and free from disease.

The measurement of contaminant loads alone cannot provide comprehensive environmental quality criteria. Biological indices have to be identified at different levels: sub-organismal, individual, population, community and ecosystem. Molecular, cellular, physiological and behavioural disturbances and pathological manifestations are needed to reflect responses at the individual organism level. At the population and community levels, effects can manifest themselves in changes in the reproductive success of species, the disruption of the dynamic balance between producers and consumers, or deviations from the natural range of biomass variability leading to abnormal phytoplankton blooms or mono-specific swarms. Regional critical habitats, such as coral reefs, estuaries, temperate and tropical wetlands including mangroves, submerged macrophyte communities and other spawning and nursery areas require identification of more specific biological indices. In all cases, biological indices have to be assessed against the background of natural variability. The monitoring of HOTO analytes, environmental variables and biological effects will provide critical insights into the level and extent of public health effects associated with marine areas and resources. The direct assessment of contaminant loads and pathogenic exposure will assist national decision makers in efforts to ensure the sustained protection of human health.

The areas of initial emphasis are:

- Development of a set of reliable, relatively easily applied ecological distress indices of the health of the marine environment;

- Monitoring of the extent of habitat loss in coastal zones;

- Monitoring concentrations and trends of contaminant loadings in coastal zones in relation to marine community responses;

- Development of methodologies for the evaluation of assimilative capacities of coastal marine areas for contaminant introductions;

- Reclamation of available data/information on contaminant levels/community responses at regional and national levels as baseline information for HOTO monitoring activities; and;

- Development of monitoring/assessment protocols directed at human health protection from marine environmental contamination.

The scientific output of the HOTO Module will optimize the socio-economic benefits of the marine environment by providing the decision makers with a sound scientific basis for the sustained development of its resources. This issue will be dealt with in the following section of this report.

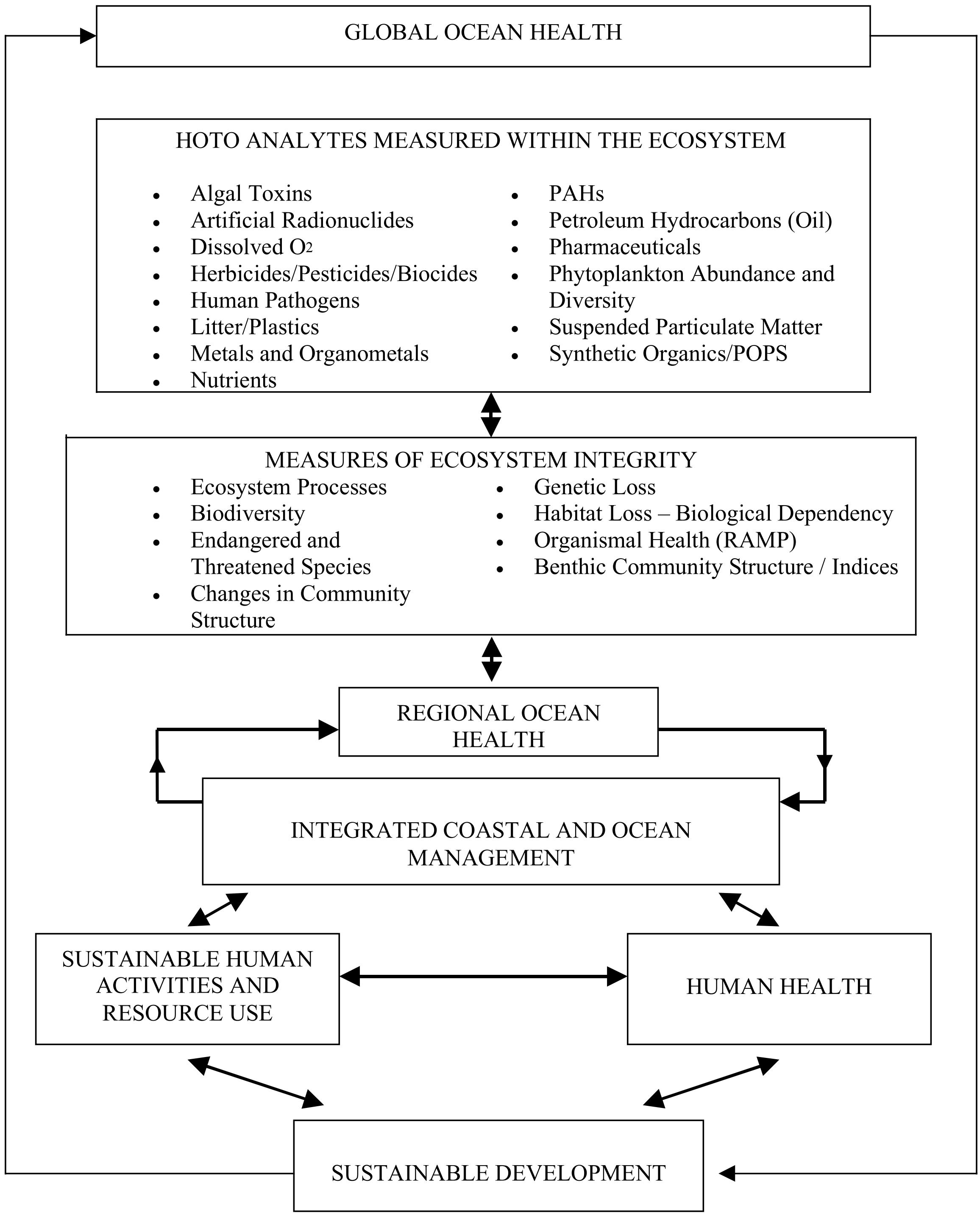
4. RELATIONSHIP BETWEEN HOTO INDICATORS, GLOBAL OCEAN HEALTH AND SUSTAINABLE DEVELOPMENT

Sustainable development is intrinsically dependent upon conserving the health of the global ocean. The Health of the Ocean Module is designed to assess the status and likely trends in global ocean health and to contribute directly to the development of strategies for maximizing the economic benefits derived from the intelligent use of marine environments and resources. Figure 1 illustrates the interrelationship between global ocean health and sustainable development. The recognition of the inter-relationships and inter-dependencies of sector-based engagement strategies is necessary for the sustainable development of the world oceans and coastal areas. Our contemporary ability to maximize such benefits and to achieve a more globally sustainable level of development is, in fact, limited by an inadequate understanding of the human influences on the environment and the environments' influence on human activity and human health.

The extent of pollution in the marine environment is not quantitatively and precisely delineated because of the absence of comprehensive information on the presence of contaminants and particularly of their effects. This, in turn, is due to inefficiencies and lack of uniformity in monitoring and assessment programmes in many parts of the world. Accordingly, there are many environmental issues that are poorly documented, many for which the impact is not recognized and certainly some that are not even yet appreciated. In addition, the incidence of certain diseases such as cholera outbreaks may be deliberately under-reported due to the sensitivity of the political and economic implications. This lack of comprehension has resulted in such extreme events as the deaths of humans from mercury poisoning in Japan many years ago, to more recent events such as deaths caused by algal blooms and seafood poisoning.

The HOTO Module provides a framework for the collection of basic information about key ecosystems and on the levels of contamination and pollution of the marine environment. Preliminary emphasis will be on measurements being made in coastal regions and on associated biological effects including population and community changes. The results will be useful in considerations of, *inter alia,* threats to human health, seafood safety, and coastal and river/estuarine drainage basin and estuarine land use and development. Regional elements will include observational networks focusing on specific regional problems presently being identified by GIPME, as well as elements allowing equitable comparison among regions as to the effects of more ubiquitously distributed contaminants. This will allow catastrophic events (e.g., fish kills and outbreaks of harmful algal blooms) to be evaluated within the background of climate variability and change derived from the Climate Module of GOOS (OOPC).

FIGURE 1.
RELATIONSHIP BETWEEN GLOBAL OCEAN HEALTH AND SUSTAINABLE DEVELOPMENT



Data collection and analysis in the HOTO Module must be based on the use of methods, standards and collection strategies producing regionally comparable data, archived in common formats, that are readily accessible to users (e.g., modellers). Sampling must also be sufficiently intensive and of sufficient duration to determine the long-term mean climatology and deviations from that mean and any anomalies, in order to devolve anthropogenic stresses from natural change.

The regional elements, which are to cover all geographic areas, will in turn, be linked to a less dense network of oceanic observations to provide a global oceanic perspective, detect broad trends, and provide early warning capability. Retrospective studies for variables to be monitored (e.g., by using sediment records) should be developed to allow establishment of an initial climatology and allow interpretation of present day levels of these variables to historic conditions. The products will also serve the needs of effective national and international implementation of several aspects of the UN Convention on the Law of the Sea, UNCED, and the provisions of the Global Action Programme for the Protection of the Marine Environment against pollution from Land-Based Activities as well as other agreements and conventions dealing with the prevention of pollution of the marine environment.

The determination of the sources and effects of marine contaminants on even a regional basis is a daunting task especially in developing nations. A study in the United States (National Research Council, 1990) concluded that many environmental monitoring programmes have failed to provide the information needed to understand the condition of the marine environment or the effects of human activity on it. Three reasons were cited: (a) monitoring programmes may be poorly designed and the technology inappropriately applied; (b) information is rarely presented in a form that is useful for developing broad public policy or for evaluating specific control strategies; and (c) there is presently limited scientific knowledge and predictive capability about complex chemical, biological and physical interactions. A consideration that exacerbates the latter situation is that it is not clear that adequate effort has been devoted to evaluating the results of all existing monitoring programmes to determine if they are meeting their goals or require revision in order to improve their overall effectiveness, including cost. There is also an additional need and that is to provide a way to deliver scientific knowledge into a form that can be used by stakeholders and users of GOOS, converting the data to knowledge in an understandable and comprehensive way.

4.1 SUSTAINABLE DEVELOPMENT PERSPECTIVES

The systematic regional and global monitoring carried out under HOTO will provide a broad-range of critical benefits in two broad, but clearly inter-related categories. Tables 1 and 2 illustrate the ways in which the HOTO programme can contribute directly to: (a) our general understanding of the present status and future trends in global ocean health and human health; and, (b) the ability of State governments to maximize socio-economic benefits derived from sustainable development and the wise and practical use of ocean/coastal areas.

A primary contribution of the HOTO programme is to develop a global perspective of the impact of human activities on ocean health. This long-term monitoring strategy will contribute directly to a more basic understanding of marine ecosystem health, human health implications of regional and global deterioration of the oceans, the ability of States to achieve goals in sustainable development, and the influence of the oceans on global climate change. A general characterization of the relationships between the variables to be monitored under the HOTO programme and measures of global ocean health is presented in Table 1. The respective assignments of the entries "3", "2" and "1" signify increasing strengths in the relationships between the variables and the issues. Blank cells represent either a weak relationship or one in which current scientific information is too limited to make an assignment.

TABLE 1: RELATIONSHIP BETWEEN GLOBAL OCEAN HEALTH, ANALYTES AND SUSTAINABLE DEVELOPMENT

	Ecological Health	Marine Ecological Integrity	Biodiversity	Endangered/Threatened Species	Changes in Community Structure	Genetic Loss	Habitat Loss	**Human Health**	Neurologic/Neurological	Cancer	Immune Systems	Developmental and Reproductive Effects	Acute Disease	**Sustainable Development**
Algal Toxins	*			3					1				1	*
Artificial Radionuclides	*									2				*
Dissolved Oxygen	*	2	3	2	2		2							*
Herbicides/Pesticides/Biocides	*	3	3	3	2	2	3		2	2	2	2		*
Human Pathogens	*												1	*
Litter/Plastics	*	3		3										*
Metals	*	3			2	3			1	3	2	2		*
Nutrients	*	2	2		2									*
PAHs	*	3			2	3				1				*
Petroleum (Oil)	*	3	3	3	2	3	1							*
Phytoplankton abundance/diversity	*	*	2		*		*							*
Pharmaceuticals	*											3		*
Suspended Particulate Matter	*	2	3		2		2							*
Synthetic Organics/POPs	*	3		3		3			1	2	1	2		*

* Directly Related
1 Strong
2 Moderate
3 Low

Although not specifically indicated in Table 1, the increase of radiatively active, or so-called "greenhouse" gases in the atmosphere could lead to a change in climate. This topic is within the purview of the OOPC but some effects of climate change will need to be considered by COOP. These effects include changes in the frequency and diversity of toxic algal blooms, changes in nutrient influxes and oxygen conditions in coastal areas, altered influxes of suspended matter and changes in atmospheric precipitation patterns.

4.1.1 Ecological Health Perspectives

Key objectives of the HOTO programme are to provide the information necessary to ensure the maintenance of biodiversity and the integrity of marine communities, minimize the loss of species, limit human influences on living marine resources (including genetic richness), protect critical habitats, and safeguard human health. All of these are vital to ensuring sustainable development of coastal and marine resources.

4.1.1.1 Ecosystem Processes

Biological systems are structured by the interactions among components (e.g., different populations, different physical compartments) as well as by the state of the components themselves. Productivity, energy flow, and nutrient fluxes are examples of processes that determine the nature of ecosystems. Alteration of these by direct intervention (e.g., anthropogenic nutrient input) or by contamination can fundamentally alter the environment. The links between ecosystem processes and impacts at the individual and population levels are often poorly understood.

4.1.1.2 Biodiversity

There is global concern regarding reductions in biodiversity. Loss of biodiversity in coastal zones is largely due to habitat losses like those associated with direct physical disturbance by sediment mobilization, fishing activities, mineral exploitation, coastal reclamation, etc. A number of marine contaminants may affect biodiversity, both locally and globally. Changes in nutrient fluxes can alter primary production, species composition of plankton, dissolved oxygen concentrations, and thereby, biodiversity. Also, the change in oxidation state of some metals may alter their toxic effect. Similarly, the chronic release of contaminants, such as oil and suspended particulate matter, may impact sensitive biological communities such as salt marshes, coral reefs and mangroves to name a few. The use of pharmaceuticals by the aquaculture industry can alter bacterial assemblages and thereby affect the vulnerability of natural biota to resistant pathogens.

4.1.1.3 Endangered and Threatened Species

Marine mammals, birds and other wildlife are affected by habitat destruction and natural and anthropogenic toxins, especially by compounds that reduce reproductive success (e.g. organochlorines), by litter that results in strangulation or drowning, by hydrocarbons from oil spills that result in narcosis, smothering or hypothermia and by the use of explosives in fishing operations.

4.1.1.4 Changes in Community Structure

A major concern of the HOTO Programme is the health of biological communities which, if safeguarded, will protect system functions. Detection of alterations in the structure and/or function of communities associated with contaminant exposure, physical disturbance and nutrient inputs is a primary objective. Measurement of biological effect signals (biomarker responses, abnormal physiological, behavioural and pathological reactions, etc.) will provide both early warning and predictive components to the programme.

4.1.1.5 Genetic Loss

Insidious degradation of biotic communities may result in the loss of unique genetic sequences that can be used to identify products of potential economic and biomedical importance. Equally, the preservation of genetic diversity is vital to the maintenance of adaptive capabilities to future environmental change. Conservation of genetic richness of marine organisms is an important concern in the development of the HOTO module.

4.1.1.6 Habitat Loss-Biological Dependency

Habitat degradation, fragmentation and loss probably pose the most serious global threat to biodiversity. The HOTO Module of GOOS monitors changes in the quality, distribution and extent of critical habitats reflecting the health of the oceans, and provide information needed to determine the cause of habitat loss. The integrity of kelp and sea grass beds, coral reefs, mangroves and other coastal communities depends on habitats constructed by organisms. These communities also provide large social and economic benefits. These systems are particularly vulnerable to environmental stress compared with purely physical habitats.

4.1.2 Human Health Perspectives

Challenges and opportunities exist in the development of a better understanding of the connection between the marine environment and human health. The ocean environment has a direct and an indirect effect on human health. Under the "Health from the Ocean" concept it is essential to recognize the benefits of the marine environment to human health. Besides providing food, nutrition, and opportunities for new pharmaceutical development, the marine environment provides other benefits such as recreation etc.

The "Health of the Ocean" aspect of HOTO encompasses Public Health which is affected by marine processes such as ocean-dependent weather and climatic effects, tropical storms, and estuarine and coastal circulation. Various waterborne marine infectious diseases including bacterial, viral, and protozoan agents result in infectious diseases in humans. The effects of weather and climate on vector-borne diseases, such as increased prevalence of malaria or cholera following El Nino events have been suggested (Epstein, 1996). Various syndromes result from exposure to algal toxins and are associated with the surrounding ecosystem and the distribution of specific algae. The fate, transport and bioavailability of xenobiotic environmental toxic agents pose severe threats to the ocean environment. It is essential to understand the link between environmental exposures, whether marine pathogen or chemical agent, to disease etiologies if one is to be able to reduce risk of exposure and prevent or intervene in the initiation or progression of disease pathology. Therefore, the need for coordinated efforts between the oceanographic community and the public health community is critical (Knap *et al.,* 2001)

It is estimated that 60% of the world's population lives in coastal areas (less than 100 km from shore (WRI, 1996). Human population growth in the coastal zone is about twice that of the global population growth. This settlement pattern has exacerbated the rate of change in coastal systems and has already placed the goal of "sustainable development" i.e., the balanced socio-economic benefit of the marine environment, out of reach to some regions of the world. The world population is estimated to increase from about 5.6 billion (at present) to 8.3 billion by 2025 with 90% of this growth occurring in subtropical and tropical countries. Over 2 billion people worldwide rely on seafood as a major source of protein in their diet. Additionally, the sustainability of remote coastal populations depends on a source of uncontaminated seafood. Seafood consumption continues to increase worldwide (FAO, 1999). Natural stocks of seafood have been supplemented by the aquaculture industry. However, marine aquaculture may cause habitat destruction and pollution of the local environment by waste products as well as introduction of genetically weaker organisms.

All these chemical, biological and physical hazards affect maritime human populations. They have a direct impact on the health status of particularly coastal communities; however, they also have an effect on all humans who rely on seafood for nutrition. Research questions on the long-term effects of anthropogenic and natural toxins on humans and the determination of early warning biological responses (biomarkers of effects) need to be answered. The determination of which effects of exposure should be monitored to determine temporal and spatial trends also need to be addressed.

There are other major health consequences which are more indirect in nature but also must be considered. An increase in risks related to seafood contamination has profound impact on coastal communities that rely on fish and shellfish for their subsistence. For example, community concerns about mercury intoxication resulted in a strong decrease in fish consumption among James Bay Crees Indians in Canada. This change in diet led to an epidemic of cardio-vascular diseases and diabetes that were virtually unknown in the 1970's (Brassard *et al.*, 1993). Similar situations have been observed in the South Pacific (Cockram, 2000). Thus, the contamination of the aquatic food chain is of public health concern, not only because of the direct risks posed by the contaminants and pathogens themselves, but also by the indirect loss of nutritional benefits by a shift in the diet caused by environmental health concerns.

The costs of illnesses due to bathing in polluted waters and by the ingestion of seafood contaminated by pathogens and marine toxins were recently estimated by GESAMP (GESAMP, 2000). It is estimated that world wide, 250 million cases of gastroenteritis and respiratory infections are due to bathing in contaminated seawater, resulting in $1.6 billion of financial loss (days and years of life lost). Similar calculations were performed for ingestion of seafood contaminated by pathogens \$7.2 billion/year and for marine toxins \$4 billion/year. This accounts for a total of \$13 billion for marine contamination-related diseases. No estimates were performed for xenobiotics such as PCBs and mercury due to the uncertainty of risk by these contaminants. These estimates also do not account for the cost associated with the loss of use of the marine environment (i.e. beach closings, restriction of sport fishing, restriction in the import or export of ocean products etc.).

There are three routes for contaminants to humans: through seafood consumption, inhalation and through direct contact. To a great extent, the degree to which human health consequences are of concern relates to the nature of the contaminant and its toxicological properties. Many marine contaminants, such as radionuclides and some organic compounds, are assumed to impose increasing risk of adverse effects with increasing exposure. Thus, the knowledge of the levels of exposure is important in order to estimate the risks to human health by the consumption of seafood and by other exposures through the marine environment. Other substances, such as essential elements, (i.e., selenium), are considered to have exposure thresholds for the induction of toxic effects. It is necessary to ensure that exposures are maintained below these thresholds.

Four contaminant categories contribute directly to human health risk from marine sources: (a) the presence of residual chemicals such as industrial organics, trace metals, agricultural chemicals and pharmaceuticals; (b) naturally occurring toxins associated with marine organisms; (c) human enteric pathogens, primarily from sewage disposal; and (d) pathogens indigenous to the environment including *V. parahaemolyticus, V. vulnificus* and *V. cholerae.* Sampling for indicator organisms, such as faecal coeliforms, in harvesting waters and shellfish stocks is an established public health protection method. However, to reduce human exposure to natural toxins such as saxitoxin, ciguatoxins and domoic acid, requires a more effective understanding and assessment of a complex set of environmental variables affecting the occurrence, duration and frequency of these harmful algal blooms (HABs). The environmental measurements provided by the HOTO Module will be beneficial by providing base environmental data to further investigate such ecologically based public health threats.

The use of pharmaceuticals and chemicals in the aquaculture industry is a subject of concern. Human consumption of aquaculture organisms, which have been exposed to a complex suite of chemicals and hormones, is one area of concern. Also of concern is the possibility of creating resistant pests and pathogens as a result of the use and discharge of pharmaceuticals, as well as the issue of reduced genetic diversity of cultured organisms depleting the vigour of wild organisms. As aquaculture programmes are increasing worldwide this is an important area of study.

4.1.3 Socio-economic Factors and Sustainable Development Strategy

In addition to making a fundamental contribution to our long-term understanding of trends in global ocean health, the HOTO/GOOS programme can provide critical insights into the development of management strategies designed to maximize the benefits of sustainable marine resource use. Table 2 provides a general assessment of the nature and scope of the relationship between marine resource/use benefits and certain contaminant/analyte classes. As in Table 1, the numbers “3”, “2” and “1” denote increasing importance and the arrows signify the direction of impact. In some cases the direction of impact is one way but in some cases the impact goes both ways. For example, in the case of dissolved oxygen and aquaculture, low dissolved oxygen levels have an impact on aquaculture, however aquaculture itself can reduce the dissolved oxygen levels in the environment. Blank cells represent either a weak relationship or one in which current scientific information is inadequate to make an assignment.

TABLE 2.IMPACT ON SOCIO/ECONOMIC BENEFITS IN THE COASTAL ZONE

VARIABLES	SEAFOOD	Finfish	Shellfish	Aquaculture	WASTE DISPOSAL	Municipal	Industrial	Agroforestry	TOURISM	MARITIME OPERATIONS	FISHING PRACTICES	OIL/GAS EXTRACTION/ PRODDUCTION	MINERAL EXTRACTION	CRITICAL HABITATS	Coral Reef Ecosystems	Estuaries	Temperate and Tropical Wetlands Including Mangroves	Submerged Macrophyte Communities	Other Spawning and Nursing Areas	COASTAL AREA DEVELOPMENT	COASTAL AGRICULTURE	HYDROLOGICAL CYCLE ALTERATIONS	RECREATION WATER
Algal toxins		↑1	↑1	↑1					↑1						← 3								**↑2**
Artificial Radionuclides							← 1			← 3													
Dissolved Oxygen		↑1	↑1	↲ 1 3		← 1	← 1	← 2	↑3	← 3		← 3				↑1	↑3	↑3	↑2	← 2	← 3	← 3	
Herbicides/ Pesticides/Biocides		↑2	↑2	↲ 2 3		← 2	← 3	← 1	← 2	← 3					↑2	↲ 2 3	↑2	↑2	↑2		← 1		
Human Pathogens		↑1	↑1	↑1		↑1			↲ 1 2	← 3													↑1
Litter/Plastics		↑3		← 3		← 1	← 1	← 3	↲ 1 2	↲ 3 2	← 3										← 3		↑2
Metals and Organo Metals		↑1	↑2	↑3		← 2	← 1	← 2		← 3			← 1			↲ 2 2				← 2	← 2		
Nutrients				↲ 3 2		← 1	← 3	← 1	↲ 3 2	← 3					↑2	↲ 2 2		↲ 2 2		↑3	↑1	↑1	
PAHs		↑3	↑2	↑3		← 2	← 2	← 3		← 3		← 1				↲ 2 2				← 3	← 3		
Petroleum Hydrocarbon/Oil		↑3	↑1	↑3		← 1	← 2	← 3	↑1	↲ 2 1		← 1			↑3	↑2	↑1	↑3	↑1				↑2
Phytoplankton abundance/diversity		↑1	↑1			← 2	← 3	← 1	↲ 3 2						↑2			↑3		↑3	↑1	↑1	
Pharmaceuticals				← 2		← 3	← 2	← 3															
Suspended Particulate Matter			↑3	↲ 3 3		← 1	← 2	← 1	↲ 2 3	← 1	← 3	← 3	← 2		↑1	↲ 2 2		↑3	↑3	← 2	← 2	← 1	↑3
Synthetic Organics/POPs		↑3	↑2	↑3		← 3	← 1	← 2		← 3					↑3	↲ 2 2	↑3			← 3			

4.1.3.1 Seafood

The ability to achieve maximum economic benefit from seafood production (both wild harvest and aquaculture) is critically dependent on water quality. One effective way to describe the manner and scope of this relationship is to consider the ways in which contaminant/analyte loads affect finfish, shellfish, and cultured organisms. Notwithstanding the admittedly important influences of over-fishing, fleet capitalization and inadequate fishery management practices, anthropogenic contaminants affect the economic value of seafood products and reduce their sustainable production. These influences include effects on the level of harvest, distribution of commercially exploitable stocks and the safety, and therefore the economic value of the product.

An important contribution of the HOTO module of GOOS is that it can contribute directly to the ability of Member States to ensure that globally uniform conditions of production are followed. As nations become increasingly insistant that imported seafood products are as safe as those domestically produced, it is likely that disruptions in the terms, conditions and direction of seafood trade will occur. One way to minimize the effects of these anticipated disruptions is for the international community to adopt a more universally acceptable basis for judging seafood acceptability and to move increasingly towards criteria based on acceptable levels and distribution of contaminant loads in seafood harvesting areas. The latter offers improved cost-efficiency over traditional lot inspection approaches.

4.1.3.2 Waste Disposal

One of the ‘services’ provided by the oceans is its capacity to assimilate or absorb wastes. A capacity which is being exceeded in many coastal areas. Wastes from municipal, industrial and agroforestry sources, particularly in near shore areas and semi-enclosed seas, have clearly begun to have widespread impact on the ability of the ocean to provide critical environmental benefits. Of these wastes, possibly the most important single source of concern is untreated and minimally treated sewage, which increases the levels of nutrients, suspended particulate matter and human pathogens in coastal waters. One area of particular concern is the apparent increase in the frequency of toxic algal blooms which may be related to changes in nutrient inputs from anthropogenic activities. Another area of concern is eutrophication caused by inputs of nutrients from anthropogenic activities into waters with poor circulation and flushing (e.g., bays). It should also be noted that these wastes may also contain a wide variety of other contaminants as discussed under section 5.1. This further emphasizes the importance of industrial pretreatment of wastewater before discharging into municipal wastewater treatment facilities. This HOTO module will provide the essential data required to elucidate this problem.

4.1.3.3 Tourism

In many areas of the world the most important economic benefit derived from coastal areas is the development of tourism. Therefore, the quality of the marine environment is of direct concern to sustainable tourism. Conversely, it should also be recognized that poorly managed tourist centres contribute to significant environmental degradation of the coastal zone. For example, a significant source of agrochemicals in Southeast Asia is the large-scale development of golf courses. Similarly, the litter resulting from discarded solid wastes, especially of a non-destructive nature such as glass, plastic, medical wastes etc. has a deleterious effect on the aesthetics of beaches and coastal areas. The development of resort complexes in close proximity to environmentally sensitive areas, such as coral reefs, can result in significant degradation of these sensitive habitats through excessive nutrient enrichment or physical damage to corals.

4.1.3.4 Maritime Operations

The impact of maritime activities contributes only around 10% of total global marine pollution (GESAMP). However, local environments can be severely impacted. Marine activities, such as dredging, carried out in support of shipping and port and harbour development/maintenance, may create severe problems locally through the mobilisation of contaminated sediments. Similarly, the unregulated discharge of ballast water can and has created severe problems in local waters from the transfer of non-indigenous species to agents of disease. Even the noise created by ship propellers in shallow waters such as lakes and estuaries has the potential of leading to the disruption of marine communities.

4.1.3.5 Fishing Activities

Apart from the direct impact on target populations, such as changed species composition and altered size structure, fishing activities can have other direct and indirect impacts on the marine environment. The discarding of litter, such as nets, fishtraps etc., discharges of waste, and through physical disruption of the benthos (e.g., by trawling and dynamite fishing). In additon, marine aquaculture can provide waste products and significant alteration of the coastal zone, as discussed above.

4.1.3.6 Oil/Gas Extraction and Production

Despite the controversy over the long-term impacts of oil spills, it is clear that the short-term effects of accidental introductions of petroleum hydrocarbons into the coastal environment can be locally severe, highly visible, and have major economic impacts on coastal communities. Further, in areas of offshore oil extraction, contaminated drilling muds do significantly alter benthic community structure and marine species distribution. Chronic discharges from poorly managed and regulated facilities, such as refineries and oil platforms, also create long term ecological damage.

4.1.3.7 Mineral Extraction

At present, the marine mineral extraction is primarily in the form of sand and gravel operations and near shore placer deposits. These extraction processes disturb the marine environment by destroying benthic communities, resuspending fine sediment and, in some instances, mobilizing trace metals and other contaminants. In some cases (e.g., beach and reef mining), mineral extraction destroys habitats directly. These activities can result in severe disruption of marine communities.

4.1.3.8 Critical Habitats

Critical coastal habitats, such as coral reefs, estuaries, wetlands (including mangroves), submerged macrophyte communities (e.g., sea grasses and kelp beds) and other spawning and nursery areas are among the most productive and diverse marine habitats. They provide environmental resources, goods and services of considerable economic benefit at local, national and global levels. These benefits include their contribution as critical spawning environments, major sources of food protein to marine communities and to humans, sources of commercially important materials and as areas for flood control and coastal protection. These habitats play a role in the way in which people define their history, culture and communities. These contributory benefits are clear and well-recognized but are often difficult to measure quantitatively. This lack of our ability to measure their economic value should not, however, result in neglect of their overall contribution to human culture and welfare.

4.1.3.9 Coastal Area Development

Population stresses in the coastal zone are primarily the result of human migration towards the coast. The growth of human population in the coastal zone is approximately twice that of the global population growth rate. This settlement pattern has exacerbated rates of change in coastal systems. Excessive rates of coastal area development have placed the goal of truly sustainable development beyond reach in some areas. Of particular importance is the need to more effectively manage waste disposal practices and future coastal development projects.

4.1.3.10Coastal Agriculture

Much of agricultural production in the developing world is located in low-lying coastal plains. Agricultural practices, if poorly managed, can introduce excessive amounts of agrochemicals into coastal environments. Of particular importance is the contribution of agricultural fertilizers to the total coastal nutrient flux. The addition of such nutrients can play an essential role in altering the productivity and amenity value of coastal environments.

4.1.3.11 Hydrological Cycle Alterations

Freshwater management practices, including extraction of groundwater, damming of rivers and diversion of river flow for irrigation have significant impacts on coastal water quality. Such practices alter coastal salinities, change nutrient levels, disrupt sediment fluxes, destroy coastal habitats, disrupt marine community structures, cause saline water intrusion into inland areas and can lead to localized subsidence.

5. SPECIFIC HOTO MEASUREMENTS

The problem areas identified in the preceding section can be best addressed through the use of appropriate suites of physical, chemical and biological measurements. In this section, the measurements selected for inclusion in the HOTO module are specified in two categories: 1) analytes ; and 2) biological effects measurements/indicators of ecosystem health.

5.1 ANALYTES

The following set of basic variables have been selected for inclusion by the HOTO Panel, and correspond both to the variables identified in the analyses depicted in Tables 1 and 2 above and those identified as priority contaminants within the GIPME Programme and in the UNEP Regional Seas Action Plans.

5.1.1 Synthetic Organics and POPs

Synthetic organic chemicals are a loosely defined group of substances, which includes all synthetic substances including endocrine disrupters, but excluding pesticides, petroleum hydrocarbons and polyaromatic hydrocarbons, introduced to the sea as a result of human activities. POP's refer to specific compounds, which are part of an international agreement. Most of these substances result from industrial activities but their introduction to the marine environment may arise from direct discharge (point sources), discharge to municipal sewage systems or rivers and venting to the atmosphere. The substances are best classified in terms of their (a) toxicity, (b) persistence, (c) tendency to bioaccumulation, (d) bioavailability, and (e) source functions (size and nature of the land-based sources). Substances of particular concern include chlorobiphenyls, chlorinated dioxins and some industrial solvents. Current scientific knowledge of the behavior, fate and effects level of these substances is limited and new priority substances are likely to be identified in the future. For example, polybrominated flame-retardants are now found in all compartments of the marine system (de Boer *et al.,* 1998). Some synthetic organic compounds that may be of some concern are also produced within the marine environment particularly as a result of the practice of chlorinating of sewage and by the introduction of free chlorine into the cooling waters of power stations.

Elevated concentrations of Persistent Organic Pollutants (POPs) have been detected in remote fishing populations in Canada (Dewailly *et al.,* 1992) and in Greenland (Mulvad *et al.,* 1996). Toxic effects of POPs may impair the immune system, leading to a high incidence of infectious diseases among children exposed during their fetal life (Dewailly *et al.,* 2000). POPs are also known to impair the normal development of the central nervous system and recently, these compounds have been found to possess endocrine properties and have been suspected to be associated in humans with endometriosis, male fertility, male sexual maturation problems and hormone-mediated cancers (Heindel, 1998). In wildlife species however, strong evidence in laboratory, semi-field studies with harbour seals and field experiments have shown correlations between contaminant exposure and endocrine-related effects such as developmental, reproductive and immune associated toxicities. The reported abnormalities range from subtle to permanent such as disturbed sex differentiation, i.e., feminised or masculinised sex organs, changes in sexual behavior, and perturbation of immune function (Kendall *et al.*, 1998).

These studies have primarily dealt with organochlorine contaminants, notably PCBs and DDT. However, hydroxylated and methyl sulfone PCB metabolites are second level contaminants that have demonstrated endocrine activity *in vitro* and *in vivo* via sex hormone receptor interactions, hormone transport protein (e.g. thyroid transport protein, TTR, Brouwer *et al.,* 1998), and/or effects on enzyme systems involved in hormone biosynthesis or metabolism. This indicates a need for further research to identify the hundreds or perhaps thousands of as yet unidentified endocrine disrupting xenobiotics in biota. For example, brominated flame-retardants like polybrominated diphenyl ethers and their hydroxylated analogues have been shown to interact strongly with TTR and on estrogen receptor or estrogen-responsive gene expression. Actual exposure data for these compounds in humans and wildlife are needed.

5.1.2 Polycyclic Aromatic Hydrocarbons (PAHs)

This group of substances are all derived from thermal transformation of fossil fuels, particularly petroleum. PAHs constitute natural components of oil formed as a result of relatively low temperature metamorphic processes. More importantly they are also produced as combustion products of oil and coal. PAHs are introduced to the marine environment as a constituent of municipal or industrial effluents or via atmospheric pathways from industrial emissions, exhaust fumes of internal combustion engines or domestic heating systems. Human health concerns primarily relate to the carcinogenic properties of some individual PAH compounds.

5.1.3 Metals and Organometals

Trace metals comprise all metals and metalloids in the marine environment. It is important to distinguish between the introduction of trace metals from anthropogenic activities and those from natural weathering processes. Although sources of trace metals in the marine environment are numerous and very diverse (elevated trace metal levels accompany almost every type of effluent), there is little evidence of widespread adverse biological effects, other than risks to human health posed by metals in seafood (Brouwer *et al.,* 1998). Concerns for elevated metal levels in seawater are usually in the immediate vicinity of sources, as in most cases metals are removed from the water column rapidly by adsorption to suspended particulate material. Organo-metallic complexes/compounds behave quite differently. For example, Tributyl-tin (used as a constituent in anti-fouling paints on boats) and methyl mercury (formed by the microbial methylation of mercury) are two highly toxic compounds, which have been responsible for well recorded marine pollution incidents. The basis of toxicity for these substances lies in their forms of speciation and more effort should be focused on speciation of other trace metals in the future. Cadmium is probably the only other trace metal known to potentially accumulate in seafood with subsequent risk to human health (i.e. consumption of shellfish in industrialized areas).

Mercury is used in a wide range of industrial processes and mining practices. Once released into anoxic environments, bacteria can rapidly methylate it. Methyl mercury (MeHg) is highly lipophilic and is biomagnified in the environment (Dewailly *et al.,* 2000). The half-life of MeHg is 60-120 days in humans and up to 2 years in fish. MeHg causes cytotoxic, kidney and brain damage, with concentrations of 1-2 mg/kg in brain tissue producing neurotoxic effects. Foetal exposure to MeHg is of great concern. Human populations with high seafood consumption have the highest risk of elevated MeHg in their tissues. Recent studies reported that highest human concentrations and related health effects were found in children living in the Faroe Islands (Grandjean *et al.*, 1997), Madeira (Gaggi *et al.,* 1996), Seychelles Island (Myers *et al.,* 1997), Coastal Peru (Marsh *et al.,* 1995) and fishing communities in Amazonia (Lebel *et al.,* 1996).

Cadmium (Cd) can also bioaccumulate in the environment, however, its uptake by humans is affected by the uptake of lead (Pb). IARC has labeled Cd as a group 1 carcinogen. The major health risk associated with cadmium is nephrotoxicity (proteinuria and renal failure). High concentrations of Cd have been found in shellfish and the kidney and liver tissues of sea mammals.

Studies attempting to link environmental exposures of Pb have shown to relate to poor neural development in children, however there are no documented cases of lead poisoning directly related from a marine source. While the use of leaded gasoline in the developed world has decreased, leaded gasoline still remains a potential environmental issue in less developed areas of the world. The connection of land based discharges and atmospheric lead emissions and its route through a marine source is not well documented at this time. Studies on human Pb blood levels in the remote areas of Greenland have indicated similar concentrations to people in industrialized Western Europe (Dewailly *et al.,* 1999).

Arsenic is also a highly toxic element, however, as with Pb, no known arsenic poisonings have occurred as a result of marine exposures or consumption of seafood. Both arsenic and lead occur in marine sediments as a result of industrial discharge. Like mercury, arsenic can be converted to more lipophilic and organic forms but contrary to mercury, organic arsenic appears to be less toxic to humans. The effects of these metals on the ecological health of the marine environment are as yet unknown and are an important subject for further investigation.

5.1.4 Petroleum Hydrocarbons (Oil)

Petroleum hydrocarbons comprise all constituents of crude oil and its refined derivatives. Pathways of the introduction of oil to the marine environment include ship deballasting operations, refinery effluent discharge, the discharge of lubricating oils to municipal sewage systems, introductions from oil production platforms and natural seepage. Marine accidents have the potential to introduce massive amounts of oil into the marine environment having locally catastrophic effects on marine ecosystems, although there is sufficient evidence to suggest that recovery occurs within decadal time scales. Chronic releases of oil to the marine environment may lead to the long term exposure of marine organisms to the toxic constituents of oil. There are few direct concerns of human exposure to oil and human health other than occupational exposure during oil spill clean-up operations.

5.1.5 Herbicides/Pesticides/Biocides

This group includes all the insecticides, marine biocides, herbicides and fungicides. The environmental half-life of the several hundred individual compounds in these categories varies from days (e.g., Malathion) to decades (degradation products of DDT). The group thus embodies a wide range of physico-chemical properties (partitioning, solubility, volatility, etc.) and effects. Because these compounds are specifically designed to modify biological systems, there exists concern about their effects on marine ecosystems although the modes and severity of such effects on the marine environment have yet to be adequately investigated. Additional concerns involve human exposure to these compounds through the consumption of contaminated seafood products.

5.1.6 Dissolved Oxygen

The level of dissolved oxygen in seawater is an important measure of the state of the health of the aquatic marine environment. Dissolved oxygen levels become depressed as a result of the inability of natural processes (physical diffusion and primary production) to supply oxygen at the rate demanded for the oxidation of organic matter or reduced chemical substances. Dissolved oxygen deficiency may be particularly acute in the case of eutrophication, discharge of sewage (and the disposal of sewage sludge) and the discharge of organic industrial, agricultural and aquacultural effluents (e.g., pulp mill wastes, food processing plants, etc.). Extreme oxygen deficiencies (e.g. anoxia) can result in the elimination of all higher life forms. Anoxic conditions can also lead to the liberation of toxic forms of metals through redox mechanisms.

5.1.7 Artificial Radionuclides

This group consists of radionuclides produced as a consequence of artificial activation, nuclear fission and fusion. These radionuclides largely consist of direct products of fission (e.g., ^{137}CS, ^{90}Sr, ^{131}I) and activation products of the nuclear fuel cladding or weapons casings containing the reaction. Historically, major sources of radionuclides are from nuclear weapons testing but currently, significant quantities of these contaminants are released in effluents from nuclear power reactors and fuel reprocessing plants. The primary concerns about these substances relate to potential risks to human consumers of contaminated food, however, few data exist regarding a direct seafood link to humans.

5.1.8 Pharmaceuticals

Pharmaceuticals include all substances used in preventing and treating human and animal diseases. The mode of introduction of these bioactive compounds is through municipal sewage systems or, in the specific case of aquaculture, by their direct and intentional introduction into fish enclosures. Except in this latter case, there is no conclusive evidence of significant adverse effects in coastal waters but research on this topic is continuing. Links to humans through marine sources are poorly understood although endocrine disruption is a very active research topic.

5.1.9 Phytoplankton abundance and diversity

The presence of abnormally dense blooms of phytoplankton is frequently a direct consequence of eutrophication (although, of course, they occur naturally). The composition, intensity and frequency of blooms reflects the state of the marine environment. Some blooms may in themselves represent a hazard to the marine environment. For example, foaming associated with *Phaeocystis* blooms destroy some fisheries resources and lowers aesthetic values. Harmful algal blooms (HABs) of dinoflagellates are often toxic. In addition to abnormal blooms and HABs, eutrophication can cause long-term changes in productivity, phytoplankton species composition, etc. Measurements of phytoplankton populations, either directly or via the quantification of pigments (i.e., by direct measurement or through satellite imagery), allow these processes to be quantified. Proper coordination of these efforts is needed if trends are to be elucidated. The human health connection here is through algal toxins discussed in 5.1.12.

5.1.10 Human Pathogens

Virus, bacteria and parasites are also harmful agents for humans and are responsible for large epidemic events such as cholera outbreaks. Increasing seawater temperature has been proposed as a contributing factor of increasing events (Epstein, 1996). Pathogens in the marine environment are a significant human health concern, both through consumption of contaminated seafood and through occupational and recreational exposures. The primary sources of human pathogens are untreated human and animal wastes, although transmission can occur between swimmers or, potentially, from seabirds or other wildlife. One of the major causes of reported seafood illnesses is the consumption of raw shellfish contaminated by sewage. There is a large amount of quantitative epidemiological and toxicological information on human risks of infectious disease from contaminated seafood consumption and other routes of exposure from seawater. Routes of human exposure include consumption of seafood, direct ingestion of seawater, and dermal exposure to both water and sediments (Clark *et al.*,1997).

Among the microbial agents related to seafood borne illnesses, viruses are the most common forms of infection, followed by bacteria and finally the protozoa. The major vectors of viral infection are marine bivalves such as oysters and clams. The effects are numerous and dependent upon the specific virus. For example, it is estimated that the Norwalk virus is responsible for 23% of reported shellfish borne and water borne gastroenteritis outbreaks (GAO, 1984). Among the bacteria *Vibrio vulnificus* has been implicated in a number of shellfish poisonings and wound infections. Other *Vibrio sp.*, toxigenic *E. coli, Shigella sp.* and *Salmonella sp.* can also be contracted from ingestion of contaminated foods and water. However, information on survival of these pathogens in seawater is limited.

There is very little information for the protozoa. *Cryptosporidium sp.* has been found to accumulate in shellfish, but to date there have been no human health sickness associated with consumption of seafood with this protozoan. *Giardia* and *Entamoeba* gastritis has been epidemiologically linked to the activity of scuba diving in sewage contaminated waters.

There appears to be a general trend of increased infections among those individuals who contact seawater through recreation and occupation. Most symptoms include gastrointestinal, dermal, respiratory, eye, ear, nose and throat infections and generally children are at greater risk than adults.

5.1.11 Nutrients

Nutrients, as defined by this report, include all the bioavailable forms of nitrogen, phosphorous and silicon introduced to the marine environment. Though the major nutrients are relatively simple variables to quantify, it is difficult to distinguish between natural and anthropogenic sources and also to identify and quantify non-point sources of these substances. Point sources include sewage, plant outfalls and fertilizer factories. Non-point sources comprise run-off from agriculture, deposition of atmospheric contaminants, upland municipal sources, etc. Nutrients recycled from sedimentary reservoirs may also have anthropogenic origins. The major effect of excessive nutrient inputs is the promotion of eutrophication and disturbance of the structure of marine ecosystems.

5.1.12 Algal Toxins

For many centuries, coastal communities had to face the presence of highly dangerous natural marine toxins in their seafood (fish and shellfish). It has been suggested that an increase in documented illness from exposure to marine biotoxins may be due to an increasingly stressed marine environment, an increase in reporting due to greater vigilance, increased seafood distribution world-wide, and a larger range of world-wide tourist travel. Algal toxins are compounds produced by marine organisms at a large enough scale to induce adverse effects on communities of higher marine organisms. In turn, humans may be exposed through consumption of seafood or through occupational or recreational exposure to the toxins, primarily through dermal contact. In the case of *Gynmodinium breve* (Florida Red Tide) and *Pfiesteria*, transfer to humans can occur through inhalation of aerosols containing the toxin. Algal toxin outbreaks are mainly confined through transfer from dinoflagellates and marine phytoplankton. Of the 5000 known species of phytoplankton, approximately 80 are toxic (Hackney and Pierson, 1994). There is strong evidence that certain blooms of phytoplankton producing toxins are induced or sustained as a result of anthropogenic destabilization of the marine ecosystems (e.g. eutrophication).

It is virtually impossible to accurately assess health risks from exposure to marine toxins, as very little data exists on their transfer through the coastal food web. Different toxins have different effects. *Physteri*a, a dinoflagellate for example, is difficult to assess as uni-algal samples are hard to collect, this neurotox has yet to be characterized and the inhalation exposure is difficult to measure. However, exposure to the aerosolized neurotoxin has been linked to nausea, respiratory problems and severe memory loss. There are 20 types of psp (paralytic shellfish poisoning) toxins currently identified; of which saxitoxin is the major toxin. Primary symptoms of exposure are parenthesis and paralysis. The nsp (neurotoxic shellfish poisoning) toxin, brevetoxin, acts in the opposite manner to saxitoxin in that it opens sodium channels rather than blocking them. The neurotoxic effects of brevetoxin are less than those related to exposure to psp toxins. However, they are easily aerosolized and inhalation by humans can lead to respiratory infection, coughing and bronchiospasms. Exposure to the asp (amnesic shellfish poisoning) toxin, domoic acid, can lead to seizures, coma, amnesia and formation of lesions in the brain. The dsp (diarrheic shellfish poisoning) toxin, Okadaic acid, is probably the most widespread marine toxin illness attributable to seafood consumption (Baden *et al.,* 1995). However, exposure to the toxin leads to self-limiting gastrointestinal symptoms and it is probably dramatically underreported. Ciguatoxin, has been documented in up to 400 species of fish, remaining in fish for over 2 years, and is responsible for more than half of all formally reported seafood related illnesses (~50,000 reported cases/year). Like other types of seafood poisoning, it is felt that a majority of cases go unreported.

5.1.13 Litter/Plastics

Litter arises principally from the improper disposal of solid waste as well as the accidental, but common, introduction of such materials as fishing gear (including drift nets). Also included are degraded petroleum products (i.e., tar balls) and solid hospital wastes. This category of contaminants have riverine, coastal (garbage disposal at coastal sites or beach littering) and marine sources (ships or platforms). The connection with human wellbeing is indirect, such as beach closures due to the presence of medical waste on the beach.

5.1.14 Suspended Particulate Matter

Suspended particulate matter (SPM), in the context of the present document, is defined as all living and non-living particulate material in the water column at a given site. Increased levels of SPM can have serious effects such as inhibition of coral reef growth and, in extreme cases, blanketing of benthos. Deforestation and inappropriate agricultural practices result in increased particle mobilization causing deleterious effects on entire ecosystems. Dredging operations, sea dumping, etc. also results in increased SPM. Impoverishments in the supply of suspended particulate matter to coastal areas can also result in adverse results, such as beach and shoreline erosion.

5.1.15 Other Considerations

The Panel recognized that sewage is a major global environmental problem. However, it is a complex mixture of chemical, biological and physical constituents that varies in composition as a function of the degree of separation of storm, industrial and municipal sewage and the diversity of industrial and human activities in the catchment basin. Sewage is of concern in relation to pathogen content, nutrient content and oxygen demand resulting from the oxidation of organic matter. All these concerns are addressed separately in other elements of this section rather than being specifically addressed in Tables 1 and 2.

5.2. BIOLOGICAL EFFECTS MEASUREMENTS

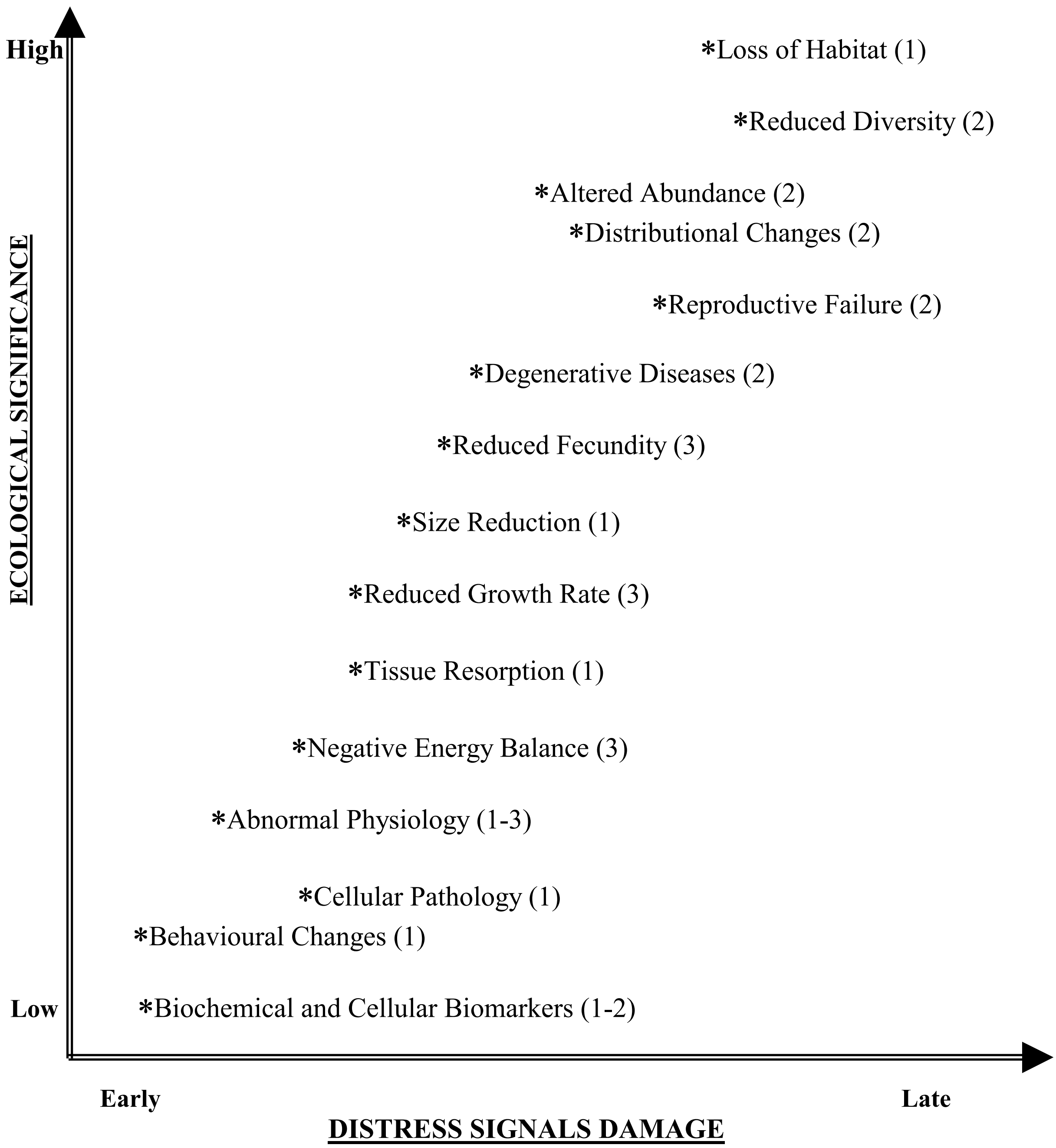
The HOTO Module will employ simultaneous monitoring at different levels of biological organization to provide a better understanding of the mechanistic links among changes at each level. Figure 2 provides a hierarchical approach of increasing ecological significance to organismal structure.

Changes at the population/community/ecosystem levels of biological organization are of ultimate concern. However, such high-level responses are generally complex and far removed from causative events and are manifestations of damage rather than predictive indices. Detection of lower level changes (molecular, cellular, physiological and behavioural responses) which underlie higher level effects and for which causality can be established, may provide early warning of impending environmental damage. Individual and sub-individual responses may also be more amenable to detection by automated monitoring systems.

It must be pointed out here that to ensure global applicability of methodology in different regions of the world and ensure uniform interpretation of results, the use of biological techniques at the organismic and sub-organismic levels (e.g., biomarkers, physiological techniques, etc.) requires the prior identification of related/analogous members of a given biological group (not necessarily the same species) considering climatic/geographical variations and differences, but corresponding in genera, family or biological class. Such use of analogous members would provide a uniform and more reliable global picture of the combined effects of particular analytes/contaminants under consideration. Furthermore, this will also enhance the global relevance of such techniques.

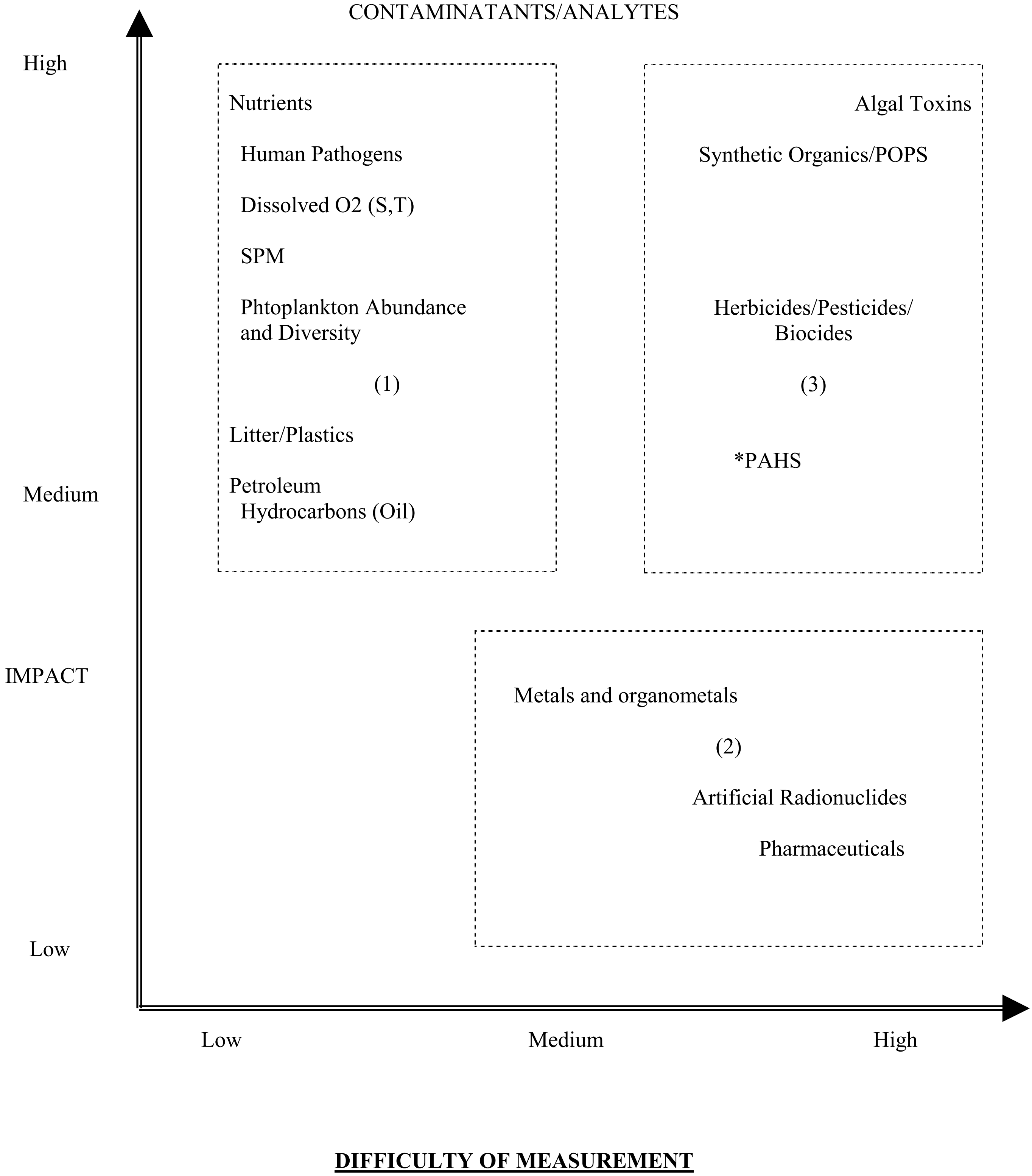
FIGURE 2.

BIOLOGICAL DISTRESS SIGNALS OF DAMAGE TO OCEAN HEALTH



1 3: Increasing Difficulty of Measurement

FIGURE 3
IMPACT VERSUS DIFFICULTY OF MEASUREMENT FOR
CONTAMINATANTS/ANALYTES



5.2.1 Molecular and Cellular Biomarkers.

The underlying basis of all stress-induced pathological/physiological changes is damage to, or perturbations of, life processes at the molecular and subcellular levels of biological organization. Consequently, detection of changes at these basic levels should, in theory, provide early warning distress signals of damage to the health of individuals if adverse reactions are sustained. Such molecular and cellular alterations will frequently reflect exposure to particular types of causative agents, thereby offering advantages over non-specific responses at higher biological levels.

Our knowledge of distress signals has grown substantially in the past decade, often drawing on the reservoir of understanding of these processes in humans and rodents. The use of biomarkers in marine environmental toxicology is increasing and their potential power is considerable. Not only do they hold out the prospect of diagnostic predictors of pathological change, but biomarkers of exposure for various classes of toxic organic chemicals and certain trace metals have now been identified. This latter type of marker has the potential to provide rapid and less costly alternatives to routine chemical analytical screening which would allow the chemical analytical efforts to be focused on more specific fingerprinting, thereby helping to link cause and effect.

Potential biomarkers include alterations in intracellular membranes (e.g., endoplasmic reticulum, Iysosomes, endosomes, transport vesicles), genotoxicity (e.g., oxidative adducts, hydrophobic adducts, micronuclei), specific proteins or enzymes (e.g., metal-binding proteins, stress proteins, oncoproteins, cytochromes P-450, multi-drug resistance protein) and inhibition of cholinesterase by neurotoxins (e.g., organophosphates, carbamates). Some of these biomarkers, such as membrane changes and stress proteins, are indicative of cell injury and potential damage to health while others, such as DNA and protein adducts, cytochromes P-450 (e.g., CYP1A and Ethoxyresorufin O-Deethylase (EROD)), multi-drug resistance (MDR) protein and metal-binding proteins, can be indicative of exposure to certain classes of xenobiotic and certain metals respectively. Molecular techniques should also be explored which detect biological damage associated with increased exposure to UV-B radiation. Ultimately the selection of biomarkers is strongly influenced by practical considerations and regional priorities.

The main advantage to be gained from the use of biomarker tests is that early biochemical and subcellular changes in cells can hopefully be linked to pathological endpoints through an integrated multi-tiered approach rather than using single isolated tests. This strategy not only has the potential for detection of early warning distress signals that will be diagnostic for both exposure and injury, but will also provide a prognostic capability for predicting the likely consequences for the health of individuals in a population if the stress is sustained.

Biomarker tests are in general relatively easy to use, require routine preparative and measuring equipment, and the resulting data can be readily interpreted. However, users need to be aware of environmental factors which can interact to produce false negatives or positives. This problem will be minimized by the use of batteries of tests. Certain tests use cells in body fluids, for example blood. These can be used non-destructively and involve pathological changes in intracellular membranes of Iysosomes, as well as other effects. In fact, Iysosomal membrane damage appears to be a universal marker for effects of stresses in most if not all nucleated cells.

5.2.2 Cellular Pathology

The use of molecular and cellular biomarkers coupled with the pathophysiology of response (or histopathology) has the potential to reveal significant differences between impacted and unimpacted (or reference) organisms. Furthermore, the compilation of tests used will indicate whether some differences result from exposure to xenobiotics, metals or other causative agents. It is important to note that by relating biomarkers of cell injury to significant pathological consequences for the individual, their diagnostic value and predictive capability for providing early warning of further damage at higher organizational levels will be strengthened (Figure 2).

Many antibody-based recognition tests for specific proteins (e.g., cytochromes P-450, stress proteins, oncoproteins, etc.) can now be applied directly to histological samples. This can provide useful information on the spatial distributions of such proteins in relation to stress-induced structural and organizational alterations in cells and tissues.

Histopathological changes can be easily and accurately quantified using microstereological procedures applied to tissue sections, and these data can be correlated with both cell injury processes and abnormal physiology. Such techniques are relatively simple, low cost, and rapid, yet are capable of providing information of a very high level of biological/pathological sophistication. Histopathological samples can be archived indefinitely and yet can be made readily available for subsequent application of advanced molecular recognition tests for specific proteins and other products ("epitomes").

5.2.3 Physiological and Behavioural Responses

Community level changes following exposure to anthropogenic stress arise in part from the differential effects of the stresses on individuals in component populations. Abnormal physiological and behavioural responses of individuals are therefore potentially valuable early warning signals of impending population and community level changes. Most physiological and behavioural responses to contaminants are non-specific. Consequently, they must be carried out in conjunction with the lower level biomarkers measurements mentioned above, and with appropriate chemical residue analyses, if causal relationships are to be established. Examples of the variables that can be measured include energy balance, circulatory and respiratory rates, feeding and locomotor activity, growth, reproductive condition and fecundity. The ecological significance of these variables is shown in context in Figure 2. Clearly, the ease with which particular measurements can be made will vary greatly depending on the species in question and its habitat. For example, simple determination of the presence or absence of species, individual feeding behaviour, growth rates, reproductive status, can be made quite readily in coastal areas with many macroinvertebrates (crustaceans, molluscs, polychaetes and echinoderms) and macroalgae. However, in many localities and with species from other phyla, such measurements are impractical. More sophisticated automated, on-line physiological and behavioural monitoring systems are also now available for recording cardiac, ventilator and feeding activity in crabs, barnacles, bivalves, and polychaetes. These can be augmented by, and related to laboratory based measurements of energy balance and behavioural changes (for examples, altered turning frequency and angle; velocity and velocity distribution). Application of such techniques is only restricted by equipment availability as they are relatively straightforward to carry out.

5.2.4 Population and Community Monitoring

Relationships between anthropogenic stresses and their adverse biological effects are more difficult to establish at the population and community levels. Nonetheless, a key objective of HOTO is to determine the extent of global biological change.

Population and community changes may result from stresses not amenable to lower level monitoring. For example, contaminants might affect larval recruitment and settlement patterns without stressing adult populations, either because adults are less sensitive to the contaminant or because of the physical separation of larval and adult populations. As another example, species can be removed by direct human intervention (e.g., fisheries), and this would not be addressed by biomarker studies.

Continuing qualitative and quantitative surveys of selected communities, especially coastal ones, will be required to assess changes in diversity, abundance, and distribution of organisms within communities. At the simplest level these will involve simple, standardized, field measurements (e.g., transects, surveys). For some communities (e.g., coral reefs), standardized methods already exist or are being developed. For other communities, the development of new methodology will be required; this will primarily involve standardization and application of existing procedures.

Recruitment to key populations will be monitored through analysis of data collected during community surveys (e.g., size-frequency data) and through direct measurement (e.g., settling plates).

Considerable progress has been made in developing automated systems for counting and identifying phytoplankters, thereby providing information on abundance, diversity, and community structure. There is potential to develop these into self-contained instruments; it might be possible, for example, to place these on merchant ships, as is done with Hardy Continuous Plankton Recorders (CPRs), to obtain broad spatial coverage.

Community structure studies can be facilitated by further technological development and application. Further development and dissemination of PC-based species identification keys, data management and statistical procedures, etc., will be emphasized in GOOS. Sophisticated technologies such as fully automated ROV devices and GIS systems should be developed for some components of GOOS; in some cases (e.g., deep-sea benthos) such technologies may be the only suitable method.

For some communities, remote sensing applications may allow broad-scale assessment of changes in community structure. Techniques are being developed for coral reefs and mangrove forests, for example. One goal of HOTO has been to develop remote sensing applications through coordination of *in situ* community structure studies with the "whole community" remote sensing studies, described below.

The procedures described above have not been applied to global scales to date. However, they have been used to assess the extent of contamination and biological effect on smaller scales. For example, metallothionein has been used effectively in the detection of trace metal exposure *in situ* in molluscs and fish (Rock and McCarter, 1984). Similarly, EROD assays provide an indication of exposure to PAHs and other xenobiotics. In the Venice lagoon region and along the UK coast, suites of biomarkers have been used to great effect to define contaminant and effect gradients (Lowe *et al.,* 1995, Wedderburn *et al.,* 2000). On the basis of these studies, sites have been identified with a view to establishing exposure-response relationships prior to taking appropriate bioremedial action. *In situ* monitoring of physiological status using automated recording equipment has also been shown to be feasible (Aagaard *et al.,* 1995). Only modest technological developments are necessary to permit long term deployment of recording equipment in estuarine and coastal areas. With regard to higher level (i.e., population and community) measures of biological effect, there are several studies which confirm the utility of the measurement procedures. For example, the influence of drilling muds on benthic communities and disturbances in coral reef fish communities by trace metals have been characterized using multi-dimensional scaling (Olsgard and Gray, 1995). It only remains to evaluate the utility of these approaches when implemented over wider spatial and temporal scales.

6. DEVELOPMENT OF HOTO

HOTO has adopted a similar strategy to that proposed by the Coastal Panel of GOOS containing three subsystems or elements. These are :

The Initial Observing Subsystem
The Communication, Network and Data Management Subsystem
The Modelling and Data Assimilation Subsystem

As discussed in the Coastal Panel Report these subsystems are driven by the following principles:

- Produce data-products that are responsive to the needs of many user groups (i.e., the system must be user driven);
- Provide timely and free access to data ;
- Provide a more cost-effective use of existing data, expertise and infrastructure than is currently the case ;

- Develop into an integrated and sustained system that is multi-disciplinary from measurements to its approach to data analysis and product development (i.e., an end to end system).

6.1 INITIAL OBSERVING SUBSYSTEM

The measurements in the initial observing subsystem must be long-term, sustained and interdisciplinary. It is important that these measures provide information that is easily translatable to stakeholders. The measures described below have been developed as part of HOTO to meet these measurement principles.

6.1.1 RAMP (Rapid Assessment of Marine Pollution)

Within the measurement subsystem is RAMP (Rapid Assessment of Marine Pollution). A diverse array of procedures currently exists for detecting the impacts of pollutants in coastal and estuarine environments (see section 5.2). These include ecological survey procedures for identifying changes in the abundance and diversity of species comprising communities, chemical and biomonitoring procedures for determining the concentrations and bioavailability of anthropogenic contaminants, and biochemical, physiological and behavioral biomarkers which signal exposure to and, in some cases, adverse effects of pollution. When these procedures are used in combination with well-designed physical chemical and biological surveys, they can provide insight into which pollutants are responsible for environmental degradation. However, in the context of a broadly applied, global monitoring programme they also have a number of practical drawbacks. They are expensive to perform; highly trained personnel must carry them out. In the case of ecological survey procedures, they are time consuming and depend on a detailed knowledge of the species composition and abundance in communities over time. With regard to analytical environmental chemistry and biomarker measurements, the need to use costly, technologically advanced equipment has previously been a major constraint. Hence there is a need to develop more pragmatic environmental assessment procedures, which can provide the basis for prioritizing among study sites, so that resources can be expended efficiently and effectively

HOTO has established a RAMP pilot project in Brazil. Brazilian scientists in Rio de Janeiro, Sao Paolo and Salvador have been trained in the use of chemical immunoassay kits and simple biomarker techniques. These procedures have proved to be easy to use, inexpensive and robust. They have made it possible to begin to survey 8000 km of the Brazilian coastline with a view to setting priorities for in-depth investigations at sites of concern, using more sophisticated techniques. The RAMP concept and procedures have also been disseminated to several other countries. For example, in September 1999, the Intergovernmental Oceanographic Commission funded a workshop in San Jose, Costa Rica to train personnel from Costa Rica, Puerto Rica, Colombia, El Salvador, Honduras, Cuba, Panama, Ecuador, Guyana, Mexico, Trinidad and Tobago.

A full description of RAMP procedures and future directions is presented in Annex II and an overview of biological effects/analytes is presented in Table 3.

6.1.2 Human Health Indicators

Environmental changes do have an impact on human health and it is important to identify which indicators have enough sensitivity and specificity to be able to detect these changes. It is unlikely that human mortality and morbidity registries alone could help to monitor environmental changes, as most chronic human diseases are multifactorial and involve genetic, lifestyle and environmental factors. It is therefore also unlikely that cancer registries or mortality rates will provide a useful indication of changes for ocean-related illnesses as there are issues regarding specificity and the delay between the exposure to environmental risk factors and cancer is long (10-20 years). However, morbidity registries on acute diseases such as marine toxin poisoning and other seafood borne diseases, the declaration of which is mandatory in most countries, could provide useful information on any incidence changes over time. As there is acceptance that most diseases are under-declared, there is an urgent need to improve and validate these surveillance systems. Health registries are a useful tool to monitor short-term events like pregnancy and pregnancy complications, such as low birth weight, congenital malformations, etc.

TABLE 3: BIOLOGICAL AND CHEMICAL MARKERS

	Cardiac Activity	Lysosomal Stability	Immunotoxicity Assay	Programmemed Cell Death	Defecation Assay	Behavioural Assays	Cholinesterase Inhibition	PAH Fluorescence	Imposex/Intersex	Metal-Binding Proteins	Genotoxicity Assay	Pathogen ELISAs	Ammonia	Chemical ELISAs	Conventional Chemical Analysis	Mouse Bioassay
Algal Toxins	**X**	**X**	**X**	**X**	**X**	**X**								**some**		**X**
Artificial Radionuclides											**X**					
Dissolved Oxygen	**X**					**X**							**X**		**X**	
Herbicides/Pesticides/Biocides	**X**	**X**	**X**	**X**	**X**	**X**	**X**							**some**	**X**	
Human Pathogens												**X**		**some**		
Litter/Plastics																
Metals and Organo metals	**X**	**X**	**X**	**X**	**X**	**X**				**X**					**X**	
Nutrients																
PAHs	**X**	**X**	**X**	**X**	**X**	**X**		**X**			**X**			**some**	**X**	
Petroleum Hydrocarbon/Oil	**X**	**X**	**X**	**X**	**X**	**X**					**X**				**X**	
Phytoplankton abundance/diversity																
Pharmaceuticals	**X**	**X**	**X**	**X**	**X**	**X**									**X**	
Suspended Particulate Matter																
Synthetic Organics/POPs	**X**	**X**	**X**	**X**	**X**	**X**			**X**		**X**			**some**	**X**	

Specific clinical effects related to contaminants have been the subjects of numerous epidemiologic studies. In low-dose exposed general populations, only subtle effects are expected to occur. For Pb and Cd, epidemiologic studies and animal experiments provide sufficient data to set thresholds for human exposure. For example, there is general consensus that 10 µg/dl is the maximum Pb blood concentration accepted for children. In this case, measuring blood Pb in a group of children is a relatively easy, cheap, validated and manageable biomarker to assess both exposure and risk in children. However, for most ocean-related contaminants such as MeHg and POPs, results from epidemiological studies are more contradictory. Cohort studies in Michigan (Jacobson and Jacobson, 1996) and North Carolina (Rogan *et al.*, 1986) provided conflicting results on neurobehavioural changes in children who were prenataly exposed to PCB's. Conflicting results were also reported on neurological impairments in children who were exposed to MeHg during their fetal life. A study in the Seychelles did not report any deleterious effects (Davidson *et al.*, 1998), whereas a cohort study in the Faroe Islands did (Grandjean *et al.*, 1997). There may be many reasons for these discrepancies, including differences in methods, exposure mixtures, nutritional interactions and genetic susceptibility.

Unfortunately, cohort studies are extremely expensive and require large multidisciplinary scientific groups. In addition, new xenobiotics and contaminant metabolites are regularly identified by analytical chemists and it is unlikely that epidemiologists will be able to react in a timely manner. In order to complement standard disease registries and epidemiological cohort studies, scientists have tried to develop early response biomarkers to detect any reversible or irreversible biological effects. Potential early warning signal markers deal with the immune system (cytokines, cell markers, antibody response to immunization, etc.), endocrine activity (hormones such as sexual or thyroid), genotoxicity (DNA and protein adducts for POPs), and enzyme induction (CYP-450, 1A2 and EROD activity using Caffeine Breath Tests for POPs). Some biomarkers are already in use (ALAD for Pb, β2-microglobuline for Cd) but most of them need to be validated. The major challenges are the lack of sensitivity and specificity.

6.1.3 Monitoring of Contaminants/Analytes

In order to monitor chemicals in the marine environment several aspects have to be considered: (i) the relationship between the type of measurement and different matrices; (ii) the relationship between difficulty of measurement and the relative importance of the measurement; (iii) the temporal and spatial aspects of contaminant variability in the ocean and the coastal marine environment; (iv) the bioavailability of contaminants and human health and (v) an evaluation of the relative importance of the variables from different regions.

Ordination techniques can be used to rank the status of study sites relative to one another and with respect to conditions at sites considered to represent background conditions. However, for successful managerial action, temporal (i.e., longitudinal) sampling series are advisable so that patterns and trends in anthropogenic stressors, contaminant levels and associated biological effects can be monitored. Usually, a significant proportion of study sites should be located in the vicinity of expected contaminant sources (e.g., in the vicinity of river discharges and urban harbours) to maximize the signal-to-noise ratio of measurements. In cases where atmospheric transport is the primary agent of contaminant delivery to the area concerned, measurements should be made of this input directly through measurement of both air and precipitation. Recognizing relationships between anthropogenic stressors, contaminant levels and associated biological responses is a prerequisite to the prediction of future environmental changes.

Once the objectives of the implementation plan in a given region have been formulated, attention must be given to sampling design. If no data are available, pilot studies will be needed to assess the scales of spatial and temporal variability of the analytes measured. These data are needed so that the monitoring programme can be designed to meet the objectives.

In addition to the incorporation of power analyses in the design of sampling programmes, there is a need to consider other new approaches such as Beyond Before-After Control-Impact (Underwood, 1991). Here, emphasis is placed on multiple controls and random sampling over time in order to distinguish effects of impacts over natural variability.

6.1.3.1 Measurements in different matrices

The Panel identified the matrices where many of the analytes/contaminants are measured and presented an evaluation of the present state of measurement in these matrices (Table 4). Three categories of difficulty were determined. The first are relatively easy measurements that can be carried out by people trained using routine technology. These have been assigned a “1”. The second group were defined by the Panel as those requiring more specialized equipment or training but could be analysed by monitoring laboratories within most nations. These have been assigned a “2”. The third group require more sophisticated measurements that would most probably be made by experienced research laboratories but perhaps do not exist in all countries. These have been assigned a “3”. The matrices chosen were seawater, groundwater and freshwater, suspended particulate matter, biological tissues (i.e., fish/seafood) and sediments. The Panel also added beaches to represent the fact that litter and oil spills (petroleum) impact these areas. Precipitation was also added as this is a mode of entry to the marine environment of some of the analytes discussed above.

TABLE 4: MEASUREMENTS OF ANALYTES IN DIFFERENT MATRICES

	Seawater	Freshwater	Suspended Material	Tissues	Sediments	Beaches	Atmospheric/Precipitation	Human Tissue/Fluids
Algal Toxins	3	3		3				3
Artificial Radionuclides	3		3	3	2		3	2
Dissolved Oxygen	1	1						
Herbicides/Pesticides/Biocides	3	3	2	2	2		3	2
Human Pathogens	2	2	1	1		1		2
Litter/Plastics			*			1		
Metals	2	2	2	2	2		3	1
Nutrients	1	1		2			2	
PAHs		2	2	2	2		3	2
Petroleum (Oil)	1	1	1	2	2	1	3	
Phytoplankton abundance/diversity	1		1		3			
Pharmaceuticals	3	3		3	3			1
Suspended Particulate Matter	1	1	*					
Synthetic Organics/POPs	3	3	2	2	2		3	2

*	Analyte and matrix are synonymous
1	Routine and widespread competence
2	More difficult but routine in most labs including PH labs
3	Relatively difficult and complex measure

6.1.3.2 Measurement versus impact considerations

The Panel evaluated the analytes/contaminants for degree of impact versus difficulty of measurement both for environmental measures and those measures for human health concerns. As discussed in the previous section, different matrices present different challenges. However, the analysis for environmental analytes is shown in Figure 3 and for human health risks, Figure 4. The analytes fall into three distinct categories.

Category 1 are those judged both to have high impact and be relatively easy to measure, such as nutrients, pathogens, suspended particulate matter and plant pigments. Also included in this category are ancillary properties for the characterization of the sampling regime such as salinity, temperature and dissolved oxygen. Litter and petroleum also have a high impact near sources (spills and dump sites) as well as at some distance from the sources. These are relatively easy to measure and also belong to Category 1. These analytes are also judged to be useful for international training programmes (e.g. TEMA). One could build an initial regional and global HOTO observing system today based on these variables. For human health issues fecal indicators in water and seafood and mercury in seafood and humans fall into this category.

Category 2 analytes were judged to be difficult to measure and have lesser impact (i.e., trace metals, artificial radionuclides and pharmaceuticals). These analytes require sophisticated instrumentation, considerable training and specialized standards and reference materials. It is worth noting that the Panel's result is contrary to public perceptions of the impact of these compounds. It is important to point out that in certain circumstances, such as near mining areas or nuclear installations, monitoring of these variables is necessary. However the panel felt that on a global basis sustained measurements of these variables is not necessary. For human health concerns, pharmaceuticals in humans; cadmium, PAHs, and radionuclides in both seafood and humans belong to Category 2.

Category 3 analytes were judged to be of high impact and are presently difficult to measure. These are most algal toxins, synthetic organics, herbicides and pesticides and, but to a lesser extent, PAHs. From a global monitoring perspective, it is imperative that efforts should be made to reduce the difficulty of measurement of these analytes as a priority. Research efforts should be focused on making these variables easier and less costly to measure. For human health concerns pathogens in humans, water and seafood; toxins in seafood and humans, POPs in seafood and humans, POP metabolites in humans and Dioxins/Furans in seafood and humans are all areas where efforts need to made to reduce these to Category 1 measures.

6.1.3.3 Time and space scale considerations

Factors that bear upon time and space scales for measurements are of three types. First are managerial considerations that involve the requirements of customers of the interpretative products from the HOTO module. Second are scientific considerations relating to the scales of change associated with changes in the locations, rates of introduction of substances and the locations and rates of physical disturbances of the marine environment. Third are the scientific considerations relating to the scales of natural variability in the marine environment of substances that have natural as well as anthropogenic sources and of natural biological communities.

Managerial Considerations: Assessments of the state and trends in environmental conditions are required for local, regional and global purposes. For local conditions, the highest spatial and temporal resolution will be required. Such resolution is reduced for regional requirements and reduced further for global purposes.

Scientific Considerations: The scales of change resulting from anthropogenic introductions of contaminants are an important consideration in selecting spatial and temporal frequencies of measurement for the HOTO Module. The spatial and temporal resolution required to detect and understand conditions and change will be greatest near to sources and lowest furthest from the sources. This aspect of measurement frequency is further discussed below. For contaminants having natural components, it will be necessary to define the envelope of variability against which anthropogenically induced change must be detected. This will be contaminant-specific but likely to impose higher spatial and temporal measurement frequencies in coastal areas than in regional and deep ocean areas.

FIGURE 4.
IMPACT VERSUS DIFFICULTY OF MEASUREMENTS FOR ANALYTES USED TO ASSESS HUMAN HEALTH RISKS

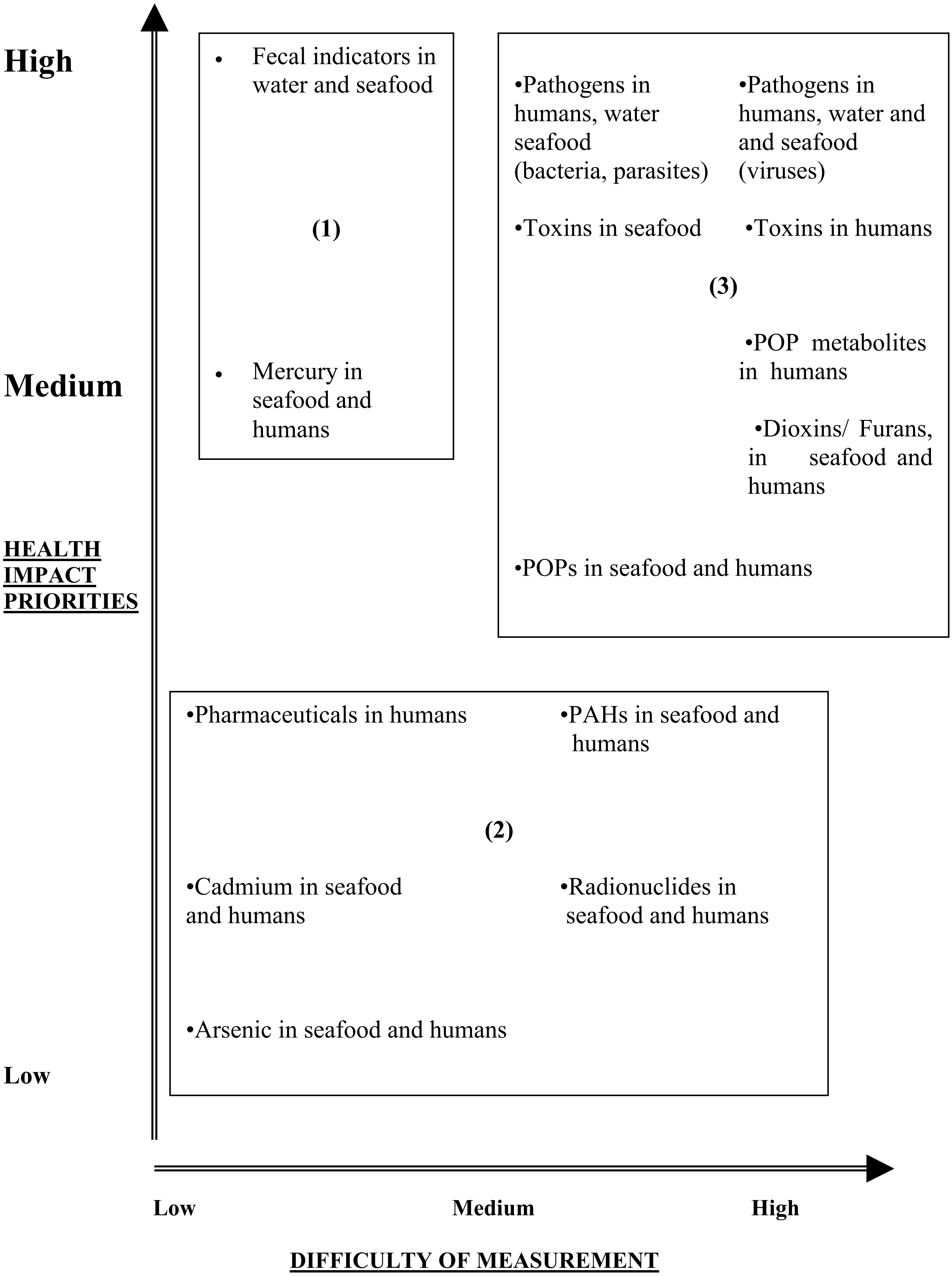


Figure 5 attempts to define measurement intervals (i.e., the inverse of measurement frequencies) appropriate for monitoring different contaminants in the context of distance from their sources. It has been formulated on the basis of scientific considerations relating to the likelihood and value of making measurements of change for local environmental and human health protection purposes and for detecting change at locations more remote from sources.

There is a need to stress explicitly at this point certain characteristics relating to the sophistication of methodologies employed in monitoring systems for the HOTO Module of GOOS. That is, all monitoring networks should use the simplest methods available, assuming that they offer appropriate precision and accuracies. If capability exists in a region to employ more sophisticated techniques and instrumentation, these may also be used. However, under no circumstances should the simpler techniques be forsaken because of the presence of the capability to employ more sophisticated alternatives.

6.1.3.4 Bioavailability of contaminants and human health

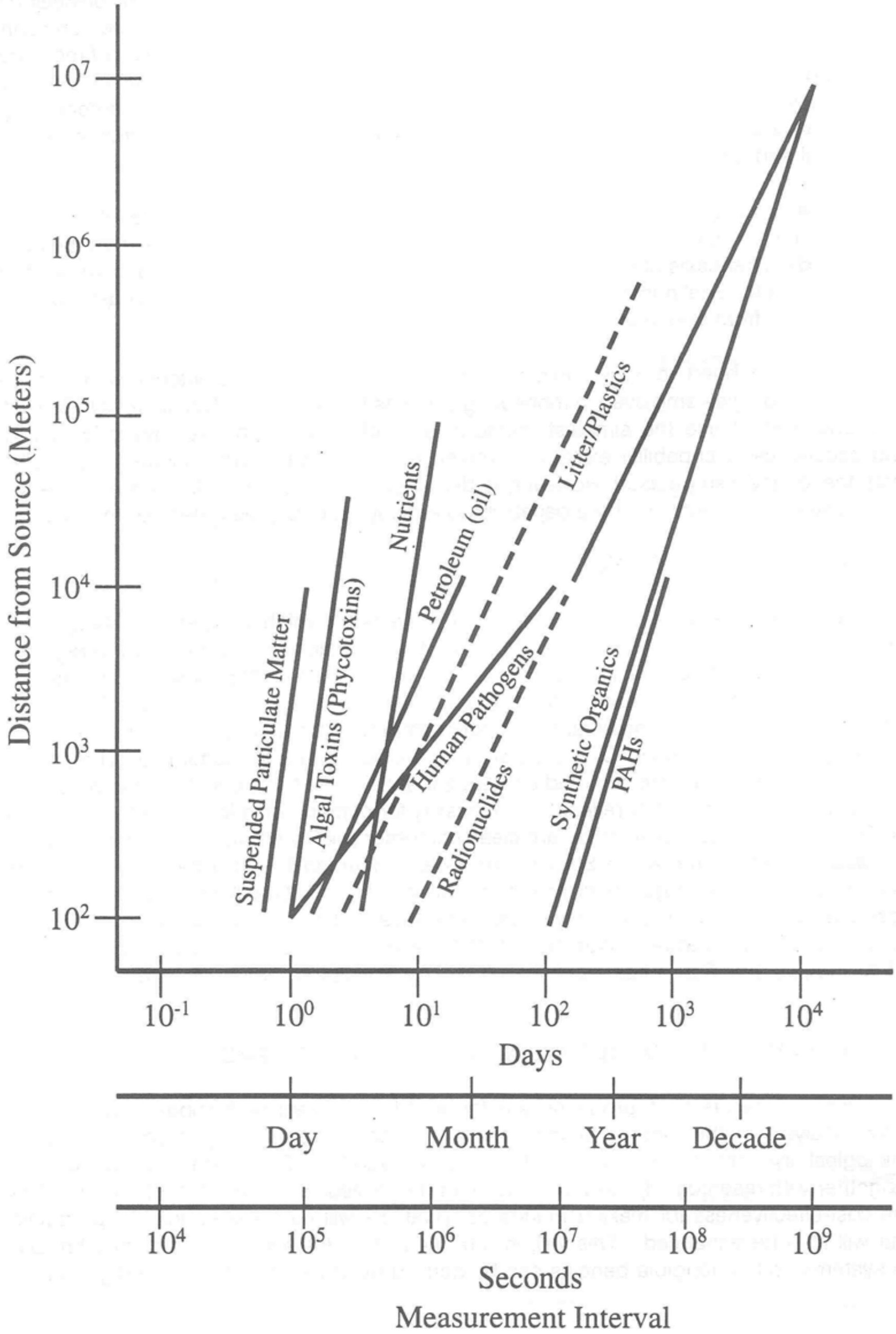
Linking exposure of xenobiotics found in marine environments with specific disease etiologies in humans is essential if one is to develop better prevention modalities in public health. In order to do so, it is critical to understand those issues related to the fate and transport and bioavailability of sources of marine contamination and pollution and how they relate to human exposure. The evolving conceptual and technical foundation of bioavailability calls for research that encompasses a broad view of the consequences of exposure. Ultimately, one needs to test hypotheses focused on mechanisms and effects across levels of biological organization, from DNA to populations and ecosystems. Such a synthesis undoubtedly will require more interdisciplinary collaboration to forge comprehensive studies designed to reduce risk and exposure. Gaining an understanding of the bioavailability of xenobiotics in the marine environment is key to comprehending the effects of these agents on humans and ecosystems; and how these agents, either singly or in simple or complex mixtures, move or are biotransformed in various milieus is part of the overall equation. Therefore, bioavailabilty needs to be looked at from three distinct perspectives: human health, ecological health, and relevant models of geosciences. Fate and transport directly related to bioavailability and determination of those relationships must be elucidated with a multidisciplinary perspective.

Bioavailability represents three distinct research areas and disciplines whose junction holds enormous implications for assessing risk. The oceans and human health paradigm has the opportunity to join these diverse disciplines and perspectives to examine how they are intertwined, to identify gaps in our understanding of their relationships, and to deliver a programme of prevention/intervention research.

For example, in human health studies of halogenated chemicals it is important to obtain a better understanding of the factors that influence intestinal bioavailability and biotransformation of lipophilic xenobiotics that may be present in the diet. Further, it is important to test the hypotheses that Ah receptor agonists cause alterations in the physiological and structural make-up of intestinal cells that affect the intestinal bioavailability and biotransformation of lipophilic chemicals; (e.g., the intestinal biotransformation and bioavailability of 3,4,3`, 4`-tetrachlorobiphenyl (TCB), 2, 4, 5, 2`, 4`, 5`-hexachlorobiphenyl (HCB) and chlorinated solvents such as trichloroethylene).

It is also essential to evaluate the interrelationships between the microbial community and contaminants, and to obtain a comprehensive evaluation of the health of the marine ecosystem. To do so it will be necessary to build on an extensive database designed to measure the distribution and transport of toxic metals throughout an area or region. In so doing research plans need to be divided into three parts: bioavailability and bioaccumulation rates of contaminants, effects of remediation efforts on ecosystem health, and the development of a microbial community biomarker of environmental stress.

Figure 5.
Spatio-Temporal Aspects of Monitoring of Contaminants
for Health of the Oceans Assessments



There are some key questions that need to be addressed if one is going to effectively deal with bioavailability within the large context of ocean health. They are:

- an understanding of the scientific processes needed to provide the confidence in the use of bioavailability factors;
- the biological, chemical and physical methods available to evaluate bioavailability. In particular, what are the criteria for validation;
- an understanding of the agent or geographical location where bioavailability information would have the greatest impact;
- when to use bioavailability information and development of a framework for its use;
- the dissemination of the importance of bioavailability to the general public.

In order to reduce risk and prevent exposures of xenobiotics in the marine environment, it is important to gain a better understanding of the issues surrounding bioavailability. Studies are needed in the area of fate and transport of chemicals through various marine matrices. Information is required to validate oceanographic and hydrogeologic models that have been developed, as well as studies to determine the bioavailability of these chemicals in relation to their fate and transport in marine environments.

6.1.3.5 Regional Priorities

In determining what analytes should be high priority versus low priority in various regions the Panel selected a number of geographic areas for which sufficient knowledge existed to assess the relative importance of contaminants. The HOTO Panel attempted to assign relative priorities to regions in the context of contamination and its effects (Table 5). This is by no means a complete list and is based on the expertise that was on hand within the Panel, but it does represent an approach that regions can take in order to develop a first list of priorities. A further discussion of this approach is presented for Canada in Annex III. In Table 5 a zero was assigned to analytes of little regional interest and low medium and high were ascribed to other analytes. While the precision of the assignments may not be high, it clearly reflects the necessity for primary attention to semi-enclosed marine coastal areas. Open-ocean oligotrophic areas are clearly of lesser priority within the context of the HOTO. It was noted, for example, that if the Asian Seas region were accounted for on a basin by basin basis, an entirely different picture would emerge. In the selection of areas for evaluation, it was apparent that enclosed or semi-enclosed seas having some uniformity in characteristics and concerns, such as the Mediterranean and Baltic Seas, were easier to assess than those that have long open coastlines such as West Africa. In concluding this analysis the Panel has benefited from the results of some of long-standing regional monitoring programmes.

6.1.4 Quality assurance/Quality control

A fundamental requirement of global monitoring programmes, such as those envisaged under the HOTO Module of GOOS, is that the resulting data must be comparable irrespective of the laboratory, country or region of origin. This presupposes that the data should be “true”. The production of “true” results is totally dependent on adherence to established Quality Assurance/Quality Control (QA/QC) procedures covering good field and laboratory practices.

TABLE 5: RELATIVE PRIORITIES FOR CONTAMINANTS AMONG MARINE AREAS

	Caribbean	Northern FSU	North Sea	West Africa	Baltic Sea	Mediterranean	Red Sea	The Gulf	SE Asian Seas	Black Sea	Oligotrophic	Great Lakes	Arctic	NE Asian Areas
Algal Toxins	H	*	M	*	M	M	L	L	H	M	*	L	L	M
Artificial Radionuclides	*	H	M	*	L	L	*	*	*	H	*	L	H	*
Dissolved Oxygen	*	*	*	M	H	M	*	*	M	H	L	H	*	H
Herbicides/Pesticides/Biocides	H	L	M	H	H	M	*	*	H	H	L	H	H	M
Human Pathogens	H	L	H	H	M	H	M	H	H	H	*	H	*	L
Litter/Plastics	M	M	L	H	M	H	M	L	M	H	L	H	*	M
Metals	L	L	M	L	L	L	L	L	L	M	L	M	H	L
Nutrients	H	L	H	H	H	H	L	M	H	H	H	H	*	H
PAHs	L	M	M	M	M	M	H	H	M	M	L	M	L	M
Petroleum (Oil)	H	M	M	M	L	M	H	H	H	H	L	L	H	H
Phytoplankton abundance/diversity	M	L	H	L	H	M	L	*	H	H	*	H	*	H
Pharmaceuticals	*	*	M	L	L	L	*	L	L	L	*	L	*	L
Suspended Particulate Matter	H	L	L	M	M	L	L	H	H	M	*	L	*	H
Synthetic Organics/POPs	L	M	M	M	M	M	L	L	L	H	L	H	H	L

*	Insignificant
L	Low Priority
M	Medium Priority
H	High Priority

The requirements for QC/QA of HOTO measurements are:

- The availability of adequately trained and motivated personnel and appropriate facilities for the execution of the defined tasks in the monitoring programme. This involves familiarity of laboratory staff with all aspects of monitoring, from sample design to validation of data. It also requires those facilities (e.g., clean laboratories) and equipment is well maintained and serviced and that expendable material (e.g., glassware, solvents, gases, etc.) should also be of suitable quality.

- Sampling design would be such as to ensure the collection of representative samples, which would be properly labelled (e.g., sample type, location, time and date of collection, environmental characteristics, etc.) and assigned numbers for archiving purposes. Those samples, which require special or particular treatment or preservation procedures to prevent their deterioration, should be treated adequately. All aspects of transportation of samples to the laboratory, further processing of samples where necessary, and storage, should follow procedures that will preserve the integrity of the samples prior to analysis. Where applicable, precise extraction procedures would be employed to isolate the analyte of interest, without contamination, alteration or loss.

- Instrumental analyses should follow for the accurate and precise measurement of the analytes of interest by a technique validated using relevant certified reference materials (CRMs) and authentic standards. A CRM is a reference material, accompanied by a certificate, and for which each certified value is accompanied by an uncertainty at a stated level of confidence (ISO Guide 30, 1992).

(i) Equipment well maintained and periodically serviced.

(ii) Intercalibration and intercomparison exercises to ensure that data provided by different laboratory are comparable.

The newly-emerging biomarker techniques and the monitoring of biological effects at the population and community levels will require additional attention to QA/QC. A prerequisite to QA in this respect will be the appropriate capacity building with regard to standardized methodology and intercalibration (e.g., through GIPME and TEMA programmes). In effect, intensive series of evaluations, training and intercalibration exercises, tuned to the various regional/global environments are needed for this purpose. QA/QC biological procedures and protocols need to be developed.

6.2 COMMUNICATION, NETWORK AND DATA MANAGEMENT

The HOTO programme must be complemented by a data management system that considers the dissemination and archiving problems from raw data to user products. Modern networking with the WWW model of data exchange should be explored.

6.2.1 Objectives

The HOTO data management system should provide:

(i) a complete, efficient and internationally accessible data base;
(ii) a whole suite of products that will quantify human impact on marine ecosystem health;
(iii) a shared database for model validation and intercomparison;
(iv) a collation of different contaminants/biochemical variable measurements from Pilot Project regions.

This data exchange should be done using the existing communication network of the WODC, RNODC, NODC established in the past years by IODE-IOC activities. In addition to that, the WWW system should be activated in each Pilot Project region for fast dissemination of results. HOTO data networking should be interfaced with the LOICZ database that contains nutrient's budgets in different world coastal areas.

Protocols for data receipt, verification and validation will need to be developed in order to ensure that the GOOS data archive contains reliable data to assess the health of the ocean. In addition, data should be 'free', i.e., for no more that the cost of reproduction and distribution.

Much of the data generated by HOTO may be considered sensitive by those providing the data. For example, toxin data in shellfish could be considered sensitive by those countries wishing to export. Even toxins in sediments could be considered sensitive. These problems need to be addressed for the successful implementation of HOTO.

6.2.2 Data Policy

The HOTO data should be released to the international community as a set of intercalibrated, fully documented measurements. The measurements should be made available to the international data-banking centers in predefined time with each programme determining a release date for final data. Initially HOTO data will be available only on delayed mode. Real-time data are expected in RAMP but protocols of data exchange still need to be determined.

6.2.3 QA/QC for Data Management

QA/QC standards for archiving the HOTO data are still to be defined. However, following the international standards for physical and biochemical data archiving two forms are envisaged:

(i) Metadata information containing a description of the Project, the measured variable, units, station location, method of data acquisition, sensor used, algorithms to convert raw data, calibration, level of processing, responsible institution or person;
(ii) Quality controlled data files containing the raw data, the level of processing, and the type and level of quality control.

6.2.4 Regional Analysis Centres

Conceptually Regional Analysis Centres could be created. These laboratories would be responsible for storing GOOS data and providing training and expertise from analytical techniques to data analysis. It is possible that this could be undertaken in conjunction with the UNEP Regional Seas Programme.

6.3 MODELLING AND DATA ASSIMILATION

The last twenty years have seen the development of dynamical models of Open Ocean and coastal ecosystems. These are models with explicit representation of the pelagic and benthic food webs up to a certain tropic level. The latest research results indicate that low tropic level (phytoplankton) dynamical ecosystem models can be predictive at the time scales of few days and they can hind cast for several months resolving a seasonal cycle. Ongoing research development in this field is related to assimilation of *in situ* and satellite ecosystem data in the models to achieve a realistic initial state.

Statistical/empirical models based on correlation matrices between different ecosystem state variables are being developed. Their predictive capabilities are being evaluated. An example is the present GLOBEC effort to relate zooplankton and fish stocks abundance to physical climate variables such as sea and air temperature, winds, precipitation, currents, etc. In order to do so, long time series of multidisciplinary data are collated, intercalibrated and analyzed by sophisticated statistical tools (empirical orthogonal functions, neural networks, etc.).

Thus, both dynamical and statistical models are ready to be used to integrate and dynamically interpolate marine ecosystem observations in space and time. However, it is only recently that these dynamical and statistical models are being considered with regard to developing a strategy toward the assessment and prediction of the health of the ocean, some examples are: (1) dynamical marine ecosystem models that are developed in conjunction with water quality models and contaminant measurements and; (2) statistical models applied to harmful algae bloom problems in order to predict the probability of human exposure to neurotoxins and occurrence of fish kills.

Key research issues for modelling and data assimilation are:

(i) To develop system analysis schemes (conceptual model formulation, quantitative specification of models, validation and model use) which will incorporate elements of health of the ocean variables, as listed in section 5 for the initial HOTO observing system;

(ii) To use dynamical ecosystem models to design optimal HOTO observing systems and observing strategies (Observing System Simulation Experiments, OSSE);

(iii) To further develop the coupling of subsystem modules such as:

a) water quality models and dynamical ecosystem models;
b) benthic with pelagic dynamical sub models;
c) waste water and river basin models with coastal dynamical ecosystem models;
d) high trophic levels compartments of the marine food chain;

(iv) To use dynamical and statistical models to investigate the significance of biomarkers for different parts of the food chain from the pelagic to the benthic compartments;

(v) To identify with dynamical and statistical ecosystem models, simple indicators of change in species composition and community structure for the pelagic and benthic subsystems;

(vi) To interface the dynamical and statistical model predictions with socio-economic development and human health impact models;

(vii) To combine monitoring and rapid assessment observing strategies (adaptive sampling, long time series stations) that could be used to validate and calibrate coastal ecosystem models.

In order to develop better models and improve data assimilation there are some important pre-operational implementation issues:

(i) The implementation of real-time data acquisition protocols at the adequate space and time frequency to be comparable and assimilated into dynamical ecosystem models;

(ii) The development of demonstration projects that show the forecasting capabilities for phytoplankton biomass and species composition in heavily inhabited coastal areas;

(iii) The implementation of observing and modelling strategies to mitigate the effects of episodic and extreme pollution events;

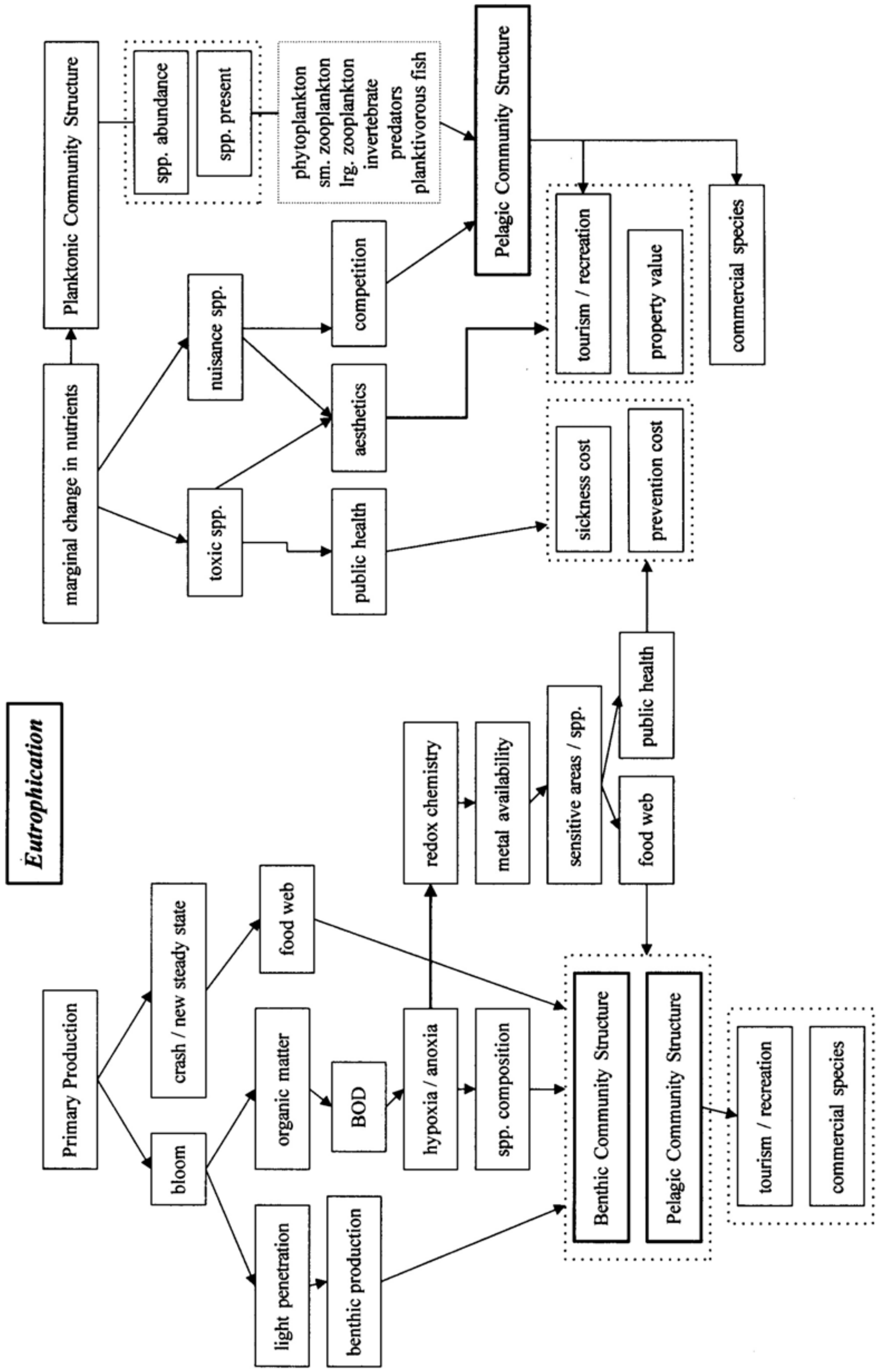
(iv) The facilitation of model use by different end users communities, from the scientific to the coastal management authorities. This can be achieved by developing user-oriented products and software interfaces.

7. RELATIONSHIP TO SOCIAL AND ECONOMIC VALUE

The consistent and long-term implementation of a HOTO-based assessment programme will contribute directly to a refined understanding of the social benefit values derived from degraded coastal ecosystems and to the evaluation of coastal management and mitigation practices. As is illustrated in Figure 1, an operational HOTO will lead to a direct and explicit understanding of the relationships between marine ecological integrity, sustainable human activities and resource uses, and marine-vectored human health risks. With such relationships more firmly in hand, decision makers will be in a better position to maximize social and economic values derived from coastal and ocean systems and, importantly, be in a better position to view the cost of a HOTO programme as a social and economic “return-on-investment”. Without continuous monitoring of critical HOTO analytes the ability of decision-makers to isolate causal-chain relationships between environmental conditions and use values will be extremely limited.

Figure 6 illustrates the functional relationship between a critical HOTO analyte (nutrient dynamics/eutrophication) its role in marine ecosystem integrity, and associated social benefit values. Marginal changes in nutrient concentrations can result in changes in phytoplankton dynamics affecting both abundance and species distribution (particularly as regards changes in nuisance and toxic species). Changes in planktonic community structure can lead to important changes in pelagic community structure. Primary production coupled with light penetration and organic matter concentration help determine the status of bloom conditions, biological oxygen demand, redox potential, as well as the speciation, bioavailability and mobility of trace metals and other anthropogenic pollutants.

Figure 6
Relationship Between Nutrient Dynamics/Eutrophication and Socio-Economic Benefits



A HOTO-based monitoring programme will contribute directly to a richer understanding of these ecological relationships at the regional level. It will also provide direct benefit to decision-makers concerned with the sustainable use of coastal systems by expanding their understanding of critical environmental drivers affecting the social value contributed by those systems. For example, tourism/recreational values may be impacted as a result of the prevalence of aesthetically displeasing nuisance species (algal foams) or toxic species that would limit access to recreationally caught shellfish or finfish species, or to recreational bathing water. Greater recreational losses would be incurred through the ramifications of eutrophic conditions (fish kills). These effects could also directly lead to reductions in coastal property values as nearby recreational opportunities are affected.

Losses to commercial fisheries can occur due to changes in the occurrence of toxic algal forms and bioaccumulation of toxins in commercially valuable stocks, losses due to the trophic transfer of changes in primary production and, most obviously, due to the creation of anoxic conditions and associated fish kills. Subsistence and artisenal fisheries could be similarly affected. In the event of particularly acute impacts on fishery stock significant and broad ranging cultural impacts could occur. It is frequently the case that the social and economic costs of these changes to cultural norms and values far exceed the direct economic losses from fishing.

Human health costs need to be assessed both in terms of sickness costs and associated prevention costs. Sickness costs must account for the possibility that incidence of acute illness or cancer could increase because of changes to nutrient dynamics. An increase in toxic algal forms could lead to increased human health risks associated with the consumption of contaminated fishery products. Increased cancer and neurotoxic risk might be associated with the consumption of seafood containing contaminants remobilized through changes in eutrophic conditions. Such costs would include the direct costs of medical treatment, lost working days, losses in productivity, and increases in litigation costs. Prevention costs could increase with associated management efforts to reduce sickness costs. These could include, increased regulatory costs, increased seafood product inspection costs and the loss of income due to health related fishery closures.

8. REQUIREMENTS FOR TECHNOLOGY AND ITS DEVELOPMENT

8.1 MARINE ECOSYSTEM ADVANCED TECHNOLOGY

Contemporary technology for contaminant measurement is largely based on sampling from platforms followed by laboratory analysis of samples. There are great opportunities for applying new technologies to overcome the limitations of this traditional approach for many contaminants. As part of GOOS, the extent of such opportunities in relation to the needs of the modules requires to be aggressively evaluated. Such technologies include development of sensors, remote sensing, unattended moorings with or without real-time data telemetering autonomous underwater vehicles, drifters and gliders.

For biological response measurements, the identification of sensitive indices that can be mechanistically linked to specific contaminant exposures is essential. This would then permit evaluations of the potential of new technologies for making more frequent, more ubiquitous and more synoptic measurements. Technologies showing most potential for biological response measurement include remote methods of assessing community structure, density and diversity, on-line, computer-aided physiological and behavioural monitoring systems, molecular and cellular biomarkers of exposure and damage. These include immunofluorescence and Polymerase Chain Reaction (PCR), for example, to detect viable but non-culturable pathogens. Currently, limitations in the measurement of biological responses in the marine environment is the most severe impediment to the development and implementation of the HOTO Module.

Systems that already exist could be improved such as networks of marine laboratories, existing time-series programmes in the coastal ocean and mussel watch activities. New camera systems for benthic surveys, remote submarines, and networks of on-line biological sensors near major point sources are just some of the tools that will be part of HOTO.

Satellites provide a great opportunity for GOOS measurements. They have already proved themselves in providing prodigious amounts of ocean data. The SeaWiFS (Sea-viewing Wide Field-of-View Sensor) provides data on ocean colour. Satellites provide sea surface altimetry data, wind scatterometer data, and information of sea surface temperature. Synthetic Aperture Radar (SAR) provides information for oil spill detection. These systems have been used in research efforts for a number of years, however these satellite systems are not operational in the monitoring sense as yet. It is essential that these programmes continue into an operational observation mode.

8.2 HUMAN HEALTH ADVANCED TECHNOLOGIES

The ability to quantify levels of gene expression and identify gene alterations (polymorphisms, deletions, and other mutations) associated with individual susceptibility and toxicity of environmental pollutants has grown rapidly in the last few years. Arrays of nucleic acid probes are proving to be very powerful tools, and are being used to identify and monitor whole sets of genes and gene products of specific interest. Application of this technology within the context of oceans and human health is feasible leading to the integration of nucleic acid sequence detection technology with research on marine organisms such as fish, molluscs and crustacean.

Newly emerging marine models, such as transgenic fish, could be widely used in research on basic biochemical processes and the adverse effects of toxic compounds. Small aquarium fish models offer the advantages of simplicity, relative low cost to generate statistically valid results, wide range of sensitivities, short development times, and ease of generating and maintaining mutant and genetically engineered strains with one or more genes inserted or deleted.

Nutritional status, disease susceptibility, and synergistic or antagonistic effects of exposure to more than one stressor add significantly to the problem of predicting human health effects associated with exposure to environmental hazards. Knowledge of whole-animal response to mixtures and varied levels of potential toxicants and carcinogens is required to establish exposure thresholds and identify genetic features that affect individual susceptibility. With marine models such as fish, behavioural as well as other endpoints can be used in investigations of sub-lethal effects.

The pool of knowledge on the genetics and metabolism of marine models, specifically fish, used in environmental health research is rapidly growing. The current data show that fish, like rodents, have many features in common with man, so that results obtained with them can be extrapolated to the human condition. Genetically manipulated organisms are of particular importance in allowing investigators to go beyond simple comparative studies between species. These advantages make it possible to realistically plan for low dose, multi-parameter studies, with the prospect of uncovering genetic patterns and biomarkers of risk associated with low-dose exposure to varied levels and types of environmental contaminants.

Expertise on the integration of the use of transgenic vertebrate models with diagnostic nucleic acid arrays is growing. This integration could easily and cost-effectively be done within the context of the marine environment and human health. Biological, engineering and chemical expertise will be required to facilitate the use of nucleic acid probes in studies with marine transgenic models. The powerful combination of transgenic fish models and nucleic acid probe technologies will lead to unprecedented advances in our understanding of environmental effects on human and ocean health.

9. CRITICAL RESEARCH AREAS

Multidisciplinary research programmes in the diverse areas of oceanography, climatology, ecology, biomedical sciences and computational biology are needed to provide for an international network of investigators and foster interconnected research approaches dedicated to understanding the complexities of linking oceans and human health. The support of fundamental, hypothesis-driven research comprising both biological and physical sciences will increase the research enterprise. The following are suggested new areas in which research efforts should be directed.

(i) The collection of data and development of research to predict and prevent marine-related public health disasters. In addition to the health disasters brought about by weather and climate phenomena linked to the oceans, many public health officials are concerned that higher than normal water temperatures will result in increasing pathogenic organisms. This would give rise to an increased incidence of such diseases as malaria and dengue fever. Ocean-related data on temperature, tropical storms, rainfall and droughts should be examined regularly and compared with comprehensive health statistics on the location, frequency, and dates of disease outbreaks, to identify connections between illnesses and environmental factors.

(ii) Early detection of harmful algae. The environmental conditions that foster large blooms of microscopic algae are not well understood and seem to vary from species to species. Further research is needed to understand the causes of these events. Red tides and other toxic algal blooms are appearing in previously unaffected areas. Research is needed to identify damaging types of algae; the physical, chemical and biological factors that promote their growth; and human health effects due to algal toxins in the food supply or through aerosols. Interaction with GEOHAB is essential.

(iii) Reducing morbidity due to water-borne and vector-borne diseases. New tests are needed to detect water-borne pathogens more quickly and efficiently. Environmental monitoring for pathogens should be coordinated with targeted epidemiological investigations to identify populations at risk. Moreover, interdisciplinary research is needed to examine the potential for global climate change to affect the spread of human diseases. For example, the cause and effect relationships among sea surface temperature, nutrients, plankton, *Vibrio cholera*, disease incidence, and climate variability need more study.

(iv) Understanding the risk associated with the ingestion of contaminated seafood. Growing demand for seafood and expansion of ocean-going transport have increased the potential for human exposure to infectious toxic agents. The risk to human health of seafood ingestion needs to be determined as well as the point sources of contamination. Exposure data via the ingestion of persistent organic pollutants (i.e., DDT, PCB) and metals (i.e., methyl mercury, cadmium) should be evaluated and put in the context of seafood consumption. Also, accurate, cost-effective methods should be developed for identifying and monitoring other xenobiotics in seafood.

(v) Understanding the interaction of environmental stress and the opportunities for development of new drugs and nutrients. Terrestrial plants, animals and microbes are the source of more than half of the medicinal drugs on the market today. Technical difficulties and lack of knowledge of the marine environment have prevented scientists and researchers from more fully exploring the use of marine life and its derivatives to prevent and treat human diseases. Multidisciplinary research is needed to investigate marine species that potentially are a source of new drugs and novel nutritional components. Although not a specific province of GOOS, economic benefits of understanding the marine environment will lead to new products.

(vi) Development and use of new technologies to help reduce human health risks. Advanced, real-time sensors should be developed and put into place to monitor marine conditions and water quality, and to be able to correlate results with exposures in humans. For example, more sensitive and specific tests are needed to detect pathogens and xenobiotics introduced into oceans through runoff from sewage, rivers and streams. Genomic-based and protein-based high throughput bioassays are needed to assess tissue-specific and species-specific differences from xenobiotic exposure. Because of the complexity of the oceans and human health links, there is a critical need to take advantage of new technologies in genetics and computing to better monitor and predict the effects of environmental changes on disease outbreaks.

(vii) Develop integrated models of coastal ecosystems impacted by the release of contaminants. New numerical models need to be developed which interface the river basin wastewater models with coastal numerical ecosystem models. The challenge will be to determine the net effect of specific contaminants on the coastal ecosystem. Numerical dynamical models of the different parts of an environment such as, a sewage system, a river-catchment, coastal area hydrodynamics and ecosystem dynamics, the atmosphere, the advection and diffusion of contaminants, do exist separately and they have been validated/calibrated in separate circumstances. It is now time to interface them and simulate the impact of different contaminants on the coastal area ecosystem, producing scenarios for mitigation and protection of the environment.

(viii) Build on the rapid assessment techniques for other matrices. In 1999, the IOC created a Benthic Indicator Group which is presently identifying numerous indicators of stress. Some of these measures compliment the rapid assessment biomarkers discussed earlier. For example, a high incidence of imposex and abnormal burrowing behaviour by benthic invertebrates has been identified as measures of benthic community stress. In addition, measures such as ratios of crustaceans to polychaetes and molluscs, and of filter-feeders to deposit feeders and carnivores are also potential indicators of stress. These are clearly easy measurements to make. The combination of biomarkers of organismal health with indicators of benthic stress clearly enhances the ecological relevance of the rapid assessment approach.

10. LINKAGES AND COLLABORATION WITH OTHER PROGRAMMES INFRASTRUCTURES AND MECHANISMS

The GOOS Health of the Ocean (HOTO) Module specifically addresses the ways and means of developing integrated mechanisms for observing, assessing and forecasting the effects of anthropogenic activities on the marine environment. This Design Plan is intended to provide a basis for developing observing systems for the determination of the prevailing conditions and trends in the marine environment in relation to the effects of anthropogenic activities, particularly those resulting in the release of contaminants to the environment. The observations and measurements planned to be made within the framework of the HOTO Module of GOOS will be concentrated in the shelf seas areas of the world's oceans. That is, the density and frequency of the observations are likely to represent those areas of the ocean that are most likely at risk.

GOOS will be built, as far as possible, on existing activities and bodies as well as on the progressive implementation of new elements and capabilities. It will be updated and improved in response to results of research programme and the development of new technology. Present national and international infrastructures and mechanisms that are the result of many years of effort and co-operation need to be exploited. The experience of those who have developed present systems is a critical requirement and will essentially constitute a collective advisory resource on scientific and management issues.

There exists a significant number of possible linkages, both conceptual and in terms of actual programme co-ordination, with other global, regional, national and individual programmes. Here we highlight some of these pertaining to HOTO in a substantial manner.

Linking HOTO with some of these programmes is necessary to establish and sustain HOTO observing systems on a scientific basis. Within the framework of the International Geosphere-Biosphere Programmes (IGBP) of the International Council for Science (ICSU), there are three "Core Projects" that are of relevance to the HOTO Module. These are the Land-Ocean Interactions in the Coastal Zone (LOICZ); the Joint Global Ocean Flux Study (JGOFS) and the Global Ocean Ecosystem Dynamics (GLOBEC) Programme. Of these, LOICZ is the most pertinent, while GLOBEC has more relevance to the Living Marine Resources Module of GOOS. JGOFS, with greater relevance to the Climate Module, has presently completed its field activities and its main efforts have shifted to a major synthesis phase. The results of JGOFS synthesis efforts on transport of nutrients in the coastal margins could provide very valuable guidance to HOTO observing system development. It is anticipated that a major programme will follow JGOFS in ocean biogeochemical cycles. It should be recognized that the "Core Projects" of the IGBP are purely research activities of limited (e.g., about 10 years) duration. Thus, they might make use of data generated through operational GOOS, but the likelihood of the HOTO Module producing significant data outputs within the life span of LOICZ, for example, is small. In contrast, the data generated through the research of LOICZ could provide significant contributions to the further elaboration and development of the HOTO Module as it reaches full global scale coverage and becomes fully operational.

The LOICZ Project is, as its name suggests, that component of the IGBP, which focuses on the area of the earth's surface where land, ocean and atmosphere meet and interact. The overall goal of this Project is to determine, at regional and global scales, the nature of that dynamic interaction; how changes in various compartments of the Earth System are affecting coastal zones and altering their role in global biogeochemical cycles; to assess how future changes in these areas will affect their use by people; and to provide a sound scientific basis for future integrated management of coastal areas on a sustainable basis. Among its four areas of focus, those involving the effects of changes in external forces on coastal fluxes and coastal biogeochemistry are of special interest to HOTO design and implementation.

Identifying and quantifying the role of the world's coastal zone in the functioning of the total Earth System and developing scenarios of change in the coastal compartment of the Earth System under anthropogenic and geocentric driving forces of change will require a considerable body of research that is detailed in the LOICZ Implementation Plan. The approaches and methods developed by LOICZ to address these research goals may have value in the further development of the HOTO Module of GOOS and in the interpretation, at wider regional and global scales, of the information and data collected and assembled through the implementation of the HOTO Module. The research networks established through the LOICZ Project could be used to provide practical advice and assistance in the implementation of the HOTO Module at local and regional levels.

To address the need for broad-based advancement in the understanding of Harmful Algal Blooms (HABs), IOC and SCOR has established jointly a scientific research programme called GEOHAB (Global Ecology and Oceanography of Harmful Algal Blooms). The mission of GEOHAB is to foster international co-operative research on harmful algal blooms in the context of their ecological systems and the oceanographic processes, which influence them. Its scientific goal is the determination of ecological and oceanographic mechanisms underlying the population dynamics of harmful algae, by the integration of biological and ecological studies with chemical and physical oceanography, supported by improved observation systems. The benefits of GEOHAB will be better methodologies for predicting the occurrence, distributions, toxicity, and environmental effects of HABs.

A broad range of research is directly relevant to the research tasks of GEOHAB. This includes: interdisciplinary process studies of HABs in comparable ecosystems; taxonomic and genetic surveys of HAB organisms from different locations, along with physiological characterization of isolates and examination of possible dispersal mechanisms; studies of the influences of turbulence or variations in nutrient fluxes on community interactions (conducted in micro- or mesocosms, modelled, and compared with observations of natural communities); and examination of temporal and spatial trends in phytoplankton dynamics (including HABs) relative to human influence and climate variability, as inferred from existing sources and a developing Global Ocean Observing System. This will be greatly facilitated through strong links between GEOHAB and the HOTO activities within GOOS.

GIPME, as jointly sponsored by the IOC, UNEP and IMO, has two major objectives: (1) To provide assessments of the State of the Marine Environment; and (2) To provide data and information to GOOS, to satisfy the requirements of GOOS and, indirectly, those of Earth watch and GCOS. However, GIPME has an additional responsibility to develop improved understanding of the processes involving the sources, transport, behaviour, fate and effects of contaminants in the marine environment. Such improved understanding will also provide benefits to the HOTO Module and to GOOS in improving the reliability of assessments and the modeling of GOOS data. It is considered that the experience of GIPME in regional monitoring activities place it in a unique position to deliver the regional assessments to GESAMP for its periodic reviews of the "State of the Marine Environment". This is done at the request of sponsoring UN Organizations along the lines defined by GESAMP for Regional Marine Assessments (GESAMP, 1994).

GIPME includes work not specifically directed at regional issues such as the development of methods for widespread application, preparation of reference materials and all projects addressing open ocean issues. Training workshops and intercomparison exercises are convened in the various regions to promote their monitoring effectiveness. The level of activity varies among regions.

In view of the foreseen requirement for GIPME to contribute to GOOS, in addition to assessments of the "State of the Marine Environment", there exists a need to reconsider the strategic requirements of GIPME in the specific context of GOOS. This should be completed before the harmonization of the respective UNEP and IOC activities relating to GIPME is undertaken to ensure that the combined programme fully anticipates its responsibilities and achieves its goals. Therefore it is imperative that HOTO and GIPME work in close collaboration to ensure all requirements of both the GOOS Module addressing the health of the ocean and the GIPME Programme are met.

In order to provide a mechanism ensuring globally available data quality assurance services for contaminant measurements, the IAEA, with support from UNEP and IOC, established the Marine Environmental Studies Laboratory (MESL) in 1986 as a section of the then International Laboratory for Marine Radioactivity (ILMR) in Monaco. MESL organizes intercomparison exercises regionally and globally and acts as a center for testing and editing the UNEP Reference Methods for Marine Pollution Studies, with technical support from the GIPME Expert Groups. It organizes specialized local and regional training courses, instrument maintenance services, pilot monitoring studies and acts as the Regional Analytical Center for the Mediterranean Action Plan. The experience gained in the operation of this center can be applied in the provision of similar services for GOOS, in general, and its HOTO Module, in particular.

Presently there exists a significant number of national, regional and global infrastructures and mechanisms with which co-operation is essential and mutually beneficial. For instance, HOTO GOOS can provide substantial assistance and advice on matters, *inter alia*, related to monitoring (trend and compliance) in regional conventions by assisting in development of new monitoring systems, improvement of existing ones and by providing complementary data. It can also assist in the efforts concerning regional and global assessment of the state of the marine and coastal environment, including watersheds, by providing data products and information.

The regional seas programme, initiated in 1974, has remained the central UNEP programme providing the major legal, administrative, substantive and financial framework for the implementation of Agenda 21, and its Chapter 17 on oceans in particular. The regional seas programme is based on periodically revised action plans adopted by high-level intergovernmental meetings and implemented, in most cases, in the framework of legally binding regional seas conventions, under the authority of the respective contracting parties or intergovernmental meetings.

Currently, 14 regions are covered by adopted action plans and eleven of the action plans are supported by regional sea conventions. The geographic regions considered as covered include: the Mediterranean, West and Central Africa, Eastern Africa, the East Asian Seas, the South Asian Seas, the North-West Pacific, the Persian and Arabian Gulf, the Red Sea and Gulf of Aden, the South Pacific, the South-East Pacific, the Wider Caribbean, the Black Sea, the North-East Atlantic and the Baltic Sea. UNEP facilitated the negotiations of the 12 regional seas conventions and action plans in the developing world and is currently supporting negotiations in the center east Pacific and the upper southwest Atlantic.

Whenever appropriate, the regional seas conventions and action plans have served as a main mechanism for implementing various ocean-related global initiatives and conventions. The more mature regional seas conventions have developed protocols complementary to global conventions and agreements such as the Convention on Biological Diversity (CBD), the Convention on International Trade in Endangered Species (CITES), the Basel Convention, and the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA). The overall coordination provided by UNEP ensures that the activities of the regional sea conventions and action plans that it has helped negotiate, although implemented regionally, remain essentially global in nature.

In the new organizational structure of UNEP, the regional sea conventions and action plans are the responsibility of the Division of Environmental Conventions. As stressed at the 20th Session of the Governing Council (Nairobi, 1-5 February 1999), a top priority of UNEP's Subprogramme on Environmental Conventions is the continued revitalization and strengthening of the regional seas conventions and action plans. UNEP is one of the co-sponsors of GOOS. The revitalized Regional

Seas Programme and GOOS would both benefit from a strong interactive linkage in their missions, among others, related to the implementation of Agenda 21, and its chapter 17 on oceans and coastal areas.

A regional programme that is worthy of establishing links with is the Arctic Monitoring and Assessment Programme (AMAP). The primary objectives of AMAP are: to provide reliable and sufficient information on the status of, and threats to the Arctic environment, and to provide scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions relating to contaminants. AMAP activities include: measurement of the levels, and assessment of the effects of anthropogenic pollutants in all compartments of the Arctic environment, including humans; documentation of trends of pollution; documentation of sources and pathways of pollutants; examination of the impact of pollution on Arctic flora and fauna, especially those used by indigenous people; reporting on the state of the Arctic environment; and giving advice to Ministers on priority actions needed to improve the Arctic condition.

AMAP's priorities are: persistent organic contaminants (POPs), heavy metals, radioactivity, acidification and arctic haze, oil pollution and environmental consequences of, and biological effects due to, global climate change and stratospheric ozone layer depletion, relevant to the Arctic.

Effects of pollution on the health of humans living in the Arctic, including effects due to increased UV radiation as a result of ozone depletion, and climate change, have been given a special priority within the future work of AMAP. Similarly, combined effects of pollutants and other stressors on both ecosystems and humans shall be addressed.

By taking note of the fact that about 80% of all marine pollution is caused by human activities on land - activities such as sewage disposal in rivers and the coastal ecosystem; inadequately treated waters from industries; discharges of nutrients of phosphorus and nitrogen used in agriculture and finally, heavy metals and persistent organic pollutants. All States adopted the Global Programme of Action (GPA) for the Protection of the Marine Environment from Land-based Activities in 1995.

The GPA was developed to address the problem of progressive degradation of the coastal and marine environments at national, regional and global levels. It calls on Member States to identify the nature and severity of problems caused by marine pollution, to assess the severity and impacts of marine contaminants, to establish priorities for action, to define specific management objectives and to identify and evaluate strategies for achieving the coastal management objectives, including the reduction of polluting emissions to the sea. It calls on UNEP to promote and facilitate, in partnership with other organizations, including UNESCO-IOC, the implementation of the GPA.

The GPA also includes development of a "clearing house mechanism" as one of its key implementation tools. This is intended to be a "referral system" through which decision makers at the national and regional levels could be provided with access to current sources of information, to marine pollution databases and to practical experience and scientific and technical expertise relevant to developing and implementing GPA strategies.

The objectives of GPA in matters relating to marine pollution are intimately related to the mission of HOTO GOOS.

The aim of the UNEP-led and GEF-funded Global International Waters Assessment (GIWA), is to produce a comprehensive and integrated global assessment of international waters. GIWA encompasses the ecological status of and the causes of environmental problems of shared water areas in the world. These international waters comprise marine, coastal and freshwater areas, and surface waters as well as groundwater. Causal chain analyses will be an essential tool used to identify and better understand links between perceived problems and their societal root causes.

The GIWA is designed not merely to analyse current problems. Scenarios of the future condition of the world's water resources will also be developed. It is also to analyse policy options with a view to providing sound scientific advice to decision-makers and to managers concerned with water resources.

Assessments are to be conducted in 66 sub-regional areas within 9 megaregions. The environmental aspects to be assessed in the context of five main issues are: freshwater shortage, water pollution, habitat and biological community modification, fisheries, and global change.

GIWA's comprehensive strategic assessment is intended to evaluate the severity of contemporary environmental compromises and to project trends in conditions in the five primary subject areas. It is also intended to include causal-chain analyses within each sub-region for identified priorities among the five primary subject areas. These causal chain analyses are used to identify underlying socio-economic causes of environmental damage and threats that, in turn, enable evaluation of the potential modes of curative action or intervention. The results are to be made available for each sub-region and will also be assembled at megaregional and global levels.

It is critically important to identify the national programmes that HOTO needs to establish linkages. It is recommended that an inventory of these programmes be made and examined closely prior to generating an implementation plan for COOP.

11. IMPLEMENTATION PLANS AND PILOT PROJECTS

Initial emphasis must be on strengthening all relevant UN System activities. A major commitment needs to be made by all countries towards the effective implementation of GOOS. This includes the dedication of both human resources and financial support specifically to GOOS Module activities. In addition, governments must be encouraged to:

(a) Make existing data available;
(b) Distribute data products;
(c) Facilitate data exchange;
(d) Develop data networks;
(e) Support the collection of satellite and *in situ* data (i.e., time series);
(f) Support data collection by volunteer ships and data buoys; and
(g) Encourage person-to person networking.

Because all countries must be involved, substantial training and assistance must be provided to developing countries. Partnerships between developed and developing countries are to be encouraged. Close collaboration is also required among relevant international organizations for proper implementation. Most countries, for example, do not have access to, or capabilities for, using the large volume of remotely sensed data becoming available. The greatly increased availability of small, inexpensive computers will allow more users to manipulate data and prepare products. Training is needed in how to apply these kinds of data to local needs.

GOOS is to be based on the principle that all countries should meet certain commitments, according to their capabilities to fulfill such commitments, in the agreed global plan, so that all countries may benefit. The UNCED process established the following criteria for capacity building:

- The capacity needs to be developed nationally and in the long term to become self-sustaining;

- It needs to be based in the short term on international, regional, and bilateral collaboration to ensure accelerated development, technology transfer and economies of scale;

- It needs to be developed only as fast as it can be used effectively; and it requires sustained action over a long period.

11.1 PLANNING REQUIREMENTS FOR IMPLEMENTATION

Annex III provides an excellent and thoughtful planning process for the implementation of a HOTO for Canada. This is a draft only but the authors, Dr. Strain and Dr. Macdonald provide a rationale for what measurements are being made in Canada as well as what can be made? Which measurements are sustainable and integrated? Each country and basin will have to take these items into consideration and the Panel felt that this approach could and should be applied to any pilot programme.

11.2 HOTO PILOT PROJECTS

Two forms of HOTO Pilot project are recommended as vehicles to establish the reliability and validity of the HOTO Design Plan.

(a) those designed to test, validate and develop discrete parts of the research protocol and measurement sub-system; and,

(b) those designed to test the applicability of a fully integrated HOTO/GOOS monitoring and assessment system.

Recommended pilot projects will be carried out within a specific regional context prior to broader implementation. A single region is suggested for early pilot project testing. The Wider Caribbean Region (IOCARIBE) is considered an ideal focal point for early HOTO pilot testing. A discussion of relationships within the region is presented in Annex IV. The concentration of pilot efforts within a single regional context is viewed as a way to maximize the use of available resources and personnel and to minimize the influence of between region variabilities further enhancing the ability of these projects to provide critical lessons toward broader and global HOTO/GOOS implementation.

As regards testing of individual parts of the HOTO plan, both the Rapid Assessment of Marine Pollution (RAMP) protocol and Ocean and Human Health Protocol for Small Island States are viewed as providing the greatest value for early testing and pilot implementation. A more integrated approach to HOTO pilot implementation is characterized well in the Canadian example provided in Annex III.

11.2.1 Rapid Assessment of Marine Pollution (RAMP) Pilot Project Protocol

The general goals of the Rapid Assessment of Marine Pollution (RAMP) approach are to develop the integrated use of rapid, easy-to-use, and cost-effective biomarkers for the combined study of sub-lethal effects and organismal health in a broad range of coastal systems and to apply and validate these biomarkers within the context key HOTO analytes. The use of a RAMP protocol will be explicitly developed within a management context accounting for critical socio-economic factors. The proposed pilot project approach is detailed in Annex V.

11.2.2 Ocean and Human Health Pilot Project Protocol for Small Island States

This pilot project effort focuses on the need to build an integrated assessment and monitoring programme directed at an effective understanding of the relationship between ocean and human health. This pilot project will be directed at testing an integrated protocol within the context of a small island state. Specifically, project principals will, in concert with regional IOCARIBE scientific and management expertise, identify communities with a broad range of shown and suspected ocean and human health concerns. An initial and comprehensive diagnosis of the current situation will be conducted assessing a broad range of human health concerns, including those connected to natural toxin, contaminant and pathogenic effects. A monitoring system will be set up to better detect changes in health impacts related to ocean usage with monitoring results communicated in available, accessible and understandable forms to responsible managers and decision makers. Details of this proposed pilot project are contained in Annex VI.

ANNEX I

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ANNEX II

DETAILED RAMP DESCRIPTION AND METHODOLOGY

RAMP Procedures

The RAMP programme involves the integrated use of both chemical and biological indicators. Data is used in an evidenced-based approach to rank the relative impact of anthropogenic pollutants at sites within a region.

Chemical Markers

Immunoassay-based tests (ELISAs) provide an inexpensive, rapid and highly selective means of measuring specific chemical compounds. The method involves using antibodies that have been raised to specific types of chemical pollutants. Test kits are designed so that the intensity of a colour reaction diminishes when the antibody and chemical combine. The intensity of the colour is used to estimate the concentration of the contaminant in samples. The analyses can be run by relatively unskilled personnel, in the field, using simple equipment, and provide obvious advantages for environmental scientists in developing countries. Limited trials have proved of great interest and some environmental agencies are discussing incorporation of the techniques into screening programmes. The purpose of the chemistry element of the Brazilian RAMP pilot programme has been to evaluate the applicability of currently available test kits and to develop and refine complementary procedures such as utilizing solid phase extraction to improve detection capabilities. Intercomparisons have been made with more traditional chromatographic-mass spectrometric techniques. The choice of determinants amenable to detection by the rapid chemical analysis procedures is broad and thus the most relevant contaminants can be selected following surveys and discussions with scientists in the study region. PAHs, PCBs, dioxins, organochlorine and organophosphorous pesticides, selected herbicides and fungicides appear to be common environmental contaminants/pollutants of relevance. Water and sediment samples can provide information regarding the distribution and environmental concentrations of contaminants. In addition, immunoassays can also be performed on tissue fluids, haemolymph and urine samples to determine the concentrations of chemicals in organisms. These can then be related to biological effects (see below). Table 3 in the main report provides a graphical representation for which analytes can be measured by these methods.

Biological markers

The biomarker approach has been adopted for the detection of biological effects. Biomarkers are defined as "biochemical, cellular, physiological or behavioural variations that can be measured in tissue or body fluid samples, or at the level of whole organisms, that provide evidence of exposure to and/or effects of, one or more chemical pollutants (Depledge, 1994). The biomarker approach was developed originally to chart the exposure of organisms to contaminants. For example, exposure to organophosphate and carbamate pesticides is signaled by the inhibition of an enzyme (cholinesterase), which is involved in transmission of nerve impulses; exposure to certain trace metals is signaled by metal-binding protein induction, and exposure to a range of organics by induction of detoxification enzymes of the mono-oxygenase system. General toxicity is reflected in the onset of cellular pathology, which can be detected using the neutral red lysosomal assay (Lowe *et al.*, 1995). This involves incubating blood cells from molluscs or crustaceans with a neutral red dye. The dye becomes incorporated within vesicles (lysosomes) within the cells. The time taken for the dye to leak out of the lysosomes reflects the health of the cells (and the organism from which they were taken); the shorter the time, the more stressed the organism.

More recently, biomarkers have been used to detect and monitor ecologically significant effects such as changes in growth rate, reproductive output and the survival of offspring. The biomarkers used in the Brazilian RAMP programme are providing the means of detecting deterioration in the condition of biota at contaminated sites. Experience gained in this project has led to identification of additional rapid assays, which may be incorporated in future studies.

Future Development of RAMP

Following the encouraging results of the Brazilian pilot project, it is proposed that a more extensive suite of easy-to-use, inexpensive, chemical and biological markers be developed and validated for use in the rapid assessment of marine pollution (RAMP) in estuaries and coastal areas. Future programmes should screen for the presence of contaminants of concern and for responses and effects in biota. Concentrations of chemical contaminants will be determined in water, sediment and biota using appropriate immunoassay kits which have been validated through intercomparisons with more sophisticated analytical procedures (ICP/MS, GC-MS/MS, LC/MS). Biological responses and effects will be assessed by the procedures listed below in a range of estuarine or marine invertebrates and fish.

Biomarkers of the general condition of invertebrate key species

1. Cardiac activity in bivalve molluscs and decapod crustaceans – Heart rate provides a general indication of the metabolic status of mussels and crabs. The CAPMON technique (Depledge & Anderson, 1990) permits the non-invasive, continuous monitoring of cardiac activity using infrared sensors attached to the shell.

2. Lysosomal Neutral Red Dye Retention in the haemocytes of bivalve molluscs, crustaceans and fish. (Lowe *et al*., 1995). This assay provides an indication of lysosomal membrane stability that in turn reflects the health of the organism.

3. Immunotoxicity Assay. This assay measures the immunocompetence of haemocytes from invertebrates, reflecting both the extent of exposure to immunotoxins and the general well being of the test organism (Raftos & Hutchinson, 1995).

4. Apoptosis assay. Apoptosis (programmed cell death) refers to the morphological and biochemical alterations that occur in dying cells. In organisms exposed to toxicants and pathogens causing disease, the occurrence of apotoptic cells increases. The assay involves using 3 fluorescent dyes that bind to plasma membranes and nuclear membranes. Upon examination, normal cells appear green, apoptotic cells blue, and dead cells red (Piechotta *et. al*., 1999).

5. Defecation assay – a practical and robust surrogate measure of feeding for use with mysid shrimps. The assay involves collecting faecal pellets over a defined time period (16h). Faecal pellet production varies with pollutant exposure (Roast *et. al*., 2000).

Behavioural Biomarker Assays

The use of behavioural biomarker assays that are sensitive to pollutant exposure, are integrative and can provide early warning of adverse effects, especially when used in combination with biochemical and physiological biomarkers is currently being used more widely. When used in conjunction with new statistical procedures (Astley *et. al*., 1999) will allow the data collected from a given site to be inputted into a multi-dimensional scaling statistical programme to facilitate detection of pollution gradients and the identification of sites with similar characteristics. The following assays will be evaluated in future RAMP programmes: -

1. Computer-aided behavioural monitoring. This involves the use of a video tracking system-providing data that can be analyzed using purpose-written computer software. This generates a comprehensive, quantitative assessment of locomotor behaviour in crabs, which has been shown to change at low concentrations of contaminant exposure (Aagaard & Depledge, 1994).

2. Burrowing Behaviour Assay. This assay has been used extensively with amphipods placed on sediment, contaminated to different degrees with anthropogenic chemicals. Standard protocols employed by the OECD will be modified to permit the assay to be

used with bivalves and polychaetes to determine the influence of sediment contaminants on burrowing times and burrowing behaviour.

3. Starfish Righting Assay. Starfish that have been collected from sites contaminated to different extents with anthropogenic chemicals are placed on their dorsal surfaces and the time taken for righting to occur is noted. Previously it has been suggested that righting is delayed in animals from contaminated areas.

Biomarkers of specific classes of chemicals

1. Pesticides: Cholinesterase inhibition assay. A simple, colourimetric method for measuring cholinesterase inhibition in the heamolymph of crustaceans and molluscs (Lundebye *et al.*, 1997). This reflects the extent of exposure to, and effects of, organophosphorous and carbamate pesticides entering the marine environment principally from freshwater runoff and atmospheric deposition.

2. Hydrocarbons: PAH fluorescence assay. A simple fluorometric assay to detect pyrenes and other PAHs and metabolites, in urine and haemolymph samples of crabs and mussels respectively. This method is modified from Aas *et al*., (1998) and has recently been shown to be effective in limited field trials (Depledge & Watson, unpublished).

3. Tributyl tin and other endocrine disruptors: Assessment of imposex or intersex in gastropod molluscs (Matthiessen & Gibbs, 1998; Oehlmann, 1998) and crustaceans (Moore & Stevenson, 1991) in relation to endocrine disrupting chemicals.

4. Metals: Metal-binding protein assay. A colourimetric assay of metal-binding proteins in homogenized tissue preparations of crabs and molluscs. Metal-binding protein (especially metallothionein) concentrations are often increased in marine organisms exposed to elevated concentrations of various essential (Cu, Zn) and non-essential Cd, Hg) trace metals (Pedersen *et al.,* 1997).

5. Genotoxins: Micronucleii assay. This assay indicates exposure to genotoxins. It involves scoring cells with one or several cytoplasmic micronucleii of reduced size associated with the main cellular nucleus. These micronucleii are formed at the end of cell division and provide evidence of DNA breakage and spindle dysfunction during cell division resulting from exposure to genotoxic agents (Mersch & Beauvais, 1997). It has been used extensively in mussels and fish but potentially has much wider application.

6. Pathogens. Detection of microbial pathogens. Colilert TM and Enterolert TM are rapid test kits for the detection of colliform bacteria and *Enterococci* that can be used in monitoring programmes.

7. Sewage. Rapid, spectrophotometric measurements of ammonia.

It is stressed that the above procedures have been selected primarily with regard to their ease of use, low cost and relevance to known environmental problems. In some cases, other procedures are available and might provide more accurate information as to the nature and extent of pollution at a particular site. However, such procedures are more expensive, more time consuming, require more highly trained personnel, and higher quality analytical facilities than are likely to be generally available within the HOTO programme. They are thus impractical to include in a rapid assessment programme.

The approach described above has been applied in modified forms in different circumstances, for example, in the Venice lagoons (Lowe *et al.,* 1995), Otago Harbour, New Zealand and in the Black Sea

Mussel Watch programme (UNEP).

ANNEX III

CANADIAN REQUIREMENTS FOR AN OBSERVING SYSTEM ON THE HEALTH OF THE OCEANS

A discussion paper prepared by P.M. Strain and R.W. MacDonald.

This paper was written as a draft under revision. All comments are welcome and should be sent to the attention of strainp@mar.dfo-mpo.gc.ca

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This discussion paper is one in a series of draft documents that ideally will evolve into a detailed plan for the implementation of a DFO observing system to monitor the health of Canada's oceans and of Canadian waters in the Great Lakes.

The present draft:

- presents background concepts ;
- defines critical terms ;
- discusses the role of research in the development and evolution of a health of the oceans (HOTO) monitoring strategy ;
- begins the process of defining Canadian requirements for ocean monitoring by listing potential threats to the health of Canada's waters, with a preliminary assessment of the severity of each threat ;
- lists existing monitoring programmes, and identifies research programmes that are candidates for conversion to monitoring programmes ;
- discusses which Canadian monitoring activities could be included in Canada's contribution to the international Global Ocean Observing System (GOOS) Health of the Oceans (HOTO) module.

This preliminary document is being distributed to elicit your input to:

- ensure that all potential threats to HOTO have been identified ;
- comment on the priorities we have assigned to threats ;
- identify suitable means for monitoring high priority threats to HOTO ;
- discuss how the details of a monitoring programme might be specified.

In the longer term, there will be a need on an ongoing basis to develop, assess and revise priorities for monitoring programmes, design detailed monitoring specifications, coordinate with other agencies, interact with the research community and lobby for the resources and long-term commitment necessary to operate the programme.

Introduction

The purpose of this paper is to outline Canadian requirements for ocean monitoring related to the health of the oceans (HOTO). Over time, it is intended that this discussion paper will evolve into a set of detailed specifications for a HOTO monitoring programme. The initial impetus for this planning stemmed from an initiative to design a Canadian ocean monitoring programme to meet international obligations and to contribute to international ocean monitoring programmes. Despite this international outlook, our goal is to define a HOTO monitoring programme from a Canadian viewpoint first, and only then identify which components of this programme could contribute to the international HOTO module of the Global Ocean Observing System (GOOS), based on the perspectives developed by the international GOOS HOTO Panel. However, we will take advantage of some of the groundwork developed by the GOOS HOTO Panel.

The GOOS HOTO Panel has defined *health of the oceans* as follows:

> *The term "Health of the Oceans" is operationally defined as … the condition of the marine environment from the perspective of adverse effects caused by anthropogenic activities, in particular habitat destruction, changed sedimentation rates and the mobilization of contaminants. Such condition refers to the contemporary state of the ocean, prevailing trends and the prognosis for improvement or deterioration in its quality.*

We will expand this definition to include the fresh waters in the Great Lakes. Any reference to oceans is meant to include the Great Lakes. The term *stress* will be used to include the impacts of habitat destruction, altered sedimentation rates and contaminant inputs.

In their strategic plan, the GOOS HOTO Panel lists possible consequences of habitat destruction and contaminant release in very general terms. This analysis of threats to HOTO is followed by a discussion of possible chemical, biochemical and physical analytes and their relative merits (IOC, 1996). In a subsequent report (IOC, 1997), the Panel presents a number of prototype '**Regional Blueprints and Pilot Projects …**' for HOTO monitoring in different areas like the Red Sea, the Black Sea and the Arctic marine environment. An evaluation of significant threats to HOTO in each region is again the first step taken in these prototype plans (and is the first step we will adopt in determining Canadian requirements). These plans also accept that it is neither possible nor necessary to monitor all contaminants or their impacts in all regions. Furthermore, we cannot with certainty predict future threats to oceans.

Monitoring can be defined as "*a process of measuring continuously or at intervals a condition with the intention of keeping it within prescribed limits*." This definition implies three components to monitoring: the measurements themselves, an objective for the monitoring, and an action that is triggered when the measurements stray outside an acceptable range. In the HOTO context, the overall objective is to identify a loss in environmental quality and the response is to control its cause, if possible. To achieve this overall goal, individual components of a monitoring programme may have somewhat different, but related objectives (Table 1). The sampling design (number, location, sample type, analytical scheme) for each monitoring activity must be defined by its objectives.

As a warning system, monitoring should alert us to trends (or events) of deterioration and provide a basis by which to judge recovery following mitigative action. For the monitoring to be scientifically valid requires that: 1) the questions asked are well formulated; 2) the monitoring has a statistically sound design to provide confident, unequivocal answers and 3) natural processes are sufficiently well understood that we can design efficient monitoring that is not confounded by natural variations. **The implicit assumption of this approach is that monitoring should be designed so as to alert us to any significant threat to the ocean.**

We must recognize at the outset that our knowledge of natural processes (seasonality, interannual and spatial variability, etc.) and the environmental threat posed by specific stresses (and the interactions between stresses) may not be sufficient to design adequate monitoring programmes at this time. There may be significant threats to HOTO for which existing monitoring tools are either not completely satisfactory or not available. This situation reflects both the current knowledge of the impacts of contaminants and other anthropogenic stresses and the state of development of indicators of ecosystem health and environmental quality. Furthermore, scientific advances will provide new methods or approaches and room must be left to incorporate these into monitoring programmes or even to alter the programmes where appropriate. A realistic monitoring programme must start by identifying and prioritizing threats to HOTO, anticipating the likely environmental manifestations of chemical or physical stress, and estimating natural variability and seasonality before initiating measurements.

It may be useful to divide the tasks of monitoring and managing the health of the oceans into the following sub-components (Figure 1):

- An assessment of anthropogenic threats to HOTO (inputs of contaminants, habitat destruction, increased sedimentation rates) on a region by region basis.
- A determination of present, future and past trends in contaminant levels, biological effects etc. (monitoring and retrospective analyses).
- The assignment of cause(s) for those trends.
- An outline of the action required to stop or reverse those trends.

At present, the identification of threats to HOTO in different regions is straightforward, prioritising them is somewhat more difficult, but both can be done in principle (see **Monitoring Requirements**, below). Designing new contaminant monitoring programmes or building onto existing networks (e.g. mussel watch) is also feasible, but careful planning and ongoing evaluation of such programmes would be required to ensure that they meet the criteria for scientific rigour outlined above. Establishing historical trends in contaminants (e.g. retrospective analyses from sediment cores) has already been done in some cases and could be extended to new areas or to different contaminants provided they are recorded in sediments or other environmental compartments. Designing monitoring programmes to observe ecosystem effects or establishing historical trends in ecosystem response to stress (e.g. loss of biodiversity, increased toxic algal blooms, eutrophication) is much more difficult than observing contaminant trends and will require research. Monitoring "effects" becomes increasingly more difficult as one moves from gross, local effects on individuals (fish kills) to large scale, subtle effects on whole ecosystems (loss of diversity, change in species distribution, increase in biomass). Finally, assigning cause for large-scale ecosystem effects (i.e. cumulative impacts) will be the greatest challenge for managing the health of the oceans and will require inputs from both monitoring and research programmes.

For the above reasons, the global HOTO programme will be the most evolutionary of all GOOS programmes due partly to the need in HOTO to measure both *impacts* and *properties* and partly to the intention to use the results of monitoring to both design mitigative action and assess its success. Since environmental stress can be manifested at every level of biological organisation, from the cellular to the whole ecosystem, HOTO monitoring must rely on biological indicators (e.g. diversity, scope for growth) as well as direct measures of causative agents (contaminants, nutrients, salinity, temperature, etc.). Indeed, the HOTO Strategic plan (IOC, 1996) calls for the development and use of indicators of biological distress. Biological indicators are presently not at all well developed and research on this topic will be required. Some such indicators can integrate exposures across different contaminants and in space and time. Such integrating measures will be essential if HOTO monitoring is to be made a manageable task. As knowledge increases, better indicators will undoubtedly emerge.

The scope of HOTO monitoring is more regional than that of ocean climate monitoring. In climate modelling, there are obvious requirements for inter-comparable data on global scales whereas most threats to HOTO are regional. The value in the international GOOS HOTO programme will be found in being able to compare trends in different regions and to seek common causative agents rather than in having global data sets. In this context, monitoring programmes that do not strictly adhere to the GOOS principles can still provide valuable contributions to the international HOTO programme.

Finally, we must acknowledge that many changes in the health of coastal oceans have already taken place and, therefore, we have already lost the "*baseline*" (i.e. the natural healthy state of the ocean) needed to assess the present and future extent of environmental degradation. Recovering this historical context through the use of retrospective data sets (e.g., dated sediment cores, records of coastal emissions from point sources, etc.) will be an important component of HOTO.

We must also recognize that we cannot presently monitor every important variable/ contaminant that will ever be a concern. Archives of biological tissue, sediment and other material provide a resource which can be interrogated later for trends in contaminants or ecosystem dynamics. Such archives should also become important components of a HOTO monitoring strategy. It is well known that these archives can be used to assess bioaccumulating contaminants and even for the identification of trophic changes. It is presently unrealistic to expect such archived material to provide hindcast information on the effects of environmental stress - however, new tools may allow such insight. Similarly, new techniques may allow us to extract these kinds of trends from sediment cores or other ecosystem recorders.

Scientific Research and HOTO Monitoring

As discussed above, the research community will play a crucial role in the design of effective HOTO monitoring strategies including especially the selection and development of suitable biological indicators. The detailed specifications required for monitoring activities (parameters to be measured, locations, frequencies etc.), must be based on sound scientific criteria. Researchers must also be involved in the regular review of monitoring programmes, to ensure that they are meeting their objectives and that the design of the programmes incorporates new knowledge on the sources and nature of environmental stress, the responses of the ecosystem to such stress and new developments in monitoring techniques.

In addition to their role in the design of monitoring programmes, researchers will also be users of the data produced by monitoring. Properly designed monitoring will provide data that is useful for the understanding of the impacts of stresses and ecosystem responses to those stresses. In addition, the process of designing and implementing monitoring programmes will undoubtedly identify important gaps in both the understanding of stresses and available monitoring techniques that are appropriate topics for research programmes.

There will also be occasions when the research community must respond to concerns raised by monitoring programmes when it becomes necessary to identify the cause of environmental deterioration indicated by generic measures of environmental quality. In such cases, it may be necessary to undertake short-term measurement programmes using techniques that are sensitive to specific contaminants or other stresses. In this context, it may be useful to distinguish between long-term HOTO monitoring and short-term research done in response to HOTO management needs or environmental crises.

Table1 is a schematic of some of the relationships between research and the components of HOTO monitoring.

Monitoring Requirements

Table 2 lists potential threats to the health of the ocean in Canada. The columns in the table include the source of the threat, the nature of the threat, what impacts are of potential concern (Element at Risk), whether technology is available to monitor the threat (Tech. Avail.), whether component(s) of GOOS within DFO or other organizations would be responsible for the monitoring (Jurisdiction), whether any monitoring of this threat is currently underway, and a tentative, qualitative assessment of the significance of the threat to Atlantic (Atl), Pacific (Pac), Arctic (Arc) and Great Lakes (GL) waters. In this assessment, threats to HOTO are ranked both by severity (the first letter in each assessment: H = high, L = low, or 0 = negligible) and by scale, i.e. the extent of the threat in time and space (the second letter in the assessment: W = widespread, L = local). Any assessment of threats to HOTO in the Arctic must balance the intensity of the environmental stress, which will often be much lower than in southern areas, with the capacity of the Arctic ecosystem to withstand such stress, which will also generally be much lower than in more populated regions.

The preliminary analysis of threats to HOTO in Table 2 does not specify how monitoring of these threats could or should be done. This monitoring could take several forms, including the measurement of impacts (e.g. contaminant residues in human food, eutrophication status of an inlet), the measurement of contaminant inputs and/or distributions, or the measurement of proxy variables related to the threat. In practice, more than one type of measurement may be necessary in some cases. For example, the measurement of contaminants in food fish might be necessary to safeguard the food supply while measurement of contaminant inputs or ambient levels in water or sediments might be necessary to understand trends in the contaminant levels in the fish.

The first entry in the table is for non-point sources of contaminants. In effect, this entry is a catchall for any source of contaminant not explicitly listed later in the table. In southern waters, these sources are predominantly local, delivered to the ocean through direct inputs, rivers, other land drainage, and short range atmospheric transport. In northern waters, the delivery of these contaminants is predominantly through the long range transport of air, water and ice. Close coordination between climate monitoring and HOTO monitoring will be required when long range transport is important so that the significance of changes in transport pathways, whether due to natural variations or climate change, can be properly assessed. Small quantities of contaminants delivered through long-range transport are of special concern in the Arctic because of the long marine food chain and the heavy reliance of indigenous people on local food. Non-point source pollution may be the most insidious of the significant threats to HOTO: impacts are cumulative, deterioration in environmental quality is gradual, and defining cause effect relationships is very difficult. Generic measures of environmental quality will be essential for monitoring this threat.

Although it is a different kind of monitoring activity, the construction and maintenance of an inventory of contaminant emissions would be a very valuable asset for the management of the health of the oceans. This information would be useful for interpreting trends seen in monitoring data, and is an important component in describing the exposure fields for contaminants in the aquatic environment.

Ongoing Monitoring Programmes

Table 3 lists ongoing HOTO-related monitoring activities in Canada. We have been able to identify only six programmes related to HOTO that involves DFO and are truly monitoring programmes. Three of the five in the Atlantic zone are facing cutbacks due to budget pressures, and the data associated with the aquaculture monitoring may not be freely available. Areal coverage is sparse. There are no active DFO HOTO monitoring programmes in the Arctic, and only two in the Pacific zone. In other words, very few of the potential threats to HOTO are the subject of active DFO monitoring programmes. Because there is so little HOTO monitoring currently underway, we have included three research programmes in the table that could contribute to monitoring requirements, or are potential candidates for conversion to monitoring programmes. Essentially, we will have to start from scratch to develop a Canadian HOTO programme.

Canadian Contributions to the International GOOS HOTO Programme

The last columns in Table 2 and Table 3 indicate whether real or potential monitoring programmes could be part of the Canadian contribution to the HOTO module of the international GOOS programme. Most of the identified threats to HOTO in Canada occur in many other parts of the world, and would be of general interest to the international environmental community. However, one requirement for participation in international GOOS is that data be made freely available. There are serious sensitivity concerns about some data that might be produced by HOTO programmes, most notably when such measurements affect the marketability of seafood. From the Canadian perspective, which programmes can be part of our contribution to international GOOS will mostly be based on this criterion.

The design principles of GOOS (IOC, 1998) call for indefinite commitments to the monitoring of specific ocean variables in order to meet well-defined objectives. Canadian requirements may sometimes make it necessary to monitor parameters whose link to a specific threat is either less direct or less well known than desirable, because such measurements are the best currently available. Over time, such parameters will hopefully be replaced by more reliable measures of the threat. In the meantime, however, since such measures do not meet the formal GOOS design principles, it might be necessary to exclude such monitoring from the international HOTO programme.

Requirements for Coordination with Other Programmes and Agencies

Clearly, there is considerable overlap in the issues being addressed by the DFO groups designing monitoring programmes for issues related to the health of the oceans (HOTO), living marine resources (LMR) and coastal (C-GOOS) modules of GOOS. Close collaboration between these groups is essential. HOTO monitoring is also very closely related to a number of other DFO initiatives, especially those that are designing policy and programmes to meet DFO's obligations under the Canada Oceans Act for Marine Environmental Health, Integrated Coastal Zone Management and Marine Protected Areas. There will also be a need to coordinate the planning and implementation of a monitoring strategy with the other federal departments with a stake in HOTO issues (including DOE, HC, DIAND, NRCan). Provincial, territorial and aboriginal governments will also be directly involved in HOTO issues. The design of a DFO monitoring programme must consider the needs and programmes of these other agencies in order to minimize duplication and maximize the return on resources.

Conclusions

This discussion paper has presented a very preliminary analysis of threats to the health of Canada's ocean waters. Translating this threat analysis into a set of priorities for HOTO monitoring will require consultation with appropriate experts to make the list of threats as comprehensive as possible and the assignment of risks as correct as possible. It will also require the evaluation of potential monitoring strategies for high-risk threats. In some cases, monitoring will not be appropriate simply because suitable tools are not available, but will have to wait for the development of new knowledge and/or monitoring tools from the research community. It will also be up to the research community to identify contaminants or activities that present new threats to HOTO.

We are at a very early stage in the development of a HOTO monitoring strategy. Successful development and implementation of this strategy will require an ongoing re-evaluation of threats to HOTO, monitoring possibilities, and priorities. Successful implementation will also require the effort necessary to coordinate the efforts of the many agencies with a responsibility for health of the oceans in Canada and the commitment of the resources necessary to do the job.

Abbreviations

CFIA	Canadian Food Inspection Agency
C-GOOS	Coastal GOOS
Cs	Cesium
EDC	Endocrine Disrupter Chemicals
GOOS	Global Ocean Observing System
Hg	Mercury
HOTO	Health of the Oceans
LMR	Living Marine Resources GOOS
OC	Organochlorine compounds
PAH	Polycyclic Aromatic Hydrocarbons
PCDD/F	Polychlorodibenzodioxins/furans
PSP	Paralytic shellfish poisoning
UV	Ultraviolet

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Table 1. Possible Monitoring Objectives

Objective	**Examples / Comments**
Determine temporal and spatial trends (provide warning signals)	e.g. Contaminants, harmful algal blooms, UV radiation at ground
Determine temporal cycles	e.g. Productivity, O2 in bottom water, river flow, tide
Evaluate success of remediation strategies	
Provide model input	Cycles / trends
Validate models	Check model output against observed cycles / trends
Improve monitoring designs	Requires constant reassessment of monitoring programme
Close / reopen fisheries (human health concerns)	Shellfish harvest (E. coli; PSP), Belledune (Cd), Howe Sound crabs and shrimps (PCDD/F)
Suspend fishing to protect fish	Fish escapement on the Fraser
Verify compliance	Effluent outflow, contaminant loadings
Enforce, prosecute violations	Violations of permitted disposal
Assign cause of environmental deterioration	Timing, location, correlation with industry

Table 2. Assessment of Threats to the Health of the Ocean in Canadian Waters (1st letter: severity (H = high, L = low); 2nd letter: extent (W = widespread, L = local)											
Source	**Threat**	**Element at Risk**	**Tech. Avail.**	**Jurisdiction**	**Current Monitoring Status**	**Atl**	**Pac**	**Arc**	**GL**	**Comments**	**Int'l HOTO**
Non-point sources (diffuse inputs, long-range transport)	OC's, PAH's, other synthetic organic chemicals, trace metals, persistent plastics	Human food supply, aquatic biota esp. higher aquatic organisms, birds	Some	DFO/HOTO DIAND CFIA ?	Some (Atl), but future funding is in jeopardy	H/ W	H/ W	H/W	H/W	Link between concentrations of contaminants and impacts not always clear.	Yes, some data sensitive
Municipal / industrial discharges	All contaminants, nutrients, heat	Ecosystem	Some	DFO/HOTO , DOE	Some	H/ W	H/ W	L/L	H/W	Some compliance monitoring	Yes, some data sensitive
Bottom trawling	Physical habitat destruction	Benthic habitat and organisms	Yes, for direct impacts	DFO/HOTO	None	H/ W	H/ W	0	0	Underlying research has been done, monitoring programme could be developed Widespread changes in benthic habitat could have general impacts on ecosystem structure	Yes

Table 2. Assessment of Threats to the Health of the Ocean in Canadian Waters
(1st letter: severity (H = high, L = low); 2nd letter: extent (W = widespread, L = local)

Source	**Threat**	**Element at Risk**	**Tech. Avail.**	**Jurisdiction**	**Current Monitoring Status**	**Atl**	**Pac**	**Arc**	**GL**	**Comments**	**Int'l HOTO**
Sewage and other organic wastes (municipal discharges)	Eutrophication	Widespread ecosystem changes, fish kills etc	Yes	DFO/HOTO	None	H/L	H/W	L/L	H/W		Yes
Sewage	Bacteria / viruses	Human food supply	Yes	CFIA, DOE DFO/HOTO	Yes (DOE)	H/L	H/W	H/L	H/W		Sensitive data
Nutrient inputs (agriculture, mining etc)	Changes in community structure, eutrophication	Ecosystem	Yes	DFO/HOTO	None	H/L	H/W	H/L	H/W	Arctic inputs may be particularly sensitive to climate variations or change	Yes
Harmful algal blooms	Algal toxins	Higher aquatic organisms, ecosystem changes	Yes	DFO/HOTO LMR	Yes (Atl), but cutbacks expected	H/L	H/L	0	?	Widespread international interest in these results	Yes
Harmful algal blooms	Algal toxins	Human food supply	Yes	CFIA	Yes	H/L	H/L	0	?	Widespread international interest in these results	Data sensitive

Table 2. Assessment of Threats to the Health of the Ocean in Canadian Waters
(1^{st} letter: severity (H = high, L = low); 2^{nd} letter: extent (W = widespread, L = local)

Source	Threat	Element at Risk	Tech. Avail.	Jurisdiction	Current Monitoring Status	Atl	Pac	Arc	GL	Comments	Int'l HOTO
Nuclear power generation	Artificial radionuclides	Aquatic and terrestrial ecosystem, human health	Yes	DFO/HOTO	Yes	H/L	0	0	H/W ?		Yes
Aquaculture	Organic wastes, nutrients, pharmaceuticals, introduction of exotic species	Inlet scale ecosystem	Some	DFO/HOTO Provinces, industry ?	Some (Atl)	H/L	H/ W ?	0	0	Compliance monitoring for benthic impacts on cage footprints. Monitoring tools for long range effects not available	Yes, but data may not be available
Pulp and paper industry	Multiple contaminants incl. dioxins & other EDC's	Aquatic organisms, human food supply	Some	DFO/HOTO	None	H/ W	H/ W	0	H/W	Significance of threat unknown. Monitoring of contaminant levels may not be adequate monitoring of threat	Yes, but some sensitive data

Table 2. Assessment of Threats to the Health of the Ocean in Canadian Waters
(1st letter: severity (H = high, L = low); 2nd letter: extent (W = widespread, L = local)

Source	Threat	Element at Risk	Tech. Avail.	Jurisdiction	Current Monitoring Status	Atl	Pac	Arc	GL	Comments	Int'l HOTO
Offshore oil/gas exploration/ production	Physical habitat destruction	Local benthic habitat	Yes	DFO/HOTO Fed/Prov Petroleum Boards ?	Some compliance monitoring	H/L	0	H/L	0	Episodic, only long lived production platforms suitable candidates for long-term monitoring	Yes, but some sensitive data
Offshore oil/gas exploration/ production	Hydrocarbon contamination	Pelagic and benthic organisms, tainting of seafood	Yes	DFO/HOTO Fed/Prov Petroleum Bd. ?	Some compliance monitoring	H/L	0	H/L	0	Episodic – only long lived production platforms suitable candidates for long-term monitoring	Yes, but some sensitive data
Coastal engineering projects	Physical habitat destruction	Sensitive nearshore habitats	Yes	DFO/HOTO or C-GOOS	None	H/ W	H/ W	L/L	?	Mapping of habitat types could be adequate monitoring	Yes
Harbour dredging	Physical habitat destruction, contaminant release	Local benthic habitat	Yes	DFO/HOTO or C-GOOS	Some compliance monitoring	L/L	L/L	0	H/W ?		No

Table 2. Assessment of Threats to the Health of the Ocean in Canadian Waters
(1st letter: severity (H = high, L = low); 2nd letter: extent (W = widespread, L = local)

Source	Threat	Element at Risk	Tech. Avail.	Jurisdiction	Current Monitoring Status	Atl	Pac	Arc	GL	Comments	Int'l HOTO
Mine tailings	Physical habitat destruction, metal contamination	Local benthic habitat	Yes	DFO/HOTO or C-GOOS	None	L/L	H/L	H/L	?		Yes
Acid mine drainage	Trace metals	Aquatic biota, food supply	Yes	DFO/HOTO or C-GOOS	None	L/L	H/L	L/L	?		
Pollution of the stratosphere	Ozone depletion: increase in UV B radiation	Surface plankton community	?	DFO/HOTO or DFO/LMR	None	L/ W	L/W	H/W	L/W		Yes
Climate change	Sea-level rise	Changes in nearshore habitat	Yes	DFO/HOTO C-GOOS	None	L/ W	L/L	H/W	0		Yes
Anti-fouling paints	Tributyltin fluoride and derivatives	Molluscs and possibly other aquatic biota	Yes	DFO/HOTO	None	?	?	0	H/W		Yes
Ballast water discharges	Introduction of exotic species, pathogens	Ecosystem structure, human health	Some	DFO/HOTO or LMR, HC	None	?	?	?	H/W		Yes

Table 2. Assessment of Threats to the Health of the Ocean in Canadian Waters
(1st letter: severity (H = high, L = low); 2nd letter: extent (W = widespread, L = local)

Source	**Threat**	**Element at Risk**	**Tech. Avail.**	**Jurisdiction**	**Current Monitoring Status**	**Atl**	**Pac**	**Arc**	**GL**	**Comments**	**Int'l HOTO**
Oil industry, offshore mining etc	Noise	Marine mammals	Yes	DFO/HOTO, DOE, DIAND	Some	H/L	H/L	L/L	0	Widespread concern, threat not well understood	Yes

Table 3. Active Monitoring Programmes related to the Health of the Oceans					
Monitoring Programme	**Zone**	**Analytes**	**Matrix**	**Comments**	**Int'l HOTO**
True monitoring programmes:					
Phytoplankton Monitoring Programme	Atl	Phytoplankton species, nutrients, hydrography		Long time series for algal components (50 yr. +). Funding of Nova Scotia component is in jeopardy	Yes
Point Lepreau Environmental Monitoring Programme	Atl	Tritium, ^{137}Cs, other artificial radionuclides	Water vapour, aerosols, plants, seawater, sediments	This programme has been operational for 20 yr. Has detected changes in tritium levels during reactor's lifetime, fallout from Chernobyl	Yes
Gulf of Maine Mussel Watch Programme	Atl	Organochlorines, dioxins/furans, trace metals and PAH's	Mussels	Programme was originally designed with a 9 yr. lifetime (to 2000). Continuation of the programme after that time is in doubt	Yes
Monitoring of Aquaculture Operations in the Bay of Fundy	Atl	Physical habitat destruction, benthic impacts		Programme managed by provincial authority, data belongs to industry	No, data sensitive, proprietary
Pulp Mill Environmental Effects Monitoring	Pac	Dioxins, furans		*Ad hoc* programme, expected to end in the short term	No
Closures of shellfish harvesting areas	Atl, Pac	Bacterial/viral contamination, algal toxins		Areas are closed to protect consumers, but it may be possible to use trends in the extent of closures as a monitoring tool	Data sensitive

Table 3. Active Monitoring Programmes related to the Health of the Oceans

Monitoring Programme	**Zone**	**Analytes**	**Matrix**	**Comments**	**Int'l HOTO**
Monitoring currently done as part of research programmes:					
Organochlorine levels in the marine food web of the southern Gulf of St. Lawrence	Atl	Organochlorines	Various plankton fractions, finfish	A 20 yr. time series exists for these measurements. A candidate for conversion to a monitoring programme	Yes, but data on food fish may be sensitive
Contaminants in biota in the St. Lawrence Estuary, Saguenay Fjord and Gulf of St. Lawrence	Atl	Trace metals, organochlorines	Crustaceans, finfish, marine mammals, sediments	Times series for a number of contaminants in various biota have been developed through research programmes. A candidate for conversion to a monitoring programme	Yes, but data on seafood may be sensitive
Contaminants in sediment cores	Atl, Pac	Trace metals, organochlorines, radionuclides	Dated sediment cores	Histories of contaminant fluxes can be reconstructed from dated sediment cores	Yes

ANNEX IV

REGIONAL CONTEXT FOR HOTO PILOT PROJECT IMPLEMENTATION THE WIDER CARIBBEAN REGION (IOCARIBE)

It is suggested that the IOCARIBE regional environment provides an excellent opportunity for early testing of both forms of HOTO pilot project protocols. It provides a broad diversity of ecosystem types, environmental degradation challenges, existing scientific and management infrastructure and is the focus of existing IOC programme efforts. With appropriate testing of existing HOTO protocols, results from regional pilot projects would allow for a broader international implementation of the HOTO strategic plan.

The IOCARIBE is a region where the problems of ecological fragility, the close interdependence of economic and ecological factors, and the vulnerability to natural hazards require close and active collaboration between member states.

National economies are heavily dependent on a wide range of marine-based economic activities including tourism, export agriculture, mineral extraction, and fisheries. Development pressures and acute concerns over ecological and associated public health risks are themes which cut across national boundaries and have been the subject of the type of regional action upon which HOTO/GOOS projects can build.

Description of the Physical Environment

The wider Caribbean region encompasses an area of about 4.31×10^6 km^2. Within this vast regional area, the Gulf of Mexico constitutes a major ecosystem as a semi-enclosed basin with an area of 1.5×10^6 km^2, a mean water depth of 1500 m and an estimated volume of 2.3×10^6 km^3.

It is bounded by a continuous landmass along its southern and western margins, whereas its northern and eastern margins are limited by the Bahamian Chain and the greater and lesser Antilles. The bathymetry shows a series of physiographic provinces with depths varying from 4100 to 7100 m. In the major body, there are 3 physiographic provinces: The Grenada Basin to the west of leeward and windward islands, the Venezuelan Basin between Venezuela and the southern shores of the Dominican Republic and Puerto Rico, and the Colombian Basin in the west, all bordered by sills of different depths.

The hydrography is dominated by the flow of the North Equatorial Current and to a lesser extent near Trinidad and Tobago the circulation is characterized by inflow from various passages in the line of islands to the north and east, together with an almost constant wind stress. Therefore, the flow is from east to west, and the core of the flow may be traced to its exit at the Yucatan Strait (Wust, 1964). The coastal population of 37 states and territories has been estimated in more than 60 million inhabitants. Most of the countries are classified as “developing”; however, their state of development varies considerably. Some have economies based essentially on the tourist trade, cash crop agriculture and extractive industries, while others have well-developed industrial economies.

Because of significant regional differences, fisheries resources vary from relative abundance along the continental shelves of the Gulf of Mexico, Central America and Northern South America to reduced catches in the coastal areas of the insular Caribbean. However, the total yield recorded in 1998 was estimated at 2.5×10^6 tons yr^{-1}, or about 3 % of the world’s catch.

Value of Monitoring and Assessment to Critical Socio-economic Factors

Importantly, the IOCARIBE is an area where there exists a strong baseline understanding of the level and effect of critical HOTO analytes. This baseline understanding is viewed as an essential in the design and location of the proposed pilot projects. A brief characterization of these themes within the IOCARIBE region includes:

1. Sewage

Marine pollution resulting from the disposal of domestic wastes in coastal areas is the most common problem in the wider Caribbean Region and it is associated with poor or nonexistent sewage treatment plants. Sewage discharges occur via rivers, streams or via short outfalls into coastal areas. In some locations, sewage pollution has already resulted in potentially hazardous conditions for human health through direct contact and the consumption of contaminated seafood.

2. Disposal of solid matter (litter)

Marine debris in the Wider Caribbean comes from a wide variety of major sources; merchant shipping, commercial fishing, offshore oil development, tourism ships and solid waste disposal practices on land. Significant amounts are generated within the region, but the North Atlantic also contributes heavily to the debris load.

There is no information available regarding the quantification of marine debris in bays and estuaries in the Caribbean Sea even though these areas are viewed as being particularly sensitive to debris accumulation. The practice of using rivers and creeks as dumping sites is widespread.

3. Disposal of urban and industrial waste waters

Problems related to the disposal of sewage and industrial waste discharge are increasing in the Caribbean. Data on location and magnitude of coastal contamination can be drawn from NOAA's National Coastal Pollution Discharge Inventory Programme and from data generated by the UNEP/CARICOU/PAHO study by Archer (1984). Identified sources of agricultural and industrial inputs include sugar cane and molasses refining, distilleries, dairy production, poultry and fish processing, breweries and oil refineries, among others.

4. Oil

The Caribbean region is potentially one of the largest oil producing areas in the world. About $5{\times}10^6$ barrels of oil are transported through the area every day creating intense tanker traffic. Tanker movements through restricted channels and in the vicinity of industrial ports accentuate the possibilities of accidents. Oil is a commonly found contaminant in the region and its impacts on coastal ecosystems and recreational beaches are well documented. One of the major problems caused by oil pollution has been the accumulation of tar on tourist beaches.

Within the region, the 1978 IXTOC-I well blowout and subsequent oil spill remained uncontrolled for almost 290 days. The accident resulted in the spill of approximately half-million metric tons of crude oil introduced in the Gulf of Mexico waters.

5. Urbanization and Tourism

There is growing evidence that pollution in coastal waters is accelerating in the region as urbanization and tourism overtakes the capacity of existing municipal infrastructures. The input of nutrients via domestic wastes has given rise to sustained harmful algal blooms (HAB) in some estuaries and semi-enclosed areas of the region, thus jeopardizing public health.

The potential for coastal ecosystem deterioration due to "coastal eutrophication" has been heightened by the increase of population and tourism activities.

6. Agriculture

Of paramount importance in the Caribbean region are the agricultural activities mainly related to cash crops such as sugar cane and banana plantations, which use large quantities of pesticides. Also, the dispersion of DDT has been a common practice in the area, mainly related to control of malaria making the Caribbean a region with increasing use of organo-chemicals and fertilizers.

Regional Collaboration

The region is host to a broad range and number of existing regional projects on which a HOTO pilot project could build and extend. They include:

- CARICOMP – Caribbean Coastal Marine Productivity
- CEPNET – Caribbean Environmental Programme– Information Management Network
- CFRAMP – Caribbean Fisheries Resources Assessment and Measurement Programme
- GLOSS - Global Ocean Sea Level Observation System
- HACA – Harmful Algae in the Caribbean
- IASI – The Intra – Americas Sea Initiative
- CPACC – Caribbean Planning for Adaptation to Global Climate Changes

In addition, several other national, regional and global programmes may contribute data and information relevant to HOTO pilot projects:

- Global Oceanographic Data Archaeology and Rescue Project (GODAR) IOCARIBE
- Regional Centre of Excellence in Integrated management of Coastal Zones (MIZC) UNEP – CUBS
- Global Ocean Ecosystems Dynamics (GLOBEC)
- Joint Global Ocean Flux Study (JGOFS)
- Land – Ocean Interaction in the Coastal Zone (LOICZ)

Regional Capacity and Unmet Needs

The implementation of these projects and programmes have built the scientific, technical and management capacity in many parts of the region necessary for the conduct of HOTO pilot projects. However, these support capabilities vary broadly in the region. For example, in a few countries, such as Trinidad-Tobago, Venezuela, Costa Rica, Colombia, Cuba, Puerto Rico and Mexico, capabilities are viewed as relatively advanced. In other parts of the region related capacity building has been relatively less successful. Nevertheless, the IOCARIBE area remains a regional environment that is viewed as well suited as a region where a directed HOTO pilot project has a high probability of finding both the necessary and sufficient institutional support for successful implementation.

ANNEX V

RAPID ASSESSMENT OF MARINE POLLUTION (RAMP) PILOT PROJECT PROTOCOL

Objectives

1. To develop the use of a suite of rapid, easy-to-use and cost-effective biomarkers for the combined study of sub-lethal effects and organismal health in a range of estuarine and coastal organisms representing different functional groups (including predators, omnivores, grazers, filter feeders, and detritus feeders).

2. To apply and validate the suite of biomarkers in a range of ecosystems (study areas) exhibiting different degrees/signatures of contamination.

3. To determine the sensitivities of key species within different functional groups to a range of common contaminants and mixtures.

4. To develop a management tool linking observed biomarker responses to population and community changes, identifying appropriate protective or remedial measures.

Users and Products

1. Methodology transfer of current rapid assessment biomarkers to a broader range of newly selected, ecologically relevant key species, and undertake a laboratory-based evaluation of biomarker performance.

2. Develop and optimize new biomarkers.

3. Rank the sensitivities of key species to selected contaminants in relation to feeding strategies and habitat.

4. Validate biomarkers in test species from well characterized “clean” and contaminated estuaries linking responses to changes in benthic community structure.

5. Apply biomarkers in appropriate key species at field sites in estuarine and coastal areas in the Caribbean region.

6. Develop a management support system for guiding protective and remedial measures.

7. Critically evaluate the RAMP approach in relation to current assessment and management procedures (where available). Determine the added value and compare cost-effectiveness and ease of use in relation to conventional physico-chemical and ecological monitoring procedures.

8. Critical users of results of this pilot project include; regional, national and local environmental managers, IOCARIBE implementation staff, and the general HOTO GOOS community.

Work Plan

Relevant species that are widely distributed, generally common, easily identified in the field and that are representatives of several invertebrate phyla will be selected for inclusion in the evaluation programme. Most importantly, test species will be chosen that exhibit a variety of feeding strategies and occupy a diverse range of habitats in estuaries and coastal areas. Representatives of the following phyla will be selected:

Porifera (sponges),
Annelida (polychaetes),
Mollusca (gastropods and bivalves),
Arthropoda (crustaceans),
Echinodermata (starfish),
Urochordata (sea squirts)

Biomarker assays will be modified to accommodate species differences and applied to appropriate key species listed above. Evaluations of biomarker responses will be undertaken following exposure–response experiments with individual chemicals and mixtures.

As it is proposed using a broader range of species, representing different phyla, new biomarkers will need to be developed. For example, following preliminary encouraging results (Hansen et. al., 1995) it is proposed to develop a sponge self-recognition assay in which the effects of contaminants on the ability of individual sponge cells to re-aggregate will be determined.

Only those biomarkers shown to give clear, pollution-induced responses will be used in fieldwork. Biomarker responses will be related to community structure and contaminant data for water and sediments determined using chemical immunoassays.

In addition, a field experimental programme will be undertaken in which clean reference site animals will be transplanted in cages to some of the contaminated sites to assess acute toxicity of the water.

Statistical procedures (the PRIMER package) will allow the data collected from a given site to be input into a multi-dimensional scaling statistical programme to facilitate detection of pollution gradients and the identification of sites with similar characteristics (see Astley *et al.*, 1999).

Capacity Building and Management Support System

Criteria will be determined for characterizing the extent of pollutant impacts at the field sites using the suites of biomarkers, applied to key species from several phyla. This will be formulated, together with community structure information and contaminant data, into a management support system to aid decision-making. The management system will build upon earlier work by (Depledge and Fossi, 1994).

Data and Information Management

All methods cited above will be rigorously evaluated with regard to sensitivity, repeatability and reliability. Data will be subject to quality control to identify anomalous values or procedural errors at an early stage so that they can be rectified.

New methods developed within the project will be standardized and quality assured through the production of standard operating procedures and blind trials. A web page will be created for the input and sharing of data for the region.

ANNEX VI

HOTO – HEALTH PILOT PROJECT PROTOCOL FOR SMALL ISLANDS STATES

Communities living on small islands and in remote coastal regions are the most sensitive to, and possibly the most affected by, adverse changes of the environment. The United Nations has recognized that small island developing nations are at particular risk to global change because of their greater dependence on the ocean and coastal environment. Survival, and ultimately sustainable development, are closely related to global environmental changes for these populations. It is for these reasons that the proposed HOTO pilot project will be focused on small islands and coastal regions. All human health agents identified in this report (i.e pathogens, marine toxins, and xenobiotics contaminants)are believed to be of critical importance in these ecosystems.

Objectives

1. To assess the current state of concern regarding HABs, contaminants, and pathogens in small islands;
2. To set up an integrated and sustained monitoring system that will be able to detect changes in health impacts related to ocean usages;
3. Provide knowledge and tools that will help to prevent public health problems for the future.

Products

1. Record and mapping of seafood borne diseases (HABs and infectious), health indicators related to ocean degradation and human body burden for contaminants;
2. Baseline data on seafood consumption;
3. Database on nutrients and contaminants in seafood;
4. Integration of these data with ecosystem data in an appropriate information database e.g., GIS.

Work plan and activities

1. Collection of Available Health Information

A set of human health indicators specific to island states will be selected by health departments of the participating countries. Indicators such as morbidity and mortality and data from specific surveys conducted in the region will be used. Mortality indices for seafood-borne diseases such as cholera will be recorded. Moreover, chronic diseases mortality (cardio-vascular, cancer) will be also considered since they could be influenced positively (nutritionally) or negatively (contaminants) by seafood consumption. Morbidity data will be used for monitoring data from available reportable diseases surveillance systems (HABs, gastro-enteritis, etc.). Other morbidity registries, that may exist such as cancer and birth registries will also be used. Potential other indicators include birth weight, hormone-mediated cancers, diabetes etc.

2. Fish Consumption Survey

A dietary questionnaire on seafood consumption can be developed and used to estimate levels of consumption and species consumed by residents. Food frequency questionnaires oriented on fish and shellfish consumption could be developed for pregnant women.

3. HAB Programme

Marine toxins especially Ciguatera are extremely common in tropical islands. In order to monitor this health problem, to detect any change in the incidence rate and to improve prevention, different activities will be conducted. Gathering data on the extent of the problem and the way small island States are surveying and managing this issue will need to be reviewed by all health Ministries. The final goal will be to build an integrated monitoring system within the region with common surveillance tools (questionnaires, detection technics, medical and public health management strategies).

4. Contaminants

As heavy metals (mercury) and organochlorinated compounds (PCBs, DDT and other pesticides) accumulate in the aquatic food chain, the most exposed populations are those living by, and depending on the sea. There is very few available data on the contamination of tropical islands by methylmercury (MeHg). The high consumption of pelagic and predator fish species by inhabitants indicates that a non-negligible portion of the population might be at risk of over exposure to MeHg. There are similar concerns for exposure to POPs. Chlorinated pesticides such as DDT have been/are extensively used in these regions and are present in the marine food web.

The first activity will consist in gathering data (names) of the ten most consumed fish species in each state. Data will come from catch data and interviews of nursing mothers.

A seafood quality inventory will be established based on MeHg and organic toxicants (PCBs, DDT and other chlorinated pesticides). The 10 aquatic species most frequently consumed by residents will be collected and analysed. In parallel to this work, fish samples will be used to assess nutritional benefits from seafood consumption. Nutrients from the ocean, such as trace elements (selenium), vitamins (vitamin A, D), and long chain fatty acids (EPA, DHA) are suspected to protect maritime populations from numerous chronic diseases.

An exposure assessment programme will then be developed. Biological measurements of human exposure can be carried out using blood surveys (approx. 30 samples per community/state). Previous experience in the Arctic (AMAP) has shown that maternal blood-hair samples are the most appropriate medium to assess contaminant levels in exposed populations. As the foetus is the most sensitive human being to these contaminants and most births occur at a central location (e.g., regional health centres) these areas would be the best places for central sampling. POPs can then be measured in plasma lipids using high resolution gas chromatography and electron capture detection. MeHg will be measured by cold vapor atomic absorption in whole blood samples. These women will also be asked to participate to the fish consumption survey.

5. Pathogens

For pathogenic diseases data will be collected by active surveys through regional health centers and reportable disease systems where they exist. For assessment of disease threats to humans during recreational use of coastal waters, it is proposed applying and validating the use of immunoassay kits for pathogens (e,g., Enterobacter).

6. Users, Capacity Building and Management Support System

All data will be first available for national and regional public health authorities. In the case of childbirth studies, individual results will be sent to the mother involved in the programme via local public health agencies. It is not the purpose of this proposed monitoring system to manage locally public health problems. However, it is possible that network participants will decide to have a common approach to manage problems related to these issues. All data will be analysed at a regional data center that will produce an annual situation report available to the region through the worldwide web.

7. Data and Information Management

All methods cited above will be rigorously evaluated with regard to sensitivity, repeatability and reliability. Data will be subject to quality control to identify anomalous values or procedural errors at an early stage so that they can be rectified. New methods developed within the project will be standardized and quality assured through the production of standard operating procedures and blind trials. Statistical analyses and all methodological procedures will be detailed on the web server.

Through this approach, national surveillance systems are expected to improve as well as a general improvement on the capacity of laboratories within the region for toxin detection, pathogen detection, recreational water surveillance programmes etc.

Depending upon the success of an initial three-year phase, it will be possible to later expand the network to other communities and seek funds for sustained programmes from donor agencies.

ANNEX VII

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ANNEX VIII

LIST OF ACRONYMS

ALA-D	Delta Aminolevulinic Acid
AMAP	Arctic Monitoring and Assessment Programme
ASP	Amnesic Shellfish Poisoning
BATS	Bermuda Atlantic Time Series
CALCOFI	California Cooperative Ocean Fisheries Investigation
CARIPOL	Caribbean Pollution Programme
CBD	Convention of Biodiversity
CITES	Convention on International Trade in Endangered Species
COOP	Coastal Ocean Observations Panel
CPR	Continuous Plankton Recorder
CRM	Certified Reference Material
DDT	Dichloro Diphenyl Trichloroethene
DFO	Department of Fisheries and Oceans (Canada)
DNA	Deoxyribonucleic Acid
DSP	Diarrhetic Shellfish Poisoning
EROD	Ethoxyresorufin O-Deethylase
FAO	Food and Agriculture Organization of the UN
GCOS	Global Climate Observing System
GEOHAB	Global Ecology and Oceanography of Harmful Algal Blooms
GEMSI	Group of Experts on Methods, Standards and Intercalibration
GESAMP	Group of Experts on Scientific Aspects of Marine Environmental Protection
GIPME	Global Investigation of Pollution of the Marine Environment
GIS	Geographic Information System
GIWA	Global International Waters Assessment
GLOBEC	Global Ecosystem Dynamics
GLOSS	Global Sea-Level Observing System
GODAE	Global Ocean Data Assimilation Experiment
GODAR	Global Oceanographic Data Archaeology and Rescue Project
GOOS	Global Ocean Observing System
GPA	Global Programme of Action
HELCOM	Helsinki Commission
HOOP	Health of the Ocean Panel
HOT	Hawaiian Ocean Time-series
HOTO	Health of the Ocean
IAEA	International Atomic Energy Agency
IARC	International Agency for Research on Cancer
ICES	International Council of the Exploration of the Sea
ICSU	International Council for Science
IGBP	International Geosphere-Biosphere Programme
I-GOOS	Intergovernmental Committee for GOOS
IGOSS	Integrated Global Ocean Services System
ILMR	International Laboratory of Marine Radioactivity
IMO	International Maritime Organization
IOC	Intergovernmental Oceanographic Commission
IODE	International Oceanographic Data and Information Exchange
JGOFS	Joint Global Ocean Flux Study
J- STC	Joint Scientific and Technical Committee for GOOS
LMR	Living Marine Resources
LOICZ	Land-Ocean Interactions in the Coastal Zone
MDR	Multi-Drug Resistance
MEDPOL	Mediterranean Pollution Programme
MESL	Marine Environmental Studies Laboratory
NOAA	National Oceanic and Atmospheric Administration (USA)

NODC	National Oceanographic Data Center
OECD	Organization for Economic Co-operation and Development
OOPC	Ocean Observations Panel for Climate
OSSE	Observing System Simulation Experiments
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenil
PCR	Polymerase Chain Reaction
PICES	North Pacific Marine Sciences Organization
POPs	Persistent Organic Pollutants
PSP	Paralytic Shellfish Poisoning
QA/QC	Quality Assurance/Quality Control
RAMP	Rapid Assessment of Marine Pollution
RNODC	Responsible National Oceanographic Data Centres
ROV	Remotely Operated Vehicle
SAR	Synthetic Aperture Radar
SeaWIFS	Sea-Viewing, Wide Field-of-view Sensor
SCOR	Scientific Committee for Ocean Research
SPM	Suspended Particulate Matter
TEMA	Training, Education and Mutual Assistance
TOGA	Tropical Ocean and Global Atmosphere
TTR	Transthyretin
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UV-B	Ultraviolet Radiation-B
WHO	World Health Organization
WMO	World Meteorological Organization of the United Nations
WOCE	World Ocean Circulation Experiment
WODC	World Ocean Data Centre
WRI	World Resources Institute
WWW	World Weather Watch