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ASSESSING HEALTH OF THE BAY OF FUNDY – CONCEPTS AND FRAMEWORK

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Reprinted from: *Health of the Bay of Fundy: Assessing Key Issues, Proceedings of the 5th BoFEP Bay of Fundy Science Workshop and Coastal Forum, Wolfville, Nova Scotia, May 13–16, 2002,* P. G. Wells, G. R. Daborn, J. A. Percy, J. Harvey and S. J. Rolston, Eds., Environment Canada–Atlantic Region, Occasional Report No 20, Sackville, NB and Dartmouth, NS. In press, November 2002.

Abstract

A discussion of health and ecosystem health concepts and a conceptual framework for assessing health of the Bay of Fundy are presented. The framework includes:

1. **Concepts** – What is health? What is ecosystem health (EH) and marine ecosystem health (MEH)? How does EH relate to other closely related concepts and principles, i.e. environmental quality (especially marine), ecosystem integrity and ecosystem sustainability ?
2. **Importance** – Why is EH important, and what are the linkages to people, i.e. human health?
3. **Approaches and techniques** – How do we monitor and measure EH, and in that context, ecosystem or ecological change? What are the monitoring approaches and tools? What is an appropriate set of EH indicators and indices for the Bay of Fundy and Gulf of Maine? At the present time, can we make unequivocal statements about the status and trends in EH measures of the Bay of Fundy? Do we have adequate guidelines, objectives and standards for assessing environmental quality and EH?
4. **Connecting with management needs** – Do we have adequate mechanisms in place to address MEH, marine environmental quality (MEQ) and environmental sustainability in the Bay of Fundy? What is the role of periodic marine assessments (e.g., state of the marine environment reports) in this activity? What kinds of new directions and new ecosystem science should be given priority, given the above analysis and the collective answers of the workshop participants? What kinds of other new activities should be pursued?

For the Bay of Fundy Coastal Forum at the workshop, five core questions flowing from the health framework served to initiate and focus the discussions:

1. **Current State** – What is the present health or condition of the Bay of Fundy?
2. **Changes** – Are conditions improving or deteriorating?
3. **Indicators** – What kinds of indicators do we consider most useful in trying to answer these questions?
4. **Existing Resources** – Are there adequate resources (e.g., institutional, financial, scientific, regulatory) to protect or restore the health of the Bay?
5. **Needs** – What kinds of new information and approaches do we need to protect the health of the Bay?

The background information and ideas of this paper were intended to assist discussion at the workshop, and to help identify the next steps, both individual and collective, for assessing the health of the Bay of Fundy.

Contents

> For whoever knows the ways of nature will more easily notice her deviations; and on the other hand, whoever knows her deviations will more accurately know her ways.
>
> Francis Bacon 1620, cited in Sherman, B. H. 2000

1. Introduction

The Bay of Fundy is a large macro-tidal embayment, forming the north-eastern arm of the Gulf of Maine. It is closely linked oceanographically to the greater Gulf of Maine, the Scotian Shelf and North-western Atlantic, and receives the inputs of 44 major rivers and countless smaller ones. It is bounded by two provinces with 1.5–2 million people, is extensively used by the fishing, shipping, aquaculture and other industries, and has two moderate-sized cities and many towns and villages along its shores.

The workshop's theme was the "Health of the Bay of Fundy – Assessing Key Issues". The Bay of Fundy is faced with a number of major issues, 38 by our count at the first workshop in 1996 (Percy et al. 1997, Chapter 6). At this workshop, we wished to assess progress since 1996 (Percy et al. 1997) in identifying and clarifying the issues, and through panel and informal discussions to plot a path forward for research, monitoring and management action. A primary objective of the workshop, through the Coastal Forum, was to contribute to the state of environment (SOE) assessment activities of both the Global Programme of Action Coalition for the Gulf of Maine (GPAC) Summit process, and the third Action Plan (2001–2006) of the Gulf of Maine Council on the Marine Environment (GOMCME 2002).

For such SOE or health assessments, data and information are required from a large number of indicators used for monitoring and describing the health of the environment – in this case, the Bay of Fundy. Also required is a process (an outline or framework) for producing periodic, carefully prepared, peer-reviewed reports on the Bay's health, in the context of the greater Gulf of Maine. Such monitoring, analysis and reporting involves the contributions of many people and organizations (a consideration of many perspectives on the approach and necessary information), understanding of some key concepts, and the incorporation of the experiences and knowledge of people who know the Bay. It also requires commitment, time and some money!

The task of assessing the Bay's health is not simple. Many other 'state of the environment' reports have shown the task of objective analysis and synthesis to be challenging – ecosystems are complex, incompletely known and always changing, and the measures of health, ecosystem health and environmental quality are in their infancy. It is important to avoid the pitfalls of the recent tome *The Skeptical Environmentalist* (Lomborg 2001), where oversimplification, incomplete knowledge and bias colored the analysis, according to most reviewers. Once a credible approach is chosen for the Bay of Fundy, there is a very large literature and experience to distill. The north-west Atlantic and the Gulf of Maine benefit from more than 100 years of oceanographic study (from the works of Bigelow and Huntsman, to Plant 1985, Backus and Bourne 1987, and Percy et al. 1997, amongst many other sources).

The challenges notwithstanding, we should try to produce a current assessment of the Bay of Fundy, and in turn, a report for the greater Gulf of Maine. It is hoped that the current series of Fundy Science Workshops, the GPAC forums, and many other meetings occurring in the Gulf of Maine watershed will contribute substantially to this effort.

Given these objectives, this paper presents a brief review of current concepts of ecosystem health, environmental quality and ecosystem integrity; a summary of what is required in health measurements, e.g., the indicators of ecosystem health, for the Bay of Fundy; and a framework for the process for assessing the health of the Bay of Fundy and its key issues.

2. Concepts of Health and Ecosystem Health

Various conceptual frameworks have been presented for assessing ecosystem health and environmental quality. Rapport (1986) described a stress-response framework and used it as the basis for Canada's early SOE reports. The Marine Environmental Quality (MEQ) Working Group of Environment Canada built on Rapport's stress-response model and presented a framework with four components – characteristics and uses, stress factors, ecosystem responses (using indicators), and health or condition of the environment (Wells and Rolston 1991). Harding (1992) presented the MEQ model as including stressors, characteristics of exposure, measurement of effects, and indicators of quality. Most recently, Smiley et al. (1998) presented a modified MEQ framework, with the components being condition, stress, effects and response (indicators). Finally, Fisheries and Oceans Canada (2000) succinctly described MEQ in the new Oceans Act as involving guidelines and objectives, indicators and assessment. Westhead elaborates on this framework in these Proceedings (see page XX).

The various approaches show some common needs in coastal and ocean assessments. These are: (1) understanding of the habitats and ecosystem(s) under consideration, and recognition of what we do not know well or at all, given ecosystem complexity; (2) indicators of 'health' and 'quality' that can be developed by research and used in monitoring; and (3) a feedback loop via assessments, monitoring, and management and societal action (through a range of mechanisms, including regulations). Mechanisms are required to complete the loop, such as this workshop, and periodic reports and report-cards on progress.

By necessity, various terms are used in this field, but not always in the same way. After all, the field is interdisciplinary and evolving. However, this causes confusion both in conceptualizing the issue of 'ecological or ecosystem health' and in its application, i.e. conducting assessments and prioritizing issues. One solution, a major part of this paper, is to discuss the key terms and concepts; they include health, ecosystem health, ecological health, coastal health, ecological condition, ecological integrity, ecological change, and (marine) environmental quality.

One view of the relationship between the various health concepts, time and space, and level of biological organization is shown in Table 1. Health and integrity are a description of the current state, condition or status, a view over the short term (one to a few generations, varying with organism, lasting from hours to decades). Quality and change are a description of trends from the 'baseline' or original, undisturbed conditions, a view over the longer term (many generations and life spans, covering decades to centuries). In practice, as shown below, ecological or ecosystem integrity are used to describe both short- and long-term conditions. Importantly, the terms are used precisely in relation to level of biological organization, i.e. an individual organism is healthy or unhealthy, whereas a community has or lacks ecological integrity. These distinctions are not trivial as they reflect the need for quite different indicators of condition across the structural and functional components of ecosystems.

Table 1. How the terms and concepts on health and ecosystem health relate, across time, space and levels of biological organization

	Levels of Biological Organization		
	Individuals	Populations	Communities/Ecosystems
Time/space scale			
Short term, local, current state	Health	Health	EH*, Integrity**
Long term, regional, changes/trends	–	Quality, Change	Change, EQ*** Integrity**

* Ecosystem health
** Ecological or ecosystem integrity
*** Environmental quality

2.1 Current Health and State of the Ecosystem

2.1.1 Health

Health, as in ocean health or health of the oceans, is a commonly used and publicly accepted term referring to the condition or state of the seas (note Goldberg 1976; Kullenberg 1982; Wells and Rolston 1991; McGinn 1999; Knap et al. 2002). But, curiously, its users usually avoid exact definitions of the word or phrase! Health is defined in the Oxford dictionary as "soundness or condition of body (good, poor, bad, ill, health)" (Sykes 1976). Health means freedom from or coping with disease on the one hand (the medical view), and the promotion of well-being and productivity on the other (the public health view); "in essence, there are two dimensions of health – the capacity for maintaining organization or renewal, and the capacity for achieving reasonable human goals or meeting needs" (Nielsen 1999). Importantly, Nielsen states that "health is not a science per se; it is a social construct and its defining characteristics will evolve with time and circumstance". Earlier, Rapport et al. (1980) considered the concept of health and the need to recognize vital signs, a topic explored below under "indicators". Finally, health is usually defined by what is NOT, such as "the occurrence of disease, trauma or dysfunction" (Gove 1993). Therefore, a healthy marine environment requires individuals (ecologically, individual organisms) with signs of wellness and productivity, based on vital signs, and the absence of obvious disease or lack of function. Health as a concept is readily understood, has social capital, is transferable to ecosystems (as shown in Table 1 and below), and is measurable.

2.1.2 Ecosystem health

Ecosystem health, as a concept and practice, has been discussed at length for two decades. Papers include Costanza et al. (1992); Fairweather 1999; IJC (International Joint Commission) 1991; Kutchenberg 1985; Rapport (1989, 1992, 1998); Rapport et al. (1980, 1998, 1999); Schaeffer (1996); B. H. Sherman (2000); Tait et al. (2000); Vandermeulen (1998); and Wood and Lavery (2000).

Rapport and his colleagues are leaders in exploring the field of ecosystem health. Rapport et al. (1980) discussed early warning indicators of disease, hypersensitivity, epidemiological models, the crucial role(s) of certain parts of a living system, Selye's concept of stress without distress (Selye 1974), and immune antibody responses. These topics have advanced further due to research in medicine, toxicology, and environmental toxicology since the 1980s. Rapport et al. (1980) stated that "the corresponding ecological concept to health might be ecosystem persistence, or ecological resilience. Presumably this property can be assessed using a range of indicators ...; candidate vital signs include primary productivity, nutrient turnover rates, species diversity, indicator organisms, and the ratio of community production to community respiration." A very important observation was that "once ecosystems are adequately characterized in terms of vital signs, the development of more comprehensive diagnostic protocols might be the next logical step". Developing and standardizing such protocols have been at the heart of applied ecotoxicology for years now. In addition, this step has been taken by groups such as HEED (Center for Health and the Global Environment at Harvard University) (Sherman, B. H. 2000) and Kenneth Sherman of NOAA with his internationally recognized work on large marine ecosystems or LMEs (Sherman, K. 2000). Much work is continuing with molecular biomarkers (M. Depledge, pers. comm.), and the connections across levels of biological organization to populations and communities (e.g., Downs and Ambrose 2001).

A review of the core studies of ecological health and ecosystem health reveals some key observations:

On indicators and indices, "ecosystem health is a characteristic of complex natural systems ... defining it is a process involving a) the identification of important indicators of health; b) the identification of important endpoints of health; and c) the identification of a healthy state incorporating our values. Historically, the health of an ecosystem has been measured using indices of a particular species or component" (Haskell et al. 1992). It is clear that we need to choose indicators and monitor ecosystems with them, and then to summarize and interpret the responses using indices. This in fact is being done, for example, in EPA's estuarine programs, in larger comprehensive coastal programs such as in Chesapeake Bay, and in a multitude of community-led monitoring programs around the Gulf of Maine (Chandler 2001).

On the components of ecosystem health, Schaeffer et al. (1988) gave ten guidelines for assessing ecosystem health (Haskell et al. 1992). At two 1991 workshops, participants developed a working definition of ecosystem health, defining health in terms of four characteristics applicable to any complex system – sustainability, which is a function of activity, organization, and resilience. Sustainability implies that the ecosystem can maintain its structure and function over time. The conclusion was that "an ecological system is healthy and free of 'distress syndrome' if it is stable and sustainable – that is, if it is active and maintains its organization and autonomy over time, and is resilient to stress". This, of course, implies that activity, organization and resilience can be measured for each, at least major, component of each ecosystem, a daunting task indeed.

One problem of defining ecosystem health is choosing the appropriate scale, i.e. which ecosystem are we managing and what level are we focusing on? For example, for Chesapeake Bay, is the Bay and its many estuaries being considered, or is it the whole Chesapeake watershed? The same question applies to the Bay of Fundy – do we focus on the whole Bay (there are already 38+ issues), the extensive watersheds (the proposed approaches of the GOMCME, and the Minas Basin Working Group of BoFEP), or just one part (e.g., Passamaquoddy Bay)? Choosing the appropriate spatial scale has implications for a wide range of activities associated with managing and maintaining ecosystem health; issues of policy, governance, research, assessment, management tools, monitoring, communication, and stakeholder involvement ultimately have to be considered.

The human health assessment model was described by Haskell et al. (1992). It has six parts: a) identify symptoms; b) identify and measure vital signs; c) make a provisional diagnosis; d) conduct tests to verify the diagnosis; e) make a prognosis; and f) prescribe a treatment. For a large marine ecosystem, in this case the Bay of Fundy (part of the greater Gulf of Maine), this model of health assessment could work as below. A compendium for #a and #b is as yet incomplete, so examples come from previous Fundy Science Workshops, ongoing projects, and an aging memory!

a) **Identify symptoms**: What are the first signals that the system is 'unhealthy'? From the physical to the biotic environment, some are: physical changes to shorelines (e.g., barriers, such as causeways and dykes; increased coastal development, especially homes along the shorelines); changed sediment patterns in estuaries; contaminants in sediments and tissues; increased numbers of aquaculture sites in bays; abundant debris on shorelines; reduced fisheries catches or failing fisheries; the requirement to open new fisheries on new or previously 'under-utilized' species; reduced numbers of seabirds (Phalaropes), and marine mammals (Right Whales); and increased small boat traffic in bays and inlets (noise, water and air pollution).
b) **Identify and measure vital signs**: There are a number of critical changes in key attributes of the ecosystem that collectively show the system is under stress or change, e.g., loss of/reduced fisheries (herring); loss or reduction of species (wild Atlantic salmon, *Salmo salar)*; changed distributions of seabirds such as the Red-necked Phalarope, *Phalaropus lobatus*; high levels of some chemicals in biota (e.g., Cu in crustaceans, and PCBs in birds and mammals); changed water flows or hydrologies in estuaries; and overall reduced salt marsh acreage in the upper Bay.
c) **Provisional diagnosis:** At the 1996 Fundy Science Workshop (Percy et al. 1997), the participants concluded that the Bay of Fundy was showing a number of signs of poor health and lowered quality, and a listing of 38 key issues was made. Many of these have been discussed

at subsequent Fundy Science Workshops, and many other recent meetings around the Gulf of Maine (e.g., Regional Association for Research on the Gulf of Maine (RARGOM) Conference, Wallace and Braasch 1997; Rim of the Gulf Conference 1997; habitat conferences; further RARGOM meetings, e.g., Pesch 2000). The Conservation Council of New Brunswick has recently expressed concerns for coastal habitats throughout the Bay, with a careful record of habitat loss or modification (Harvey et al. 1998), and there are marked changes in fisheries over 200 years and the presence of chemical burdens in Passamaquoddy Bay species (Lotze and Milewski 2002).

d) **Tests to verify diagnosis:** Diagnostic tests include: monitoring for trace contaminants in mussels and in the food chain (levels, responses of biomarkers, effects); monitoring for algal toxins; monitoring for bacterial pathogens; monitoring for effects of salmon aquaculture wastes on benthic species and communities; assessment of condition of remaining salt marsh habitat; and assessment of effects of tidal barriers (e.g., the 2000–02 tidal restriction audits being completed in New Brunswick and Nova Scotia). This important verification step ensures that the ecological health issue is real and important (economically and ecologically). It is also more tractable to address single issues than the whole system at once. With multiple issues, the potential for cumulative effects and the potential for confounding with natural variables in ways difficult to predict, diagnosing the whole system is the goal but can be achieved most successfully with 'bite-sized' efforts.

e) **Make a prognosis for the Bay:** This is the 'ecosystem health report' and a statement of the future for the Bay's habitats, inhabitants, and natural and living resources (also see Section 2.1.4). Is there a good chance of 'recovery', or 'maintaining the status quo' if we continue to act through protection, conservation and remediation efforts? This prognosis is probably most effective if looked at by sector – fisheries, marine mammals, wildlife, sediments, coastlines, estuaries, etc. – and by regions within the Bay – from Passamaquoddy Bay around to Annapolis Basin, St. Mary's Bay and the coast to Yarmouth. The prognosis is best captured in periodic State of the Bay of Fundy and State of the Gulf of Maine reports.

f) **Treatment:** This step describes the actions required to restore ecosystem health to the Bay of Fundy. For example, recent positive actions include working with the International Maritime Organization (United Nations) to select sea lanes away from the Northern Right Whale feeding areas (a real success!); remediation of unused salt marsh in Shepody Bay; better management plans for specific fisheries species such as bait worms (polychaetes) and green sea urchins (*Strongylocentrotus droebachiensis*); gradually improved sewage treatment, such as at Saint John; efforts to remediate a tidal river e.g., Petitcodiac River; improved aquaculture practices in south-western NB; and identifying the potential for opening selected causeways and restoring tidal flows in estuaries, e.g., Windsor, NS. Actions are small and large, most are opportunistic, but all contribute to the momentum of addressing issues confronting the Bay.

What is our capacity to conduct ecosystem health assessments? Many traditional state of the environment reports have been prepared, some very thoroughly (e.g., AMAP 1997, 2002; see Section 2.1.4). But we may only be in the early stages of being able to do actual 'ecosystem health assessments' well because we lack the medical encyclopedia for ecosystems (Haskell et al. 1992). As Norton et al. (1991) and Haskell et al. (1992) point out (everyone knows this, but it is worth recalling), medicine deals with the individual, whereas "ecosystems exist on many levels, can be described on many scales, and require a consensus of public goals on the road to having diagnostic tests for ecosystem stress". A framework for starting to evaluate an ecosystem could consist of a) types of stress; b) response variables or symptoms of ecosystem distress; and c) monitoring, fiscal resource, management and other needs. The table in Percy et al. (1997), pages 140–141, is an excellent tool but requires an update! We have to move from the traditional environmental report, a valued but often uninspired tally of characteristics of the system, to an actual health assessment, which is an analysis of how the whole system is functioning or not. The Gulf of Maine and Bay of Fundy offer an opportunity few if any other places have to prepare such an ecosystem health assessment.

There are obviously limitations to the concept of ecosystem health, and especially to putting the concept into practice. The concept has a history in Western-based science, medicine and conservation. It first formally "emerged in the mature thought of Aldo Leopold as a bridge between technical management and formulation of management goals" (Leopold 1949; Haskell et al. 1992), hence it is not only a scientifically-based concept. This is very important because there is great value, indeed crucial value, in the link to environmental management goals (see Section 3.4), and metaphorically, the concept and term have the strength of communicating the problem to a wide audience. The term 'ecosystem health' was used in the 1960s and 1970s in the context of the Great Lakes, especially Lake Erie, once considered 'dead', rather than having impaired 'ecosystem health'! Lake Erie survives, with impaired but improving health (it is alive and productive) and a lower quality (its current condition compared to the original state of the lake). Likewise, in the United States, the ecosystem health concept has been applied to the important estuaries and coastal bays, such as Chesapeake and San Francisco (see numerous EPA reports, such as EPA 1998, 1999, 2000a,b).

However, several important limitations with the ecosystem health concept should be kept in mind, as we consider the Bay of Fundy. First, "no longer are communities (natural) considered normative. Disturbance is common; communities and ecosystems are in constant flux. Knowing what is natural is difficult" (Ehrenfeld 1992). That is, the normal range for a variable may be quite wide (particularly note Schindler 1987), and in this age of marked climate change, even more so, e.g., air temperature, storm events and levels of precipitation. The baseline for 'normal ecosystem health' fluctuates! Secondly, "a determination of ecosystem health can be a function of which process you are looking at, which in turn is determined by your own values" (Ehrenfeld 1992). Ecosystem health has a social context, as does the science behind it. Thirdly, the word 'health' should not be defined or applied too rigorously because communities of plants, animals and micro-organisms comprising ecosystems vary greatly in their state of equilibrium. Hence, the term is best used as a bridging concept between the science and non-scientists (Ehrenfeld 1992), a starting place for dialogue on issues, priorities and indicators.

Systems ecologists also have views as to what is meant by ecosystem health. These views shed light on the selection of suitable indicators for the Bay of Fundy. For example, Ulanowicz (1992) states that "a healthy ecosystem is one whose trajectory towards a climax (referring to ecological succession) is relatively unimpeded and whose configuration is homeostatic to influences that would displace it back to early successional stages. Assessing the health of ecosystems requires a pluralistic approach and a number of indicators of system status" (also see Karr 1991; Schaeffer et al. 1988). Ulanowicz uses the approach of network ascendancy, an index that captures four key properties of quantified networks of trophic interactions in healthy systems: greater species richness, more niche specialization, more developed cycling and feedback, and greater overall activity. This approach could be usefully applied to the Bay of Fundy and its various ecosystems and regions; one could hypothesize that in some places, e.g., near aquaculture sites, in urbanized harbors, near industrial effluent locations, these properties have been diminished, and then investigate them accordingly (as in the aquaculture studies of G. Pohle, Huntsman Marine Science Centre).

Karr, a fisheries biologist, stated that "a biological system can be considered healthy when its inherent potential, whether individual or ecological, is realized, its condition is stable (meta-stable), its capacity for self-repair when perturbed is preserved, and minimal external support for management is needed" (Karr et al. 1986). One can analyze the Bay of Fundy using this approach (Table 2). Hence, when evaluated as a system, the Bay of Fundy's condition could be considered as deteriorating and in need of enlightened integrated management.

Table 2. A hypothetical health status of the Bay of Fundy (based on approach in Karr 1992 and earlier papers)

System Criterion	Health Status		
	Good	Fair	Poor
Inherent potential	+ >		
Condition		+ >	
Self-repair	+ >		
Management support		<+	

Finally, and following from above, consider which components of ecosystem health are required. Costanza (1992) discusses ecosystem health in the context of a system's overall performance. "To understand and manage complex systems, we need some way of assessing the system's overall performance (its relative health)". He summarizes the components of ecosystem health as:

- homeostasis
- the absence of disease
- diversity or complexity
- stability or resilience
- vigor or scope for growth
- balance between system components

"Systems are healthy if they can absorb stress and use it creatively, rather than simply resisting it and maintaining their former configurations". "An ecological system is healthy and free from distress syndrome if it is stable and sustainable – that is, if it is active and maintains its organization and autonomy over time, and is resilient to stress". To be healthy and sustainable, the system must maintain its metabolic activity level, maintain its internal structure and organization, and be resilient to outside stresses.

Costanza (1992) has attempted to quantify ecosystem health:

HI=overall health index
HI=V*O*R

where V=system vigor; O=system organization index (0-1); and R=system resilience (to stress) (0-1). (See Box 1, Rapport et al. 1998.) This approach, producing an Overall Health Index, could be tried for the various regions, habitats and trophic levels of the Bay of Fundy. In fact, Rapport et al. (1998) have taken this approach and advanced upon it. They stated that "many ecosystems are unhealthy – their functions have become impaired". They looked at the literature and presented several case studies. Using their choice of indicators of ecosystem health, a hypothetical assessment of the Bay of Fundy might appear as Table 3.

Table 3. Hypothetical assessment of ecosystem health of the Bay of Fundy using Rapport's indicators of stress (Rapport et al. 1998)

Stress results in	Location			
	Bay of Fundy	Passamaquoddy Bay	Minas Basin	Saint John Harbour
Biotic impoverishment	Yes	Yes	?	Yes
Impaired productivity	?	?	Yes	Yes
Altered biotic composition	Yes	Yes	Yes	Yes
Reduced resilience	?	?	?	Yes
Increased disease prevalence	Yes	Yes	?	Yes
Reduced economics	Yes	Yes	Yes	Yes
Risks to human/organism health	Yes	Yes	?	Yes

2.1.3 Marine ecosystem health

In an early paper on ecological terms for large lakes, Pamela Stokes' description (Stokes 1981:86) of 'healthy', in the context of aquatic ecosystem health, was that "it includes: 1) stability – gross structure unchanged over many years; 2) balance; and 3) functioning. In the context of lakes, an example of 'unhealthy' would be a condition caused by the addition of toxins; if algae are killed and bacteria increase out of balance, the lake is not healthy".

For coastal and open ocean systems, the term 'marine ecosystem health'or MEH is often used (amongst others, Wells and Rolston 1991; Wells 1996, 1999a; Smiley et al. 1998; Vandermeulen 1998; Sherman, B. H. 2000; Sherman, K. 1994, 2000). Paul Epstein's definition of marine ecosystem health is: "to be healthy and sustainable, an ecosystem must maintain its metabolic activity level, its internal structure and organization, and must be resistant to stress over a wide range of temporal and spatial scales" (Epstein 1999).

B. H. Sherman (2000) states that "ecosystem health is a concept of wide interest for which a single precise scientific definition is problematical". He describes the HEED approach of Harvard University – "a marine health assessment that is a rapid global survey of possible connections and costs associated with marine disturbance types". This program was initiated in 1995; it published its first survey in 1998 (Epstein and Rapport 1996; HEED 1998). Eight disturbance types are described, shown below (Table 4) in the context of Bay of Fundy. "The 8 general types of disturbance may provide a first approximation of the comparative health of coastal marine ecosystems." Mortality, disease and chronic disturbances are the three major variables or changes "reported across a wide spectrum of taxonomic groups" (Sherman, B. H. 2000). Assessments using a marine epidemiological approach can track these changes in ecosystem health (Epstein and Rapport 1996).

Table 4. Disturbances in the Bay of Fundy. A preliminary list, following from Epstein and Rapport (1996), HEED (1998) and B. H. Sherman (2000)

Type of Disturbance*	Bay of Fundy Occurrence	
	Y/N	Comments
Biotoxin and exposure	Y	Toxic algal blooms Beach closures
Anoxic/hypoxic	N	Unlikely due to tidal exchange
Trophic-magnification	Y	Toxic algal blooms Contaminants
Mass lethal mortality	N?	—
Physically-forced (climate/ocean)	Y	Severe storms
Disease	Y/N?	Imposex in snails; none in birds
New, novel occurrences and invasives	Y?	Crabs (Green, Japanese Shore)
Keystone endangered and chronic cyclical	Y	Algal blooms; beach closures; fisheries closures; invertebrate declines; bivalve contamination

Kenneth Sherman's large marine ecosystem (LME) approach (Sherman et al. 1996; Sherman and Skjoldal 2002; other LME publications), is applicable to the Gulf of Maine and Bay of Fundy. Indeed, the Gulf of Maine is part of an LME and is identified as the Northeast Shelf Ecosystem (unfortunately, the boundaries of which may be jurisdictional rather than ecological!). Methods to assess the health of LMEs are being developed from modifications to a series of indicators and indices described by several investigators (see Costanza and Mageau 1999); the methods form part of the pollution and ecosystem health module of the LME approach. Recent workshops sponsored by NOAA (USA) and the Nordic Council of Environment Ministers (Europe) considered the concepts of ecosystem health and marine ecosystem health (Sherman, K. 2000). The Pollution and Ecosystem Health module consists of eutrophication, biotoxins, pathology, emerging disease and health indices. Five health indices (bio-diversity, productivity, yield, resilience, stability) are included as experimental measures of changing ecosystem states and health. Hence, the module emphasizes stresses and indices (based on numerous indicators), consistent with current thought on how to approach marine ecosystem health.

In practice, the pollution and ecosystem health module of the LME uses benthic invertebrates, fish and other biological indicator species, and accepts the following set of measures (Sherman et al. 1996; Sherman, K. 2000):

- bivalves (Musselwatch) (similar to Gulfwatch employed in Fundy, Chase et al. 2001)
- patho-biological examination of fish
- estuarine and nearshore monitoring of contaminants and contaminant effects in water, sediments and organisms (note NOAA's programs, Wade et al. 1998)
- routes of bioaccumulation and trophic transfer of contaminants
- examination of critical life stages and food chain organisms to demonstrate exposure
- impaired reproductive capacity
- organ disease
- impaired growth
- impacts on individuals and populations

Sherman et al. (1996) adopted a holistic approach inherent in the LME concept, as it encourages agencies and other stakeholders to address issues of over-fishing, habitat loss, pollution, and recreation needs from a multi-disciplinary ecosystems perspective.

Vandermeulen (1998), in a Canadian summary, stated that MEH indicators are being identified in five categories: contaminants; biotoxins, pathogens and disease; species diversity and size spectrum; primary productivity and nutrients; and instability or "regime shifts". These were adopted from the literature, and hence are similar to MEH indicators chosen by the many expert groups involved in the LME approach (Sherman, K. 2000).

The terms marine ecosystem health (MEH) and marine environmental quality (MEQ – see below) are often used inter-changeably in the literature and in common practice when communicating about the health of coastal seas and the oceans (Wells 1991). The case made in this paper, however, is that the terms health and quality are not the same (Section 2, Introduction), and that there are benefits from using them more precisely in an assessment of the health of coastal waters, in this case the Bay of Fundy, i.e. we want to maintain and sustain a healthy bay of high quality!

2.1.4 Ecological condition and state of the environment

Ecological condition and state of the environment are terms used in statements or reports on the current condition of specific ecosystems, terrestrial to marine. Encouragingly, there are many recent examples of such marine reports (AMAP 1997, 2002; Birkett and Rapport 1996; Crawford et al. 1994; EPA 1998, 1999; GESAMP 1990; Kay 1989; Konrad et al. 1990; Marine Institute 1999; Sheppard 2000; Waldichuk 1989; Wallace and Braasch 1997; Wells and Rolston 1991; White and Johns 1997; Zaitsev and Mamaev 1997). Some reports are popular accounts for the general reader and the decision maker (e.g., Atkinson et al. 2000; Earle 1995; GESAMP 2001a; GOMCME 1989; Johnston et al. 1998; Marx 1999; McGinn 1999; Milewski et al. 2001). The 'state of the environment' literature reflects the popular and accessible (not necessarily current) concepts of ecosystem health, and the suite of most useful indicators deployed by scientists and community volunteers to monitor the state of the marine environment (i.e. ocean health).

For example, Birkett and Rapport (1996), Crawford et al. (1994) and others have evaluated the ecological health of specific coastal areas. Birkett and Rapport (1996) presented a summary table identifying some of the common signs of ecosystem stress. This has been adapted below to assess the Bay of Fundy (Table 5):

Table 5. Common signs of ecosystem stress, and preliminary subjective assessment of their occurrence in the Bay of Fundy

Sign of Stress*	Bay of Fundy	Level of Severity#
Habitat changes	Yes	++
Elevated nutrient levels	Yes (in places)	+
Biological productivity changes	Yes	++
Biotic composition and characteristics	Yes	++
Bioaccumulation of contaminants	Yes	+
Disease prevalence	? (perhaps localized)	++
Effects of exotic species	?	?

* From Birkett and Rapport (1996) # ++ high; + moderate; ? no information

The above discussion shows that there is considerable commonality of the key components of any assessment of ecosystem health. What is needed are the monitoring programs providing systematically collected data over long time periods so that such assessments can be made reliably (see GESAMP 1994b).

2.1.5 Ecological integrity

Ecological integrity (also called ecosystem integrity) is "the dimension of health that reflects the capacity to maintain organization; it is akin to the term 'integrity', especially when used at the scale of ecosystems" (Karr, many refs.). It incorporates the ideas of resilience, vigor and homeostasis. "Many regard integrity, when used in a purely ecological sense, to refer to the evolution of the ecosystem without human disturbance" (Nielsen 1999). Key papers include Karr (1981, 1992), Woodley et al. (1993), Noss (1995), Nielsen (1999), and Campbell (2000). Karr (1992) and Campbell (2000) discussed the concept in detail. Integrity "implies an un-impaired condition, or the quality or state of being complete or undivided" (Karr 1992). It also means "un-impaired when compared with the original condition" (Campbell 2000).

Systematic assessments of the status of ecological resources (i.e. ecological integrity) have three requirements: they must be based on biology and biological processes; there must be a selection of measures of health or integrity appropriate for the place and biological attributes of concern; and there must be biological benchmarks or reference conditions (Karr 1992). On the second requirement, an array of attributes of biological/ecological integrity is used. Collectively, they must be very diagnostic of local conditions. For example, five attributes (individual health, species richness, relative abundance of species, population age structure, genetic diversity) measured together can describe local conditions. Efforts to assess ecological integrity are more likely to detect degradation if those efforts are conceptually diverse – from the use of individuals to populations to assemblages to landscapes, for the measurement of attributes (Karr 1992).

Karr uses the terms 'conditions', 'ecological health' and 'integrity' interchangeably, not surprising given the similarity of their components but unhelpful to using the concepts in practice with precision! Campbell (2000) agrees with previous writers (Suter 1993) that we need operational definitions of concepts such as ecosystem health, and by analogy, ecological integrity. Campbell concludes that "ecological integrity is an ecosystem property that is greatest when all the structural components of a system that should be there, are there (i.e. structure is complete), and all the processes operating within the system are functioning optimally (i.e. the ecosystem is 'healthy')". Perhaps what is important is that condition, ecological health and integrity refer to the current state of a system, how well it is composed and functioning now. Semantic arguments fall prey to practical needs!

Can we assess the Bay of Fundy with the more operationally useful definition of Campbell (2000) – Are all the structures/parts and functions of the Bay of Fundy's ecosystems present and operating optimally? Are we monitoring enough to be able to describe the integrity of natural communities and ecosystems in the Bay of Fundy as a whole, or will we do this only for selected sites e.g., salmon aquaculture sites, tidal barriers, harbors, points of industrial discharge?

Finally, which of the terms, ecosystem health or ecological/ecosystem integrity, has more social capital associated with it? It is noteworthy and very encouraging that the GOMCME, in Goal 2 of its third five-year action plan (GOMCME 2002), addresses "… human health and ecosystem integrity", with three social, management oriented objectives: increasing awareness and improving management of priority contaminants, identifying reduction strategies for priority contaminants, and enhancing citizen stewardship. Protecting and assessing the ecological or ecosystem integrity of the Gulf of Maine and the Bay of Fundy has been identified as a long-term social goal of institutions around the Gulf.

2.1.6 Coastal health

Coastal health is a broad term signifying the interconnections and overlap between three areas – human health (as above); environmental health (as above, MEH and ecological integrity); and community health. Community health involves all of the public(s) – all of the communities that are present along the shores of a water body, and within the watersheds. It covers many functions of each coastal community. Community health includes consideration of economic sustainability and opportunities, and appropriate civic planning and conduct to enhance the quality of life in the community, e.g., parks, green spaces, public health and health care, education, opportunities for the young. Community health and the ecological/environmental health of the surrounding watersheds and marine ecosystems of the Bay of Fundy and Gulf of Maine are closely linked. There are many examples in the fishing communities, as the economies of the fisheries are affected by issues such as contaminants (mercury, hydrocarbons), natural toxins (PSP), and tourism and recreation.

Coastal health should be considered in the design and practice of integrated coastal management plans/programs. It also should be included in any assessment of the Bay of Fundy's health, as it is a holistic representation of people, their activities and their impacts integrated with the ecology and living resources of the coast.

2.2 Longer Term Ecosystem Change

Change is constant, i.e. continual, in Earth's ecosystems. Marine ecosystems are no exception to this rule. What is important is to distinguish between natural ecological change, important anthropogenically driven change, and the two combined (Schindler 1987; Spellerberg 1991; Ollerhead et al. 1999; Wells 1999b; Jackson 2001; amongst others), and to identify the important adverse change(s) that can be ameliorated (e.g., ozone depletion due to CFCs; contamination of food supplies and ecosystems by other synthetic chemicals; climate change if we control carbon dioxide emissions). Changes should be observed or measured over the long term and compared to measurements of or approximations of the original conditions (set at some arbitrary time). The choice of appropriate indicators (see section 3.3.2), the monitoring design, and modeling (Jakeman et al. 1993) are critical to success. "The question is how to better identify, monitor, anticipate, and respond to the network of changes in the ecosystem" (Zelazny 2001), and how best to report periodically on and interpret such change for the Bay of Fundy-Gulf of Maine.

2.2.1 Change and ecological change

Change and ecological change have been studied and/or discussed by Baird and Burton (2001); Clark and Frid (2001); Duarte et al. (1992); Epstein and Rapport (1996); Earle (1995); Harvell et al. (1999); HEED (1998); Jackson (2001); Jickells 1998; Lotze and Milewski (2002); Mann 2000; McGowan et al. (1998); McMichael (1993); Myers (1995); Rapport (1990); Rapport and Whitford. (1999); Rose et al. (2000); Schindler (1987); Spellerberg (1991); Wells (1999b); and others. Ecological change has been taking place over the geological epochs, and in 'recent time' in the Bay of Fundy region. Since the last ice cover 12,500-15,000 years ago (Atlantic Geoscience Society 2001), sea levels have risen and the land has been re-occupied by plants and animals. Both gradual change and occasional abrupt occurrences (disturbances, including extinction events) are normal to ecosystems. Organisms, populations and communities adapt in a variety of ways, from physiological to reproductive to shifted distributional patterns. What must be understood is how ecosystems accommodate to the natural change and the changes imposed by human activity at the same time, particularly when the latter includes large perturbations such as biomass removal, habitat destruction or modification, chemical effects (toxicity), and competition from bio-invaders or exotics in coastal waters (Wells 1999a).

Ecological change can be subtle. A change in the health of the system may lead to a change in the systems overall quality, without being noticed or measured. Examples are numerous – the ecological effects of new fisheries for so-called under-utilized species (e.g., sea urchins, sea cucumbers, rockweed, gastropods, polychaetes), the impacts of barriers on tidal rivers on mudflats and other intertidal zones, the progressive loss of freshwater reproductive habitat (e.g., salmon), and the potential impact of tourism on migratory shorebirds (i.e. disturbance at critical feeding and roosting areas in the intertidal zones and on islands).

Ecological systems are complex and chaotic, many interactions are non-linear (Myers 1995), and some species play pivotal roles in the transfer of energy between trophic layers (e.g., keystone species such as *Corophium volutator,* D. Hamilton, pers. comm.). Once disturbed by an anthropogenic stress(or), the ecosystem may not recover or offer the possibility for remediation (e.g., over-fished areas, water bodies with introduced species, areas of coastal development, highly contaminated sites), the system entering a new and different ecological state.

Ecological change(s) occurs at different spatial and temporal scales. For example, compare the impact of a single fishery for a keystone benthic species such as urchins, the change caused by removal occurring rapidly over many hectares, to the predicted impacts of global climate change on sea temperatures and sea surface levels, the change occurring gradually, by years and decades, over tens of thousands of square kilometers. This range of change is probably very common in ecosystems, though most of it goes undetected and unaccounted for. The challenge is to examine the Bay of Fundy as a system and ecosystem, and to determine the type of change(s) occurring, the causes, the interactions, and the pragmatic actions society should take.

2.2.2 Marine environmental quality (MEQ)

Papers covering the concepts and practice of marine environmental quality (MEQ) include DFO (2000), Harding (1992), IOC (1996), Lane (1998), NOAA's many programs re the long-standing USA MEQ Status and Trends Program (T. O'Connor and D. Wolfe, pers. comm.), Percy and Wells (2002), Rapport's many papers, Wells and Côté (1988), and Wells and Rolston (1991).

In Canada, MEQ was defined during the 1980s and early 1990s by the Environment Canada MEQ Working Group (Wells and Côté 1988; Wells and Gratwick 1988; Wells 1991, 1996), and accepted by the federal Interdepartmental Committee on Oceans in 1989.

> MEQ is the condition of a particular marine environment measured in relation to each of its intended uses and functions. It can be described subjectively, especially if stresses impinging on the system are large and if the ecosystem or habitat are obviously degraded. However, MEQ is usually assessed quantitatively for each environmental compartment, on temporal and spatial scales. It is measured using sensitive indicators of natural condition and change. Such measures are interpreted using objectives and limits set by environmental, health and resource agencies (Wells 1991).

MEQ differs from MEH; quality denotes historical recorded change in the condition, whereas health is the present condition and the direction of change (as discussed above; A. Gaston, pers. comm.). However, the terms MEQ and MEH are often used synonomously in the literature, especially the non-technical literature, and importantly in day-to-day practice by conservation and protection groups, to mean 'ocean health' (e.g., IOC 1996; Frith 1999; McGinn 1999). The social and political currency of the term 'health' captured in the context of 'oceans' and 'coastal' was the compelling reason for calling the 1991 report on Canadian MEQ, *Health of Our Oceans*, and likely the reason for the earlier report *Health of the Northwest Atlantic* (Wilson and Addison 1984).

Harding (1992) further explored the MEQ concept and measures, developing a framework focused on chemical contaminants and incorporating the ecological risk assessment components of sources, exposure, effects (indicators), and risk estimation; this was an important conceptual advance to understanding the breadth of MEQ and the importance of linking stresses and effects to management action through risk analysis and management. Chang (1999) and Chang and Wells (2001) developed an MEQ framework for the Bay of Fundy. It shows the linkages between research, monitoring (indicators), objectives/guidelines, assessments, and management response. This framework was very useful at evaluating selected stresses on the ecosystem, e.g., PCBs, mercury and algal toxins.

As with assessments of health and ecological health, MEQ requires indicators and marine environmental guidelines, objectives and standards. The objective is to take measurements of key ecosystem variables and compare values to original baseline conditions. Quantitative guidelines, objectives or standards for air, water, sediments, tissues, and habitats are essential. Underpinning both the choice of indicators and guidelines is research. For example, the Gulf of Maine mussel watch program

(Gulfwatch) is an MEQ program, using an indicators species approach (the mussel), guidelines (largely from human health), and supportive research. Contaminant levels in mussel tissues are measured annually at various stations around the Gulf of Maine; values are compared to earlier ones, and all measurements over time, as part of a status and trends analysis, and the values are compared with environmental and health advisory guidelines (Chase et al. 2001; Jones et al. 2001). The program has given a picture of trace chemical contamination around and across the Gulf in the 1990s; tissue levels of trace contaminants are elevated, stable or often declining, and largely below health guideline values (Chase et al. 2001).

Within the new Canadian Oceans Act (1997), MEQ focuses on the requirement for objectives and guidelines for protecting ocean health, the latter not being defined. However, MEQ activity under the Oceans Act plans to cover research on and testing of indicators of ocean health, the development and use of objectives and guidelines, and the production of assessments of ocean health (DFO 2000). It has also taken on a broader context than just chemical contaminants, although that appears to be the emphasis in an excellent review of contaminants on the Scotian Shelf and the adjacent coastal waters (e.g., Stewart and White 2001). Most recently, the Oceans Strategy of DFO (DFO 2002a,b) considers MEQ under the umbrella of "Understanding and Protecting the Marine Environment", with an emphasis on science support for oceans management (which includes "assessing the state of ecosystem health"), marine protected areas (MPAs) and MEQ guidelines. Canada now has a mandated operational concept of MEQ that should stimulate co-operative multi-agency and multi-partner research, monitoring, MPAs, ecosystem-based guideline development, and ecosystem assessments for its oceans, including the Bay of Fundy and its adjacent waters.

2.3 Connections Between Human Health and Ecosystem Health and Integrity

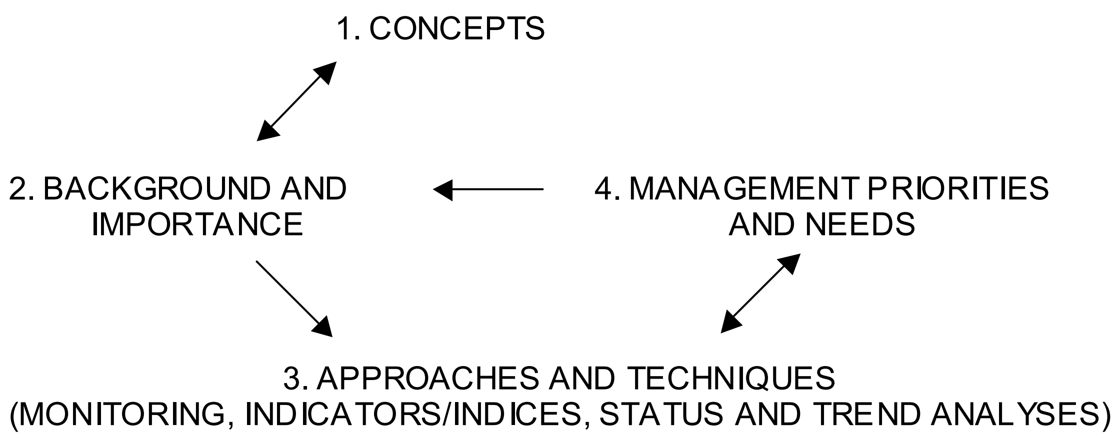
There are obvious connections between human and ecosystem health through air, water, and sediments and soils that have been discussed by many previous authors (e.g., McMichael 1993; di Guilio and Monosson 1996; Knap et al. 2002). These connections are well recognized by environmental scientists, resource managers and policy makers in the context of the Bay of Fundy and greater Gulf of Maine, and they are the imperative for much action in its coastal waters (GOMCME 2002). The second goal of the GOMCME 2001–2006 action plan is to "protect human health and ecosystem integrity" from contaminant exposures – to ensure that " contaminants in the Gulf of Maine are at sufficiently low levels to ensure human health and ecosystem integrity". The plan is currently addressing sewage, mercury and nitrogen. Sewage is the one priority pollutant in the Gulf and Bay of Fundy emphasizing the human-ecosystem health connections without doubt (Hinch et al. 2002, in prep; GESAMP 2001a,b), justifying the large expenditures to reduce the inputs.

3. A Framework for Assessing Health of the Bay of Fundy

The previous section reviewed the concepts of 'ocean health'. This understanding is central to a rigorous technical assessment of the various environments and ecosystems of the Bay of Fundy and Gulf of Maine, including their watersheds. What follows is a brief discussion of some considerations in conducting such an assessment. These include: how (i.e. the contents and approach), how often (i.e. the number and frequency of reports) and with what resources should we be tackling the task of reporting on the State of the Bay of Fundy report(s), and ultimately, preparing the State of the Gulf of Maine report(s)? Such assessment reports will likely appear as a State of the Gulf report or reports as planned for the next few years by the GOMCME (GOMCME 2002), GPAC (GPAC 2001) through its Coastal Forum and Summit process, and BoFEP through its Minas Basin Working Group.

Assessing health of the Bay of Fundy includes: a) understanding the concepts, b) background considerations and importance, c) approaches and techniques, d) indicators and early warning signals, e) status and trends analysis, f) identifying mechanisms for action, and g) identifying new directions for scientific, management and community-led activities. This framework (Figure 1) is meant as a starting point to preparing a comprehensive ecosystem health assessment on the Bay.

Figure 1. Components of a framework for an ecosystem health assessment for the Bay of Fundy/Gulf of Maine



3.1 Dimensions of the Marine Ecosystem Health Concept – A Synopsis

Understanding the concepts of ecosystem health and environmental quality is a cornerstone of any successful report on the health of the Bay and the Gulf. The concepts have been reviewed in the above sections. Marine ecosystems are complex, partially understood (even after >100 years of research), likely to change in unpredicted ways, and perceived differently by the various stakeholders. Having some consensus on the elements of 'healthy ecosystems' to measure and monitor in the habitats around the Bay, i.e. the indicators, and the integration of the data and information into statements of 'health' would allow comparable assessments over the long term, and real knowledge of 'how the Bay and Gulf are doing'. Whereas the 1989 GOMCME report (GOMCME 1989) and the Bay of Fundy report (Percy et al. 1997) were primarily descriptive of the current state or condition, new reports should benefit from the current science of ecosystem health, and advances in many related areas, such as environmental monitoring, data retrieval, analysis and synthesis, and information management and display.

3.2 Background Considerations and Importance of 'Healthy Marine Ecosystems'

The Bay of Fundy and the greater Gulf of Maine are data and information rich areas, historically one of the most studied marine areas on the globe. The region has a number of large, well-established research institutions, many smaller ones, and many active community groups (e.g., GPAC, Coastal Communities Network) and university groups (e.g., RARGOM) (see Schroeder et al. 2001). This puts the region in the unique position of basing new 'health assessments' on the most current and state of the art ecological and resource information, and a background of enormous knowledge and understanding (see the references cited, but note the holdings of libraries such as at the Marine Biological Lab (MBL) at Woods Hole, MA and the Bedford Institute of Oceanography (BIO), Dartmouth, NS). The challenge will be in the approach, selection of indicators, analysis, synthesis and interpretation.

There are now well-recognized linkages between ecosystem health and human health (McMichael 1993; di Guilo and Monosson 1996) or ocean health and human health in its widest context (Knap et al. 2002; many refs.). For the marine environment, examples abound, e.g., algal toxin effects, sewage impacts, trace chemical effects, quality of seafood, reduced use, aesthetics, quality of life. Internationally, the linkage between ocean and human health is being pursued actively through the IOC/UNESCO (Knap et al. 2002; A. Knap, pers. comm.), especially in the context of native subsistence users, and the inhabitants of small island states. For the Bay of Fundy, closed or restricted shellfish beds are the most obvious sign of the social and health impacts of a degraded system (also see Section 2.3).

The other major imperative is an ethical one – that the Fundy and Gulf of Maine ecosystem and their inhabitants equally deserve protection and conservation, and that this should be done as a matter of good ethics and citizen and corporate responsibility. Arguments for the protection and conservation of the natural living resources come before the economic ones. The use of the non-living resources, e.g., minerals or aggregate rocks, which is a growing interest, solely for economic reasons should be pursued with great caution.

3.3 Approaches and Techniques for Assessing the Bay's Health

This section describes some of the essential approaches and techniques for acquiring the data and information, and the analyses essential for an assessment of the Bay of Fundy's health. It refers back to how we study, measure and analyze ecosystem health, and in that context, ecological and ecosystem change (Section 1). There is a large literature and many active programs pertaining to approaches and techniques, not only relating to the Bay of Fundy and the Gulf of Maine. This section is simply meant to be a checklist of components to consider while organizing an assessment.

3.3.1 Monitoring approaches

In Canada, the importance of monitoring and the data that it produces has been reiterated recently with the passage of the Oceans Act (1997). The MEQ component of the Oceans Act includes indicators, guidelines, assessments, but not research and monitoring, explicitly. However, the key role of ocean monitoring is assumed and is slowly being strengthened in the context of programs such as GOOS or Global Ocean Observing System (P. Strain, pers. comm.) and harbor monitoring (e.g., Halifax, J. Hellou, pers. comm.). MEQ has been discussed at the CZC 2000 session on ocean health in Saint John, NB (S. Courtney, pers. comm.) and a Department of Fisheries and Oceans (DFO) winter 2001 meeting on objectives and indicators for ecosystem-based management in Victoria (Jamieson et al. 2001). There is continued monitoring, such as with the Gulf of Maine GOMCME EQ Monitoring committee, with Gulfwatch (Chase et al. 2001; Jones et al. 2001; Jones and Wells 2002). There are the offshore EEM programs, using sophisticated methods of monitoring ocean change and contaminant sources, fate and effects (Gordon et al. 2000). There are also the environmental effects monitoring (EEM) programs applied to and by the pulp and paper industry that use current field ecotoxicology techniques for monitoring.

It is important to mention monitoring activity sponsored by the United Nations system. The Gulf of Maine GOOS program is part of the larger global GOOS of UNESCO/IOC. Some of it goes on under the auspices of Global Inland Waters Assessment (GIWA) and the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA). There is also Global Environmental Facility/Large Marine Ecosystem (GEF/LME) activity (IUCN 1998), with LME assessments taking place globally. There is one for the US Northeast Shelf and one for the Scotian Shelf, both of which overlap the Bay of Fundy (Sherman and Skjoldal 2002). As described above (Section 2.1.3), the pollution and ecosystem health module of each LME covers eutrophication, biotoxins, pathology, emerging disease, and health indices.

> Systematic monitoring data of bio-indicator species including bottom fish and mollusks (Musselwatch) are examined for endocrine disrupters and organ pathology. Water quality and plankton examinations are made for phytoplankton toxicity, eutrophication, persistent organic pollutants, and evidence of emerging disease. Examinations of changing states of health of LMEs are based on indices of ecosystem biodiversity, productivity, yield, resilience, and stability (K. Sherman, pers. comm.).

These examples reiterate the role that systematic monitoring plays in providing the data, short and long-term, essential for any ecosystem health assessment. The initial challenge is two-fold: agreeing on the indicators and finding support for the programs. It should also be recognized that effective marine monitoring programs would benefit from having components of data analysis and interpretation, sample and data management, research on new techniques, and communication, in addition to the basic, routine sampling programs (Jones and Wells 2002).

3.3.2 Indicators and indices

There has been fair agreement in the area of MEH and MEQ indicators over the past few years. Useful papers and reports include: Bilyard 1987; Burger and Gochfeld 2001; EPA 2000a,b; GESAMP 1994a; IJC 1991; Long and Buchman 1989; Nettleship 1997; NOAA 1999; O'Connor and Dewling 1986; Rapport 1991b, 1999; Salánki 1986; Schwaiger 1997; Soule and Kleppel 1998; Thompson and Hamer 2000; Vandermeulen 1998; Van Dolah 2000; and Wichert and Rapport 1998. A synthesis of indicators currently used in USA NOAA coastal programs was assembled for the GOMCME (W. O'Bearne, pers. comm.). The reader should also refer to Section 4, the Coastal Forum, as one of the challenges of this workshop was to discuss, identify and reach consensus on the suite (assemblages) of suitable indicators of health and quality for the Bay of Fundy (Question 3, Coastal Forum).

When one views and considers the size, dynamics and various ecologies and species in the Bay, it is very hard to imagine the Bay's ecosystems being significantly impaired through human activity (with the obvious exception of fisheries; Jackson et al. 2001). The Bay simply appears too large, dynamic, biologically diverse, and ever renewed by the tides. However, scientific programs of research and monitoring tell a different story (e.g., see Proceedings of the first four Fundy Science Workshops – Percy et al. 1997; Burt and Wells 1998; Ollerhead et al. 1999; Chopin and Wells 2001). Parts of the system can become impacted or impaired, in both the short and long-term. So the question becomes: which indicators and indices, used in combination, give the 'best' measure of the state of the Fundy system and/or its component places and parts?

Schaeffer et al. (1988) described four major measures of ecosystem health, which can be tested here – sustainability, activity, organization, and resilience. As stated above, "sustainability implies that the system can maintain its structure and function over time". Basically, the authors are saying that the best indicators are structure, function and resilience of each ecosystem, and that there are readily measured endpoints of these indicators to incorporate into a monitoring program. Karr (1992) states: "the development of indicators is, arguably, the most important step needed to mobilize social support for reversal of the trend towards biotic impoverishment". Many ecological concepts, such as resilience, resistance, connectivity, and ascendancy, may suggest important indicators of a systems condition, but they have practical difficulties – what do you measure operationally in the real world?

It is crucial to use practical, measurable, interpretable and current indicators. There may be a disconnect between the people discussing the concepts of ecosystem health and indicators (Rapport et al. many refs.; Constanza et al. 1992), basic ecologists, and those in the aquatic science field who have been deploying techniques in the field and assessing areas as to health and quality, i.e. condition, for several decades (Soule and Kleppel 1998; Simon 2002). Immense advances have been made in marine environmental monitoring approaches and techniques over the past 3–4 decades. We are not starting at the beginning (e.g., B. H. Sherman's work HEED and Ken Sherman's work LME, above; the existing Gulfwatch program, and similar programs worldwide; many others, especially in selected specialized fields such as the fate and effects of oils spills)! Dr. John Pearce, who has worked in this area for several decades (note McIntyre and Pearce 1980; Pearce 2000; Pearce and Wells 2002; Pearce, this volume, pages XX) has offered valuable insights as to the appropriate set(s) of indicators to use for measuring ecosystem health in the Gulf of Maine. As shown by Butler (1997), even single well-known species act as easily monitored 'sentinel species'.

Finally, Smiley et al. (1998), in an internal Canadian review of indicators on MEH (not differentiated from MEQ), reached two conclusions useful to the discussion of appropriate indicators for the Bay of Fundy: (1) The development of indicators to measure MEH generally involves the following key steps: a) scope the issues, b) evaluate the knowledge base, c) select indicators, and d) conduct targeted research and monitoring of the indicators; and (2) The ABC's of selecting indicators are: a) some indicators should be related to ecosystem structure and function, b) some indicators should be selected (and deployed!) in combination, and c) indicators should be selected using the guidance of criteria acceptable to all involved parties.

3.3.3 Status and trends analysis

Indicators should be deployed so as to answer the question: Is the quality of the Fundy marine ecosystem (or parts of it) getting better or worse in the short and longer term? This requires substantial data bases for status and trends analysis. A number of monitoring programs for coastal waters have selected measures of health and quality that allow for such analysis. That is, measurements of selected variables in water, sediments and biota are conducted over space and time to provide a longer term picture of the magnitude of the response and the direction of change.

Examples include: Gulfwatch for trace chemical contaminants (Chase et al. 2001; Jones et al. 2001); algal toxins (as per the Harmful Algal Blooms program); input of aerial contaminants (Clair et al. 2002, acid rain; R. Cox, pers comm., toxic chemicals in fog; E. Sunderland, pers. comm., mercury in air and marine sediments); bacterial levels along the coasts, especially at shellfish beds; condition, i.e. catch statistics, of specific fisheries; state of the water and benthic environments around aquaculture operations; numbers and locations of tidal barriers or obstructions; location of dykes, maintained and un-maintained; sediment quality at selected sites (K. Tay, pers. comm.); nutrients, especially nitrogen; and sewage treatment and effects. Ultimately, the current status and trends programs will provide data for a major chapter on this question of 'better or worse' or no change in the State of the Bay of Fundy/ Gulf of Maine Report(s).

3.4 Connecting with Management Priorities and Needs

A section of the planned State of Fundy/State of the Gulf Reports should address management priorities and needs (at various levels, in various sectors), and present recommendations as to how to proceed with future reports. The whole process is started with and finished with management support and involvement. No single report or report card on the Bay will be perfectly completed. How can such reports be improved? What do we need? Is a series of reports on different issues, treated in depth separately, more useful than periodic tomes covering all issues? These questions were addressed more fully in the Coastal Forum (this Proceedings, pages XX). This is simply an introduction to stimulate discussion between the practitioners of monitoring and assessments, and the clients, the managers and the coastal communities.

3.4.1 Mechanisms for action

Do we have the information, human capacity and resources to produce periodic State of the Bay of Fundy Reports? Importantly, do we have the resources to continue to monitor selected variables, i.e. indicators in the Bay, so that the data and information bases remain current and relevant? What else do we need to have? Who do we direct these to?

3.4.2 New directions

There are a number of needs and new directions to consider (also see discussion from the Coastal Forum), given the role of research, monitoring, assessment and information management in reports on the ecosystem health of the Bay of Fundy. They include:

1. More of a collective vision of the stakeholders as to what they envisage the Bay of Fundy and its watershed(s) to be like in 20, 50, 100 years time, and the mechanisms to protect and conserve their natural features and living resources.
2. More research as per practical monitoring tools (e.g., Rapid Assessment of Marine Pollution (RAMP), Wells et al. 2001; the expanded Gulfwatch program).
3. More resources into MEQ and MEH monitoring and data analysis (such as HEED effort).
4. More attention to the networking of existing programs involved in monitoring and assessment and guidelines – linked together.
5. More practitioners in monitoring and assessments are needed.

4. The Coastal Forum: "Taking the Pulse of the Bay of Fundy"

4.1 Guiding Questions for Discussion

There are five important questions – simply stated but not necessarily simply answered. This was a starting point to the open workshop discussions. It assumed and hoped that other pertinent questions pertaining to the overall goal would likely appear! The five questions are:

1. What is the present health or condition of the Bay of Fundy?
2. Are conditions improving or deteriorating?
3. What kinds of indicators do we consider most useful in trying to answer these questions?
4. Are there adequate resources (institutional, financial, scientific, etc.) to protect or restore the health of the Bay?
5. What kinds of new information and approaches do we need to protect the health of the Bay?

As shown in these Proceedings (Section XX, pages XX), the workshop participants addressed the questions from their own perspectives, using their own knowledge, and making use of the new information presented at the meeting (as well as at the previous meetings).

4.2 Developing the Synthesis

To assess the health of the Bay of Fundy, it is necessary to summarize and evaluate the data from the chosen suite of ecological health/environmental quality indicators. For example, and following from previous examples (various US Environmental Protection Agency (EPA) reports; Wells and Rolston 1991; Costanza et al. 1992), one could take ten indicators, reached by consensus, and summarize the data for them in a number of locations around the edges of the Bay (Note: stresses often occur at edges or interfaces, a topic in itself!). The process is: rank the results of each of the ten indicators, each indicator being marked out of 10 (e.g., 1 – very clean/undisturbed, 10 – very dirty/very disturbed). Then add the scores, 100 being the top score (1–25: very good; 26–50: good to marginal; 51–75: compromised and disturbed; 76–100: very affected/extreme disturbance).

For some indicators, the values assigned could and should be determined by comparison with existing guidelines, objectives or standards, e.g., contaminant levels in sediments, using the Canadian Environmental Protection Act values; tissue concentrations of contaminants, US Food and Drug Adminstration (FDA). The scores (1 to 100) could be portrayed as circles (open to filled in) or circles with colors (green, yellow, orange, red – an EPA technique), and be placed on a map of the Bay of Fundy to give a visual portrayal of the health and quality, in general, of the Bay. (See EPA reports that have used this technique (EPA 1998), as well as Chapter 6, Wells and Rolston 1991.) Arrows can also be included to show direction of change. The summary across the table, in a row, gives the extent of the problem across the Bay using each indicator. The summary down the table, in a column, gives an impression of the number of stresses affecting one ecosystem or area of the water body (i.e. the Bay of Fundy), hence an impression of the potential for cumulative change in one area of the Bay.

It is important to recognize the problems with the above approach. The big problem with this approach is its linearity – all indicators and indexes are given the same weight in the analysis, whereas in reality, some stresses, e.g., habitat loss, may exceed in total impact another stressor, e.g., periodic low DO (dissolved oxygen). However, this could be accommodated at a local level, with different indicators being given different percentages of the total scores (up to 100). A second problem is that the relative impacts of stresses will change across seasons, e.g., bacterial levels in shellfish growing areas; tourism-wildlife interactions; harmful algal blooms. Finally, a number of the stresses cannot be easily or accurately quantified, i.e. measured, so judgement has to be used, e.g., impact of whale watching boats on the behaviour of whales. Certainly, the reader can think of more limitations and resolve them! The limitations notwithstanding, the approach is a beginning of a comprehensive discussion, ranking and synthesis of the issues and stresses on the Bay. As shown in these Proceedings, it was used successfully in the Coastal Forum.

5. Summary and Conclusions

The paper discusses the concepts of health and ecosystem health, and introduces components of a framework for assessing the Bay of Fundy. Several challenges faced the participants of this 5th Bay of Fundy Science Workshop and Coastal Forum, as they met and discussed issues, approaches and indicators for two and one half days. Some conclusions were reached by this author. We collectively have to address and understand the concepts and dimensions of the topic of 'marine ecosystem health' and 'marine environmental quality (MEQ)' in the context of the Bay of Fundy and Gulf of Maine, if the goal remains to produce a 'health assessment'. We will have to organize, assimilate and summarize a large amount of historical and recent data and information in order to evaluate the 'health' of the Bay. We should strive to be constructively critical when interacting between disciplines and between sectors, in this activity of ecosystem health assessment. Finally, we have to consider how often and with what venue we should continue to meet and discuss the benchmark measures or indicators, to organize a synthesis, and finally to assess whether we are or are not achieving the task of protection, conservation and restoration of the Bay, its vital watersheds, and their natural resources.

6. Acknowledgments

Many scholars have contributed to this field; they are thanked for their obvious dedication to an understanding of ecosystem health and to the ecology of the Bay of Fundy. Discussions with colleagues, especially those with BoFEP, GESAMP, GOMCME and GPAC, encouraged continued thought about this topic. Questions for the Fundy Coastal Forum were developed in discussion with Graham Daborn, Barry Jones, Jon Percy and Maxine Westhead, all members of BoFEP. The paper is dedicated to the memories of three outstanding Bay of Fundy scientists at the Bedford Institute of Oceanography, Dartmouth, NS – Dr. Kathy Ellis, Mr. Nicholas (Nick) Prouse, and Dr. Peter Schwinghamer.

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