Developing an Environmental Health Index for the Bay of Fundy

Prepared for the Bay of Fundy Ecosystem Partnership by
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EXECUTIVE SUMMARY

The Bay of Fundy Ecosystem Partnership (BoFEP) has undertaken a project to determine the feasibility of producing an environmental health index (EHI) for the Bay of Fundy. EHIs typically combine the assessments of a number of environmental indicators, such as dissolved oxygen levels, population densities, greenhouse gas emissions, etc. into one score, number, or grade. This score is meant to represent the overall state or health of an ecosystem. EHIs are seen as a simple way to communicate complex information about the state of an ecosystem to stakeholders, policy makers, and the general public. BoFEP believes the development of an EHI will allow it to answer the question, "How healthy is the Bay of Fundy?" Knowing and communicating this will help promote protection of the Bay's ecological integrity, which in turn will enhance the social and economic well-being of the Bay's coastal communities.

The project has three parts. The first part identified seven marine EHIs that could be used as models for a Bay of Fundy EHI. The second part of the project was to conduct a workshop on April 3, 2013 in St. Andrews, New Brunswick, to gather input on the development of a Bay of Fundy EHI from individuals knowledgeable about the Bay's culture, ecology, and economy. The final part of the project is the writing of this report. It provides to readers a short introduction to EHIs, summaries of the seven example EHIs, outcomes of the workshop, a listing of likely environmental indicators that are available for use in a Bay of Fundy EHI, and BoFEP's next steps in developing a Bay of Fundy EHI.

At the conclusion of the workshop, the attendees proposed that the methodology of the Ocean Health Index (OHI) be tested by trying to develop an OHI score for the Southwest New Brunswick Bay of Fundy Marine Resources Planning Area. The OHI was developed by a group of over 60 marine researchers who published a global score for the world's oceans in 2012. This report compares the OHI to the desired characteristics of an EHI for the Bay of Fundy. This comparison highlights reasons why use of the OHI has potential. In particular, people who live around the Bay of Fundy value it not simply for its ecological aspects, but also for its social, cultural, and economic uses. Unlike most EHIs, the OHI includes indicators that encompass these four values. For this reason, it is believed on OHI score for the Bay of Fundy will resonate with stakeholders.

The OHI is not perfect. The calculation of an OHI score for the Bay of Fundy will require a lot of data, all of which may not be available. Also, while the calculation of the final OHI score is relatively straight-forward, determining the status of the ten indicators that comprise the score requires the use of complex calculations, most of which will not be understood by the public. There are also concerns the OHI places too much emphasis on human uses of oceans.

The report concludes with the premise that there is no perfect EHI for the Bay of Fundy and that continuing to search for this mythological beast will not be fruitful.

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1. BACKGROUND TO THE PROJECT

The Bay of Fundy Ecosystem Partnership (BoFEP) is a knowledge network that is dedicated to: 1) promoting the ecological integrity, vitality, biodiversity and productivity of the Bay of Fundy ecosystem, in support of the social well-being and economic sustainability of its coastal communities, and 2) facilitating and enhancing communication and co-operation among all citizens interested in understanding, sustainably using and conserving the resources, habitats and ecological processes of the Bay of Fundy. It is a "virtual institute" that links people and organizations who work together for the promotion of an ecologically and socially sustainable Bay of Fundy.

Throughout its work, members of BoFEP are repeatedly asked by community members, policy makers, media, etc., "Is the Bay of Fundy healthy?" However, as those who work in the environmental sciences know, eyes often quickly glaze over when one tries to communicate "ecosystem health" using multiple trends, analyses, and statistics. What's typically wanted is a yes/no answer and a simple explanation why.

Looking at the work of other organizations, BoFEP believes that an environmental health index (EHI) score or report card grade would be an effective way to communicate information about the condition of the Bay of Fundy ecosystem. What is it now seeking is a methodology for the creation of this score or grade. With support from Environment Canada, BoFEP has undertaken this project to determine the feasibility of producing an EHI for the Bay of Fundy. (Throughout the remainder of this report environmental health indexes and report cards, although somewhat different, will be referred to collectively as EHIs.)

The project has three parts. The first part of the project focused on researching different marine EHIs used by various organizations around the globe. From this review, seven marine EHIs were chosen as possible models for a Bay of Fundy EHI.

The second part of the project was to conduct a workshop on April 3, 2013 in St. Andrews, New Brunswick. The purpose of the workshop was to gather input on the development of a Bay of Fundy EHI from individuals knowledgeable about the culture, ecology, and economy of the Bay of Fundy. Prior to the workshop, a summary of the seven example EHIs was written and shared with workshop invitees.

The final part of the project is the writing of this report. It provides to readers a short introduction to EHIs, summaries of the seven example EHIs, outcomes of the workshop, a listing of likely environmental indicators that are available for use in a Bay of Fundy EHI, and BoFEP's next steps in developing a Bay of Fundy EHI.

2. ABOUT ENVIRONMENTAL HEALTH INDEXES

2.1 What is an "environmental health index"?

An **environmental health index** is a single value (or score) that represents the aggregated individual scores of a group of **environmental indicators** (UNEP 2006, Veale 2010, de Sherbinin *et al.* 2013). A grade point average (GPA) can be thought of as an index of your academic standing. Each course, such as math, science or English, is an individual indicator for which you receive a mark. Your GPA is the average of the marks you received for all of your courses. An **environmental report card** takes this one step further by assigning a value statement, and perhaps a grade, to an index score. For example, an ecosystem with an index score of 80 and above might be described as "very good" and receive an A+ grade.

2.2 What is an environmental indicator?

De Sherbinin *et al.* (2013: 6) define **environmental indicators** as being **"**metrics derived from observation (i.e., data) that are used to identify indirect drivers of environmental problems (e.g., population or consumption growth), direct pressures on the environment (e.g., overfishing), environmental conditions (e.g., air pollution concentrations), broader impacts of environmental conditions (e.g., health outcomes), or effectiveness of policy responses (OECD 1991). Indicators can either represent current status or trends (e.g., percent change or slope over some specified time period)."

The OECD (2001: 133) description of indicators is similar, with an indicator being "a parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/ environment/area, with a significance extending beyond that directly associated with a parameter value".

There are a huge number of indicators being used, or suggested, to measure the state of various segments of the environment. The International Institute for Sustainable Development (IISD) reported that in 2005 there were 669 entries in its *Compendium of Sustainable Development Indicator Initiatives* (Pintér, Hardi, and Bartelmus 2005). Halpern *et al.* (2012a: 1) noted that "hundreds of specific indicators exist to measure various aspects of ocean condition". Choosing which indicators to use in an EHI is a science itself.

2.3 Purposes of environmental indicators and indexes

After an extensive review of the literature, Veale (2010) provides a list of the purposes of environmental indicators. Quoting from her thesis (at p. 49), she writes that indicators can be used to:

1. Track progress towards sustainability objectives and targets,
2. Report on current conditions and key social, economic, environmental, and decision-making trends,
3. Identify information gaps and research priorities,
4. Anticipate undesired conditions before they happen,
5. Identify causative agents,
6. Demonstrate interdependence between indicators to make the assessment process more cost-effective,
7. Promote public awareness and dialogue that will improve decision making, guide policy, and increase the transparency of possible trade-offs,
8. Facilitate action and community empowerment, and
9. Create a shared vision for the future of the [ecosystem in question, such as a watershed].

In other words, environmental indicators help us to assess the state of an ecosystem, quantify human impacts on an ecosystem, and verify the results of management and conservation efforts directed towards an ecosystem (Rombouts *et al.* 2013). As Wells (2005) points out, environmental indicators are invaluable in helping us comprehend the state of large and complex ecosystems like the Bay of Fundy.

As EHIs are simply aggregates of environmental indicators, EHIs can be and are used for these same purposes. At the same time, there are advantages to calculating and reporting an EHI score versus simply providing a list of findings for the assessments of one or more indicators. As discussed earlier, extrapolating from a small number of indicators may not provide an accurate picture of the state of an ecosystem. Providing data from too many indicators can also be confusing. Environmental indexes "have the advantage of giving an overall picture of a system's performance in a simple but compelling way and are often the means of choice in [State of the Environment] reporting to inform decision-makers [and the public]" (UNEP 2006: 5). Also, because index scores are typically calculated using some method of weighting, e.g., by area, the state of an ecosystem in one region can be ranked in comparison to the state in other regions (Halpern *et al.* 2012a).

Returning to the earlier example, a grade point average is useful because it provides in one concise number a snapshot of your academic achievements, rather than having to explain, "I scored an 80 in math, a 70 in science, and a 75 in English." As well, perhaps you are a math whiz and struggle with English. Looking at a score from only one of these courses would not provide an accurate picture of what kind of student you are. Finally, comparing your GPA to another student's would quickly tell someone whether you are the better or worse student academically.

2.4 Some shortcomings of environmental indexes

Oversimplification

Ecosystems and the relationships within them are incredibly complex. We also have a limited understanding of what causes changes to ecosystems, or if we can identify the agents of change, how they cause the changes. If we describe the state of an ecosystem using too few indicators or with one EHI score, we run the risk of hiding or diminishing the importance of these complexities. UNEP (2006) describes an example of using the indicator of fishing catch to assess the state of a fish stock. High fishing catches may mean there are lots of fish. Unfortunately, collapses of fish stocks, like cod, are often preceded by high catches. Therefore, we either need to use an indicator that better reflects what is going on in the ecosystem or another indicator to complement the fishing catch indicator.

What to measure

To be meaningful to an audience, or have *resonance* (de Sherbinin *et al.* 2013: 11) with it, an EHI has to report on what matters to that audience. There is also a problem with bias in the selection of indicators for the EHI. If you want to "prove" an ecosystem is in poor health or vice versa, you are likely to select indicators to support your view. As such, choosing indicators is not simply a scientific exercise, but one that involves values and politics (Veale 2010).

Data availability

A review of different EHIs reveals they all struggle with the tension of what indicators they would assess in a perfect world versus those they can practically and realistically assess. Data for some possible indicators in an EHI may not be available, or believed to be too expensive or to take too long to collect. As a result, EHIs often have to rely on less than ideal indicators, resulting in a score that is less accurate or representative of the state of an ecosystem than it could be. (As highlighted by Veale above though, the development of an EHI can identify information gaps and research priorities.)

The use of thresholds

The measurement of an indicator results in a value or number (e.g., level of dissolved oxygen, number of fish species), or a time series of values such as a trend over a period of years. The development of an EHI score requires the comparison of these values to a reference condition, benchmark, or threshold so that a score can be determined for each indicator used in the EHI. For example, if the expected number of fish species that should be observed in an area is 50 and monitoring shows there are only 40 species, that indicator might receive a score of 80 or 80%. The difficulty lies in picking thresholds that are ecologically correct or relevant and are not biased or skewed to support a pre-conceived result.

Weighting

How much should each individual indicator score contribute to the final EHI score? Do they all receive the same weight (e.g., if there are 10 indicators, do they each contribute 10% to the EHI score)? As will be seen in the review of seven EHIs below, some EHIs assign different weights to different indicators. There can be bias in assigning these weights (Pintér, Hardi, and Bartelmus (IISD) 2005). As Halpern *et al.* (2012a: 3) note, "Because goal weights can influence index scores, it is critical to determine societal values (weights) before index calculation."

Masking of problems

Because EHI scores are the aggregate of the scores for a series of indicators, they may hide the poor state of a particular indicator or a sub-region of the ecosystem being scored, resulting in the delay of or failure to take action to address the problem. Returning to the earlier grade point average example, on its face a GPA of 7.5 out of 10 may look good, but without looking deeper, you would not know that it resulted from the student scoring 100% in math and 50% in English.

3. EXAMPLES OF ENVIRONMENTAL HEALTH INDEXES AND REPORT CARDS

As part of this project, BoFEP reviewed a number of different marine environmental health indexes and report cards. Following this review, the seven examples below were chosen as possible models for the development of a Bay of Fundy EHI.

3.1 *Ocean Health Index* (OHI)

The OHI was chosen for several reasons. First, it is used at the largest scale. It calculates scores for countries' exclusive economic zones (EEZs) and aggregates these to come up with a score for the world's oceans. Unlike many other EHIs, it incorporates indicators that assess human uses of the ocean, such as food provision and tourism, rather than those that only assess its ecological state. Finally, whether one agrees with the OHI or not, there is no doubt that it is the result of a significant amount of time, money, and scientific knowledge and expertise.

3.2 *U.S. EPA National Coastal Condition Report IV* (NCCR IV)

The U.S. EPA's NCCR IV was chosen as an example because it assesses an ecosystem, the U.S. Northeastern coastal area, which is ecologically similar to the Bay of Fundy. It uses a much less complex methodology than the OHI. It is also the result of a significant expertise and resources.

3.3 *European Water Framework and Marine Strategy Framework Directives* (WFD and MSFD)

Like the OHI and NCCR IV, the WFD and MFSD are aimed at the assessment of the state of larger systems. What makes the WFD and MSFD different from the OHI and NCCR IV is they rely on normative definitions to assess a waterbody's ecological status versus the use of pre-determined numeric threshold values. This provides flexibility in how the WFD and MSFD can be used by different countries.

3.4 *South East Queensland Environmental Health Monitoring Program* (EHM Program)

The EHM Program was chosen as a model because it is well respected and displays its scoring results in an effective way. Its methodology is less complex than the OHI, but it also uses some indicators that are atypical of most EHIs, such as the results of sewage plume mapping.

3.5 *Integration and Application Network Chesapeake Bay Report Card*

The Chesapeake Bay Report Card was provided as an example of an EHI that is calculated using a very straight-forward methodology and a small number of indicators.

3.6 *Australia State of the Environment (2011) – Chapter 6: Marine Health* (AUS SOE)

Unlike the other examples, the AUS SOE used a system of polling marine science experts to determine the status of Australia's marine waters.

3.7 *Eastern Scotian Shelf Integrated Assessment* (ESS IA)

The ESS IA is not an EHI or report card. It was provided as an example of a different way to analyze data and display the results of this analysis in the event that BoFEP could not settle on a suitable EHI method for the Bay of Fundy.

Provided below are summaries of the above seven EHI examples. The summaries provide overviews of the seven examples and the methodologies they use to arrive at their grades or scores. The summaries also list the indicators used by each of the example EHIs and a significant pro and con of each example as a possible model for a Bay of Fundy EHI.

3.1 Ocean Health Index

The goal of the Ocean Health Index (OHI) is to provide "a robust, widely applicable tool for **ongoing assessment of ocean health** based on well-accepted societal goals and a key benchmark against which to compare future progress and inform comprehensive ocean policy" (Halpern *et al.* 2012a: 4). The OHI is based on the assessment of ten goals, and for some goals, their sub-goals for all waters within 171 exclusive economic zones (EEZs). The OHI allows comparisons of rankings across goals, countries, and the globe. The OHI is presently being tested at smaller regional scales in the United States, Brazil and Fiji (Halpern *et al.* 2012a).

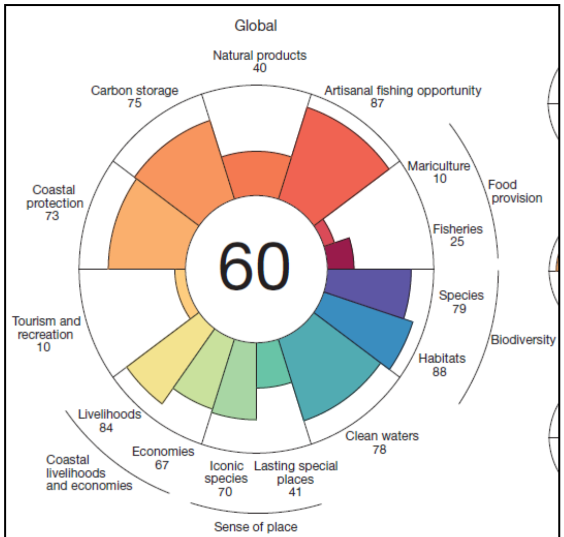


Figure 3 (from Halpern *et al.* 2012a): Index scores (inside circle) and individual goal scores (coloured petals) for global area-weighted average of all countries.

The OHI does not measure ocean health by determining how far from "pristine" (i.e., without human impacts) the ocean's state is. Instead, its developers have taken the position that humans are now deeply part of all ecosystems. As a result, the OHI approach to scoring ocean health, rightly or wrongly, "departs from a purely protectionist one that would aim to maintain natural systems with minimal human impact. The index credits sustainable non-extractive and extractive use, except in places where such uses are prohibited (for example, no-take reserves), as well as preservationist goals" (Halpern *et al*. 2012a: 3). This view of the ocean as a "coupled human-natural system" influenced the selection of the OHI goals.

One concern about the OHI is that it favours human use of the oceans too much. For example, certain goals, such as 'natural products', receive better scores when harvest levels are higher. A country can receive a low score for the goal 'food provision' if its fishing catch is below 75% of maximum sustained yield (MSY). Halpern *et al*. (2012a) stress a good OHI score is predicated on these catches being sustainable, but an all-too-easy to do over-calculation of MSY can have a disastrous impact on a fish stock. Also under the OHI methodology, a high score in one goal such as 'food provision' likely leads to a lower score in another goal, such as 'biodiversity'. As Halpern *et al.* (2012a: 2) note, 'Trade-offs probably occur among many goals, such that simultaneously achieving perfect scores on all goals would be difficult." As a country would receive the same OHI score if its score for the extractive goal 'food provision' was 80 and the preservationist goal 'biodiversity' was 20, and vice versa, the OHI appears to give exploitation and protection of the ocean the same weight.

Finally, Halpern *et al.* (2012a: 5) discuss three issues they faced in their development of the OHI. "First, we limited the index to ten constituent goals primarily for parsimony and ease of communication…We recognize that this structure significantly influences our results. Second, gaps existed in many data sets that we used, requiring proxies or models to fill those gaps. For example, international arrivals data provide a modest proxy for coastal tourism ('tourism and recreation' goal) and undervalue the goal in nations with significant domestic tourism. Likewise, no global data exist for important stressors such as illegal fishing, habitat loss rates and point-source pollution. By identifying these data gaps, the index can help motivate future data collection. In other cases, we had to forgo better quality, region-specific data to maintain global consistency...Finally, key knowledge gaps remain, particularly regarding reference points. The 'mariculture' sub-goal provides an example, where production data are available with appropriate global coverage <u>but sustainability indicators are incomplete</u>..." (emphasis added).

Method for calculating the Ocean Health Index Score

- The developers of the OHI used a list of criteria (see **Table 3**) for the development of the OHI and the selection of the OHI's goals (i.e., indicator) and sub-goals (i.e., sub-indicators).
- The score for each goal (max. = 100) is calculated by combining the values of four dimensions (current status, trend, pressures, and resilience). (See Figure 1 from Halpern *et al.* 2012a).
    - "Present Status is a goal's current value (based on the most recent available data) compared to a reference point" (OHI undated).
    - "Trend is the average percent change in the present status for the most recent 5 years of data" (OHI undated).
    - "Pressures are the sum of the ecological and social pressures that negatively affect scores for a goal" (OHI undated).
    - "Resilience is the sum of the ecological factors and social initiatives (policies, laws, etc.) that can positively affect scores for a goal by reducing or eliminating pressures" (OHI undated).

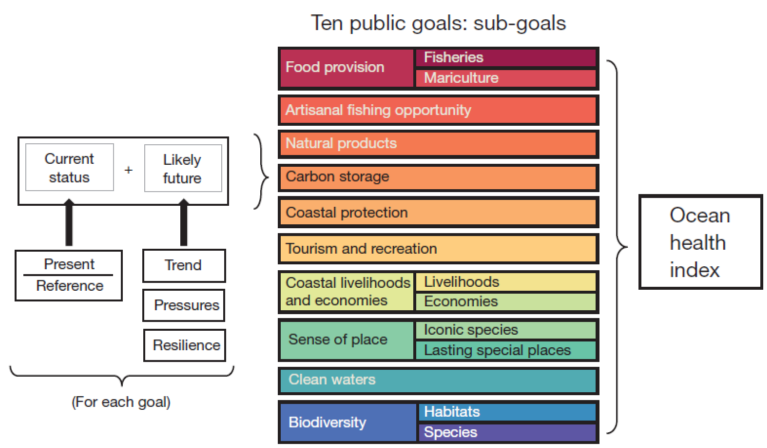


Figure 1 | **Conceptual framework for calculating the index.** Each dimension (status, trend, pressures and resilience) is derived from a wide range of data. Dimensions combine to indicate the current status and likely future condition for each of ten goals (see equations in Methods Summary and equations (1) and (4) in Methods). Colour scheme is also used in Figs 3–6.

From Halpern *et al.* 2012: 1.

- The value of a dimension for each goal was calculated using a distinct, and in some cases complex, equation, which in turn incorporated data and reference points from a large number of sources.
    - Close to seventy data layers were used in the calculation of the global OHI score. (See **Table 2** for an example of the data layers used to calculate an OHI score for the OHI goal 'Food Provision'.)
    - The proper summarization of the multitude of equations used in calculating the OHI is beyond the ability of the writer. The methods summary from Halpern *et al.* (2012a) for calculating the global OHI score is reproduced below as an example of the type of calculations used in the OHI (see **Figure 1**). Further methods and supplementary information for each goal and weighting method are available from Halpern *et al.* (2012b).
- Reference points for the OHI were determined four ways: mechanistically using a production function (e.g., maximum sustainable yield, MSY, for fisheries), spatially by means of comparison with another region (e.g., country X represents the best possible known case), temporally using a past benchmark (e.g., historical habitat extent), or in some cases via known (e.g., zero pollution) or established (e.g., 20% of waters set aside in MPAs) targets (Halpern *et al.* 2012b).
- Quoting from OHI (undated), "The score for each goal is the average of the values for the Present Status and Likely Future Status. Likely Future Status is determined by combining the Trend, Pressures, and Resilience values. Trend is considered twice as important in indicating the likely future state as the combined role of Resilience and Pressures, because trends are a more direct measure of the future trajectory of a goal. Resilience measures require more time to take effect, and changes are often slow to register. The Ocean Health Index does not attempt to indicate conditions further than 5 years into the future.

Likely Future Status is calculated as:

Likely Future Status = Present Status x {1 + (0.67 x Trend) + 0.33 x (Resilience – Pressures)}

Using Likely Future Status, each goal score is computed as:

Goal Score = (Present Status + Likely Future Status) divided by 2."

- Quoting from OHI (undated), "The Ocean Health Index combines the 10 goal scores to calculate the overall score for each Exclusive Economic Zone (EEZ). The global score is the area-weighted average of the scores for all EEZs."
  - "The weights that are applied to the ten goals to calculate the single Index score were assumed to be equal [10 percent each], even though we know this assumption does not hold for the value sets of most individuals, or likely even averaged across individuals within communities" (Halpern *et al.* 2012b: 12).
- By averaging the goal scores, a single score can be generated for a country (EEZ) or the globe.

Significant pro and con as a model for a Bay of Fundy report card:

Pro: The OHI allows for easy communication of a tremendous amount of complex information.

Con: Calculating scores for the OHI requires using complex equations that will not be understood by the public.

Website: http://www.oceanhealthindex.org/

Videos that describe the Ocean Health Index:

- AAAS 2012 Presentation B. Halpern: Assessing the Health of the World's Oceans (http://vimeo.com/47266403)
- OHI Methodology (http://vimeo.com/47257137)
- AAAS 2012 Presentation K. McLeod: From Metaphor to Measurement (http://vimeo.com/47266404)
- AAAS 2012 Presentation C. Longo: Flexible Applications of the Ocean Health Index (http://vimeo.com/47266407)
- AAAS 2012 Presentation J. Samhouri: Reference Points for Ocean Health (http://vimeo.com/47266406)
- AAAS 2012 Presentation H. Leslie: Applying Knowledge of Human-Ocean Connections at the Local Scale (http://vimeo.com/47266408)

TABLE 1: Example of OHI goals and scores for globe and Canada.

Goal	Global score	Global score x 0.1	Canada score	Canada score x 0.1
Food provision	24	2.4	63	6.3
Artisanal fishing opportunity	87	8.7	96	9.6
Natural products	40	4.0	74	7.4
Carbon storage	75	7.5	55	5.5
Coastal protection	73	7.3	98	9.8
Tourism and recreation	10	1.0	15	1.5
Coastal livelihoods and economics	75	7.5	68	6.8
Sense of place	55	5.5	46	4.6
Clean waters	78	7.8	89	8.9
Biodiversity	83	8.3	93	9.3
OHI Score		**60**		**70**

TABLE 2: Data layers used in each dimension for the OHI goal 'Food Provision' (taken from Halpern *et al.* 2012b: Table S22).

Goal	Sub-goal	Dimension			
		Status	**Trends**	**Pressures**	**Resilience**
Food Provision	**Fisheries**	Multispecies maximum sustainable yield (mMSY)	Change in Status over time	Chemical pollution	CBD[1] habitat
				Nutrient pollution	
				Habitat destruction: subtidal hard bottom	Marine protected areas, Exclusive Economic Zone
				Habitat destruction: subtidal soft bottom	
				Habitat destruction: Intertidal	Fisheries management effectiveness
				Alien species	
		Taxonomic reporting quality		Genetic escapes	Access to artisanal fishing
				Commercial fishing: high bycatch	
				Commercial fishing: low bycatch	Ecological integrity
				Artisanal fishing: high bycatch	
				Artisanal fishing: low bycatch	Worldwide Governance Indicators
				Social pressure	
	Mariculture	Mariculture yield	Change in Status over time	Chemical pollution	CBD[1] water
					CBD mariculture
		Degree of sustainability of culture		Nutrient pollution	Mariculture regulations
				Social pressure	Worldwide Governance Indicators

[1] Convention on Biological Diversity

TABLE 3: OHI design criteria for indicator development and data selection (taken from Halpern *et al.* 2012a).

1. **Known functional form and reference point.** One needs to have a reasonable idea of the functional form for the response of a goal or component of a goal to changes in intensity of a driver of change, as well as the reference point against which to compare any given state.	8. **Multiple methods to calculate.** The components of the Index can be calculated using different methods that allow for and respond to different qualities and quantities of data.
2. **Consistent directional change.** The Index or component needs to change in a consistent direction across systems and geographies to allow for direct comparability across systems.	9. **Captures coupled social-ecological system**. Accurately and comprehensively represents the interactions and interdependencies of natural and human systems.
3. **Robust to inclusion of missing values.** Because data quality can vary greatly among and within data sets, components of the Index must be robust to missing or poorer quality data.	10. **Allows for discounting.** In cases where components are more or less important, and when considering the Index across different time frames, it is clear and possible how to include discounting of different parts of the Index.
4. **Responsive to management.** Changes in management or policy need to create changes in the Index so that there is proper incentive for action.	11. **Cost effective, practical, and available data**. Without easily available data, the Index cannot function.
5. **Applicable across scales.** The Index must work at any and all scales to ensure its relevance and applicability to any potential management situation.	12. **Complementary and not redundant.** With so many existing indicators, the Index needs to complement and leverage these indicators and avoid producing similar output.
6. **Responds quickly.** The Index needs to respond quickly to any change within the system so that it is meeting the purpose of having an Index.	13. **Transparency.** The construction of the Index needs to be transparent and open-access to allow full access to how it is calculated.
7. **Understandable.** The purpose, intent, and construct of the Index and its components need to be easy to understand and straightforward to communicate.	

We define the index as the condition of ten widely accepted public goals for ocean ecosystems and Supplementary Information), which include but are not limited to established ecosystem services (for example, 'coastal livelihoods and economies' is not an ecosystem service). The index (I) score is the weighted sum of ten goal-specific index scores (I_i):

$$I = \sum_{i=1}^{N} x_i I_i$$

where $\propto_i$ is the goal-specific weight ($\sum \propto_i = 1$; default is $\propto_i$ = 1/N) and I_i is the average value of present and likely future status, $I_i = (x_i + \hat{x}_{i,F})/2$, for each goal i. The present status of goal $i(x_i)$ is its present status value (X_i) relative to a reference point $(X_{i,R})$ uniquely chosen for each goal following guiding principles, and rescaled $0 - 100$. The likely future status ($\hat{x}_{i,F}$) is a function of present status (x_i), recent (~5 year) trend (T_i), pressures (p_i), and factors that promote resilience (r_i), such that

$$\hat{x}_{i,F} = (1 + \delta)^{-1}[1 + \beta T_i + (1 - \beta)(r_i - p_i)]x_i$$

where the discount rate $\delta = 0$ and the weighting term $\beta = 0.67$, giving trend twice the importance of the difference between resilience and pressures in determining likely future state. We tested the sensitivity of results to assumptions about δ and β and found minimal differences for near-term timeframes. Assessment of the likely future status captures whether the present status is likely to persist, improve or decline in the near-term future, based on current status (x_i) and trends, and is therefore an indication rather than prediction of the near-term future. Ecological pressures fall into five broad categories—pollution, habitat destruction, species introductions, fishing and climate change—and are weighted equally to social pressures (such as poverty, political instability and corruption), with resilience measures such as international treaties and ecological resilience included when they address pressures relevant to a particular goal. The inclusion of these factors ensures that the index is responsive to changes that are reflected more slowly in the current state.

Figure 1: Methods summary for calculating the global OHI score. (From Halpern *et al.* 2012a: 5-6.)

3.2 U.S. EPA – National Coastal Condition Report IV

The purpose of a National Coastal Condition Report (NCCR) is to provide an **assessment of the state of U.S. coastal areas** in a format that is accessible to the public and decision-makers. An NCCR aggregates the results for a series of indicators and converts the score (0 to 5) to a grade ranging from poor to fair to good. The first NCCR was published in 2001. NCCR IV (U.S. EPA 2012) reports on data collected from 2003 – 2006 and rates the overall condition of U.S. coastal areas as fair. It also rates the condition of the Northeast coast as being between poor and fair (see Figure 3-1 from NCCR IV).[1]

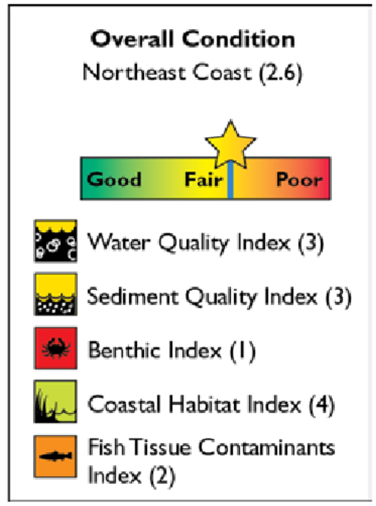


Figure 3-1. The overall condition of Northeast Coast coastal waters is rated fair (U.S. EPA/NCA).

From U.S. EPA 2012: 3-1.

For the Northeast Coast, data, with a few exceptions, was collected primarily during the summer months from 2003 to 2006 at 1,119 water, 1,024 sediment, and 902 benthic monitoring locations. The sampling sites were selected at random using a probabilistic sampling design. Finally, "[t]he NCCR IV presents four main types of data: (1) coastal monitoring data, (2) national coastal-ocean condition data, (3) offshore fisheries data, and (4) advisory and closure data" (U.S. EPA 2012: ES-2). This report focuses (see methods below) on coastal monitoring data as they are what is used to calculate the coastal condition grade.[2]

Method used to calculate NCCR IV report grade

- The national and regional grades for the NCCR IV are based on the combined condition of five indexes (Water Quality Index, Sediment Quality Index, Benthic Index, Coastal Habitat Index, Fish Tissues Contaminants Index). The NCCR IV also reports on the condition of the component indicators for the Water Quality Index and Sediment Quality Index (see **Table 4).**

TABLE 4: NCCR IV Indicators and component indicators used to assess coastal condition.

Indicator	Water Quality Index	Sediment Quality Index	Benthic Index	Coastal Habitat Index	Fish Tissues Cont. Index
Component Indicators	• *DIN • *DIP • Chlorophyll *a* • Water clarity (amount and type of light at 1 metre) • *DO	• Sediment toxicity • Sediment contaminants • *Sediment TOC	• For the Northeast Coast – Acadian Province, see Hale and Heltshe 2008	• Wetland acreage (does not include sub-tidal habitat, such as submerged aquatic vegetation)	• Concentrations of 16 contaminants (e.g., arsenic, mercury, poly-chlorinated hydrocarbons)

*DIN – Dissolved inorganic nitrogen, DIP – Dissolved inorganic phosphorous, DO – dissolved oxygen, TOC – Total organic carbon.

[1] Note "that Chesapeake Bay, the largest estuary in the nation, represents nearly 60% of the coastal area in the Northeast; therefore, the area-weighted statistical summaries are heavily influenced by this major estuary" (U.S. EPA 2012: 3-2).

[2] For reference, the NCCR IV Indicators and component indicators used for coastal ocean monitoring – Mid-Atlantic Bight are provided in **Table 6**.

- For each monitoring site, the condition of each Water Quality Index and Sediment Quality Index component indicator, and the Benthic Index and Fish Tissues Contaminant Index, were assessed against a rating "cutpoint" (threshold).
    - For example, the cutpoints for the Northeast Coast component indicator 'dissolved inorganic nitrogen' (DIN) were: < 0.1 mg/L (good); 0.1—0.5 mg/L (fair); > 0.5 mg/L (poor).
    - To see cutpoints for the Benthic Index and the Fish Tissues Contaminant Index, see **Table 5**.
- For each monitoring site, after the ratings of the individual component indicators were determined, the condition of the site's Water Quality Index and Sediment Quality Index were assessed against a rating cutpoint.
    - To see cutpoints for the Water Quality Index and Sediment Quality Index, see **Table 5** below.
    - The Coastal Habitats Index was only calculated at the regional level.
- After all sampling sites in a region were assessed, regional (e.g., Northeast Coast) index scores were calculated.
    - "An areally weighted cumulative distribution function (CDF) was calculated for each index and component indicator (except for the fish tissue contaminants index) to show what percentage of the area in each region had scores of 1 (poor), 3 (fair), and 5 (good) (Diaz-Ramos *et al.,* 1996). The CDF was calculated for the distribution of sites in each region over all years (2003-2006) cumulatively. Error estimates and 95% confidence intervals were also calculated for the CDF" (U.S. EPA 2012: 1-8).
- For each region, each index or component indicator was then rated overall as good, fair, or poor, based on the percent area that was rated good, fair, and poor for each index or indicator (See **Table 5** below).
    - For each of the five indexes, the "fair" rating could be assigned a score of 2, 3, or 4. From the NCCR III (U.S. EPA 2008), the index cutpoints for scores of 2, 3, and 4 were based on the amount of area in a region that received a grade of poor.

NCCR IV Ranges of Percent Area Rated Poor that Result in Scores of 1 – 5 (taken from U.S. EPA 2008: 270):

Index	Poor = 1	Fair to Poor = 2	Fair = 3	Good to Fair = 4	Good = 5
Water Quality Index	> 20%	18—20%	13-17%	10—12%	< 10%
Sediment Quality Index	> 15%	13—15%	8-12%	5-7%	< 5%
Benthic Index	> 20%	18—20%	13-17%	10—12%	< 10%
Fish Tissue Contaminants Index (% of sites)	> 20%	18—20%	13-17%	10—12%	< 10%

- The overall condition for each region was calculated by aggregating the scores of the five indexes (or of the indexes available) and dividing by 5 (or the number of indexes available). This meant that each index was weighted equally.
    - The range of grades for regional coastal conditions was: 1 = *poor*; 2 = *poor to fair*; 3 = *fair*; 4 = *fair to good*; 5 = *good*.
- The National overall condition and index scores were calculated through the areally weighted average of the regional scores for each index (percentage of each region's coastal area as part of the total national coastal area). (Note that weighting for the national coastal habitats index was based on the percentage of each region's coastal wetland area as part of the total national coastal wetland area). The national overall condition score was calculated by summing each national index score and dividing by 5.
    - The range of grades for the national coastal condition was: less than 2.0 = *poor*; 2.0 to less than 2.4 = *fair to poor*; 2.4 to less than 3.7 = *fair*; 3.7 to 4.0 = *good to fair*; greater than 4.0 = *good.*

TABLE 5: Rating cutpoints for NCCR IV indexes (adapted from U.S. EPA 2012).

Rating	Good	Fair	Poor
Water Quality Index			
- Monitoring sites	A maximum of one [component] indicator is rated fair, and no indicators are rated poor.	One of the [component] indicators is rated poor, or two or more indicators are rated fair.	Two or more of the five [component] indicators are rated poor.[1]
- Regions	Less than 10% of the coastal area is in poor condition, and more than 50% of the coastal area is in good condition.	10% to 20% of the coastal area is in poor condition, or 50% or less of the coastal area is in good condition.	More than 20% of the coastal area is in poor condition.
Sediment Quality Index			
- Monitoring sites	None of the individual component indicators is rated poor, and the sediment contaminants indicator is rated good.	None of the component indicators is rated poor, and the sediment contaminants indicator is rated fair.	One or more of the component indicators is rated poor.
- Regions	Less than 5% of the coastal area is in poor condition, and more than 50% of the coastal area is in good condition.	5% to 15% of the coastal area is in poor condition, or 50% or less of the coastal area is in good condition.	More than 15% of the coastal area is in poor condition.
Benthic Index			
- Monitoring sites (Northeast Coast – Acadian Province)	Benthic index score is greater than or equal to 5.0.	Benthic index score is greater than or equal to 4.0 and less than 5.0.	Benthic index score is less than 4.0.
- Regions	Less than 10% of the coastal area is in poor condition, and more than 50% of the coastal area is in good condition.	10% to 20% of the coastal area is in poor condition, or 50% or less of the coastal area is good condition.	More than 20% of the coastal area is in poor condition.
Coastal Habitats Index			
	The index value is less than 1.0.	The index value is between 1.0 and 1.25.	The index value is greater than 1.25.
Fish Tissue Contaminants Index			
- Monitoring sites	For all chemical contaminants listed in Table 1-21, the measured concentrations in fish tissue fall below the range of the EPA Advisory Guidance values for risk-based consumption associated with four 8-ounce meals per month.	For at least one chemical contaminant listed in Table 1-21, the measured concentration in fish tissue falls within the range of the EPA Advisory Guidance values for risk-based consumption associated with four 8-ounce meals per month.	For at least one chemical contaminant listed in Table 1-21, the measured concentrations in fish tissue exceeds the maximum value in the range of the EPA Advisory Guidance values for risk-based consumption associated with four 8-ounce meals per month.
- Regions	Less than 10% of the monitoring stations where fish were caught are in poor condition, and more than 50% of the monitoring stations where fish were caught are in good condition.	10% to 20% of the monitoring stations where fish were caught are in poor condition, or 50% or less of the monitoring stations where fish were caught are in good condition.	More than 20% of the monitoring stations where fish were caught are in poor condition.

[1]At sites the Water Quality Index can also be given a rating of "missing" - two component indicators are missing, and the available indicators do not suggest a fair or poor rating.

- The cutpoints in **Table 5** were developed from the following sources of information (U.S. EPA 2012: 1-7 to 1-8 (citations omitted from References):[3]
  - Water Quality Index: Best professional judgment; consultations with experts and selected state water quality managers.
  - Sediment Quality Index: Best professional judgment; consultations with experts and selected state water quality managers.
  - Benthic Index: Engle *et al.* 1994; Weisberg *et al.* 1997; Engle and Summers 1999; Van Dolah *et al.* 1999; Paul *et al.* 2001; Hale and Heltsche 2008.
  - Coastal Habitat Index: Best professional judgment; consultations with experts at U.S. FWS.
  - Fish Tissue Contaminants Index: U.S. EPA 2000c; consultations with experts
  - Dissolved Inorganic Nitrogen, Dissolved Inorganic Phosphorus), Chlorophyll *a*: Bricker *et al.* 1999; selected state criteria for chlorophyll *a* in coastal waters.
  - Water Clarity: Smith *et al.* 2006; best professional judgment; consultations with selected state water quality managers.
  - Dissolved Oxygen: Diaz and Rosenberg 1995; U.S. EPA, 2000b; selected state criteria for dissolved oxygen in coastal waters.
  - Sediment Contaminants: Long *et al.* 1995; consultations with experts
  - Sediment Total Organic Carbon (TOC): Best professional judgment; consultations with experts and selected state water quality managers.
  - Benthic Diversity (in lieu of Benthic index): Best professional judgment; consultations with experts.

Significant pro and con as a model for a Bay of Fundy report card:

Pro: Ecologically, the Northeast Coast region assessed in NCCR IV is similar to the Bay of Fundy.

Con: Data assessed is the result of a regular monitoring program of a large number of sample sites (e.g., 1,119 water monitoring sites for the Northeast Coast).

Website: http://water.epa.gov/type/oceb/assessmonitor/nccr/index.cfm

TABLE 6: NCCR IV Indicators and component indicators used for coastal ocean monitoring – Mid-Atlantic Bight.

Indicator	Water Quality[1]	Sediment Quality[1]	Benthic Condition[1]	Fish Tissues Cont. Index	
Component Indicators	• *DIN • *DIP • Chlorophyll *a* • *Water clarity (TSS) • *DO	• Sediment contaminants • *Sediment TOC	• Density of offshore fauna • Mean number of taxa • Mean diversity • Presence of non-indigenous species.	• Concentrations of 16 contaminants (e.g., arsenic, mercury, poly-chlorinated hydrocarbons)	

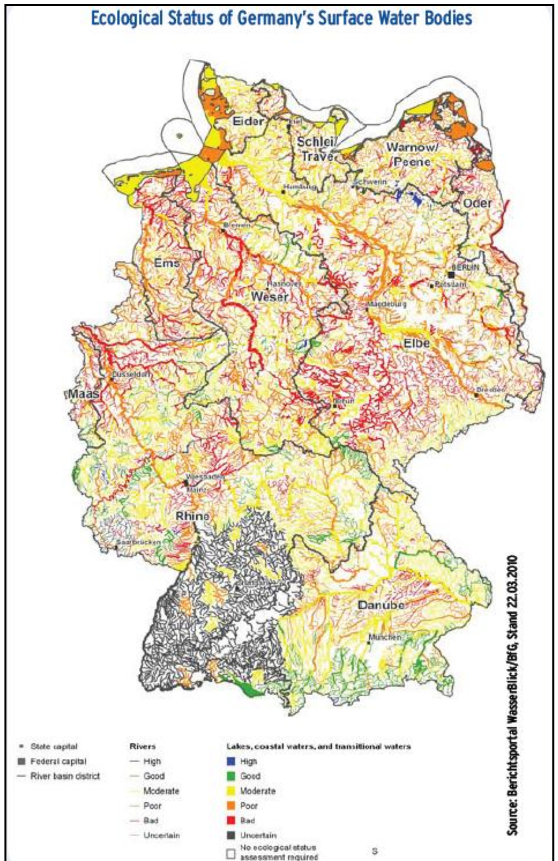
*DIN – Dissolved inorganic nitrogen, DIP – Dissolved inorganic phosphorous, TSS – total suspended solids, DO – dissolved oxygen, TOC – Total organic carbon.

[1]Overarching indexes were not determined for these indicators. Reporting was based on results for component indicators.

[3] Note: "The regional cutpoints (i.e., percentages used to rate each index of coastal condition) were determined as a median of responses provided through a survey of environmental managers, resource experts, and the knowledgeable public" (U.S. EPA 2012: 1-8).

3.3 European Water Framework and Marine Strategy Framework Directives

The European Water Framework (WFD) (EU 2000) and the European Marine Strategy Framework Directive (MSFD) (EU 2008) both require that the ecological or environmental status of European marine waters be monitored, assessed, and reported on. The WFD applies to inland waters along with coastal (boundaries are map based) and estuarine waters and requires that these waters achieve "good ecological status" by 2015. For offshore waters, the MSFD requires that "good environmental status" be achieved by 2020.



From German FME 2010: 23.

Method used to determine the status of a waterbody under the European Water Framework Directive

In General

- Under the WFD, the ecological status of a waterbody is determined by evaluating the condition of a series of biotic and physico-chemical quality elements (i.e., indicators). (See **Table 7** for examples of WFD quality elements.) Each quality element is compared to a non-impacted reference condition (real or modelled) and then classified as having high, good, or moderate ecological status (anything less than moderate is either fair or poor).
- The overall ecological status of the waterbody is represented by "the lower of the values for the biological and physico-chemical monitoring results for the relevant quality elements." (EU 2000: L 327/58-59).
- Each waterbody is then to be mapped using a colour classification of blue (high ecological status), green (good), yellow (moderate), orange (poor), and red (bad).
- The "chemical status" of the waterbody is also determined by comparing its levels of regulated pollutants against EU environmental quality standards (EQS). The waterbody's overall chemical status is then rated as "good" or "failing to achieve good" (one or more pollutants fail to meet the EQS) and shown on a map as either blue (good) or red (failing to achieve).

TABLE 7: WFD quality elements for the classification of ecological status.

Transitional Waters (i.e., estuaries)	**Coastal Waters**
Biological elements • Composition, abundance and biomass of phytoplankton • Composition and abundance of other aquatic flora • Composition and abundance of benthic invertebrate fauna • Composition and abundance of fish fauna	**Biological elements** • Composition, abundance and biomass of phytoplankton • Composition and abundance of other aquatic flora • Composition and abundance of benthic invertebrate fauna
Hydro-morphological elements supporting the biological elements *Morphological conditions* • depth variation • quantity, structure and substrate of the bed	**Hydro-morphological elements supporting the biological elements** *Morphological conditions* • depth variation • structure and substrate of the coastal bed

• structure of the intertidal zone *Tidal regime* • freshwater flow • wave exposure	• structure of the intertidal zone *Tidal regime* • direction of dominant currents • wave exposure
Chemical and physico-chemical elements supporting the biological elements *General* • Transparency • Thermal conditions • Oxygenation conditions • Salinity • Nutrient conditions *Specific pollutants* • Pollution by all priority substances identified as being discharged into the body of water • Pollution by other substances identified as being discharged in significant quantities into the body of water	**Chemical and physico-chemical elements supporting the biological elements** *General* • Transparency • Thermal conditions • Oxygenation conditions • Salinity • Nutrient conditions *Specific pollutants* • Pollution by all priority substances identified as being discharged into the body of water • Pollution by other substances identified as being discharged in significant quantities into the body of water

More Specifically

- Quoting from Borja *et al.* (2009: 1, references omitted), "In the case of the WFD, some methods exist to determine the status of each [quality] element, such as: chemical; physico-chemical…and fishes. These approaches establish an ecological quality ratio (EQR), by comparing monitoring data with those of reference conditions (e.g. from pristine areas, using historical data before being affected by human activities, etc.). This EQR, which ranges between 0 (bad) and 1(high), is divided then into five quality status levels (high, good, moderate, poor, and bad status), depending on the distance to reference conditions."
- However, as discussed earlier, the WFD (and MSFD) does not set out specific reference conditions (i.e., thresholds) for assessing the state of a quality element. Instead, it relies on the development of site-specific reference conditions (see **Table 8**) and the use of normative definitions to describe the high, good, or moderate ecological status of a particular quality element (see **Table 9** for an example of the definitions of ecological status for coastal waters). While these both provide flexibility in the application of the WFD from state to state, it also makes using the WFD difficult.
    - "The methodologies for integrating such quality elements into a unique [Water Framework Directive] evaluation of a waterbody are scarce presently…" (Borja *et al.* 2009: 2).
- Borja *et al.* (2009) provide a suggested "decision-tree" for the application of the WFD for the coastal waters of Basque Country, Spain. (See Figure 2 taken from Borja *et al.* 2009 below). Germany has also made progress on classifying its surface waters under the WFD (see: German FME 2010).

TABLE 8: Water Framework Directive – Establishment of type-specific reference conditions for surface waterbody types.

WFD ANNEX 2 – Part 1.3.
(i) For each surface waterbody type (e.g., coastal waters) …, type-specific hydromorphological and physicochemical conditions shall be established representing the values of the hydromorphological and physicochemical quality elements specified in point 1.1 in Annex V for that surface waterbody type at high ecological status as defined in the relevant table in point 1.2 in Annex V. Type-specific biological reference conditions shall be established, representing the values of the biological quality elements specified in point 1.1 in Annex V for that surface waterbody type at high ecological status as defined in the relevant table in section 1.2 in Annex V.
(ii) *omitted*
(iii) Type-specific conditions for the purposes of points (i) and (ii) and type-specific biological reference conditions may be either spatially based or based on modelling, or may be derived using a combination of these methods. Where it is not possible to use these methods, Member States may use expert judgement to establish such conditions. *remainder omitted*
(iv) For spatially based type-specific biological reference conditions, Member States shall develop a reference network for each surface waterbody type. *remainder omitted*
(v) Type-specific biological reference conditions based on modelling may be derived using either predictive models or hindcasting methods. *remainder omitted*
(vi) Where it is not possible to establish reliable type-specific reference conditions for a quality element in a surface waterbody type due to high degrees of natural variability in that element, not just as a result of seasonal variations, then that element may be excluded from the assessment of ecological status for that surface water type. *remainder omitted*

TABLE 9: Water Framework Directive – Normative definitions of ecological status classifications.

WFD Annex V – Table 1.2. General definition of ecological quality for rivers, lakes, transitional waters and coastal waters.			
Element	**High status**	**Good status**	**Moderate status**[1]
General	There are no, or only very minor, anthropogenic alterations to the values of the physico-chemical and hydromorphological quality elements for the surface waterbody type from those normally associated with that type under undisturbed conditions. The values of the biological quality elements for the surface waterbody reflect those normally associated with that type under undisturbed conditions, and show no, or only very minor, evidence of distortion. These are the type-specific conditions and communities.	The values of the biological quality elements for the surface waterbody type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface waterbody type under undisturbed conditions.	The values of the biological quality elements for the surface waterbody type deviate moderately from those normally associated with the surface waterbody type under undisturbed conditions. The values show moderate signs of distortion resulting from human activity and are significantly more disturbed than under conditions of good status.

[1] Waters achieving a status below moderate shall be classified as poor or bad.

TABLE 9: cont'd.

WFD Annex V – Table 1.2.4. Definitions for high, good and moderate ecological status in coastal waters.			
Element	**High status**	**Good status**	**Moderate status**[1]
Biological quality elements Phytoplankton	The composition and abundance of phytoplanktonic taxa are consistent with undisturbed conditions. The average phytoplankton biomass is consistent with the type-specific physico-chemical conditions and is not such as to significantly alter the type-specific transparency conditions. Planktonic blooms occur at a frequency and intensity which is consistent with the type specific physicochemical conditions.	The composition and abundance of phytoplanktonic taxa show slight signs of disturbance. There are slight changes in biomass compared to type-specific conditions. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbance to the balance of organisms present in the waterbody or to the quality of the water. A slight increase in the frequency and intensity of the type-specific planktonic blooms may occur.	The composition and abundance of planktonic taxa show signs of moderate disturbance. Algal biomass is substantially outside the range associated with type-specific conditions, and is such as to impact upon other biological quality elements. A moderate increase in the frequency and intensity of planktonic blooms may occur. Persistent blooms may occur during summer months.
Table 1.2.4 continues with definitions for remaining coastal waters biological quality elements: Macroalgae and Angiosperms, Benthic invertebrate fauna, Tidal regime, Morphological conditions	*omitted*	*omitted*	*omitted*

[1] Waters achieving a status below moderate shall be classified as poor or bad.

Significant pro and con as a model for a Bay of Fundy report card:

Pro: Final results (map) are understandable.

Con: No apparent single method for applying the WFD and MSFD, and the methodology is difficult to understand and explain.

Websites:

Water Framework Directive:
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:327:0001:0072:EN:PDF

Marine Strategy Framework Directive:
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040:EN:PDF

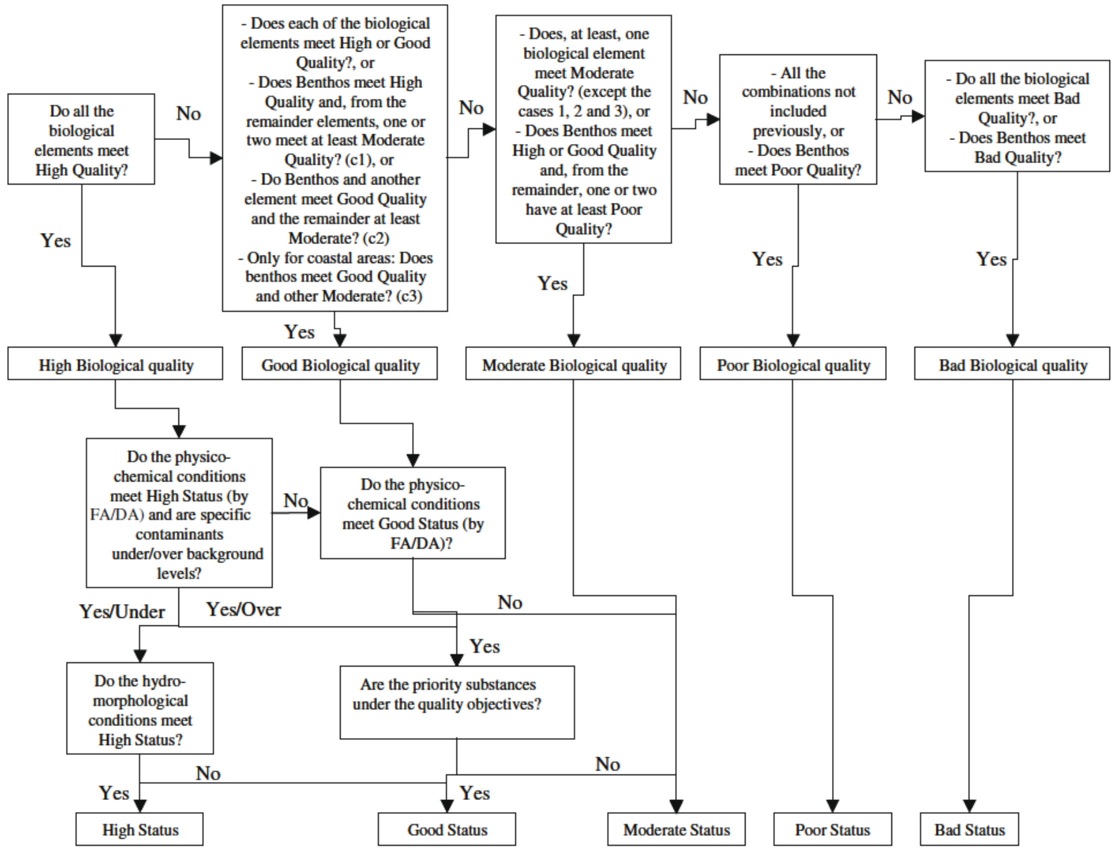


Fig. 2. 'Decision-tree' used in assessing the integrative ecological status, within the Water Framework Directive (modified from Borja et al. (2004a)). *Key:* FA/DA – factor analysis/discriminant analysis; c-cases.

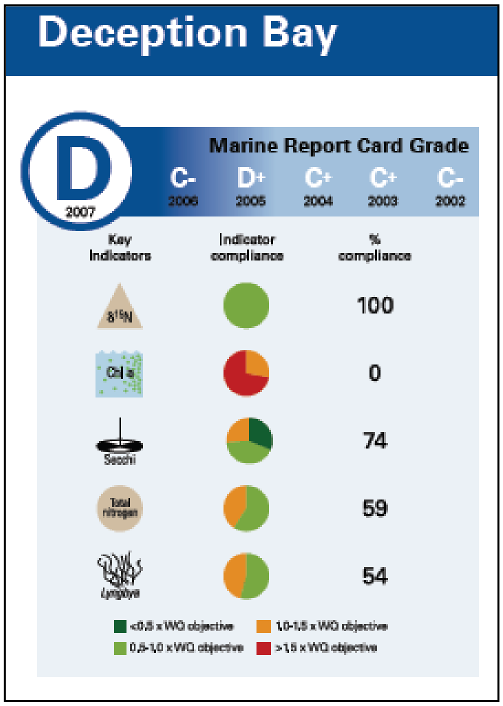
From Borja *et al.* 2009: 57.

3.4 Ecosystem Health Monitoring Program – Ecosystem Health Report Card

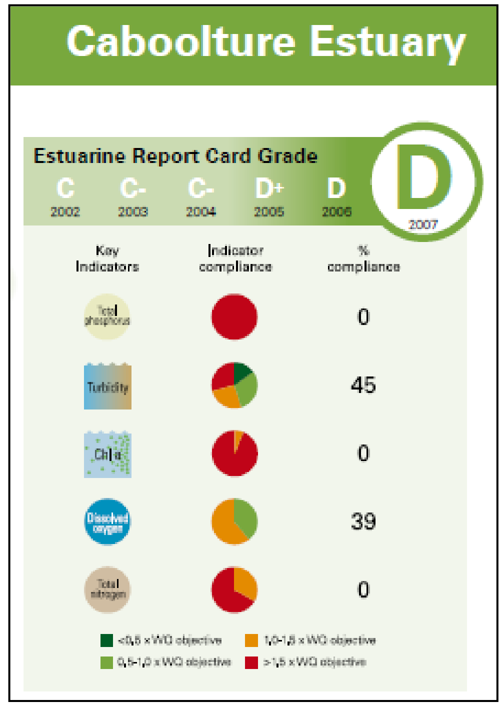
For over 10 years, the Ecosystem Health Monitoring Program (EHM Program) has produced an annual **Ecosystem Health Report Card** that gives a grade to each of South East Queensland, Australia's forty-six waterways (nineteen major watersheds, eighteen estuaries, and nine zones of Moreton Bay). The EHM Program uses slightly different methods, both described below, to calculate and represent the grades for freshwater systems and for coastal areas.

Method used to calculate EHM Program report card grade for estuaries and zones of Moreton Bay (from EHMP 2008).

- Water quality parameters (see **Table 10**) are measured monthly at 254 sites.
    - Biological health parameters (see **Table 10**) are measured less frequently (e.g., sewage plume mapping – annually at selected water quality sites).
- An EHI (ecosystem health index) based on five indicators, and BHR (biological health rating) based on three indicators, is calculated for each reporting area (estuary or bay zone) (see **Table 10** for a list of indicators).
- Calculation of the EHI:
    - Compliance scores (versus the Queensland Water Quality Guideline) for each EHI indicator in a reporting area are determined. An indicator compliance score is the average of all compliance scores for that indicator from all sites in a reporting area.
        - Values of < 1 show compliance with water quality guideline, > 1 show non-compliance.
        - To assist in graphically representing the data, compliance is also broken down into four categories:
            - <0.5 x WQ guideline
            - 0.5 to 1.0 x WQ guideline
            - 1 to 1.5 x WQ guideline
            - >1.5 x WQ guideline
    - The EHI value (0.0 to 1.0) for a reporting area (waterway) is the average of the compliance scores of the five indicators.
- Calculation of the BHR:
    - The state of the three BHR indicators at each site in a reporting area is compared to a reference condition, i.e., undisturbed site.
    - Based on its state, each indicator is given a rating of 1 to 4 (higher score means better condition) and the average of all ratings for each indicator across all sites in a reporting area is calculated.
        - For bay zones, the BHR is the average of the three indicators, while for estuaries, the BHR is 50% riparian assessment indicator and 50% nutrient processing indicator and sewage plume mapping indicator.
- The EHI and BHR scores are then combined to create a final score for each reporting area (bay zone or estuary). (Note the use of unequal weighting of the BHR and EHI scores.)
    - Bay zone score = 20% BHR + 80% EHI
    - Estuary score = 30% BHR + 70% EHI
- Based on their combined EHI and BHR scores, a grade is assigned to each bay zone and estuary.
    - A – score ≥ 90, plus each individual indicator must achieve a high score
    - F – score ≤ 70
    - B to D – equally distributed between A and F
    - + and – can be assigned (no A+, no F+ or F-)



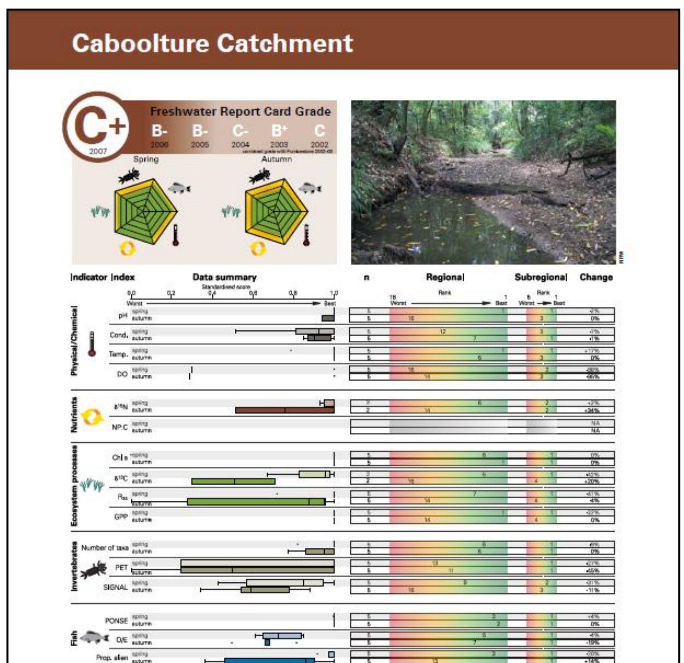
From EHMP 2008: 77.



From EHMP 2008: 78.

Method used to calculate EHM Program report card grade for freshwater systems (from EHMP 2008)

- Summer and winter measurements of sixteen indices (see **Table 11** for list) are taken at each site (127 sites over 19 watersheds).
- One summer and one winter standardized score is calculated for each of the sixteen indices at each site (see **Figure 2** for EHM Program standardization method).
- One summer and one winter score is calculated for each of the five indicators at each site. This is the average of the indices' scores for that indicator at a site.
- One summer and one winter score is calculated for each of the five indicators for an entire watershed. This is the average of the individual indicator scores across all sites in a watershed.
- One summer and one winter score is calculated for each of the 18 watersheds. This is the average of the five indicator scores for a watershed.



From EHMP 2008: 76.

- A final score for each of the eighteen watersheds is calculated. This final score is the average of the summer and winter scores for a watershed.

- A letter grade is assigned to each watershed.
    - A – score ≥ 90, plus each individual indicator must achieve a high score
    - F – score ≤ 70
    - B to D – equally distributed between A and F
    - + and – can be assigned (no A+, no F+ or F-)
- Data is also summarized using whisker plots for indices, pentagonal ecosystem health plots for indicators, etc.

Calculation of each standardised score involves an initial comparison of each index value against the corresponding guideline and WCS value. Index values satisfying the criteria specified in the table of guideline values (i.e. <operand> <guideline value>) are awarded a score of 1.0, whilst any 'worse' than/equal to the WCS value are awarded a score of 0.0. The score for all other values is calculated using the equation:

$$\text{Score}_{ij} = 1.0 - \left| \frac{(x_{ij} - \text{Guideline}_{ij})}{(\text{WCS}_{ij} - \text{Guideline}_{ij})} \right|$$

where: x_{ij} is the value of index i at a site within stream class j,

Guideline$_{ij}$ is the corresponding 'ecosystem health guideline' value, and

WCS$_{ij}$ is the corresponding 'worst case scenario' value.

FIGURE 2: Calculation of standardized scores for EHM Program freshwater grades. (From EMHP 2008: 26).

Significant pro and con as a model for a Bay of Fundy report card:

Pro: Calculation of the EHM Program grades does not require statistics – repeatable by the public.

Con: Relies on several complex indicators that are not readily available for the Bay of Fundy, such as determining stable isotope ratios for nitrogen and carbon.

Websites:

1. South East Queensland "Healthy Waterways" website: http://healthywaterways.org/home.aspx
2. SEQ EHM Program website: http://healthywaterways.org/ehmphome.aspx

TABLE 10: EHM Program Estuary & Marine (Moreton Bay) parameters and indicators.

Water quality parameters	Biological parameters	[1]EHI indicators (estuaries)	[1]BHR indicators (estuaries)	EHI indicators (bay)	BHR Indicators (bay)
Water column (physical and chemical properties) • Turbidity • *DO • Salinity • pH • Temperature *Water clarity* • Secchi disc *Phytoplankton biomass* • Chlorophyll *a* *Surface water nutrients* • *TN • *TP • *NO_x • *NH_4+ • *FRP	• Sewage plume mapping • Seagrass depth • Seagrass distribution • Coral (bottom cover) • Toxic algal blooms (*Lyngbya majuscule*) • Nutrient mixing • Riparian assessment	• Turbidity • *DO • Chlorophyll *a* • *TN • *TP	• Sewage plume mapping (based on the ratio of ^{15}N to ^{14}N in algae) • Nutrient mixing • Riparian assessment	• Secchi disc • Chlorophyll *a* • TN • Toxic algal blooms • Sewage plume mapping (based on the ratio of ^{15}N to ^{14}N in algae)	• Seagrass depth • Seagrass distribution • Coral (bottom cover)

*DO – dissolved oxygen, TN – total nitrogen, TP – total phosphorous, NO_x – oxides of nitrogen, NH_4+ - ammonium, FRP – filterable reactive phosphorous.

[1]"Five carefully selected indicators are used for determining the EHIs … The indicators chosen are those less correlated so as to limit bias in the EHI calculation." For example, TP is not used in the Bay EHI calculation as it is highly correlated with TN." (EMHP 2006-07 Technical Report at p. 40; www.healthywaterways.org/EcosystemHealthMonitoringProgram/ProductsandPublications/AnnualTechnicalReports.aspx.)

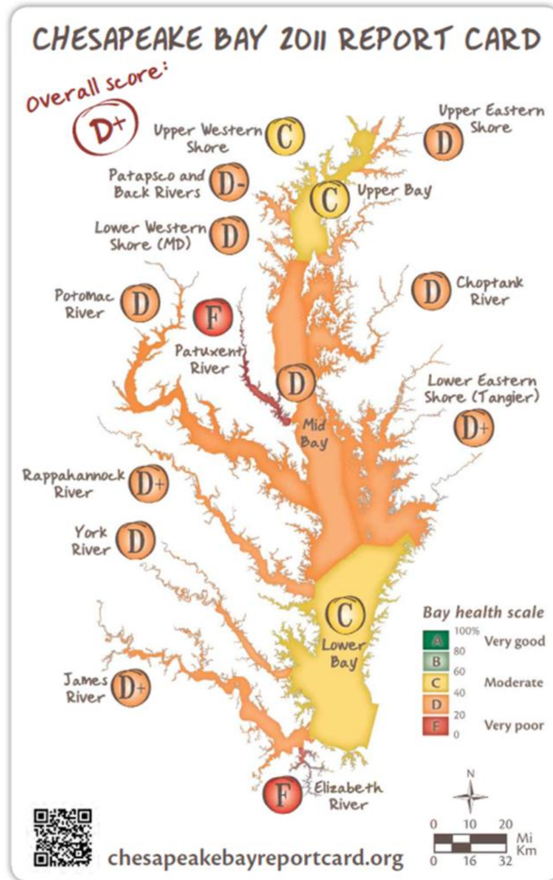
TABLE 11: EHM Program freshwater indicators and indices.

Indicator	Physical & Chemical	Nutrient Cycling	Ecosystem Processes	Aquatic Macro-Invertebrates	Fish
Indices	• pH (min) • pH (max) • Conductivity • Temp (max) • Temp (range) • *DO (min) • *DO (range)	• changes in ratio of ^{15}N to ^{14}N in algae or aquatic plants • Algal bioassay	• Algal Growth • changes in ratio of ^{13}C to ^{12}C in algae or aquatic plants • *R_{24} • *GPP	• No. of taxa • *PET richness • *SIGNAL score	• *PONSE • *O/E_{50} • Proportion alien fish

*DO – dissolved oxygen, R_{24} – respiration measured over a 24 hour period, GPP – Gross Primary Productivity, PET – Plecoptera, Ephemeroptera, Trichopetera, SIGNAL – stream invertebrate grade number - average level, PONSE – percentage of native species expected, O/E_{50} – ratio of observed to expected species.

3.5 University of Maryland's Center for Environmental Science – Integration and Application Network Ecocheck Report Cards

Ecocheck is **ecosystem health reporting** with a particular focus on Chesapeake Bay, Maryland. It is a program of the University of Maryland's Center for Environmental Science (UMCES) Integration and Application Network (IAN). The main service of Ecocheck has been producing, in collaboration with other groups, a report card for Chesapeake Bay.



From IAN (undated).

The Chesapeake Bay Report Card combines and averages a water quality index (comprised of three indicators) and a biotic index (comprised of three indicators) across a series of management segments and reporting regions in Chesapeake Bay to produce a single Chesapeake Bay Health Index score (0 to 100). A letter grade (A to F) is then assigned to the Health Index score. The 2011 Chesapeake Bay Report Card gave the Bay a grade of D+.

Method used to calculate Chesapeake Bay Report Card Grade (from Williams *et al.* 2009):[4]

- Chesapeake Bay is divided into seventy-eight monitoring and management segments. These are grouped into fifteen reporting regions.
- The three water quality indicators (chlorophyll *a*, dissolved oxygen, water clarity (secchi depth)) and the three biotic indicators (submerged aquatic vegetation (SAV) (hectares), benthic index of biotic integrity (B-IBI), phytoplankton index of biotic integrity (P-IBI)), are sampled during the year at stations located throughout the fifteen reporting regions (e.g., 152 water quality stations).
- The indicators, excluding SAV, are "scored by calculating the proportion of observations meeting or exceeding [pass/fail] a specific threshold or index value within a Bay segment. For SAV, the score was the SAV coverage in each segment as a percent of its restoration goal coverage. This procedure puts the scores for each [Chesapeake Bay Health Index] indicator on a common scale of 0% (impaired) to 100% (unimpaired) …" (Williams *et al.* 2009: 17-18).
- "The resulting percentages for the six [indicators] were weighted by segment area and then summed to obtain results for each reporting region. The chlorophyll-*a*, DO, and Secchi depth percentages were averaged to obtain the WQI (Water Quality Index); the P-IBI, B-IBI, and SAV percentages averaged to obtain the BI (Biotic Index); and the WQI and BI were averaged to obtain the BHI (Chesapeake Bay Health Index)" (Williams *et al.* 2009: 17-18).

[4] Other sources for methods were: 2010 State of Baltimore Harbor's Ecological and Human Health (http://ian.umces.edu/pdfs/ian_report_342.pdf), Calculating the 2006 Chesapeake Bay Report Card Scores. (http://ian.umces.edu/pdfs/ian_newsletter_163.pdf), and Sampling and data analysis protocols for Mid-Atlantic tributaries protocol (http://ian.umces.edu/pdfs/ian_report_313.pdf).

- Annual WQIs were "generated for each station by averaging the frequencies of passing scores for the three [WQI indicators]. Next, all the station WQIs within a segment were averaged. Then, segment WQIs within a reporting region were weighted by [each segment's] areal proportion relative to the reporting region and summed to obtain a [reporting region] WQI" (Williams *et al.* 2009: 18).
- "Individual P-IBI scores are evaluated against a threshold criterion of 3.0 on a scale of 1.0–5.0. Scores >3.0 pass; scores <3.0 fail. The annual frequency of passing scores in each segment is weighted by the segment's areal proportion of the reporting region in which it is located. Area-weighted frequencies are then summed to obtain an overall frequency of passing P-IBI scores in each reporting region" (Williams *et al.* 2009: 19).
- The WQI and BI were "both expressed as the average of the percent attainment of their component metrics and biotic indices, were averaged to obtain the BHI. We used a simple averaging technique for the WQI and BI that assumes these indices are of equal weight …" (Williams *et al.* 2009: 19).
    - Note that materials on the IAN website suggest that to arrive at a final BHI score and grade for the entire Chesapeake Bay, the Water Quality Index and Biotic Index scores from each reporting region were area-weighted (the area of the reporting region divided by the total area of the bay) and then averaged to arrive at a bay-wide WQI score and BI score. These were then added together and divided by 2.
- A grade is then assigned to the BHI score.
- More recent iterations of IAN Ecocheck report cards have moved from calculations based on the pass/fail of a sample vs. a single threshold, to ones where each sample's measurement is placed in a range of threshold values for the indicator. Each sub-range of threshold values is assigned a score starting at 0. For example, for chlorophyll *a*, the ranges (in mg/L) and corresponding scores are: (poor) >25 (0), 20-25 (1), 15-20 (2), 10-15 (3), 5-10 (4), <5 (5) (good). A chlorophyll *a* sample with a measurement of 17 mg/L would receive a score of 2. (Sources for indicator threshold values were scientific literature and U.S. EPA guidance documents.)
- Using the range of thresholds method, the average scored measurement for each indicator for each station is calculated (sum of scored measurements/# of samples). A percent score is then calculated for each indicator at each station (average scored measurement/highest threshold value score) (e.g., /5 for chlorophyll *a* X 100).

Significant pro and con as a model for a Bay of Fundy report card:

Pro: Uses a small number of indicators and many of the Chesapeake indicators used are similar to those being collected for the Bay of Fundy.

Con: The Bay of Fundy and Chesapeake Bay are different marine systems. For example, the average depth of Chesapeake Bay (excluding tributaries) is approximately 15 metres, the Bay of Fundy – 75 metres (in places it has 16 metre tides). As well, Chesapeake Bay is decidedly impacted by population growth.

Website:

2011 Chesapeake Bay Report Card: http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2011/

3.6 2011 Australia State of the Environment – Chapter 6: Marine Environment

Australia's National State of the Environment Reporting system requires assessments of the condition of Australia's ecosystems. For Australia's marine ecosystems this is a challenge because of the small number of data sets and monitoring programs being used to collect information for and assess indicators of marine health. As a result, "In the absence of strong regional or national indicator datasets, and to limit the bias inherent in a narrow information base, the [Australia 2011 State of the Environment Report (AUS SOE)] process has consulted experts to gauge expert opinion about the condition of Australia's marine ecosystems" (Ward 2011: 1). This iterative process, the **National Marine Condition Assessment** (NMCA), drew on the knowledge of individual experts about smaller scale, disparate studies to reach consensus on the condition of Australia's marine five bioregions, which were in turn aggregated to arrive at one grade for Australia's entire marine environment.

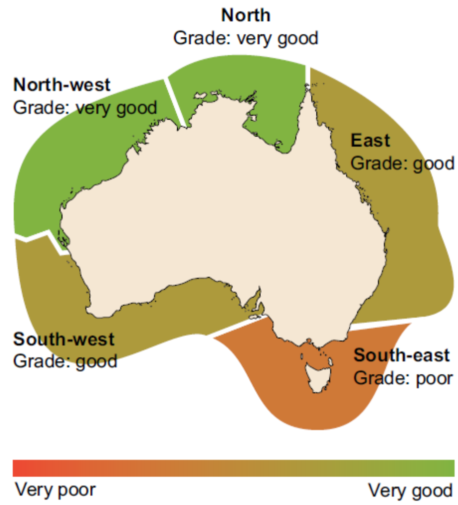


Figure 6.10 The overall condition of most components of biodiversity in each SoE reporting region

Australia □ State of the Environment 2011 389

From AUS SOE 2011: 389.

Method used to determine the state of Australia's marine environment

- Australia's marine waters were divided into five bioregions and "parameters" were established. The parameters were determined prior to the expert consultation process to avoid bias, i.e., to prevent experts from including or excluding parameters because of preconceived views on the state of the parameter. The parameters (i.e., indexes, such as 'Quality of Habitats for Species') chosen were:

  <u>Marine Biodiversity</u>
  - Quality of Habitats for Species
  - Populations of Species and Groups of Species
  - Ecological Processes

  <u>Marine Ecosystem Health</u>
  - Physical and Chemical Processes
  - Pests, Introduced Species, Diseases and Algal Blooms
  - Pressures Affecting the Marine Environment

- A workshop of experts was held for each marine bioregion.
- At the regional expert workshops, components (i.e., indicators, such as 'Seabed lower slope (700–1500 m)') were chosen. Components were "the level at which scoring was conducted [for each parameter], and they represent the natural biophysical and taxonomic hierarchy of ecosystems and biodiversity of the region under consideration" (Ward 2011: 2). (See **Table 12** for an example of components for the parameter 'Quality of Habitats for Species'.)

TABLE 12: Components for AUS SOE 2011 parameter 'Quality of Habitats for Species'.

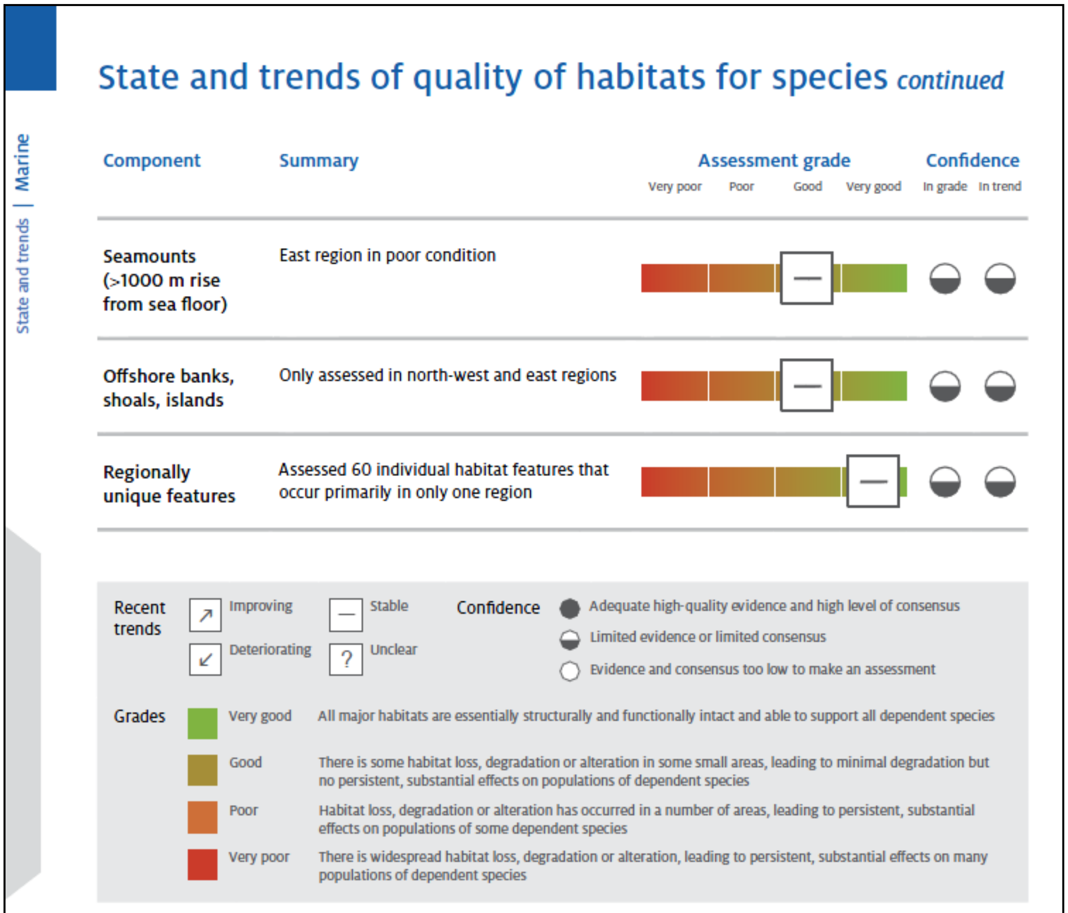
• Seabed lower slope (700–1500 m) • Seabed abyss (>1500 m) • Water column, shoreline (0–20 m), not estuaries • Water column, inner shelf (20–50 m) • Water column, outer shelf (50–200 m)	• Water column offshore (>200 m) • Mangroves • Seagrasses • Algal beds • Coral reefs (<30 m) • Deepwater corals and sponges (>30 m)	• Bryozoan reefs • Canyons and shelf break • Seamounts (>1000 m rise from sea floor) • Offshore banks, shoals, islands • Regionally unique features

- Expert consensus was reached on the national performance or condition of each component as compared to the benchmark of what the component would have looked like prior to European settlement (or a substituted estimate of pre-European conditions).
    - First, a regional component score was determined. This was the median of the scores from 0 to 10 (*poor* to *very good*) the experts in a region gave to a component. Grading statements were used to guide the experts in their assignment of scores (see **Table 13** for an example).

TABLE 13: Example of grading statements for scoring components for the AUS SOE 2011 parameter 'Quality of Habitat for Species' (from Ward 2011: 4).

Quality of Habitat for Species	*Applies to habitat components and what is best understood about their status and trends expressed in terms of habitat quality for species.*
Very Good (>7.5-10)	All major habitats are essentially structurally and functionally intact and able to support all dependent species.
Good (>5-7.5)	There is some habitat loss, degradation or alteration in some small areas, leading to minimal degradation but no persistent substantial effects on populations of dependent species.
Poor (>2.5-5)	Habitat loss, degradation or alteration has occurred in a number of areas, leading to persistent substantial effects on populations of some dependent species.
Very Poor (0-2.5)	There is widespread habitat loss, degradation or alteration, leading to persistent substantial effects on many populations of dependent species.

    - The five regional component scores were averaged and this average (the assessment grade) was put into one of four quartiles (0-2.5, *poor*; 2.5-5, *fair*; 5-7.5, *good*; 7.5-10, *very good*).
    - Expert consensus was also reached on the recent trend of each component's condition regionally and then nationally (*improving, stable, deteriorating*).
    - The regional expert working groups also rated their confidence in a component's grade and trend. This rating was based on their level of consensus and the quality of the information used to determine a condition's grade and trend. These confidence ratings were aggregated into a national confidence rating for each component.
    - All of the above information was then placed in a summary diagram for each parameter. (See next page for summary diagram for the parameter 'Quality of Habitats for Species'.)
- Finally, "[t]he workshop assessments for quality of habitats, condition of species, and condition of ecological processes were combined to form a single assessment for marine biodiversity in each of the five marine bioregions," and "marine ecosystem health was determined [for each of the five marine bioregions] by combining [workshop] assessments of the of the major physical and chemical processes with the outbreaks of diseases, non-natural algal blooms and infestations by pests and introduced species" (Ward 2011: 10 and 13). These assessments of marine biodiversity and marine ecosystem health used the same grades as used in the assessment of the individual components (0-2.5, *poor*; 2.5-5, *fair*; 5-7.5, *good*; 7.5-10, *very good*).



From AUS SOE 2011: 394.

Significant pro and con as a model for a Bay of Fundy report card:

Pro: Brings experts together and does not require use of comprehensive monitoring programs or data sets.

Con: Likely could not be done annually as it requires commitment of time and knowledge of experts. As well, grading from report card to report card may be inconsistent, particularly if different experts are used.

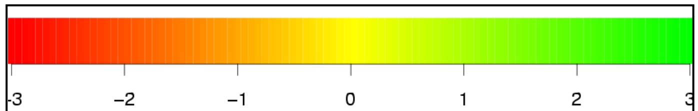
Website: http://www.environment.gov.au/soe/2011/report/index.html

3.7 Eastern Scotian Shelf Integrated Assessment (from Choi *et al.* 2005)

An integrated assessment (IA) does not produce a single score or grade for an ecosystem. However, as described and used, it provides a **method to assess the status of an ecosystem beyond simply identifying trends in data**. IA also allows for the use of disparate data sets. In their IA of the Eastern Scotian Shelf ecosystem, Choi *et al.* (2005) determined that the two largest drivers of change to the ecosystem were: 1) a shift in the system from being dominated by large bodied groundfish to a system dominated by pelagic fish and macro invertebrates, and 2) changes in ocean climate conditions, such as ocean bottom temperatures. They also showed that much of this change took place during the late 1980's to early 1990's.

Method used by from Choi *et al.* 2005

- A series of 55 indicators (see **Table 14** below) were chosen for the assessment. These indicators addressed biotic (e.g., abundance of finfish), abiotic (e.g., ocean climate measures), and human variables (e.g., population of Nova Scotia).
- All the indicators were converted to the same scale by expressing them as anomalies in standard deviation units[5] (from long-term means) and then colour-coded. Missing values were coded as white.



Colour coding of anomalies from Choi *et al.* 2005.

- Choi *et al.* used Principal Components Analysis (PCA) to order the indicators so that those with similar changes over time were grouped together. This grouping allowed Choi *et al.* to determine what the main causes of changes to the Eastern Scotian Shelf ecosystem were and when these changes occurred.
    - PCA is a statistical method used to find patterns in sets of data. In PCA, data is transformed into a series of principal components. These principal components can be thought of as axes on a graph (there can be an infinite number of axes, not simply *x* and *y*). The data is transformed in a way that makes the first principal component responsible for the largest amount of variability in the data (the slope of the data on the graph is the steepest).

Significant pro and con as a model for a Bay of Fundy report card:

<u>Pro:</u> Can be done using a variety of datasets collected for different purposes, i.e., does not require a devoted ecosystem health monitoring program.

<u>Con:</u> Is not a report card or index; i.e., does not produce a single score or grade.

[5] Standard deviation units are "where the mean is subtracted from each observation and this difference is divided by the standard deviation of the series" (NOAA 2009).

TABLE 14: Indicators used by Choi *et al.* (table taken from Choi *et al.* 2005).

Indicators of Change
The variables used as indicators in this study are listed and described in the following:

Ocean climate: Atmospheric/oceanic indices are readily available from a variety of sources including Fisheries and Oceans Canada, Environment Canada and the Northwest Atlantic Fisheries Organization.

- Bottom area >3°C — surface projected area (km2) on the eastern Scotian Shelf with bottom temperatures >3°C from the July groundfish hydrographic survey.
- Bottom temperature — average bottom temperatures (°C) of the whole of the ESS.
- Bottom temperature (6 yr) — running average of the average bottom temperatures of the ESS for the previous 6 yr.
- Emerald bottom temperatures — 250 m annual temperature (°C) anomaly for Emerald Basin, central Scotian Shelf.
- Gulf Stream front position — annual average north-south position (km) of the Gulf Stream.
- Halifax SST — annual anomaly of sea surface temperature (°C) at Halifax.
- Ice coverage — annual anomaly of ice cover (m2) for the eastern Scotian Shelf.
- Misaine bottom temperatures — 100 m annual temperature anomaly at Misaine Bank.
- NAO anomaly — anomaly of December–February sea level atmospheric pressure difference (kPa) between the Azores and Iceland. This index has been shown to be related to air temperatures, SST, convection and circulation changes in the North Atlantic and through atmospheric teleconnections, even broader-scale forcings.
- NAO anomaly (6 yr integral) — the 6 yr running average of the NAO anomaly.
- No. of storms — the number of storms on the ESS.
- RIVSUM — annual anomaly of freshwater inflow (m3 s–1) from the St. Lawrence, Ottawa and Saguenay rivers.
- Sable Is. temperature — annual air temperature anomaly (°C) for Sable Island.
- Sable Is. total stress — annual anomaly of total wind stress standard deviation (Pa), independent of direction, for Sable Island.
- Shelf front position — annual average north-south position (km) of the shelf-slope water temperature boundary.
- Stratification anomaly (0–50 m) — annual anomaly of the density difference between 0 and 50 m divided by 50 m (kg m–3 m–1) for the ESS.
- Volume CIL source water — volume (m3) of the cold intermediate layer (water temperature <3°C) in the Gulf of St. Lawrence from the September groundfish hydrographic survey.

Plankton: Plankton relative abundance estimates were obtained from the continuous plankton recorder (CPR), the longest consistent plankton time-series in the Northwest Atlantic (Beaugrand 2004). Surveys begun in 1961 were discontinued in 1976 but reinstated in 1991 and continue to the present. Data collected in 1961 and 1974–1976 were incomplete and therefore excluded from analysis of interannual variability.

- *Calanus finmarchicus* (CPR) — relative abundance.
- Colour index (CPR) — relative colour index, a proxy for phytoplankton abundance.
- Diatom: dinoflagellate ratio (CPR) — ratio of diatom to dinoflagellate densities, a proxy of the ocean mixing conditions.
- Diatoms (CPR) — relative abundance.
- Dinoflagellates (CPR) — relative abundance.

TABLE 14: cont'd.

Fishes and other organisms: Fish species abundance and distributions were derived from fisheries-independent research surveys of commercial and non-commercial fish species resident on the eastern half of the Scotian Shelf off Nova Scotia.

- Grey seal numerical abundance — the numerical abundance of grey seals, estimated for Sable Island, the primary breeding colony.
- Groundfish biomass — biomass densities (kg km–2) from summer research surveys.
- Groundfish diversity (Margalef) — Margalef species diversity index.
- Fish species diversity (Shannon) — Shannon species diversity index.
- Length age 6 cod — size-at-age of age 6 Atlantic cod.
- Length age 6 haddock — size-at-age of age 6 haddock.
- Length age 6 pollock — size-at-age of age 6 pollock.
- Length age 6 silver hake — size-at-age of age 6 silver hake.
- Macroinvertebrate biomass (CPUE) — catch per unit effort of shrimp and crab landed from the ESS.
- Mean body mass — geometric mean mass of bottom-trawled fish on the ESS.
- Metabolic rate — total metabolic rate estimated from body size frequency distributions and summer bottom temperatures (see Methods).
- Pelagic biomass — biomass densities (kg km–2) from summer research surveys.
- Pelagic: demersal ratio (biomass) — ratio of pelagic biomass to demersal biomass.
- Pelagic: demersal ratio (numbers) — ratio of pelagic numbers to demersal numbers.
- Physiological condition —mean condition of all fish (see Methods).
- Size-abundance intercept —intercept of log10(number) vs. log2(mass) relationship of fish species, an indicator of the total biomass in a system.
- Size-abundance slope —slope of $\log^{10}$(number) vs. $\log^{2}$(mass) relationship of fish species, an indicator of the relative distribution of the biomass in a system.
- Species composition 1— first axis of variation resulting from a spatially and temporally explicit correspondence analysis of the fish community of the ESS.
- Species composition 2 — second axis of variation resulting from a spatially and temporally explicit correspondence analysis of the fish community of the ESS.
- Species richness predicted — predicted number of fish species based upon annual species richness vs. surface area relationships for the ESS fish community, using a spatially constrained fractal-like approximation method.
- Species-area intercept — average intercept derived from a species richness vs. surface area relationship for the ESS fish community, using a spatially constrained (locally calculated saturation curves within a radius of 10–300 km) fractal-like approximation method.
- Species-area slope — average scaling exponent derived from a species richness vs. surface area relationship for the ESS fish community, using a spatially constrained (locally calculated saturation curves within a radius of 10–300 km) fractal-like approximation method.
- Specific metabolic rate — mass specific metabolic rates (see Methods).

Human influences: Human/anthropogenic indices were obtained from Fisheries and Oceans Canada and Environment Canada.

- Human population (NS) — total population size of Nova Scotia, Canada, a proxy of the human influence upon the ESS.
- Groundfish landed value — total landed value of groundfish.
- Groundfish landings — total landings of groundfish.
- Invertebrate landed value — total landed value of invertebrates.
- Invertebrate landings — total landings of invertebrates.
- Landed value/total landings — the price of all biomass landed.
- PCB concentrations in seals — poly-chloro-biphenyl concentrations in seal blubber.
- Pelagic landed value — total landed value of pelagic fish.
- Pelagic landings — total landings of pelagic fish.
- Trawled surface area — total surface area (km^2) trawled.

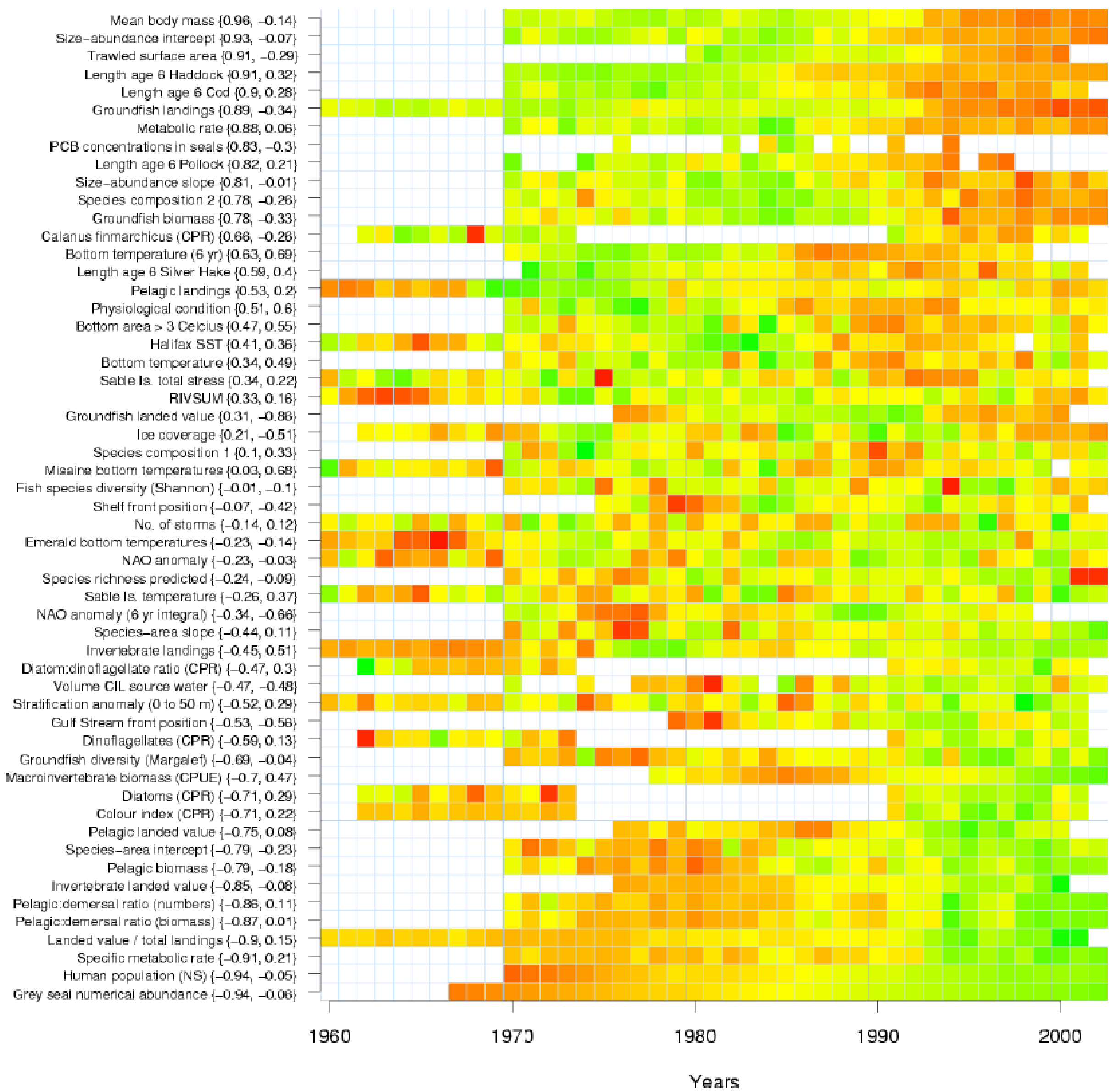


Figure 3 from Choi *et al.* 2005: Sorted table of standardised anomalies (standard deviation units) of the indicators of the ESS. [Note the grouping of negative anomalies for large bodied groundfish indicators in the top right of the figure that began in the early 1990s.]

4. A RECOMMENDED PATH FORWARD

4.1 The necessary characteristics of a Bay of Fundy environmental health index

At the April 3, 2013 workshop at the St. Andrews Biological Station in St. Andrews, N.B., the attendees agreed that an EHI for the Bay of Fundy needed to be:

- Transparent: The public and others should be able to understand in general how the EHI score was determined and where the data came from. However, how the index score is calculated, i.e., the math used, or how the individual indicators are assessed, can be complicated. A good EHI for the Bay of Fundy should not be sacrificed because of a lack of simplicity.
- Defensible: The elements that go into the calculation of the EHI score should be based on evidence. However, any EHI chosen needs to make it clear that there is a subjective element to the calculation of the score. For example, what indicators are assessed or what makes a score an A vs. B or C is a decision made by the designers of the EHI (often with the input from experts).
- Practical: There was a general agreement that not all the data/information we might want for the whole Bay or regions of the Bay is available.
- Able to calculate one final score for the Bay: The group agreed this was a good idea, but that it should allow for different regions within the Bay to calculate their own EHI score.
- Able to address "sustainable development": An EHI for the Bay of Fundy should measure not just the ecological and biophysical state of the Bay, but also its state as a social and economic resource. At the same time, a Bay of Fundy EHI should calculate the physical/biological aspects of the EHI score separately from the human/social aspects, and combine them to make one EHI score.

In addition to these characteristics, de Sherbinin *et al.* (2013) write that there are four factors which determine whether an environmental index will be effective, meaning it will result in change. These factors are:

- Resonance
- Salience
- Context
- Rankings and media outreach

Resonance is described by de Sherbinin *et al.* (2013) (at p. 11) as the environmental index "striking a chord" with its intended audience. Resonance requires the index to have *content* and *legitimacy*. A more effective index will have content (e.g., data) that is valid and reliable. Legitimacy "concerns the degree to which indicators incorporate appropriate viewpoints from relevant stakeholders, are consistent with dominant political and social norms, and are produced in a way that is seen as sufficiently transparent and fair" (de Sherbinin *et al.* 2013: 11). For an environmental index to be *salient*, the information it provides must be relevant to stakeholders, such as the public, resource planners and users, and political actors. The *context* of an environmental index can be thought of as what and who drove the development of the index. If the issue is not seen as important, the environmental index will have little meaning. De Sherbinin *et al.* also note (at p. 14) that an index created at the behest of government (the "who") will likely lead to more policy change than one developed by an outside agency. Finally, *rankings* may help improve the effectiveness of an environmental index by inducing laggards to improve their standing and leaders to maintain theirs, while *media outreach* will obviously draw attention to the results of the environmental index.

Finally, any EHI for the Bay of Fundy should also advance the main goals of BoFEP. As discussed above, BoFEP is dedicated to: 1) promoting the ecological integrity, vitality, biodiversity and productivity of the Bay of Fundy ecosystem, in support of the social well-being and economic sustainability of its coastal communities, and 2) facilitating and enhancing communication and co-operation among all citizens interested in understanding, sustainably using and conserving the resources, habitats and ecological processes of the Bay of Fundy.

4.2 Using the Ocean Health Index as a test case for a Bay of Fundy EHI

After discussing the seven EHI examples, the workshop attendees proposed that the *methodology of the Ocean Health Index (OHI) be tested by trying to develop an OHI score for the Southwest New Brunswick Bay of Fundy Marine Resources Planning Area*.[6] This area was chosen as a test case for a Bay of Fundy EHI for several reasons. First, the development of any EHI requires good and abundant data. The southwest New Brunswick Bay of Fundy region, and in particular Passamaquoddy Bay, was and is ecologically rich, which in turn fueled the founding of the St. Andrews Biological Station (SABS) (Hugh Akagi, *pers. comm*.). In turn, because of the SABS, there is much more scientific data available for the Marine Resources Planning Area compared to the rest of the Bay of Fundy. Another reason the Marine Resource Planning Area was chosen as a test case was because the Southwest New Brunswick Marine Advisory Committee (SWNBMAC) has determined, using various public participation methods, what the community values about the region. Quoting from the SWNBMAC (2009: 8), those values are:

- **Natural Resource.** The area is highly valued as a natural phenomenon and resource – its environment, its marine life – and there is value seen in keeping it as a healthy (in a determined desired state) resource.

- **Culture & Heritage.** Values in the area are linked to the life and culture in this region and to the associated history and heritage that has contributed to and supported this way of life.

- **Recreation.** Residents enjoy the area for its recreational and leisure activities. This includes public access to coastal waters.

- **Employment.** The industry and employment based on the resources of the area are of high value to many residents in the area.[7]

The reasons why the OHI was chosen over the other examples was not explained in great depth by the workshop attendees. However, when viewed in the light of the characteristics discussed above, its selection is easily understood.

The biggest question that remains about using the OHI as a method for the development of an EHI score for the Bay of Fundy is how *practical* is it. The OHI relies on close to 70 data layers and whether all this information is available for the Bay of Fundy is unclear. (See **Appendix 7.1** (**Table 15**)) for a listing of some potential indicators with data available for the Bay of Fundy.) As the OHI is presently designed, it "must have a value for each data layer included in the analysis, unless it is known to not be relevant to a location. In other words, missing data are not acceptable" (Halpern *et al.* 2012b: 2).

[6] The Marine Resources Planning Area extends from the southwestern limits of the Saint John Harbour Authority to the U.S. border and from the high water mark to the mid-bay line between New Brunswick and Nova Scotia (for a map, see: http://www.bofmrp.ca/home/index.php/phase2/planning_area/).
[7] An expanded list of these values can be found in Appendix 7.1 of SWNBMAC 2009.

Desired EHI characteristic	Ocean Health Index response
Transparent (EHI Workshop)	The OHI uses a published methodology that has been peer-reviewed.
Defensible (EHI Workshop) Resonance: content (de Sherbinin *et al.*)	The OHI score results from the use of quantitative data.
Addresses "sustainable development" (EHI Workshop) Resonance: legitimacy (de Sherbinin *et al.*) Promoting the ecological integrity…of the Bay of Fundy…in support of the social well-being and economic sustainability of its communities (BoFEP)	The OHI is based upon the idea of a "coupled human-ocean system". The ten OHI indicators encompass what the community values about the Southwestern Bay of Fundy region and the elements of BoFEP's first goal.
Results in a single EHI score, but also provides information for each indicator and can be used regionally (EHI Workshop)	Yes, although at how small a scale the OHI can be used is still unclear.
Salience and context (de Sherbinin *et al.*)	By looking at more than just the ecological state of the Bay, use of the OHI should provide information that is important to a wide range of stakeholders.
Rankings and media outreach (de Sherbinin *et al.*) Facilitating communication…among all citizens interested in understanding, sustainably using and conserving the resources, habitats and ecological processes of the Bay of Fundy (BoFEP)	The OHI provides rankings for the ocean health of 171 ocean countries that could be compared to a Bay of Fundy OHI score. Also, the OHI is a communication tool well supported academically and financially and received significant media attention when first released.

4.3 Brief reasons why the other EHI examples were not chosen as a Bay of Fundy EHI

1. *EPA National Coastal Condition Report IV* (NCCR IV)
   Several workshop attendees did not believe the U.S. EPA's NCCR IV properly represented the state of the U.S. Northeast Coast. As well, questions were raised about whether data was available that would allow the NCCR IV methodology to be easily replicated for the Bay of Fundy. The NCCR IV methodology also relies upon an extensive monitoring program. Finally, it is focussed on the ecological state of the coast rather than encompassing all dimensions of sustainable development.

2. *European Water Framework and Marine Strategy Framework Directives* (WFD and MSFD)
   The main concern raised about the WFD and MSFD is that it is unclear how they are to be applied. Use of these frameworks by BoFEP as a Bay of Fundy EHI methodology would require the assistance of someone well versed in their use.

3. *South East Queensland Environmental Health Monitoring Program* (EHM Program)
   One concern about the EHM Program was that it was developed for an ecosystem (Moreton Bay, Australia) that is smaller, shallower, and warmer than the Bay of Fundy. It is also very much focussed on assessing the impacts of nutrient inputs to Moreton Bay. It also relies on several indicators, such as the results of sewage plume mapping, for which data is not readily available for the Bay of Fundy.

4. *Integration and Application Network Chesapeake Bay Report Card*
   Like Moreton Bay, Australia, Chesapeake Bay is a much different ecosystem than the Bay of Fundy. Also, it relies on a suite of indicators that is too small and narrow in focus to properly assess the state of the Bay of Fundy.

5. *Australia State of the Environment (2011) – Chapter 6: Marine Health* (AUS SOE)
   The AUS SOE methodology was rejected because of its reliance upon expert opinion. Concerns were raised about objectivity and how repeatable would the results be if different experts were used in subsequent assessments.

6. *Eastern Scotian Shelf Integrated Assessment* (ESS IA)
   While the use of the ESS IA methodology appealed to the scientist workshop attendees, they were concerned that the results of a Bay of Fundy integrated assessment would not be easily understood by the public or policy makers. Also, it would not produce an actual EHI score for the Bay of Fundy.

4.4 Next steps

1. Identify and recruit a working group for the development of an Ocean Health Index score for the Bay of Fundy.
2. Make contact with the Ocean Health Index group about the project and discuss the Bay of Fundy project with accessible OHI scientists. Identify other instances where the OHI has been used for smaller ocean regions.
3. Start small and develop Bay of Fundy scores for four OHI goals that address the four community values of the Bay of Fundy (i.e., ecological, social, cultural, and economic) identified by the Southwest New Brunswick Marine Advisory Committee.
4. Communicate undertaking of EHI project to BoFEP members and draw attention to the Ocean Health Index.

5. CONCLUSION

Don't let the perfect ruin the good.

As discussed above, there are hundreds of potential environmental indicators that could be used to assess the state of the Bay of Fundy. In addition to the seven EHI examples discussed in this report, there are tens of others that could be used as potential models for a Bay of Fundy environmental health index. There are also questions about the amount and quality of data available for the calculation of an EHI score for the Bay of Fundy. Combining all of these things can make the task of designing an EHI for the Bay of Fundy seem overwhelming. One possible solution, conduct more research. Another solution is to accept that there is no perfect environmental health index for the Bay of Fundy that is going to satisfy everyone. Knowing this and that the Ocean Health Index is a good EHI, it makes sense for BoFEP to test the OHI in the Bay of Fundy.

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7. APPENDICES

7.1 POTENTIAL INDICATORS FOR A BAY OF FUNDY REPORT CARD

The Gulf of Maine Council on the Marine Environment (GoMC) has two programs that report on the status of indicators in the Gulf of Maine that may in turn be used for a Bay of Fundy report card or environmental health index. The first program is the "State of the Gulf of Maine Report". The report is actually a series of reports on a variety of themes and their associated indicators. The other program of the GoMC is the EcoSystem Indicator Partnership (ESIP). Both programs report on the status and trends of various indictors but neither program issues an EHI score for the Gulf of Maine or Bay of Fundy.

ESIP describes ecosystem indicators as "measurements that reflect the condition of the environment. Indicators can be social, economic, environmental, or a combination of indexes. The main purpose of an indicator is to make complex systems understandable in simple terms." Data for most of these indicators is available for the Bay of Fundy. The descriptions of some indicators below need refinement.

TABLE 15: Indicators used in State of the Gulf of Maine Reports and by ESIP.

GoMC State of the Gulf Reports indicators (includes reports completed to January 2013)	**ESIP Priority Indicators**
Climate change and humans • Average annual land and water temperatures • Land subsidence • Sea level in the Gulf of Maine • Coastal vulnerability indices • Occurrence of storm events	**Aquatic Habitats** • Extent of eelgrass (not in Bay of Fundy) • Extent of salt marsh • Locations of tidal restrictions
Climate Change and its Effects on Ecosystems, Habitats and Biota • Global mean air temperature • Population density • Water temperature • Precipitation • Salinity • Sea level in the Gulf of Maine • Ocean acidification • Thermal habitat • Shifts in species distribution • Ecological timing of events • Community assemblage • Ecosystem productivity	**Climate Change** • Sea level change • Precipitation trends and anomalies • Air temperature trends and anomalies
Microbial Pathogens and Toxins • Percent harvest area classified as approved • Annual percent of days beaches were under notification actions • Frequency of shellfish harvest closures due to PSP toxin levels • Occurrence of storm events • Annual incidence of PSP poisoning, vibriosis and gastroenteritis	**Coastal Development** • Point sources • Population density • Employment density • Impervious surface coverage

Table 15: cont'd.

Coastal Ecosystems and Habitats • Location of Tidal Restrictions • Extent and Distribution of Salt Marsh • Extent and Distribution of Eelgrass • Abundance of Migrating Shorebirds • Contaminant Levels of Blue Mussel	**Contaminants** • Sediment contamination and toxicity • Shellfish Sanitation data • Gulfwatch data
Eutrophication • Nutrients • Chlorophyll a • Macroalgae (rockweed) • Dissolved oxygen • Loss of seagrass • Harmful Algal Blooms	**Eutrophication** • Nitrogen loading • Secchi depth • Dissolved oxygen • Chlorophyll *a*
Offshore Ecosystems and Habitats • NAO Index • Total fisheries landings, Bay of Fundy • Community Structure (benthic/pelagic balance) • Species diversity • Disturbance from human activities (fishing, shipping) • Number of invasive species • Total area of habitat protected in the Gulf of Maine	**Fisheries and Aquaculture** • Production/area for aquaculture • Economic value of aquaculture • Ocean jobs • Dominant fish species metric • Fish species diversity in subregions • Population of fish species in subregions
Invasive Species • Number of established marine invasive species • Distribution and spread of marine invasives	

7.2 Minutes of April 3, 2013 EHI Workshop

Bay of Fundy Ecological Health Index Workshop,
"Finding an Ecological Health Index for the Bay of Fundy"

April 3, 2013
St. Andrews Biological Station Conference Centre

prepared by Scott Kidd

1. BACKGROUND TO WORKSHOP:

The Bay of Fundy Ecosystem Partnership (BoFEP) is a knowledge network that promotes and facilitates the creation, sharing and use of knowledge about the Bay of Fundy. BoFEP is dedicated to: 1) promoting the ecological integrity, vitality, biodiversity and productivity of the Bay of Fundy ecosystem, in support of the social well-being and economic sustainability of its coastal communities, and 2) facilitating and enhancing communication and co-operation among all citizens interested in understanding, sustainably using and conserving the resources, habitats and ecological processes of the Bay of Fundy. It is a "virtual institute" that links people and organizations who work together for the promotion of an ecologically and socially sustainable Bay of Fundy.

BoFEP believes that the development of an environmental health index (EHI) or report card would be an effective way to determine and communicate information about the Bay of Fundy's ecosystem health. With support from Environment Canada, BoFEP has undertaken a project to determine the feasibility of producing this EHI.

The first part of the project focused on researching marine report cards and EHIs used by various organizations around the globe. A summary of seven of these EHIs was then written and shared with invitees to the workshop.

The second part of the project was to conduct the April 3, 2013 workshop to gather input on the development of a Bay of Fundy EHI from individuals knowledgeable about the culture, ecology, and economy of the Bay of Fundy. The workshop was conducted using a "town hall" format. During the workshop, the attendees discussed four main questions:

1. What do attendees believe are the general characteristics of a "good" index?
2. Based on the seven examples of marine report cards and EHIs presented to workshop attendees, is there a preferred index for the Bay? Why? What is appealing about that index? What is not "good" about the other indexes (perceived shortcomings).
3. If there is a preferred index, are there indicators that need to be added or subtracted?
4. If there is not a preferred index, what are the components (anything in addition to the list generated by Question 1) and indicators that are required?

The final part of the project will be the production of a report that outlines how BoFEP can move forward with the development of a Bay of Fundy EHI or report card.

2. WORKSHOP ATTENDEES:

Scott Kidd – BoFEP EHI Project Coordinator
Heather Breeze – DFO, EHI Project Steering Committee
Marianne Janowicz – BoFEP, EHI Project Steering Committee
Christine Tilburg – Ecosystem Indicators Partnership (ESIP), EHI Project Steering Committee
Peter Wells – BoFEP and Dalhousie University, EHI Project Steering Committee
Hugh Akagi – Passamaquoddy First Nation and BoFEP
Maria-Ines Buzeta
Blythe Chang – DFO
Karen Coombs – Govt. of N.B., Dept. of Agriculture, Aquaculture and Fisheries
Andrew Cooper – DFO
Jack Fife – DFO
John Hallen – NATech
Alex Hanke – DFO
Sharon McGladdery – DFO
Gerhard Pohle – Huntsman Marine Science Centre
Amanda Smith – Sweeney International Mgmt. Corp.

3. OUTCOME OF THE WORKSHOP:

As will be discussed further below, at the end of the workshop it was proposed that the methodology of the Ocean Health Index (OHI) be tested by trying to develop an OHI score for the Southwest New Brunswick Bay of Fundy Marine Resources Planning Area. The Marine Resources Planning Area extends from the southwestern limits of the Saint John Harbour Authority to the U.S. border and from the high water mark to the mid-bay line between New Brunswick and Nova Scotia (for a map, see: http://www.bofmrp.ca/home/index.php/phase2/planning_area/). The development of an OHI score is data intensive and requires an understanding of community values. This area was chosen as a test case for a Bay of Fundy EHI for several reasons. First, the area was and is ecologically rich, which in turn fueled the founding of the St. Andrews Biological Station (SABS). In turn, because of the SABS, there is much more scientific data available for the Marine Resources Planning Area compared to the rest of the Bay of Fundy. Another reason the Marine Resources Planning Area was chosen as a test case was because the Southwest New Brunswick Marine Advisory Committee has determined, using various public participation methods, what are the community values (e.g., ecological, cultural, social, economic) in the area.

4. WORKSHOP MINUTES:

Introduction

- Marianne provided a brief background on BoFEP, the project, and the agenda and format of the workshop.
- Attendees introduced themselves.
- Scott briefly discussed what he believes is the “value of environmental health indexes or report cards”. They: 1) Look at the state of a whole ecosystem, 2) Provide a baseline, 3) Synthesize data/information, 4) Set the agenda, 5) Are useful as a communication tool, 6) Poor scores or grades can act as a form of “shock and awe”, thereby spurring action to address the poor score, and 7) Provide a target for management.
- Scott provided a brief background on the seven report cards and EHIs chosen as models for a potential Bay of Fundy EHI.

1. Ocean Health Index (OHI)
2. EPA National Coastal Condition Report IV (NCCR IV)
3. European Water Framework and Marine Strategy Framework Directives (EWF)
4. South East Queensland (Australia) Environmental Health Monitoring Program (EHMP)
5. Integration and Application Network Chesapeake Bay Report Card (Chesapeake Bay)
6. Australia State of the Environment (2011) – Marine Health: Example of an expert knowledge iterative process (AUS SOE)
7. Eastern Scotian Shelf Integrated Assessment (ESS IA)

- These seven examples were chosen because they provide a range of options. For example, the OHI provides an index score for the entire world's oceans, although it also has been used at a smaller scale to provide OHI scores for individual countries. It is data intensive and requires a lot of complex calculations. The NCCR IV includes coverage of the Northeastern U.S., allowing for comparisons between it and the Bay of Fundy. It does not require as much data as the OHI. The EWF uses more qualitative vs. quantitative descriptions of marine ecosystem health. How the EWF is actually being used is unclear. The EHMP is a long-standing, well respected report card system. One drawback to using the EHMP is that Moreton Bay, Australia is a much different marine system than the Bay of Fundy. The Chesapeake Bay report card uses very few indicators. Scott described this as being both an advantage and disadvantage. The AUS SOE is a qualitative assessment of marine ecosystem condition done through the polling of marine experts. While this process gets around issues of data availability and quality, Scott raised concerns about its repeatability. Finally, the ESS IA does not provide an index score. However, it was presented as an option for a different way to interpret and present data for the Bay of Fundy.
- More complete descriptions of the seven examples can be found in the BoFEP background report for the workshop.

<u>Question 1:</u> What do attendees believe are the general characteristics of a "good" index?

- Initial discussion focussed on whether an index for the Bay of Fundy should be made up of only <u>biological/ecological indicators</u> or should it include indicators that measure other aspects of sustainable development, e.g., <u>social, cultural, economic</u>. (*Supplementary note:* In answering Question 2, there was consensus that a Bay of Fundy EHI should calculate the physical/biological aspects of the score separately from the human/social aspects, and potentially combine them to make one index.)
  Points raised:
  - The Southwest NB Marine Advisory Committee includes social, cultural and economic values, in addition to ecological, when making recommendations regarding development in SW NB Marine Planning Area.
  - We choose indicators that evaluate the ecosystem services delivered by the Bay.
  - A Bay of Fundy Index should focus on ecological indicators. Some of these indicators will capture human use of the Bay, e.g., indicators dealing with fishing.
  - Social indicators are often good and bad at the same time. For example, one OHI indicator is tourism. A high score for tourism (good) often results in a poor score for coastal condition (bad).
  - It needs to be recognized that we are part of the ecology of the Bay.
  - Need a balanced approach with indicators that are relevant to people.
- There was discussion about some "over-arching" details of an index.
  Points raised:

    - In calculating an index score, a lack of monitoring/data should result in a poor score for an indicator.
    - Aggregation of individual indicator scores can be a problem—it can hide a really important high or low score for a particular indicator. (*Supplementary note:* The European Water Framework addresses this in part by basing its grade for the overall ecological status of a waterbody on the lower value of the waterbody`s biological or physico-chemical monitoring results.)
    - A good index is one that has a definition of "health".
    - Data used must have quality control, cover a time series, and be repeatable.
    - We need to look at the physical parameters of the Bay – they underpin everything else. For example, sea level changes impact other conditions in the Bay.
    - We should think of the index and indicators in terms of, "What do we need to know, what is changing, where is this change occurring, and what does this change mean?"
- Scott asked some specific questions about an index for the Bay of Fundy. There was agreement that the index needed to be:
    - <u>Transparent</u>: The public should be able to understand in general how the score/grade was determined and where the data came from. However, how the index score is calculated, i.e., the math used, or individual indicators are assessed, can be complicated. A good EHI for the Bay of Fundy should not be sacrificed because of a lack of simplicity.
    - <u>Defensible</u>: The elements that go into the calculation of the score should be based on evidence. However, any index needs to make it clear that there is a subjective element to the score. For example, what indicators are measured, what weight you assign to each indicator in calculating the index score, what are the threshold levels, and what makes a score an A vs. B or C, are all subjective decisions (although they are typically based upon expert opinion).
    - <u>One final score for the Bay</u>: The group agreed this was a good idea, but that it should allow for different regions within the Bay to calculate their own score.
    - <u>Practical</u>: There was a general agreement that not all the data/information we might want for the whole Bay or regions of the Bay is available.

<u>Question 2:</u> Based on the seven examples of marine report cards and EHIs presented to workshop attendees, is there a preferred index for the Bay? Why? What is appealing about that index? What is not "good" about the other indexes (perceived shortcomings).

- Scott was asked which example he thought was most amenable to being used in the Bay of Fundy. He answered that it was the method used in the US EPA's National Coastal Condition Reports because of ecological similarity of US Northeast coast to Bay of Fundy, and data used to calculate NCCR scores was available for Bay of Fundy.
    - Subsequent discussion detailed there is significant subjectivity in the NCCR grades (what score = good, fair, poor) and that not all the data needed for an NCCR grade for the Bay of Fundy is available.
    - Concerns were raised about the OHI placing too much weight on human use of a marine ecosystem.
- Any example chosen would likely require some modification to address local conditions and values, and availability of data.
- There is more data for the region near the St. Andrews Biological Station.
- Concern was raised about the "snapshot" aspect of a first report card. How do we make comparisons to past conditions? Has the condition of the Bay improved or worsened?
- At the end of the discussion of question 2, there was <u>consensus</u> that:

- Because of problems of repeatability, the AUS SOE method not be used as a model.
- The Southwest New Brunswick Marine Resources Planning Area be used as a test case for any model chosen.
- A Bay of Fundy EHI should calculate the physical/biological aspects of the score separately from the human/social aspects, and potentially combine them to make one index.

Question 3: If there is a preferred index, are there indicators that need to be added or subtracted?

- The group discussed indicators not listed in ESIP or the State of the Gulf Reports that they would like considered in future discussions (see BoFEP background report for the workshop for a list of these indicators). (*Supplementary note:* More work needs to be done to review the relevance of these indicators for the Bay of Fundy.)
  - sea turtles
  - sea and shorebirds
  - zooplankton – changes in timing of population events
  - iconic species, e.g., whales
  - herring
  - temperature and salinity
  - contaminants
  - accurately measuring invasive species
  - (*Supplementary note:* UNESCO is developing a list of Essential Ocean Variables (EOVs). See "A Framework for Ocean Observing" at: http://unesdoc.unesco.org/images/0021/002112/211260e.pdf.)
- Be practical, use indicators with data, but should also make it clear what other data are needed to make the EHI more complete.
- Discussion returned to the issue of what are indicators measuring and what is EHI describing.
  - Are we talking about the state of the system vs. health of the system?
- BoFEP should report on overall "health" of the Bay. Governments report on the status of various indicators, which is not the same thing.
- Consensus: Concerns were raised about using the word "health" – what does it mean? It was determined that this is not a good term for BoFEP to use. Should consider using words/terms such as, "Index, Condition, Status, Quality, Ecological Integrity". Whatever word used must be clearly understandable to the public, as one of the purposes of an environmental index/report card is to be a public communications tool.

Question 4: If there is not a preferred index, what are the components (anything in addition to the list generated by Question 1) and indicators that are required?

- The SW NB Marine Advisory Council has done a lot of work in determining the community's ecological, social, cultural, and economic values for the SW Bay of Fundy Marine Resources Planning Area.
  - See: http://www.bofmrp.ca/home/images/uploads/Community%20Value%20Criteria%20Table.pdf
- Scott raised the point that any index or report card uses threshold values to determine the status of an indicator. (For example, the NCCR IV thresholds for the Northeast Coast indicator "dissolved inorganic nitrogen" were: < 0.1 mg/L (good); 0.1—0.5 mg/L (fair); > 0.5 mg/L (poor).) He asked the group how thresholds should be approached.

Points raised:

- Thresholds need to be sensitive to broadscale changes.
- They need to represent what is outside natural variability or statistically expected.
- Where possible, they should be based on existing guidelines, such as those of Health Canada or Canadian Council of Ministers of the Environment (CCME), DFO fisheries measurements, and US EPA guidelines, as well as guidelines from peer reviewed literature and those used in other indexes.
- Don't forget about questions of scale – different data are collected for different purposes and areas.

5. CONCLUSION

- Although not a planned outcome of the workshop, the attendees coalesced around the recommendation that as a test case, the methodology of the Ocean Health Index (OHI) be used to develop an OHI score for the Southwest New Brunswick Bay of Fundy Marine Planning Area.
    - The OHI was seen as an attractive example because:
        - It has received the support of big players such as UNEP (UN Environment Programme) and NOAA (National Oceanic and Atmospheric Administration).
        - It has scientific rigour (published in journal Nature).
        - There are ongoing efforts to use the OHI for smaller regions.
        - It uses social and ecological indicators.
        - There is an OHI score for Canada, so data must exist.
        - BoFEP has links to some individuals involved in developing the OHI.
- In using the OHI, some questions to be addressed include:
    - How fully does it touch on the biotic aspect of the Bay of Fundy?
    - What happens when you remove some layers?
    - Can you separate out social indicators?
    - Perhaps only tackle one or two of the OHI goals at this time.

6. NEXT STEPS

- Scott would send out minutes of workshop. Attendees would review and provide clarification where necessary.
- A call for the establishment of a working group to implement the OHI test case. This would be done after attendees and others view some videos that describe the OHI. They can be found at:
    - AAAS 2012 Presentation Ben Halpern: Assessing the Health of the World's Oceans (http://vimeo.com/47266403)
    - OHI Methodology (http://vimeo.com/47257137)
    - AAAS 2012 Presentation Karen McLeod: From Metaphor to Measurement (http://vimeo.com/47266404)
    - AAAS 2012 Presentation Catherine Longo: Flexible Applications of the Ocean Health Index (http://vimeo.com/47266407)
    - AAAS 2012 Presentation Jameal Samhouri: Reference Points for Ocean Health (http://vimeo.com/47266406)
    - AAAS 2012 Presentation Heather Leslie: Applying Knowledge of Human-Ocean Connections at the Local Scale (http://vimeo.com/47266408)
    - The Ocean Health Index website is: http://www.oceanhealthindex.org/
    - OHI method papers can be accessed at: https://www.adrive.com/public/FxScxz/OHI-Paper