**Measuring the health of Canada’s oceans**

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**Abstract**

**Introduction**

The well-being of people and the health of the oceans are inextricably linked ([Council 1999](#_ENREF_4), [Knap, Dewailly et al. 2002](#_ENREF_9)). However, how to measure ocean health has been a long-standing challenge ([Costanza 1992](#_ENREF_3), [Rapport, Costanza et al. 1998](#_ENREF_10)). A multitude of indicators have been used, each of which measures relatively narrow aspects of ocean condition that should be relevant to specific management objectives, such as maintaining biodiversity or the integrity of marine communities, minimising the endangerment of species or loss of habitat, limiting human influence, safeguarding human health or delivering the countless goods and services provided by the sea ([Cairns, McCormick et al. 1993](#_ENREF_1), [Center 2008](#_ENREF_2), [Kershner, Samhouri et al. 2011](#_ENREF_8)). Arguably, oceans in a desirable (‘healthy’) state should be able to deliver all of these goals, hence a useful index of ocean health should be able to capture the widely disparate aspects measured by multiple indicators ([Rapport, Costanza et al. 1998](#_ENREF_10), [Halpern, Longo et al. 2012](#_ENREF_6)). The challenge of combining indicators potentially expressed in different units, measured on different scales, or that are fundamentally different (e.g., quantitative vs qualitative) is great, but this is necessary task if we are to move beyond simply equating ocean health with the extent to which the marine environment has been degraded by human activity ([UNESCO 1996](#_ENREF_12)).

Recently, Halpern et al. (2012) proposed an Ocean Health Index (OHI) that comprises 10 public goals for a healthy system that couples human and ocean interests. The OHI is different from previous attempts at measuring ocean health because it focuses on the delivery of ecosystem benefits to people rather than on activities that damage ocean integrity. The goals range from concrete benefits, such as food provision, to seemingly more subjective values, such as sense of place. The method allows the combination of disparate measurements into a single index, which can be tracked over time to reflect trends in overall ocean wellness. Each goal is assigned a score that is based on a combination of current status and likely future status, which is based on trends, the strength of current pressures and scope for resilience. Most importantly from a management perspective, the performance of each goal is assessed in relation to reference points that are realistic targets for sustainability rather than to a pristine state ([Samhouri, Lester et al. 2012](#_ENREF_11)). By comparing the performance of the different goals and their respective contributions to the overall OHI score, the index can potentially be used to identify the most beneficial areas for management intervention.

Analyses at a global scale are, however, too coarse to guide specific interventions at the regional, national or sub-national levels, which are the scales at which such decisions are usually made. However, a strength of the OHI is that is it can be customised to accommodate data sources available at different resolutions for finer-scale analyses. As proofs of concept, two regional applications of the OHI have been undertaken: the west coast of the USA ([Halpern, Longo et al. 2014](#_ENREF_7)) and Brazil (Elfes et al. 2014). In both cases, the analyses used higher-resolution data, place-specific reference points, and regional proxies for calculating each of the 10 goals, as originally defined by Halpern et al. (2012). There was much more variation in overall OHI scores among the 17 Brazilian coastal states (score range: 54-71) than among the 5 sub-regions examined along the west coast of the USA (65-73). At least in Brazil, consistently low goal and sub-goal scores (e.g., for mariculture) and the identification of data gaps led to specific policy recommendations regarding fisheries management and habitat protection ([Elfes, Longo et al. 2014](#_ENREF_5)). ([Halpern, Longo et al. 2014](#_ENREF_7)) also demonstrated how a regional OHI can be used to explore the consequences of past and hypothetical future management interventions, as well as to reconstruct historical trends for goals for which time-series of data exist.

Scaling down the assessment of ocean health to national and subnational level can be achieved by using nation- or state-specific data ([Elfes, Longo et al. 2014](#_ENREF_5), [Halpern, Longo et al. 2014](#_ENREF_7)). However, such analyses also present an opportunity to reflect national values in a way that a global analysis cannot capture. Different cultures value different aspects of the oceans, their resources and biodiversity, which can be reflected in the OHI by weighting different goals in relation to the importance accorded to them by people. In the regional analysis of the west coast of the USA, Halpern et al. (2013) used a multi-criteria decision-making approach to elicit a ranking of OHI goals from expert stakeholders with specific interests in various ocean sectors(e.g., fisheries, conservation NGOs, etc.). Surprisingly, the weights elicited were relatively similar across most goals, although the goals of Clean Water and Sense of Place were 3-4 times higher than the rest (Halpern et al. 2013). The weighted averaging of goals resulted in higher overall OHI scores in some subregions and lower scores in others ([Halpern, Longo et al. 2014](#_ENREF_7)). It is not clear, however, how the values elicited by experts with vested interests in certain goals reflect the values held by the population at large.

The goal of this study was to assess the overall health of Canadian oceans using the framework of the OHI. Our approach differs from previous regional assessments of ocean health in two main ways. First, we carefully evaluated the 10 goals defined in the global OHI and asked how well they reflected the Canadian context. This led us, for example, to redefine the ‘Artisanal Fishing Opportunities’ goal of the global OHI ([Halpern, Longo et al. 2012](#_ENREF_6)) as an ‘Aboriginal Needs’ goal that reflects access of Canadian aboriginal people to fishing and hunting grounds – a right that is enshrined in the Canadian constitution. Second, we generated a weighting scheme for the 10 goals that reflects the values of the Canadian public at large. To this effect, we designed a customised online survey, distributed in a stratified manner across Canadian provinces, which generated both an absolute quantitative score and a relative ranking for each goal. Our objectives were (1) to produce a quantitative estimate of the health of Canadian oceans to be used as a baseline for future assessments, (2) to examine the effect of various methods of goal weighting on the Canadian OHI, and (3) to describe regional variation in OHI arising from regional variation in goal rankings across Canada.

**Materials and Methods**

*The OHI in a nutshell*

Our methods and data sources were based on those of (B. Halpern, Longo, & Hardy, 2012; B. S. Halpern et al., 2012) and modified as described below to improve the quality of the data and to address specific Canadian issues (Table 1). These modifications involve data substitutions, additions, the definition of a new goal “Aboriginal Needs” which replaces “Artisanal Fishing Opportunities”, and finally, a web-based survey to quantify the relative importance of each goal to Canadians.

## Canadian Index of Wellbeing

As a Canadian alternative to the Worldwide Governance Indicators used in the original OHI (B. S. Halpern et al., 2012; World Bank Group, 2010), we have decided to use the Canadian Index of Wellbeing (CIW) as a measure of social pressure and resilience (Canadian Index of Wellbeing, 2012). The CIW is a composite index that measures 8 quality of life categories: Community Vitality, Democratic Engagement, Education, Environment, Healthy Populations, Leisure and Culture, Living Standards, and Time Use. Normally, the CIW is set to 100 for 1994 levels and it is often compared to GDP to investigate whether economic growth translates into similar gain in quality of life. To use it in COHI we have scaled it to Canadian GDP (also set to 100 for 1994 levels) so that a value of 1.0 indicates that the GDP to CIW ratio is as it was in 1994.

## Methane Clathrates and Subsea Permafrost

Lower sea levels during the last glaciation allowed some now-submerged shelf sediments to become frozen (ref). Permafrost is often found to a depth of 120 m (ref); therefore, we have assumed that all the benthic area between 0 and 120 m which lies north of 60°N potentially contains permafrost. Similarly, we assumed that all benthic area below 300 m potentially contains methane clathrates since these only form under specific temperature pressure combinations that are quite common below 300 m (ref).

A study by Archer & Buffett (2005) revealed that an ocean temperature increase by 3°С from 2005 levels may result in destabilization of most (84%) oceanic gas hydrate deposits and release of 4200 Gt of carbon. We have defined the health of the Methane Clathrate and Subsea Permafrost “habitats” as the northern hemisphere sea surface temperature anomaly above pre-industrial levels scaled to 3.65°C which corresponds to a 3°С from 2005 levels (ref). That is to say, an anomaly of 3.65°C would correspond to a habitat health of 0 and an increase of 2.15°C would correspond to a habitat health of 0.5.

## Aboriginal Needs

* Sparrow decision in 1990
* Describe how RNFB was estimated for all communities
* Describe how the ice data was handled to calculate ice cover for each community

The Aboriginal Needs (AN) index is calculated as:

|  |  |  |
| --- | --- | --- |
|  |  | (1) |

where *Pi* and *Ptot* are the population in community *i* and the population sum for all communities, respectively; *Fi* is the estimated price, in dollars, of the Revised Northern Food Basket for community *i* (Aboriginal Affairs and Northern Development Canada, 2010); *Gi* is the price of gas (cents per litre) in the nearest major city (Statistics Canada, 2014); *Ii* is the average yearly percent ice cover in a 300 km radius circle around community *i*; and finally, *Fbi*, *Gbi* and *Ibi* are the 1979 baseline levels for food, gas and ice cover respectively. This means that the AN is set to 1 in 1979 and decreases as ice cover decreases and/or the price of gas increases relative to the cost of the Revised Northern Food Basket. If *Ii* was 0 for the entire time series, *Ii* ÷ *Ibi* was set to 1. In these cases, there was no decrease in availability of ice cover for hunting and fishing near those aboriginal communities; therefore, there is no decrease in AN due to ice.

*OHI revisions* – Table 1

*Goal weighting* - Survey

**Results**

*Aboriginal needs goal*

Figure 1 – Changes in AN goal over time

*Canadian OHI*

Figure 2 – Daisy plots OHI vs COHI weighted and unweighted

Figure 3 - Daisy plots OHI vs COHI unweighted and weighted (1 weighting) – Regional variation

**Discussion**

Criticisms of OHI

Preferred weighting

*In a global analysis, Canada scored highly, with an OHI = 70 (out of 100) and 9th place among 172 countries (Halpern et al. 2012). The global average was 60, and the maximum score was 86 (Jarvis Island). In the last global iteration of the OHI in 2013, Canada scored 68% - 1% lower than the previous year – and ranked 61st out of 221 countries in the world.*

Acknowledgements

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