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Salmon and Eulachon in Ecosystem Space and Time: A Plea for Wider Collaboration and Data Integration

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Abstract.—Aboriginal people developed integrated ecosystem-based management long before European contact in the 1750s. Ecosystem knowledge contributed the lion's share of precontact wealth. Fisheries drove the early British Columbia economy, but now account for less than 0.5% of gross domestic product. Even thought West Coast research shows that precontact ecosystems could sustain many times current catch value, this still would not weigh heavily against other economic sectors. Single species management has failed to avert the depletion of many fisheries; hence, we now hear calls for ecosystem-based management as opposed to integrated management (used in reference to managing multiple sectors such as fisheries, farmed salmon, oil, and gas, as well as climate change). We suggest that reintegrating ecosystem-based and integrated management necessitates the cooperation of other ocean sectors in generating the information necessary to monitor and restore ecosystems while ensuring that their own operations are sustainable. Currently, there are a number of scientific initiatives, ocean and biological observing platforms, and high-powered models to help develop new management regimes. We consider how this new technology could help to understand the collapse of eulachon *Thaleichthys pacificus*. Eulachon are of great importance to Native peoples but could well be described as the forgotten anadromous fish of the research community. It is important that both industry and governments recognize the importance of maintaining the long-term viability of these important tools and invest appropriately to ensure sound ecosystem management practices into the future.

Introduction

> We believe that life supports life, that we are one with the animals of air, land and water. What you call "biodiversity" is only a part of it. (Chief Simon Lucas 2007)

Fisheries drove the early British Columbia economy. All fisheries, commercial, sport, aquaculture, and processing now account for less than 0.5% of gross domestic product (BC 2002). Commercial fisheries account for only 0.1%, a decline of 15% since 1984 (BC 2002). Within the fisheries sector, the relative importance of Pacific salmon and eulachon *Thaleichthys pacificus* mirrors the overall decline in fisheries value. Eulachon are of great importance to Aboriginal people (Drake and Wilson 1991; Hay and McCarter 2000; Hume 2007). Eulachon could equally be described as

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the "forgotten anadromous fish" of the research community. Eulachon are not mentioned in the 1986 anadromous fish conference (Dadswell et al. 1987) and, what is even more remarkable, by other contributors to this volume, given their collapse throughout their range. For this reason, we consider how new tracking systems might provide some insight into the cause of decline in eulachon as well as insight into salmon and other species.

Balancing conservation of coastal ecosystems with immediate need for jobs and revenue requires a larger investment in knowledge acquisition than can be justified in our current economic assessment of fisheries value. How then can we justify the expenditure? This paper presents a vision for the harmonious use of ocean space where human activities that exploit living marine resources and other civil, industrial, and military sectors will together contribute to our knowledge base for integrated, ecosystem-based management, with subsequent benefits for all.

To do this, we do not look at the ecosystem at one point in time, but instead develop an integrated understanding of the extent of ecosystem change over long time periods and the natural and human drivers of that change. This is the vital context within which ecosystem-based management (EBM) efforts must operate, even though they also, of necessity, focus on the ecosystem as we see it today based on its very recent past. Broadening our temporal scope separates EBM from the struggle over who owns and manages the current system and requires us to frame questions over longer temporal scales and many different spatial scales. We now need to extend the concept of adaptive management to include modeling, seasonal, and real-time science in collaborative iteration with the maritime community (Figure 1). We see an urgent need to link relatively large-scale food web,

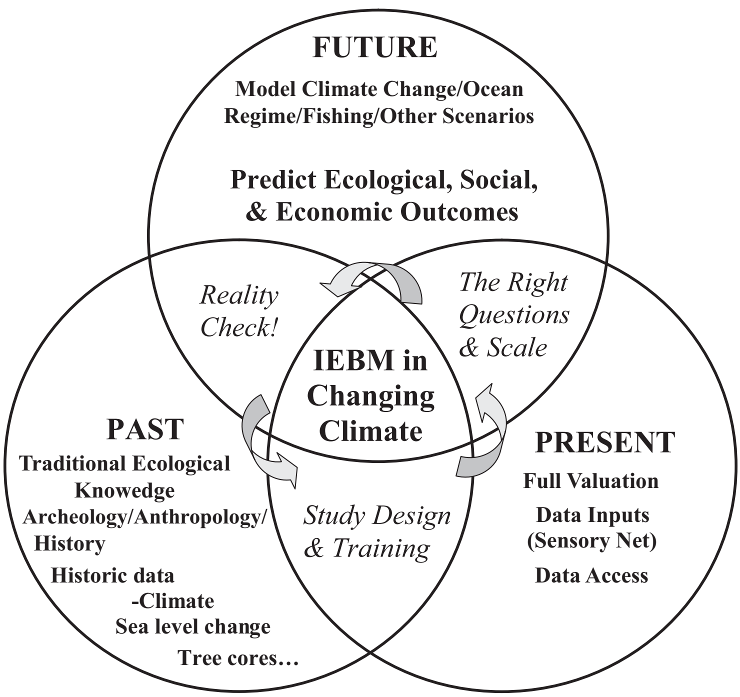

Figure 1.—Integrated ecosystem-based management (IEBM) concept: linking knowledge of the past, present research, and computer modeling facilitates prediction of ecosystem response to natural variability and human factors from fishing to climate change. Full valuation of present and future benefits of productive ecosystems is needed to assess the social, cultural, and economic consequences of different actions. Data inputs include traditional and local knowledge, single and multidisciplinary research, and anticipate a sensory net of ecological and ocean observation system assets. Present and future data volumes present a significant management and access challenge.

oceanographic, and climate models with the fine-scale spatial optimization capability of MARXAN[1] and geographic information system (GIS) platforms. We do not envisage one monster model for the entire West coast, but rather the capability to link whatever models are necessary to answer the questions at hand. This requires data that are standardized and permanently accessible. Here we envision a sensory net that links existing real-time data collection projects and anticipates collaboration between fisheries and ecological researchers, fishers, and other civil, industrial, and military users of ocean space in maintaining the net and data management systems.

Including all players in sensory net, model, and process construction builds social capital between collaborators and intellectual capital in the models and approaches (Haggan 2000). It also facilitates restoring depleted fish populations or reinvestment in natural capital, with benefits for coastal people and the community at large.

A Short History of British Columbia Ocean Space

Research indicates that Aboriginal people developed integrated ecosystem-based management (IEBM) several thousand years ago (Haggan et al. 2005). Advanced scientific knowledge of the biology, behavior, and genetics of Pacific salmon and other marine and terrestrial species contributed to a stable food supply and, in turn, cultural and economic wealth (Anderson 2005; Haggan et al. 2005, 2006; Turner 2005). For Aboriginal people, the commercial fishery was the new kid on the block. Aboriginal IEBM was replaced by single species management. By the 20th century, the breakdown of Canadian salmon catch of all species was 92% commercial, 4% recreational, and 4% Aboriginal (Pearse and Larkin 1992). The Canadian Aboriginal catch was also restricted to a stringently regulated food fishery, none of which might be sold. This contrasts with the United States where the Supreme Court Boldt decision returned 50% of salmon to the Washington State tribes.

By the 1990s, the new kids included salmon wars between Canada and the United States, a sport fishery taking increasing numbers of prime species and conservation organizations calling for reduced catch. Aboriginal people were also re-emerging as major players flowing from constitutional recognition of Aboriginal rights (Canada 1982).

The inadequacy of single species management under such complex conditions underpins calls for ecosystem-based management. The advent of farmed salmon, oil and gas, wind farms, natural gas pipelines, and so forth is behind the current call for integrated management. New geopolitical issues such as climate change and opening of the Northwest Passage make it critical that we reinvent integrated, ecosystem-based management, defined as the ability to understand and manage cumulative effects. As in the ancient past, our success will depend on two things: (1) the quality of knowledge and our ability to share it, and (2) our understanding of the full range of present and future benefits to humanity.

A new IEBM has to take into account three differences between the situation prior to European contact and the present day:

1. Precontact physical and cultural wealth derived from biota. By contrast, modern economies put more value on other resource sectors, with, in general, a shorter return on investment than most fish populations;
2. Apart from major river systems like the Fraser and Skeena,[2] precontact managment operated on a small scale. This is a very different model from today's coast-wide and international management, but new findings that many marine species are composed of numerous distinct subpopulations (e.g., Cury 1994; Hauser et al. 2002; Hutchinson et al. 2003; Prince 2003) point to the urgent need for management at a much finer spatial scale and a need for cross-scale linkages.
3. Precontact management was precautionary, based on respect for the intrinsic worth of salmon. There were also dire consequences for greed, waste, and disrespect, consisting of social sanctions, penalties, and even death for infra-

[1] MARXAN is a spatial optimization program used extensively in the design of marine reserves (Stewart et al. 2003) and identification of areas of high conservation utility (Arsron et al. 2002).

[2] Major river systems like the Fraser and Skeena required communication and negotiation to ensure that upstream tribes received sufficient salmon (Johnsen 2001), but the absence of major coastal interception fisheries made the type of coast-wide communication mediated through international salmon and halibut commissions unnecessary.

tion. This precautionary approach is reflected in the abundance of salmon at European contact, despite the existence of trap and weir technology capable of wiping out salmon runs many times over on all but the bigger rivers Anderson 1996; Johnsen 2001).

Changing Values

The chiefs are instructed so that when they deliberate on the serious matters of the council, they are to consider the impact of their decisions on the seventh generation into the future. (Chief Oren Lyons: Opening Speech for UN Year of the Indigenous Peoples 1993[3])

The lion's share of precontact wealth came from the coastal and marine ecosystems. The ability to create this wealth demanded knowledge of the environment and ways to maintain and enhance resource productivity into the far future. This long view is common to Aboriginal peoples and many longstanding communities that depend on natural resources for their distinct identity and continuing existence. The long view is well articulated in the Seventh Generation principle of the Haudenosaunee or Six Nations (Clarkson et al. 1992). We note in passing that Thomas Jefferson and Benjamin Franklin drew on the Haudenosaunee "Great Law of Peace" for the principle of representative democracy in the U.S. Constitution (Grinde and Johansen 1990). From this perspective, catching all the fish to generate cash to invest in something else is illogical. It may also be illegal given that almost all resource management legislation requires consideration of future generations.

[3] www.ratical.org/many_worlds/6Nations/OLatUNin92.html.

Today, we have many other sources of wealth: the information technology sector, service industries, pharmaceutical and bioengineering industries, entertainment, automotive, consumer electronics, construction, and so forth. Power and wealth tend to be measured in dollars. Fisheries are the most obvious source of dollars from marine ecosystems, but fisheries are a tiny fraction of 21st century economies (Table 1).

The small percentages in Table 1 explain why governments are reluctant to take fisheries seriously and why other investment opportunities such as offshore oil and gas and salmon farming appear so attractive to decision makers. Another key reason is that dollars grow faster than fish. Specifically, extinction is likely when the economic discount rate is more than twice the species population growth rate (Clark 1973a, 1973b). This accounts in large part for the depletion of ecosystems. Modern society tends to want money for a whole variety of reasons in less time than the ecosystem can produce fish to sell. It also accounts for government reluctance to invest in rebuilding depleted ecosystems (Sumaila 2004). These concerns can only be addressed through a thorough understanding of ecosystem response to natural variability, multiple human use, and climate change from the distant past to at least 100 years into the future. The problem is that the fisheries values in Table 1 do not justify the necessary computer models, data collection assets, collaborative research, and field studies. A full ecosystem valuation is needed.

Table 1.—Fisheries as percentage of gross domestic product (GDP) of the United States, Canada, and British Columbia.

Country/region	% of GDP	Source (and remarks)
USA (2003)[a]	0.30	FAO country profiles (including forestry and and hunting)
Canada (2000)[b]	0.21	Fisheries and Oceans Department of Canada (commercial, aquaculture, and processing)
British Columbia (2001)[c]	0.50	BC government statistics (commercial, sport, aquaculture, and processing)

[a] www.fao.org/fi/fcp/en/usa/profile.htm.
[b] www.dfo-mpo.gc.ca/communic/statistics/oceans/economy/contribution/table3_4_e.htm.
[c] www.env.gov.bc.ca/omfd/reports/BC-Fisheries-Aquaculture-Sector-2002.pdf.

Full Ecosystem Valuation

The "total economic valuation" approach (Millennium Ecosystem Assessment 2003; National Research Council 2005) identifies five categories of value: (1) direct use (e.g., fisheries); (2) nonconsumptive use (e.g., eco-tourism); (3) indirect use (e.g. ecosystem services); (4) option value (e.g., the ability to enjoy something that you may not be aware of now or later in your lifetime); and (5) existence value, generally expressed as willingness to pay (e.g., to protect species).

The decline in fisheries and other natural resources has drawn increasing attention to new and more comprehensive ways to value the natural world. Costanza et al. (1997) valued the Earth's ecosystem services at $US33 trillion/year. While the approach has been criticized, it is generally agreed that ecosystem services (e.g., the air we breathe and the role of the coupled oceanic–atmospheric circulation in moderating climate) have value even when not traded in the market. New methods allow us to compute the ecological and social as well as the market value (Angelsen et al. 1994; Angelsen and Sumaila 1996; Sumaila et al. 2001) and to include the value to future generations (Sumaila 2004; Ainsworth and Sumaila 2005; Sumaila and Walters 2005).

Considering each category of value and reducing the discount rate from 7% to 3%, (i.e., taking a longer view of the value of renewable resources), U. R. Sumaila et al. (University of British Columbia, unpublished data) found that the net present value of U.S. fisheries increased from $33 to $879 billion. While this is an important step beyond the current >0.5% of GDP, it did not, or did not fully include, the higher value of waterside property: the percentage of waterside recreation and vacation sector value attributable to a view of the ocean as pristine, vast, mysterious, and providing the opportunity to see whales, birds, fish; and the physical and mental health benefits that marine ecosystems provide to stressed city dwellers.

While these values are the subject of vigorous debate, we believe that a full accounting of the natural benefits is essential to sustain the level of effort needed to understand ecosystems and to engage the support of the wider users of ocean space. Indeed, our models of ecosystems, ocean regime, and climate change can only acquire the necessary power, elegance, and sophistication through wider collaboration in model construction. The models also need a sensory net of data collection assets supported by government, industry, foundations, environmental nongovernment organizations (ENGOs), academia, and stable repositories of data in accessible formats.

Ocean management requires (1) the ability to understand and model ecosystem response at multiple temporal and spatial scales, (2) collaboration on the design of a sensory net greater than the sum of its parts, and (3) standards and accessibility for existing and new databases. Sustainability requires a new look at the interface between big science projects, traditionally the role of academia and government, and the intellectual property that gives business its competitive edge. Benefits could include (1) more timely and comprehensive environmental impact assessments, (2) ongoing assurance of safety and sustainability, (3) more efficient and cost-effective operation, and (4) new technology that can be marketed at home and abroad.

The Separation of Ecosystem-Based and Integrated Management

Aboriginal IEBM made sense because of the immediate link between ecosystems and wealth. Most of what we now count as wealth comes from other sources, each with its own specialized field of knowledge. This explains the separation of ecosystem-based management from integrated management in Canada's Oceans Act and Oceans Strategy (Haggan et al. 2004). What has been lost between the period prior to European contact and the present is the ability to understand and allow for cumulative effects. The ecosystem principles are good, but the game of integrated management pits the potential revenue from depleted ecosystems against the money-making potential of oil and gas and farmed salmon and weighs ecosystem health against the costs of proper treatment of urban and industrial waste.

This is a bleak picture. What it suggests is that even if we get the science right, even if we could attain the level of ecosystem knowledge of an hereditary chief of the precontact era, able to draw on many generations of knowledge and trained from infancy in the ecology and management of their territory, we would still have to contend with the perception that fisheries are trivial and ecosystem considerations are, at best, a barrier to development.

We also have to address a tradition that is deeply rooted in single-species management and unduly influenced by industry and government priorities (Finlayson 1994). The majority of fisheries science and management funds still go to single-species approaches. This is not entirely a bad thing. There is a great deal of excellent single-species work. What we are not doing with any consistency is relating these individual studies to an ecosystem framework that connects species, habitats, people, and environment. Figure 1 presents a concept that links computer models (food web, oceanographic, climate, and socioeconomic) to traditional and local knowledge and data collection. (Pitcher et al. 2007) present a formal ecosystem evaluation framework that can assess the extent of our knowledge or, as the title suggests, plumb "the depths of ignorance" to suggest where research and modeling effort may best be deployed.

Linking the Models

"Baseline shift" (Pauly 1995) describes a tendency of fishers and fisheries scientists to equate the amount of fish an ecosystem ought to produce with abundance at the start of their careers. Perception of productive potential thus ratchets down over the generations. MacGregor et al. (2009, this volume) illustrate baseline shift in American eel *Anguilla rostrata* with accounts of extremely high catch rates in indigenous and early fisheries. Eels were a mainstay of Aboriginal culture and economy and were once the most valuable fishery of Lake Ontario, but are now of deep conservation concern (MacGregor et al. 2009).

The "back to the future" project attempts to reverse this cognitive ratchet at a whole ecosystem level (Haggan 2000; Pitcher et al. 2005). The Coasts Under Stress project (Ommer et al. 2007) used Ecopath with Ecosim (Christensen and Pauly 1992; Walters et al. 1997) to model northern BC waters in collaboration with Aboriginal people, commercial fishers, and others (Ainsworth et al. 2002). Figure 2 compares the biomass of key model groups before European contact in the 1750s, the 1900s, the 1950s, and the present day (2000). Twenty-five-year fishing simulations with current gear types indicate that the 1750s ecosystem could sustain a catch 7–9 times higher than the actual 2000 catch, as reported by Department of Fisheries and Oceans Canada (DFO; Ainsworth 2006), and more than 20 times more (Haggan et al. 2007, Table 4.2) if fished in accordance with the Food and Agriculture Organization of the United Nations (FAO) Code of Conduct (FAO 1995).

The goal is to use benchmarks of past abundance, diversity, and trophic structure to set res-

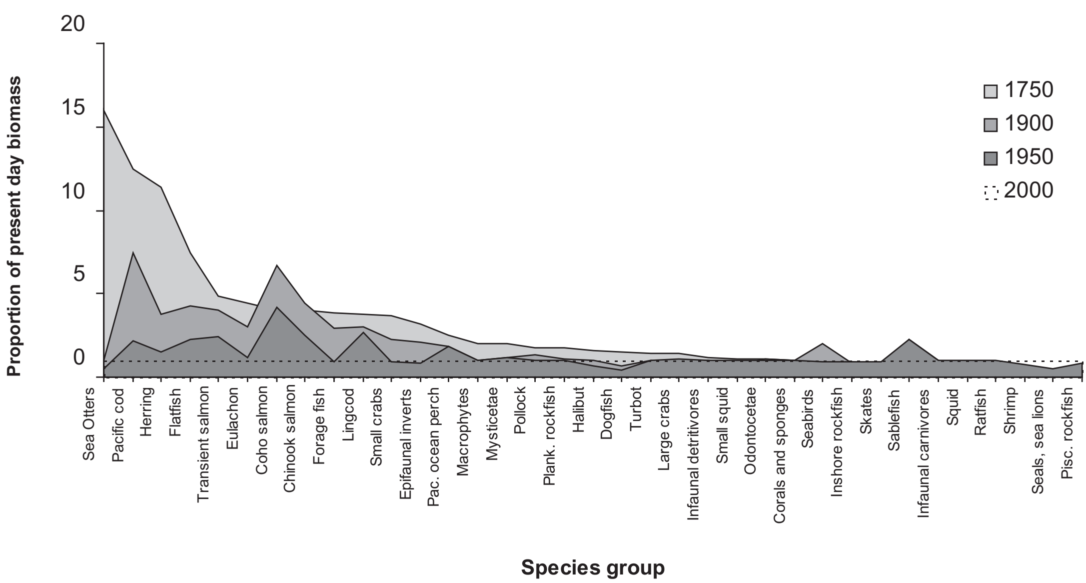

Figure 2.—Biomass of major marine species groups in northern British Columbia in the 1750s, 1900s, and 1950s compared to present day (dotted line), as modeled by Ainsworth (2006).

toration goals that relate to productive potential rather than present scarcity, not to restore some past golden age. Extinctions, exotic species, climate change, and possible (though unproven) irreversible effects of overfishing make this impossible. Accordingly, climate change modeling scenarios would adjust the benchmarks of Figure 2 to account for new species assemblages (e.g., warmer water ecosystems similar to those of Oregon or California). Rochard et al. (2009, this volume) explicitly consider future climate regimes in anadromous fish restoration in the Seine basin. Lassalle et al. (2009, this volume) model future distribution in a pan-European context.

Over the same period, the DFO Hecate Strait Ecosystem Project built a parallel model of Hecate Strait (HecStEP, no date). There is great potential to combine the regional food web models (e.g., Ainsworth et al. 2002; HecStEP, no date) with the spatial optimization capability of MARXAN used for conservation and marine use planning in British Columbia and the growing GIS databases of federal and provincial governments, Aboriginal people, and ENGOs. These models can in turn be driven by regional climate change models.

The Sensory Net

The sensory net consists of current and planned sensor arrays to track salmon and other species and anticipates linkage with a proliferating range of ocean observation systems (OOS). This linkage is critical. While the ecological arrays are visionary, they are subject to funding constraints related to our current assessment of fisheries values (Table 1). Ocean observation systems relate to the entire range of scientific enquiry, impact assessment, and development in the world's oceans and coupled ocean-atmospheric systems. The annual market for new OOS technology is approximately $2 billion (Douglas-Westwood 2006). Current ecological assets include, by geographic scale, the following:

The Victoria Experimental Network Under the Sea

The Victoria Experimental Network Under the Sea (VENUS) is the first of a new type of seafloor observatory (Tunnicliffe et al. 2003; Dewey et al. 2007). Instrument arrays are connected via cable to the shore and thus to unlimited power and two-way communication. This has three major advantages: (1) experiments are unconstrained by battery life; (2) instruments can be accessed anywhere at any time, not only to receive data, but to command and control; and (3) data and view events can be shared in real time with collaborators and students. The first VENUS array began operations in Saanich Inlet, British Columbia in February 2006. The second, commissioned in fall 2007, includes three seafloor instrument suites in the Strait of Georgia south of Vancouver. Receivers deployed across the mouth of the Fraser River will communicate information from tagged salmon, white sturgeon *Acipenser transmontanus*, or eulachon, as discussed below, in a daisy chain back to an acoustic modem cabled into the VENUS node. The capacity for higher frequency interrogation and notification once an emerging—or returning—cohort crosses the line lends immediacy to data return and may be of considerable value for alerting other detection systems or management agencies. The multitude of sensors also allows researchers to measure ocean parameters, including temperature, salinity, gas pressure, and plankton abundance, both at times of fish presence and absence. It would be possible, for example, to examine current records from the full Strait depth to determine the flow conditions at the times fish were crossing the receiver line.

VENUS provides simple graphical analyses for a quick inspection of conditions. Fish records can be displayed with a GoogleMap interface currently used to display instrument locations and metadata. The VENUS Web site (www.venus.uvic.ca) provides a convenient display and communication tool that is especially valuable for teaching. The Web site also allows researchers to perform data searches and multisensor integration using the Data Management and Archive System. The Data Management and Archive System is a highly sophisticated structure to deal with many types of ocean data: scalar, acoustic, and visual. The challenge for fish tracking is to develop a rapid response and alerting system and a data policy to integrate with partners such as the Pacific Ocean Shelf Tracking Project and the Ocean Tracking Network.

The Pacific Ocean Shelf Tracking Project

The Pacific Ocean Shelf Tracking Project (POST) mission is to "assess and explain the changing diversity, distribution and abundance of marine species, from the past to the present, and project future marine life" (Yarincik and O'Dor 2005). POST is funded by the Census of Marine Life (CoML, www.coml.org) and the Moore Foundation's Wild Salmon Ecosystems Initiative. POST is intended as a permanent continental-scale telemetry research platform. POST currently spans more than 2,500 km from Icy Strait in southeast Alaska to Oregon and extends almost 900 km up the U.S. Columbia–Snake River (Figure 3). Future plans anticipate continental shelf coverage from Baja California to the Bering Sea.

The acoustic frequencies selected allow the system to work seamlessly between freshwater and marine environments. Engineering standards applied in deployment and array geometry enable a more than 95% detection of fish passing the array. Surgical techniques have been standardized and refined to enable routine tagging of fish as small as 12.5 cm, with close to 100% survival. POST is now beginning to answer critical questions on salmon migration and survival:

- Where do salmon go?
- What do they do when they get there?
- How do they return to spawn in their home rivers?
- How do changes in the ocean environment affect their survival?

POST can also help to facilitate the evaluation of proposed networks of marine protected areas for salmon and other key species likely to be affected by climate change. The current situation of accelerating climate change is now well documented (e.g., Parmesan 2006). Although there are many unknowns, temperature alone may continue to push salmon populations north. This would severely limit the distribution of some species (e.g., steelhead *Oncorhynchus mykiss*,

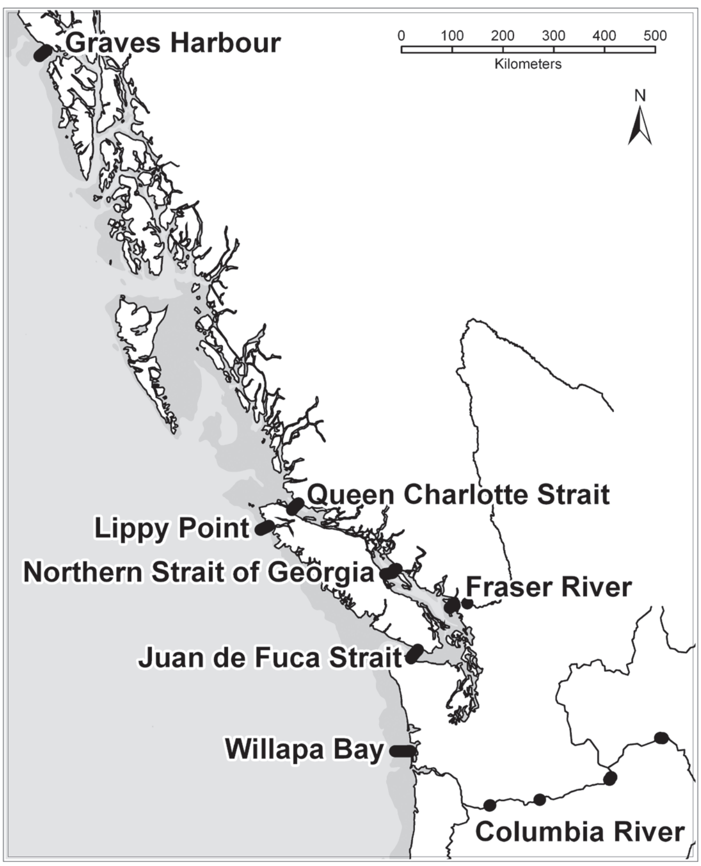

Figure 3.—The Pacific Ocean Salmon Tracking Project array configuration in 2007.

Welch et al. 1998) or even exclude others from the Pacific entirely (e.g., sockeye *O. nerka*, Welch et al. 1998). It is important that POST continues to collect baseline data on salmon movement, migration, and survival. A time series is needed to monitor how climate change and other anthropogenic influences might affect salmon populations.

Other species and globalization.—POST can provide insights into the ecology of nonsalmonids, which advance fisheries and ecosystem management and assist in conservation of important species. POST dramatically demonstrated that a white sturgeon tagged in the Sacramento River spent several months in the Fraser River (Welch et al. 2006). This finding has significant management implications as some sturgeon populations are protected while others are not. Key species for which POST can answer important questions include Pacific halibut *Hippoglossus stenolepis*, spiny dogfish *Squalus acanthias*, sablefish *Anoplopoma fimbria*, and invertebrates such as squid (e.g., Pecl et al. 2006; Stark et al. 2005), octopus, and Dungeness crab *Cancer magister*.

O'Dor and Gallardo (2005) anticipate that: "The POST arrays will be a coastal component of GOOS" (Global Ocean Observing System, www.ioc-goos.org). This is the critical linkage among tracking anadromous fishes and other aquatic species, ecosystem modeling, and the entire range of human activity in the oceans of the world.

The Ocean Tracking Network

POST is the flagship project in the Ocean Tracking Network (OTN) (www.oceantrackingnetwork.org), an international scientific endeavor to integrate animal movement and migration patterns with oceanographic data. The Ocean Tracking Network encompasses all seven continents and 14 ocean regions. Plans to deploy 5,000 receivers in 600 listening lines around the world will make it possible to track 1 million animals simultaneously. The volumes of data to be collected will be huge, requiring the development of new data structures and analysis tools. The Ocean Tracking Network will be working closely with both POST and ultimately the Ocean Biogeographic Information System (OBIS) for archiving, distributing, and analyzing the data.

The OTN will be able to track migrating animals, undertake global ocean physics modeling, and study how climate change will influence both. Conservation and resource management questions will determine where OTN lines are deployed and what species are tracked.

The OTN will drive acoustic technology forward to create new and innovative ways of tracking marine organisms. Step 1 will use miniature acoustic receivers or "business card" tags to transform predators such as sharks or seals into roving receiver platforms able to record interactions with the ecosystem. Step 2 will double tag predators with business card and geolocating archival tags to correlate individual movements of tracked animals to depth and temperature, giving us the clearest picture ever available of how organisms use the aquatic environment. Step 3 will develop new generation fast Communicating Histogram Archiving Transmitter (CHAT) tags (O'Dor et al. 2006) and new receivers to allow oceanographic and predator–prey interaction data to be downloaded as the organism crosses an acoustic line (Holland et al. 2001). Step 4 will combine the business card, archival geolocating, and fast CHAT tag functions in fully integrated tags (FITs). When the organism swims over the new generation listening line, the FIT will download location, oceanographic, and biological interaction data without need for recapture—essentially a complete underwater Argos system independent of satellites. This will ultimately lead to many more species being tagged with increasingly smaller tags and the acquisition of archival data at a much lower cost. For a more complete description of OTN, see Stokesbury et al. (2009, this volume).

Tracking eulachon: the next step.—Eulachon are suffering a severe decline and may have been extirpated from several rivers in the central coast of British Columbia (Hay and McCarter 2000), with profound impact on Aboriginal people (Hume 2007). Eulachon, the first species to enter the rivers in springtime when dried salmon and other food sources had run low or out, were referred to as "salvation fish" (Harrington 1967). For the same reason, eulachon are thought to be a keystone species based on the number of predators attending their arrival (Willson and Halupka 1995) and may be critical to the energetics of Steller's sea lion *Eumetopias jubatus* (Sigler et al. 2004). However, many aspects of their ecology remain unknown. Offshore abundance indicated by substantial bycatch in the BC shrimp trawl fishery is not reflected in numbers migrating into the rivers (Hay and McCarter 2000). Likewise, there appear to be interesting parallels between population levels of eulachon and salmon. Both salmon and eulachon appear to be doing better in Alaskan waters than in southern British Columbia. This suggests that there is likely an ocean survival problem with both groups of fish, with the impact not affecting Alaskan waters to the degree that it is in waters further south. POST is well placed to test hypotheses of eulachon survival in the ocean. By tagging individuals in the ocean, it would be possible to obtain a better indication of where individuals are moving and why there are low numbers returning to natal rivers.

Stokesbury et al. (2009) discuss how FITs attached to salmon sharks *Lamna ditropis* could track salmon throughout their ocean range, providing a major extension to POST and other arrays. Eulachon are important prey items of endangered beluga whales *Delphinapterus leucas* in Cook Inlet, Alaska and white sturgeon in the Fraser River system. It would be feasible to turn both belugas and sturgeon into roaming acoustic receivers by fitting them with OTN business card tags, providing a strong scientific framework with which to study trophic interactions of all three species. Central to any of these efforts is the ability to catch and tag sufficient numbers of eulachon.

Tagging eulachon at sea would then allow them to be counted over the POST array and as they move up the Fraser River. A more extensive array would enable tracking migration into other eulachon-bearing rivers such as the Nass and Skeena and even depleted systems such as the Bella Coola River and Rivers Inlet where their presence is revealed only by intensive field surveys (Moody 2008) and sporadic sightings by local people.

Ocean Gliders and Ocean Observing Systems

Ocean gliders provide a conceptual link between predators as mobile receptor platforms in OTN and the wider world of OOS. Ocean gliders are battery-powered, ocean-going robots that operate for periods up to 6 months in depths typically down to 1,000 m. Gliders use Global Positioning Systems and dead reckoning for positioning and can achieve speeds of 0.9 km/h by shifting buoyancy to descend and ascend at shallow angles. Ocean gliders surface to uplink data and receive updated mission instructions via satellite. Different sensor packages enable measurement of physical properties, location of marine mammals, and surveillance in areas where it is difficult to otherwise obtain information. In 2007, the Canadian Centre for Ocean Gliders, together with DFO, completed a project that demonstrated the capability of ocean gliders to provide mobile monitoring of the ocean under tough winter conditions (D. Gueret, Fisheries and Oceans Canada, personal communication). Key advantages of relative ease of operation, low capital and operations costs, extended mission duration, and flexibility must be balanced against limitations in speed, payload, and power.

Ocean Observing Systems

The global Ocean Observing Systems (OOS) market is conservatively projected to increase from $1.8 billion in 2006 to $2.2 billion by 2011, with governments as the main client and source of funding (Douglas-Westwood 2006). Key market drivers are the role of the oceans in climate change, environmental pollution, and industry needs to operate in an environment of increasing regulation. The complex nature of OOS, with multiple stakeholders and financing requirements, is a consequence of carrying out integrated management in the ocean. Douglas-Westwood (2006) identified 1,200 OOS applications in 500 programs currently underway. The United States is by far the largest player with 2002 expenditures of $750 billion, 50% generated by the oil and gas industry, with 33% attributed to the Navy.

These expenditures dwarf the largest sums allocated to fisheries and ecosystem considerations, underscoring the need for collaboration. Canada's fisheries budget actually decreased in recent years. Clearly, the future of IEBM lies in networking OOS systems with integrated physical, biological, environmental, and economic models, as contemplated in Figure 1.

Data Management, Accessibility, and Sustainability

The Sea Around Us Project—A Global Fisheries Database

Until the end of the 20th century, the FAO was the sole source of global fisheries data. The Sea Around

Us Project (SAUP), funded at the University of British Columbia Fisheries Centre by the Pew Charitable Trusts, was founded in 1999 to "provide an integrated analysis of the impacts of fisheries on marine ecosystems, and to devise policies that can mitigate and reverse harmful trends while ensuring the social and economic benefits of sustainable fisheries" (Pauly and Pitcher 2000). The SAUP database (www.seaaroundus.org) divides the world's oceans into 180,000 half-degree squares and applies a rule-based method to reassign FAO and other catch data to their ecosystems of origin (Watson et al. 2004). The Sea Around Us Project is extending FAO data to include discards and illegal, unregulated, and unreported catch. These figures are substantial (Pauly et al. 2002; Figure 1) but do not yet include a significant portion of artisanal fishery catch conservatively estimated at 30 million metric tons (Pauly 2006). The proportion of recreational catch included is also unclear.

The SAUP database is deep-linked to Fishbase (www.FishBase.org), the online global finfish database (Froese and Pauly 2007). The Sea Around Us Project, in partnership with the Oak Foundation, has recently launched SeaLifeBase (www.seaLifeBase.org), which currently includes more than 80,000 of an estimated 200,000 marine species. The SAUP database now includes or is linked to databases of cephalopods (www.cephbase.utmb.edu/), coral reefs, sea grass beds, estuaries, seamounts, and marine-protected areas. The SAUP database also processes data from the SeaWiFS satellite (http://oceancolor.gsfc.nasa.gov/SeaWiFS/) at a spatial resolution of ~6 min (11 km) to estimate the phytoplankton production using a model by Platt and Satyendranath (1988) that integrates primary production by depth based on chlorophyll pigment concentrations and photosynthetically active radiation (Hoepffner et al. 1999; Lai 2004).

These linkages facilitate the rapid construction of basic ecosystem models for any area, over and above those existing on the Ecopath with Ecosim Web site (www.ecopath.org). The Sea Around Us Project also contains a global database of exvessel fish prices (Sumaila et al. 2007), which, combined with the catch data, yields a database of catch value. It also includes a database of fishing agreements.

The entire SAUP edifice is sustained by the energy and vision of Dr. Daniel Pauly and the Pew grant. Individual pieces are sustainable, notably FishBase, which has evolved from a project of ICLARM to a consortium of eight institutions, including four museums. The risk is not limited to SAUP. The sheer volume of data that VENUS, POST, OTN, and affiliated networks will generate, the new database structures and analysis tools needed, and the 2010 CoML POST funding sunset call for sustaining partnerships. The Ocean Tracking Network is addressing this through more than 30 partnership agreements leveraging more than $160 million in cash and in-kind services, where partners have agreed to track, observe, maintain equipment, and upload data. The POST vision (O'Dor and Gallardo 2005) also anticipates the sustainability issue: "by 2010 POST will have tested and demonstrated continental-scale acoustic tracking. . . .It will enter the accumulated migratory tracks in the Ocean Biogeographic Information System (OBIS)"

The Ocean Biological Information System—A Global Marine Biodiversity Database

The Ocean Biological Information System (www.iobis.org) is the CoML data depository. The Ocean Biological Information System is a Web-based, georeferenced catalog on marine species that currently houses more than 10 million records and incorporates marine data from other institutions and programs (Costello et al. 2007). As OBIS continues to grow and becomes more comprehensive, it will become an increasingly powerful resource on marine biodiversity. The Ocean Biological Information System will be a means to create linkages between programs and databases and will assimilate not only biological data on depth and location, but also distribution data such as that generated by POST and OTN.

Data Needs and Initiatives in the Pacific Northwest

While SAUP provides a useful model, the half degree or 30 × 30 nautical mile spatial resolution is too coarse for most EBM and management applications in Pacific West Coast waters. Access to data in standard formats is an issue for all EBM activities from whole ecosystem models to the GIS-based traditional-use studies of Aboriginal people. By their holistic nature, ecosystem models require a wide variety of biological, oceanographic, and socioeconomic information. Collaboration across disciplines is required to satisfy diverse data needs.

Centralized data repositories are critical for broad-swath modeling systems. They also hold many advantages, not the least of which is streamlining research and helping to overcome data sharing hurdles. This is especially true for modeling systems like Ecopath with Ecosim, Atlantis (Fulton et al. 2004), and other modeling platforms reviewed in Fulton et al. (2007). Thus, while both Ecopath with Ecosim and Atlantis are open source, freely available and flexible enough to represent many types of ecosystems and study areas, the question of gathering sufficient data for them to produce meaningful results remains.

Major ecosystem modeling projects such as Back to the Future (Haggan 2000; Pitcher et al. 2005), MARXAN spatial optimization analyses (Ardron 2002, 2003, 2005; Ardron et al. 2002), and GIS-based traditional-use studies by Aboriginal people all wrestle with data access[4] and standardization. These projects have each made huge investments of time in gathering and formatting data for comprehensive analyses. Because current data-sharing agreements usually preclude further sharing, other researchers have to do it all over again. This is unnecessarily costly and labor-intensive. It also means that issues addressed by one team may be missed by others and that data are not standardized across models, making comparisons of results more difficult. Many projects simply cannot get off the ground because they are denied access to data, resulting in a limited field of a few players who have had data access.

The field of ecosystem modeling and EBM in general would benefit greatly from a centralized and standard repository of oceanographic time series information. Data monitoring networks, such as POST, VENUS, and OTN, could contribute to such a collaboration, increasing the scientific dividends of the submarine acoustic monitoring network. Availability of highly resolved regional data is also conducive to the development of additional modeling platforms and capabilities to capitalize on the valuable site-specific information.

[4] For example, the georeferenced Pacific groundfish catch database collected by Canada's Department of Fisheries and Oceans in the 1990s has never, to our knowledge, been integrated into an ecosystem model due to stated concerns about identification of individual fishers and confusion about who actually owns and has rights to the data. The Fisheries and Oceans Department of Canada is still without a data-sharing policy, which would offer guidance in such situations.

The Cooperative Ocean Information Network for the Pacific.—The Cooperative Ocean Information Network for the Pacific (COINPac) was formed to address the issue of access and sustainability by creating a portal to all major databases and a mechanism to translate data from various formats. COINPac was successful in creating a BC user community forum, developing and reaching agreement on the portal and access mechanism. This forum, which represents a substantial investment in partnership building, has relocated to the University of Victoria. In early 2007, the Ocean Science and Technology Partnership (www.ostp-psto.ca), with COINPac as the BC partner, completed a strategic document that called for national and regional policy changes and investment to support the development of OOS (OSTP 2007). The report calls for a national strategy to facilitate and help coordinate the emerging OOS systems to maximize their value to society. Coordinating multiple ocean users as OOS stakeholders, using systems approaches to ocean observations, and concentrating on lessons learned elsewhere, were identified as key approaches. The north coast was identified as the location for an OOS in British Columbia.

The Pacific Marine Analysis and Research Association.—The Pacific Marine Analysis and Research Association (PacMARA, www.pacmara.org) grew out of a series of multi-stakeholder meetings held in 2002–2003, where users, practitioners, regulators, and advocates for the sea identified a number of common research needs. PacMARA seeks to develop and encourage the use of cross-disciplinary marine science in ecosystem-based decision making. PacMARA takes an impartial, nonadvocacy approach, believing that access to data, good science, and clear results are at the heart of sustainable oceans management.

It has been suggested that PacMARA could act as an honest broker between data sources and data users. Processed data sets (often compiled from a variety of sources, as described above) could be held by PacMARA and distributed to EBM modelers and users based upon agreed data protocols. Additionally, PacMARA could compile and relay back to data sources those corrections or issues that have arisen with regard to particular source data.

While the above arrangement would not represent the ideal of open Internet access often promoted by data-sharing advocates, it would nonetheless represent a significant step forward, allowing EBM research in British Columbia to proceed more broadly, based on standardized data sets, and allow for regular updates while adhering to protocols that would satisfy data sources.

Long-Term Sustainability—Global and Local

Even major biotech and health databases face problems of sustainability (Anon 2007). If health, which accounts for ~50% of tax dollars, cannot sustain the basic information needed to support research into human life and health, the problem of sustaining the sensory net and databases needed for EBM is even more acute. The risk that substantial collaborative projects such as SAUP or POST or even OTN might not survive the retirement of visionary leaders or the sunset of foundation funding is unacceptable. Nor is it reasonable that foundations should carry the entire cost. We hope that this brief overview of analytic tools and data collection and management assets will at least set the stage for a broader based collaboration between government, ENGOs, and industry to build sustaining partnerships.

The case for business support.—The information systems needed to understand the drivers of ecosystem abundance and response to fishing, climate change, and other factors can benefit multiple users of ocean space. There is therefore a cogent argument for the design of data acquisition assets to provide multiple data streams. This coordination is not cheap, but it is achievable through cost sharing between government and industry, provided that the benefits to operations as diverse as ports, national defense, marine navigation, ocean energy (renewable and hydrocarbon), wind farms, waste management, and so forth can be identified. We take the positive view that all sectors, new, old, large, and small, share a desire to maintain ecosystem health and keep options open for future generations. Collaboration and data sharing are much more likely to reveal effective ways to do this than campaigns against the presence of certain sectors.

The case for government support.—Coastal and marine ecosystems provide a wide range of public goods for which no market currently exists. Healthy marine ecosystems provide a wide range of natural resources and a growing number of pharmaceuticals and other marine products. Most Pacific salmon die after spawning, contributing nitrogen, phosphorus, and carbon to freshwater and forest ecosystems (Stockner 2003). The size of past salmon runs is reflected in the growth rings of riverside trees (Reimchen 2001; Naiman 2009, this volume), but it does not stop at the bank or lakeshore. At least 40 creatures from people to bears to insects transport nutrients from salmon carcasses into the forest (Watkinson 2001). We know this because marine nitrogen is a different isotope (^{15}N) from terrestrial nitrogen (^{14}N) and has been used to trace the influence of salmon carcasses up to 1 km away from the water's edge (Watkinson 2001). Gresh et al. (2000) estimated historic salmon escapements to the Pacific Northwest at 160,000–226,000 metric tons, versus 11.8–13.7 today, indicating that nutrient inputs are about 6–7% of pre-European contact levels. Out-migrating salmon smolts require significant amounts of nitrogen (Moore and Schindler 2004), so reduction in spawning runs may also impact freshwater and early marine survival.

Marine ecosystems also absorb, detoxify, and sequester significant amounts of industrial and human waste; support tourism, vacation, and outdoor recreation; enhance property values; and provide a source of psychological rejuvenation and inspiration for the arts (Peterson and Lubchenko 1997; National Research Council 2005). On a global scale, oceans sequester carbon, moderate climate, and provide half of the oxygen we breathe (Field et al. 1998). Given the significant impact of private investment and ownership on ecosystem health, there is a pressing case for government to protect and, where necessary, restore ecosystem services. Salzman (2005) outlines workable approaches.

Conclusion

While we need employment and prosperity today, we also need to ensure that the ecosystem goods and services that sustained rich Aboriginal societies and jump-started the BC economy continue into the far future. It is simplistic to cast this as a struggle between good (conservation) and evil (development). It is unhelpful to categorize ecosystem values as priceless or infinite (given future generations). It is, however, vitally important that we strive to understand each other's values and explore ways in which they can coexist.

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References

Ainsworth, C. 2006. Strategic marine ecosystem restoration in northern British Columbia. Doctoral thesis. University of British Columbia, Vancouver.

Ainsworth, C., J. J. Heymans, T. J. Pitcher, and M. Vasconcelos. 2002. Ecosystem models of northern British Columbia for the time periods 2000, 1950, 1900 and 1750. University of British Columbia, Fisheries Centre Research Report 10(4), Vancouver.

Ainsworth, C., and U. R. Sumaila. 2005. Intergenerational valuation of fisheries resources can justify long-term conservation: a case study in Atlantic cod (*Gadus morhua*). Canadian Journal of Fisheries and Aquatic Sciences 62(5):1104–1110.

Anderson, E. N. 1996. Ecologies of the heart: emotion, belief, and the environment. Oxford University Press, New York.

Anderson, K. 2005. Tending the wild: Native American knowledge and the management of California's natural resources. University of California Press, Berkeley.

Angelsen, A., O. H. Fjeldstad, and U. R. Sumaila. 1994. Growth, development and sustainability. Development Matters 1(2):19–22.

Angelsen, A., and U. R. Sumaila. 1996. Hard methods for soft policies: environmental and social cost-benefit analysis. Forum for Development Studies 1:87–114.

Anon. 2007. The database revolution. Nature (London) 445(7125):229.

Ardron, J. 2003. BC Coast Information Team Marine Ecosystem spatial analysis, v. 1.2. Excerpted and revised from C. Rumsey, J. Ardron, K. Ciruna, T. Curtis, F. Doyle, Z. Ferdana, T. Hamilton, K. Heinemyer, P. Iachetti, R. Jeo, G. Kaise, D. Narver, R. Noss, D. Sizemor, A. Tautz, R. Tinger, and K. Vance-Borland, editors. An ecosystem analysis for Haida Gwaii, central coast, and north coast British Columbia. Available: www.livingoceans.org/files/PDF/mpa/CIT_marine_report1-2b.doc (November 2008).

Ardron, J. A. 2005. Protecting British Columbia's corals and sponges from bottom trawling. Living Oceans Society, Sointula, BC, Available: www.livingoceans.org/files/PDF/sustainable_fishing/Protecting_BCs_Corals_and_Sponges.pdf (November 2008).

Ardron, J. A. 2002. A recipe for determining benthic complexity: An indicator of species richness. Pages 169–176 *in* J. Breman, editor. Marine geography: GIS for the oceans and seas. ESRI Press, Redlands, California.

Ardron, J. A., J. Lash, and D. Haggerty. 2002. Modelling a network of marine protected areas for the central coast of British Columbia. Living Oceans Society, Sointula, BC. Available: www.livingoceans.org/files/PDF/mpa/LOS_MPA_model_v31_web.pdf (November 2008)

BC (British Columbia). 2002. British Columbia's fisheries and aquaculture sector British Columbia Ministry of Management Services, Victoria, BC. Available: www.env.gov.bc.ca/omfd/reports/BC-Fisheries-Aquaculture-Sector-2002.pdf (February 2008).

Canada. 1982. The Constitution Act. Enacted by the Canada Act, 1982. (UK), c. 11, Schedule B.

Christensen, V., and D. Pauly. 1992. ECOPATH II—a system for balancing steady-state ecosystem models and calculating network characteristics. Ecological Modeling 61:169–185.

Clark, C. W. 1973a. The economics of overexploitation. Pages 155–159 *in* L. G. Anderson, editor. Fisheries economics: collected essays. volume 1. International Library of Environmental Economics and Policy, Aldershot, UK.

Clark, C. W. 1973b. Profit maximization and the extinction of animal species. Journal of Political Economy 81(4):950–961.

Clarkson, L., L. V. Morrissette, and G. Régallet. 1992. Our responsibility to the seventh generation. International Institute for Sustainable Development, Winnipeg, Manitoba, Canada.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Ecological Economics 25(1):3–15.

Costello M. J., K. Stocks, Y. Zhang, J. F. Grassle, and D. G. Fautin. 2007. About the Ocean Biogeographic Information System. Available: www.iobis.org (July 2007).

Cury, P. 1994. Obstinate nature: an ecology of individuals. Thoughts on reproductive behavior and biodiversity. Canadian Journal of Fisheries and Aquatic Sciences 51(7):1664.

Dadswell, M. J., R. J. Klauda, C. M. Moffit, R. L. Saunders, R. A. Rulifson, and J. E. Cooper, editors. 1987.

Common strategies in anadromous and catadromous fishes. American Fisheries Society, Symposium 1, Bethesda, Maryland.

Dewey, R., Round, R., Macoun, R., Vervynck, J., and Tunnicliffe, V. 2007. The VENUS cabled observatory: engineering meets science on the seafloor. In Proceedings of the OCEANS 2007 MTS/IEEE, Vancouver, Canada, October 2007. Available: http://venus.uvic.ca/resources/documents/Oceans07paper-070427-015.pdf (November 2008).

Douglas-Westwood. 2006. Global markets for ocean observation systems. Available: www.ostp-psto.ca/Files/Intro_and_OOS_Strategy.ppt (July 2007).

Drake, A., and L. Wilson, 1991. Eulachon: a fish to cure humanity. 32. University of British Columbia, UBC Museum of Anthropology, Museum Note No. 32, Vancouver.

FAO (Food and Agriculture Organization of the United Nations. 1995. Code of conduct for responsible fisheries. Food and Agriculture Organization of the United Nations, Rome.

Field, C. B., M. J. Behrenfeld, J. T. Randerson, and P. Falkowski. 1998. Primary production of the biosphere: integrating terrestrial and oceanic components. Science 281(5374):237.

Finlayson, A. C. 1994. Fishing for truth: a sociological analysis of northern cod stock assessments from 1977 to 1990. ISER Press, St. John's, Newfoundland, Canada.

Froese, R., and D. Pauly. 2007. FishBase. Available: www.fishbase.org (November 2008).

Fulton, E. A., T. Morato, and T. J. Pitcher. 2007. Modelling seamount ecosystems and their fisheries. In T. J. Pitcher, T. Morato, P. J. B. Hart, M. Clark, N. Haggan, and R. Santos, editors. Seamounts, ecology, fisheries and conservation. Blackwell Scientific Publications, Oxford, UK.

Fulton, E. A., J. S. Parslow, A. D. M. Smith, and C. R. Johnson. 2004. Biogeochemical marine ecosystem models II: the effect of physiological detail on model performance. Ecological Modelling 173(4):371.

Gresh, T., J. Lichatowich, and P. Schoonmaker. 2000. Salmon decline creates nutrient deficit in northwest streams. Fisheries 15(1):15–21.

Grinde, D. A., Jr. and B. A. Johansen. 1990. Exemplar of liberty: native America and the evolution of democracy. University of California Los Angeles, American Indian Studies Center, Los Angeles.

Haggan, N. 2000. Back to the future and creative justice: Recalling and restoring forgotten abundance in Canada's marine ecosystems. Pages 83–99 *in* H. Coward, R. E. Ommer, and T. J. Pitcher, editors. Just fish: ethics in the Canadian coastal fisheries. ISER Books, St. John's, Newfoundland, Canada.

Haggan, N., C. Ainsworth, T. J. Pitcher, and J. J. Heymans. 2007. Life in the fast food chain: où sont les poissons d'antan? Pages 51–74 *in* C. C. Parrish, N. Turner, and S. Solberg, editors. Resetting the kitchen table: Food security, culture, health and resilience in coastal communities. Nova Science Publishers, New York.

Haggan, N., A. Narcisse, U. R. Sumaila, C. S. Lucas, and N. Turner. 2005. Pacific ecosystems, past, present and future: integrating knowledge and values, anticipating climate change. Proceedings of the Proceedings of the Indigenous Peoples' Restoration Network Earth in Transition Session, Society for Ecological Restoration International Conference, Zaragoza, Spain, September 12–18, 2005. Available: www.ser.org/iprn/pdf/Nigel_Haggan.pdf (July 2007).

Haggan, N., N. J. Turner, J. Carpenter, J. T. Jones, C. Menzies, and Q. Mackie. 2006. 12,000+ years of change: linking traditional and modern ecosystem science in the Pacific Northwest. UBC Fisheries Centre, Working Paper #2006–02, Vancouver. Available: www.fisheries.ubc.ca/archive/publications/working/2006/2006-02.pdf (November 2008).

Haggan, N., T. J. Pitcher, and U. R. Sumaila. 2004. Back to the future in the Strait of Georgia. Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference, Vancouver, BC.

Harrington, R. 1967. Eulachon and the grease trails of British Columbia. Canadian Geographic Journal (January):28–31.

Hauser, L., G. J. Adcock, P. J. Smith, J. H. Bernal Ramírez, and G. R. Carvalho. 2002. Loss of microsatellite diversity and low effective population size in an overexploited population of New Zealand snapper (*Pagrus auratus*). Proceedings of the National Academy of Sciences of the United States of America 99(18):11742.

Hay, D., and P. B. McCarter. 2000. Status of the eulachon, *Thaleichthys pacificus* in Canada. Department of Fisheries and Oceans Canada, Canadian Stock Assessment, Secretariat, Research Document 2000-145, Ottawa.

HecStEP. No date. HecStEP. HecStEP Strait Ecosystem Project. Available: Hecwww-sci.pac.dfo-mpo.gc.ca/sa-hecate/default.htm (February 2008).

Hoepffner, N., Z. Finenko, B. Sturm, and D. Larkin. 1999. Depth-integrated primary production in the eastern tropical and sub-tropical north Atlantic basin from ocean colour imagery. International Journal of Remote Sensing 20:1435–1456.

Holland, K. N., A. Bush, S. M. Kajiura, C. G. Meyer, B. M. Wetherbee, and C. G. Lowe. 2001. Five tags applied to a single species in a single location: the tiger shark experience. Pages 237–247 *in* J. R. Sibert, and J. Nielsen, editors. Electronic tagging and tracking in marine fisheries. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Hume, M. 2007. Collapse of the eulachon and the loss of a culture. The Globe and Mail, Toronto (June 20).

Hutchinson, W. F., C. van Oosterhout, S. I. Rogers, and G. R. Carvalho. 2003. Temporal analysis of archived samples indicates marked genetic changes in declining North Sea cod (*Gadus morhua*). Proceedings of the Royal Society of London B 270:2125–2132.

Johnsen, D. B. 2001. Customary law, scientific knowledge, and fisheries management among northwest coast tribes. Environmental Law Journal 10(1):1–69.

Lai, S. 2004. Primary production methodology. In A global database on marine fisheries and ecosystems. University of British Columbia Fisheries Centre, Vancouver. Available: www.seaaroundus.org/primaryproduction/interpolation_method.htm (November 2008).

Lassalle, G., M. Beguer, E., Rochard, and L. Beaulaton 2009. Learning from the past to predict the future: responses of European diadromous fishes to climate change. Pages 175–193 *in* A. J. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, R. A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. Challenges for diadromous fishes in a dynamic global environment. American Fisheries Society, Symposium 69, Bethesda, Maryland.

Lucas, S. 2007. Life supports life. Pages 61–70 *in* N. Haggan, B. Neis, and I. G. Baird, editors. Fishers' knowledge in fisheries science and management. Coastal Management Sourcebooks 4. UNESCO, Paris.

MacGregor, R. B., P. C. Thompson, A. Mathers, J. M. Casselman, J. M. Dettmers, and S. LaPan. 2009. Natural heritage, anthropogenic impacts, and biopolitical issues related to the status and sustainable management of American eel: a retrospective analysis and management perspective at the population level. Pages 713–740 *in* A. J. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, R. A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. Challenges for diadromous fishes in a dynamic global environment. American Fisheries Society, Symposium 69, Bethesda, Maryland.

Millennium Ecosystem Assessment. 2003. Ecosystems and human well-being: a framework for assessment. Island Press, Washington, D.C.

Moody, M. 2008. Eulachon past and present. Master's thesis. University of British Columbia, Vancouver.

Moore, J. W., and D. E. Schindler. 2004. Nutrient export from freshwater ecosystems by anadromous sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 16:1582–1589.

Naiman, R. J. 2009. Marine-derived nutrients and the dynamics of riverine ecosystems. Pages 395–425 *in* A. J. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, R. A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. Challenges for diadromous fishes in a dynamic global environment. American Fisheries Society, Symposium 69, Bethesda, Maryland.

National Research Council. 2005. Valuing ecosystem services: toward better environmental decision-making. The National Academies Press, Washington, D.C.

O'Dor, R., and V. A. Gallardo. 2005. How to census marine life: ocean realm field projects. Scientia Marina 69(Supplement 1):181–199.

O'Dor, R., M. Stokesbury, and G. D. Jackson. 2006. Tracking marine species, taking the next steps. In Australian Society for Fish Biology 2006 Workshop Proceedings, 28-29 August 2006, Hobart, Tasmania.

Ommer, R. E. and the Coasts Under Stress Team. 2007. Coasts under stress: understanding restructuring and social-ecological health in coastal communities. McGill-Queens University Press, Montreal.

OSTP (Ocean Science and Technology Partnership). 2007. Prosperity through SMART ocean management: enabling Canada's ocean economic future through a new ocean science and technology strategy for Canada. Available: www.ostp-psto.ca/Files/SmartOceanMan-FEBRUARY2007.pdf (November 2008).

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecological and Evolutionary Systems 37:637–669.

Pauly, D. 2006. Major trends in small-scale marine fisheries, with emphasis on developing countries, and some implications for the social sciences. Maritime Studies 4(2):7–22.

Pauly, D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. Trends in Ecology and Evolution 10:430.

Pauly, D., V. Christensen, S. Guénette, T. J. Pitcher, U. R. Sumaila, C. J. Walters, R. Watson, and D. Zeller. 2002. Toward sustainability in world fisheries. Nature 418:689–695.

Pauly, D., and T. J. Pitcher, editors. 2000. Methods for assessing the impact of fisheries on marine ecosystems of the North Atlantic. Fisheries Centre Research Reports 8(2).

Pearse, P. H., and P. Larkin. 1992. Managing salmon in the Fraser. Report to the Minister of Fisheries and Oceans on the Fraser River salmon investigation. Department of Fisheries and Oceans Canada, Vancouver.

Pecl, G. T., S. R. Tracey, J. M. Semmens, and G. D. Jackson. 2006. Use of acoustic telemetry for spatial management of southern calamary *Sepioteuthis australis*, a highly mobile inshore squid species. Marine Ecology Progress Series 328:1–15.

Peterson, C. H., and J. Lubchenko. 1997. Marine ecosystem services. Pages 177–194 *in* G. C. Daily, editor. Nature's services: societal dependence on natural ecosystems. Island Press, Washington, D.C.

Pitcher, T. J., C. Ainsworth, E. A. Buchary, W. L. Cheung, R. Forrest, N. Haggan, H. Lozano, T. Morato, and L. Morissette. 2005. Strategic management of marine ecosystems using whole-ecosystem simulation modelling: the 'back-to-the-future' policy approach. Pages 199–258 *in* E. Levner, I. Linkov, and J. Proth, editors. The strategic management of marine ecosystems. Springer, NATO Science Series: IV: Earth and Environmental Sciences, Dordrecht, Netherlands.

Pitcher, T. J., T. Morato, P. J. B. Hart, M. R. Clark, N. Haggan, and R. S. Santos. 2007. The depths of ignorance: an ecosystem evaluation framework for seamount ecology, fisheries and conservation. Pages 476–488 *in* T. J. Pitcher, T. Morato, P. J. B. Hart, M. R. Clark, N. Haggan, and R. S. Santos, editors. Seamounts: ecology, conservation and management. Blackwell Scientific Publications, Oxford, UK.

Platt, T., and S. Satyendranath. 1988. Oceanic primary production: estimation by remote sensing at local and regional scales. Science 241:1613–1620.

Prince, J. D. 2003. The barefoot ecologist goes fishing. Fish and Fisheries 4(4):359–371.

Reimchen, T. E. 2001. Salmon nutrients, nitrogen isotopes and coastal forests. Ecoforestry 16:13–17.

Rochard, E., P. Pellegrini, J. Marchal, M. Beguer, D. Ombredane, G. Lassalle, and E. Menvielle. 2009. Identification of diadromous fish species on which to focus river restoration: an example using an eco-anthropological approach (the Seine basin, France). Pages 691–711 *in* A. J. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, R. A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. Challenges for diadromous fishes in a dynamic global environment. American Fisheries Society, Symposium 69, Bethesda, Maryland.

Salzman, J. 2005. Creating markets for ecosystem services: notes from the field. New York University Law Review 80(3):870–961.

Sigler, M. F., J. N. Womble, and J. J. Vollenweider. 2004. Availability to Steller sea lions (*Eumetopias jubatus*) of a seasonal prey resource: a prespawning aggregation of eulachon (*Thaleichthys pacificus*). Canadian Journal of Fisheries and Aquatic Sciences 61(8):1475–1484.

Stark, K. E., G. D. Jackson, and J. M. Lyle. 2005. Tracking arrow squid movements with an automated acoustic telemetry system. Marine Ecology Progress Series 299:167–177.

Stewart, R. R., T. Noyce, and H. P. Possingham. 2003. Opportunity cost of *ad hoc* marine reserve design decisions: an example from South Australia. Marine Ecology Progress Series 253:25–38.

Stockner, J. G., editor. 2003. Nutrients in salmon ecosystems: sustaining production and biodiversity. American Fisheries Society, Symposium 34, Bethesda, Maryland.

Stokesbury, M. J. W., R. K. O'Dor, G. D. Jackson, D. Pincock, and K. N. Holland. 2009. Tracking diadromous fishes at sea: the electronic future using hybrid acoustic and archival electronic tags. Pages 311–320 *in* A. J. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, R. A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. Challenges for diadromous fishes in a dynamic global environment. American Fisheries Society, Symposium 69, Bethesda, Maryland.

Sumaila, U. R. 2004. Intergenerational cost benefit analysis and marine ecosystem restoration. Fish and Fisheries 5:329–343.

Sumaila, U. R., D. Marsden, R. Watson, and D. Pauly. 2007. Global ex-vessel fish price database: construction, spatial and temporal applications. Journal of Bioeconomics 9(1):39–51.

Sumaila, U. R., T. J. Pitcher, N. Haggan, and R.R. Jones, 2001. Evaluating the benefits from restored ecosystems: a back to the future approach. Pages 1–7 *in* R. S. Johnston, R. S. and A. L. Shriver, editors. Proceedings of the 10th International Conference of the International Institute of Fisheries Economics and Trade. Corvallis, Oregon, USA, July 2000. (CD-ROM).

Sumaila, U. R., and C. J. Walters. 2005. Intergenerational discounting: a new intuitive approach. Ecological Economics 52:135–142.

Tunnicliffe, V., R. Dewey, and D. Smith. 2003. Research plans for a mid-depth cabled seafloor observatory in western Canada. Oceanography 16:53–59.

Turner, N. J. 2005. The earth's blanket: traditional teachings for sustainable living. University of Washington Press, Seattle.

Walters, C. J., V. Christensen, and D. Pauly. 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. Reviews in Fish Biology and Fisheries 7:139–172.

Watkinson, S. 2001. The importance of salmon carcasses to watershed function. Master's thesis. University of British Columbia, Vancouver.

Watson, R., A. Kitchingman, A. Gelchu, and D. Pauly. 2004. Mapping global fisheries: sharpening our focus. Fish and Fisheries 5(2):168–177.

Welch, D. W., Y. Ishida, and K. Nagawasa. 1998. Thermal limits and ocean migration of sockeye salmon (*Oncorhynchus nerka*) long-term consequences of global warming. Canadian Journal of Fisheries and Aquatic Sciences 55:937–948.

Welch, D. W., Y. Ishida, K. Nagawasa, and J. P. Eveson. 1998. Thermal limits on the ocean distribution of steelhead trout (*Oncorhynchus mykiss*). North

Pacific Anadromous Fish Commission Bulletin 1:396–404.

Welch, D. W., S. Turo, and S. D. Batten. 2006. Large-scale marine and freshwater movements of white sturgeon. Transactions of the American Fisheries Society 135:140–143.

Willson, M. F., and K. C. Halupka. 1995. Anadromous fish as keystone species in vertebrate communities. Conservation Biology 9(3):489–497.

Yarincik, K., and R. O'Dor. 2005. The census of marine life: goals, scope and strategy. Scientia Marina 69(Supplement 1):201–208.