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Towards an integrated database on Canadian ocean resources: benefits, current states, and research gaps

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Abstract

Oceanic ecosystem services support a range of human benefits and Canada has extensive research networks producing growing datasets. We present a first effort to compile, link and harmonize available information to provide new perspectives on the status of Canadian ocean ecosystems and corresponding research. The metadata database currently includes 1,094 individual assessments and datasets from government ($n=716$), non-government ($n=320$), and academic sources ($n=58$), comprising research on marine species, natural drivers and resources, human activities, ecosystem services, and governance, with datasets spanning from 1979-2012 on average. Overall, research shows a strong prevalence towards single-species fishery studies, with an underrepresentation of economic and social aspects, and of the Arctic region in general. Nevertheless, the number of studies that are multi-species or ecosystem-based have increased since the 1960s. We present and discuss two illustrative case studies—marine protected area establishment in Canada, and herring resource use by the Heiltsuk First Nation—highlighting the potential use of multi-disciplinary datasets drawn from metadata records. Identifying knowledge gaps is key to achieving the comprehensive, accessible and interdisciplinary datasets and subsequent analyses necessary for new sustainability policies that meet both ecological and socioeconomic needs.

Keywords: Marine environment; ecosystem services; research trends; meta-analysis, Canada.

20 **Introduction**

21 Availability, integration, and access to information on ocean resources and research have been
22 identified as key challenges for Canadian ocean management (Expert Panel on Canadian Ocean
23 Science 2013). Such integrated information repositories are needed to inform research that
24 increasingly addresses broader ecological, spatial and temporal dynamics and how these affect
25 social-ecological systems at various scales (Arkema et al. 2006, Díaz et al. 2015). Providing new and
26 updated information regularly is a prerequisite of adaptive governance (Dietz et al. 2003), and
27 requires varied forms of data from multiple disciplines to map the effects of natural changes (e.g.
28 fish stock abundance) driven by human pressures (e.g. overfishing) and management intervention
29 (e.g., marine protected areas) on ocean environments. This has been formally expressed within the
30 UN Convention on Biological Diversity (CBD), whose targets aim to reduce pressures on natural
31 systems (Tittensor et al. 2014), but also to encourage sustainable industries and enhance the
32 benefits derived from ecosystem services (UNEP 2010). These objectives are clearly aligned with
33 Canada’s national legislation and marine policy goals, despite questions on the effectiveness of
34 Canada’s ocean biodiversity policies and lack of full implementation of existing legislation (Kearney
35 et al. 2007, Ricketts and Hildebrand 2011, Bailey et al. 2015).

36
37 With mounting changes and challenges to Canada’s (and global) marine ecosystems, and increasing
38 recognition of ocean and fisheries management as a complex adaptive system, interdisciplinary
39 policies and analyses at multiple spatial and temporal scales have been highlighted as a vital
40 component of future governance frameworks (Ricketts and Hildebrand 2011, Hutchings et al. 2012,
41 Okey et al. 2012, Cheung et al. 2015). Canadian marine research is relatively comprehensive and
42 systematic compared to many other countries; however, the research is undertaken by a diversified
43 but often unrelated set of research networks (including government agencies, universities,
44 independent research institutes and non-governmental organizations) producing data on a range of
45 topics. As a result, data and information are available at different scales, units, and in various

formats, limiting their visibility and hindering their combination for interdisciplinary analyses (Expert Panel on Canadian Ocean Science 2013). Better data are certainly not sufficient on their own to ensure good governance (Gupta 2010), yet a lack of information is consistently identified as a challenge for policy makers, and often as a reason for continuing with status quo policies (McNie 2007). Rather than simply providing more information, however, extracting the right information from data needs to be prioritized (McNie 2007, Gupta 2010).

A key first step in data integration is to systematically identify existing research on a range of complementary topics, both to highlight information that is currently available (though perhaps not otherwise easily found), and information gaps that may need to be addressed. A lack of available published information does not necessarily mean that no research has been conducted on a given topic or region (Costello et al. 2010), yet it is at least indicative of a need for further integration into scientific knowledge repositories. Once information is identified it can be integrated for interdisciplinary analyses beneficial both for ecological status and subsequent economic performance (Chu et al. 2015), with remaining knowledge gaps addressed through targeted research.

This paper has two main objectives. Firstly, we aim to both contribute to the amount, quality and accessibility of available data by introducing an integrated metadata database on Canadian marine resource research. This searchable and freely-available repository will contribute to a holistic understanding of ocean ecosystem and resource trends, identifying emerging knowledge gaps and, ultimately, supporting policy making. Secondly, using this database, we assess existing research on marine resources across disciplines in the three Canadian oceans to highlight opportunities and gaps for future research. Other regions can use this effort as a template for integration of qualitative and quantitative data on marine resources, thus enhancing understandings of community, environment, and policy dynamics, and contributing to the sustainable use of those resources.

72

73 **Materials and methods**

74 **Data compilation**

75 We compiled available Canadian ocean resources data and categorized them into broad themes
76 representative of social-ecological system organization (Fig. 1). This framework is important for
77 categorization and subsequent meta-analysis of what are often significantly different types of
78 research and results. Fisheries and Oceans Canada (DFO), UN-Food and Agriculture Organization
79 (FAO), and British Columbia Marine Conservation Analysis (BCMCA) were the largest repositories of
80 information, with other datasets identified and gathered through primary and secondary literature,
81 institutional repositories, and personal contacts. Available datasets and assessments were reviewed,
82 entered in the metadata table, and—whenever possible—integrated into the database.

83

84 [Figure 1]

85

86 **Data sources**

87 DFO publishes information including stock assessments, official guidelines for assessments,
88 management strategies and frameworks, and technical, data, and scientific research reports. Online
89 search tools are available to access Portable Document Format (PDF) files stored by year, either from
90 a list of Canadian Scientific Advisory Secretariat reports (DFO 2015a) or a broader repository of
91 documents and reports (DFO 2015b). Specific data files including, for example, georeferenced catch
92 information, are often only accessible through a formal Access to Information request. Reports were
93 categorized within our database structure and, when applicable, time-series (e.g. stock assessment)
94 data were extracted from each report—including for individual stocks if available—either from
95 tables, or from graphs by scanning images into raster files. In cases where reports added new data to
96 a previous report’s time-series, only data in the most recent report were acquired and integrated.
97 The DFO also maintains online data files on fishing effort (e.g. yearly fishers, licenses, vessels), catch

(more coarsely aggregated than FAO data, see below), landed value, and recreational fisheries effort and economic impact, by year and region. These are available as individual tables with varying formats and for different years and spatial resolutions (DFO 2015c); all datasets were accessed, re-formatted and integrated into the database.

The DFO recently performed a risk assessment of climate change impacts on marine ecosystems which included identification of available datasets and evaluation of trends in Canada's oceans, compiled in a set of technical reports (Steiner et al. 2013). Associated reports summarize impacts and identify risks with respect to ecosystem and fisheries status. They also provide detailed analysis regarding species reorganization and displacement, as well as infrastructure issues such as emergency response capacity, physical infrastructure status and change in access and navigability of waterways.

Climate data archives are maintained by Environment Canada (Environment Canada 2015a) and the US National Oceanic and Atmospheric Administration (NOAA 2015), and can include data records from local communities. Projected trends from earth system modelling efforts and related regional downscaling involve climate modelling centres around the world, with model data collated in publicly accessible data repositories and often reformatted to improve usability on a national level (Environment Canada 2015b).

The British Columbia Marine Conservation Analysis (2006-2013) was a collaborative project that collated spatial data and created online tools to help inform marine spatial planning on the British Columbia coast. The results included a detailed PDF atlas including over 300 biodiversity and socio-economic ocean features and a series of analyses that identified areas of high biodiversity and importance to human users. Many of the spatial datasets, complete with detailed metadata, are available for download from the online repository (BCMCA 2011a).

124

125 The Food and Agriculture Organisation of the United Nations (FAO) publishes yearly statistics on
126 fisheries production and trade values on behalf of member countries (FAO 2015a). All available
127 datasets for Canada from 1950 to 2012 (the latest year available online), by species and/or
128 commodity, and area, were re-formatted and integrated into our database (see 'Data integration'
129 below).

130

131 The Ransom A. Myers Legacy Stock Assessment Database (Ricard et al. 2012) is a compilation of
132 fishery stock assessment results from around the world, including Canadian stocks. Data include
133 time-series of abundance, recruitment, fishing mortality, and catch, by stock and area, from around
134 the 1970s to the late-2000s (Ricard et al. 2012).

135

136 The Fisheries Economics Research Unit and *Sea Around Us*, both based at The University of British
137 Columbia, collect data on marine fisheries and related information at the global level, including catch
138 (Watson et al. 2004), landed value (Sumaila et al. 2007, Swartz et al. 2013), subsidies (Sumaila et al.
139 2010), recreational activities (Cisneros-Montemayor and Sumaila 2010, Cisneros-Montemayor et al.
140 2010), fisheries jobs (Teh and Sumaila 2013), and fishing costs (Lam et al. 2011). Data produced for
141 Canada by these projects (Pauly and Zeller 2015) were accessed, including estimates of unreported
142 and subsistence catch by ocean, marine fisheries and ecotourism employment, ex-vessel prices,
143 landed value, downstream economic benefits, and taxonomic information for most marine fishes
144 and invertebrates.

145

146 Existing repositories focusing particularly on the Arctic, notably the Polar Data Catalogue (CCIN and
147 ArcticNet 2015) and Nunaliit Atlas Framework (Taylor and Hayes 2015), provide large sets of
148 metadata and information on both qualitative and quantitative research, and were included as
149 single records. A number of additional datasets were integrated into the metadata database,

including information on marine protected areas (Wood 2007, CCEA 2015), national social, economic, and ecological trends (World Bank 2015), whale watching participation, employment, and economic impacts (O'Connor et al. 2009), seafood certification (Ocean Wise 2015), international governance treaties, endangered species, critical habitats, and qualitative ocean-related research.

Data integration

A challenge in integrating the many datasets outlined above is the various formats in which they are produced. Furthermore, not all identified datasets are publicly (and/or readily) accessible, and this is noted in the metadata. Nevertheless, including these assessments in the metadata is a significant step in allowing users to identify and make further efforts to obtain data useful for their research. In terms of the metadata database, “assessments” refer to individual records that each represent a dataset or a published report including data (either in tabular or graph form).

The central metadata repository includes, for each record (i.e. assessment or dataset), the year of publication and first and last years of data, title, reference (e.g. URL), and subject name (e.g. species). Following from Figure 1, we also categorize each record by social-ecological component, as well as type of research activity (e.g. fishery, oceanography, conservation), and type of data (e.g. abundance, catch, economic value). We also noted whether the record refers to a specific species, multiple species (without necessarily including ecological interactions), or is presented explicitly as an ecosystem-level analysis. When possible, this was determined based on assessment titles (e.g. to identify those including “ecosystem”, “predation”, “habitat”, etc.), though assessments were individually reviewed whenever titles were unclear as to their scope or content (for this and any other categorizations).

Assessments were individually reviewed to note the number of individual time series included. For example, an individual report on a fishery might include, for various areas, time series on catch, total

allowable quota, biomass, effort, and mean annual length, each constituting an individual time series. This allows for a distinction between the simple number of assessments on a given theme, and a measure of its data richness.

Spatial resolution was noted as Local (specific georeferenced locations), Distinct Area (e.g. Northwest Atlantic Fisheries Organization [NAFO], DFO, and academic statistical areas and sub-areas), Region (e.g. "West Coast of Vancouver Island", "Southern Gulf of St. Lawrence"), Provincial (11 marine coastal provinces of Canada), Ocean (Atlantic, Arctic and Pacific) and National (e.g. for national-scale assessments, or frameworks and guidelines without a specific spatial scope). Another key category 'Data Accessed', notes if data reported in an assessment were available and obtained.

Information on all accessed datasets and assessments was re-formatted and compiled into the metadata database, using standard descriptive categories and references to corresponding data. All catch and production weights were converted into metric tonnes, all currency units into real 2015 CAD and USD, and spatial information was matched to a series of sequentially larger units whenever possible. Effort information, such as vessel numbers by various sizes, or fishing license categories, was re-categorized into standardized classes. "Subject" names were also standardized; for example, records referring to "sockeye", "sockeye salmon", "sockeye salmon fillets", etc., match to "Sockeye salmon" (*Oncorhynchus nerka*). It is important to note that not all data indicated in metadata records were extracted but, rather, the metadata provides researchers with a link to its repository so that they may acquire the most recent data available.

Case study applications

We provide two case studies to illustrate the potential benefits of data integration: 1) analysis of social and ecological factors in MPA establishment, and 2) interdisciplinary analysis of Pacific herring (*Clupea pallasii*) fisheries by the Heiltsuk First Nation (BC). For each case, we consult records in the

metadata database to present information that could be used to address such multi-faceted and interdisciplinary issues, in Canada and elsewhere. This highlights the benefits of an integrated database where such information can be found, and emphasizes the potential pathways to add new data to this repository.

Case study 1: Marine Protected Area establishment in Canada

Marine Protected Areas (MPAs) are increasingly used for marine and coastal conservation and are one of the few concrete strategies of the Convention on Biological Diversity 2020 Targets (CBD and UNEP 2014). After delayed policies over the past decade (Bailey et al. 2015), Canada has now committed to establishing a network of MPAs covering 5% of Canada's oceans by 2017, and 10% by 2020 (Trudeau 2016). Despite setting these goals, and engaging with existing research networks like the Canadian Healthy Oceans Network (CHONe), the identification and establishment of MPAs is wrought with trade-offs, uncertainty and potential conflict (Guénette and Alder 2007, Devillers et al. 2014, Robb et al. 2015). Here, we draw on datasets documented in our metadata database as a means of identifying possible MPA establishment trade-offs at the national scale, though a similar analysis could also be performed at regional scales.

Case study 2: Herring management and the Heiltsuk First Nation

The Heiltsuk First Nation territory is located on the central coast of British Columbia ("Central Coast" DFO area), including the town of Bella Bella. There have been recent conflicts between the Heiltsuk Nation and the Federal Government over the management of herring resources, which are currently being resolved through a consultation process (Harris 2000). This has highlighted the need for analyses of marine trends at various scales, as well as the recognition of historical and legal precedents (Harris 2000). Addressing these issues requires both qualitative and quantitative information, and we provide examples of such data drawn from the metadata database.

Results

The metadata database includes almost 1,100 records representing assessments and datasets on Canadian ocean resources and related research, comprising over 370 subjects including more than 260 unique species. On average, each record involves 15 individual time-series; most are available only through direct requests from government sources, though data are also commonly displayed graphically in reports and can be extracted, using graph scanning software. The metadata can be freely obtained from the authors upon request, or from the Dryad online repository (*datadryad.org*).

Based on the time span included in individual assessments, there is an increase in available information from the 1960s onward, including an increase in research involving either a multi-species or ecosystem scope (Fig. 2). Note that the apparent decline in publications at the end of the time period most likely reflects publication lags, which could influence recent trends. On average, the start and end years for all assessments included in the analysis were 1972 and 2012, respectively.

[FIGURE 2]

With respect to research themes, there is a strong prevalence of research focused on production specifically (59% of assessments and 67% of time series) (e.g. fishery landings, aquaculture production) and on other applied topics such as other human activities or governance (Fig. 3). In addition, 72% of all records regarding “Marine Resources” corresponded to fisheries specifically. Basic research, such as information on environmental drivers or ecosystem services more generally, accounted for 14% of total assessments and 23% of time series.

[FIGURE 3]

Notably, ecosystem-level research was somewhat more common than multi-species research, though single-species research accounted for 73% of all records and 66% of time series (Fig. 3). When ranked by the number of time series appearing in metadata, the top 1% of species account for 30% of total time series, and the top 10% of species account for 60% of total time series. Species with the most time series in the metadata were (in order) snow crab (*Chionoecetes opilio*), Atlantic cod (*Gadus morhua*), scallop (*Placopecten magellanicus*), Atlantic herring (*Clupea harengus*), Northern shrimp (*Pandalus borealis*), American lobster (*Homarus americanus*), Atlantic salmon (*Salmo salar*), Arctic char (*Salvelinus alpinus*), Atlantic halibut (*Hippoglossus hippoglossus*), and beluga (*Delphinapterus leucas*).

In terms of regional availability of assessments, there is a clear disparity between the Arctic (7% of total assessments) compared to the Atlantic (45%) and Pacific (40%) Coasts (Fig. 4). The Atlantic and Pacific Coasts show a similar prevalence of production-focused research, though the Pacific in particular has more available information on ecosystem services and other human activities (Fig. 5) that is partly due to the efforts of the BCMCA (BCMCA 2011a).

[FIGURE 4]

In addition to national research trends, we provide two case studies illustrating the potential use of the metadata database to find and integrate interdisciplinary data. For each of the case studies below, in addition to the literature reference, we provide a reference to the metadata record ID to highlight its usefulness in quickly identifying available data.

Case study 1: MPA establishment factors

Data on MPAs in each of Canada's oceans show an inverse relationship between the total MPA area and the area protected as a percentage of total ocean area (Arctic: 1.2%; Atlantic: 1.5%; Pacific: 4%;

Fig. 5) (ID 9, 1086; Wood 2007, CCEA 2015). Fisheries catch (ID 1, 2, 1088; DFO 2015d, FAO 2015, SAU 2016), landed value (ID 1089; DFO 2015e), and employment (ID 1188; DFO 2015f) are lowest in the Arctic region, yet it has the largest total area protected, which is constituted by a few (32) very large (~10,170 km²) individual MPAs (ID 9, 1086; Wood 2007, CCEA 2015). In contrast, MPAs in the Atlantic region, where commercial fisheries are significant (there are few data on First Nations communities and subsistence fisheries [ID 1087; Cisneros-Montemayor et al. in review], but this should also be recognized), are numerous (429) yet much smaller (~29km²). The Pacific region has an intermediate number (122) and mean size (~425 km²) of MPAs, and affords the highest percentage of marine protection. Notably, there are almost the same amount of fisheries and non-fisheries-specific research studies in the Pacific (Fig. 4). These general patterns afford interesting insights for future research. This includes questions for policy, such as finding optimal trade-offs between high-use areas (including both commercial and other uses) and effective protection. However, it may also allow for analysis of the role of scientific research in directly or indirectly shaping policy outcomes, for example through geographical or topical gaps in research that may stem from logistical constraints or academic paradigms.

[Figure 5]

Case study 2: herring fisheries of Heiltsuk First Nation

The Heiltsuk First Nation territory is located on what is now commonly known as the “Central Coast” of British Columbia, with most of its members living in Bella Bella, Campbell Island (ID 1087, 1185; Cisneros-Montemayor et al. in review, The Bill Reid Centre 2016). Modern commercial fisheries have been a key economic activity for over a century (ID 1185; The Bill Reid Centre 2016), but marine living resources are furthermore integral to Indigenous cultural identity. BC coastal First Nations show an average yearly seafood consumption of 61 kg per capita (ID 1087), over three times the Canadian average (ID 770; FAO 2015b). Nevertheless, their right to access fish resources has been

contested through legal actions since the late 1980s (Harris 2000). In 2015, the Heiltsuk contested the DFO herring roe fishery commercial quota, arguing that abundance was overestimated and these quotas would lead to overfishing that would jeopardize their economic and food security. Legal and civil actions were undertaken, and ended with a final decision to suspend the commercial herring fishery in the Central Coast.

General recent declines in the Central Coast herring stock perceived by the Heiltsuk are supported by available data, despite an increase in the most recent DFO stock assessments (ID 11, 744; Ricard et al. 2012, DFO 2014) (Figure 6). It is important to recognize the legal rights to harvest and importance of herring to the Heiltsuk (ID 729; DFO 2014b) (Figure 6), which includes fisheries but also is reflected in the history of their traditions and territory (ID 883; BCMCA 2011b). As shown here, integrated data can be highly useful for local cases, though a full analysis clearly requires further qualitative information, additional finer-resolution data, and, ideally, the involvement of the local community.

[FIGURE 6]

Discussion

The analysis of available Canadian marine research presented here highlights ongoing trends and gaps, some of which have been identified by experts in the field (Expert Panel on Canadian Ocean Science 2013). Canadian ocean research has steadily increased throughout the 1980s-2000s (Fig. 2), and despite a strong prevalence of data and reports dealing with single-species fisheries production—particularly in the Atlantic region (Fig. 4)—there is also an ongoing increase in ecosystem-based research (Fig. 3). This highlights the current challenge in providing information to support ecosystem-based management, which requires a consideration of a much broader range of environmental, ecological and socio-economic attributes (Borja et al. 2010). The Pacific region shows

a somewhat more even set of assessment themes, with the Arctic region—perhaps due to research collection and dissemination challenges (Canadian Polar Commission 2015)—significantly underrepresented in available assessments (Fig. 4).

The benefits of an integrated metadata repository are shown here through the use of two case studies at national and local scales. In the case of Canadian MPA establishment policy, initial analyses show trends towards protection of very large areas where human industry is relatively limited (Fig. 5). This supports previous research in Canada and globally (Devillers et al. 2014, Robb et al. 2015), and quantitative data could be expanded upon to support a deeper analysis of policy objectives and implementation constraints. These could address questions rooted both in policy, such as the legal recognition for historical resource use and access rights, and in natural science, including the expected impacts of climate change on local ecosystems. In the case of the Heiltsuk First Nation, there are legal precedents establishing their right to access fish resources, including herring specifically (Harris 2000). Available data strengthen the argument that herring is a crucial component of Indigenous economic and food sovereignty (Fig. 6B) and qualitative observations of decline over the past generation (Fig. 6A). Climate change is expected to further impact local stocks, with recent research suggesting a 30-50% decline in catches of herring by the Heiltsuk if current projections continue (Weatherdon et al. 2016). This does not intend to critique the accuracy of government stock assessments. Rather, the use of data from a range of sources—including qualitative information including local management goals and observations of resource abundance—could aid in co-management efforts to promote sustainability while addressing Indigenous rights that transcend natural science (Harris and Millerd 2010).

A report by the Royal Society of Canada highlighted concerns regarding the health of all Canadian ocean ecosystems, and a lack of strategic planning for sustainable management of marine living resources (Hutchings et al. 2012). Our results suggest that, while data exist on marine resources

358 themselves, there are significant research gaps regarding policy, governance, and other human-
359 related dynamics aside from production (e.g. Fig. 3). A recent study assessed whether existing
360 scenario analyses of Canadian fisheries and marine ecosystems provided the necessary socio-
361 ecological perspective to understand the sustainability of Canadian coastal communities and
362 ecosystems under future environmental and socio-economic change (Teh et al. *in review*). The study
363 found that there was considerable national-level modeling and monitoring of climate variables (e.g.,
364 by Environment Canada and the DFO), and generally sufficient quantitative methods and data to
365 inform scenarios and projections of environmental change in Canadian ecosystems. Most existing
366 scenario studies tended to focus on the impact of future climate change on marine ecosystems,
367 particularly for salmon on the Pacific Coast (e.g. McDaniels et al. 2010, Martins et al. 2012). The
368 reviewed scenarios, however, provided no clear indication about human and policy responses to
369 future changes, while there was a limited focus on future socio-economic impacts arising from
370 environmental and socio-economic drivers.

371
372 In the review by Teh et al. (Teh et al. *in review*), scenarios which did assess socio-economic impacts
373 were constrained to measurable costs and benefits (e.g. Hotte and Sumaila 2012, Sumaila and Lam
374 2015) but did not incorporate qualitative social and human perspectives. In addition, the majority of
375 studies tend to focus on one ocean or coast, and not on all three Canadian oceans simultaneously.
376 Such specificity of marine research (e.g. Fig. 4) is perhaps partly due to the very large size of
377 Canada's marine territory, though it also reflects a focus on single-species production (Fig. 3).
378 Indeed, the top 1% of species with the most identified time series in the metadata accounted for
379 30% of all time series. While these species are undoubtedly important—and sometimes iconic, e.g.,
380 Atlantic cod—for human industry, over 120 different species are reported in official fishery landings
381 (FAO 2015a) and many more are essential components of ecosystems and the services they provide
382 along Canada's coasts (Canada and Environment Canada 2010, Okey et al. 2012).

While single-species focus has historically been the norm of management in Canada and elsewhere (Simberloff 1998, Walters et al. 2005), this has evolved to current recognition of cross-scale, ecosystem-level dynamics (Cheung et al. *in prep.*, Walters et al. 2005, Canada and Environment Canada 2010). Our results indeed show an increase in ecosystem-based research (Fig. 2), though it would be worth analyzing how many in fact represent a new focus and not simply re-branding (Arkema et al. 2006). Despite the ongoing prevalence of single-species research (Fig. 2), the increasing recognition of the importance of multi-species and ecosystem-level research is itself an encouraging trend, and has resulted in highly useful insights into the importance for management of ecosystem-level dynamics (e.g. Frank et al. 2005).

Although many sources of structured data (e.g., national statistical registries and datasets) exist and provide critically important information to researchers, they are often incomplete or not directly compatible. Thus, methods of harmonization of multiple datasets to cover critical gaps between data sources become essential and can greatly improve the utility of existing data. These methods include scaling across spatial, temporal and organization scales, metric conversion and benchmarking (Cheung et al. *in prep.*). In addition, integrating between qualitative data generated through local ecological knowledge, and quantitative data, can help make sense of 'silences' and gaps in existing databases. For example, real-time evidence of environmental change can be found with inhabitants of coastal communities, who are often the first to witness and experience climate-related effects. However, this poses methodological challenges in harmonizing and making available these different systems of information and knowledge. While it is theoretically possible to develop an automated framework for identifying, locating, accessing, and updating current and new datasets, this would be extremely difficult and would undoubtedly require significant ongoing modifications and quality-testing. The current metadata database is limited to published assessments and datasets (which avoids potential accessibility issues), and is intended as a template that can grow as researchers use it to both obtain and contribute information, and develop improvements to its structure and data-

access strategy. This may be bolstered by growing research networks, and the increasing institutional and academic focus on interdisciplinary collaboration.

One key issue regarding harmonization of available data across spatial scales is the use of more abundant coarse spatial resolution (regional) data for local policy contexts that often require fine resolution spatially-explicit information. Finer-resolution information exists, but is often difficult to access and has limited coverage. This is most evident in the Arctic, where data are still decentralized, requiring greater coordination among existing programs and databases (Canadian Polar Commission 2015, Lee et al. 2015). By showing the usefulness of an integrated analysis of existing assessments, we hope to create a motivation and avenue by which more datasets can be added and made available to researchers. Then, research tools such as upscaling, downscaling or multi-scaling analyses to link and harmonize datasets with diversity of spatial and temporal scales could be developed and applied. The usefulness of such integration is already evident in similar research efforts, including the BCMCA and Ocean Tracking Network, that provide both a repository for data and a platform for collaboration (BCMCA 2011a, OTN 2016). The benefits of the BCMCA are evident in our results regarding research trends in the Pacific, and it would be highly useful undertake similar efforts in the Atlantic and Arctic regions.

Data gaps highlighted by this study do not necessarily imply non-existence; it may be that data are available in smaller local or regional datasets disconnected from broader repositories or search engines, or only accessible in the form of metadata. Large interdisciplinary analyses such as this one rely on searches of centralized repositories (including the Internet itself), and on information that has been reported on. These are significant issues faced by scientific data systems in general (Lynch 2008, Reichman et al. 2011) and are particularly challenging for very broad fields such as ecology; indeed, it has been estimated that only 1% of ecological data is made available after results are published (Savage and Vickers 2009). Repositories such as our metadata database provide

researchers with a list of identified datasets and where they might be obtained, and a framework to add sources of information that are known to experts if they do not already appear. This dynamic has helped the repository grow throughout the development phase, and will hopefully continue as it is exposed to a wider research community.

In the Canadian context, these issues are especially prevalent in the Arctic region. Challenges for data collection itself include limited access to field sites, high costs, and short field seasons that reduce the availability of year-round data (Danielsen et al. 2014). Existing databases thus tend to be small and, due to the lack of a centralized database for Canadian Polar organizations, independently managed (Vossepoel 2013). When data do exist and are available via searchable databases, they are primarily available as metadata only. For example, the comprehensive Polar Data Catalogue (Friddell et al. 2013) includes metadata as a current standard to increase interoperability and data discovery among data centres, but does not often include links to the data itself (Michener 2006, Friddell et al. 2013). A current aim highlighted for Arctic research in particular, but clearly applicable to all regions and research themes, is to “function locally and reach globally” by integrating and making data widely accessible (Vossepoel 2013, Mokrane and Parsons 2014).

The ultimate goal of an integrated metadata database is to allow researchers, managers and stakeholders to easily find, navigate between, and access complementary datasets for interdisciplinary analyses. This can provide the multidisciplinary input needed for developing policy scenarios for the future sustainability of Canadian marine ecosystems and coastal communities facing environmental and socio-economic change. The inclusion of full reference information for every record allows for cross-validation by peers and users, enabling them to “ground-truth” findings, a common challenge when using large datasets. Researchers working in the field or on local challenges may be able to contextualize initial findings or contribute to evidence of emerging trends. The metadata database also supports and facilitates the development and application of Integrated

Assessment Models to support policy decision (Harfoot et al. 2014). Importantly, key information gaps—including temporal, spatial, or thematic—have strong implications for subsequent research and policy, and require specific strategies for improvement. Highlighting possible contradictions or disconnects between self-reported observed changes to species by individuals on the ground and multi-scale scientific reports can help provide a more complete picture of threats to coasts and oceans, and lead to potential solutions.

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Figure captions

Figure 1. Relationships between social-ecological components (white boxes) and associated attributes (grey boxes) linked to ocean assessments and datasets; grey arrows represent feedback mechanisms. (Adapted from the Intergovernmental Platform on Biodiversity and Ecosystem Services Conceptual Framework (Díaz et al. 2015). In 'Human Activity', 'Production' refers to catch, harvest, etc.

Figure 2. Number of assessments (total, and multi-species or ecosystem-based) in the metadata including data for a given year.

Figure 3. Summary of assessment themes and characteristics included in the analysis. Themes include social-ecological components (as shown in Fig. 1); corresponding activity; breadth of focus (single species, multi-species, and ecosystem); and spatial resolution.

Figure 4. Spatial coverage of assessments included in the analysis, by ocean region and social-ecological theme. The "National" category refers to nation-wide research, or frameworks and guidelines without a specific ocean region.

Figure 5. Comparison of possible factors affecting MPA establishment in Canadian Oceans. "Protection %" is the total area protected as a percentage of total ocean area. "Fish Employment" includes both fisheries and aquaculture. "Fish Value" is landed value. "FN Population" refers to coastal First Nations on each coast. The values for each factor are normalized to the maximum value across the three oceans. Data from Cisneros-Montemayor et al. in review, Wood 2007, CCEA 2015, DFO 2015d, 2015e, 2015f, FAO 2015, SAU 2016b (metadata IDs 1, 2, 9, 1086-1089, 1188).

747 Figure 6. A: Herring abundance (spawning stock biomass) in the Central Coast of British Columbia.
748 Regression line applied to previous 25 years with data (1989-2013). B: British Columbia First Nations
749 (includes “Indian”, “Native”, “Communal”, “Reduced Fee”) fishing licenses by species. Data from
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