Adaptive capacity, coastal communities, and marine conservation planning in the face of climate change

by

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Master of Science, University of British Columbia, 2012
Bachelor of Science (Honours), University of British Columbia, 2009

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We acknowledge with respect the Lekwungen peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̲SÁNEĆ peoples whose historical relationships with the land continue to this day.

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Abstract

With the growing threats of climate impacts on social-ecological systems, conservation planning must be adaptive in order to maintain the wealth of ecological, economic, and social services derived from functioning ocean systems. Despite the growing application of tools to manage risk and disturbance to social-ecological systems, little work has integrated the temporally dynamic effects of climate change, such as shifting species distributions, with either management tools (e.g. spatial planning) nor the perspectives of the human communities that are affected (e.g. communities, planners). I conducted a multi-scale research project looking at adaptive capacity to climate change using the case study of temperate marine system, the coast of British Columbia, Canada. I approached this overarching topic using: 1) a workshop and review of existing frameworks used to study adaptive capacity for coastal communities to climate change impacts (Whitney et al. 2017); 2) an applied and collaborative evaluation of climate change impacts and adaptation responses within a coastal region (Whitney and Conger 2019); Whitney et al. in review); 3) a comparison of methods to apply projections of marine species range shifts with marine spatial planning tools (Whitney et al. in prep (a)); 4) an evaluation of the perceived climate change risks and adaptive strategies across the same region, from the perspective of regional planners and managers (Whitney and Ban 2019); and 5) a study of the perceptions of adaptation actions for climate change impacts from the perspective of coastal Indigenous peoples (Whitney et al. in prep (b)). This work can serve as a guide for other research in this field – such as adaptive capacity assessments, or marine planning processes that aim to integrate climate change projections in management. Overall, I highlight the importance of appreciating the complex historical context in social-ecological research, and the need to raise up Indigenous voices, leadership, and decision-making authority in addressing climate change in (post-) colonial systems. By integrating these component parts I contribute to our understanding of how climate change adaptation actions can be realized from the perspectives of adaptive capacity theory (academia), coastal planning and management in practice (policy), and Indigenous communities (people). When combined, I hope that this body of work serves as a contribution to foster adaptive capacity to climate change in coastal communities.

Table of Contents

Supervisory Committee ii

Abstract iii

Table of Contents iv

List of Tables vi

List of Figures viii

Acknowledgements x

Dedication xii

Chapter 1: Introduction 1

Dissertation objectives and research questions 9

Positionality statement: My personal relationship to this work 15

Chapter 2: Adaptive capacity: From assessment to action in coastal social-ecological systems 18

Introduction 18

Overview of approaches to assess adaptive capacity 20

Synthesis of lessons learned 32

Fostering adaptive capacity: Linking assessment to action 37

Conclusions and future directions 40

Chapter 3: Synthesizing and communicating climate change impacts to inform coastal adaptation planning 43

Introduction 43

Methods 45

Results 53

Discussion 76

Uncertainties and knowledge gaps 77

Next Steps and Conclusions 78

Chapter 4: Considering the effects of climate-induced species range shifts in marine protected area planning 80

Introduction 80

Methods 82

Results: 85

Discussion 89

Chapter 5: Barriers and opportunities for social-ecological adaptation to climate change in coastal British Columbia 94
Introduction 94
Methods 97
Results 101
Discussion 112
Conclusions 117
Chapter 6: "Like the plains people losing the buffalo": Perceptions of climate change impacts, fisheries management, and adaptation actions by Indigenous peoples in coastal British Columbia, Canada 120
Introduction 120
Social-ecological background 123
Methods 125
Results 127
Discussion 145
Chapter 7: Conclusions 151
Methodological lessons learned 155
Limitations and research gaps 157
Contributions and challenges for policy and management 159
Bibliography 163
Appendix A: Supplementary Material, Chapter 2 200
Appendix B: Supplementary Material, Chapter 3 208
Expert Elicitation Questions 208
References, Tables 3.1 and 3.2 208
Appendix C: Supplementary Material, Chapter 4 211
Appendix D: Supplementary Material, Chapter 5 250
Appendix E: Supplementary Material, Chapter 6 262

List of Tables

Table 2.1: Summary of approaches used to measure and assess adaptive capacity of social, ecological, and social-ecological systems. Assessment approaches are in order of typical spatial scale of application, from large scale to small. See Appendix A for a detailed description of these approaches with references to example empirical studies and reviews. 23
Table 2.2: Examples of generic social and ecological measures used in assessments of adaptive capacity. Many of these are operationalized as indicators in assessments. 30
Table 2.3: Key considerations for operationalizing adaptive capacity research and practice 33
Table 3.1: Summary, projected climate impacts, projected changes, and sector-specific impacts anticipated for the Northern Shelf Bioregion. 51
Table 3.2: Continued summary, projected climate impacts, projected changes, and sector-specific impacts anticipated for the Northern Shelf Bioregion. 52
Table 3.3: Summary of some climate change impacts on key fisheries target species in BC (Beamish 2008, Healey 2009, 2011, Chandler et al. 2016, Weatherdon et al. 2016c) 65
Table 3.4: General actions for proactive adaptation to climate change recommended in the literature for conservation and management of fisheries and coastal areas. 71
Table 4.4: Top 5 BC MPAs that lose and gain the most marine species of interest by 2060 under RCP 8.5 relative to 2016. . 86
Table 4.5: Summary of time steps by decade at the low and high emissions scenarios (RCP 2.6 and 8.5, respectively), showing key results of the best solution at each time step, the number of planning units selected, the cost, and the number of planning units that fall outside of the BC Exclusive Economic Zone (EEZ). All scenarios were run with a Species Penalty Factor (spf) of 4. Targets were set at 30% of the relative abundance of each species within the BC Exclusive Economic Zone at the 2016 RCP 2.6 scenario. 87
Table 4.6: Summary of time steps by decade at the high and low emissions scenarios (RCP 2.6 and 8.5), showing key results of the best solution at each time step, the number of planning units selected, the cost, and the number of planning units that fall outside of the BC Exclusive Economic Zone (EEZ). All scenarios were run with a Species Penalty Factor (spf) of 4. Targets were set at 30% of the relative abundance of each species at each time and emissions scenario. 89
Table 5.1: Focal adaptation actions under either social or ecological themes covered in the survey. See Appendix B for the full survey. 100
Table 5.2: Participant professional characteristics: Years working in the field, roles in their organizations, and primary employer (First Nations, state government, other). 101
Table 5.3: Observed climate impacts as shared by participants, in response to the question, "What type of climate related impacts have you seen or heard about?" 102
Table 5.4: Responses to the question, "What do you see as the consequence(s) of failing to adapt? 103
Table 5.5: Barriers and opportunities: Responses to survey questions regarding the existing and perceived knowledge gaps in incorporating climate change adaptation into existing work on management and planning in BC's coastal region (top section), and opportunities for incorporating climate change adaptation in marine planning and management (lower section), in response to a question asking how practitioners suggest improving their ability to incorporate climate change adaptation into their work. 110
Table 6.1: Perceived climate impacts on the marine and coastal environment. Quotes without direct attributions are anonymous. 128
Table 6.2: Values related to participants' ways of life. Quotes without direct attributions are anonymous. 130
Table 6.3: Perceived consequences on participants' way of life from climate change impacts on the marine and coastal ecosystem. Quotes without direct attributions are anonymous. 132
Table 6.4: Perceived concerns and fears related to climate change in terms of values and ways of life. TEK = Traditional Ecological Knowledge. 133
Table 6.5: Adaptation strategies, descriptive icons used during interviews, detailed explanations, and proportions who selected certain actions as the primary effective adaptation strategy. (48 participants spoke to the topic of ecological adaptation strategies, and 47 to the question of social adaptation strategies. Icons courtesy of https://thenounproject.com/. 135
Table 6.6: Adaptation actions suggested by interview participants for particular scales of management and priority adaptation themes. 141
Table A.1: Comparison of 11 Approaches for Analyzing Adaptive Capacity: Strengths, weaknesses, insights, implications and applications. Key references are included of case study examples and reviews for each method, where available. 200
Table B.1: Species that did not meet targets, 2060, RCP 2.6. PU = planning unit. 247
Table B.2: Species included in the analysis, 2016-2060. Sp. 600142 was not included by 2060, RCP 8.5 due to projection uncertainty as reflected in Weatherdon et al. 2016. 248
Table D.1: Characteristics of interview participants (completed interviews, n=21) 250

Table D.2: Thematic codes from open-ended questions 251
Table D.3: The three most common responses to open-ended questions on adaptation planning, summarized by the governance scale at which practitioners work. Bolded text reflects issues that were identified by more than 2 levels. 252
Table D.4 Semi-structured interview themes and questions 260

List of Figures

Figure 1.2 The framing for my dissertation examines the direct (solid lines) and indirect (dashed lines) interactions between environmental change, social systems, and management responses (circles) around an overarching question (centre box) using four main questions and five research chapters. 11
Figure 2.1: Comparison of 11 approaches that can be used for assessing adaptive capacity at different spatial scales with varying attention to social, ecological, and social-ecological systems. These methods may overlap in practice, especially in application to social systems where the application of multiple methods is common. 27
Figure 2.2: Example measures of adaptive capacity in ecological or social systems across spatial scales. Measures are examples only and are not meant to be prescriptive or specific to a given scale as shown here. 29
Figure 2.3: A conceptual framework to link adaptive capacity assessment to adaptive capacity building in social-ecological systems. The adaptive capacity of the linked social-ecological system is first identified by assessing the level of ecological and social adaptive capacity (i.e. by conducting multiple, or integrated assessments). With knowledge of the current state of the system, actions can be taken to build further adaptive capacity (e.g. improve ecological adaptive capacity) to move the system to a more desirable state. If considerations of trade-offs are not included, the system's adaptive capacity could shift in focus without gains in total adaptive capacity (e.g. ecological adaptive capacity increases at the cost of decreasing social adaptive capacity). Model is based on a similar schematic by (McClanahan et al. 2008) and (Ban et al. 2013); actions build on (Salafsky et al. 2008) and (Cinner et al. 2012). This is illustrative of potential examples of actions which can lead to beneficial outcomes, not prescriptive. 39
Figure 3.1: The Northern Shelf Bioregion (NSB), showing the boundaries of the four MaPP sub-regions and main communities. The sub-regional boundaries follow the Northern Shelf Bioregion boundary, except for a small area near the western tip of North Vancouver Island. 47
First Nations ( ) and non-First Nations communities ( ) are distinguished by request of MaPP. 47
Figure 3.2: Schematic showing the global and smaller scale data sources informing the reporting of climate impacts on key sectors within the NSB. Particular sectoral impacts from climate projections that were of interest to the planning group, and informed our focus, are shown on the third row. 48
Figure 4.2: Geographical extent of the study area for the first analysis (MPAs under provincial jurisdiction, in red), the Northern Shelf Bioregion of coastal British Columbia, Canada, also showing 6 federal MPAs and 59 provincial parks and protected areas with a marine component (MPAs) included in analysis. Other MPAs were excluded because of data limitations. 83
Figure 4.3: Increasing and poleward shifting selection of priority planning units in the best solution (blue) over decades from 2016 (a), 2040(b, d), 2060 (c, e) at RCP 2.6 and 8.5. Grey planning unit grid represents the BC Exclusive Economic Zone. 88
Figure 5.1: Practitioner perceptions of social (n=23, top half) and ecological (n=22, lower half) actions that may support adaptation to climate change. Responses are ranked by the percentage of perceived positive influence within social and ecological actions, respectively. 105
Figure 5.2: Perceived barriers to incorporating climate change into marine protected areas planning. Management action = application of policy action, i.e. implementation. 108
Figure 6.4: The study region encompassing the four First Nations we worked with: Heiltsuk (Bella Bella), Kitasoo/Xai'xais (Klemtu), Nuxalk (Bella Coola), and Wuikinuxv (Oweekeno). Names within parentheses are the present day main communities of each Nation. 124
Figure 6.5: Radar plots describing the different primary social (left) and ecological (right) adaptation actions identified by participants in the four First Nations (Heiltsuk, Kitasoo/Xai'xais, Nuxalk, Wuikinuxv). Adaptation strategies are the same as those listed in Table 4. FN = First Nation; EBM = Ecosystem Based Management; MPAs = Marine Protected Areas. 136
Figure 6.3: Adaptation actions that emerged from these interviews across scales, from federal and provincial governance, to regional umbrella organizations, to First Nations governance. Throughout, reconciliation and governance transformation are processes that all scales can work towards. IK: Indigenous Knowledge; CCIRA: Central Coast Indigenous Resource Alliance. 137
Figure B.1: Increasing and poleward shifting selection of priority planning units in the summed solution (green) over decades from 2016 (a), 2040(b, d), 2060 (c, e) at RCP 2.6 and 8.5. Grey planning unit grid represents the BC Exclusive Economic Zone. 245
Figure B. 2: 'Resilience' scenarios where the target file was allowed to vary with the projection year and RCP pathway. Increasing and poleward shifting selection of priority planning units in the summed solution (green) over decades from 2016 (a), 2040 (b, d), to 2060 (c, e). Grey planning unit grid represents the BC EEZ. 245
Figure B.3: 'Resilience' scenarios where the target file was allowed to vary with the projection year and RCP pathway. Increasing and poleward shifting selection of priority planning units in the summed solution (green) over decades from 2016 (a), 2040 (b, d), to 2060 (c, e). Grey planning unit grid represents the BC EEZ. 246

Figure D.1: Scales of decision-making thought to be most effective to achieve success in climate change adaptation (n=24). 250
Figure D.2**:** Responses to climate change impacts and marine planning question: How should protected areas planning and management respond to shifting species ranges as environmental conditions change (n = 24)? 253

Acknowledgements

This is not a dissertation where I present a problem and claim to have a solution. This is a dissertation about *not* knowing, about exploring and probing some big, scary issues, and some potential ways forward.

Perhaps more than any other time in history, this is a confusing and confounding era. We know so much about the world, yet so little about how to manage our place in it. I hope that changes. I hope this work contributes, at least in a small way, to that change. I'd like to thank the numerous places and people who helped me along this journey.

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Dedication

Not everything that counts can be counted, and not everything that can be counted, counts."

-William Bruce Cameron, 1963

To the fish, and the people who depend upon them.

Chapter 1: Introduction

Climate change threatens marine social-ecological systems

The world's oceans have sustained human communities for thousands of years (Worm et al. 2006, Ommer 2007, Berkes 2012, 2015, Turner et al. 2013). Many more people live near and depend on coastlines than inland regions due to access to marine resources, high biodiversity, and the opportunity for transportation and trade (Halpern et al. 2008b, Jones et al. 2018). Historically, the nearshore waters along the coast were reliable sources of abundant food, and in cases where otherwise challenging environments and rugged terrestrial ecosystems would have limited the growth of human communities, the ocean provided (Jackson et al. 2001, Jackley et al. 2016). But now, things are changing. Overfishing threatens wild fish populations, puts marine ecosystems at risk, and has reduced the ability of millions of people to pursue their way of life and feed their families (Jacquet et al. 2009, Britten et al. 2016, Pauly and Zeller 2016, Worm 2016). Climate change is a further threat to the future of biodiverse ecosystems, particularly in the ocean (Pinsky et al. 2019).

In the marine environment, climate change impacts encompass environmental changes that include ocean temperature change (Oliver et al. 2018), sea level rise (Hallegatte et al. 2013, Mora et al. 2018), increasing intensity of extreme weather events, ocean acidification (Haigh et al., 2015), ocean de-oxygenation, and other related physical and chemical changes (Ainsworth et al. 2011, Okey et al. 2014c, IPCC 2019). Rising sea temperatures mean that fish and invertebrates will move poleward as temperatures rise (Sunday et al. 2015), changing access and availability of marine species for local fishers (Weatherdon et al. 2016b, Bonebrake et al. 2017, Young et al. 2019). Ocean acidification, caused by rising levels of carbon dioxide dissolving into the ocean, is increasing and threatens a myriad of species from calcium-forming shelled organisms to the larval life stages of many fish (Doney et al. 2012). Oxygen levels are dropping in the ocean (Breitburg et al. 2018), and as water temperatures increase this effect will grow worse, as cooler water contains more oxygen and ocean stratification due to warming leads to an expansion of the oxygen minimum zone (Whitney et al. 2007, Levin and Le Bris 2015, Gattuso et al. 2015b, Breitburg et al. 2018). Inland, glaciers are rapidly melting, and are projected to diminish much more by the end of the 21st century (Clarke et al. 2015). As glacier mass loss accelerates in the coming decades, meltwaters will contribute to sea level rise, changing hydrology, decreased water availability, and cooling river systems (Solomon et al. 2009, Clarke et al. 2015c). All of these factors will affect wild fish, ecosystems, and the humans who depend upon them for wellbeing and livelihoods.

With the increasing threats of anthropogenic climate change (IPCC 2014a), it is important to investigate how biological changes in species distribution and abundance (Okey et al. 2014c, Carroll et al. 2015) are perceived by human communities (Gattuso et al. 2015b, Bond et al. 2019). The sensitivity of marine systems, habitats, and species to climate impacts vary (Stuart-Smith et al., 2015), which in turn affects social systems differentially, and complicates management responses (Perry et al. 2010). It is also necessary to understand the local and regional social-ecological context at multiple spatial and temporal scales (Hill and Engle 2013) to develop a greater understanding of the direct and indirect effects of climate impacts on social-ecological systems.

This dissertation aims to fill this gap by investigating these component parts within a coastal social-ecological system using diverse methodologies. I use a social-ecological systems (SESs) framing in this research (Ostrom 2009) which acknowledges the interacting human and ecological elements where changes to ecosystems and processes affect human communities, and vice versa. SESs provide a framework that can be used to study and design effective conservation efforts (Palomo et al. 2014), and are increasingly applied in a marine spatial planning context (e.g. Cinner et al., 2013), particularly when considering resilience (Holling 1973), vulnerability, and adaptive capacity to environmental change (Perry et al. 2011). The important themes that occur throughout this dissertation – and to which my research contributes – includes adaptive capacity, marine conservation planning, perceptions of environmental change, and Indigenous knowledge. The sections that follow dive a little deeper into each of these themes to explain the context, key relevant studies to date, and the gaps in knowledge that my research aims to fill.

Adaptive Capacity and Resilience

Resilience, vulnerability, and adaptive capacity are interrelated terms used to describe and predict a system's response to change. The application of adaptive capacity, vulnerability, and resilience theories to climate change is tied to a wide range of research on social-ecological systems and ecological resilience (Holling 1973, Berkes 2003, Folke et al. 2005, Gallopín 2006). Resilience is defined as the ability of a system to adjust to a disturbance, learn and re-organize while maintaining its current identity, structure and function (Adger 2000, Walker et al. 2004). In contrast, vulnerability is a measure of a community's susceptibility to change, and inability or ability to adapt to that change (Gallopín 2006).

Resource dependence tends to make a community especially vulnerable to climate change and other environmental stressors, but this vulnerability can in theory be offset through collaborative learning, strategic skill development, alternative economic activities, climate awareness, and financial security (Marshall, 2010). Adaptive capacity refers to the latent ability of a system to respond proactively and positively to stressors or opportunities (Whitney et al. 2017). Adaptive capacity is often used as a metric of a system's ability to cope with environmental change. For social-ecological systems, this relative measure can vary based on biophysical components (ecological system) and social components (the socio-economic capacities of the community, society, and country) (Perry et al. 2011). In short, adaptive capacity is used to describe a set of conditions that may allow adaptation to external stressors (Adger, 2003; Gallopín, 2006; Marshall, 2010).

Operationalizing adaptive capacity assessments has proven difficult (Marshall & Marshall, 2007), although there is a growing depth of scholarship working to do so (e.g. Bennett, Dearden, & Peredo, 2014; Cinner et al., 2013; Ford et al., 2008; Marshall & Marshall, 2007; Smit & Wandel, 2006). Ecosystems that have high adaptive capacity may exhibit characteristics including high functional redundancy across species, high connectivity amongst habitats, or contain species with high population diversity or phenotypic plasticity (Biggs et al. 2012). Individuals and/or communities that have high adaptive capacity are able to respond to stressors and adapt through social capital, institutional learning, network re-structuring, use of experiential knowledge, and flexible problem solving (Marshall, 2010). When considered together, the adaptive capacity of a *linked* social-ecological system is understood as the ability of a system to cope with environmental change and maintain or improve its functions, so as to maintain both viable socio-economic activities and ecosystem functions (Gallopín 2006). Social-ecological adaptive capacity is thus determined by the interaction of scale-specific environmental and social dynamics, and various cultural, social, economic, and political functions therein that provide a framework to the system (Mendoza et al. 2012). It follows that adaptive capacity assessment methodologies also vary by both scale (local to global) and framing (in terms of social or ecological lens). The adaptive capacity of coastal communities can be studied from a 'top-down' (from the perspective of governance) or 'bottom-up' (from the perspective of communities) approach; the latter has the ability to yield important insight into local responses to environmental changes where climate forecasts at a coarse spatial scale might not (Dolan and Walker 2006a).

While a diversity of methods can be used to assess adaptive capacity, each of which returns different insights, opportunities, and recommendations, there has been limited efforts to synthesize these approaches across systems and scales. I attempt to fill this gap by synthesizing adaptive capacity assessments across scales and systems and by providing recommendations for applying those in certain contexts (Chapter 2). I also completed a focused assessment of climate change impacts and adaptation recommendations for specific coastal sectors in collaboration with a marine planning body, the Marine Plan Partnership (Chapter 3).

Marine spatial planning and conservation in a time of rapid change

In order to protect natural ecosystems and the benefits they provide (Potts et al. 2013), management and conservation tools are required that support both ecological and social needs in the long-term (Halpern et al. 2008b, Halpern, Lester, & McLeod, 2010). Conservation planning is applied to support biodiversity and offset increasing human impacts on ecological communities (Halpern et al. 2008b) in the form of protected areas development. The two overarching goals of conservation planning are biodiversity representation and species persistence through time (Margules and Pressey 2000, Pressey et al. 2007). In the marine environment, a much less regulated and delineated ecosystem than land, protected areas are an important tool that can support both fisheries management and conservation objectives (McClanahan et al. 2006, Jennings 2008). Marine conservation planning and protected areas design is a growing body of science that aims to improve and delineate effective marine protected areas (MPAs) to support both ecosystem function and provide conservation benefits for fisheries and human communities (e.g. (Pressey et al. 2007, Ban et al. 2019).

While Indigenous approaches to environmental stewardship have existed for thousands of years, contemporary marine conservation areas originated in the early years of the 20th century, based on a recognition of the need to protect coastal and marine ecosystems from overexploitation from fisheries and other industries such as shipping (Jones 2002a, Wells et al. 2016). Broadly, MPAs are defined by the International Union for the Conservation of Nature (IUCN) as “any area of littoral or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part of all of the enclosed environment” (Kelleher and Kenchington 1992). MPAs are thought to provide benefits beyond those offered by other management tools, including protection for critical habitats, inherent protection against overfishing, and opportunities to augment fisheries target species (Allison et al. 1998). MPAs are now one of the fundamental management tools that are used to protect biodiversity, support ecosystem services, promote fisheries recovery, and offset the general negative effects of human activities (Lubchenco et al. 2003, Lester et al. 2009, Halpern et al. 2010). The establishment rate of new MPAs has dramatically increased over the past several decades (Kelleher and Kenchington 1992, Jones 2002b, Devillers et al. 2015, Jessen et al. 2017). Under the United Nations Convention on Biological Diversity (CBD), the global target for marine protected areas is set at 10% of marine areas by 2020 (https://www.cbd.int/sp/targets/). The global community is broadly failing to meet this target (Boonzaier and Pauly 2015), despite agreement that it is still insufficient to protect biodiversity and preserve functioning social-ecological systems (Larsen et al. 2014, Locke 2014, O'Leary et al. 2016).

While systematic conservation planning (Margules and Pressey 2000) is now commonly applied to conservation and management across the globe, there is significant room for improvement in implementation and application of these tools to marine systems in the context of global environmental change (Boonzaier and Pauly 2015, Butchart et al. 2015). Spatial protection through MPAs and MPA networks is generally based on conservation of habitat types, an inherently static factor, as a proxy for biodiversity (Kelleher and Kenchington 1992, Roberts et al. 2003). Ecological processes, which govern ecological structure, function, and diversity, are not static and are therefore difficult to map spatially on landscapes or seascapes, but are integral to understanding, predicting, and protecting ecological persistence (Pressey et al. 2007). A key process that is especially relevant for marine species, many of which have a life history that can be highly dependent on dispersal, is ecological connectivity. Many marine species have an early life history that is highly dispersive and indicative of population structure across the seascape. Over time, connectivity amongst habitats determines recruitment rates and patterns of recruitment for populations and species in the marine environment (e.g. coral reef species; Magris *et al.* 2015). Extirpated species can re-colonize if adjacent habitats are connected through adequate dispersal corridors and for some species dispersal to new habitats is also made possible through the same corridors (Doerr et al. 2011, Correa Ayram et al. 2015). Due to changes in habitat suitability because of climate change, at least 60% of marine species are projected to be replaced by others in their current habitats, with greater impacts in higher latitudes (Cheung et al. 2009, 2016b). The direct impacts of these changes on biodiversity are either continuous: shifts in species ranges, changes in phenology (timing of life cycle events), changes in species interactions and ecological community composition (Parmesan and Yohe 2003, Parmesan 2006), or discrete: massive coral bleaching events, and extreme weather events such as floods or storms (Hansen et al. 2016). Given the time lag between these direct effects of climate change and the response of species (Menéndez et al. 2006), it is probable that climate impacts will only increase in the coming century, driving ecological changes and species extinctions for years to come (IPCC 2014a, Pinsky et al. 2019).

Overall, MPAs can increase the resilience of marine systems to the impacts of climate change, especially by supporting recovery of species after disturbance (Gurney et al. 2013, Mellin et al. 2016, Álvarez-Romero et al. 2017). Conservation planning cannot stop the drivers of climate change or protect marine systems from the extensive impacts of it. As climate change leads to shifting habitats and species ranges, many species are likely to be forced out of current protected areas (Araújo et al. 2004, Pressey et al. 2007). The static nature of current conservation planning schemes tends to lack the flexibility necessary to fulfill conservation benefits under climate change scenarios (Pressey et al. 2007, Alagador et al. 2014). In order to develop effective MPA networks, conservation planning must be developed in tandem with climate change modeling and predictions of global change and implemented and managed for the uncertain effects of climate change. Despite the adaptive terminology used in management in recent years, marine spatial planning and MPA planning has so far remained largely static (McCook et al. 2010, Alagador et al. 2014, Maxwell et al. 2015b, Mills et al. 2015a). This remains an important gap in both planning and implementation of MPAs. MPA planning should reflect climate change impacts on species distribution (Johnson et al. 2011, Okey et al. 2014, Sunday et al. 2015), as human resource extraction (e.g. fisheries) is likely to track biological distribution shifts, both in the ocean (Maxwell et al., 2015; Sunday et al. 2012) and on land (Hamann and Wang 2006). Spatial conservation efforts must therefore shift as well to remain relevant. I attempt to address this gap by applying projections of species range shifts derived from species distribution models (SDMs) to the case study region of the BC coast, asking where priority areas for MPAs will be over time for species of cultural and economic value to coastal First Nations (Chapter 4).

Climate change, adaptive capacity, and adaptation strategies in coastal social-ecological systems

Proactive planning for the effects of climate change is inherently a sociocultural issue. Culture plays an important role in understanding the effects of climate change on societies, and in understanding mitigation and adaptation to those effects. Different cultural practices reflect the ways that certain communities or regions tend to, or are expected to, respond to environmental change in different ways.

Research on environmental and climate change is ideally suited to collaborative community-based research and application as local and indigenous ways of knowing offer contrasting and complementary opportunities and insights to deal with changing conditions (Hovelsrud and Smit 2010). Coastal communities have recently been calling for collaborative research on multiple drivers of change in areas already experiencing climate and environmental stress (Andrachuk and Smit 2012, Reid et al. 2014, Ford et al. 2015). When framing social-ecological systems in application, the local social and ecological context matters. By living in place and developing relationships over time with the environment that surrounds them, people develop perceptions and understanding of ecological processes, which are generally described as traditional ecological knowledge (TEK) or local ecological knowledge (LEK) (Berkes et al. 2000, Ainsworth and Pitcher 2005). While several terms and definitions for TEK exist, a broad definition was proposed by Berkes et al. (2000, p. 1252):

> *"Traditional ecological knowledge (TEK) is a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with the environment".*

TEK can contribute to a greater and more nuanced understanding of biodiversity, livelihoods (Fernández-Llamazares et al. 2015, Savo et al. 2017), resilience in social-ecological systems (Berkes et al. 2003, Chapin et al. 2006), and climate change adaptations (Turner and Spalding 2013, Chisholm Hatfield et al. 2018). The United Nations, through both the Convention on Biological Diversity (CBD) and the Framework Convention on Climate Change (UNFCCC), has recognized the value of TEK in helping to contribute to biodiversity conservation and management, and adaptations to environmental change in a changing global climate (Prior and Heinämäki 2017, Tengö et al. 2017). As climate change threatens the structure and function of social-ecological systems, TEK and LEK has the potential to contribute to increasing resilience and adaptive capacities (Turner and Spalding 2013, Chisholm Hatfield et al. 2018, Canada 2019a). Given that the traditional knowledge and practices of Indigenous Peoples helped those communities to survive and thrive through millennia, TEK is highly relevant and useful for the conservation and sustainable management of biodiversity. While TEK is typically used to understand historical and cultural relations with the land and environmental change in the context of long standing (usually Indigenous) cultures, LEK can also offer comparable insights to environmental change. Both knowledge systems, while gained through insights of historical environmental change, can offer insight into current and future adaptations to environmental change. When this knowledge is lost or diminished, the potential to respond to global change is reduced.

TEK/LEK is valued for the potential to improve resource management, conservation, habitat restoration, and adaptive capacities to climate change, yet this research is all too often done through narrow epistemological worldviews that distill Indigenous knowledge and misappropriate it through and for the benefit of conventional management regimes (Berkes 2012, Latulippe 2015). Perceptions research is rooted in ontology, or the way we view reality, as part of a paradigm or worldview. Indigenous ontology is intrinsically relational, perhaps in contrast to 'Western' or certainly colonial worldviews (Kirmayer et al. 2011, Caillon et al. 2017). It follows that Indigenous perspectives on adaptation are therefore relational to place, connections, and relationships: "everything is connected" (Pauline Waterfall, pers. comm. 2018; Atleo, 2011)). In doing research in Indigenous contexts, it is these relationships and connections that produce knowledge driven theory (Wilson 2008). Indigenous knowledge systems (IKS) are framed in place-based perspectives developed with shared histories on the land and sea, and transmitted through culturally dependent processes and experiences (Latulippe 2015). Understanding Indigenous perspective on issues of landscape, regional, and global change can thus lead to deep insights for governance, management, and proactive planning.

Context: First Nations in British Columbia, Canada

My research uses case studies from what is now known as British Columbia, Canada, an area of high biodiversity, rich Indigenous cultural heritage, and complex governance across land and sea. In Canada, Coastal Indigenous Peoples have been particularly affected by the criminalization of traditional Indigenous management practices (Jones et al. 2004) and the decline of marine species through contemporary commercial fisheries (Ommer 2007, Berkes 2015). Traditional cultural practices such as potlatches, which were both celebratory feasts and central governance mechanisms both within and among First Nations, were banned, as were fish harvesting practices which had been present for thousands of years such as fish weirs (Brown and Brown 2009a, White 2011). Indigenous peoples were forcibly removed from their seasonal villages and placed inside small Indian Reserves, limiting access to traditional harvesting areas and species. Children were removed from their families and culture through the residential schools program from 1879 to when the final school in B.C. was closed in 1996 (Truth and Reconciliation Commission 2015; Kirmayer et al. 2000), as well as through the 'Sixties Scoop' whereby children were removed from their homes and placed in non-Indigenous foster care across the country (McKenzie et al. 2016). The cumulative impact of these policies inflicted severe intergenerational trauma on Indigenous people, leaving lasting impacts on individual and community knowledge, stewardship practices, and culture (Truth and Reconciliation Commission 2015). These lived experiences trickle down to affect Indigenous peoples' health and wellbeing – suicide rates relative to non-Indigenous people range from 2-3 times higher in Australia and the United States, and up to 7 times higher in Canada (Lavallee and Poole 2010).

Knowing this context, Indigenous and local community engagement is an important aspect of effective conservation action (Adams et al. 2014). TEK and LEK are powerful bodies of knowledge with which to engage local communities as well as to improve our understanding of complex social-ecological systems (Drew 2005, Turner and Clifton 2009, Shackeroff and Campbell 2014). Ethnoecological research in marine conservation has been used in combination with natural science methods to identify priority areas and build local support for marine reserve design (Ban et al. 2009), and the application of these tools are growing (Adams et al. 2014). In particular, more research is needed that brings together ethno-ecological knowledge and western sciences in order to better understand complex social-ecological systems (Satz et al. 2013). Proactively planning for the effects of climate change on marine systems may allow coastal communities to adapt and persist, especially for remote regions. Human responses to climate change will affect ecosystems, too. Scenario planning can help to improve human understanding of climate impacts and reduce panic-based responses (Turner et al. 2010). Integrating the study of social-ecological adaptive capacity to climate change in the marine environment, with marine spatial planning as one potentially effective management tool, is thus a challenge of scale, dynamism, and adaptation (Abecasis et al. 2013; Alexander & Armitage, 2014; Botsford et al., 2009; Burt et al., 2014). I used multiple methods to investigate both multi-sector and Indigenous perceptions of climate change, management actions, and governance strategies in the coastal region of BC (Chapter 5) and specifically the Central Coast of BC (Chapter 6).

Dissertation objectives and research questions

The overarching goal of this dissertation was to link social and ecological adaptation theory with the specific needs and perspectives of coastal planners and communities to contribute to our understanding of how climate change adaptation options may apply in coastal social-ecological systems (Figure 1.1).

By linking theoretical and empirical natural and social science, I studied different aspects of adaptive capacity to climate change via five chapters and case studies in the temperate marine social-ecological system of the coast of British Columbia, Canada. I asked five main research questions:

1) How is adaptive capacity assessed in social-ecological systems, and how can these assessments lead to actions to improve adaptive capacity for coastal communities to climate change?
2) What is the current state of research related to climate change impacts and adaptation strategies within a coastal region?
3) How can projections of marine species range shifts be applied to marine spatial planning?
4) How do regional planners and managers perceive climate change risks and adaptation strategies?
5) How do coastal First Nations perceive climate change impacts and adaptation strategies?

I first asked what the key indicators of social-ecological adaptive capacity are, and what variety of assessment methods have been used in both social and ecological systems across scales (Chapter 2; Whitney et al. 2017). Using a mixed-methods approach (literature review with expert interviews), I then developed an updated sector-specific overview of the state of knowledge of climate change impacts, with associated adaptation interventions, for the Northern Shelf Bioregion of British Columbia (Chapter 3; Whitney & Conger 2018; Whitney et al. in review). I then used existing projections of climate change impacts on marine species ranges to ask how marine protected areas planning and management may incorporate these changes (Chapter 4; Whitney et al. in prep). The last two chapters investigate 1) how climate change could be better incorporated into marine planning and management from the perspective of regional planners (Chapter 5; Whitney et al. 2019), and 2) the diversity of individual perspectives on climate change impacts and adaptation actions within four Indigenous groups (First Nations) on the BC coast, using semi-structured interviews (Chapter 6; Whitney et al. in prep). Throughout my work I aim to relate indigenous knowledge with knowledge from natural and social sciences to develop a deeper understanding of social-ecological adaptive capacity to climate change in the temperate marine environment.

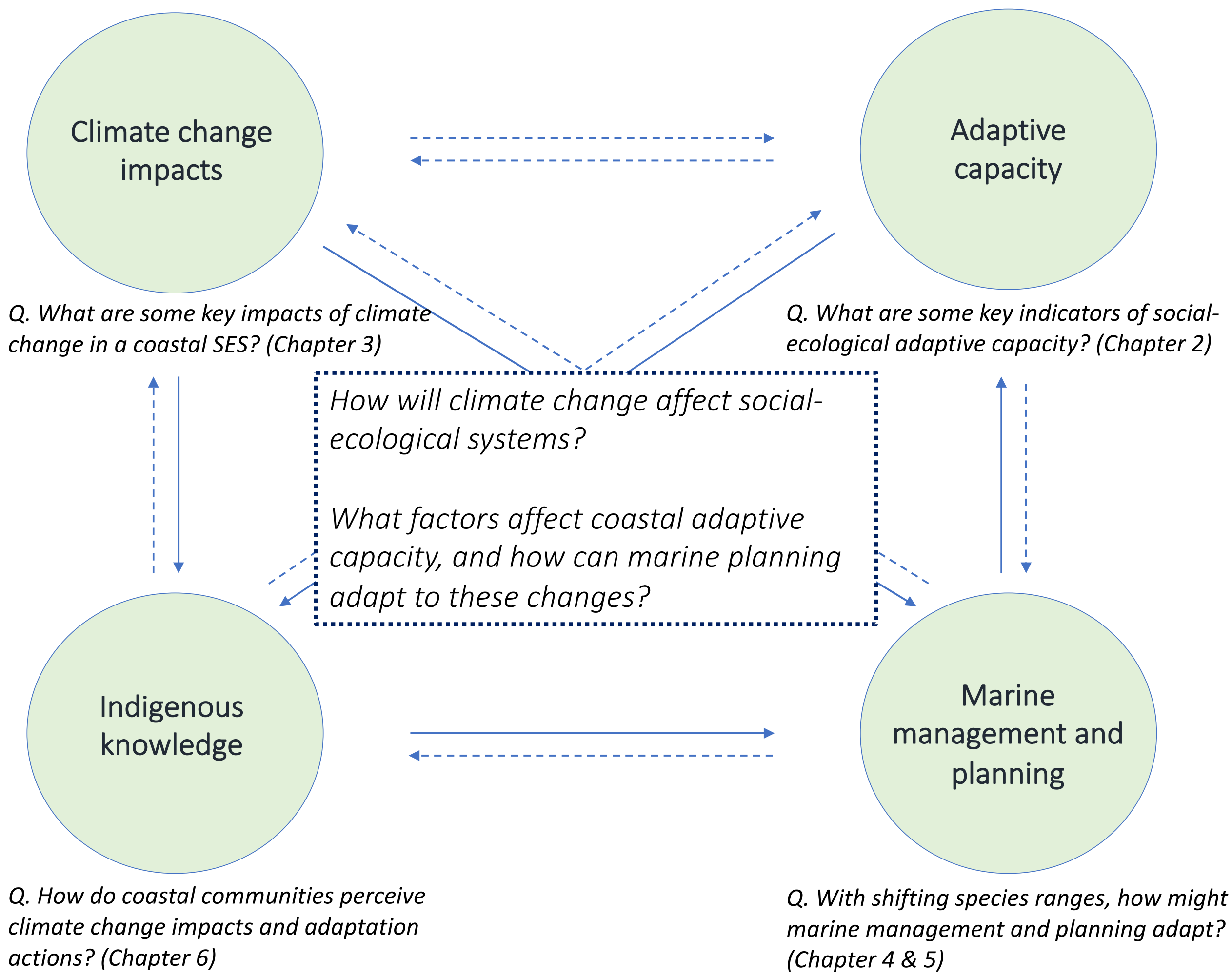


Figure 1.2 The framing for my dissertation examines the direct (solid lines) and indirect (dashed lines) interactions between environmental change, social systems, and management responses (circles) around an overarching question (centre box) using four main questions and five research chapters.

Specifically, I aimed to fill existing gaps in the literature in the following ways. In Chapter 2, I used a workshop and literature review to examine how adaptive capacity in social-ecological systems is assessed across systems and scales (Whitney et al. 2017). I brought together experts with experience in assessing adaptive capacity to environmental change in social, ecological, and social-ecological systems to develop a model of best practices for adaptive capacity assessment in coastal social-ecological systems, and to identify a framework for building adaptive capacity given such an assessment.

In Chapter 3, I report on the results of a scoping exercise of climate change impacts on a coastal region, the Northern Shelf Bioregion, with applied adaptation recommendations for key sectors of interest to a regional marine planning organization – the Marine Plan Partnership for the North Pacific Coast

(MaPP). In collaboration with MaPP, I completed a wide-ranging review with supporting expert interviews to establish a baseline of evidence for climate change impacts to ecosystems, fisheries, marine infrastructure, and human communities within the region. In combining these findings with recommendations for adaptation actions, this chapter provides the basis for directing both further research and communicating management needs in this complex social-ecological system which is also currently undergoing a marine planning process.

In Chapter 4, I asked how coarse-scale information on projected marine species range shifts could be incorporated into marine planning. I used decadal scenarios of modeled relative abundance data from a biodynamic climate model to reflect changes in species richness contained within marine parks along the coast of BC, and as inputs into spatial prioritization software (Marxan) to consider protected area priority areas over time considering both low and high emission scenarios.

In Chapter 5, I asked how marine planning and management in a coastal region could better adapt to climate change. I used a survey instrument and interviews to investigate perceptions of climate change impacts and marine planning from the perspective of coastal managers and marine planners from multiple governance scales (First Nations, provincial, and federal governments) and proposes several key barriers and opportunities for better climate change adaptation planning and more effective incorporation of climate change into marine planning.

In Chapter 6, in collaboration with Indigenous partners, I asked how coastal First Nations communities perceive climate change impacts in the marine environment, and what adaptation strategies may be most effective. I used semi-structured interviews to explore the perceptions of climate change impacts on marine based food security and Indigenous ways of life, and how social and ecological adaptation actions may influence people's ability to adapt to global environmental change. I worked with a collaborative regional Indigenous partnership organization to develop the research project and conduct interviews with people from the Heiltsuk, Kitasoo/Xai'xais, Nuxalk, and Wuikinuxv First Nations based in the Central Coast of British Columbia. Drawing from this dialogue, I explored the values and ways of life that Central Coast First Nations prioritize, how people have experienced climate change impacts to date, and their perception of adaptation actions that could improve their ability to adapt to ongoing climate change impacts. I discuss these insights through an adaptive capacity lens to illustrate ways that centralized management and colonial governance could shift and transform to support Indigenous management, governance, ways of knowing, ways of being, and ways of life in this coastal region.

Finally, in Chapter 7, I provide a synthesis of key points and findings from all previous research initiatives described above (Chapters 2-6), and discuss how they contribute to our understanding of adaptive capacity to climate change, management and planning opportunities, and social-ecological systems theory. I also discuss both the limitations and future opportunities stemming from this work, including emerging research opportunities.

Methodological approach

I used diverse methodologies within this dissertation, including literature review (Chapter 2 & 3), spatial analysis (Chapter 4), surveys (Chapter 5), and interviews (Chapter 6). Some of these components were through a disciplinary lens (e.g. Chapter 4), yet when viewed in its entirety this body of work transcends disciplines. By bridging these component parts and building from Chapter 2 to 6, I combined both qualitative and quantitative methods as well as western and Indigenous worldviews. Throughout these projects, I aimed to be aware of my own positionality as a settler trained in natural sciences working at the intersection of Indigenous rights with western science and management. I aimed to frame the applicable components of this research using a participatory and engaged lens (Rathwell et al. 2015), along the lines of community based participatory research (CBPR) (Leung et al. 2004, Horowitz et al. 2009). Participatory methodologies are a critical central tenant of decolonial research (Kimmerer 2013, de Leeuw 2016, Simpson 2017). In application to this research, this means that in Chapter 6 the views of both the participants (community and knowledge holders) were explicitly engaged in the process and results of the work, and thus the research was product *by* and *with* communities rather than *for* or *about* them (Pacheco-Vega and Parizeau 2018, Salomon et al. 2018). This process included developing formalized research protocol agreement with the Central Coast Indigenous Resource Alliance (CCIRA), a collaborative research and supporting organization of four Central Coast First Nations and by ensuring that the research representation and benefits were equitable for the Nations.

For my 6th chapter, I conducted in-person semi-structured interviews with First Nations in four Nations along the central coast. While the other components of my research were mainly desk based exercises, or involved telephone interviews and survey instruments (Chapter 5), this interview work as an opportunity to see the issues for myself, connect with people living on the coastal margin and who are experiencing the impacts of climate change first hand. Conducting interviews is not always easy, but it was crucial to connect the theory and projections of future change with those who are most directly affected, and in so doing attempt to give back through relationship building, community engagement, and communication (Castleden et al. 2012). In each and every case I spoke with community leaders and members who in their own way had deep insights on not just climate change adaptation, but also threads and themes that I did not anticipate: History, governance, reconciliation, residential schools. The beauty of a semi-structured interview is that while I did have a set outline of questions which I hoped to address, I was able to let the conversation develop naturally and with deep respect for the context and situation of the interviewee. In many cases, I did far more listening than talking – which I felt was appropriate and effective. The interviews ranged in duration from 30 minutes to almost two hours, and all interviews were recorded with permission in order to produce detailed transcripts. These were offered back to the community Stewardship Department and in some cases the participants (when requested) for their assurance and verification of the data being used for the project.

Privacy and confidentiality

While I did not necessarily expect this, the topic of adaptation to climate change in the coastal region often led to topics including governance, and the reality of the very violent history of the Canadian colonization of Indigenous Peoples and their land and sea. I aimed to be aware, empathetic, and to acknowledge these issues with the participants of this stage of my work, given the context-specific and diverse experiences that have colored their perception of what a socially just and ecologically sustainable future might look like. This history and ongoing current reality is at the crux of the challenges of adaptation planning for governance at all scales in BC and Canada. What participants felt comfortable to share with me may in some cases have potentially negative repercussions for them. In some cases, participants declined to have their names associated with their interview data. As such, all interview data has been kept confidential, and the transcriptions, quotes, and analysis for this component were shared and verified with the participating First Nations before publishing.

Positionality statement: My personal relationship to this work

Given the context of this dissertation, I think it’s important to be open and transparent about my background, evolving worldview, and personal relationship to this place and research. Particularly considering the interdisciplinary lens of this work, and the setting of Indigenous and non-Indigenous cultures, I want to take a few lines to lay the groundwork for how I got here, and what motivated me in this research. I grew up steeped in the ecological system of western Canada and the Pacific Ocean. I was born in Haida Gwaii (then known as the Queen Charlotte Islands), to educator-activist-scientist parents well connected to the Haida people and the coast. I spent most of my childhood aboard our sailboat, a platform from which my parents ran an educational eco-tourism operation focused on sharing and celebrating art, anthropology, and adventure. This work was initially based along the central and north coast of BC, with a central goal of bringing “movers and shakers” to appreciate and in turn advocate to protect South Moresby, now the Gwaii Haanas National Park Reserve and Haida Heritage Site, from extensive clear-cut logging. While we later spent many years sailing around much of the world continuing to run this business, we always maintained the connection with BC and the north coast and returned home to BC each year so I could attend some modicum of school while planning for the next season. Much to my surprise, my sense of 'home' has remained in Haida Gwaii and the north coast of BC, and in my adult life I've continued to trace connections back to those places and peoples. This work, in some ways, feels like I've come almost full circle.

My values have always been situated in appreciation of the wild and wondrous aspects of life on this dynamic Earth, and a feeling that humanity has much to be blamed for in terms of their broad and small impacts on it. From an early age, I was steeped in appreciation for Indigenous ways of life, but largely in terms of appreciation of culture and not necessarily the nuances of alternative governance paradigms or social-ecological systems. My beliefs centered around the basic tenants of conservation from a natural sciences perspective, in particular a conservationist or even preservationist perspective – that humans are by nature destructive, that for natural systems to thrive we must manage and contain our impacts which are already far too widespread. This paradigm was moderated by time spent in a forestry faculty and working in fisheries – but was not fully threatened until arriving in the social sciences. Through the process and journey of working towards the completion of this dissertation, and by spending time with a diverse range of people contributing to a better social and ecological system, I have started to un-learn this somewhat limited perspective. By working with Elders, Guardian Watchmen, and others in the Central Coast, I have started to learn and understand more about place-based worldviews, and that humans can be more than simply consumers. Even more so, I have learned more deeply that the western scientific method is not the only way of measuring or understanding our place in the world.

I have come to consider that perhaps there is another path for humanity. Perhaps we might learn to celebrate our place and space, rather than vanquish it. I hope that this work can contribute to a greater understanding of the interconnected nature of social and environmental challenges (climate change being both), and that in the coming years we might work towards a greater 'Indigenization' (Kimmerer 2013), in that we may all feel a deeper connection to place and a responsibility to consider the implications of our actions across scales. My hope is that this work, through a combination of perspectives and methods, might contribute to a greater understanding of some sustainable and equitable ways forward.

Co-authorship statement

Chapter 2 is published in Ecology and Society. CKW and NJB designed the study; CKW and NJB conducted the primary research and analyzed data; CKW led the writing of the manuscript with input from the entire author team.

Citation: Whitney, C.K., Bennett, N.J., Ban, N.C., Allison, E.H., Armitage, D., Blythe, J.L., Burt, J.M., Cheung, W.L., Finkbeiner, E.M., Kaplan-Hallam, M., Perry, I., Turner, N.J., Yumagulova, L., 2017. Adaptive capacity: from assessment to action in coastal social-ecological systems. Ecol. Soc. 22. https://doi.org/10.5751/ES-09325-220222

Chapter 3 is published as a report to the Marine Plan Partnership and submitted for publication to FACETS. CKW, TC, NCB, and RM designed the study; CKW and TC analyzed the data; CKW and TC wrote the report and manuscript.

Citation: Whitney, C.K., Conger, T., 2019. Northern Shelf Bioregion Climate Change Assessment: Projected climate changes, sectoral impacts, and recommendations for adaptation strategies across the Canadian North Pacific Coast. https://doi.org/10.31230/osf.io/rfnk3

Whitney, C.K., Conger, T. Ban, N.C., McPhie, R., 2019. Northern Shelf Bioregion Climate Change Assessment: Projected climate changes, sectoral impacts, and recommendations for adaptation strategies across the Canadian North Pacific Coast. In Review, FACETS.

Chapter 4 is in preparation for submission to Marine Policy. CKW and NCB designed the study; CKW analyzed the data and wrote the manuscript.

Whitney, C.K., W.W.L. Cheung, Ban, N.C. Considering the effects of climate-induce species range shifts in marine protected area planning. In prep.

Chapter 5 is published in Ocean and Coastal Management. CKW designed the study; CKW conducted the research and analyzed the data with support from NCB. CKW wrote the manuscript.

Citation: Whitney, C.K., Ban, N.C., 2019. Barriers and opportunities for social-ecological adaptation to climate change in coastal British Columbia. Ocean Coast. Manag. 179, 104808. https://doi.org/10.1016/j.ocecoaman.2019.05.010

Chapter 6 is in preparation for submission to Ecology & Society. CKW, NCB, and AF designed the study; CKW and AF collected data; CKW analyzed the data and wrote the manuscript with support from NCB and AF.

Citation: Whitney, C.K., Frid, A., Edgar, B., Walkus, J., Siwallace, P., Siwallace, I., Ban, N.C. “Like the plains people losing the buffalo”: Perceptions of climate change impacts, fisheries management, and adaptation actions by Indigenous peoples in coastal British Columbia, Canada. In prep.

Chapter 2: Adaptive capacity: From assessment to action in coastal social-ecological systems

Introduction

Coastal communities are experiencing complex social and ecological changes at multiple scales and speeds (Steffen et al. 2011, Kareiva and Marvier 2012, Kueffer and Kaiser-Bunbury 2014, Moore 2015). The oceans are severely affected by human-induced global environmental change – with warming and acidifying waters, changing currents and declining fish stocks – which simultaneously drive related impacts on coastal ecosystems and human communities (Harley et al. 2006, Worm et al. 2006, Johnson et al. 2011). Economic globalization and markets can also drive changes in demands for certain marine species, pressure on resources, migration to coastal communities, and changes in nearshore vessel traffic (e.g., Tuler et al. 2008; Bennett et al. 2015a). Both biophysical and social drivers of change are presenting as risks or opportunities in coastal social-ecological systems (Adger et al. 2005b, Sales 2009), making it especially relevant to understand whether communities are able to adapt (Gallopín 2006, Cinner et al. 2012, Bennett et al. 2014a, 2015a). Assessments of adaptive capacity – "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, take advantage of opportunities, or to respond to the consequences" (IPCC 2014b) – can provide such an understanding (Armitage and Plummer 2010a, Mcleod et al. 2015).

Along with vulnerability analysis, assessments of adaptive capacity are often used to provide the basis for planning adaptations or management actions to mitigate impacts in efforts to achieve beneficial social or ecological outcomes (McClanahan et al. 2008, Marshall et al. 2010, Hill and Engle 2013). These assessments tend to draw either from theories of ecological resilience (Holling 1973) or social resilience (Adger 2000, Folke et al. 2002, Engle 2011). In natural systems, ecological adaptive capacity is an indicator of evolutionary adaptive potential, suggesting that a species or ecosystem has the existing natural ability to persist over time and through change (Dobzhansky 1968, Smit & Wandel 2006). In contrast, the adaptive capacity of social systems refers to the ability of human actors and communities to respond to change and maintain human well-being over time (Smit & Wandel 2006). Numerous qualitative, quantitative, and participatory approaches have been developed to analyze adaptive capacity, each giving varying levels of attention to different components of the social or ecological system. As a result, each approach to assessing adaptive capacity produces different results, insights, and recommendations. Yet, there have been few comparative reviews of the different adaptive capacity assessment approaches that contrast their relative measures, outcomes, and applications (Gupta et al. 2010, Engle 2011, Fabinyi et al. 2014).

Given today's global challenges, an important objective of adaptive capacity assessments, indeed of all sustainability science, is to foster positive real world action that improves the ability of a given system to adapt to change (Kates et al. 2001, Wiek et al. 2012, Glandon 2015). Yet it is generally unclear the extent to which previous efforts to measure or characterize adaptive capacity have led to on-the-ground actions to increase adaptive capacity. Furthermore, disparate assessment methodologies produce dissimilar descriptions of system properties and can lead to identification of different and even divergent interventions. By describing, clarifying, and contextualizing a diversity of assessment methods, we aim to improve the consistency and quality of adaptive capacity assessments. This chapter examines the strengths and drawbacks of eleven approaches for evaluating adaptive capacity, with a particular focus on coastal communities as linked social-ecological systems (SES). Coastal communities are at significant risk to the cumulative impacts of anthropogenic change, from coastal development to climate change, and also support a large proportion of the world's human populations (Hallegatte et al. 2013, Weatherdon et al. 2016a). As such, measuring and fostering the adaptive capacities of coastal social-ecological systems is of particular importance for researchers, planners, and policy makers (Wong et al. 2014). We identify the insights and implications of employing each approach, and propose some best practices for selecting and applying different adaptive capacity techniques. We also provide a conceptual framework that links adaptive capacity assessments to management and planning actions to foster adaptive capacity across both social and ecological systems.

Overview of approaches to assess adaptive capacity

The variety of ways in which adaptive capacity is defined, applied, assessed, and measured reflect a diversity of interests, areas of expertise, and theoretical rationales (Table 2.1). As with the application of resilience theory, understanding the adaptive capacity 'of what to what' helps to frame an appropriate assessment approach, and also the corresponding actions or interventions (Fabinyi et al. 2014). While the diversity of adaptive capacity assessment tools might be useful in different contexts, the multitude of different definitions and ways of conceiving of the problem can be unclear. This complexity and lack of conceptual clarity may increase the likelihood that an approach to assess adaptive capacity is not chosen mindfully, which is problematic given that the recommendations stemming from assessments may have real consequences for social-ecological systems.

Our aim is to provide direction to adaptive capacity assessments so as to foster and improve proactive interventions. Based on a literature review of adaptive capacity studies using key word search terms (adaptive capacity; adaptation; vulnerability; coastal communities; social-ecological systems) in Google Scholar and Web of Knowledge for papers published between 1990-2015, we identified adaptive capacity assessment approaches that spanned a range of scales from local to large-scale, and also varied in their emphasis on social or ecological methodologies. We were particularly interested in research that was framed with a social-ecological systems lens. The approaches were grouped into eleven categories based on differences in methodologies, scale of application, and social or ecological focus: 1) Large scale social indicators; 2) Large scale ecological indicators and models ; 3) Integrated social-ecological indicators; 4) Governance approaches; 5) Multiple community surveys; 6) Social experiments; 7) Species level experiments; 8) Historical ethnographic approaches; 9) Participatory planning approaches; 10) Qualitative community based approaches; and, 11) Mixed methods approaches (Table 1, Appendix 1). This list covers broad categories of adaptive capacity analyses to illustrate the range of possible approaches, and may not be comprehensive. While these approaches are described as distinct for the purposes of clarity, we acknowledge that in many cases approaches could be taken that combine aspects of several of these tools.

We then held a workshop (in November 2015) with 12 academic researchers who had experience (as reflected in their publication and implementation experience) in adaptive capacity research across those categories in coastal social-ecological systems. The workshop served as an opportunity to guide discussion and provide expert opinion on the diversity of ways that the concept of adaptive capacity is applied. The group was convened to explore the following overarching questions: What are the strengths, drawbacks, and insights of the range of approaches for analyzing adaptive capacity? How might these different approaches be applied to analyze the adaptive capacity of linked social-ecological systems? What lessons can be learned from previous efforts to bridge analyses of adaptive capacity with taking actions to build adaptive capacity? For each identified approach to assess adaptive capacity, one participant was asked to present and prepare a brief synopsis based the following questions:

1. Describe the approach used to analyze adaptive capacity?
2. What type(s) of indicators were used?
3. At what scale was the approach applied?
4. What are the main strengths and benefits of the approach?
5. What are the main weaknesses and drawbacks of choosing this approach?
6. What insights and related practical solutions emerged from using the approach?
7. To what extent did the approach engage with and link to both social-ecological components of the system?
8. Does the approach take a past, present, or future orientation to understand adaptive capacity?
9. How have or how can the results be integrated into decision-making?
10. What are the implications for communities of using each approach (e.g., of the process, of outcomes, of outputs or of recommendations)?
11. What key references best reflect this approach to analyzing adaptive capacity?

Using these questions as a framework, we compared and contrasted the different approaches (see Appendix 1 for more details). To illustrate the different approaches, we drew on our own case studies and examples from the literature. Rather than simply describe each approach (summarized in Table 2.1), we aimed to illuminate parallels and opportunities for developing better and more integrated assessments of adaptive capacity that incorporate indicators of both social and ecological change and associated risks, and that link knowledge to action. This guiding comparison of the 11 approaches were directed by five key considerations: 1) attention to social or ecological systems, 2) spatial scale, 3) temporal scale and orientation, 4) social or ecological indicators, and 5) implications and outcomes to clarify the trade-offs in choosing a particular approach to assess adaptive capacity in a particular context.

Table 2.1: Summary of approaches used to measure and assess adaptive capacity of social, ecological, and social-ecological systems. Assessment approaches are in order of typical spatial scale of application, from large scale to small. See Appendix A for a detailed description of these approaches with references to example empirical studies and reviews.

Approach (SES focus)	Description	Strengths	Drawbacks	Methods and types of indicators
Large scale social indicators	Cross-regional comparisons based on defined indicators of social adaptive capacities or vulnerabilities	Policy relevant; useful for describing relative differences across regions or communities	Generic; relative composite estimates; difficult to incorporate local knowledge and perspectives; relative measures can be difficult to apply to policies for building adaptive capacity	Relative measures of adaptive capacity across regions using additive indicators of social adaptive capacity including risk exposure, sensitivity, social assets: wealth, learning, capital, livelihoods, among many.
Large scale ecological indicators and models	Large-scale modeling of ecological indicators to understand species and ecosystem adaptations to change	Understand large scale patterns of adaptive responses across multiple species; useful application in detecting change for fisheries; can inform species management	Data intensive; coarse resolution due to limitations of data; uncertainty in modeled projections	Modeling based on fisheries catch data, species distributions, oceanographic data
Integrated social-ecological indicators	Uses integrated social-ecological understanding to gain a systems-based understanding of adaptive capacity	Policy relevant; examines both social and ecological drivers of change and their interdependencies	Data intensive; outcomes are relative measures; difficult to apply to local communities for management applications	Relative measures of adaptive capacity using indicators that integrate social and ecological dimensions of change in a region(s) or communities. Example framework: I-ADApT assessment tool
Governance approaches	Literature review combined with community-based engagement is used to build understanding of governance institutions and processes	Explores the role and context of governance arrangements and decision-making processes in facilitating adaptive actions.	Limited to processes, not mechanisms or context of change; inadequate attention to the nature of change	Interviews, governance specific attributes and indicators. Example frameworks: Institutional Analysis and Development (IAD), Interactive Governance (IG).
Multiple community surveys	Survey or interview methods provide a comparison of adaptive capacities among multiple communities or across regions	Generates qualitative understanding of cultural, historical, and realized adaptive actions; can identify perceived barriers to adaptation.	Community engagement is time consuming; interpretation and interview bias; may address responses more than mechanisms; link to specific stressors not always evident	Surveys and/or interviews across multiple communities using a range of social indicators.

Social experiments	Behavioural economic experiments that give insight to decision making behaviours of fishers or other stakeholders	Experimental approach is controlled and replicable; helps illuminate fisher/stakeholder decisions in response to uncertainty or risk	Community engagement is time consuming: does not reveal mechanisms of behavior, unless combined with other tools (interviews or surveys).	Choice experiments, economic experiments
Species level experiments	Experimental assessments of the adaptive potential of populations and species to a particular stressor	Experiments provide quantitative estimates of genetic variation, heritability, phenotypic plasticity to a stressor; helps to understand evolutionary potential	Focus on single (or few) specific traits; often cannot account for natural variability or interacting factors; often limited to single life history stage; subject to sample size and logistic constraints	Lab or field-based experiments to evaluate phenotypic plasticity, tolerance limits, genetic variation; common garden experiments; holding studies
Historical ethnographic approaches	Oral history, interviews, and literature are used to understand how past adaptations of communities or households may relate to present or future adaptive capacities.	In depth understanding of past types and scales of change, and adaptations that occurred in response, links made to present situation	Community engagement is time consuming, requires social networks and trust; not scalable. Past changes and adaptations may not be relevant in the present.	Interviews, analyses of past records, community knowledge sharing
Participatory planning approaches	Risk assessment and community planning are used to address resilience of communities or regions to change	Comprehensive utility-based understanding of viable actions and proactive planning for change.	Community engagement is time consuming; require community buy-in/knowing the gatekeepers.	Combination of mixed methods: interviews, surveys, participant observation during planning events. Participatory action research.
Qualitative community-based approaches	Inductive methods are used to understand the adaptive capacities within a single community	In-depth, context-specific, qualitative understanding; community based; builds relationships based on understanding self-perceived adaptive capacity	Community engagement is time consuming; requires community buy-in and acceptance; results are context specific and may not be applicable to other communities	Interviews, focus groups, participant observation
Mixed methods approaches	Combined methodologies are used to understand and compare diversity and flexibility of communities	Gives a nuanced understanding of communities, sectors or regions; enables comparison/identification of weaknesses/strengths, generic or common leverage points.	Community engagement is time consuming; expensive; difficult to confirm the recommendations/outcomes across multiple communities.	Combination of interviews, surveys, focus groups, participatory methods, policy analysis, literature reviews

Attention to social or ecological adaptive capacity

Adaptive capacity assessments have tended to focus on either ecological or social adaptive capacity, with emerging approaches increasingly bridging social and ecological methodologies (see Figure 2.1). Ecological adaptive capacity can be assessed at a range of scales using field or laboratory experiments (species level experiments; e.g. Crozier & Zabel 2006, Eliason et al. 2011, Whitney et al. 2013), or large scale analyses and models of thermal tolerance, species traits, fisheries catches, biomass, ocean conditions, or market-based data on fisheries landings over time (large scale ecological indicator approaches; Sunday et al. 2011; Cheung et al. 2015). Both small- and large- scale ecological assessments offer valuable information about adaptive capacities to disturbances such as climate change, and build our understanding of ecosystem responses to changes such as increasing temperatures. However, in isolation, the response or management applications of these empirical and model-based studies remain theoretical and without context to the appropriate or feasible policy changes and other responses that result in meaningful action. Social adaptive capacity assessments tend to focus on aspects of governance at different scales (e.g. local rules or actions, or macro policies at the federal level); agency (of communities); norms and beliefs; the ability to predict and have foresight related to environmental conditions and change; occupational mobility and diversity, social capital and leadership; and/or the political and economic context for adaptive capacity (Armitage 2005, Folke et al. 2005). Reflecting the diversity of social-system components and the different social scales at which they can be applied, a broader range of approaches to assess social adaptive capacity have emerged (Figure 2.1). Integrated social-ecological approaches consider a set of bridging adaptive capacity concepts that apply to both social and ecological systems, or that incorporate the feedbacks and interactions between ecological and social systems by incorporating metrics of both. For example, in systems where flexibility is assessed in both social and natural systems, it is possible to describe how social groups (e.g. fishers) respond to changes in natural conditions (e.g. fisheries abundance), just as to changes in governance or other social structures (Blythe et al. 2014, Aguilera et al. 2015, Finkbeiner 2015).

Spatial scale

Adaptive capacity can be assessed at different interacting spatial scales, using a range of scale-appropriate measures in either ecological or social systems (Adger et al. 2005a, Hill and Engle 2013; see Figure 2.1). Large scale approaches, based on large scale ecological (Aguilera et al. 2015) or social indicators (e.g. Allison et al. 2009, Himes-Cornell & Kasperski 2015), ecological modeling based studies (Cheung et al. 2015, Gattuso et al. 2015a), and governance analyses (Dietz et al. 2003, Armitage and Plummer 2010a, Gupta et al. 2010) provide rapid comparative results for policy decisions, and in some cases may be operationalized more quickly than in-depth assessments at smaller scales. Yet, a limitation of large-scale studies is that they do not incorporate local, traditional, or cultural knowledge, address household or individual capacities, and because of their large scale and coarse approach, often do not allow for local validation of results or vetting of recommendations. Community-based participatory methods, on the other hand, can provide nuanced understandings of the dynamic nature of a group or community, its historical, present, and potential adaptive responses, and include the views and preferences of community and stakeholders (e.g. Henly-Shepard et al. 2014). Participatory methods may also integrate well with qualitative methods, such as interviews, and quantitative methods, such as surveys, in developing a deeper and more holistic understanding of household- to community-level adaptive capacities and strategies (Bennett et al. 2014a, 2014b, 2015c). However, action-research, community-based methods, and mixed-method approaches may require significant time commitments (e.g., years, decades for historical approaches) that exceed research program and funding timelines. Each approach to assessment has different strengths and weaknesses, of which the researcher needs to be mindful.

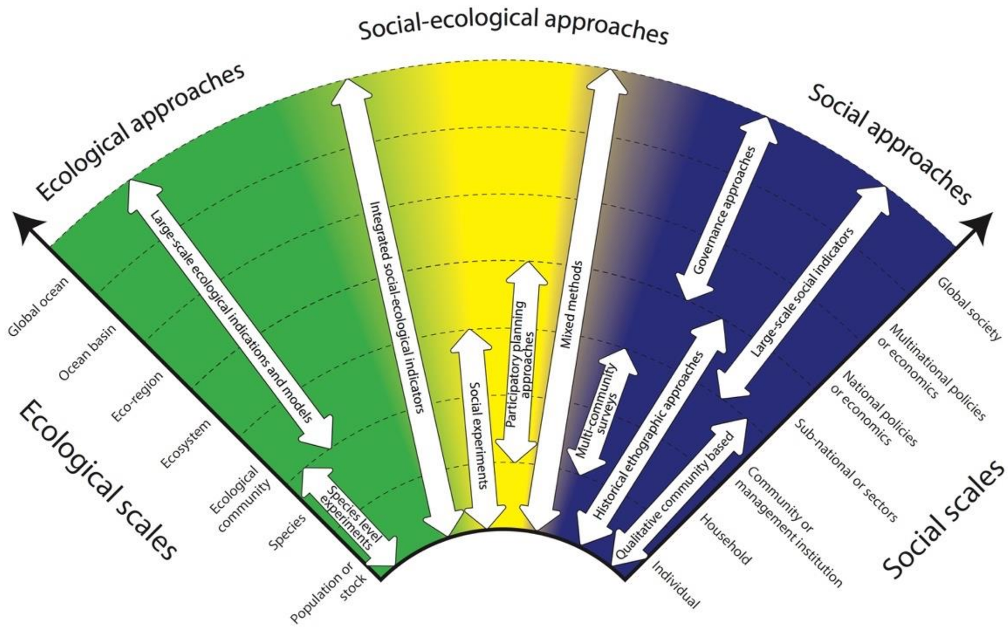


Figure 2.1: Comparison of 11 approaches that can be used for assessing adaptive capacity at different spatial scales with varying attention to social, ecological, and social-ecological systems. These methods may overlap in practice, especially in application to social systems where the application of multiple methods is common.

Temporal scale and orientation

The measurement of adaptive capacity is generally for a given time period, based on available data and the selected indicators. Assessments of adaptive capacity can focus on short-term time scales (measuring coping or acclimation potential), or over longer time scales (enabling social adaptation or evolutionary adaptation). In ecological systems, short term adaptive strategies usually refer to acclimation to a new (or temporary) environmental state; acclimation may draw upon phenotypic plasticity, habitat diversity, or short term behavioral responses (Stillman 2003). If an environmental stressor or shift continues, long term adaptive strategies depend upon evolutionary responses at the species level, or migration strategies (leaving the area for better suited habitats) (Jensen et al. 2008, Chown et al. 2010, Ekstrom et al. 2015). Social communities may cope with change in the short term through social networks, informal arrangements, alternative income generating activities, or financial remittances from overseas family members (Adger 2003, Adger et al. 2007).

The temporal orientation of adaptive capacity assessments can also focus on learning from the past, examining the present, or predicting future response capacity. Rarely are assessments of adaptive capacity conducted over multiple time periods (although see Cinner et al. 2015), with the majority of assessment methods focusing on the recent past or present (Engle 2011). An exception to this are historical ethnographic methods which focus specifically on how human communities have adapted to changing environmental conditions in the past, with insight for present or future adaptive capacities (Berkes and Jolly 2001, Turner and Clifton 2009, Blythe et al. 2014). Conversely, ecological modeling techniques (Cheung et al. 2009, 2010, Weatherdon et al. 2016c) or analyses of governance and institutions (Brooks et al. 2005) can apply scenario planning to assess future adaptive capacities (Peterson et al. 2003, Tompkins et al. 2008, Tschakert and Dietrich 2010, Bennett et al. 2015c, Oteros-Rozas et al. 2015). Future predictions of adaptive capacity are especially relevant for urban planning and disaster planning in coastal settings, where assessments can indicate important vulnerabilities for policy or management action (Adger et al. 2005b, Malakar 2013, Henly-Shepard et al. 2014). Planning approaches to adaptive capacity include 'participatory futures approaches' for community-based climate change adaptation, which engage and empower community members to be active collaborators in developing community scenarios that facilitate co-evolutionary adaptation to climate change rather than passive adaptation (Gidley et al. 2009).

Indicators: Social, ecological, or integrated

We broadly categorize indicators that are commonly used for measuring the adaptive capacity of both social and ecological systems (Table 2.2, Figure 2.2) in an effort to provide useful insights to guide policy and management improvements across scales (Armitage and Plummer 2010a). Indicators can be quantitative measures of adaptability summarized as indices (Yohe and Tol 2002), or comprise qualitative perceptions of individuals or communities as to their capacity to adapt (Armitage and Plummer 2010a, Hinkel 2011, Bennett 2016). Ecological indicators of adaptive capacity (Figure 2.2) are based on diversity and flexibility across a range of traits (e.g. life history or behavioural) and organizational levels (e.g. genetic, species, populations, etc.) as well as access to, and interactions with, suitable habitats (Aitken et al. 2008, Mawdsley et al. 2009, Hutchings 2011, O'Connor et al. 2012, Benscoter et al. 2013). Social indicators of adaptive capacity (Figure 2.2) can be grouped into four broad categories: access to assets, diversity and flexibility, learning and knowledge, and governance and institutions (Adger 2003, Brooks et al. 2005, Allison et al. 2009, Hinkel 2011, Bennett et al. 2014a). Some indicators of social and ecological adaptive capacity complement each other (e.g. diversity, flexibility, modularity, access to assets or habitats), while others do not have an ecological equivalent (e.g. social capital, innovation, institutional structures, governance strategies) (Walker and Salt 2006, Nemec et al. 2014; Table 2.2). An important distinction between social and natural systems is that humans have agency and foresight, theoretically leading to learning and proactive decision-making power, whereas natural systems and species assemblages generally do not (Walker et al. 2002, except for in some indigenous world views; Kimmerer 2013, Turner 2014).

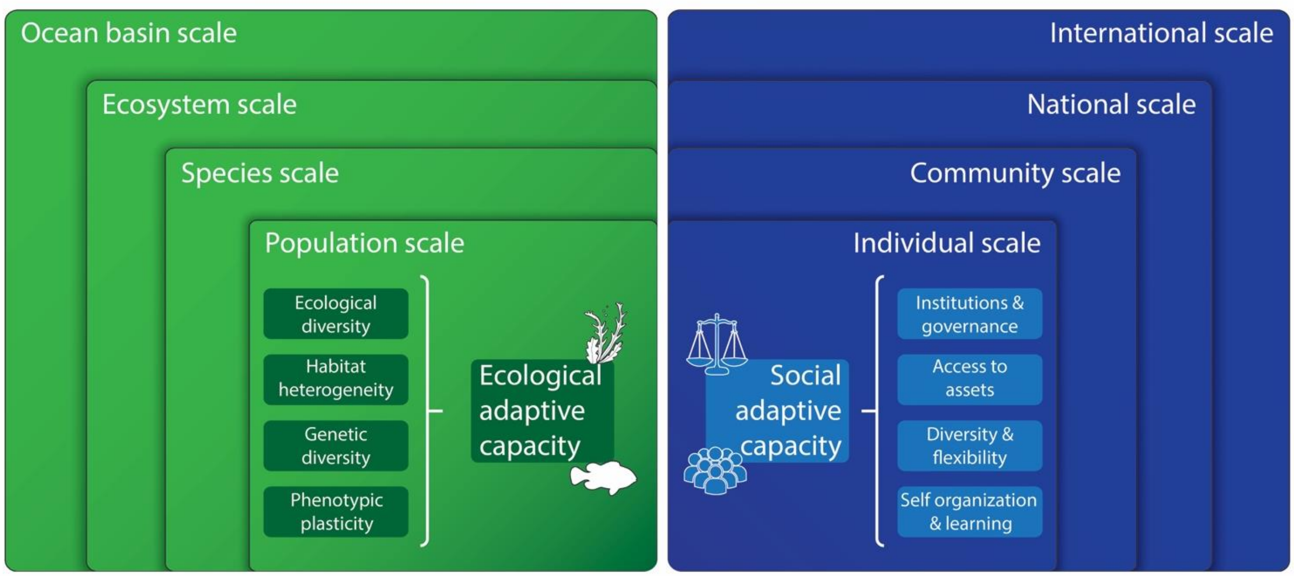


Figure 2.2: Example measures of adaptive capacity in ecological or social systems across spatial scales. Measures are examples only and are not meant to be prescriptive or specific to a given scale as shown here.

Table 2.2: Examples of generic social and ecological measures used in assessments of adaptive capacity. Many of these are operationalized as indicators in assessments.

Characteristics of Social Adaptive Capacity	**Characteristics of Ecological Adaptive Capacity**
Category and Indicators	Category and Indicators
Diversity and Flexibility	*Diversity and Flexibility*
Livelihood and income diversity Economic opportunities Level of dependence on natural resources Occupational mobility Place attachment Migration patterns Willingness to change	Species diversity Genetic diversity Functional redundancy across species Response diversity across species Species' life history traits (e.g. metabolic rates, size, reproductive strategies such as generation time, fecundity) Broad habitat range & tolerance
Access to Assets	*Habitats and interactions*
Household material assets (e.g., boats, gear) Community infrastructure Levels of education Financial status and access to sources of credit Access to markets Bridging social capital and institutional supports Natural capital Equity, rights and access to resources Cultural memory, traditions and assets	Habitat availability Habitat heterogeneity Habitat connectivity (opportunity) Rate and magnitude of habitat disturbance Habitat diversity Phenology
Learning and knowledge	*Capacity to adapt within species*
Resource monitoring and feedback mechanisms Knowledge of disturbance (e.g. climate change) Perceptions of risk Spaces and platforms for learning Diversity of knowledges and information sources Ability to anticipate change Recognition of causality and human agency Intergenerational learning capacity	Behavioural change (e.g. prey switching) and learning Phenotypic plasticity Tolerance limits Rapid genetic adaptation of traits through behavior change and acclimation Reproductive rate and capacity for dissemination Dispersal capacity Migration capacity
Governance and institutions	*Self-organizing systems*
Levels of trust, social capital and networks Gender and race relations Levels of participation and quality of decision-making processes Planning capacity Presence of local environmental institutions and strength of social norms Quality of governance and leadership in environmental policies and agencies Accountability of managers and governance bodies Active risk management and adaptive governance processes	Community structure and dynamics

Implications and applications of adaptive capacity approaches

If applied to the same case study, each of the eleven approaches highlighted here would reveal varied insights and produce very different recommendations for policy or management. For example, an assessment of the ecological adaptive capacity of a commercially valuable fish species might suggest managers restrict harvesting or target particular stocks with higher adaptive capacity (e.g. Pacific salmon; Whitney et al. 2013). In contrast, assessments of social adaptive capacity of the same fishing community might recommend gear restrictions, livelihood diversification programs, or basic service provision support in order to support the human community dependent on that fishery. Thus, choosing any one approach inevitably involves the prioritization of different actions and potential trade-offs, such as different scale of analysis and insights, level of attention to social and/or ecological, temporal orientation, as well as methods and indicators (Table 2.1.). The approach chosen will also be driven by the objectives and skills of the researcher or research team. Overall, one consistent weakness across all methods included here is the lack of direct connection between assessments and actions taken to augment adaptive capacity. In order to select the most relevant and impactful approach, it is important to be mindful of the many choices to be made prior to assessment and good practices for evaluating and building adaptive capacity.

Synthesis of lessons learned

Drawing on our review, we present: 1) a set of considerations for framing the problem and choosing an appropriate assessment approach, 2) key challenges that require attention when analyzing adaptive capacity in social-ecological systems, and 3) good practices for linking results to action in order to foster adaptive capacity (Table 2.3).

Framing adaptive capacity research: Choosing an assessment approach

Adaptive capacity assessments are commonly limited by a lack of clarity on the assumptions and contextual outcomes of a particular method, or lack of attention to the applicability of an assessment tool to the context, scale, or stressor in consideration (Engle 2011, Adger & Vincent 2005). These barriers limit the accuracy of the relative estimates of adaptive capacity and the applicability of results when seeking to identify policy solutions, and thus diminish the potential for implementing proactive measures for fostering adaptive capacity within and among systems. Some approaches can contribute to more than one of these goals. Being clear and transparent about the purpose and mindful of methods will strengthen the analysis. To address these challenges, we highlight seven key questions to ask when selecting an assessment approach (Table 2.3), which include: the adaptive capacity of what, to what, of whom and for whom; adaptive capacity at what scale and orientation; what types of indicators and methods are available and relevant; and what is the purpose of the analysis. By highlighting these framing questions, as well as key challenges and good practices, the intention is that adaptive capacity assessments can become more transparent, intentional and the results more applicable.

Table 2.3: Key considerations for operationalizing adaptive capacity research and practice

Stage of Research or Application	Considerations	Explanation and Examples
Framing the research: Key questions and considerations when choosing an adaptive capacity assessment approach	Adaptive capacity of what?	Systems: Social, ecological or both
	Adaptive capacity to what?	Ecological: population(s), species, communities, ecosystem(s)
	Adaptive capacity of whom and for whom?	Social: Individuals, households, communities, nations, governance systems, organizations, policies, politics, infrastructure, economic industries, sectors
	At what scale?	Single exposures: e.g., climate change or governance change
	At what orientation?	Multiple exposures: e.g., climatic, environmental, governance, economic, and social combined
	What types of indicators and methods?	Rate of change: Rapid onset acute (discrete) shocks or continuous (chronic) exposures, or both.
	What is the purpose of the analysis?	Impact: Stressors or opportunities, or both.
Evaluating adaptive capacity: General factors and challenges to take into account when engaging in integrated adaptive capacity assessment in coastal social-ecological systems	Equity and access	Groups and individuals have differing levels of vulnerability and adaptive capacity. Pay attention to: social differentiation, marginalization, politics and power dynamics, inclusion of diverse voices and perspectives.
	Diverse worldviews, knowledges and perspectives	Different worldviews: e.g. western science, local knowledge Be cognizant of the biases and assumptions therein.
	Cumulative effects of multiple exposures	Ecological: e.g., increasing storm severity, ocean acidification, and biodiversity loss Social: e.g., coastal development, population growth, and economic crisis Changes can present as stressors or opportunities in systems, and be additive, mitigative or multiplicative.
	Change and complexity	Change is constant and systems are dynamic. Links among system components and feedbacks cause complex and unpredictable changes in exposures and adaptive capacity.
	Social-ecological interactions	Consider both social and ecological components of linked systems.

		Consider adaptive and coping responses of both ecological and social communities/ systems within an integrated assessment framework. Prioritize actions that are holistic, benefiting both human well bring and ecological integrity.
	Scalar interactions	Scales of adaptive capacity are not independent. Evaluate interactions between components of adaptive capacity at higher and lower scales.
	Trade-offs in responses	Feedbacks between adaptive responses: e.g., amplifying or diminishing impacts on coastal resources resulting from behavioural changes Identify and analyze tradeoffs in ecological management or social planning. Incorporate decision-making tools and planning techniques that account for trade-offs into adaptive capacity analyses.
	Be proactive, not reactive	Anticipate known and unknown disturbances and identify opportunities for increasing adaptive capacity in advance. Reflect on potential unintended consequences of actions to build adaptive capacity. Expand planning for specific stressors (e.g. sea level rise) to include possible impacts from unexpected shocks (e.g. earthquakes, tsunamis).
	Limits and barriers to adaptive capacity	Stressors may overwhelm the adaptive capacity of social-ecological systems. Certain factors – be they ecological, technical, social, cultural, and political – can also undermine ability of systems to adapt. Recognition of limits and barriers is an essential part of assessing adaptive capacity and identifying actions.
Fostering adaptive capacity: Good practices for bridging adaptive capacity assessments with action-taking.	Learn by doing and adapt	Encourage and integrate cycles of action with observation, reflection, learning, and revision (i.e., adaptive management).
	Collaboration and co-production of knowledge	Build teams that include: researchers, practitioners, policy-makers, community leaders and implicated stakeholder groups. Seek co-identification of problem; collaborative processes of knowledge gathering and integration, and the co-production of tools to manage the problem.
	Shared learning	Promote knowledge sharing and social learning within and among communities and across generations. Create opportunities and

	knowledge sharing platforms and or meetings to facilitate knowledge exchange (e.g., community exchanges).
Promote networks and social capital	Strong networks and social capital across families/communities/nations can strengthen adaptive capacity and enable the uptake and implementation of recommendations. Risks and impacts are lessened when there are others from outside who can help.
Build capacity across scales	Work with local communities or leaders in the implementation of recommendations to strengthen local capacity to assess and respond to stressors and change. Ensure that actions are being taken at higher scales to support local capacity building efforts.
Communicate results	Results of adaptive capacity assessments analysis need to be communicated with those implicated (e.g., communities, resource users, etc.) and key decision–makers, including managers and policy makers. Information needs to be presented in various formats.

The adaptive capacity of a social-ecological system (SES) is inherently normative and scale-dependent; the assessed adaptive capacity of an ecosystem or social community could be interpreted differently from the eyes of a policy analyst, facilitator, or stakeholder, as each of those have different perceptions of the system and stressor(s) in question (Adger 2003, Cote and Nightingale 2012, Bennett 2016). The spatial scale of assessment is selected by the analyst and influences the results and recommendations of the assessment. Temporal scale also matters; indicators of adaptive capacity reveal impacts and responses over both slow and fast temporal scales. Building adaptive capacity of either social or ecological components of a system will also impact or benefit certain groups more than others. If the impact or change continues, coastal communities will need to develop long term adaptive strategies that may be more dependent upon governance, planning, infrastructure, adaptive management, sense of place, or even emigration (retreat) from factors such as rising sea levels (Tol et al. 2006, Adger et al. 2007, Berman et al. 2012, Joakim et al. 2015).

Evaluating adaptive capacity: Influential factors and key challenges

Following the framing of an adaptive capacity assessment approach, there are several key considerations or challenges that researchers and practitioners should be cognizant of during their evaluation. Different groups or individuals can be politically marginalized or more vulnerable leading to differential adaptive capacities (Tschakert 2007, Bunce et al. 2010). The perspective and worldview of the researcher and stakeholders, governance and change agents, will doubtless affect the assessment and any actions to build adaptive capacity. Tools such as the social-ecological systems framework may help to understand the diversity of perspectives within an SES and the interactions therein (Basurto et al. 2013, McGinnis and Ostrom 2014). Depending on the timeline of assessment, certain tools may offer deep understanding yet be too expensive or time consuming (e.g. qualitative community engagement), while others may offer comparability across systems (e.g. large-scale indices-based approaches). Ongoing evaluations of adaptive capacity are important to understand how response capacity changes over time. Adaptive capacity assessments are frequently a single project for a particular system and stressor, resulting in estimates that are quickly outdated and likely fail to connect with post-assessment action (although this is rarely evaluated). Monitoring how adaptive capacity may change as the system reacts to change may allow a deeper understanding of feedbacks, tradeoffs, and potential improvements to techniques for assessing and building adaptive capacity (see Cinner et al. 2015). We stress that post-assessment evaluation should be a component of many adaptive capacity studies, rather than single non-repeated assessments. While integrating across social and ecological components of a system can be beneficial, is not always applicable in adaptive capacity studies. The IMBER-ADApT decision support tool, based on a database of adaptive capacity case-studies that can be used to generate evidence-based solutions to comparable systems, is a valuable example of an integrated social-ecological adaptive capacity assessment framework (Bundy et al. 2015). In choosing an integrated social-ecological system perspective, it is more likely that multiple key characteristics of adaptive capacity, as well as important tradeoffs and feedbacks, will be incorporated, leading to more robust analyses.

Fostering adaptive capacity: Linking assessment to action

Based on our research, experience, and review of the literature, assessments and studies of adaptive capacity are rarely effectively linked to policy change or actions that promote adaptive capacity, despite clear directives or calls for doing just that. For example, only one of the assessment approaches we examined linked to action based on that assessment (participatory planning; Appendix 1). The importance of participation and knowledge co-creation for enhancing adaptive capacity has long been emphasized (Folke et al. 2002). Participatory vulnerability assessments can help identify adaptation strategies that are most feasible and practical in communities with a focus on current risks, allowing for integration with resource management, disaster preparedness and sustainable development initiatives (Smit and Wandel 2006). At the community level, linking assessments with actions may mean supporting forums for sharing knowledge within and across generations (social learning: Berkes & Jolly 2001, Pelling & High 2005). At the coastal community scale, this can mean supporting cross-generational knowledge sharing platforms such as elder-youth groups, integrating harvesting trips among community members, or recording historical social norms that are relevant for the local ecological system (Senos et al. 2006, Turner 2014). At larger scales, linking assessment to evaluation and response offers researchers and managers the opportunity to learn from past mistakes and generate opportunities for fostering adaptive capacity (Perry et al. 2010a). This might entail financial support mechanisms, government led investments in jobs or other economic incentives, or educational platforms for community or regional leaders (Brooks et al. 2005, Bronen and Chapin 2013). Building adaptive capacity through social learning can support the success of other related adaptive management opportunities both within a project and across international processes (e.g. adaptive spatial planning; Mills et al. 2015).

Overall, it is increasingly important to shift from a reactive to a proactive framework for adaptive planning. For managers and policy makers, identifying the barriers to adaptation through evidence-based indices is valuable, especially across systems and at regional scales. For coastal communities and managers, considering the linked nature of social-ecological systems could lead to sustainable policies that support both social adaptive capacity factors as well as the adaptive capacity of the ecosystem. Considering the adaptive capacity of both social and ecological systems together can help to avoid social-ecological traps (Carpenter and Brock 2008, Cinner 2011). While there are commonalities across assessment tools and conceptual models of what makes up high adaptive capacity for both social and ecological systems (e.g. diversity, redundancy, capital), indicators cannot truly be integrated for practical applied analyses (Nemec et al. 2014). It is, however, useful to consider social and ecological indicators of adaptive capacity as additive metrics that cumulatively characterize an integrated social-ecological system as having high or low adaptive capacity to a certain impact.

We propose a conceptual framework with which to prioritize potential actions based on integrated social-ecological adaptive capacity assessments (Figure 2.3), building off themes proposed by McClanahan et al. (2008). In four quadrants, we illustrate example systems where ecological and social adaptive capacity ranges from high to low and identify example actions that could foster adaptive capacity in either the social or ecological realm to move the system towards a state where both capacities are increased. If an assessment indicates that social and/or ecological adaptive capacity is low, we suggest potential actions that are designed to build capacity. If an assessment indicates that adaptive capacity is already high, we suggest actions that are intended to support existing capacity against future shocks or disturbances. The suggested actions are meant to be illustrative, not prescriptive, and the appropriate actions taken will depend on the social and ecological context. The actions are also not meant to be exclusive, and in some cases multiple actions across scales will be possible and/or necessary.

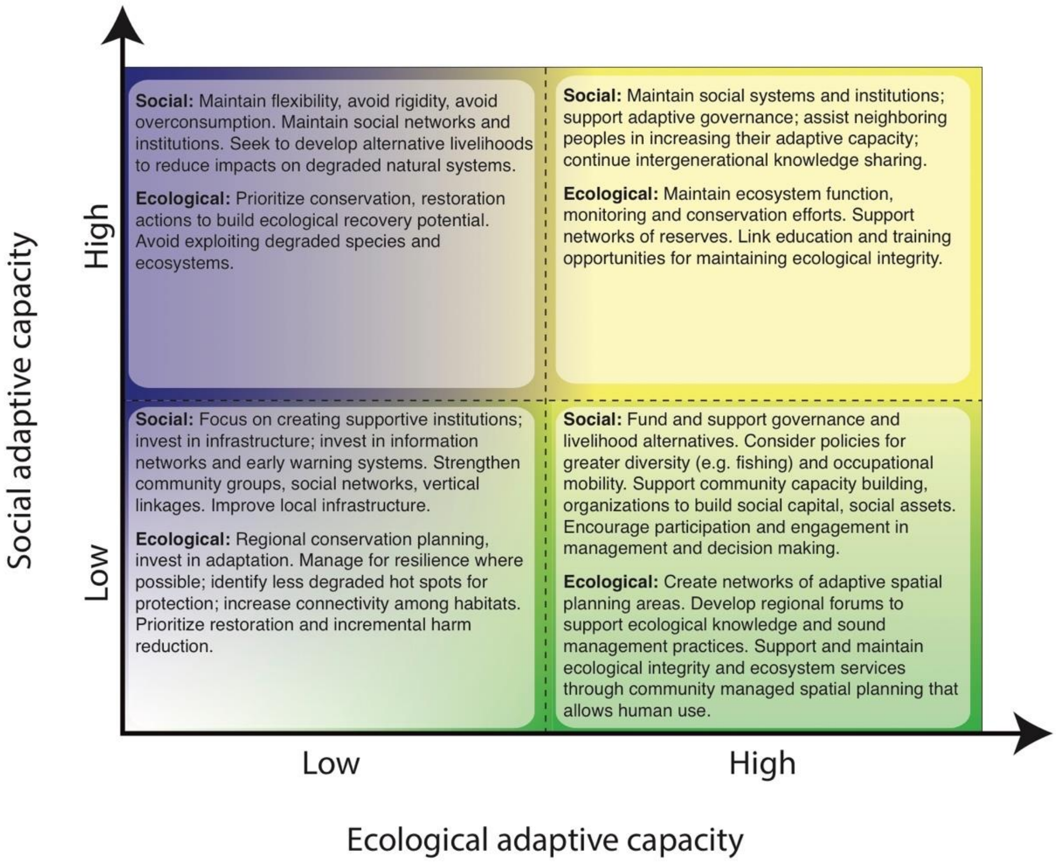


Figure 2.3: A conceptual framework to link adaptive capacity assessment to adaptive capacity building in social-ecological systems. The adaptive capacity of the linked social-ecological system is first identified by assessing the level of ecological and social adaptive capacity (i.e. by conducting multiple, or integrated assessments). With knowledge of the current state of the system, actions can be taken to build further adaptive capacity (e.g. improve ecological adaptive capacity) to move the system to a more desirable state. If considerations of trade-offs are not included, the system's adaptive capacity could shift in focus without gains in total adaptive capacity (e.g. ecological adaptive capacity increases at the cost of decreasing social adaptive capacity). Model is based on a similar schematic by (McClanahan et al. 2008) and (Ban et al. 2013); actions build on (Salafsky et al. 2008) and (Cinner et al. 2012). This is illustrative of potential examples of actions which can lead to beneficial outcomes, not prescriptive.

Limitations in bridging assessments to action

Suggesting a set of potential actions to build adaptive capacity (Figure 3) demands some important caveats. First, important trade-offs exist between and across scales, and across social and ecological systems (Walker et al. 2009). For example, building social adaptive capacity might involve diversifying or intensifying fisheries, for example, which could have the effect of decreasing biodiversity, abundance, and ecological adaptive capacities in that system (Coulthard 2012). Similarly, national level policy changes to decrease fossil fuel production according to international agreements may negatively impact local economies, for example by limiting fishing activity, at least in the short run (Biggs et al. 2012). Likewise, there may be temporal trade-offs, whereby actions to build short term adaptive capacity might imply a tradeoff for future outcomes if those actions create barriers for future options. It is important to foster adaptive capacity that allows a SES to cope with change, while not losing adaptive options for the future (Folke et al. 2002, Armitage and Plummer 2010a). Moreover, we recognize the existence of taboo trade-offs or choices between morally incommensurable values, such as trade-offs between the conservation of a particular species and human health (Daw et al. 2015).

Second, we recognize that building adaptive capacity requires situated research that is sensitive to particular contexts. The development of a universal framework for adaptive capacity is neither realistic nor desirable. For example, advocacy for institutional criteria (such as flexibility, diversity, legitimacy) can lead to highly differentiated and unpredictable impacts on the ground. Rather, principles for assessing and building adaptive capacity must be drawn out of the specifics of each case where unique social-ecological processes and social relations of power are observable (Cote and Nightingale 2012). However, reluctance to simplify complex phenomena into useable metrics can result in their gradual omission from research and practice. That which cannot be measured can disappear from public debates and political consciousness. Conversely, indictors or metrics allow us to define what is important, measure change, and direct research and investment (Hicks et al. 2016). Therefore, this framework is intended as a starting point for developing more targeted and context specific actions that build adaptive capacity in coastal social-ecological systems.

Conclusions and future directions

The extent and speed of global change has catalyzed broad interest in understanding and supporting the capacity of social-ecological systems to respond to, cope with, and adapt to change. Adaptive capacity assessments that focus on climate change have been applied in many contexts – including forestry (Pramova et al. 2012), agriculture (Marshall et al. 2013, Wang et al. 2013), fisheries (Kalikoski et al. 2010, Cinner 2011, Cinner et al. 2013, Aguilera et al. 2015), conservation (McClanahan et al. 2008, Mcleod et al. 2015) and disasters (Adger et al. 2005b, Cutter et al. 2008, Taylor 2011, Henly-Shepard et al. 2014). Several important points emerge from this literature, and the broader literature and case studies on adaptive capacity. First, both the local and broader context of change matter. Adaptive capacity may vary depending on the changes occurring, the linkages between local contexts and global processes, the ways these manifest as impacts on systems and individuals, local perceptions of desirable and undesirable system states and outcomes, and the characteristics of the system that determine the suite of available responses. In other words, it is crucial to define adaptive capacity "of what", "to what" and "for whom" (Carpenter et al. 2001, Adger and Vincent 2005, Lebel et al. 2006, Adger et al. 2012).

Second, spatial and temporal scales of social and ecological change matter. Social-ecological systems produce a suite of interacting ecosystem services at multiple scales, which support interdependent social systems. These complex systems are affected by cross-scale interactions, whereby large scale decisions affect small scale systems, and small scale adaptive characteristics add up to region-wide norms (Klein et al. 2014). Changes, impacts, and responses are all critical factors for assessing adaptive capacity, and occur and interact at multiple scales. Thus, the scale of assessment ('of what') is dependent upon the scale of the given stressor ('to what') (Adger 2003, Adger and Vincent 2005, Folke et al. 2005, Biggs et al. 2012). Adaptive capacity in social and ecological systems can therefore be measured across scales, from the household or population, to cross-community or ecosystem assessments, to national or regional levels. In an era of rapid transformative change, it is important that both social and ecological indicators be both robust and transparent, and applicable to the scale of assessment, in order to have meaningful policy applications (Adger and Vincent 2005).

Third, increasing interest in the concept of adaptive capacity has led to the development of numerous definitions as well as conceptual and analytical frameworks with associated measures and indicators. Many of these definitions and frameworks have primarily addressed either social or ecological adaptive capacity without integrating them. There is a need for integrated ways of thinking about adaptive capacity, with the caveat that not all social-ecological systems have tightly connected feedbacks. The direct feedback mechanism between changes in social or ecological systems may be missing or delayed in some contexts (buffered by social structures or other scales of resource availability, governance or institutions beyond the scope of the study). Furthermore, adaptive capacity should be assessed both in terms of the ability to react and change in response to opportunities (positive change) as well as stressors or challenges (negative change). There is no absolute measure of adaptive capacity, only adaptive capacity relative to the specific context, scale of disturbance, and scale of analysis.

Moving forward, some important gaps in adaptive capacity application are evident. There is much to learn about which measures and indicators of social and ecological adaptive capacity are the most powerful predictors of adaptive responses. Unfortunately, there are few instances where assessments of adaptive capacity are followed up with monitoring or post-assessment evaluation of change in that system through time. The reasons for this are unclear, but we hypothesize that this is likely due to funding and capacity constraints, as well as governance inconsistencies. Future efforts should be made to follow up on single assessments of adaptive capacity to observe and describe whether assessments were accurate and which factors in particular enabled effective responses to both slow and rapid change. In addition, more attention is needed to develop integrated social-ecological assessments. In policy relevant time scales, fostering adaptive capacity is most applicable to social systems, although it is possible to evaluate historical change in ecological adaptive capacity over longer time scales. Thus, it is imperative that management focus on preventing the erosion of ecological adaptive capacity (e.g. through over-fishing), and on building social adaptive capacity through positive proactive action (futures thinking; Tschakert and Dietrich 2010). A learning opportunity for building consistency in adaptive capacity assessment could come from the fields of environmental impact assessment, management effectiveness evaluation, and social impact studies where metrics for monitoring, evaluation, and reporting have a more developed history. Finally, there are limited published examples of assessments that demonstrate the linking of the results from assessments to the building of adaptive capacity. If adaptive capacity is to be a useful concept for fostering real world change, it is imperative that researchers and decision makers work across disciplines to develop clear, consistent methods that can support action-oriented outcomes that resonate with communities.

Chapter 3: Synthesizing and communicating climate change impacts to inform coastal adaptation planning

Introduction

Global climate change is widely recognized as the singular greatest threat to the world's ecosystems, cultures, and economies (IPCC 2014a, Mora et al. 2018), including for marine systems (Hoegh-Guldberg and Bruno 2010b, Gattuso et al. 2015b, Weatherdon et al. 2016a). Anthropogenic climate change has led to increased global temperatures, changes in precipitation patterns, sea level rise, and increasing frequency and severity of extreme weather events (IPCC 2014a). While these changes are global, the ramifications occur at all scales, and decisions for adaptation must be made (Game et al. 2011). Coastal regions are unique and especially vulnerable to climate change (Frusher et al. 2015, Pinsky et al. 2019), and the impacts are diverse and often cumulative. Governments, regions, and communities need to understand what is happening, what knowledge gaps exist, and how they may be able to respond (Hobday et al. 2016).

Global climate change adds complexity to the already convoluted area of coastal marine planning. Changes in habitat suitability are predicted to cause an overall shift in global marine biodiversity by up to 60% by 2050 (Cheung et al. 2009). The direct impacts of these changes on ecosystems are either continuous: shifts in species ranges, changes in phenology (timing of life cycle events), changes in species interactions and ecological community composition (Parmesan and Yohe 2003, Parmesan 2006), or discrete: massive coral bleaching events, and extreme weather events such as floods or storms (Hansen et al. 2016). As climate change leads to shifting habitats and species ranges, many species are likely to be forced out of current marine protected areas (MPAs; Araújo et al. 2004, Pressey et al. 2007). The static nature of current conservation planning schemes tends to lack the flexibility necessary to fulfill conservation benefits under climate change scenarios (Pressey et al. 2007, Alagador et al. 2014). Even more difficult to predict are the indirect impacts of climate change caused by the human responses to climate change, such as migration, changing agricultural practices, shifting fisheries areas, renewable energy development, or seawall construction (Maxwell et al. 2015a, Jones et al. 2016).

Regional climate change planning and policy development can be informed by understanding the impacts, risks, vulnerabilities, and opportunities, and by adaptive capacity assessments (Moser and Ekstrom 2010). While vulnerability assessments can provide information that is useful for policymakers (e.g. risk assessments, infrastructure exposed to flooding, etc.), these summaries are only one component of effective adaptation planning. Vulnerability assessments typically focus on one or two climate impacts (e.g. sea level rise), do not identify adaptation strategies that are applicable to specific regions (Reiblich et al. 2017), and are not accessible and therefore actionable by local or sub-regional planners (Beier et al. 2017). While there has been ample research on coastal climate risks and adaptation recommendations specific to sea level rise (Lin et al. 2017), coastal retreat (Hino et al. 2017), and planning to protect coastal infrastructure (Brown et al. 2018), more integrated studies of climate impacts and adaptation planning in collaboration with practitioners are needed (Becker et al. 2018, Ng et al. 2018).

Integrated climate change assessments can inform in-process coastal planning and management. In the Arctic, a recent assessment of risk associated with climate change on an MPA network found that climate risks will exceed those of industrial activities, and that Indigenous-led additional MPAs are recommended because of the implications of climate change on the presence and function of the species and ecosystems that MPAs are meant to protect (Bone 2018). In Portugal, expert judgement was applied to evaluate environmental properties, conservation features, and climate change pressures to the ecological components of the MPA network (Stratoudakis et al. 2019). Developing a functional MPA network that is informed by ecological information including current and observed climate impacts, and considers social aspects is typically challenged by data limitations and research capacity.

We applied a mixed-methods approach to integrate projections of climate change impacts with adaptation planning considerations to a NE Pacific coastal region (hereafter referred to as the 'North Pacific Coast') that is undergoing an integrative marine planning and plan implementation process. The purpose of the project was to summarize the state of scientific understanding of climate change impacts and projected further climate changes for the NSB region. In addition, we presented potential adaptation strategies to inform future work within the region, or strategic next steps for adaptation that could be taken to address the needs of coastal communities. The literature in this field is wide ranging and growing rapidly, and much of the work is in progress and therefore not published or readily available. Thus, our research is based on peer-reviewed literature and government agency reports (federal and provincial) and informed by the insights offered by key experts.

Methods

In this section, we describe the project process, the methodology for the review of climate impacts for the North Pacific Coast, and the analysis to evaluate the body of evidence for relevant climate variables and related impacts. We then explain how we evaluated the adaptation strategies in response to those impacts, our ongoing efforts to engage local and sub-regional planners in this topic, and the next steps. The methodology of the research presented here consists of the following systematic steps: literature and data review, interviews, assessing and recommending adaptation strategies.

Process

Marine planning through the Marine Plan Partnership for the North Pacific Coast (MaPP) started in 2011 in British Columba (BC), Canada, and four sub-regional marine plans for the North Coast, the Central Coast, North Vancouver Island, and Haida Gwaii were completed in the spring of 2015 (www.mappocean.org). MaPP is a co-led process between 16 First Nations and the Government of the Province of British Columbia that developed and is implementing plans for marine uses on B.C.'s North Pacific Coast, now and into the future. A Regional Action Framework (RAF) followed and was completed in the spring of 2016. Together, the four sub-regions make up the Northern Shelf Bioregion (NSB; Figure 3.1). Through MaPP, provincial and Indigenous (First Nations) governments in BC are working towards sustainable development, improving economic opportunity, and supporting ecological integrity for the North Pacific Coast.

This project was co-developed with MaPP through the Climate Change Sub-Committee coordinated by the Regional Projects Coordinator, to shape our objectives, framing, and end products. We met with the Regional Projects Coordinator and Climate Change Sub-Committee co-chairs of the Marine Plan Partnership on a biweekly basis over a 9-month period and presented draft and final reports to the Climate Change Sub-Committee, which is comprised of First Nations and provincial MaPP Partner technical planners and staff from each sub-region. These meetings helped to ground the project's goals and focus our research on relevant topics to practitioners and communities in the region. The draft and final products were also shared with the same audience to elicit feedback and target the end product to the needs of the MaPP Partners. We also presented a summary webinar to an inclusive audience of marine planners and managers who work within the NSB in order to advance the goals of increasing communication and awareness of climate impacts. We emphasized communicating climate impacts and relevant adaptation actions because studies have shown that this is important for adaptation planning (Carpenter et al. 2001, Walker et al. 2004, Malakar 2013). Finally, the ongoing work in this project includes sharing the results through a graphically designed report, and interactive HTML web-based platform whereby First Nations, local and provincial marine planners, educators, and the general public can engage with the material and have further conversations (Nerlich et al. 2010) about the impacts and opportunities related to these climate change impacts in the NSB.

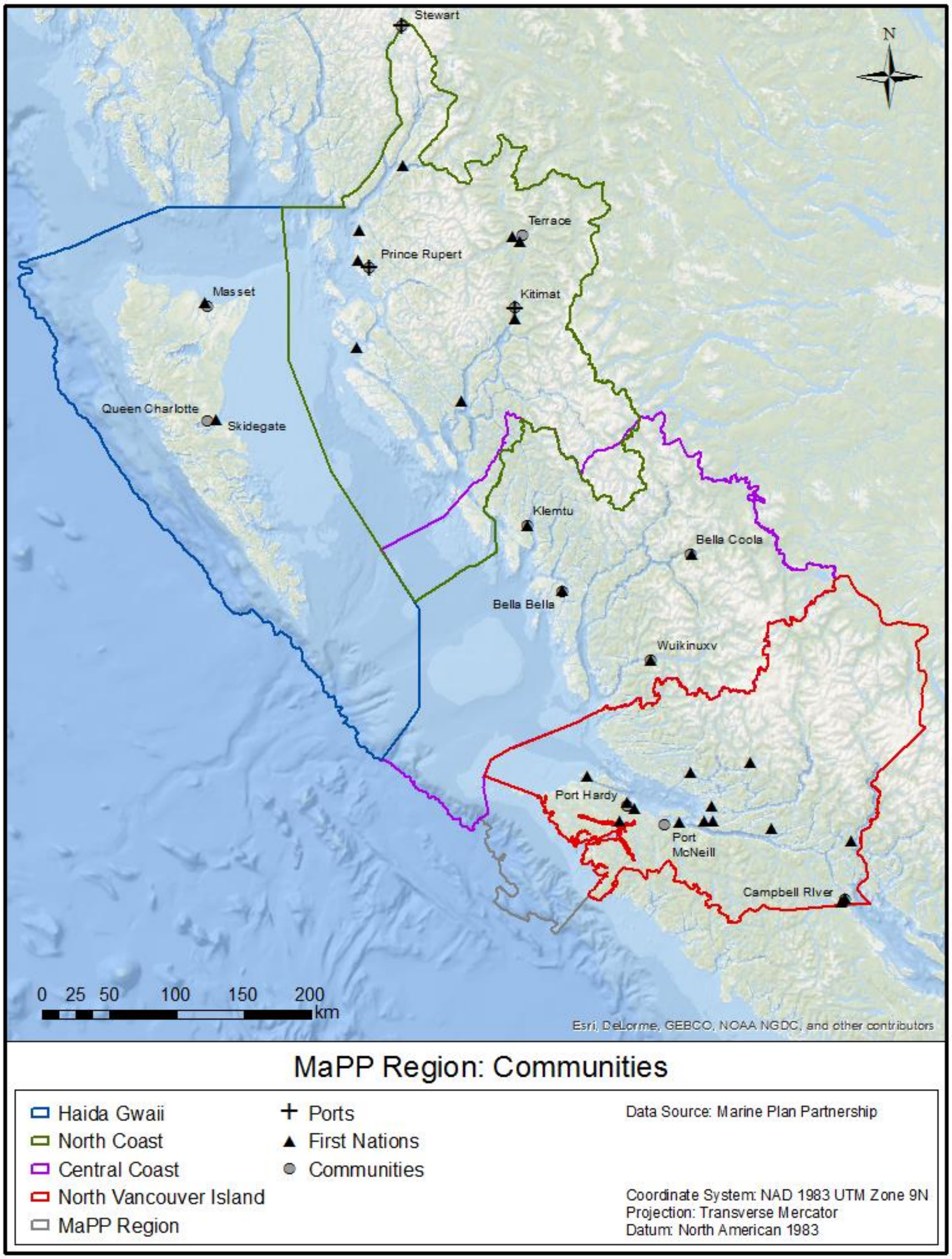


Figure 3.1: The Northern Shelf Bioregion (NSB), showing the boundaries of the four MaPP sub-regions and main communities. The sub-regional boundaries follow the Northern Shelf Bioregion boundary, except for a small area near the western tip of North Vancouver Island.
First Nations (▲) and non-First Nations communities (●) are distinguished by request of MaPP.

Literature, data review, and expert elicitation

We integrated both peer-reviewed and grey literature, and spatial data, to summarize climate change projections, impacts, and adaptation strategies. Sources included previous climate change vulnerability and risk assessment work from MaPP and associated contractors (including from the MaPP data portal; http://mappocean.org/resources/data/); publications from the Intergovernmental Panel on Climate Change (IPCC) reports; peer reviewed academic studies on climate change impacts (last searched July 15, 2017); assessment methods for climate change vulnerabilities and risks; external reports on predicted climate changes, impacts (e.g. BC Parks Shoreline Sensitivity Analysis 2014 (Biffard, D., Stevens, T., Rao, A., Woods 2014), Environment Canada downscaled global climate models (Canadian Centre for Climate Modelling and Analysis 2017), and Natural Resources Canada reports (Figure 3.2). Except for some fundamental background information, we only included publications from the year 2000 and newer.

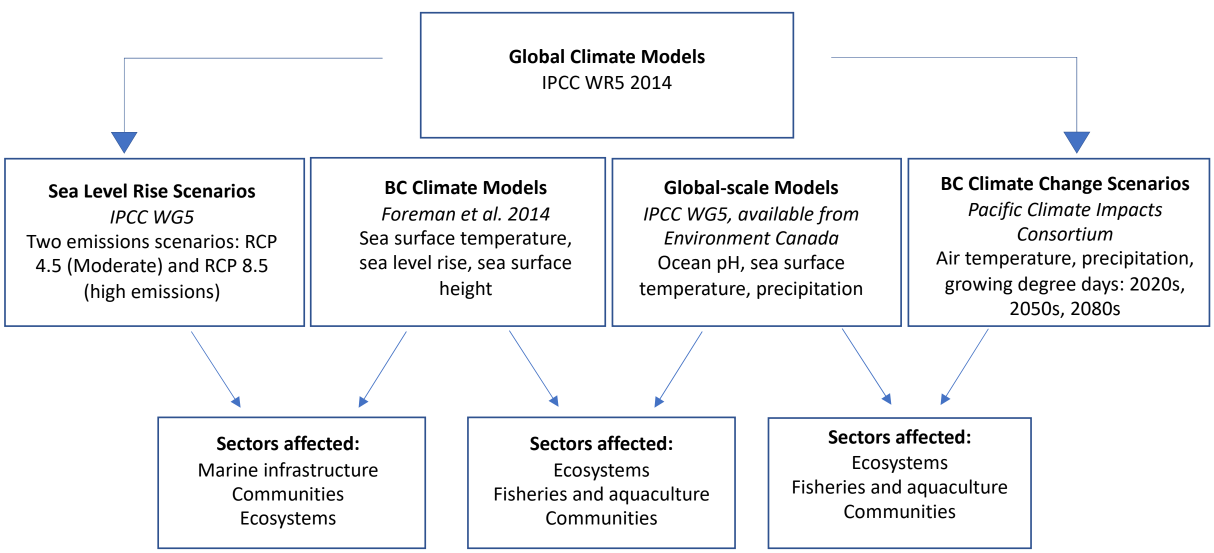


Figure 3.2: Schematic showing the global and smaller scale data sources informing the reporting of climate impacts on key sectors within the NSB. Particular sectoral impacts from climate projections that were of interest to the planning group, and informed our focus, are shown on the third row.

We reviewed the literature and extracted relevant information for the region, where possible, to categorize climate projections and associated sectoral impacts and exposure to four key sectors of the coastal social-ecological system in the NSB: 1) ecosystems; 2) fisheries and aquaculture;

3) human communities; 4) marine infrastructure. We included both observed and projected information on a set of climate variables that were determined as most relevant to MaPP through a series of discussions: air temperature, sea surface temperature, ocean acidification, sea level rise, ocean deoxygenation, sea surface salinity, and precipitation.

In order to present the uncertainty in climate change projections, we included the projections for climate change variables at the lowest and highest IPCC Representative Concentration Pathway (RCP) scenarios (IPCC 2014c), or the 'best case' and 'worst case' scenario, whenever possible. Long-term projections or trends within BC are expected to align with global trends in a general sense (i.e. warmer temperatures, more acidic ocean, more marine stratification, rising sea levels), but climate changes may result in regional and sub-regional interactions with localized ocean and atmospheric conditions. The ecological complexity of the BC coast and Northern Shelf Bioregion is high, as is the uncertainty in regionally resolved climate change projections. Understanding the ecosystem and the projections of climate effects on the various components of the MaPP social-ecological system was therefore challenging. In some cases, the spatial data for climate projections within BC were only available for certain scenarios (e.g. sea level rise projections, available for RCP 4.5 and RCP 8.5 only). Many of the available regional and sub-regional climate projections are available through the Pacific Climate Impacts Consortium (https://www.pacificclimate.org/), who use an average set of climate models from the IPCC to conduct regional analyses for the BC region at a 'business as usual' level of emissions (RCP 8.5) (Murdock and Spittlehouse 2011, Sobie and Murdock 2017). The current state of uncertainty means that our findings include relatively simplified, generalizable impact statements, adaptation actions, and recommendations for climate change impact planning in mind.

To enquire about ongoing projects and to further inform our methods, data sources, and findings, we also contacted and interviewed key practitioners and experts in the region involved in the climate change science and adaptation planning.
The criteria used to select the participants included:

(1) A lead author on a previously published seminal paper or report on climate change impacts in the study area, and/or

(2) A researcher recommended through snowball sampling; we asked each of our expert contacts whom else we should contact.

After the participants were identified, they were contacted through their publicly available email addresses. The semi-structured interview format was selected to allow for a range of responses, and to enable clarifying questions and additional discussions. The interviews were conducted either in person or on the phone and a range of questions were asked regarding their knowledge on the ongoing projects in BC, data sources, and quality of reports and other publications (Appendix B).

Assessing evidence qualities

To assess reporting of climate change projections and sectoral impacts, vulnerabilities, and risks, we used three systematic steps. First, we applied a reliability score used by the IPCC to qualitatively assess document quality and reliability of information. We ranked each reference on a 3-point evidence quality scale based on our literature review, expert interviews, and research team's knowledge and expertise on the field. Next, we documented all the relevant information and references of each climate variable (existing and projected) and sector (Ecosystems, Communities, Fisheries and Aquaculture, and Marine Infrastructure) for the NSB. Lastly, we calculated overall evidence qualities by averaging evidence qualities scores for each climate variable and sector based on the literature (Table 3.1, Table 3.2).

Table 3.1: Summary, projected climate impacts, projected changes, and sector-specific impacts anticipated for the Northern Shelf Bioregion.

Symbols reflect: Ecosystems, Communities, Fisheries, Marine Infrastructure. References are linked in the supplementary information.

Northern Shelf Bioregion - Summary table for climate impacts, projected changes and sectoral impacts					
Climate Impact	**Projected Changes**	**Evidence Quality**	**Sectoral Impacts**	**Impacts Summary**$^{\alpha}$	**Evidence Quality**
Air Temperature	Average air temperatures may increase by 1.8°C (1.3°C to 2.7°C) by 2050 and 2.7°C (1.7°C to 4.5°C) by 2080[1, 2, 3]; and average temperatures may reach ~7.8°C with low emission scenario (RCP 2.6) and ~11.6°C with high emission scenario (RCP 8.5) by 2091-2100[4*]; Growing degree days: +283 (+179 to +429) 2050 and +468 (+262 to +769) by 2080[1]; Frost free days: +20(+12 to +29) by 2050 and +30 (+16 to +48) by 2080[1]; Winter minimum temperatures in northern BC may increase by 4–9°C by 2080 and summer maximum temperatures may increase by 3–4°C. Increases in frost-free periods, growing-degree days, and frequency of extremely warm days[5].	High	Threats to fisheries[2], ecosystem, hydrology, and habitats[3,5], nearshore marine mammals[5,6], fisheries related tourism[2], water supply[2], human health and well-being[7]; Potential increases in frequency and intensity of toxic algal blooms[6], Potential benefits to tourism due to longer warm seasons[2].	Ecosystems, Fisheries, Communities	High
Precipitation	Increasing average annual precipitation by 6% (2% to 12%) by 2050 and 9% (4% to 17%) by 2080, 10% decrease in summer[1,2*]; up to ~18% more precipitation (low emissions, RCP2.6) and ~25% (high emissions, RCP8.5) by 2091-2100 compared to 1961-1990 baseline[4]; Declining winter snowfall by -10% (-17% to +2%) by 2050 and -12% (-26% to -1%) by 2080[1]; Winter precipitation increase by 10-25%, summer precipitation increase by 20% by 2050[8]; overall precipitation increase in fall, winter and spring seasons[2,3,9,10,11].	High	Threats to marine infrastructure, operations and transportation lanes[10]; Increased freshwater discharges and associated turbidity, flow of conteminants, pathogens and nutrients[6,11,12], summer drought and water scarcity for communities due to earlier freshet in the spring[9]; Changing salinity levels and stronger Vancouver Island Coastal Current[12]; Potential damaging impacts on ecosystems, ecosystem dynamics, and habitats[2]; Changes in access and seasonality of traditional foods and food availability[2].	Ecosystems, Fisheries, Communities, Marine Infrastructure	High
Sea Level Rise	Rising sea levels from 80cm to 120cm[13] or from 20cm to 130cm[3] by 2100; Increases by ~25.1cm in Prince Rupert; ~9.3cm in Queen Charlotte; ~8.4cm in Bella Bella; ~13.9cm in Winter Harbour by 2100[8]; Moderate rate of sea level rise until 2025, and rapid rate from 2025 up to 2100. May be counteracted by vertical land movement (uplift) by 1 and 3 mm/yr, but not enough to moderate SLR rates[14].	High	Threats to fish, invertebrates[6], coastal plants, algae and inter-tidal habitat[6], First Nations' heritage sites[10,12,15,16,17], groundwater quality due to salt water intrusion[15]; Increased coastal flooding and erosion risks on communities[10,12,15,16,17]; Economic impacts on built environment and communities[10], marine infrastructure, operations and transportation lanes[16,17,18].	Ecosystems, Fisheries, Communities, Marine Infrastructure	Medium
Sea Surface Temperature	Average sea surface temperatures may reach ~11.4°C with RCP 2.6 and ~14°C with RCP 8.5 by 2091-2100[4]; Increases between 0.5°C and 2.0°C and average temperatures to be around 10-14°C by 2065-2078 compared to 1995-2008 baseline[12].	High	Threats to water quality[15,23,24], nearshore habitats and ecosystems[6,15,19,24], diversity, abundance, growth, movement, range, interactions, distribution and survival of species[4,6,11,19,23,24, 25], cascading impacts on ecosystems[6]; Increased incidence of marine diseases, harmful algal blooms and invasive species[15,23,24]; Economic, social and cultural impacts on communities as fisheries migrate across regional and political boundaries[15,19].	Ecosystems, Fisheries, Communities	High

Table 3.2: Continued summary, projected climate impacts, projected changes, and sector-specific impacts anticipated for the Northern Shelf Bioregion.

Symbols reflect: Ecosystems, Communities, Fisheries, Marine Infrastructure. References are linked in the supplementary information.

Northern Shelf Bioregion - Summary table for climate impacts, projected changes and sectoral impacts					
Climate Impact	**Projected Changes**	**Evidence Quality**	**Sectoral Impacts**	**Impacts Summary**[α]	**Evidence Quality**
Oxygenation	Declining dissolved oxygen levels for the Northeast Pacific Oce	High	Threats to species with low mobility or species adapted to low oxygen[6], primary productivity, growth and distribution of fish populations [6,11,22], fished species compared to unfished species[11,19,22]; Impacts on the ecosystem and habitat of groundfish[15,22,23]; Economic, social and cultural impacts due to changes in fisheries[11,19,22].		High
Streamflow	Increases in spring flow with slight increases in during summer by 2080[8,15]; Stronger Vancouver Island Coastal Current, stronger flows in Queen Charlotte Sound, Hecate Strait and Dixon entrance[12]; Decreased summer flows in glacier and snowmelt dominated watersheds[9,15].	High	Threats to nearshore marine mammals due to alterations to temperature, salinity and stratification in ocean surface layers[6], ecosystems due to oxygen and nutrient upwelling[6,12]; Increased and periodic water scarcity during the summer[9].		High
Sea Surface Salinity	Decreases in sea surface salinity by ~1.25% with RCP 2.6 and ~3.2% with RCP 8.5 by 2091-2100 compared to 1961-1990 baseline[4]; Decreases in sea surface salinity by ~1% (~0.2 decrease in psu unit) by 2065-2078 compared to 1995-2008 baseline[12].	High	Threats to species range and food web structure[19], fisheries industry[19]; Reduction in total ecosystem biomass[19]. Economic, social and cultural impacts on communities as fisheries migrate across regional and political boundaries[19].		High
Winds, Waves and Storms	More intense and more frequent winter storms, surges and waves[2,26]; Increases in damaging extreme high-water events[15]; Increases in coastal wind strength in summer[6].	High	Threats to ecosystems and habitats[2], recruitment for fisheries[6], traditional way of life and First Nations food supply due to altered timing of seasons[27], marine infrastructure, operations and transportation lanes[10,15]; Increase in marine infrastructure maintenance and insurance costs[10,15], coastal erosion and flooding[28]; Alterations in the timing or strength of the spring weather transition, coastal currents and upwell strength and timing[6].		Medium
General	Increasing occurance and frequency of climate impacts [2,15,23,24,28].	High	Threats to access to traditional foods[25,26], species abundance and distribution[25], catch potential for all commercial fisheries[25], fish spawning[13]; 21% decline in sockeye salmon, 10% decline in Chum salmon, 15% decline in sablefish stocks, and 1.33$, 0.77$ and 0.65$ increase per pound, respectively[22]; 15.0% to 20.8% decline in commerically and culturally important fisheries species relative abundance by 2050[25]; Economic, social and cultural impacts due to changes in fisheries[22,25].		High

Adaptation strategies

Across Canada, awareness of climate change impacts and the necessity of adaptation planning is increasing (Lemmen et al. 2016). In BC, the provincial Adaptation Strategy (Government 2010) aims to prepare the province for the impacts of climate change to the environment and social systems. Under the BC Climate Action Plan, there are a range of actions that are intended to help increase resilience to climate change and reduce vulnerabilities. This adaptation plan is based on three key components: building a strong knowledge base with tools for decision makers to prepare for climate change, incorporating climate adaptation within policy decisions, and improving assessment and implementation of appropriate adaptation actions in especially vulnerable sectors (Government 2010). While these reports and adaptation plans are encouraging and signify a shift in management and governance investment in climate adaptation, there has been until recently far less investment in adaptation research and planning for coastal management and fisheries sectors when compared to terrestrial areas and sectors such as forestry and agriculture (Warren and Lemmen, D.S. 2014).

We defined adaptation recommendations broadly to include current and potential proactive strategies that could help to address the impacts to coastal ecosystems, fisheries, coastal communities, and marine infrastructure. Recommended adaptation strategies were included that would be feasible and effective in increasing the potential for the sectors to adapt to diverse climate impacts.

Results

Trends and Projections of Climate Variables

Along the coast of BC, ocean water temperatures are warming, and nearshore waters are becoming less salty, less oxygenated, and more acidic (a chemical process resulting from them becoming enriched in carbon dioxide; Chandler et al. 2017; Table 3.1). These changes are contributing to biological changes such as shifting species distributions (Bond et al. 2015, Cheung et al. 2015). In order to understand and anticipate climate change impacts, a range of modeling approaches have been used to characterize and predict ecological and biological responses along the BC coast and the surrounding marine area. Research focused on and within the NSB has included descriptions of the ecological communities and context, trophodynamic modeling, and the effects of climate change on fisheries and ecosystems (Ainsworth et al. 2002, 2008, 2011, Guénette and Alder 2007, Okey et al. 2014a, 2015, Clarke Murray et al. 2015). There is a lack of reliable downscaled projections or regional climate modeled data for most climate impacts in the marine environment of BC, and within the Northern Shelf Bioregion. Much of the climate impacts work within BC is focused on terrestrial impacts (e.g. Hamann & Wang 2006), and as such is of limited applicability to the marine and coastal focus of the Northern Shelf Bioregion (T. Murdoch, PCIC, pers. comm. July 2017).

Air temperature

Air temperatures have increased throughout BC by ~1.3ºC over the past century (from 1900-2013; 0.12 - 0.13ºC per decade (BCME, 2016; PCIC, 2013a; Rodenhuis et al., 2006; Vadeboncoeur, 2016), slightly more than the global average during the same period (IPCC 2014c) but less than the rest of Canada (Warren and Lemmen, D.S. 2014). The northern portion of BC has warmed at twice the global average (1.6 to 2.0ºC per century versus 0.85ºC per century globally), while the south coast has warmed at a rate of 0.8ºC per century, roughly the same as the global average (BCME 2016). Most of this warming trend has been observed during the winter months (average increase of 2.2ºC per century), and in the north (3-3.8ºC per century) and south-central (2.6 to 2.9ºC per century) areas of BC (Rodenhuis et al. 2006, BCME 2016). Average daily minimum temperatures have increased the most (increased 2.3ºC this century) across the province, while average daily maximum temperatures have increased by 0.7ºC per century (BCME 2016, Chandler et al. 2017). Both daily average and daily minimum air temperatures in BC reached record high levels in 2016, and monthly temperatures in the winter of 2016 were more than 5ºC higher than the baseline period of 1971-2000 (Chandler et al. 2017). These higher temperatures contribute to other changes in climate, and both negatively as well as positively affect ecosystems and human activities. For instance, increasing air temperatures are associated with decreased heating requirements over the past century in BC, especially in northern BC (BCME 2016). Meanwhile, the energy demand for cooling built infrastructure has increased, especially in the southern interior of BC (BCME 2016), directly related to changes in average daily air temperature.

BC is expected to experience more warming than the global average (Pike et al. 2008, Spittlehouse 2008). Even though air temperature is moderated by the ocean, air temperatures are projected to increase by 1.8°C by the 2050s and 2.7°C by the 2080s, and could reach of 3-5°C by the end of the 21st century if emissions continue at current rates (Pike et al. 2008, Spittlehouse 2008, Mote and Salathé 2010). On average, air temperatures are likely to increase by 0.1-0.6°C per decade (PCIC, 2013b; Table 3.1).

Sea surface temperature

Average annual sea surface temperatures have warmed between 0.6 to 1.4°C per century across the coast of BC (BCME 2016), as monitored at lighthouse stations along the BC coastline. This rate is similar to the global average of 1.1°C per century (IPCC 2013, BCME 2016), although there is significant variation along the BC coast in that some areas have warmed by up to 2.2°C per century (e.g. Strait of Georgia, Entrance Island) (BCME 2016). In BC waters, recent sea surface temperature trends have been the result of the interaction of three things: climate change warming, El Niño effects (2015-2016), and the 'warm blob' phenomenon (2013-2016) where a large area of very warm water (3°C warmer than usual) settled off the BC coast (Bond et al. 2015, DiLorenzo and Mantua 2016). In 2016, average sea surface temperatures were 1-2°C warmer than the historical average within the Northeastern Pacific Ocean (Chandler et al. 2017). The average daily sea surface temperature anomaly was higher in 2016 according to both lighthouse station data (0.98°C ± 0.33°C) and weather buoy data (0.7°C average) as compared to the 22-year historical average (1989-2010), which reflects the long term warming trend (Chandler et al. 2017).

In BC, sea surface temperatures are likely to increase by between 0.5°C to 2.0°C by the end of the century (Foreman et al. 2014; Figure 3). The rate of ocean temperature increase may accelerate, as consistent with the accelerating rise in global sea surface temperatures (Klein et al. 2014, Okey et al. 2014a).

Ocean acidification

Ocean acidification is occurring faster as higher latitude areas, due to the effects of temperature on carbon dioxide absorption (Byrne et al. 2010, Doney et al. 2012, Gerber et al. 2014).

Globally, ocean acidification is projected to increase by 100% or more by 2100, but there is large uncertainty and variation among regions and climate scenarios (IPCC 2013, Haigh et al. 2015, Weatherdon et al. 2016a)**.** In the Northeastern Pacific Ocean, ocean acidification is one of the most urgent threats to both marine ecosystems and human communities. These waters are already among the most acidic of the world's ocean regions, due to ocean currents and upwelling of deep ocean waters (Okey et al. 2014b, Haigh et al. 2015, Chan et al. 2017). Upwelling waters already have relatively low pH, and organic matter production driven by upwelling currents further lowers the pH of those waters by remineralization. Within the Northern Shelf Bioregion, acidification is projected to continue to increase as carbon dioxide emissions continue to rise.

The existing state of knowledge for ocean acidification is limited, and other than global datasets, there are currently no projections at the scale of the BC coast (Hunter et al. 2015). This is partly due to a lack of empirical data as model inputs. Sampling for alkalinity and dissolved organic carbon has occurred as a regular part of Fisheries and Oceans Canada (DFO) surveys since 1992 and 1986 respectively, but the data have been fragmented and inconsistent (Hunter et al. 2015). Very little is known about the state of the nearshore waters. Ongoing efforts to model changes in ocean chemistry (nitrogen, carbon, and oxygen) will improve the overall understanding of coastal biochemical processes and nearshore acidification and hypoxia levels (K. Hunter, Fisheries and Oceans Canada, pers. comm. July 2017). In addition, further efforts to model changes and extremes in pH (Ianson and Monahan, in progress; Hunter & Wade 2015) will improve the understanding of projected changes in acidification and the associated impacts.

Ocean deoxygenation

Across the NE Pacific Ocean, dissolved oxygen levels have been declining over at least the past several decades, at a range of depths from 100-1000m deep down to the sea floor, and oxygen levels between 100-400m depth have decreased by 22% over the past 50 years (Okey et al. 2014b). Oxygen levels are likely to continue to decline in the northeast Pacific Ocean, and coastal shelf and slope marine ecosystems are likely to lose well oxygenated habitats (Whitney et al., 2007; Figure 4). Seafloor habitats in the North Pacific could experience a reduction of 0.7-3.7% in oxygen levels by 2100 (Sweetman et al. 2017).

Sea level rise

In BC, the average sea level between 1910-2014 has risen along most of the coast, at a rate of 13.3 cm/century at Prince Rupert, 6.6 cm/century at Victoria, and 3.7cm/century at Vancouver (BCME 2016). Sea levels at Prince Rupert and Victoria continue to increase, while off the west coast of Vancouver Island tectonic uplift (isostatic rebound from the weight of ice age glaciers) offsets sea level rise such that water levels appear to be declining (removing this uplift would result in a sea level increase of 13.5 cm per century) (BCME 2016, Chandler et al. 2017). Changes in sea level threatens coastal systems through coastal erosion, seawater inundation, contamination of freshwater systems, and can affect food crops grown in low lying areas.

Relative sea level across the coast of BC is projected to rise by an average of 20-30 cm by 2100 (Table 3.1). However, there are many uncertainties in the projections for sea level rise. Localized ocean currents, tidal patterns, and river discharge rates will also influence the observed rate of sea level rise to particular areas. For instance, some models project higher observed sea surface height (SSH) values along the northern coast of BC during the next century in winter and spring related to wind patterns and increasing river discharge (Foreman et al. 2014).

Sea surface salinity

Ocean salinity is declining globally, along the BC coast, and within the Northern Shelf Bioregion (Chandler 2017). Empirical data from lighthouse station monitoring stations in 2016 reflect a long-term trend towards decreasing sea surface salinity (SSS) across the BC coast, except within the Strait of Georgia (Chandler 2017). Longer term data from lighthouse station monitoring shows the same freshening trend; however, this is not associated with longer term climate trends, but with local freshwater sources (Cummins and Masson 2014). Freshwater discharge from glaciers is a significant contributor to the nearshore waters of BC. Glacial coverage in BC has declined since 1985, and the volume of glacial ice declined by an average rate of 21.9 km^3 from 1985-2000 (BCME 2016). In the coastal mountain area of BC, which includes the Northern Shelf Bioregion, glacier area decreased by approximately 6.4% from 1985-2000 (BCME 2016). Coastal runoff contributes to maintaining the salinity levels along the coast, driven by glaciers, as well as watersheds driven by fall and winter seasonal precipitation. Large river systems (Fraser River, Naas River, Skeena River) also drain large watersheds and experience pronounced spring freshets. Coastal salinity levels are controlled mainly by these processes at the local scale rather than large-scale climate changes (Cummins and Masson 2014).

Precipitation

Precipitation is a key indicator of climate change, and changes will affect all sectors, ecosystems, and communities. In BC, precipitation has increased over the last 50 years in all seasons by some estimates, or just in the summer months by other reports, with variation across the province (Rodenhuis et al. 2006, Walker and Sydneysmith 2008, Okey et al. 2014b). Province-wide, annual average precipitation has increased by 12% per century (BCME 2016). However, these changes have been so far statistically insignificant and can largely be explained by the high natural variation in precipitation patterns across the province (PCIC 2013a, BCME 2016, Vadeboncoeur 2016). Winter warming trends led to higher snowpack density (wetter snow) across much of BC from 1950-2014, and as winter temperatures increase, winter snows are likely to continue to be wet and heavy, or be replaced by rain (BCME 2016). This trend has not yet been significant for the BC coastal region that includes the Northern Shelf Bioregion (BCME 2016). Changes in the amount, type, and timing of precipitation in BC will certainly affect both terrestrial and marine systems, although the relatively high uncertainty in historical monitoring data means that estimating current precipitation trends and associated impacts is a challenge (BCME 2016). In 2016, precipitation levels were higher than average for most regions in BC (Chandler et al. 2017).

Projected changes in precipitation in BC are expected to be relatively minor, especially when compared to the historical variability in the province (Figure 3). Wetter winters are projected to lead to increased runoff in rivers and streams in the winter. Less precipitation will fall as snow in the winter, which is likely to result in a reduction of the spring snowpack by 55% by 2050 (Rodenhuis et al. 2006). Glacial runoff in the spring has already declined in southern BC, and this is projected to occur for northern BC glaciers through 2050 and beyond (PCIC 2013a, BCME 2016). Due to this reduction in snowpack, the spring freshet will likely occur earlier in the spring in many rivers. By the end of the century, spring streamflow will likely have increased significantly, while summer river levels will have decreased (Thomson et al. 2008).

Extreme precipitation events will likely increase during some seasons and in some areas of the province (Mote and Salathé, 2010; Okey et al., 2014; Pike et al., 2008; Rodenhuis et al., 2006; Table 3.1). Heavy precipitation events in BC include phenomena known as ‘atmospheric rivers’ where highly concentrated water vapour streams move moisture from tropical regions towards the poles. These occur frequently in the fall and winter in BC, and impact coastal areas with periods of intense precipitation and flood events (Rodenhuis et al. 2006, Pike et al. 2008, Nyland and Nodelman 2017). More frequent atmospheric river events after 2040 (approximately double the current number per year) will affect ecosystems along the coast (Nyland and Nodelman 2017). Changes in wind and wave patterns may interact with other climate change projections such as sea level rise, but the projections of future winds and storm events are highly uncertain (IPCC 2014c). Storm intensities in the North Pacific increased during 1940-1998, and storm surge related winds and storms may become more frequent and intense as air and ocean temperatures increase (Dolan and Walker 2006a, Thomson et al. 2008).

Observed and Projected Climate Change Impacts

Ecosystems

Increasing sea surface temperatures and declining oxygen levels have affected the northern Pacific Ocean, which has likely led to reduced habitat availability and decreased survival for many fishes and invertebrates (Whitney et al. 2007). The ‘warm blob’ (2014-2016), a mass of water characterized by water temperatures from 1-3°C above the 30-year average, developed off the west coast of BC, affecting phytoplankton community composition, ocean stratification, and associated with abnormal and dramatic species range shifts (Chandler et al. 2017). Harmful algae blooms during the ‘warm blob’ event could also be associated with climate warming (Perry and Peña 2016). During that event, warm water zooplankton were much more abundant than cold water species in 2016 (Galbraith and Young 2017). Changing zooplankton species has potential implications for fish, as warm water zooplankton species have lower nutrient quality (Perry and Peña 2016). Other unusual biological events during that anomalously warm water period included low chlorophyll levels (2014), potentially due to increased stratification and reduced nutrients (Whitney 2015). This mass of abnormally warm water dissipated in 2016 (Chandler et al. 2017). Species sightings that could indicate dramatic species range shifts include ocean sunfish and warm water sharks off Washington State and Alaska, high catches of albacore tuna off the Washington and Oregon coasts, juvenile pompano sightings near the Columbia River, and widespread stranding of *Velella velella* off the coast of BC throughout the summer of 2014 (Bond et al. 2015). Warm ocean temperatures have affected the waters off the west coast of Vancouver Island, and the zooplankton community has shifted to more gelatinous species (overall lower nutrient food) and less crustaceans, leading to poor forage conditions for juvenile fish and seabirds (Galbraith and Young 2017).

Further increasing sea surface temperatures are likely to affect zooplankton biomass, contributing to overall biomass declines of lower trophic level species (Hunter and Wade 2015). Increasing ocean temperature and the northerly shift in the California Current may lead to higher abundance of low nutrient zooplankton, which would in turn affect juvenile fish species such as herring and salmonids (Cleary et al. 2016, Galbraith and Young 2017). Phytoplankton species composition is also likely to change, which could also affect higher trophic levels who depend on high quality zooplankton (Johnson et al. 2011, Ainsworth et al. 2011, Perry and Peña 2016, Galbraith and Young 2017). Kelps (giant kelp and bull kelp) and eelgrass (*Zostera marina*) are also likely to be negatively affected by warming sea surface temperatures; the cumulative impact of temperature along with decreasing salinity and increasing sedimentation from runoff will influence the productivity and distribution of these important habitat forming species (Okey et al. 2012). Projected changes to climate variables are likely to interact to affect the likelihood of species invasions in BC waters, as habitats and oceanographic conditions change to facilitate the establishment of warm water species through species range expansions (Bond et al. 2015, Cheung et al. 2015). Marine diseases are also likely to increase in frequency and intensity, as species already stressed due to direct climate changes such as rising ocean temperatures are also more susceptible to infection (Okey et al. 2014b). The biological interactions and additive effects of disease and invasive species, such as green crab which is already invading BC waters (Gillespie et al. 2015), are highly uncertain (Clarke Murray et al. 2014, Okey et al. 2014b, Jones and Cheung 2017).

Ocean acidification will certainly continue to affect coastal BC, although there are significant knowledge gaps in terms of the effects of ocean acidification on marine organisms (Haigh et al. 2015). Where data exist, it is more reliable for commercially viable shellfish species (e.g.

oysters) and issues that may affect human health (e.g. harmful algae blooms) (Haigh et al. 2015). Already, the ocean below 300m depth is corrosive to aragonite shells, and it is likely that the saturation depth will continue to decrease, threatening shelled organisms and the fishes that feed on them, including Pacific salmon (Cummins and Haigh 2010, Haigh et al. 2015). There is a strong likelihood that the negative impacts associated with ocean acidification could increase rapidly, and that the effects on marine species could potentially cause large shifts in species distribution and community assemblages across both latitude and depth (Sweetman et al. 2017). Ocean acidification may affect habitat availability and the abundance of those species dependent upon calcifying organisms for structural habitats, and those whose larval stage is affected by decreasing pH. For example, by 2100, cold water corals are projected to degrade due to ocean acidification, which will affect habitat availability for fish populations, therefore affecting fisheries productivity (Sweetman et al. 2017). The effects of ocean acidification on trophic dynamics (food web interactions) and the synergistic effects of ocean acidification with other climate change projections, such as increasing ocean temperature and declining oxygen levels, are uncertain and requires further research (Hunter et al. 2015, Haigh et al. 2015).

The expansion of low oxygen zones will affect ecosystem structure and function, especially in the deep sea (Sweetman et al. 2017), and in the deep coastal fjords of the northern coast of BC due to their geomorphological and chemical conditions (Okey et al. 2014b). The effects of warming temperatures are likely to combine with those of deoxygenation, resulting in further habitat contraction for fish and other marine species. Deoxygenation at deeper depths may drive mobile marine species to seek refuge in shallow water; yet those habitats will be more likely to be too warm. The interaction of these impacts may result in physiological stress. The combination of warming temperatures in shallow depths and deoxygenation at deeper depths may lead to habitat compression, unless species can adapt by migrating along continental slopes into more oxygenated environments, where they exist (Sweetman et al. 2017).

Due to the reduction in snowpack associated with decreased winter precipitation and warmer air temperatures, the spring runoff (freshet) will likely occur earlier in the spring in many rivers. This will have downstream effects on freshwater habitats, and linked marine systems (Foreman et al. 2014, BCME 2016), which will already be warmer and less oxygenated. These changes are likely to negatively impact the reproductive capacity and survival of fish and other aquatic species (Rand et al. 2006, Okey et al. 2012). The sheer increase in freshwater volume entering coastal marine waters will also affect salinity and stratification of ocean surface waters. Changes in the timing of spring currents is also likely to affect biological interactions such as plankton availability, in turn affecting larval fish and invertebrates (Hunter and Wade 2015). These changes could negatively affect marine fish and invertebrate recruitment, but the specifics of this impact are currently unknown (Hunter and Wade 2015).

Increased precipitation may lead to more runoff of contaminants and terrestrially derived nutrients - which, when combined with higher water temperatures, could increase the likelihood of toxic algae blooms in freshwater and marine ecosystems (Hunter and Wade 2015). The increase in freshwater volume entering coastal marine waters may also decrease sea surface salinity and increase ocean surface stratification. These stressors are likely to affect marine fishes and mammals that depend on nearshore habitats and are adapted to current oceanographic conditions (Hunter and Wade 2015). Changes in salinity can affect both sexual reproduction and vegetative propagation of seagrasses (Hunter and Wade 2015, Rahman et al. 2017). Declining salinity levels may affect the habitat, survival, and growth of marine fish and shellfish; in the Arctic, declining salinity has been shown to reduce phytoplankton size, which in turn affects productivity of higher trophic levels (Sweetman et al. 2017)

Sea level rise may affect coastal ecosystems through changes to habitat, especially for nearshore areas if important intertidal habitat becomes permanently sub-tidal, affecting nearshore plants, algae, and shellfish. Sea level rise is likely to cause an increase in the inland penetration of saltwater in tidal systems. The abundance and species composition of coastal plants and algae, along with associated invertebrate habitats, could be altered if important intertidal habitat becomes permanently sub-tidal as sea levels rise (Hunter and Wade 2015). Generally, coastal sensitivity to sea level rise depends on the physical geology of the coastline, and as such low-lying sandy regions will be most impacted. Most of the shoreline of BC has low sensitivity to sea level rise due to the rocky, fjordal coastline, but some areas (near Prince Rupert, Bella Bella, and most of Vancouver Island) are moderately sensitive (Biffard, D., Stevens, T., Rao, A., Woods 2014).

Fisheries

Fisheries and aquaculture are an especially important sector for coastal communities and First Nations. For many, fishing is a way of life which cannot be measured by the contribution to the economy alone, as social and cultural values play a large role. The fishing industry has already declined significantly across the province due to multiple factors including overfishing and fleet restructuring; since the 1980s, the fishing fleet has shrunk by 60% and there are 70% fewer fishers employed in the industry (Suzuki 2015). Existing stresses and impacts on BC's coastal fisheries are expected to be exacerbated by climate change, in particular for those species which are highly vulnerable to warming conditions (e.g. salmon; Healey 2011; Cheung et al. 2015; Weatherdon et al. 2016b). Some of the effects of climate change on fisheries in this region are reflected in projected species range shifts: the abundance of current target species is projected to decrease, and the species currently available across the region are likely to change (Ainsworth et al. 2011, Cheung et al. 2015, Teh et al. 2016, Weatherdon et al. 2016c). The impacts of these projected changes in fisheries catches could lead to or amplify other socio-economic impacts of climate change on fisheries and communities through reduced food security and economic loss (Weatherdon et al. 2016c). Fisheries and Oceans Canada has an ongoing project to model climate change vulnerabilities in some fisheries (Karen Hunter, pers. comm. July 2017), and other work is focused on modeling the impacts of warming river temperatures on juvenile salmon (K. Hunter, Fisheries and Oceans Canada, pers. comm. July 2017).

In southern BC, the impacts of warming freshwater and marine water temperatures have been observed, leading to declining productivity and diminished returns of Fraser River sockeye salmon (Walker and Sydneysmith 2008). Low returns of Fraser River sockeye salmon have been observed (e.g. returns in 2016 were the lowest on record) (Grant et al. 2017), and Fraser River sockeye were recently recommended for listing with the Species at Risk Act (Semeniuk 2017). While observations and field evidence are still limited, the interacting effects of ocean temperature and acidification is also of critical concern for many taxa (e.g. molluscs, corals, calcareous algae). Ocean acidification has affected calcifying organisms, especially larval survival in the oyster aquaculture industry (e.g. Strait of Georgia; Hunter et al. 2015; Ianson et al. 2016a, 2016b). Melting glaciers across BC may also be releasing historical pollutants into freshwater ecosystems, also affecting freshwater fish and downstream marine areas (Whitney

2017). Increasing rates of ocean acidification are likely to negatively affect calcifying organisms, many of which are important for aquaculture and traditional food resources, including molluscs, bivalves, sea urchins, and sea cucumbers (Haigh et al. 2015, Ianson et al. 2016b).

Further fisheries responses to climate change impacts will vary both regionally and by species (Walker & Sydneysmith 2008; Table 3.1). Species particularly vulnerable to increasing ocean temperatures include Pacific salmonids (Crozier et al. 2008, Healey 2011, Martins et al. 2011, Muñoz et al. 2014). For example, there is a 17-98% chance of 'catastrophic' loss of a Chinook salmon population by 2100, depending on the emissions scenario (Muñoz et al. 2014). Many fish species may expand their range northward (at an average rate of 10-18 km/decade), and in many cases their abundance may decline precipitously (Walker and Sydneysmith 2008, Ainsworth et al. 2011, Weatherdon et al. 2016c). These impacts are more severe at higher latitudes, so that the relative catch potential is projected to decline more in the North Coast, Haida Gwaii, and Central Coast than southern BC waters (Weatherdon et al. 2016c). Pelagic fisheries that may be especially affected by increasing sea surface temperature include Pacific herring, Pacific sardine, and Pacific salmon (Hunter and Wade 2015, Weatherdon et al. 2016c). Warming ocean surface temperatures will also likely decrease the habitable range of sessile species such as shellfish, which are less likely to be able to move northward at the rate of climate change. However, species' responses to climate change will also depend on species-specific adaptive capacity and sensitivity; assessing species specific responses to climate change is highly limited by the lack of data on species traits and potential adaptive responses (Jones and Cheung 2017).

Table 3.3: Summary of some climate change impacts on key fisheries target species in BC (Beamish 2008, Healey 2009, 2011, Chandler et al. 2016, Weatherdon et al. 2016c)

Fisheries species of interest	Ecological variable affected by climate change	Probable impacts
Sablefish (*Anoplopoma fimbria*)	Ocean temperature	May negatively affect egg, larval and juvenile survival. Declining ocean productivity may affect recruitment. Overall: Climate change over the next 50 years may not impact adult sablefish or long term population dynamics. Projected change in relative abundance of -9 to -11% by 2050.
Pacific herring (*Clupea pallasii*)	Ocean temperature	Herring ocean habitats will be affected. Predation from increasing populations of Pacific hake may affect herring populations Overall: Abundance is projected to decline by 32-49% by 2050.
Pacific hake (*Merluccius productus*)	Ocean temperature	Hake biomass may increase. More migration into northern range (BC waters) Overall: Abundance may increase.
Pacific halibut (*Hippoglossus stenolepis*)	Ocean temperature	Overall: May reduce recruitment. Projected change in relative abundance of -12 to -13% by 2050.
Pacific ocean perch (*Sebastes alutus*)	Ocean temperature	Overall: Recruitment may decline if Aleutian Lows decrease.
Pacific sardine (*Sardinops sagax*)	Ocean temperature Oceanographic conditions	Unlikely to impact or unknown Projected change in relative abundance of 33-44% by 2050.
Pacific cod (*Gadus macrocephalus*)	Ocean temperature	Likely to severely deplete populations by reducing or eliminating recruitment. Projected change in relative abundance of -13 to -35% by 2050.
Pink salmon (*Oncorhynchus gorbuscha*)	Ocean temperature River temperatures Oceanographic conditions	Overall: Abundance is likely to decline, particularly for southern populations. Projected change in relative abundance of -40 to -44% by 2050.
Sockeye salmon (*Oncorhynchus nerka*)	Ocean temperature River temperatures Oceanographic conditions	Mortality is likely to increase during all life stages when exposed to warm water temperatures. Overall: Abundance is very likely to decline, particularly for southern populations. Projected change in relative abundance of -10 to -36% by 2050.
Chum salmon (*Oncorhynchus keta*)	Ocean temperature River temperatures Oceanographic conditions	Mortality is likely to increase during all life stages, but uncertainty is high. Overall: Abundance is likely to decline, particularly in the southern portion of the coast. Projected decline in relative abundance of 10-12% by 2050.

The effects of ocean acidification on fisheries are largely unknown, including on the important salmon and Pacific halibut fisheries (Hunter et al. 2015; Haigh et al. 2015; Table 1). In tropical fish, ocean acidification affects behavior and results in increased mortality, but species responses in temperate regions are unknown (Haigh et al. 2015). Adult fish may be more tolerant of ocean acidification than early development stages, but there is limited research on life stage specific responses to pH for BC fishes specifically (Haigh et al. 2015). The effects of ocean acidification on shelled organisms, however, are much more understood (Cooley et al. 2009, Gazeau et al. 2013, Haigh et al. 2015, Ekstrom et al. 2015). Across BC, capture fisheries landings are either in decline or somewhat stable, while aquaculture continues to grow (with some exceptions due to recent ocean acidification issues, e.g. Strait of Georgia, (Linnitt 2014). Acidification will also affect fisheries through negative impacts on lower trophic level organisms (Lynn et al. 2013). Shellfish are likely to be affected across life stages, and this decline in economically important species (oysters, scallops, abalone, mussels) will affect the economies of coastal communities in the region. In the Northern Shelf Bioregion, aquaculture is of great interest to coastal communities and First Nations. Ocean acidification is likely to negatively affect shellfish aquaculture (Gazeau et al. 2013), and changes to oceanographic conditions including acidification are likely to affect finfish aquaculture as well (Haigh et al. 2015). The specific effects of ocean acidification on shelled molluscs varies by species, and a recent review suggested that acidification most negatively affects survival and shell growth (calcification), followed by respiration and clearance rates (Gazeau et al. 2013).

Ocean deoxygenation will affect commercial fish species by reducing high quality fish habitat. Declining oxygen levels across the Pacific Ocean will contribute to the general decline and potential collapse of sessile (immobile) marine species, or sediment-dwelling organisms, as well as any other species who are intolerant of low oxygen levels. Declining oxygen levels are likely to especially affect groundfish species, whose deep water habitat seems to already be decreasing by 2-3m per year as deoxygenated strata increase (Cummins and Haigh 2010). Declining oxygen levels, and increasing hypoxia, will also likely affect aquaculture operations for vulnerable species, such as Dungeness crab and spot prawns (Hunter and Wade 2015). Some hypoxia tolerant species (e.g. squid, jellyfish) may increase in abundance and/or distribution, potentially outcompeting less tolerant species (e.g. finfish) (Doney et al. 2012, Sweetman et al. 2017).

The associated impacts of sea level rise on land erosion and increased runoff is likely to directly affect nearshore species, especially filter feeders (shellfish) if water quality declines. Existing shellfish beds are likely to be affected, which will have implications for many species which depend upon the intertidal ecosystem for habitat and food, especially as juveniles (salmon, crab, eelgrass, algae, clams, humans) (Lynn et al. 2013). Spawning habitat for forage fish, and rearing habitats for invertebrates, could decrease or be lost due to erosion, subsidence, and submersion due to sea level rise (Hunter and Wade 2015). This may be particularly problematic for Pacific herring, as that species prefers coastal marine algal species for spawning substrate, habitats that may potentially be lost as sea levels rise (Hunter and Wade 2015).

Communities & Marine Infrastructure

Coastal First Nations and non-First Nations communities depend on the ocean and nearshore environments for economic, social, and cultural values. The coastal economy of British Columbia is largely based on the recreational tourism (33%), transport (29%), and seafood (12%) sectors (Suzuki 2015, Foundation 2017). These communities are at risk for land loss, damage to coastal infrastructure, and changes to resource availability, all of which will affect economic, social, and cultural historical values (Walker and Sydneysmith 2008). Especially for First Nations communities, access and availability of traditional foods has decreased as ecosystems have been exploited or converted to other uses, and the productivity of remaining intact ecosystems has been impacted by factors including pollution, management actions, or invasive species. An example of an observed impact of climate change on community food security is the changing timing of wild plant ripening and harvest (Turner and Clifton 2009, Lynn et al. 2013). Increasing ocean temperatures will impact coastal communities that are reliant on fisheries and other marine species for food security and economic activities. Many species that are currently important to coastal communities (First Nations and non-First Nations) are projected to shift northwards from their current species range (at rates of 10-18 km/decade) and also decline in relative abundance (up to ~40% decline depending on the species and climate scenario) (Weatherdon et al. 2016c). Ocean acidification will impact coastal communities that are directly dependent on calcareous organisms such as shellfish for food and income (Haigh et al. 2015). Decreased access to these traditional foods also has implications for human health and culture (CIER 2006).

Increasing storm surge events have been observed along the BC coast, along with an increasing frequency of 'king tide' events (extreme high tides). First Nations cultural sites may be impacted by rising sea levels, storm surge, and king tide events. For example, cultural sites near Prince Rupert and Metlakatla are experiencing erosion and loss of cultural artifacts (A. Paul, pers. comm., November 24, 2017). First Nations communities have observed changes to seasonality of local food gathering practices (Turner and Clifton 2009). Increasing sea levels may be affecting coastal built infrastructure (Walker et al. 2006, Sales 2009), and increasing frequency and intensity of storm events may affect marine infrastructure (at sea and near-shore; Walker & Sydneysmith 2008). Increasing intensity and frequency of storms is likely to increase inundation risk (flooding) and erosion risk to marine infrastructure, especially for low lying communities (Barnard et al. 2015). Properties along the coast also will experience increased risk of wave damage, which is associated with coastal erosion. It is highly likely that climate changes, especially during El Niño events, will lead to high coastal erosion across the entire eastern Pacific region (Barnard et al. 2015). Extreme weather events are expected to create disruptions to marine transportation lanes, potentially lead to wave and wind damage to infrastructure and utilities, and reduce access to critical services (Andrey and Palko 2017). Extreme precipitation events in particular may damage fixed coastal infrastructure such as airports (e.g. Sandspit Airport on Haida Gwaii), and ports (e.g. Port of Prince Rupert), and well as affect marine transportation lanes (Andrey and Palko 2017, Nyland and Nodelman 2017).

Most communities within the Northern Shelf Bioregion are highly dependent on marine infrastructure for transportation of goods and services, as support for the fishery and aquaculture industries, and for providing connections with other essential infrastructure and utilities such as roads, sewage systems, power and communications cables. The greatest threats to marine infrastructure in the Northern Shelf Bioregion are likely to be sea level rise and increasing extreme weather events. Sea level rise will not affect areas along the BC coast equally due to differences in vertical land movement (Warren and Lemmen 2014). Notable exceptions include the northeastern coast of Graham Island, Haida Gwaii, an area which is amongst Canada's most sensitive coastlines to climate change (Walker and Sydneysmith 2008).. In addition, groundwater quality could decline due to saltwater intrusion as sea levels rise (Walker and Sydneysmith

2008). Sea level rise already threatens coastal infrastructure, and the added risk of storm surge flooding increases the vulnerability of coastal infrastructure across the province (Lemmen et al. 2016, Nyland and Nodelman 2017).

Overall, climate-related impacts to marine infrastructure are likely to be high, as many communities in coastal BC already have infrastructure deficits that will require increased investment (Suzuki 2015, Foundation 2017). Future winter and spring sea surface height (SSH) levels, which can be due to the expansion of warming waters, are also projected to be consistently higher, which will further exacerbate the flooding impacts of sea level rise (Foreman et al. 2014). Large peak flows and storms can interrupt delivery of goods such as fuel and food to remote places. On the other hand, climate change may also offer some opportunities for the marine transportation sector: longer construction seasons and reduced winter maintenance could reduce costs and increase annual operating budgets. In the longer term, increased sea levels may mean that vessels with deeper draughts will be able to enter existing ports, perhaps an opportunity for marine shipping (Andrey and Palko 2017).

Other impacts on human communities include changing energy demands for heating, which have declined for buildings across BC, especially in northern BC, as average air temperatures have increased (BCME 2016). Increasing air temperatures mean that winter heating requirements are likely to continue to decrease across the province, while summer cooling requirements and costs will increase (BCME 2016). Most homes along the BC coast lack air conditioning, and it is likely that increasing air temperatures, especially during extremely high temperature events, will lead to greater incidence of heat stroke and potential mortality (Henderson et al. 2013). However, increasing air temperatures may attract more tourism for a longer summer season, which will have positive economic implications for coastal communities.

Climate change impacts are likely to continue to unevenly affect communities along the coast due to different exposures to those impacts. An added dynamic is that any climate related impact has a cumulative effect on non-climatic issues already affecting these communities, such as declining resource industries, economic or social restructuring, and ongoing land claims agreements in the case of First Nations. In general, rural and remote communities in BC tend to have a lower socio-economic index, indicative of economic hardship, education, health, and other risk factors. These trends suggest low adaptive capacity to manage large stressors like climate change (Suzuki 2015).

Adaptation Recommendations

Climate change impacts on ecosystems are diverse and cumulative. Managing for ecological resilience and adaptation to climate change will require integrative approaches that will also benefit ecological productivity and people. Across sectors, proactive approaches to direct adaptation, such as integrated vulnerability and risk assessments that incorporate climate projections, using effective guidelines for data interpretation by managers and decision-makers, could improve adaptive learning and decisions. Incorporating the results of climate change vulnerability and risk assessments into planning and adaptation efforts for the marine transportation sector could help to reduce the risks from climate impacts. Some planning strategies may limit human activities and development in areas vulnerable to sea level rise, protect coastal ecosystems that provide flooding and erosion protection (Klein et al. 2003), or help communities prepare to retreat from hazardous areas. In this section, we discuss general adaptation strategies that could be applied to the context of coastal BC, with specific examples relevant to the context when possible (Table 3.2).

Table 3.4: General actions for proactive adaptation to climate change recommended in the literature for conservation and management of fisheries and coastal areas.

Climate change impact	Regional impacts, by sector	Suggested Adaptation Actions and some Regional Research Gaps
Warming ocean temperatures	Fisheries: Shifting species ranges	Consider adaptive or dynamic ocean management (Maxwell et al. 2015b, Mills et al. 2015a) Fisheries: Adapt fisheries allocations after species abundance/distributions have changed (Morrison and Termini 2016) Adjust fishing practices or gears to new species or changing fishery openings (Morrison and Termini 2016)
Ocean acidification	Aquaculture: Declining productivity, larval survival, and reproductive capacity of calciferous organisms	Consider land-based saltwater flow-through aquaculture systems as an alternative to at-sea net pen aquaculture systems
Sea level rise	Ecosystems: Intensifying storms and warming oceans will affect coastal regions through erosion and degradation of shorelines and wetlands	Land-sea parks: Nearshore habitat protection can reduce loss and damage, and promote intact habitats that offer natural coastal defense, ultimately supporting human livelihoods and ecological recovery (Roberts et al. 2017)
Wind, waves, and storm events	Higher coastal erosion and flooding	Apply a precautionary approach: Use extreme recurrences for both winds and water levels in setting scenarios for mitigation and adaptation. Research gaps: Impacts of storm surges, especially on low lying regions. More modeling is needed to improve projections of storm events and impacts including changes in frequency, intensity, and direction of future extreme events.

In order to build adaptive capacity, it is important to build on existing programs and attributes. Governments and communities need to remain open to communication and collaboration in order to develop tools and resources to enable regional and sub-regional decision making for effective adaptation action. They need to adopt integrated and adaptive management practices that increase access to and distribution of resources, such as allocating roles and responsibilities, distribution of relief goods and provision of relief services; developing early warning and evacuation systems; creating education and awareness programs; and making arrangements for secure shelter and food, and access to health care, education, economic and social resources (Adger et al. 2005a, Pelling and High 2005, Green et al. 2006, Pelling et al. 2008, Klein et al. 2014). In addition, through adaptive management practices, higher sectoral, institutional, and stakeholder representation can be achieved in decision-making processes (Pelling and High 2005).

Ecosystems, Fisheries, and Aquaculture

Proactive management options aim to increase the resilience of a fishery, fishers, or ecosystem, based on predicting the effects of change. As fish distributions and abundances shift with climate change, fisheries will have to adjust by changing target species, fishing areas, fisheries openings, and processing locations (Pinsky and Mantua. 2014, Morrison and Termini 2016). Scenario planning exercises can help to identify management options to move the spatial extent of fisheries or add value to fishery products if landings are projected to decline. For instance, adjusting fisheries regulations and harvest licensing prior to species shifting their range could allow fishers to target new species and exotics as opportunities arise (Walker and Sydneysmith 2008, Johnson and Welch 2009, Morrison and Termini 2016). As the distribution of target species changes, it is also important to adapt fisheries infrastructure, and increase the flexibility of processing and supply chains for fisheries in order to reduce the impact on local fishing-based economies (Morrison and Termini 2016). Insuring fishers to provide stability in low income years and decrease ratcheting up and overfishing, analogous to crop insurance, could help to support fishing-based communities. Marine conservation tools such as MPAs can also be adapted to climate change by protecting both the current and future habitats of priority species, or by using dynamic reserves where the boundaries change over time (e.g. dynamic ocean management) (Hobday et al. 2013, Creighton et al. 2016). Fisheries management that promotes the adaptive capacity of target fish species and populations can also help to support fisheries adaptation. Specific examples include population-based fisheries management, which depends on understanding the genetic diversity of fish species and population distributions, to protect weak populations or populations on the edges of species distributions (Perry et al. 2010b, Pinsky and Fogarty 2012). Fisheries can also aim to protect fish population age structure to increase resilience to changing environmental conditions by using size limits, modifying fishing gear (e.g.

net size, and reducing post-release mortality of non-target individuals (Morrison and Termini 2016).

In some cases, reactive management approaches may be suitable or successful given that predictive modeling of future environmental conditions and associated fisheries may be uncertain (Johnson and Welch 2009, Miller et al. 2010, Morrison and Termini 2016). Reactive management approaches for fisheries and fishing-based communities include flexible and adaptive management systems that reward innovation, coordination, and collaboration between regions and management bodies. Increased monitoring and use of indicators can help to prepare managers and planners as conditions change and management needs shift, for example to manage dynamic spatial closures to adjust fishing activity based on real-time data on environmental conditions and fish distributions. Adjusting fisheries reference points to reflect changes in species or stock abundance depends on high quality monitoring data of fisheries and environmental variability but would be effective in supporting fisheries abundance as target species ranges and abundance shifts (Botsford et al. 2009, Morrison and Termini 2016, Young et al. 2019). If species distributions or abundances have already changed, adjusting fisheries allocations can support adaptive fisheries management, but this depends on high quality monitoring and modeling of species distributions and abundances and clearly defined allocation rules based on indicators of change (Young et al. 2019). Finally, adjusting fishing practices or fishing gear once fish communities change is also a reactive adaptation strategy. As fish species distributions and abundances change in response to climate impacts, fishers will adjust their fishing practices or gear to reduce interactions with non-target stocks or protected species. This strategy can have negative tradeoffs based on economic costs, and changes to social structure of communities (Johnson and Welch 2009, Young et al. 2019). It also depends on involving fishers early in management discussions (Yates 2014). First Nations may have fewer options for adaptation, especially given their dependence on marine resources for food security and cultural values (Walker and Sydneysmith 2008, Turner and Clifton 2009, Weatherdon et al. 2016c). In these cases, Indigenous knowledge may offer examples of adaptive strategies to enhance food security and thus community resilience in these systems. As an example, recent research on clam garden mariculture illuminated the historical importance of First Nations aquaculture on this coast (Pinkerton et al. 2014, Jackley et al. 2016). Learning from these traditional techniques may offer adaptive strategies for communities now and in the future.

Communities and Marine Infrastructure

Building adaptive capacity and resilience in remote communities is dependent on a variety of factors, including: 1) existing local and regional institutional capacity; 2) local socio-economic development; 3) infrastructure development and condition; and 4) local experience with extreme weather events and other environmental or socioeconomic stress (Pelling and High 2005, Butler et al. 2015). Other factors that can contribute include social networks and cohesion, income diversification, and self-reliance (Walker and Sydneysmith 2008, Whitney et al. 2017). However, current social and economic stressors are likely to reduce the capacity for remote communities to undertake or even consider climate change adaptation. Many coastal communities within the region already experience economic hardship and are limited in their capacity to undertake new initiatives or projects, even if the long-term benefits are relevant. Building on initiatives that are already in place to address environmental and economic changes and incorporating considerations of the impacts of climate change should be more effective for those communities (Walker and Sydneysmith 2008).

In BC, the provincial government has conducted vulnerability assessments for highway systems and continues to monitor sea level rise. The British Columbia Ministry of Transportation and Infrastructure is one of the first jurisdictions to require infrastructure design work for the ministry to include climate change implications. However, infrastructure operators in BC have primarily been responding reactively, rather than anticipating and proactively preparing for projected changes or impacts (Nyland and Nodelman 2017). This approach typically results in impacts being more costly or severe than if proactive adaptation actions had been taken. Some communities in BC have begun to take action to reduce the risk of sea level rise through investments in built infrastructure for shoreline protection as an adaptation measure (Lemmen et al. 2016). Further adaptation examples can be found in urban areas near the Fraser River floodplain, an area that is highly vulnerable to sea level rise due to low lying geology and dense population (Yumagulova and Vertinsky 2017). A recent analysis found that the costs of sea level related damage to on-shore built infrastructure would be higher in coastal BC than any other coastal region in Canada (Withey et al. 2016). Regional models of sea level rise and seasonal climatic variability patterns would improve the ability of coastal managers to predict flood hazards and associated risk factors for the region.

Adaptive capacity building at the community level should be supported by national, regional, and sub-regional institutions and policies. Regional and sub-regional management should understand how local communities and local institutions function and are managed in order to support local adaptation actions and community resilience to major change. A transparent knowledge- and data- based climate change adaptation process can enhance existing adaptive capacities (Pelling 1997, Pelling and High 2005, Berke et al. 2008, Miller et al. 2010, Murphy 2014). Particularly, by empowering local organizations (e.g. First Nations offices), socio-economic groups that may be already vulnerable can be included in decision-making processes (Green et al. 2006, Cutter et al. 2008). Especially for First Nations communities, past experiences with historical social, cultural or economic changes can offer lessons for adapting to climate change. Key attributes of social adaptive capacity such as social capital and community networks are often already evident in place-based communities and community ties. However, climate change impacts and adaptation needs to be seen as relevant for present-day local community planning and management (Walker and Sydneysmith 2008, Reid et al. 2014). While attributes of resilience may exist inherently, the impacts of climate change challenge long term adaptive capacities through rapidly rising sea levels and coastal storms, new impacts that threaten coastal communities who are dependent on vulnerable infrastructure and may lack essential relief services (Walker and Sydneysmith 2008). Additional financial support to cope with these increasing impacts, with land use planning that considers climate change, can improve the adaptive capacity of coastal communities.

To date, most climate change related adaptations documented in British Columbia have been reactive responses to unpredicted events, such as extreme forest fires or the mountain pine beetle epidemic (Parkins and MacKendrick 2007, Baynham and Stevens 2014, Government 2017). Planning for climate change seems to compete with a host of other priorities for the limited capacity of local and regional governance, as only one of the many stressors that affect the ecosystems, industries, and communities of British Columbia. For these reasons, cumulative impacts assessment (Halpern et al. 2008a, Ban et al. 2010, Clarke et al. 2015b, 2015a) may be highly applicable for regional (and/or sub-regional) adaptation planning. Proactive adaptation examples for coastal marine infrastructure include investments in early warning systems, particularly for storm surge related activities. Additional options include planning for emergency management, such as alternative routes for evacuations, identifying infrastructure under risk (roads, docks, rail routes, etc.), and programs to either mitigate impacts, or retreat and relocate if necessary.

Discussion

Effective climate change adaptation requires a strategic stepwise approach that includes identifying climate impacts and adaptation strategies. Here we presented an initial literature review and synthesis of current and potential future effects of climate change in the Northern Shelf Bioregion (NSB) that can help identifying adaptation actions. We aimed to: (1) to develop a baseline of understanding of the expected climate changes and associated impacts across coastal BC and the NSB over the coming decades, and (2) provide targeted adaptation strategies and actions that apply to specific sectors of interest to a marine planning process. We also described the process whereby we worked with a marine planning team to develop reporting on climate change impacts and provide strategic recommendations. Our research is a starting point for additional work on climate changes, vulnerability and risk assessments, and climate change adaptation efforts in the NSB.

The available data project that rising air temperatures and changing precipitation patterns will lead to warmer summers, milder winters with less snowpack, and drier summer months. Sea surface temperatures will likely continue to increase. Ocean acidification is likely to increase as carbon dioxide is absorbed by the ocean. More extreme weather events can be expected, with more storms, atmospheric river events, and coastal flooding. These impacts will likely have cumulative effects across the region. The climate changes – both observed and projected – outlined in our research are likely to result in multiple impacts to the key sectors in the NSB. Long-range planning and early, proactive adaptation efforts will be very important to accommodate predicted and also unanticipated impacts. This is also the baseline for communicating likely climate change impacts, as the initial report (with more detail than this manuscript) is being developed into an interactive web-based portal as a communications tool for sharing climate change impacts and adaptation recommendations with local and sub-regional managers and communities (to be available on the MaPP website; www.mappocean.org).

Our approach of synthesizing a range of climate change impacts relevant to particular sectors, with direction by a marine planning organization, is intended to be actionable within the NSB but also comparable to other regions undertaking similar processes. The level of cross-sectoral assessment that we provided is atypical; more often, climate change assessments focus on a particular sector or specific climate change impact (e.g. flood control for sea level rise; (Yumagulova and Vertinsky 2017). The social-ecological implications of climate change are not novel in and of themselves; the impacts of warming oceans, increasing air temperatures, ocean acidification, and sea level rise are well known (e.g. Foreman et al. 2014; Savo et al. 2017; Frölicher et al. 2018; Pinsky et al. 2019). By bringing together research on four key sectors of interest, in collaboration with a regional planning and plan implementation partnership, our research provides a more complete picture of the scale and scope of climate change impacts across social and ecological spheres within this region. We highlight the lack of regionally downscaled information available within this management scale (of the NSB), and in particular the lack of readily available information for ocean and coastal areas (vs. terrestrial). Improved climate projections and vulnerability and risk assessments would advance integrated decision-making and marine planning supporting healthy coastal communities and economies. In addition, proactive planning for adaptation based on these climate projections and associated risks would decrease the likely impacts on all sectors.

Uncertainties and knowledge gaps

There is still a great deal of uncertainty in global climate change projections for coastal regions, and the associated vulnerabilities, risks, and gaps in knowledge (IPCC 2014a, Cheung et al. 2016a, Oppenheimer et al. 2016). Part of this uncertainty is due to lack of or limited access to reliable and continuous data sources, with regions with large populations often drawing most of the resources for long-term observations. This uncertainty in global climate projections and knowledge of local vulnerabilities and risk is further amplified by regional variations in local climate which interact with climate change, such as the El Niño – Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) (IPCC 2014c, Okey et al. 2014b, Fleming et al. 2017). The other part of uncertainty is the unpredictability of humans and their actions. New technologies are developed every day, but the diffusion and adoption of these technologies is often relatively slow. Particular knowledge gaps both globally and in our study region include extreme weather events including storm surges (Nyland and Nodelman 2017, Sainsbury et al. 2018) and sea level rise (ACCASP 2017). These data will improve the ability of regions, communities, and sectors to manage infrastructure and development in a way that facilitates effective adaptation to the risks associated with sea level changes.

While there are likely to continue to be uncertainties and knowledge gaps, understanding vulnerability and risk is more meaningful in smaller scales as characteristics of each community, their socio-economic structure, coastal context, environmental conditions, and institutional capacity contributes to their local vulnerability. Statistical downscaling can be used to map coarse-scale global climate model outputs to finer scale (regional or local) detail, using the empirical relationship between observed climatology at the finer resolution, and coarse-scale model fields. Regional climate models can also produce local projections, which may better represent the local responses to climate change (Salathé et al. 2007). Therefore, for uncertainties surrounding vulnerability and risk, the main knowledge gap lies with the lack of existing studies investigating the local and regional exposure and sensitivity to various climate change impacts.

Next Steps and Conclusions

The partnership approach which we used to develop a focused review of climate change impacts on particular sectors – ecosystems, fisheries, communities, and marine infrastructure – was aimed at directing future efforts for climate change vulnerability assessment and adaptation planning. These types of efforts can help practitioners and policymakers to understand priority risks, and to identify and implement actions to increase adaptive capacity with a region or sector (Becker et al. 2018). Even more importantly, developing a dialogue around climate change adaptation will require engaging multiple sectors, governments, and society. For example, further south, the Cascadia Partner Forum is working to bring together both science and people to explore future scenarios, explore adaptation options, and broadly develop a shared adaptation strategy by focusing on specific priority issues within a transboundary region (Forum 2019). By developing the initial report into a public facing interactive web portal, we hope that the process, key outcomes, and recommendations from this work make a larger contribution than a report would alone. Investments in monitoring and research will also improve our understanding of climate change projections and impacts across the coastal region and at finer scales such as the MaPP sub-regions. Within BC, monitoring of climate change- related variables, such as sea surface temperature and salinity, is underway within the MaPP sub-regions carried out by Guardian programs, and there are plans to advance regional-level monitoring. Additional monitoring programs through the Hakai Institute (https://www.hakai.org/) and MEOPAR (http://meopar.ca/) are in progress to monitor key climate change indicators including ocean acidification.

Climate change is an inherently dynamic threat with both continuous and discrete impacts on the marine environment and is a threat that continues to grow as humans continue to contribute greenhouse gas emissions to the atmosphere. Above all, it is imperative that climate change mitigation – reducing greenhouse gas emissions – is prioritized in order to minimize the effects of climate change. When new global projections are available from the IPCC, and new regionally downscaled projections are available within BC and the Northern Shelf Bioregion, a more specific understanding of the multiple impacts of climate change may be possible. Vulnerability and risk assessments may be conducted to set regional priorities for further research and monitoring, to understand the economic costs of climate impacts, and to inform planning and implementation of adaptation actions. However, acting now on climate change adaptation is important to prepare for the predicted changes ahead, to increase resilience, and to ensure that economic, social, and cultural opportunities are still available to the communities of the Northern Shelf Bioregion. We emphasize that given the uncertainty that currently exists in climate change projections and associated impacts, adaptation actions should be chosen that support resilient social-ecological systems and are flexible to allow management and communities to evolve as climate change unfolds.

Chapter 4: Considering the effects of climate-induced species range shifts in marine protected area planning

Introduction

Marine ecosystems are at risk from the effects of climate change on marine species physiology, population and species diversity, and ecological interactions (Hoegh-Guldberg and Bruno 2010c, Doney et al. 2012). As ectotherms, fish and invertebrate species are especially vulnerable to ocean warming, as their body temperature is largely determined by the surrounding environment (Sunday et al. 2011b, Pinsky et al. 2019). Species ranges, an outcome of a species' potential and realized habitat niche, are driven by environmental conditions and moderated by biological interactions such as competition, predation, and long-term interactions among species (such as mutualism, commensalism, and parasitism, and others) (Ackerly et al. 2010). The distribution of many species and populations have already changed as species move in space, such as poleward or to deeper waters (marine species), higher altitudes (terrestrial species), and/or in time, as seasonality of species lifecycles shifts to earlier or later times of the year (Parmesan and Yohe 2003, Tingley and Beissinger 2009, Brown et al. 2015). Marine species range shifts are likely to continue under projected warming and other changes in ocean conditions, with consequences for ecosystems, economies, societies, and management (Cheung et al. 2015, Patrizzi and Dobrovolski 2018).

Climate change impacts on species ranges can change where marine protected areas (MPAs) should be situated (McLeod et al. 2009, Gerber et al. 2014), and can also disrupt connectivity between protected areas by changing dispersal pathways and species physiology (Álvarez-Romero et al. 2017). Well established conservation planning tools have been applied in response to climate change predictions, such as emphasizing MPA networks, increasing spatial connectivity, habitat heterogeneity, and improving management of the core and edges of reserves (Hannah et al. 2002). Designating new MPAs could augment the existing global network of MPAs and provide potential benefits of connectivity and redundancy for existing species ranges (Hannah 2008, Araújo 2009). However, adding more MPAs today might not provide future benefits to the specific species or habitats they were designed to protect because of climate change.

To date, others have proposed a range of methods to incorporate climate change into conservation planning (see reviews by Jones et al., 2016; Magris et al., 2014). Previous research has aimed to identify thermal refugia, or areas that may warm less rapidly and thus offer some protection from increasing temperatures (Ban et al. 2016, Lima et al. 2016). However, data limitations – especially in terms of understanding how protecting future habitat might increase species adaptive capacity to climate change – makes these methods challenging and uncertain (Groves et al. 2012, Magris et al. 2014). Others make a case for 'conserving the geophysical stage' whereby conversation plans are defined by geophysical indicators such as topography as surrogates for biodiversity features (Groves et al., 2012), an appropriate approach for some but not all species. Others still promote incorporating ecological processes in systematic conservation planning, such as river flows, flood patterns, or animal migration patterns (McCook et al. 2009, Groves et al. 2012, D'Aloia et al. 2017). Typically, conservation planning methods and data have remained temporally static; much more adaptive and proactive adaptation strategies are necessary (Groves et al. 2012). Another technique is to ensure protection of habitat distributions over time (temporal connectivity), which would allow species to track their climatic niche as habitats change with climate change (Hodgson et al. 2009). Ecological niche theory – the environmental conditions that an organism is dependent upon to survive and reproduce (Wiens et al. 2009) - can be applied to models in order to describe how species may respond to future environmental change by identifying habitats that are likely to be used in the future. These forecasts are called species distribution models (SDMs) or bioclimatic niche models (e.g. Cheung *et al.* 2015). These SDMs then be applied to a spatial decision support tool such as Marxan or Zonation to prioritize for those future habitat needs of species of interest (Magris *et al.* 2014; e.g. Alagador *et al.* 2014).

In this paper, we explored two ways that marine conservation planning could incorporate projected changes in species distributions. Firstly, we focused on the Northern Shelf Bioregion in B.C., Canada (Figure 4.1), where MPA network planning is actively being pursued jointly by federal, provincial, and First Nations government representatives (https://mpanetwork.ca/bcnorthernshelf/; Canadian Science Advisory Secretariat, 2017). The bioregion, approximately 100,000 square kilometres in size, is one of thirteen ecologically defined bioregions in Canada's Exclusive Economic Zone (Government of Canada 2011). There are 118 conservancies, ecological reserves, and parks with a marine component that are under the jurisdiction of the Provincial BC government through BC Parks (hereafter referred to as BC MPAs), and 6 federal MPAs within the bioregion not included in this analysis as we were focusing on provincial MPAs. We used outputs of an existing dynamic bioclimate models of shifting species distributions (Weatherdon et al. 2016c) to (1) determine where species ranges overlap within BC MPAs in the present and future (2060), and (2) as inputs into spatial prioritization software (Marxan) to identify priorities for MPAs to represent biodiversity now and into the future across the coast of BC (within the Exclusive Economic Zone, EEZ, and including the transboundary region of southeastern Alaska).

Methods

Application of climate change projections: Species presence in current MPAs

We used projections of species range shifts based on an earth system model (ESM) (Weatherdon et al. 2016c) that models the effects of warming and other changes in ocean conditions to project changing species presence/absence in MPAs under provincial jurisdiction both now (2016) and in the future (2060). Species distributions are projected using a dynamic bioclimate envelope model (DBEM) (Cheung et al. 2009). This model projects the effects of large-scale ecological change for 98 species of commercial interest and cultural value to coastal First Nations communities in BC (Weatherdon et al. 2016c). Projection of ocean conditions, including temperature, oxygen, salinity and net primary production were from the Geophysical Fluid Dynamic Laboratory ESM-2M (GFDL ESM2M). The spatial resolution of the model and the input data were harmonized at 0.5 ^{o} latitude x 0.5^{o} longitude (see Cheung et al., 2016 for details). These projections have been calculated for two of the Intergovernmental Panel on Climate Change (IPCC)'s Representative Concentration Pathways (RCPs), the low emissions 'strong mitigation' scenario RCP 2.6, and the high emissions 'no mitigation' RCP 8.5 scenario (IPCC 2014a). Based on current geopolitical norms and national agreements on emissions reduction targets, it seems unlikely that emissions will be reduced to mirror the RCP 2.6 scenario (Raftery et al. 2017). As such, for this practical portion of the paper we used only the 'no mitigation' RCP 8.5 data for the analysis of future change to marine species in MPAs in 2060. We then calculated the difference in species presence or absence and reported the number and specific species whose projected range changes in relation to BC MPAs. We also calculated modeled species presence/absence for current and future conditions within each of the 59 MPAs included in the analysis (see Supplementary Material for details). These MPAs were selected as they were a) of interest to the provincial BC Parks organization, and b) within the study area.

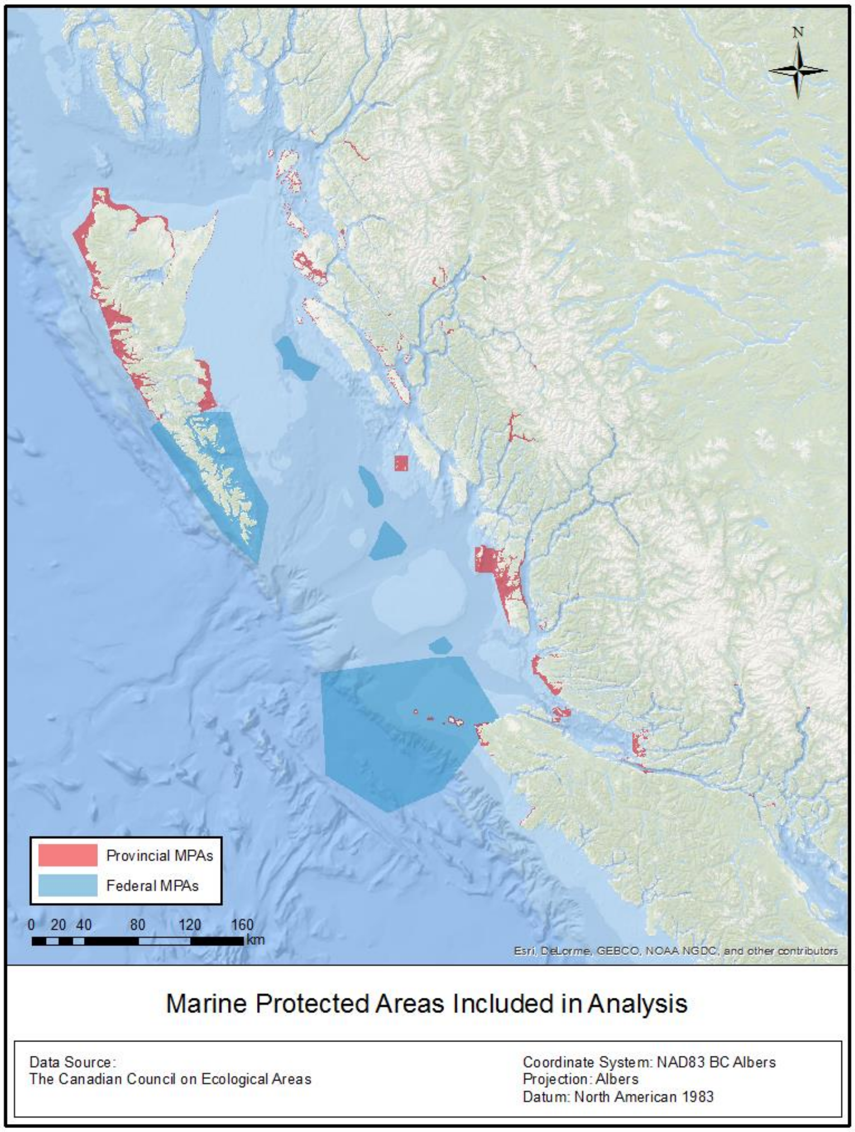


Figure 4.2: Geographical extent of the study area for the first analysis (MPAs under provincial jurisdiction, in red), the Northern Shelf Bioregion of coastal British Columbia, Canada, also showing 6 federal MPAs and 59 provincial parks and protected areas with a marine component (MPAs) included in analysis. Other MPAs were excluded because of data limitations.

Spatial priority areas for future range distributions

To identify priority areas for marine species, we used the conservation planning software Marxan (Ball, Possingham, & Watts, 2009). Marxan produces a 'best case' solution for an MPA network by comparing the conservation goals and costs for planning units (cells) across a given area of management, and suggests a network of areas that meet the given conservation objectives at the lowest costs over many iterative configurations (Ardron et al. 2010). Input features can be species distributions, subspecies, habitats, physical features, or anything that the user wishes to use as a target or surrogate target. The number of times that a planning unit is selected, termed the selection frequency, can be interpreted as a measure of the conservation value (Carwardine et al. 2009). Where planning units contain features that need to be included, planning units with lower cost are more likely to be included in the network solution.

Due to the constraints of the available species distribution projections (coarse resolution data) and knowing that species are shifting poleward rapidly with transboundary management consequences, we applied these projections across a large planning area including the southern coast of Alaska (139-114ºW, 45-60ºN). We used projections of species ranges and relative abundance data at both the low (RCP 2.6) and high (RCP 8.5) emissions scenario to illustrate the differential implications for marine conservation planning and the likelihood of persistence of present-day species distributions and abundance. Here, we used area as a cost as other costs (future fishing areas, for example) will change and those data were not available. We set a 10x higher cost for planning units that fell outside of the BC EEZ than planning units within the BC EEZ to reflect the goal of protecting species within BC, and to reflect the likely challenge of transboundary MPAs (Gissi et al. 2018). We ran two sets of scenarios: 1) Resistance: we set the species abundance targets for all scenarios at 30% of the baseline modeled relative abundance within the BC Exclusive Economic Zone (at 2016, RCP 2.6) to reflect the intent to maintain species of importance at that abundance within BC; 2) Resilience: we set the species abundance targets to 30% at each time step, allowing the target abundance values to shift with the changing relative abundance projections across the planning unit grid. We considered the following scenarios for all 98 species included in the dataset:

1) Baseline case: MPA priorities using modeled species distributions in 2016 (RCP 2.6);

2) MPA priorities in potential future climates: Modeled future distributions in 2030, 2040, 2050, 2060 at both 'high mitigation' and 'low mitigation' scenarios, RCP 2.6 and 8.5;
3) MPA priorities including 2016 and into the future to attempt to maintain protection of species through time (overlaying modeled distributions, including 2016 to 2030, 2040, 2050 at RCP 2.6).

Results:

Provincial MPA analysis

We examined how shifting species ranges may affect how well BC MPAs are protecting marine species within the next half-century. Model projections showed that marine species generally shift northward along the coast of BC. As species shift northwards, species will 'leave' some MPAs, while others 'enter' (Table 1) (see Supplementary Material for full results). The MPAs that lost the most species were largely at the southern extent of the region in the Broughton Archipelago (e.g. Octopus Islands Marine Park, 9 species lost) whereas some MPAs in the Central Coast (e.g. Kilbella Estuary Conservancy) may experience a turnover (sum of species gain and loss) in species with a slight overall gain (n = 1; Table 4.1). Most MPAs are likely to experience some species turnover as oceans warm and species ranges shift north following their thermal optima.

Ten species 'left' BC MPAs most often (3 MPAs), including fish (starry flounder, longspine thornyhead, China rockfish, longnose skate), bivalves (butter clam, Olympia oyster, Pacific geoduck, Pacific littleneck clam, and northern horse mussel), and invertebrates (red sea cucumber). The species that may 'enter' BC MPAs most often included Pacific sardine (10 MPAs), sidestriped shrimp (6 MPAs) and Manila clam (1 MPA).

Table 4.1: Top 5 BC MPAs that lose and gain the most marine species of interest by 2060 under RCP 8.5 relative to 2016.

Park name	Baseline presence of modeled species of interest within MPA (2016, RCP 2.6)	Species lost by 2060 within MPA (RCP 8.5)	Species gained by 2060 within MPA (RCP 8.5)	Difference
Octopus Islands Marine Park	67	26	17	-9
Rock Bay Marine Park	67	26	17	-9
Small Inlet Marine Park	67	26	17	-9
Kilbella Estuary Conservancy	62	22	23	+1
Dzawadi/Klinaklini Estuary Conservancy	21	19	19	0

Spatial prioritization analysis

Over time, protecting species using spatial prioritization through MPAs becomes more and more difficult, and more planning units are required in order for species to meet their target abundance (set at 30% of 2016 relative abundance within the BC EEZ). In order to reach conservation targets in mid-century and under the high emissions scenario (RCP 8.5), almost the entire coastline of BC and much of SE Alaska is required to conserve 30% of the current relative abundance of these marine species in BC (a 3.5x increase in priority planning units by 2050; Table 4.3). The distribution of priority planning units shifting north tracks the distributional shift of marine priority species (Figure 4.2). Between 2040 and 2050, a shift occurs whereby many more planning units (2.8x) may be needed in 2050 than 2040 (at RCP 8.5). By 2060, 19 species are unable to meet their targets (RCP 2.6) as their relative abundance is projected to decline; these species included rockfishes (yellowtail, yelloweye, yellowmouth, copper), lingcod, and bivalves (butter clam, Olympia oyster) (see Supplementary Material). At the high emissions scenario (RCP 8.5) the species seem to shift outside of the planning area grid by such a degree that less planning units are required within this spatial extent, highlighting the challenges of spatial planning over periods of rapid change.

Table 4.2: Summary of time steps by decade at the low and high emissions scenarios (RCP 2.6 and 8.5, respectively), showing key results of the best solution at each time step, the number of planning units selected, the cost, and the number of planning units that fall outside of the BC Exclusive Economic Zone (EEZ). All scenarios were run with a Species Penalty Factor (spf) of 4. Targets were set at 30% of the relative abundance of each species within the BC Exclusive Economic Zone at the 2016 RCP 2.6 scenario.

Year	RCP scenario	Best solution			
		# Species did not meet targets	# planning units selected	Cost	# of planning units outside BC EEZ
2016	2.6	0	43	43	0
2030	2.6	0	50	50	0
2030	8.5	0	56	56	0
2040	2.6	0	47	56	1
2040	8.5	0	52	52	0
2050	2.6	2	65	65	0
2050	8.5	0	142	574	51
2060	2.6	19	278	1403	142
2060	8.5	0	102	291	33
2016-2050 (inclusive, w/ years: 2016, 2030, 2040, 2050)	2.6	0	65	74	1

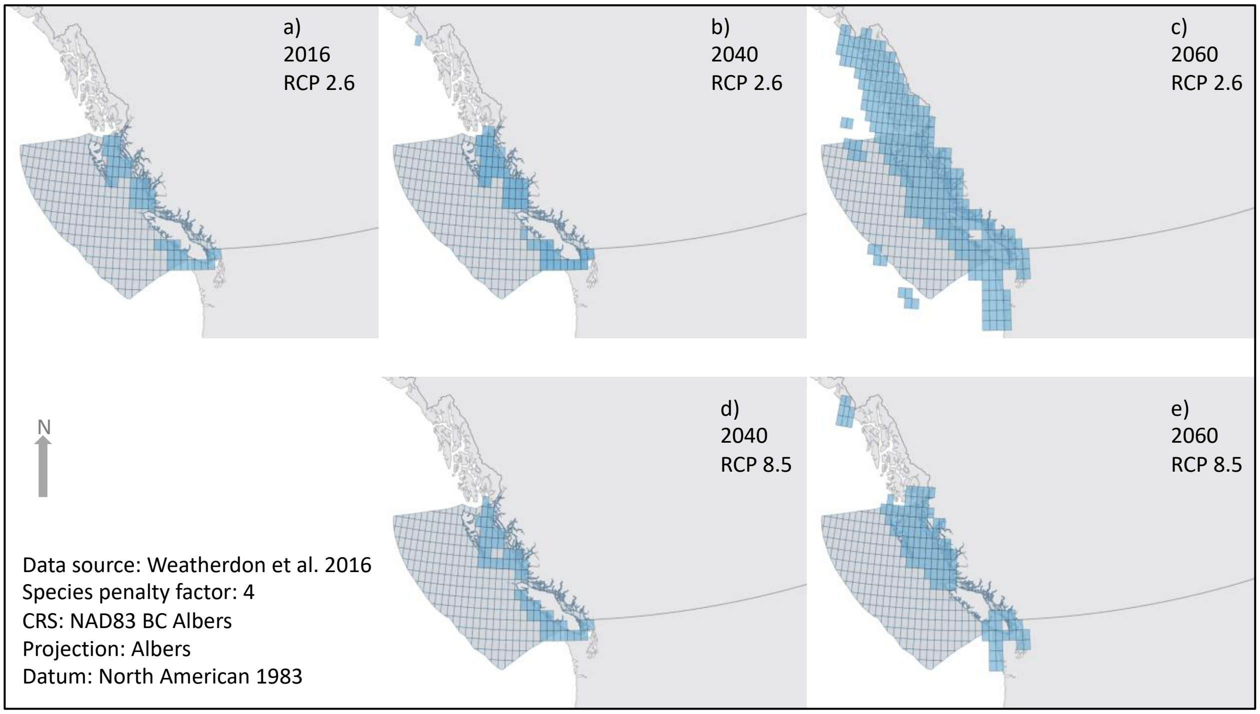


Figure 4.3: Increasing and poleward shifting selection of priority planning units in the best solution (blue) over decades from 2016 (a), 2040(b, d), 2060 (c, e) at RCP 2.6 and 8.5. Grey planning unit grid represents the BC Exclusive Economic Zone.

By allowing the target abundance file to shift along with the projected species ranges and relative abundance values across the entire planning unit grid (which included SE Alaska), the results were quite different (Table 4.3). In particular, the selected areas were not forced outside of the BC EEZ, and additional area was selected within provincial waters (see Supplementary Material). This highlights the necessity of transboundary conservation planning – in order to conserve a portion of the baseline relative abundance (as in Table 4.2), it will likely become necessary to develop protected areas management beyond the current Canadian jurisdiction.

Table 4.3: Summary of time steps by decade at the high and low emissions scenarios (RCP 2.6 and 8.5), showing key results of the best solution at each time step, the number of planning units selected, the cost, and the number of planning units that fall outside of the BC Exclusive Economic Zone (EEZ). All scenarios were run with a Species Penalty Factor (spf) of 4. Targets were set at 30% of the relative abundance of each species at each time and emissions scenario.

Year	RCP scenario	Best solution			
		# Species did not meet targets	# planning units selected	Cost	# of planning units outside BC EEZ
2016	2.6	0	55	55	0
2030	2.6	0	54	72	2
2030	8.5	0	176	176	0
2040	2.6	0	57	75	1
2040	8.5	0	175	184	1
2050	2.6	0	54	63	1
2050	8.5	0	185	185	0
2060	2.6	0	52	61	1
2060	8.5	0	54	63	1

Discussion

Considering climate change impacts is important for marine conservation planning, as climate changes will affect species' ranges, larval dispersal, population connectivity, and thus compromise the performance of marine protected areas and MPA networks (Álvarez-Romero et al. 2017). We present two approaches to incorporate existing climate change projections for species of cultural and economic importance within a coastal region. Marine protected areas and networks have largely lacked consideration for climate change (Bruno et al. 2018a, Sala and Giakoumi 2018). Rapidly accelerating climate impacts makes the Pacific region especially vulnerable to current and future impacts of global change (Okey et al. 2014c, Asch et al. 2017). In the first of such analyses in this region, we showed that BC MPAs are likely to protect less species by 2060 than they do currently, as species ranges are projected to shift polewards and 'leave' current MPAs. Similarly, spatial priority areas as selected by Marxan shifted north as species ranges shifted north, and more spatial priority areas were required for species to reach conservation targets. Knowing this, strategically adding new MPAs farther north as species ranges shift north would help to support conservation goals and objectives. It is also important to note that species abundance is also projected to decline during this time period (Weatherdon et al. 2016c), and as such it could become harder for the same number of MPAs to protect the same abundance of species. Strategically working with other adaptation policies, for example with fisheries management, and across jurisdictions could help to improve the effectiveness of MPAs in BC considering climate change.

Climate change confronts the assumptions of conventional spatial approaches to conservation (Lawler et al. 2015). In order to maintain 30% of the baseline (2016) relative abundance of species within BC waters, large amounts of the NE Pacific coast may require some type of spatial protection. Given the uncertainty inherent in projecting species range shifts, and the effects of ocean warming on dispersal capacity of many marine species, larger MPAs will also be necessary to maintain population recruitment and recolonization after discrete disturbances (Álvarez-Romero et al. 2017). However, given the rapid pace of change and the numerous biological outcomes that are not accounted for in these range shift projections (e.g. changing species interactions), area-based conservation effort is unlikely to be sufficient to support species persistence in the long term, and managers will also have other trade-offs to consider. While large MPAs may have high ecological value (Edgar et al. 2014), smaller MPAs may support human wellbeing (Ban et al. 2019), which is important in the coastal context. Overall, adaptation strategies and unconventional conservation approaches will be necessary as part of a portfolio response to support resilience to climate change (Millar et al. 2007, Galatowitsch et al. 2009). For example, temporally dynamic MPA design that releases redundant MPAs as species shift with climate change and adds new MPAs while species shift to new ranges have been proposed (Alagador *et al.* 2014). In addition, as climate change progresses, more controversial conservation actions may become necessary. When applied to address climate change threats, assisted migration is the human movement and release of organisms beyond their current climatic range to predicted future habitats, and is increasingly advocated and sometimes applied in both terrestrial and marine ecosystems as a conservation measure (Swan et al. 2015). Assisted migration (also termed translocations) may have particular merit in situations where dispersal rates are low, habitat fragmentation is high, or other factors have decreased a species dispersal potential in response to rapid change (Hannah 2008, Green et al. 2010). While the majority of marine translocations have to date been to achieve ecological restoration goals, with carefully designed guidelines and well-informed practitioners, as well as active monitoring, this tool could be applied to benefit globally threatened marine species as part of a suite of conservation measures (Swan et al. 2015, Lawler et al. 2015).

The data typically available for projecting specific climate impacts in the marine environment are limited and the implications on species distributions is available at a coarse resolution relative to the scale of marine parks in BC. By necessity, bioclimatic models incorporate a great deal of complexity and species data, but this adds uncertainty to the predictions of future species distributions (Ackerly et al. 2010). The projected species ranges data that we used as inputs into both analyses are highly uncertain due to uncertainties around emissions and geopolitics, and also around species responses to climate change (Heikkinen et al. 2006, Wiens et al. 2009, Cheung et al. 2016a, IPCC 2018). While anticipating future conditions for marine planning is plagued with uncertainty, that is no excuse for failing to plan for this increasing global threat. As well, more area-based conservation measures (including MPAs) are expected to be implemented in the coming years (MacKinnon et al. 2015). Using climate velocity, or the localized speed and direction of climate contours as they are predicted to shift as a proxy for how species' distributions will shift to track those thermal niches, could be a simpler method of incorporating climate effects on species movement than modeling species ranges (Loarie et al. 2009, Molinos et al. 2015), although these data are not yet available for this region. Climate velocities can also be combined with species traits where those data are available to build more robust predictions of species range shifts (Sunday et al. 2015). In addition, future research could incorporate the effects of MPAs on species population dynamics, and how conservation targets would be met through spatial planning (e.g. increasing species' abundance). For example, MPAs could buffer or offset the impacts of climate change on declining species abundance (Fox et al. 2012).

This research highlighted the implications of rapidly accelerating climate change, and additional policy considerations specific to this coastal region. Without transboundary MPAs or coordination across borders (Gissi et al. 2018), it is unlikely that managers will be able to conserve these culturally and economically important marine species in this region. The coarse resolution of the state of knowledge of species range shifts highlights challenges – and opportunities – for precautionary marine conservation planning but is at a very different resolution than the relatively small BC MPAs. These data and maps are useful for managers within BC to understand conservation potential of BC MPAs now and in the future, and to advocate for increased protection measures which can support the resilience of marine ecosystems in an increasingly uncertain climate. To add to this challenge, the MPAs included in the first analysis are managed by the provincial BC government, which has limited capacity to protect species or their habitats in the marine environment (Nowlan 2015). Temporally dynamic MPAs would also be a challenge in Canada, where it can take years or decades to establish an MPA (Jessen et al. 2017). In addition, large MPAs that are well managed and enforced are an opportunity for lasting conservation impact (Davies et al. 2017, Sala and Giakoumi 2018).

Our results highlight a scalar mismatch between current BC MPAs and future priority areas for marine species under climate change. These methods also represent an approach that could be applied in other regions where data are limited. The resolution of these data makes it difficult if not impossible to provide precise estimates of future change, particularly for the relatively small scale of MPAs. In the overlay analysis with BC MPAs, we used presence or absence of species rather than assign an arbitrary cut off in abundance projections; as such, these results should be taken as a cautious estimate of species presence now and in the future. In the Marxan analyses we used modeled relative abundance data available through SDMs (Weatherdon et al. 2016c). Relative abundance data are uncertain and vary according to the GCM model, and applying SDM abundance data to systematic conservation planning has several assumptions and potential associated errors (Tulloch et al. 2016). These include the assumption that count data that are used as inputs into SDMs reflect true species abundance; many of the areas where species may be present according to these data either now or in the future timestep may not be abundant enough to have a minimum viable population size (Tulloch et al. 2016). As well, these projections assume that species detectability is constant across species, whereas there are known irregularities in species-specific data availability for model inputs (Weatherdon et al. 2016c). These assumptions may lead to either omission or commission errors in conservation planning – and errors in prioritized areas may reflect sampling biases in the input data (Tulloch et al. 2016). As well, there is uncertainty in real-world future emissions which will affect biological outcomes, and adaptation strategies which could be developed at local, regional, or national scales to mitigate these impacts (Gattuso et al. 2015a, IPCC 2018).

Maintaining biological diversity for resilience to environmental change is a key policy issue for local and national governance in this era of accelerating climate change. The first analysis focuses largely on provincial MPAs. While the provincial government has little ability to effect change in fisheries management policy, as marine waters are within federal jurisdiction in Canada, provincial managers can encourage that areas be closed to resource use by the federal government. The key challenge is thus to understand and develop management approaches across jurisdictions that can support adaptation and response to global environmental change. While conservation planning cannot prevent the impacts of climate change, the effects can be predicted and integrated into conservation planning decisions. Depending on the adaptive capacity of species and populations, based on thermal tolerance estimates, some species will be adaptable to changing climates over some time, while others will disperse rapidly if possible in response to changing habitats and environmental conditions (Sunday et al. 2012). Managing for resilience through precautionary conservation planning would suggest that incorporating what we do know about climate change impacts, rather than focusing on what we don't, is a more appropriate management choice.

Chapter 5: Barriers and opportunities for social-ecological adaptation to climate change in coastal British Columbia

Introduction

Marine and coastal regions are dynamic social-ecological systems (SESs) that are threatened by climate change, among other anthropogenic stressors (Harley et al. 2006, Hoegh-Guldberg and Bruno 2010a, Poloczanska et al. 2016). The direct effects of climate change on the ocean, including increasing ocean temperatures, ocean acidification, rising sea levels, and changing storm cycles, also have indirect effects on coastal social and ecological systems (Connell and Russell 2010, Turner et al. 2010). Despite international agreements to reduce emissions, which are intended to stabilize atmospheric greenhouse gas (GHG) concentrations and mitigate the impacts of climate change (i.e. the Paris Agreement, 2016), emissions and associated impacts continue to increase (IPCC 2018). Due to the lag time of GHG concentrations and the warming of the ocean, climate-related changes will continue for the next several centuries no matter what mitigation activities occur (Solomon et al. 2009). This current stasis demands adaptation at all scales. At local and regional scales, adaptation planning can be an effective means of focusing action on climate change (Butler et al. 2015, Hine et al. 2016).

Adaptation actions are those that minimize the negative effects and/or maximize the potential benefits of climate change impacts, ultimately improving the social and/or ecological outcome (Smit & Wandel 2006, McClanahan et al. 2008; Eisenack & Stecker 2012; Bennett et al. 2014; Whitney et al. 2017). Adaptation actions can be categorized into engineering and infrastructure interventions; policy, governance and institutional changes; and conservation and restoration approaches (Jones et al. 2012, Biagini et al. 2014). To date, implemented adaptation actions have tended to be reactive, and have focused on managing ecosystems or social systems separately rather than through a linked social-ecological approach (Berrang-Ford et al. 2011). Theoretical research has aimed to frame and identify indicators of adaptive capacity, or the latent potential for a system, or group of individuals to adapt to change or take advantage of the opportunities (Yohe and Tol 2002, Brooks 2003, Mortreux and Barnett 2017). A recent review (Whitney et al. 2017) summarized various ecological, social, and social-ecological actions to proactively increase adaptive capacity through a social-ecological systems lens. Effective ecological adaptation actions included developing larger and more effective protected areas, improving connectivity among protected areas through network planning, and diminishing cumulative effects and non-climate stressors (e.g. resource extraction, pollution, infrastructure development; Hannah et al. 2002; Groves et al. 2012; Hagerman & Satterfield 2014). Social adaptation actions included developing alternative livelihoods, infrastructure improvements, or supporting programs which develop social capital such as supportive institutions and community organizations (Adger and Vincent 2005, Nelson et al. 2007, Adger et al. 2009). Since implementing adaptation actions will have impact across social-ecological spheres and scales, iterative monitoring and post-assessment evaluation of such actions is important for realizing benefits and preventing mal-adaptations (Cinner et al. 2018, Owusu-Daaku 2018).

Many scientists now argue that to manage the 'wicked' problem of climate change, innovative and potentially controversial adaptation actions that aim to support linked social-ecological adaptation are necessary (Araújo et al. 2011, Hobbs et al. 2011, Serrao-Neumann et al. 2013). For example, proactive conservation planning may help both ecological and human communities to adapt to climate change impacts (Roberts et al. 2017). Implementing dynamic protected areas versus traditional static protected areas (Maxwell et al. 2015b) may help maintain both ecosystems as well as provide social benefits to adjacent communities as species ranges change. Conservation triage decision-making (e.g. focusing on viable species or ecosystems rather than those which are threatened; Lawler, 2009; Wiens and Hobbs, 2015) has been proposed due to limitations of capacity, funding, and doubts about the long term efficacy of conventional actions including protected areas (Agardy et al. 2011, Gill et al. 2017, Bruno et al. 2018b). Examples of proactive and unconventional adaptation strategies include managing for novel ecosystems as species and habitats change (Hobbs et al. 2009, Doney et al. 2012, Corlett 2015), adaptive co-management, in particular for Indigenous peoples (Berkes et al. 2000, Folke et al. 2005, Armitage et al. 2009), and implementing adaptive fisheries management policies (Perry et al. 2010a, Pinsky and Mantua. 2014, Creighton et al. 2016, Ogier et al. 2016).

Implementing adaptation actions falls on people involved in the 'front lines' of planning and adaptation work, i.e. managers and planners who work for governance and management organizations across scales (hereafter "practitioners"). Incorporating climate change adaptation is now a component of work for practitioners in a wide range of backgrounds and careers (Cohen

2010, Eisenack and Stecker 2012). There has been extensive research on the views and perceptions of the average citizen, or ‘lay people’, on climate change impacts and adaptive strategies (Lowe et al. 2006, Knapp et al. 2014, Capstick et al. 2015, Lotze et al. 2018). The perspectives of academic researchers have also been explored at global and regional scales, specific to marine conservation (Rudd 2014), biodiversity conservation and protected areas (Rudd 2011), climate change adaptation and risk (Lowe and Lorenzoni 2007), and biodiversity conservation considering climate change (Hagerman and Satterfield 2013, 2014). Since effective responses to climate change impacts will depend on responses at the local scale (Adger 2001), understanding the perceptions of practitioners within a community of practice about the barriers and opportunities for adaptation can inform and direct better adaptation (Cinner et al. 2018). The perceptions of practitioners has been explored specific to adaptation to sea level rise (in coastal California; Moser and Luers, 2007; Tribbia and Moser, 2008), to terrestrial protected areas (in the Canadian province of Ontario; Lemieux and Scott, 2011), and within a US federal management institution (US Forest Service; Hagerman, 2016). What remains unclear are the actions to support adaptive capacity to climate change that would be most effective across multiple perspectives. Generalized theories of adaptive capacity are unlikely to apply across contexts, as adaptation actions, actors, and barriers to adaptation are diverse and complex (Eisenack and Stecker 2012). Thus, it is important to develop a broad understanding of adaptation actions that could contribute to implementing adaptation strategies. What are the pragmatic approaches derived from theoretical adaptive capacity research that could support regional adaptation, if any? What are the barriers and opportunities to effecting change in current conservation and fisheries management approaches?

The purpose of this research was to explore the perceptions of a diverse set of practitioners including Indigenous peoples in regard to climate change adaptation within a coastal region, filling an important gap in the literature. We conducted a survey and semi-structured interviews with technical staff, marine planners, and fisheries managers working in British Columbia (BC), Canada, to explore how they perceive (1) climate-related risks to marine social-ecological systems, (2) social and ecological adaptation actions derived from the resilience and adaptive capacity literature, and (3) barriers and opportunities for adaptation in this context.

Methods

Case study and context

Climate change is likely to have negative ecosystem effects in productive and biodiverse coastal and marine areas of BC (Okey et al. 2014b), and those impacts are already being observed (e.g. "warm blob" event, unusual algae blooms, warm water species arrivals; Chandler et al. 2017). However, many future impacts are poorly understood, especially at local scales and for social systems. Projections indicate that marine species will shift to higher latitudes and decline in abundance as ocean temperatures increase (Weatherdon et al. 2016c, Morley et al. 2018). These suggest forthcoming social inequality issues among the diverse Indigenous (First Nations in western Canada) and non-Indigenous human communities in the region as access to marine resources and associated socio-economic and cultural benefits change and decline (Weatherdon et al. 2016c). The coastal region of BC is an ideal place to investigate and describe the perspectives of experts working in planning and management in relation to climate change adaptation and marine planning because the effects of climate change are already being felt, and because there are active marine spatial planning and marine protected area processes underway.

There are several adaptation strategies being implemented in coastal and marine BC that at least partially or potentially relate to climate change. Canada has committed to international agreements under the Convention of Biological Diversity to protect 10% of national marine waters by 2020, and have made strong statements on climate change mitigation and adaptation strategies (Jessen et al. 2017, Lemieux et al. 2019). An ongoing marine protected area planning process is underway in the northern coastal portion of the province (MPANetwork 2019), which involves practitioners and decision makers across governance scales. Many of those involved are also part of the Marine Plan Partnership (MaPP 2019), a partnership between First Nations and Provincial governments to develop and support implementation of effective marine planning. Across the BC coast, First Nations are heavily involved in governance, management, and monitoring. The Guardian Watchmen in the traditional territories of 7 First Nations (Haida, Gitga'at, Metlakatla, Kitasoo/Xais Xais, Heiltsuk, Nuxalk, Wuikinuxv) work to monitor and steward their respective lands and waters and carry on traditional stewardship practices. Since 2005, independent Watchmen programs have been coordinated and supported through a collaboration with the regional Coastal Guardian Watchmen program (Initiative 2019).

Awareness and rhetoric on climate change mitigation and adaptation is increasing both across Canada (Lemmen et al. 2016) and in BC (Nyland and Nodelman 2017), in that both federal and provincial governments have made statements and set targets on limiting carbon emissions and establishing sector-specific and provincial adaptation pathways (Andrey and Palko 2017, Vogel et al. 2018). However, the successful consideration of climate change impacts into management, and the development of adaptation actions, will be strongly influenced by practitioners working on applying policy proclamations.

Survey methodology

We conducted a web-based survey of practitioners working in coastal BC. The survey framing and questions were developed over the preceding months with feedback and discussion with regional First Nations governance organizations (Central Coast Indigenous Resource Alliance, Coastal First Nations/Great Bear Initiative) to ensure that the results would be informative. This collaboration also serves to develop Indigenous perspectives in climate change adaptation planning, which have typically been underrepresented (Wolf et al. 2013, Ban et al. 2018, Sheremata 2018). Our selection criterion was people working in the coastal BC region with First Nations, Provincial, or Federal government organizations related to coastal and/or marine management and planning.

We obtained a regional sample of experts within this tight-knit community in two main ways: by email through existing relationships with First Nations organizations, and through emails to regional fisheries managers and marine planners accessed through the provincial government and federal Fisheries and Oceans Canada (Department of Fisheries and Oceans, hereafter DFO) website. Several participants also sent it on to others (snowball sampling). Invitation emails included a description of the project, information about planned follow-up work, and a link to the survey. Initial invitations were sent in early August 2017, and two reminder emails were sent prior to closing the survey in early November 2017 (following a modified Dillman schedule; Dillman 2000). While there is no one directory or listing of relevant practitioners, we estimate that there are ~40 people working in relevant jobs that met our selection criteria of managers and planners working on the coastal system of BC.

The survey questions focused on perceptions of observed climate impacts, actions on climate change adaptation so far, and opinions of set of proposed adaptation actions. The proposed adaptation actions were drawn from the literature within the field of applied conservation planning and social-ecological adaptation (Whitney et al. 2017; Table 5.1; for the complete survey, see Appendix D). As part of the survey, we included open-ended questions and opportunities for respondents to include context and commentary to enliven their quantitative responses and to allow for responses that we had not anticipated. We also provided the opportunity for individuals to express their willingness to participate in a follow-up telephone interview, which included questions related to adaptation actions, barriers and opportunities for adaptation within the experience of the participants and their work (Appendix D). Interviews were on average 30 minutes long (20-45 minutes).

Table 5.1: Focal adaptation actions under either social or ecological themes covered in the survey. See Appendix B for the full survey.

Adaptation action	Social, ecological, or social-ecological (SE)
Develop alternative livelihoods	Social
Support local adaptive governance	Social
Infrastructure improvements	Social
Create supportive institutions (e.g. community organizations)	Social
Strengthen social networks and community groups	Social
Support intergenerational knowledge sharing	Social
Consider adaptive policies for economic diversity and occupational	Social
mobility (help people to change careers)	
Encourage increased participation and engagement in management and	Social/SE
decision making	Social/SE
Invest in monitoring and early warning systems	
Prioritize conservation: develop better networks of marine protected areas	Ecological
Incorporate climate modelling into management and resource allocation	Ecological
decisions	Ecological
Manage for ecological resilience where possible	Ecological
Identify less degraded areas for 'hot spots' of ecological integrity, and	Ecological
protect them	Ecological
Identify more degraded areas as critically important, and protect them	Ecological/SE
Improve connectivity among habitats	Ecological/SE
Avoid over-exploitation in fisheries	
Take an ecosystem-based approach to fisheries management: manage for	Ecological/SE
population, species, and ecosystem diversity	
Develop regional forums to support ecological knowledge and sound	Ecological/SE
management practices	
Develop education and training opportunities for maintaining ecological	
integrity	

Analysis and thematic coding

The survey used both Likert and open-ended questions throughout. We synthesized relevance of each of the adaptation options by summing positive and negative responses along a five-point Likert scale using the 'likert' package in R (www.r-project.org). We coded open-ended survey and semi-structured interview responses to develop initial codes followed by focused coding to categorize common responses to specific questions (Charmaz 2006). In this method, categories of responses emerged from dominant or frequently observed themes rather than through preassigned categories (Thomas 2006). Participant responses to a single question often contained multiple themes. We calculated proportions of responses rather than respondents, and we reported sample sizes for individual questions as not all respondents replied to all questions. For example, if 6 respondents mentioned 10 themes, and 3 of the themes were about A, then the response proportion was 30%. We also identified additional codes relating to common issues that arose throughout the survey and interviews that were not specific to our initial questions. Given the small target population and hence sample size, the diversity of nuanced responses, and the limitations of our non-random sampling design (i.e. a focused target group, and snowball sampling), we did not use inferential statistics to generalize trends and results.

Results

Professional characteristics of respondents

A total of twenty-six individuals (65% estimated response rate) participated in the survey between August and November 2017 (Table 5.2; Appendix D). Sample sizes for different questions varied because not all respondents answered all questions (while 26 participated, 21 completed the entire survey). The high proportion of participants who self-reported as employed by First Nations governance we think reflects the current governance system and status of marine network planning on the northern BC coast, as well as interest in the topic. Eight survey participants also agreed to a semi-structured interview to elaborate on specific issues of interest and identify points of special concern (participant numbers are standardized to the survey participants; interviewed participants gave their consent and contact information to be interviewed).

Table 5.2: Participant professional characteristics: Years working in the field, roles in their organizations, and primary employer (First Nations, state government, other).

Professional characteristics	Total sample (n = 21 complete surveys)
Years working in this field	38% 1 to 5 years 29% 5 to 10 years 24% 11 to 15 years 10% 16 to 20 years
Professional role	43% Planning 33% Management 14% Policy or Research 10% Other/multiple roles
Primary employer	62% First Nations 19% Federal 14% Provincial 4% other/no response

Climate risks to marine social-ecological systems

Most participants (96%, 25 of 26 responses) noted direct or indirect observations of change that they attributed to climate change, including changing species and species' ranges (19%), warmer ocean temperatures (12%), changes in seasonality and other weather patterns (19%), and decreases in culturally important food resources (33%. e.g. *Porphyra* seaweed, salmon; Table 3). A few commented that they had observed increasing instances of warm water species, which they associated with the 'warm blob' phenomena of 2014-2016 (Bond et al. 2015).

Table 5.3: Observed climate impacts as shared by participants, in response to the question, "What type of climate related impacts have you seen or heard about?"

Change	Percentage of noted observations (total = 52)	Illustrative quote
Decreasing food resources	33%	*"Last year the seaweed (Pryopia) we harvest for food failed to grow in the normal abundance we were accustomed to. In living memory of our folks, the seaweed had never failed to grow like this before and I attribute this to the acidity associated with the [Warm] Blob."*
Changing species ranges	19%	*"More fish species moving north associated with the south like Mackerel and Hake"*
Changes in weather patterns	19%	*"Warmer and drier summers, warmer and lower rivers affecting salmon's health and ability to travel up river to spawn."*
Warmer ocean temperatures	12%	*"Warm water species that have never been seen here before, including pelagic tunicates and snails. Unprecedented die-off of canopy kelps."*
Diminishing glaciers and freshwater levels	10%	*"I have noted that the glacier fields on top of the mountains in the Valley are disappearing at an alarming rate. Smaller creeks and rivers too."*
Increasing storms and erosion	8%	*"Erosion to cultural and archaeological sites from storm events could be related to climate change as well."*

Importance and scale of adaptation actions

Almost all (96%, 23 of 24 responses) participants agreed that climate change adaptation is very important for regional planning (scored ≥8, 10-point scale). Most respondents identified national governance as the more effective scale of governance to implement adaptation actions (67% of responses, n=21), followed by provincial (58% of responses) and First Nations governance (42% of responses). The least effective scale for interventions were individual (75% of responses were negative) and community-based adaptation (62% of responses were negative). Participants shared a range of concerns about consequences of failing to adapt to climate change, from impacts to social systems (43% of 23 responses), economic impacts (27%), and others (Table 5.4). We also described the most common responses by respondents working with First Nations, Provincial, and Federal governments (See Appendix D, Figure 1).

Table 5.4: Responses to the question, "What do you see as the consequence(s) of failing to adapt?

Change	% (of 23 participants)	Illustrative quote
Social impacts (food security, culture, conflict, property)	43	*"The places most at risk to erosion and storm surge are the cultural sites, such as ancient village sites and petroglyph sites. For the First Nations on the coast, climate change can destroy thousands of years' worth of culturally significant resources and areas."*
Economic impacts (jobs, infrastructure)	27	*"Costs to coastal infrastructure, increased uncertainty and disruption to coastal economic activities with resultant impacts on jobs and livelihoods, conflict among different interests…"*
Ecological impacts	13	*"Loss of ecological functions, loss of economic opportunities for coastal communities, community instability"*
Social-ecological effects	10	*"Declines in biodiversity, ecosystem services and other values (e.g., loss of fisheries, impacts to cultural and spiritual values)"*
Management challenges	7	*"Poor choices with respect to locations of any new area-based conservation measures"*

Social and ecological adaptation actions

Most of the adaptation actions we asked about had more positive than negative responses, which may reflect the scarcity of climate change action in this region. Ecological actions were seen as more beneficial overall than social actions (Figure 5.1), and social actions had higher levels of uncertainty attributed to them (neutral or unsure responses). Some specific social adaptation actions arose as more important: for instance, participants indicated that investing in monitoring and early warning systems, and supporting local governance was most likely to be effective to support social adaptation (91% perceived a positive influence of these actions, of 21 responses), while avoiding fisheries overexploitation was the most important ecological adaptation action (91% of 21 responses). Incorporating climate change modelling into management was also perceived as important, perhaps reflecting the comment of one fisheries manager who noted: *"Fisheries work does not currently subscribe to any climate change related policy or decision-making mandates" (Participant #23, Province).*

Investing in community programs and supportive institutions was the social action most ambiguous or perceived to be less likely to affect change (52% perceived either action to be of benefit; Figure 5.1). Some of these potential actions are limited at this stage by uncertainty, as illustrated by this quote: *"Other than food security, infrastructure needs gaps are unknown. How do coastal communities prepare infrastructure for climate change?" (Participant #12, First Nations).* Interestingly, 35% of respondents did not support the idea of developing alternative livelihoods as an adaptation strategy. The least supported ecological actions were about regional forums that could support sound management practices or protecting more degraded habitats as critically important through marine planning (59%, n=21) (Figure 5.1).

		Positive influence (%)	Negative influence (%)	Neutral or unsure (%)
Social adaptation actions	Support local adaptive governance	91	0	9
	Invest in monitoring	91	9	0
	Infrastructure improvements	87	4	9
	Policies for occupational mobility	78	9	13
	Support intergenerational knowledge sharing	74	4	22
	Encourage increased participation in management	65	9	26
	Develop alternative livelihoods	52	35	13
	Create supportive institutions	52	13	35
	Strengthen social networks and community	52	4	43
Ecological adaptation actions	Avoid over-exploitation in fisheries	91	5	5
	Incorporate climate modelling into management	86	5	9
	Take an ecosystem-based approach to management	82	9	9
	Develop management education and training opportunities	82	5	14
	Improve connectivity among habitats	82	9	9
	Develop better networks of marine protected areas	77	5	18
	Manage for ecological resilience where possible	73	5	23
	Protect less degraded areas for 'hot spots'	73	14	14
	Develop regional forums to support management practices	59	5	36
	Protect more degraded areas as critically important	59	18	23

Figure 5.1: Practitioner perceptions of social (n=23, top half) and ecological (n=22, lower half) actions that may support adaptation to climate change. Responses are ranked by the percentage of perceived positive influence within social and ecological actions, respectively.

In an open-ended question to generate other adaptation ideas, nine participants suggested actions ranging from economic investment in local value-added industries, improvements in housing infrastructure, improvements in forestry and resource management (linked to concerns over increasing forest fires), and regional level communications and education related to climate change impacts. Three responses were actually mitigation actions related to consumer behavior (e.g. reducing transportation emissions and reducing carbon-intensive behaviors and improving water efficiency practices in communities). One participant suggested transplanting threatened species to better habitats (assisted migration).

Marine planning and adaptation

Most participants (77%, n= 22) thought that climate change was an important part of comprehensive marine planning (scored ≥8, 10-point scale), and that climate change projections should be included in the design of marine protected areas (MPAs) (68%, n=22, scored ≥8, 10-point scale). Participants had diverse opinions about how MPA planning and management should respond to projected changes in species ranges (Weatherdon et al. 2016a; Supplementary Material, Figure 2). Practitioners thought that MPA networks that protect both current and future habitats would be most effective to support adaptation to climate change (91% positive responses) and some respondents noted that current MPA networks (which are in the design phase, but not yet implemented) would be insufficient to protect species as climate change continues to affect species distributions (44% of responses). As one respondent noted*: "A combination of static and dynamic MPAs seems like a good approach but is a somewhat new concept for management and policy makers" (Participant #24, First Nations).*

Two additional themes emerged as important elements of incorporating climate change into marine planning. First, practitioners noted the need for further work at the community level to understand the support for different management actions across scales. As one respondent stated,

> *"Understanding the potential outcomes from different management actions and finding community support would help to implement climate change into MPA planning." (Participant #19)*

Second, the importance of co-management between provincial, federal, and First Nations governments as a component of regional management and conservation planning initiatives was reflected in some responses. As one participant noted:

> *"If MPAs were well designed to ensure habitat connectivity and collaboratively and adaptively managed with coastal Nations to support various types of uses rather than being no-go or no-take areas, they will have a better chance of supporting long-term climate adaptation." (Participant #1, Federal)*

Community adaptation planning

In the context of shifting species ranges (Weatherdon et al. 2016a), we asked about strategies and policies that could contribute to community adaptation. Participants indicated that communities will need further support from governance and management to prepare for new fisheries as species shift north (95% positive responses, n=21). Responses to whether communities should shift away from fisheries as an adaptive response were less positive (only 59% positive responses, n=21), a result mirrored in the negative perception of alternative livelihood development in the previous social adaptation actions question (Figure 5.1).

The communities within the remote coastal region of BC are small, isolated, and little is known about the impacts and strategies that may be useful in those contexts (but see Reid et al. 2014 for a description of a community based adaptation planning process for the Gitga'at Nation). Participants commented on the importance of the issue of food security throughout the open-ended component of the survey. In a follow up interview, one participant noted how these changes are already an issue along the coast:

> *"[The] food security piece is so important in this context. It's really hard. Last year… So much less pyropia [edible seaweed]…this year, it's been much better… What is the driver? What can we do to nurture the communities when they rely on certain food sources from year to year?' (Participant #12, First Nations).*

Barriers and opportunities for adaptation

Most (81%, n=21) practitioners acknowledged major knowledge gaps in their ability to incorporate climate change adaptation into marine planning. Over three-quarters (76%) identified gaps in policy action as a leading barrier to climate change adaptation, followed by gaps in management understanding, and then management action (Figure 5.2). Incorporating climate projections in marine planning also demands high quality data and management understanding. As one respondent noted; *"We have a poor understanding of the conditions species require or prefer in the current environment, let alone under future scenarios. We have little baseline data for most species as to where they occur now." (Participant #17, Federal)*

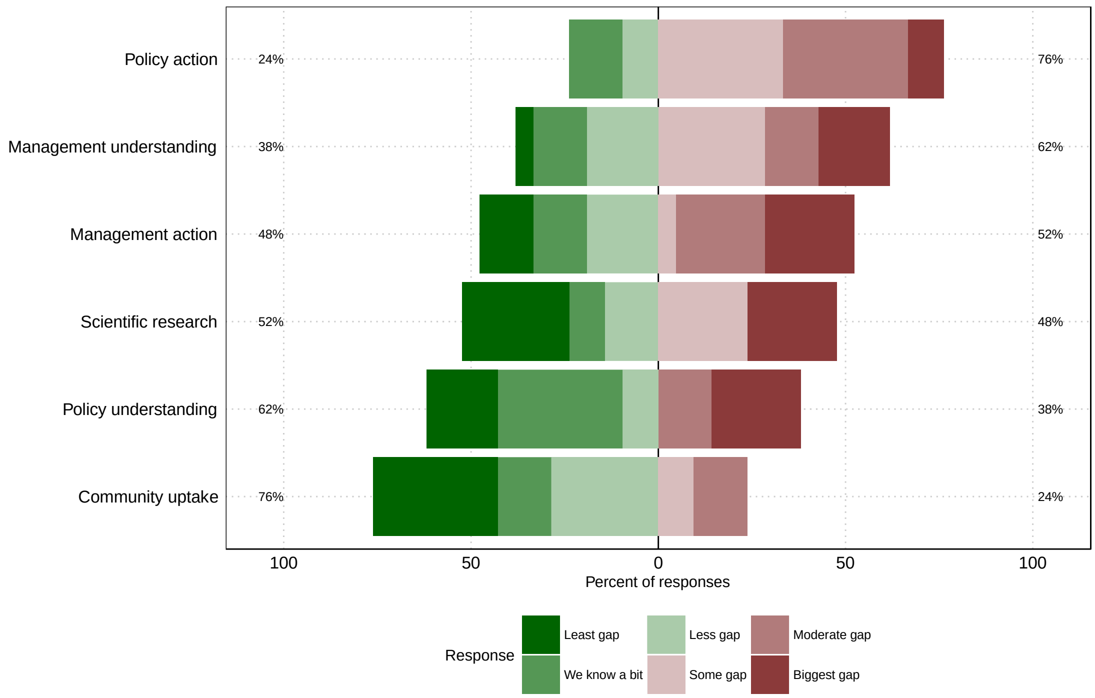


Figure 5.2: Perceived barriers to incorporating climate change into marine protected areas planning. Management action = application of policy action, i.e. implementation.

In the survey, most respondents (81%, n = 21) indicated that there were knowledge gaps that could be addressed to better incorporate climate change into their work. Many participants reported that they simply lack the resources to incorporate climate change adaptation in their current work plans (76% reported 5 or less on a 10-point scale, in response to "Do you feel that you have the resources available to successfully incorporate climate change into your work").

Four overarching implementation and knowledge gaps that emerged from the open-ended survey responses included a lack of government action (35% of 34 statements), uncertainty in scientific understanding and data availability (29%), communication and misinformation (26%), and capacity, including education and training (9%) (Table 5.5). Little is known about the vulnerabilities or adaptive capacity of communities along the coast of BC, the infrastructure needs gaps, and the preferences of communities as to social adaptation actions. Participants noted that ecological uncertainty arises from both a disconnect between scales of data collection and data sharing, and around science communication. Concerns were also raised about the lack of clear objectives on climate change adaptation planning, the lack of coordination on outreach and education among communities along the BC coast, and uncertainty about how to progress considering the lack of capacity. Several participants expressed frustration in regard to the current jurisdictional context, including the limited ability of First Nations to enforce fisheries closures or other major rules. The challenge of implementing adaptation planning also relates to funding, as one respondent noted: "*Province or country-wide adaptation will be very expensive and neither the provincial or federal governments are likely to be interested in footing the bill" (Participant #21, First Nations).*

Table 5.5: Barriers and opportunities: Responses to survey questions regarding the existing and perceived knowledge gaps in incorporating climate change adaptation into existing work on management and planning in BC's coastal region (top section), and opportunities for incorporating climate change adaptation in marine planning and management (lower section), in response to a question asking how practitioners suggest improving their ability to incorporate climate change adaptation into their work.

Implementation or knowledge gap (Barriers)	**Total statements (34)**	**% of responses**	**Illustrative quote**
Lack of action	12	35	
Climate change is not incorporated in management/planning	8	67	*"Fisheries work does not currently subscribe to any climate change related policy or decision-making mandates" – Participant 23, First Nations*
Lack of action related to government and policy	4	33	*"Government doesn't have to change, so they don't." Participant #12, First Nations* *"We're reacting to outside events and crises instead of proactively planning for climate change." – Participant #21, First Nations*
Scientific uncertainty	10	29	*"Over the region, there are big gaps on climate change indicators data. Who is analyzing the data? Who can communicate the results effectively? This is the gap… Regional data for climate indicators is missing." – Participant #12, First Nations*
Data sharing and communication challenges	9	26	*"Science needs [are relevant], but communication and coordination needs are more important. [We need to] increase public awareness – these are the changes, these are how we are going to adapt." –Participant #3, Province* *"… we could be developing policy guidance on how to account for trade-offs between management decisions for different fisheries in an ecosystem context. These would both be useful precursors to more explicitly considering climate change in fisheries management." – Participant 4, Federal* *"(The) gap in communication is the issue. Often, people know things are changing, but they don't know what to do, or how things might change… There's a real gap between knowledge and communities so that the knowledge is accessible." – Participant #12, First Nations*
Capacity	3	9	*"Incorporating climate change adaptation requires more capacity" - Participant #8, First Nations* *"Capacity is a huge problem, especially in First Nations communities… especially long-term capacity. Training and people need to stay involved. People get training and capacity in a moment in time, or people from outside the community come in, and then they move on. [This is a] Major challenge in implementing anything." – Participant #19, Province*

			"Guardian Watchmen don't have the capacity to enforce major rules or closures…There's not a lot of government support, [they] don't shift power to the Watchmen program but just apologize after the fact. Along the coast there's 11,000 km with Watchmen monitoring, while DFO made it up there twice. [We need to] shift power to the local community." – Participant #5, First Nations.
Suggested solutions (Opportunities)	**Total mentions (23)**	**% of responses**	**Illustrative quote**
Capacity	8	35	*"Increased capacity to develop and assess the application of 'dynamic' MPAs within a network" – Participant #24, First Nations*
Funding	6	26	*"Breaking through rigid practices and protocols that do not yet acknowledge climate change impacts as an important aspect in future scenario planning, for example." – Participant #1, no named affiliation* *"There is significant misinformation on behalf of many stakeholders - fishers, First Nations, marine shipping, regional districts and local governments…Federal and Provincial governments need more funding to be able to get the word out and execute their messaging and science efficiently." – Participant #13, Province*
Research	4	17	*"It would be helpful to be able to describe potential impacts to biodiversity, species, and people and how different management actions would influence the outcomes of climate change. Also, it would be good to understand how people perceive impacts and willingness to accept policies/management actions that may impact them today, especially given the uncertainty of how climate change will impact them in the future." – Participant 19, Province*
Policy action and leadership	3	13	*"Currently we lobby our leadership for the mandate to either a) just do it at our expense or b) to search out partners or funders" – Participant #11, First Nations*
Education	2	9	*"Educate ourselves on the effect climate change has on all concerned." – Participant #2, First Nations* *"It is tough to scientifically attribute climate change to observations we make on the ground. Training or guidance in gathering information on the ground would help me in my job." – Participant #11, First Nations*

In terms of opportunities, participants suggested a diversity of ways to better incorporate climate change adaptation into marine planning and management. Opportunities ranged from improving capacity (35%) and funding (26%), to better research (17%), policy action (13%), and education (9%) (Table 5.5). Determining how to support remote coastal communities through this time of change is a critical next step, and opportunity for future research. As one respondent noted, *"The uncertainty around the impacts of climate change will persist. (We need) tools and policy guidance that prepare management agencies, communities, and users to adjust in the face of that uncertainty" (Participant #4, Federal).*

Several participants also took the opportunity to suggest other tools or ideas, such as incorporating more traditional ecological knowledge (TEK): *"First Nations have adjusted in the past by transplanting species such as salmon, seaweed, clams to enhance and protect them, we need to consider how this could work under these situations." (Participant #2, First Nations)*

Discussion

This research is one of very few studies that we know of (e.g. Picketts et al. 2012a, 2012b) to survey practitioners' perceptions of climate change adaptation actions, particularly in the context of a coastal region. Focusing on British Columbia's coast, we described practitioners' perceptions of climate-related risks to the coastal social-ecological system, social and adaptation actions, and barriers and opportunities for adaptation. Most adaptation actions that we included were thought to be helpful, though practitioners particularly highlighted improving sustainable fisheries and supporting local governance and monitoring as most useful. Barriers to climate change adaptation are perceived obstacles that can be overcome, either through shifts in perspective, organization, institutions, resources, or creativity (Adger et al. 2009, Moser and Ekstrom 2010, Gifford 2011). The four key barriers and opportunities for climate change adaptation that emerged through both quantitative and qualitative results are comparable to those that others have noted when examining conservation and fisheries issues in the context of climate change adaptation: policies and political action for incorporating adaptation strategies (Mills et al. 2015b, Miller et al. 2017), uncertainty (Cvitanovic et al., 2014; Picketts et al., 2012a), capacity and funding (Picketts et al., 2012a; Vogel et al., 2018), and lack of effective communication and knowledge of adaptation strategies (Kettle and Dow 2014, Cvitanovic et al. 2015b, 2015a). These barriers fall within what Moser and Ekstrom (2010) categorize as the understanding and planning phases of the adaptation process. Adaptive capacity can be developed at multiple scales, but strategies for building adaptive capacity are likely to interact with other social and ecological dynamics in unpredictable ways. This is particularly important when considering the mechanisms that might enable opportunities for innovative adaptation actions (Sieber et al. 2018). Here we unpack the perceptions of adaptation actions, those key challenges, and discuss potential opportunities.

Adaptation actions and marine planning responses to climate risks

Our findings suggested that while protected areas and other conventional fisheries management actions are still promoted, practitioners are aware that they are not a panacea for effective adaptation to climate change in coastal marine systems. This shifting perspective to innovative and less conventional management strategies (e.g. assisted migration, conservation triage, dynamic protected areas) mirrors previous work at the global scale by Hagerman & Satterfield (2014) who found that previously novel conservation actions are sometimes becoming more acceptable, perhaps as the risks from climate change increase. Certainly, the practitioners in our study region consistently reported observing diverse impacts and risks from climate change; these observations are also reflected in previous work on perceptions of climatic changes along the BC coast (e.g. Reid et al., 2014; Turner and Clifton, 2009).

While we found support for most adaptation actions, there was stronger support for ecological than social adaptation actions, and more uncertainty around social adaptation actions. This may be due to trust in established, better understood actions, an ecologically-minded bias in adaptation planning, and a perception that conventional ecological management actions are less risky (Hagerman and Satterfield 2013). While there is research on what investments can improve peoples' capacity to adapt (Pelling 2011, Whitney et al. 2017, Cinner et al. 2018), there are very few examples of implemented social or social-ecological adaptations to changing ocean conditions (yet many examples of ecological adaptation projects) (Miller et al. 2017).

All of the adaptation actions that we considered in the survey would address climate change challenges, with various implications. Conventional management strategies were highly ranked by these participants, namely reducing fisheries over-exploitation and investing in monitoring efforts. In this region, fisheries abundance has declined precipitously in recent decades (Healey 2009, Walters et al. 2018) Projections of the impacts of shifting species ranges due to warming ocean temperatures suggest that this area will be further affected by declining abundance and access to commercially and culturally important species (Weatherdon et al. 2016c). Knowing this, it follows that addressing fisheries over-exploitation and implementing more precautionary fisheries policy would help to support social-ecological resilience to climate change. Similarly, developing monitoring efforts, in particular which incorporate early warning systems for climate impacts, would inform practitioners' choices for both fisheries and marine conservation management (Brown et al. 2018, Haasnoot et al. 2018). To enable better monitoring for changing environmental conditions at local and regional scales would require First Nations involvement; the framework for this is already in place through the Coastal Guardian Watchmen program and Coastal First Nations' Regional Monitoring System (Lagasse et al. 2014). Incorporating more community perspectives for monitoring environmental change (e.g. in Gitga'at territory; Thompson, 2018) and specific climate indicators (both social and ecological) through Indigenous perspectives should be encouraged (Leclerc et al. 2013, Tribal Adaptation Menu Team 2019).

Unconventional management actions, such as dynamic protected areas or assisted species migration, could also support social-ecological adaptation to climate change. While the political feasibility of unconventional actions such remains a question (Cvitanovic et al. 2014, Maxwell et al. 2014), our research highlights practitioners are interested in unconventional planning tools such as dynamic protected areas, and improving co-management processes to better support adaptation to climate change impacts. Considering that an MPA network planning process is currently underway in BC, it may be timely to incorporate adaptation actions into such plans. Many of the respondents to this survey also communicated a lack of integration of climate change impacts or adaptation strategies in conventional fisheries management. Similar to Ogier et al. (2016) in Australia, ecosystem-based management (EBM) and co-management arrangements were identified by practitioners to be an effective adaptation action. In the study region, co-management arrangements such as the Guardian Watchmen program and Marine Plan

Partnership are intended to facilitate Indigenous voices in place-based management. By supporting leadership and control over the planning process (Moser and Ekstrom 2010), such co-management structures may enable greater flexibility in fisheries and resource management than larger governance structures (Armitage et al. 2009, Cvitanovic et al. 2015b, Ogier et al. 2016). Ownership over the planning process can thus enable adaptive policy making for the uncertain dynamic impacts of climate change (Nagy et al. 2014).

The need for more flexible management actions was certainly reflected in this study, and should be developed further as the indirect effects of climate change on human communities are likely to appear more rapidly than expected (Mills et al. 2013). Other adaptive or flexible management structures that may facilitate fisheries adaptation includes quota transfer mechanisms that may allow fishers to target different species as species ranges shift, capacity adjustment schemes, and programs to help fishers transition or develop alternative livelihoods (McIlgorm et al. 2010, Pinsky and Mantua. 2014, Lindegren and Brander 2018). Surprisingly, developing alternative livelihoods as an adaptation strategy was not positively perceived by many respondents in this study, which could be due to the numerous other values associated with fishery livelihoods beyond monetary value (social, cultural values) (Young et al. 2016).

Barriers and opportunities: Capacity, uncertainty, and co-management

Broadly, the themes that emerged through this research highlight a need for a transformative change in governance in order to effectively tackle the diverse challenges of climate change (Pelling 2011). The barriers and opportunities that emerged from this work are systemic and persistent in the literature, and stem from governance paradigms that undermine the capacity of other actors and institutions to implement adaptations (Moser and Ekstrom 2010). Similar to previous work on community level adaptation in BC (Picketts et al., 2012a), our results suggest that the main barriers to climate change adaptation are political will and action, followed by management capacity and understanding. Policy action would mean leadership and support for the development of effective adaptation plans that incorporate information on climate impacts from multiple scales and lead to proactive management responses. This mirrors the findings of Miller et al. (2017), who found that the most common barriers to implementing climate change adaptations in marine systems worldwide have related to institutions, governance, and capacity.

Many people in our study highlighted the lack of capacity, both in terms of people and funding, which limits the ability to conduct research and inform the public. Funding cuts that affect government scientist capacity to anticipate and evaluate environmental change have been a challenge in Canada in recent years (Barnett and Wiber 2018), and a lack of funding for climate change adaptation in particular has been a problem in British Columbia (Picketts et al. 2012a). When climate change projects have focused on adaptation, they have tended to explore specific climate impacts at the scale of communities, such as sea level rise (Dolan and Walker 2006b, Abeysirigunawardena and Walker 2008), storm water management (Flood and Land 2011, Withey et al. 2016), or changes in forest composition (Spittlehouse 2008, Aitken et al. 2008). Down-scaling adaptation planning to the local and regional scale has been shown to reduce government costs of adaptation as well as result in higher acceptance of adaptation strategies (Pinkerton 1989). Recent Canadian federal funding awarded to expand the Indigenous Guardians Pilot Program (Canada 2019; November 2018) is an opportunity to develop adaptation planning in collaboration with existing co-management and planning processes.

We noted the issue of uncertainty, both in scientific understanding (i.e. data and projections, or epistemic uncertainty) and practitioner understanding (i.e. linguistic uncertainty; Regan et al., 2002) as a barrier to climate change adaptation action. A lack of understanding of how adaptation actions would work has been cited as a barrier to implementing adaptive management of MPAs in both California (Hopkins et al. 2016) and Australia (Cvitanovic et al. 2014). Another communication challenge that emerged was 'mis-information,' and ineffective communication of existing scientific knowledge on climate change. Similarly to Picketts et al. (2012a), we also noted several instances of confusion between mitigation activities and adaptation actions in the responses. While anecdotal, this supports the message from practitioners that adaptation planning is still in its infancy, or nonexistent in some cases, within the study region. Indeed, a recent analysis of 39 BC communities found that while 25/39 Official Community Plans do explicitly address climate change, their strengths lay in policies and goal-setting rather than implementation, and mitigation goals far outweigh adaptation goals or policies (Baynham and Stevens 2014). Burch (2010) noted that adaptation planning has rarely translated into effective action at the municipal scale, related to issues of uncertainty. In Australia, a study of planners' knowledge of climate change adaptation found that planners have limited and often questionable information sources, and no professional support for learning more (Lyth et al. 2007). Communicating future climate scenarios and adaptation actions in a simple matter for practitioners to understand and utilize can be a challenge (Picketts et al. 2012a). In Canada, national studies of climate impacts and adaptation have increased in recent years (e.g. Lemmen et al. 2016), but the commentary in our study suggests that those improvements are not yet having an effect at the regional scale.

Practitioners shared a perception that climate change adaptation actions would be most effectively implemented by national government. Yet, we noted many participants indicated a lack of trust, a lack of action, and a lack of support from national government agencies. This is a problematic conflict, considering that management actions require the social acceptance and buy-in of those affected in order to be successful (Mascia et al. 2003, Watson et al. 2015, 2018). This could be attributed to the study population (i.e. just 4 participants were employed by the federal government while 13 represented First Nations), and the issues of communication that arose throughout our survey. Engaging First Nations communities in adaptation planning and adaptive co-management would be an opportunity to develop diverse and effective adaptation actions that reflect local voices and needs, particularly as Indigenous well-being is intimately linked with ecological health (Donatuto et al. 2014b). For example, for the St'at'imc people in central British Columbia, the impacts of climate change on the availability of sockeye salmon will have dramatic effects on their culture, traditions, and sense of community (Jacob et al. 2010). As some of the practitioners in our study commented, traditional knowledge and Indigenous-led management tools could, and should, be engaged and supported in adaptation planning and decision making (Turner and Spalding 2013). Participatory values-based approaches to involve Indigenous communities, as exemplified by adaptation planning with the Gitga'at Nation in Hartley Bay (Reid et al. 2014), are particularly effective in this context.

Conclusions

Our findings suggest some future research directions to identify the most effective and socially relevant planning and management actions given a certain context. Climate change adaptation planning is more likely to be implemented if it is incorporated into existing management plans and processes, rather than developed as separate strategic documents (Smit and Wandel 2006, Füssel 2007). A much better integration of climate change adaptation research with fisheries management and conservation planning processes would be useful to develop the dialogue among fisheries managers, conservation planners, and adaptation practitioners. However, we hypothesize that as climate change impacts continue apace (IPCC 2018), and given that practitioners in our study noted the lack of climate change strategy in, for example, fisheries management, it may be important to also develop stand-alone adaptation plans at least at regional levels (Kates et al. 2012). In this region and more broadly, research is needed at the community level in regard to local perceptions of climate impacts, risks, and opportunities, as well as support for various adaptation approaches (e.g. Reid et al. 2014). Framing climate change impacts and adaptations in the values of local peoples, for example in the context of Inuit communities of Labrador (Wolf et al. 2013), can reduce the uncertainty of the impacts of adaptation actions, and increase the likelihood of implementing effective adaptation actions. In cases where Inuit views and values have not been explicitly addressed, adaptation efforts risk perpetuating inequality and effectively increasing vulnerability of local peoples (Cameron 2012, Reid 2019). Additional research on the social implications of climate change impacts and adaptation actions would improve our ability to understand how adaptation planning might support and incorporate Indigenous ways of knowing and ways of life (Turner and Clifton 2009, Turner and Spalding 2013, Artelle et al. 2018).

Supporting the capacity of Indigenous governance and management is likely to have multiple benefits that reflect effective adaptation actions, including avoiding over-exploitation, achieving effective ecosystem-based management, and enabling local monitoring for climate impacts. Since bottom-up approaches to management can be more efficient and therefore affordable, supporting a governance transformation to enable Indigenous management is likely to decrease funding needs as well, enabling the ability to act. We propose that one solution to this is reframing the focus on proactive adaptation actions at multiple scales given what we *do* know, rather than merely developing a better consensus on scientific uncertainty and knowledge gaps. While the ongoing and future realities of climate change on social and ecological systems may be unclear, the necessities of developing more conscientious and perhaps, more contentious proactive responses are evident.

Limitations

Our research had several limitations. The format of an electronic survey, even with the addition of semi-structured interviews with some recipients, may have limited our ability to capture nuance and details in the perspectives of practitioners. We simplified the descriptions of the adaptation actions and management responses as much as possible based on multiple iterations and comments through reviews of the survey and pilot testing. However, we acknowledge that due to the complexity of the topic, the description of some of the strategies may have been challenging or difficult to understand, even given the focused sample for this survey. Finally, while the community of practitioners who we targeted is relatively small in this area and we were able to hear the perspectives of many working across the region, our sample size was nonetheless limited to those who had the time and capacity to respond.

Chapter 6: "Like the plains people losing the buffalo": Perceptions of climate change impacts, fisheries management, and adaptation actions by Indigenous peoples in coastal British Columbia, Canada

Introduction

Indigenous place-based peoples are closely connected to natural systems and particularly sensitive to climate change impacts (Wildcat 2013, Green and Minchin 2014, Whyte 2016a). Worldwide, they are already experiencing rapid changes in weather patterns, species distributions, and phenology of their food resources (e.g. changing berry harvest time; Turner and Clifton 2009, Petheram et al. 2010, Savo et al. 2016, 2017). Vulnerability studies have informed planning and policy, yet often have perpetuated colonial biases by failing to acknowledge the Indigenous capacity for decision making at multiple scales (O'Brien et al. 2009, Cameron 2012, Mcleod et al. 2015). When unaware of this procedural vulnerability, research methods and process can limit participation or omit important context, further marginalizing Indigenous voices (Kelly and Adger 2000, Veland et al. 2013, McClanahan et al. 2015).

International agreements and policy tables have begun to recognize that Indigenous perspectives, knowledge and rights are important to the development of adaptation pathways (Shawoo & Thornton 2019). Post-colonial discourse has started to shift the framing of Indigenous peoples as victims of colonization who are vulnerable to environmental change to adaptable peoples occupying geographies of hope (Coombes et al. 2012, Whyte 2013). Efforts to include Indigenous voices in adaptation and mitigation strategies are essential, but social and institutional barriers that reflect the legacy of settler colonialism may limit such efforts (Cameron 2012, Coombes et al. 2012, Whyte 2016a, 2016b). This concern is mirrored in the disregard of Indigenous voices, values, and worldviews in climate research, policy, and decision making at all scales (Petrasek MacDonald et al. 2013, Ford et al. 2016, Maldonado et al. 2016).

The United Nations, through the U.N. Declaration on the Rights of Indigenous Peoples (UNDRIP), has provided an international framework for applying existing human rights standards to all Indigenous peoples (United Nations General Assembly 2007, Kavanagh et al.

2018). At the international policy level, a platform for including Indigenous peoples within the UNFCCC (United Nations Framework Convention on Climate Change) process for implementing international climate action was formalized in 2017. Indigenous peoples, however, are still unable to vote at International climate negotiations (Shawoo and Thornton 2019). At national and regional scales, Indigenous governance has also had little influence to date on climate policies (Adams et al. 2014), perpetuating a colonial history of marginalization (Brugnach et al. 2017). It has been suggested that this loss of political influence, along with reduced access to traditional resources following colonization, has diminished the overall resilience of Indigenous peoples (Turner et al. 2008).

The orientation of Indigenous knowledge systems – as collective, place-based, connected bodies of knowledge, practice and belief developed over generations - paradigmatically differs from ‘western’ worldviews (Berkes 2012, Simpson 2014). Indigenous resource management systems are values based (Simpson 2014, Artelle et al. 2018), connecting ecosystems with human social histories through a paradigm of reciprocity and relationship between humans and nature (Cruikshank 2012, Sheremata 2018). Indigenous, traditional, and local ecological knowledge (IK, TEK and LEK) are increasingly recognized as ecological data that are complementary to ‘western’ science with applications to fisheries management (Drew 2005, Eckert et al. 2017), ecological monitoring, and climate change adaptation research (Leclerc et al. 2013, Petrasek MacDonald et al. 2013, Ristroph 2017, Chisholm Hatfield et al. 2018). In particular, place-based peoples with interconnected long-term perspectives can provide insights into gradual and often subtle environmental change that scientific data may fail to capture (Adams et al. 2014).

Due to their long-term place-based knowledge, Indigenous communities may have intrinsic capacity to respond to novel environmental changes by adapting their way of life accordingly. Certainly, Indigenous peoples have experienced and persisted through environmental change over long time scales and developed cultural practices and knowledge related to invasive species (Reo et al. 2017), floods (Brown and Brown 2009b, Horne 2012), and changes in weather patterns (Cunsolo Willox et al. 2012, Turner and Spalding 2013). In the Canadian Arctic, some Inuit engaged in climate change adaptation planning “do not see themselves as victims of climate change... Rather, they see themselves as part of the solution” (Berkes 2012:189). Experiential learning of IK has persevered in many First Nations in British Columbia (BC), Canada, through cultural revitalization programs (e.g. ReDiscovery youth camps, http://rediscovery.org/; SEAS program, http://www.emergingstewards.org/seas-program) which provide hopeful examples of how Indigenous peoples may reclaim self-determination and lead their own adaptation pathways (Turner and Spalding 2013, Reid 2019). First Nations are also adopting modern scientific research, often through partnerships with academic institutions or by working together (e.g. the Central Coast Indigenous Resource Alliance, CCIRA, a collaborative effort for governance, stewardship, and research among four First Nations) (Frid et al. 2016, Ban et al. 2018, Lee et al. 2018, Salomon et al. 2018).

Still, due to their dependence on seasonally available resources, small populations, and geographical isolation (Donatuto et al. 2014b), Indigenous communities may be among those most affected by global climate change. The cumulative effects of colonial governance, including loss of culture and limited economic opportunities in present-day reserve lands, can exacerbate the problem (Parks and Roberts 2006, Turner et al. 2008, Whyte 2014, Savo et al. 2016). Climate change threatens not only Indigenous food security and economies (Savo et al. 2017) but also Indigenous culture, identity (Chisholm Hatfield et al. 2018), and health (Donatuto et al. 2014b, Durkalec et al. 2015). Adaptation strategies must therefore include Indigenous voices to be legitimate and effective (Berkes and Jolly 2001, Berkes and Turner 2006, Reid et al. 2014, Ban et al. 2018). Supporting communities to engage in adaptive management and governance (Pelling and High 2005, Folke et al. 2005, Mamauag et al. 2013) serves to value local peoples' perspectives in adaptation planning (Adger 2001). In turn, connecting diverse perspectives and knowledge systems can facilitate better governance responses (Rathwell et al. 2015).

Adaptation refers to actions that can be carried out in social-ecological systems to reduce an impact or to take advantage of new opportunities that develop from observed or anticipated change (Smit and Wandel 2006). Adaptive capacity is a relative measure of the latent potential to adapt; it reflects the ability of a population or group to adapt to a certain threat (Carpenter et al. 2001, Whitney et al. 2017). Adaptation planning must consider the consequences people experience as a result of an adaptation action, which may affect individuals, households, communities, or regions positively or negatively and be difficult to predict (Whyte 2014). For example, people at local scales often have limitations (perceived or actual) in their capacity or authority to influence broader policies. Their values, beliefs, and worldviews also influence their perceptions of change and future outcomes (O'Brien and Wolf 2010, Wolf et al. 2013). To identify and prioritize the adaptive actions that are most relevant to a community, therefore, it is important to explore perceptions from individuals with lived experience (Marshall and Marshall 2007, Petheram et al. 2010, Wolf and Moser 2011).

The purpose of our research was to explore and understand the perceptions of a subset of coastal First Nations regarding environmental change, climate change, and climate change adaptation strategies, and to recommend adaptation options. We interviewed individuals within four Indigenous peoples (First Nations) on the central coast of what is now known as British Columbia (BC), Canada. The interview themes included social and ecological adaptation actions (adapted from Whitney et al. 2017), barriers, opportunities, and knowledge gaps. Our results are intended to inform adaptation strategies and highlight ways in which climate change adaptation can align with governance transformation to promote reconciliation with Indigenous peoples.

Social-ecological background

Coastal Indigenous peoples of the Central Coast of British Columbia, Canada

This research is a partnership with Central Coast First Nations of B.C. (Heiltsuk, Kitasoo/Xai-xais, Nuxalk, and Wuikinuxv Nations), who live in communities ranging in population from approximately 80-1500 people (Figure 6.1), and the University of Victoria. These First Nations each have their own dialect as part of three discrete language families (Gessner et al. 2014), which reflects their diverse culture. Despite impacts from colonization and access to store-bought foods, these First Nations continue to depend upon the land and ocean for food security, trade, and cultural connection, harvesting and preserving food resources that include herring, salmon, halibut, herring eggs, eulachon, seaweed, and many others (Turner 2003, White 2011, Jackley et al. 2016, Gauvreau et al. 2017). Daily life and culture—including language, ceremony, and stories—has revolved around the harvesting of these resources for thousands of years and continues to do so in a modern context (Berkes 2012, Turner 2014).

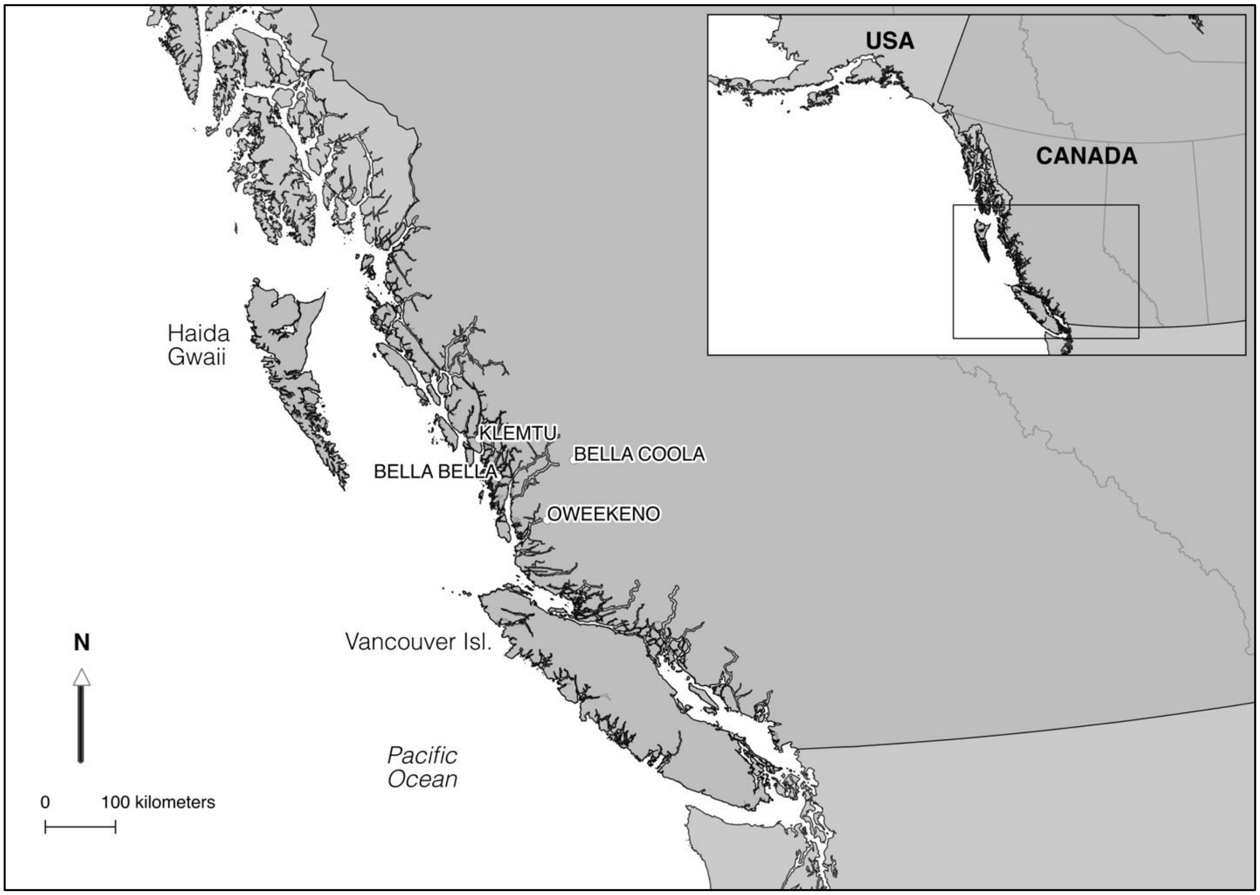


Figure 6.4: The study region encompassing the four First Nations we worked with: Heiltsuk (Bella Bella), Kitasoo/Xai'xais (Klemtu), Nuxalk (Bella Coola), and Wuikinuxv (Oweekeno). Names within parentheses are the present day main communities of each Nation.

Overall, marine governance and management of marine resources along the BC coast has been shaped by colonization over the past century (Jones et al. 2004, Ommer 2007). Prior to colonization, BC First Nations managed both terrestrial and marine areas using well developed methods of stewardship that were embodied in social, cultural, and economic practices (Trosper 2003, Johnsen 2009). At the turn of the century, growing settler populations and their open access resource extraction practices began to override Indigenous laws and practices for resource management. The criminalization of traditional Indigenous management practices (Jones et al. 2004) co-occurred with the rise of commercial fisheries and the ensuing and precipitous declines of marine species (Ommer 2007, Berkes 2015), including cultural keystones such as salmon (Garibaldi and Turner 2004) and eulachon (Hilland 2013). Systematic privatization of fishing rights and access, combined with federal decision making and enforcement, diminished access to local resources for many coastal Indigenous peoples (Ommer 2007, Turner et al. 2008, Healey

2009, Berkes 2015). These policies indirectly affected the well-being of First Nations, with lasting impacts on individual and community knowledge, stewardship practices, and culture (Truth and Reconciliation Commission of Canada 2015).

Current federal management of marine fisheries is under the jurisdiction of Fisheries and Oceans Canada (DFO). This federal agency also is responsible for scientific monitoring and research and for determining allocation for capture fisheries and aquaculture operations. Meanwhile, Central Coast First Nations have maintained their own Indigenous laws and management practices, and assert jurisdiction by actively managing fisheries, informed by living in place for thousands of years (Brown and Brown 2009b, Johnsen 2009, Hilland 2013, Kirby and Kotaska 2018).

Climate change impacts

Along the B.C. coast, ocean temperatures are warming, and inshore waters are becoming less oxygenated, less saline and more acidic (Chandler et al. 2017). These changing ocean conditions are contributing to northward shifts in the distribution of species attempting to track their ecological niche (Ainsworth et al. 2011, Okey et al. 2014b, Cheung et al. 2015). Marine fish and invertebrates important to First Nations are projected to decline by up to 64% by 2050 under the IPCC high emissions scenario (Representative Concentration Pathway (RCP) 8.5 (Weatherdon et al. 2016c). For example, the five anadromous salmon species, which collectively are a staple for First Nations, are projected to decline by 12.1 – 46.8% by 2050 under RCP 8.5 (Weatherdon et al. 2016c), which would severely reduce First Nations access to essential nutrients (Marushka et al. 2018). A systematic summary of climate change impacts on ecosystems, human communities, and fisheries, with recommendations for adaptation actions for the northern coast of BC was recently completed (Chapter 3; Whitney and Conger 2019).

Methods

Interview methodology

We carried out individual semi-structured interviews with community members. The interview guide and adaptation actions were developed among the author team with feedback from CCIRA and partner First Nations. Our interview questions also were informed by a recent review of recommended actions for increasing adaptive capacity in coastal communities (Whitney et al. 2017). The semi-structured interviews allowed for spontaneous dialogue and insights that might not emerge during a more structured approach (Huntington 2000), and drew on the participant's values and perceptions of climate impacts on those values (Wolf et al. 2013). We framed climate change impacts as changes in marine species distributions and availability and, using dialogue and printed index cards, asked participants for their preferences on a set of proposed (and hypothetical) social and ecological adaptation actions. Additional questions explored perceived barriers, opportunities, and knowledge gaps for developing effective adaptation strategies (see Appendix A for the complete interview guide). During the interview, we also discussed projections impacts of climate change on marine species and food security (Weatherdon et al. 2016) as related to adaptation responses.

In one community (Bella Bella, Heiltsuk First Nation), we held a meeting with the hereditary Chiefs to introduce the project and to identify study participants. Elsewhere, we worked with stewardship staff and a local community liaison to identify participants; some participants were identified through snowball sampling (suggested by other interviewees). We aimed to interview people across demographics; both men and women were included as they may have different roles and experience within the community in terms of food gathering, harvesting, and management (stewardship). The selected interviewees had experience in at least one of the following activities: 1) commercial fishing, 2) fishing and/or food gathering for food and cultural purposes, 3) traditional food preparation, 4) local governance and management of marine areas. On average, interview duration was 1 hour (range ~30–90 min).

Analysis

We completed 50 interviews (39 men and 11 women) between May and August of 2018, including 17 participants in Bella Bella (Heiltsuk Nation), 10 in Klemtu (Kitasoo/Xai'xais Nation), 13 in Bella Coola (Nuxalk Nation), and 10 in Wuikinuxv (Wuikinuxv Nation). We describe the participants based on the community rather than the Nation because 4 participants (8%) were non-First Nations; these people worked for a Nation in a planning capacity (e.g. fisheries manager, community planner), or were selected because of their long-standing role in the community. Participant ages ranged from 25 to 85, with an average age of 53; we estimated ages for 19 participants who did not share this information. Not all participants responded to all questions, and therefore sample sizes vary by question.

The first author transcribed the recorded interviews completely, including references to humour and dialogue (e.g. laughter), aiming to capture the richness and context of the interview in an intermediate style between true naturalism and de-naturalism (Oliver et al. 2005). We initially coded interview responses according to specific questions (e.g. values, adaptation actions), and then coded emergent themes in the overall interviews as a second pass coding process using NVivo 12. For the latter, each theme, or code, was defined in the initial coding, and sub categories were recorded as they arose to allow themes to emerge from the participants rather than from pre-determined responses (Thomas 2006). We used descriptive statistics (frequencies) to describe and summarize coarse themes (e.g. values, concerns and fears ascribed to climate change), and detailed responses (e.g. specific social and adaptation actions, barriers, and knowledge gaps for adaptation). We used R (R Core Team 2018) to visualize adaptation actions across communities in radar plots (using the "ggradar" package; Bion 2016). The key recommendations and ways forward were synthesized from the most common adaptation actions and barriers that were shared by the participants, along with insights from the qualitative coding.

Our results include representative quotes from interviews. When participants granted permission, we attribute quotes to the specific persons who contributed them. Otherwise, quotes are presented as anonymous.

Results

> *"We need to adapt to these changes so that he could say to his kids, "let's go fishing", as opposed to saying well, "When I was two my dad took me fishing, but we can't do that anymore"." – Howard Humchitt, Knowledge holder, Heiltsuk Nation*

Observations and impacts of climate change

All interview participants noted substantial changes in the availability and abundance of traditional marine resources in recent decades. Some participants acknowledged that species declines may also reflect fisheries and aquaculture mismanagement, and therefore climate change was not necessarily the sole driver of change (Quote 1, Supplementary Material). Nearly all (49 of 50) shared observations of impacts that they attributed to climate change: earlier berry harvests, temporal shifts for salmon migration and increasing salmon spawning synchrony, rapid glacial melt, warmer and drier summers, more intense winter storms, and changing volume and timing of peak river flows (Table 6.1; Quote 2, 3, Supplementary Material). Some also noted the interconnectedness of ecosystem function and climate change. "*Lots [has changed]…! Because everything changes around the climate… that cycle is out of line now, because of the climate*" (Crystal Tallio, Marine Use Committee Member, Nuxalk Nation).

Table 6.1: Perceived climate impacts on the marine and coastal environment. Quotes without direct attributions are anonymous.

Perceived climate impact	Main concerns	Representative quote
Milder temperatures	Human health Salmon spawning success Berry quality	*"Well, you look at the winters now, it's so warm now. There's no winters anymore. That's when you could tell when the fish are going to come, it freezes up solid you know, water and everything protects the fish. No other animal can get at them, like... everything's for a reason. Now those reasons are taken away by man made errors."* (Cecil Moody, Elder, Nuxalk Nation)
Less snow, glacial retreat	Summer drought and fire hazard Glacial retreat Reduced river flows for local hydropower generation (mitigation efforts) Reduced river flows for spawning salmon	*"…when I was younger, we never used to have water shortages here. You know, the rainforest, living in the summer, it would rain right through… it's just going to start staying dry until September.* (Justin Neasloss, Hereditary Chief, Kitasoo/Xai'xais Nation) *With all those glaciers gone that used to be up and down our valley and all the way to...out to the open sea…It's just not cold anymore.* (Jason Moody, Fish & Wildlife Coordinator, Nuxalk Nation) *…forest fire is a concern, and, I guess for me, the biggest one…is all about infrastructure, and the biggest thing is our hydropower; because I've seen over the past five years where we've actually got into a low water situation three times now, two times during the summer, once in the winter. I never thought we would see low water, this was during the winter but then again we were used to colder weather during the winter in the past, but it has always been so mild over the course of the past, maybe 20 years…"* (Darren Edgar, Executive Director, Band Office, Kitasoo/Xai'xais Nation)
Changing seasonality	Shorter harvesting season	*"Sometimes you'll have herring spawns that are early or late, you know, a couple of years ago we didn't have seaweed at all… Now this year we're harvesting seaweed while the herring are spawning… nobody's ever done that. You know, so I think about impacts... climate change [is] impacting the timing of when we're*

	Unpredictable harvesting season	*harvesting…. our people relied really heavily on things like the moon… the size of the moon to help you know and predict when things like the herring were going to spawn… those things are shifting."* (William Housty, Hereditary Chief, Heiltsuk Nation) *"Probably one of the biggest things is the trends of resources that are available… they are so unpredictable now. For seaweed…for herring…for salmon returns… a lot of these have changed in the last at least five years"* (Kelly Brown, Stewardship Director, Heiltsuk Nation)
Increasingly intense storms	Increased risk while traveling or fishing from a vessel Inability to leave the village to purchase foods/supplies	*"…it seems like between the spaces, between one storm and the next, it's shrinking."* (Peter Siwallace, Marine Use Planner & Hereditary Chief, Nuxalk Nation) *"We are noticing more and more that the winds are picking up more in the summer time and less in the winter time. It still blows in the winter time, but I've seen it… I've seen it where it's more rough in the summer time than in the winter time now. There's climate change, definitely."* (Wally Webber, Hereditary and Elected Chief, Nuxalk Nation)
More marine invasive species	Impacts to native species Disgust/disinterest in harvesting invasive species	*"Yeah, certain different species, so many different fish that aren't native to here. They are showing up more and more in the past years, and we've talked about El Nino, but even in the off years, they are showing up anyway."* (Fisher, Heiltsuk Nation) *"Well, I'm really concerned about the, you know, the green crab. I think that's gonna affect a lot of our, you know, ceremonial and traditional food gathering, yeah... because they say it's very invasive..."* (Teacher, Heiltsuk Nation)
Algae blooms	Interference with fishing Fear/concern about impact on fish	*"…it's just terrible. Other times I would be fishing with my net and would pick up so much as plankton and algae, you couldn't get any fish with it. Not at all."* (Stu Humchitt, Fisher, Heiltsuk Nation)

More than half (62%) of participants stated the importance of spending time on the water and land as the primary value in their way of life, particularly with a focus on food harvesting as a way to connect with the land and sea (Table 6.2):*"In our way of life? Oh, the food…".* (Hrwana (Eleanor Schooner), Elder, Nuxalk Nation). Younger participants shared that is important to them to connect with their territory; as Charles Saunders (mid 20s Guardian Watchman, Nuxalk Nation) stated: *"I just like being out on the land. Don't have to worry about much, where you are going, or what you are doing."*

Table 6.2: Values related to participants' ways of life. Quotes without direct attributions are anonymous.

Value	Expression	Representative quote
Identity	Food sustenance	*"…food harvesting is a big part of our culture. Language, ceremony… Those are all cornerstones of our culture and that's what makes us Heiltsuk people, being able to do those things."* (William Housty, Hereditary Chief, Heiltsuk Nation) *"It'll probably have to be the food that we get out in the sea and the land. You can live off there. I could eat fish every day if I can."* (Rick Neasloss Sr., Fisher, Kitasoo/Xai'xais Nation) *"Salmon. I never tire of eating it."* (Peter Siwallace, Marine Use Planner & Hereditary Chief, Nuxalk Nation)
	Knowledge of the Land	*"My whole sense of identity comes from the territory and my connection to it and my ability to be out on it and to be able to understand and predict my reactions to it. And I think that's where a lot of the fear and uncertainty for people comes in, is that you can't predict anymore what your relationship will be."* (Councillor, Heiltsuk Nation)
	Sense of belonging	*"I value my way of life, being able to eat my fish, my foods, and to continue our trading… The work I need to be able to do as a Staltm'c, as a hereditary chief…"* (Rhonda Sandoval, Hereditary Chief, Nuxalk Nation) *"I am who I am, I'm Nuxalkmc. I value that now. Not not only that. You think of a white man. He's only got one name. One last name. Me? I've got a name that's got a story behind it, I can say that I have a name, a story behind my name."* (Cecil Moody, Elder, Nuxalk Nation) *"I think everything starts and ends with the water and the land. So for me it's everything is tied into it. Whether you look at our complex social hierarchies we've had prior to colonization, to our stories, our creation stories for placing geographical areas...so that's what it means to be place-based peoples."* (Saul Brown, Reconciliation negotiator, Heiltsuk Nation)
Tradition	Connection to ancestors	*"The teachings, the information that was passed down. Really thankful for being able to have the knowledge to preserve food, salmon and wild meats."* (Ernie Tallio, Guardian Watchman, Nuxalk Nation) *"What do I value about my life? My spiritual place and the people that raised me...and family."* (Derik Snow, Fisher, Nuxalk Nation)
	Intergenerational responsibility	*"Values? Protecting the resources for my kids and my grandkids. So...My values is protection of the future."*(Roger Harris, Guardian Watchman, Nuxalk Nation) *"I have to say the ocean has a lot to do with that, but not only that, the protection of our land and the areas we live in. Taking care of sensitive, cultural areas, to conserving fishing areas that need being... if you see stocks are low, start conserving in areas, so they are not lost for the future generations."* (Justin Neasloss, Hereditary Chief, Kitasoo/Xai'xais Nation)

Freedom	Access to the land/ocean	*"I feel like it is hard to explain sometimes, because things like this seems so obvious to me, and to say yeah, the ocean has always been part of my life. It's right there."* (Des Lawson, ReLaw Project, Heiltsuk Nation) *"Just living here, is something. I mean... Keeps you alive, I guess. Connection with the earth. Basically."* (Frank Johnson, Elder, Wuikinuxv Nation)

First Nations in this area are already seeing the impact of changes that can be attributed to climate change, and in some cases are adapting accordingly. On the outer coast communities (Bella Bella, Klemtu) some participants noted that they already traveling further north to access fish than earlier in their lives (Table 6.3). Many noted the impacts on their abilities to harvest (Table 6.3; Quote 4, 5 in Supplementary Material)

Table 6.3: Perceived consequences on participants' way of life from climate change impacts on the marine and coastal ecosystem. Quotes without direct attributions are anonymous.

Perceived climate impact	Consequence	Representative quote
Lower fish/seaweed abundance	Farther travel to fish	*"Some families will target other species, and some guys, myself included will go further…. getting to the [fishing] spot and then moving around and finding the fish out there, and spending the whole day of fishing out there, I'm looking at a 100-mile day, where a 100-mile day was nowhere near what we would ever even imagine growing up… that would be at most a 60-mile day, if not less. Yeah, so access to plentiful amounts is definitely getting further away from the village."* (Howard Humchitt, Knowledge holder, Heiltsuk Nation)
	Reduced catch rates	***"**I do think oolichan was an early harbinger of climate change. Because there's next to no oolichan."* (Jennifer Walkus, Community leader & Researcher, Wuikinuxv Nation) *"Everything is getting harder to get as time changes, climate change. Slow coming."* (Murray Barton, Knowledge holder, Kitasoo/Xai'xais Nation)
	Less sharing within community	***"**Yeah... so I don't know if that has to do with climate change, or if it's being overfished, or if people just aren't sharing anymore. But that's definitely another pattern that I see that has changed."* (Teacher, Heiltsuk Nation)
Socio-cultural impacts	Less resources available to share & trade	*It's terrible, we're having to travel further and that's at a higher risk to harvest the things that are necessary to us. That's a big concern of mine.* (Travis Hall, Marine Use Planner, Heiltsuk Nation)
	Fishers taking more risks People shifting away from fishing	*"I don't really know much about fishing, but from what I'm picking up these past few years, it's really declining. That's one of the reasons why my mom kept me on land."* (Charles Saunders, Guardian Watchman, Nuxalk Nation)
	Fear about natural hazards (e.g. forest fires)	*"…the way the weather is now, lightning can touch off a real forest fire here, and we're far from being equipped to do anything about it... We will sit in our boats and watch the forest burn, if that's what happens, you know…* (Darren Edgar, Executive Director, Band Office, Kitasoo/Xai'xais Nation)

Concerns about the impacts of environmental change on social and cultural values were apparent throughout the interviews (Table 6.4). Many participants shared themes of cultural loss—as climate change impacts have already affected the seasonality and location of important food species—and how future changes in marine resources will further affect the ability of Elders to pass on traditional knowledge (Table 6.4; Quote 6 in Supplementary Material). The changing biocultural relationship between First Nations and their traditional territory was also a concern for participants as a harbinger of cultural loss (Table 6.4; Quote 7 in Supplementary Material).

Table 6.4: Perceived concerns and fears related to climate change in terms of values and ways of life. TEK = Traditional Ecological Knowledge.

Value	Concern	Representative quote
Tradition	Food insecurity	*"With the changes, and if it continues the same way, maybe there's just going to be no harvestable food in the ocean. It won't be a reliable way to feed our families anymore, if it continues."* (Justin Neasloss, Hereditary Chief, Kitasoo/Xai'xais Nation) *"The temperatures changing, that's our concern because it's going to affect our wild salmon."* (Roger Harris, Guardian Watchman, Nuxalk Nation) *It makes my stomach turn to think about whether or not we will never have salmon come back here. That's hard for me to contemplate. You know, that that would ever happen. It may not be in my lifetime, but it might happen in somebody else's lifetime. That's scary.* (Kelly Brown, Stewardship Director, Heiltsuk Nation) *"If they don't look after it [local resources, especially salmon] now, they'll [the community] have a tough time later on. That welfare gets cut off. And I see that day coming... It will be pretty damn tough."* (Cecil Moody, Elder, Nuxalk Nation)
Identity	Cultural loss Loss of TEK	*"When I look at our mountains and I see no snow, I wonder what's going to happen to us..." (Hrwana, Elder, Nuxalk Nation)* *"So I asked my grandfather and he was telling me…you got to be careful because there's a lot of things changing so fast, I don't recognize it. Which is very fearful because our institutions of knowledge may not be able to adapt quickly enough to the climate change. So that's the first thing that comes to mind."* (Saul Brown, Reconciliation negotiator, Heiltsuk Nation)
	Changing access	*"…we're looking through a pinhole in the wall at our territory and that's all we can see; and all these fishing lodges and stuff have full access. They can go wherever but we're just stuck looking through the little hole in our territory…We have to look through this little hole, and we have to take turns walking up to this little hole and that's what the SEAS program and stuff is, that's the little hole we look through."* (Charles Saunders, Guardian Watchman, Nuxalk)

	Changes in biocultural relationship	*"It's like the plains people when they lost the buffalo. If we lose herring, we lose a major part of who we are"* (Saul Brown, Reconciliation negotiator, Heiltsuk Nation)

Adaptation actions for ecological and social systems

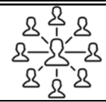
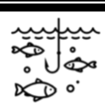
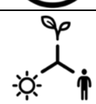
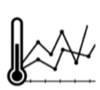
Many participants wanted to discuss climate change impacts and develop community-based strategies to manage those impacts. For instance, some commented that "*It's good that this research is happening*", and "*We never talk about these things…We need to, and this project is the beginning*". Several participants highlighted that particular actions cannot be implemented in isolation but must be part of a broader governance transformation. "*At the end of the day, we have to find balance. There's a very unbalanced ecosystem right now"* (Kelly Brown, Stewardship Director, Heiltsuk Nation).

The primary ecological adaptation action identified was to improve fisheries management (44% of participants, n = 48 responded; Table 6.5), followed by the development of regional forums for education and training opportunities to support stewardship and monitoring practices among communities (23% of participants). A Guardian Watchman (member of the First Nations monitoring and stewardship program) from the Nuxalk Nation explained how monitoring practices within and among communities could be improved.

> *"We are the frontline workers, and we have to notify our community with what's going on and what resources we have....I think we need a big reminder, tomorrow things could happen, and then we will get the blame, I think anyway, and that's why we have to notify the community we see every day and have meetings every month or every two months.* (Roger Harris, Guardian Watchman, Nuxalk)

Few participants considered marine protected areas (MPAs), ecosystem-based management (EBM), or developing and using more climate change projections in management to be priority actions. However, several participants seemed interested in MPAs if they were managed for, and/or by Indigenous peoples. For example, Randy Carpenter (Guardian Watchman, Heiltsuk Nation) stated: "*I think they should be starting to close down some areas, just for food fish only"*. Others expressed the inadequacy of current compliance monitoring and enforcement efforts for protected areas (Quote 8 in Supplementary Material).

Table 6.5: Adaptation strategies, descriptive icons used during interviews, detailed explanations, and proportions who selected certain actions as the primary effective adaptation strategy. (48 participants spoke to the topic of ecological adaptation strategies, and 47 to the question of social adaptation strategies. Icons courtesy of https://thenounproject.com/.

Adaptation strategy	Adaptation action	Detailed explanation	Primary action
Social adaptation actions		Strengthen social networks and community groups; support intergenerational knowledge sharing	18/47 or 38%
		Encourage more Indigenous participation and engagement in regional/higher level management and decision making	9/47 or 19%
		Support stronger local governance (community/First Nation)	9/47 or 19%
		Community infrastructure improvements (particularly in preparation for sea level rise)	6/47 or 13%
		Develop alternative livelihoods Help people to change careers, away from fishing, for example	5/47 or 11%
Ecological adaptation actions		Avoid fisheries over-exploitation, promote better fisheries management	21/48 or 44%
		Develop regional forums, education, and training opportunities to support stewardship/monitoring practices among communities	15/48 or 23%
		Develop better networks of marine protected areas (MPAs)	3/48 or 6%
		Take an ecosystem-based approach to fisheries management / EBM (manage for population, species, and ecosystem diversity)	3/48 or 6%
		Use more climate change projections into stewardship decisions	1/48 or 2%
		It's all connected – All of the above are needed (everything)	5/48 or 10%

For 38% of participants (n = 47) the priority social adaptation action was to strengthen social networks, community groups, and intergenerational knowledge sharing. Other priorities were stronger Indigenous governance (self-determination; 19% of participants), and more Indigenous participation in regional and higher scales of management and decision making (19%). Frank Johnson (Elder, Wuikinuxv Nation) highlighted that: *"It should be the other way around. Adapt their culture into ours, not ours into theirs"*. Some participants prioritized community infrastructure improvements in preparation for sea level rise (13%), and a need to develop alternative careers and economies (11%). As Jennifer Walkus (Community leader & Researcher, Wuikinuxv Nation) shared: "*the only thing I can think of is if we start trying to push politically to try and make the changes to slow it* [climate change] *down, but we also need to prepare for the worst because I think it will come at some point"*. Perspectives on specific ecological and social adaptation action varied by First Nation (Figure 6.2).

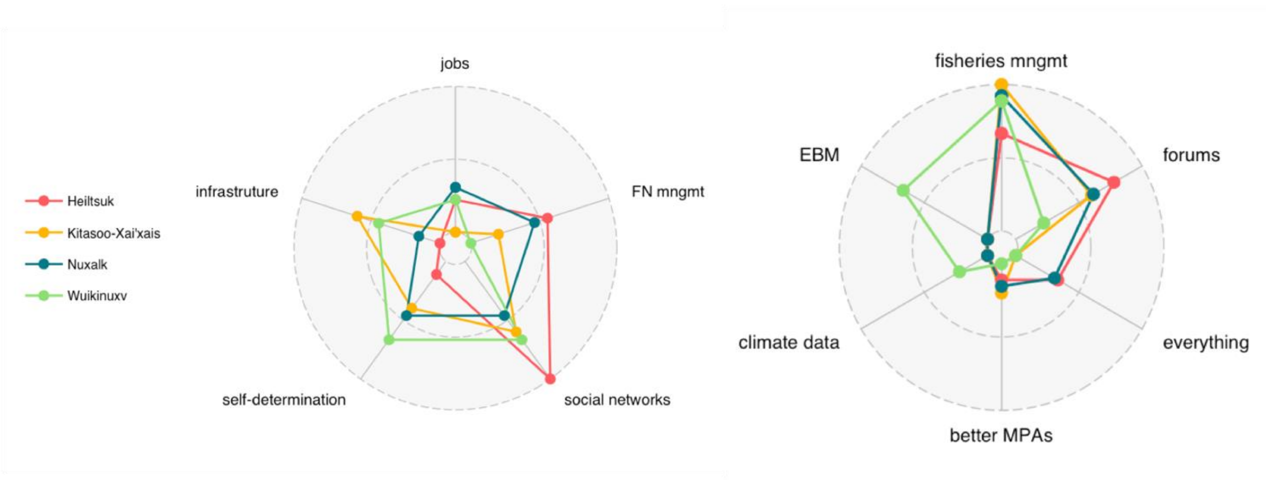


Figure 6.5: Radar plots describing the different primary social (left) and ecological (right) adaptation actions identified by participants in the four First Nations (Heiltsuk, Kitasoo/Xai'xais, Nuxalk, Wuikinuxv). Adaptation strategies are the same as those listed in Table 4. FN = First Nation; EBM = Ecosystem Based Management; MPAs = Marine Protected Areas.

Priority actions

Four additional priority actions emerged over the course of the interviews, and we highlight their actionable implementation strategies along with the previously defined adaptation actions in terms of their scales of implementation (Figure 6.3).

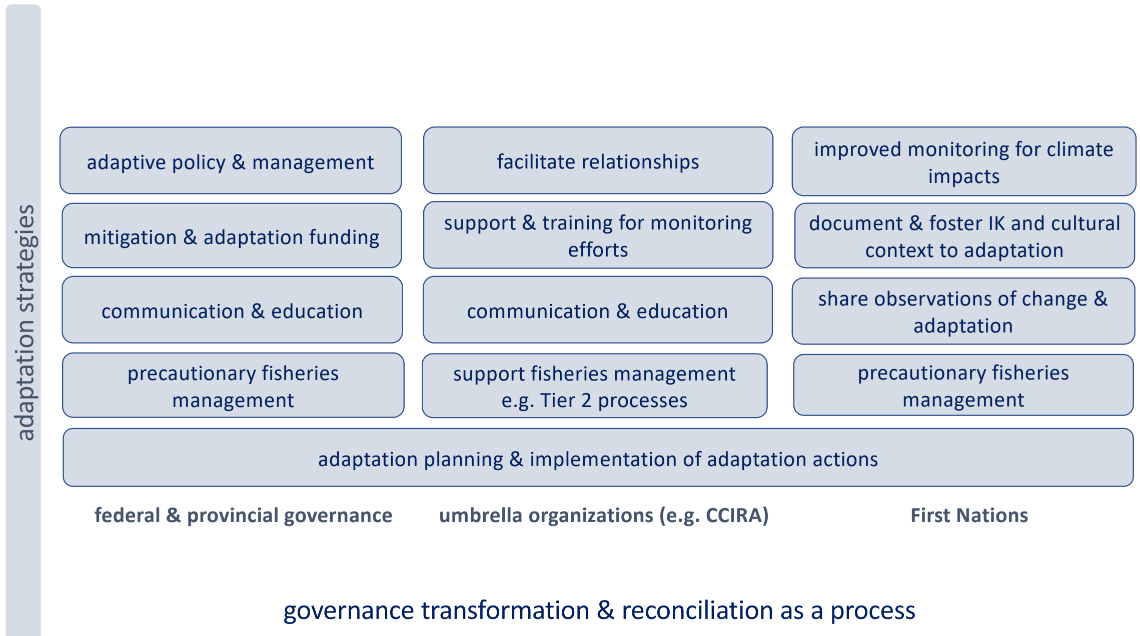


Figure 6.3: Adaptation actions that emerged from these interviews across scales, from federal and provincial governance, to regional umbrella organizations, to First Nations governance. Throughout, reconciliation and governance transformation are processes that all scales can work towards. IK: Indigenous Knowledge; CCIRA: Central Coast Indigenous Resource Alliance.

Strengthening Indigenous governance autonomy and authority

When asked about the barriers for climate change adaptation, most participants spoke to issues of self-determination, governance, and capacity for First Nations and Indigenous knowledge to influence decision making (38%, n = 47; Quote 9 in Supplementary Material). "*Our inability to be legitimized as knowledge keepers is a big factor…Until they [crown* government*] understand the legitimacy and the importance of traditional knowledge, then we're going to continue to have this struggle. I don't have any answers except to say it's really frustrating*" (Councillor, Heiltsuk Nation). The social impacts of colonialism reduced Indigenous autonomy and self-reliance over several generations; recovery will not happen overnight. The legacy of colonialism from the federal government was seen specifically by some participants (14%) as something that must shift for climate change adaptation to succeed (Table 6.6, Quote #1).

Most participants (80%) shared long-standing frustration with federal and provincial governments in the context of fisheries management and climate change adaptation. "*All this stuff* [marine resources], *it's just totally mismanaged. Totally. This is why I say they're trying to* *wipe the Native people out… A silent wake"* (Cecil Moody, Elder, Nuxalk Nation). Nuxalk Elder Hrwana (Eleanor Schooner) explained her perception of the Federal government's attitude towards First Nations in the context of adaptation: *"We have to have a voice. We have to have concern"*. However, over half of the people we spoke with (52%, n=50) expressed hope for either cultural revitalization, the potential to adapt to new food species, the ability of their community to work together for climate change mitigation, or a combination of those possibilities. "*On that front we've tried to change it, with our hydro where we're trying to change to more clean energy, trying to get away from the fuels, the fossil fuels*." (Darren Edgar, Kitasoo/ Xai'xais Nation). While the legacy of colonialism and the ongoing efforts to revitalize culture were a main focus, many participants framed the future in a positive light, highlighting that Indigenous peoples and knowledges will continue to adapt to a changing climate.

> *"Like I said, our people are really adaptable. […] It's been since time immemorial where people have amended their way of life to the resources that are coming… and making a part, an intricate part of who we are as a people, and that's what's been built over time… I think different resources that are coming here, the exotic species that enter our waters, definitely our people would consider utilizing those resources…I mean, that's, that's the kind of stuff that our people adapt to very quickly."* (Kelly Brown, Heiltsuk Nation)

Promote knowledge sharing for adaptation practices within and among communities

While Indigenous communities have always adapted to environmental change, participants expressed concern and uncertainty about how they will adapt to climate change impacts on their coastal culture. Participants identified opportunities for developing adaptation actions and practices, including increasing capacity within and among these First Nations to understand and act on climate change adaptation (Quote #2, Table 6.6). Many participants spoke to the need to develop avenues for sharing harvests to mitigate climate change impacts on access to traditional foods. When we asked about shifting species ranges, only some participants (29%, of 41 responses) thought that fishers would respond by traveling further north (Quotes 11 and 12 in Supplementary Material). The reasons ranged from access (cost of fuel, lack of fishing vessels), territorial boundaries among First Nations, and lack of institutional support for adaptive management of area-based commercial fishing licensing. Several people brought up First Nation territorial boundaries as a limiting factor for fishers travelling further to target their traditional food species (Quote 13 in Supplementary Material).

As traditionally available food species shift north, novel species (which some participants called ‘invasive’) will be more readily available near communities. Some people said, “we will adapt” and harvest other species “within reason” (39% of 41 responses; Quote 19 in Supplementary Material), while others thought they would not target novel species and harvest less (22%). Reasons given for not expecting to harvest novel species included disinterest and disgust, but some respondents suggested that education around harvesting and preparation of novel species might influence people’s decision to harvest such species. Other participants thought that trade could be part of the solution to changing access to marine food species. As Jennifer Walkus (Community leader & Researcher, Wuikinuxv Nation) explained, *“…trading for what we need has always been a part of First Nations culture and I think that'll continue”*. Some participants shared that increasing trade among First Nations might be an adaptive response to access traditional foods as marine species shift north: “*Just have to go further for it, or trade for it, eh?*” (Rick Neasloss Sr., Fisher, Kitasoo/Xai’xais Nation). Other participants highlighted that existing trade relationships are based on traditional food species, not novel ones; of the participants who responded (n = 42), 62% thought that trade will likely decline as traditional foods decline. This potential impact of climate change will affect more than just food availability, as trade relationships are tied to marriage, management, and inter-Nation politics (see Quotes 14 and 15 in Supplementary Material).

Promote adaptive co-management among governance scales

When asked about the most effective governance scales for adaptation planning and decision making, almost half of participants (49% of 45 responses) thought that First Nations local governance was the most effective scale: ”*I think it would be your local government because people back East, they don't grasp what's happening out here*.” (Alex Chartrand, Wuikinuxv Nation). Since prior to colonization, community-wide stewardship practices included managing how people use and access resources within each First Nation’s territory in the long term, as reflected in traditional use agreements among neighbouring First Nations. Participants reflected that self-sufficiency in their perspectives of environmental monitoring, climate change adaptation, and marine management (Quotes #3-5, Table 6.6; Quote 16 in Supplementary Material).

Many participants highlighted challenges caused by competing interests and industries which have affected Indigenous access to their territories and harvesting rights (Table 3). Others spoke to the need for collaboration (31% of 45 respondents) if climate change adaptation is to succeed, and the need for co-management in this context: *"I think co-management is the way governments have to go... All governments have to learn, if you can listen to First Nations of the world, you'll be in a better place, but if you try to do it all on your own you'll screw up supremely. You can't dig yourself out of it."* (Wally Webber, Elected & Hereditary Chief, Nuxalk).

Develop learning platforms for climate impacts and adaptive strategies

Many participants highlighted the need for more education and communication about climate change (Quotes #6-7, Table 6.6). Participants suggested sharing platforms within communities to educate community members as to how climate change is affecting Indigenous peoples around the world to broaden the scope of insights available to them (Quotes #8-10: Table 6). This sentiment of self-reliance and the need for proactive planning was shared by many who felt that change can come from within the Nation via education, learning, and investment in adaptation strategies. "*I think it* [adaptation] *has to come from the community…I really believe that people should be empowered to know that they can make, make those changes.* (Ernie Tallio, Guardian Watchman, Nuxalk Nation). Others specified that this is something that local stewardship offices should be focusing on more (Quotes #11-12, Table 6.6; Quote 17 in Supplementary Material). Specific education and learning platforms around harvesting novel species and developing alternative livelihoods through mariculture (shellfish aquaculture) were also discussed (Quotes #13-15, Table 6.6).

Table 6.6: Adaptation actions suggested by interview participants for particular scales of management and priority adaptation themes.

Adaptation theme	Specific adaptation action	Scale/responsibility	Representative quote
Strengthening Indigenous governance autonomy and authority		Community Regional National	#1: *"So, I think the biggest barrier honestly is the colonial legacy. And so that's, you know, the language... state sponsored residential schools, church sponsored residential schools, attacking of our knowledge systems and the intergenerational transfer of knowledge... the removal and dispossession of our land and waters, and basically putting us on these tiny reserves, relegating us to reserves and then the whole racist narrative of who and what Indigenous people are... and how that ties into climate change is because as the climate changes, scientists are finally starting to validate [Indigenous knowledge]. But that was all put at risk through colonization and so I think that's the biggest barrier right now and going forward, is reconstituting ourselves and then.... putting the land and the water at the forefront of all that decision making….* *And I think, so that's a major barrier too, is not understanding the interconnectedness that, again goes to that legacy of colonization. And we're too busy fighting to be recognized as peoples and to have our knowledge validated that we're not actually meaningfully contributing as much as we could be to the systems and solutions that be. We have a lot to offer but oftentimes we're fighting just to assert our rights to be...we have to go to court to prove our existence. That's where we start, prior use and occupancy... custom areas to fish... instead of actually trying to inform solutions in the greater Canadian society because at the very brink of it, that's what we're fighting against." (*Saul Brown, Reconciliation negotiator, Heiltsuk Nation)
Promote knowledge sharing for adaptation practices within and among communities	Support IK and cultural insights into climate change impacts and adaptation	Community National	#2: "*I think that will likely be really important to engage with the community on climate change adaptation in general, is helping them to understand it in a very cultural context because that's where people's understanding of the territory comes from. Our whole language and our calendar and the names for different things are tied to the things that we harvest in the places that we go. So much of how people see the marine and terrestrial territory is lived through the language and the culture. So, I think that cultural context will be important in giving people a sense of security that will be helpful."* (Councillor, Heiltsuk Nation)
Promote adaptive co-management among governance scales	Increased monitoring for climate change impacts & perceptions	Community Regional	#3: *Okay, in regard to the ocean, I think there should be more monitoring, more studies like what you guys are doing now, that's a good thing. So that everybody is aware of what is going on here in the territory. And then it helps us regulate, like for instance this year there was less salmon so we*

			should probably intervene and say no fishing or no overfishing. (George Johnson, Hereditary Chief & Elder, Wuikinuxv Nation) #4: *"If we don't have the salmon, we're not a people, because we are the salmon people. So we have to monitor what's going on around this world and keep reminding people of what's going on".* (Derik Snow, Fisher, Nuxalk Nation)
	More collaboration in climate change research Acknowledge multiple ways of knowing, Indigenous knowledge, in governance	Community Regional National Academia	#5: *"Probably having more conversations with science and knowledge holders here, in identifying what the trends have been, and affirming what our people are seeing… We don't do that enough...I think we should collaborate more, have Heiltsuk more involved in the research that's taking place."* (Kelly Brown, Stewardship Director, Heiltsuk Nation)
Develop learning platforms for climate impacts and adaptive strategies	Increase discussion within and among communities of climate change impacts and adaptation Share research with community members	Community Regional	#6: "*There are a lot of people here that bark about, climate change and climate change, but there is nobody here that knows a lot about it.*" (Peter Johnson, Knowledge holder, Wuikinuxv Nation). #7: *"Yeah, it's be good to get more conversation about this... Trying to adjust. Trying to adjust to the way things are, versus what they used to be..."* (George Johnson, Elder, Wuikinuxv Nation) #8: *"Well I think right now the education part of it is super important, so engaging with youth and school-age kids and elders, the in between people is important too. I think that would be a really good next step is to provide that education and get people talking and get people motivated to do something about what's going on."* (Des Lawson, Relaw Project, Heiltsuk Nation) #9: *To me, it would be education and communication, because what we do is affecting everything else around us, and a lot of our young people they don't care or they're just not involved. Having that scientific knowledge behind that when you're educating one community would be very good…It would be something to know what's going on around the world, globally, and it's not just Bella Coola… I think that's what should be implemented*

			here, but I don't know if it would work everywhere else. (Crystal Tallio, Marine Use Committee, Nuxalk Nation) #10: "*With [CCIRA, they] do lots of camera shots, video shots. It would be nice to get that into a slide show presentation for each community along the coast, and see what changes happen since they started… So it will be nice to share that for each community that they worked in and show the changes since they have started. I think that would be a start. I think that would open their community's eyes."* (Roger Harris, Guardian Watchman, Nuxalk Nation)
	Facilitated discussions about climate change and adaptation with community members	Community	#11: *"Getting it from the actual stewardship department out to the people. Newsletters are good…but other than that, actually having to go out and talk to these people, one on one, that works better, and that doesn't get done all the time right… It's better if people go out and talk to them. Pressing on how important it is, and not just sending a newsletter out saying, here, change! So, it's just better to talk, like right now, one on one, talking back and forth, you're writing stuff down. It just seems better, they would they would be able to convey their feelings better rather than just on a piece of paper. The people getting interviewed would see the importance on it, rather than just ok it's just another piece of paper."* (Alex Chartrand, Wuikinuxv Nation) #12: *Yeah. I think it's to get our people to realize like, this is happening and it's happening. We might be in this little pocket of paradise here, but it is going to affect us to a great extent too, if we can try to slow it down in any way we can, you know, the sun isn't going to help us. Just keeps getting hotter and hotter! We live in a rainforest, we need rain.* (Crystal Tallio, Marine Use Committee, Nuxalk Nation)
	Education on harvesting practices for novel species	Community	#13: *"with I guess all species of everything, learning how to harvest, something different, whether it be clams or crabs or other types of fish."* (Fisher, Heiltsuk Nation) #14: *"…people can go out to see how's its done….Then, once they... the people who harvest, and then maybe throughout the years, building up, refining the new way of fishing or harvesting, whatever it is, then they'd start taking people out, this is how we are doing it...almost start over again, like we do with the fishing now, got to start passing it on, passing it onto other people, so they know the ways to catch them [new species] too…"* (Justin Neasloss, Hereditary Chief, Kitasoo/Xai'xais)

	Proactive planning on climate change adaptation Investments in alternative livelihoods (e.g. shellfish aquaculture)	Region	#15: *"I think with respect to adapting, it would be to have that kind of detailed conversation around what's expected. I mean, I think that some people have some ideas of what's expected in certain areas. It's going to get hotter, it's going to, species range are going to shift. But that's probably the extent of a number of people. As far as the details of how it's going to pan out. You know if they could, and First Nations up and down this coast in general, get a better handle as to what would reasonably expected about species range shifts, and lead that into sort of an economic conversation rather than sort of a big depression….* *You know here's an opportunity…and shellfish is definitely one of those for sure. I think shellfish is at least you know, outside of more run of the river or whatever, is probably the easiest one to do, because it's something you can bite off. It's like a chunk that you can actually take and do something with. "* (Dave Rolston, Fisheries manager, Wuikinuxv Nation)

Discussion

Current and projected climate change impacts worried people in the central coast of BC. This awareness of climate change as an existing and ongoing impact is consistent with the perspectives of Indigenous youth (Petrasek MacDonald et al. 2013) and Elders (Irlbacher-Fox 2014, Chisholm Hatfield et al. 2018) in the Canadian Arctic, with Indigenous people in the western US (Chisholm Hatfield et al. 2018), Labrador (Wolf et al. 2013), and the northern B.C. coast (Turner and Clifton 2009). Across the four First Nations of BC's Central Coast, participants expressed consistent frustration with the decline of cultural keystone foods, particularly salmon, and the role of poor fisheries management in that decline. Since climate change presents further cumulative impacts to marine species (Pinsky et al. 2019), conservative fisheries management approaches would be prudent. Maintaining Indigenous peoples' access to traditional lands, waters and resources is critical to reconciliation and the adaptive capacity of Canada's Indigenous and coastal communities (Bennett et al. 2018). Most participants expressed uncertainty about climate change adaptation actions, and some considered reconciliation a pre-requisite to addressing adaptation actions or proactive management strategies for climate change. Priority actions included strengthening Indigenous governance, promoting knowledge sharing for adaptation strategies, implementing co-management of fisheries, and creating education and learning platforms for climate change and adaptation initiatives. Legacies from the colonial history of the Canadian government emerged as barriers to proactive climate change adaptation, and participants expressed a strong desire for self-determination and cultural revitalization as related to both management and harvesting practices. This included trade, which has always been an important part of First Nations culture (Brown and Brown 2009b, Turner 2016). These findings highlight that addressing climate change adaptation requires recognition of the diverse and cumulative challenges facing Indigenous peoples worldwide (Huntington et al. 2019) and provide insights for proactive strategies to support Indigenous ways of life.

A central theme that emerged was the importance of Indigenous self-determination in order for First Nations to engage and contribute to climate change adaptation. This was previously described by Turner et al. (2008) as an indirect lost opportunity for proactive planning. This colonial legacy persists in Central Coast First Nations who identified it as a challenge for management and adaptation. Trust, or the lack thereof, affects policy change (Huntington et al. 2011), particularly in circumstances with perceived risk and uncertainty (Adger 2003, Kettle and Dow 2014). A lack of trust between governments may limit collaboration on the transformative change necessary to engage in effective climate change adaptation actions. In eastern Canada, a study of 39 Indigenous and non-Indigenous co-management partnerships found that respect for Indigenous knowledge systems, Indigenous engagement in knowledge transfer and mobilization, and self-determination are key factors that enable Indigenous-led environmental stewardship (Reo et al. 2017). Using a comparative case study, Turner et al. (2013) demonstrated how the cumulative impacts of external problems and policies related to colonization have effectively undermined and constrained the ability of Canadian and New Zealand Indigenous peoples to engage in resource management decision making. First Nations stewardship principles and values-based management practices have been well documented (Turner and Berkes 2006, Artelle et al. 2018); today, First Nations continue to wield their authority against non-Indigenous resource management decisions that are often deemed as extractive, un-sustainable, and made without appropriate consultation with Indigenous communities (Atleo 2011; Coburn & Kam'ayaam/Chachim'multhnii (Cliff Atleo) 2016; Norman 2017). Restoring Indigenous identity and culture in the mental health field is also a precursor to intergenerational healing from the lasting impacts of colonization (Lavallee and Poole 2010). Acknowledgment of Indigenous self-determination by provincial and federal governments would contribute to a governance transformation that may enable sustainable livelihoods while environmental change is ongoing (Turner et al. 2008, Donatuto et al. 2014a, Whyte 2016a).

Specific climate change adaptation actions included sharing knowledge of traditional harvesting practices and stewardship of traditional territories. Declining access to seafood was a recurring theme, and participants feared the future loss of food security due to climate change among other social-ecological phenomena. Similarly, Indigenous perspectives from western US tribes have highlighted climate change impacts on traditional foods to be part of broader and interlinked environmental, cultural, and socio-political concerns (Chisholm Hatfield et al. 2018). In many cases, Indigenous people on the Central Coast are no longer able to travel to harvest marine food species, as they have fewer boats due to economic hardship and limited access to their traditional territories due in part to industrial impacts. Indigenous peoples in this region historically tended landscapes in ways that increased the abundance of traditional foods, including clam gardens which increase shellfish productivity (Groesbeck et al. 2014, Jackley et al. 2016). Re-establishing such practices could support both food sovereignty and autonomy (Menezes 2001), while helping First Nations engage in place-based monitoring practices (e.g. Gitga'at First Nation monitoring program; Thompson et al. n.d.).

As traditional marine food species shift north with warming ocean temperatures (Weatherdon et al. 2016c) and warm adapted species move north into the region, some First Nations may be willing – and supported through learning new harvesting practices – to adapt by harvesting novel species. In contrast to what has been observed in East Coast fisheries (Young et al. 2019), not all First Nations in the central coast have the capacity to travel further north to access target species. Developing learning platforms for harvesting and preparation practices for novel species may be effective as part of adapting to climate change. Globally, human communities have developed novel harvesting and food production practices over millennia, which illustrates the human capacity for both ecological transformation and the potential for human adaptation to ecological change (Boivin et al. 2016). While non-native or novel species are typically perceived as a negative impact on natural and human systems, re-framing this narrative to consider the potential benefits of novel species – including economic, conservation, (Schlaepfer et al. 2011) and food security benefits – is an important first step.

Many of the climate change adaptation actions perceived to be effective related to governance and policy changes, including a need for a governance transformation that legitimizes fisheries co-management. In B.C., salmon fisheries have declined in recent decades, which has in turn affected coastal and Indigenous communities (Turner et al. 2008, Walters et al. 2018); as Cullon (2017) explains, *"no longer are salmon the basis of well-being for a community….People speak of a fear that their grandchildren will not know a life with salmon"*. In recent years, the culture of Canadian federal fisheries management has started to shift towards reconciliation with Indigenous peoples. Examples of this include joint technical working groups between Fisheries & Oceans Canada and First Nations for a variety of species including salmon and crab, perhaps signaling the beginning of a new governance paradigm, and the recently announced fisheries reconciliation agreement (Canada 2019b). Further south, First Nations and DFO have engaged in a lengthy process to successfully develop the Fraser Salmon Management Council, a co-governance structure for Fraser River salmon management (https://frasersalmon.ca/). Also for salmon, the almost 15-year old national Wild Salmon Policy is guided by principles including honoring the importance of salmon to First Nations and including First Nations in salmon governance, management, and conservation (Irvine 2009). Very little progress has been made to implement these strategies (Price et al. 2017) although an implementation plan was recently produced (Fisheries and Oceans Canada 2018).

The interest in learning and sharing platforms for adaptation strategies by interview participants suggests an opportunity for Indigenous peoples to develop adaptation options across geographies and scales. The rapid and recent rate of change, and the enormity of the challenge, may be why education and communication arose so often. Developing visualization tools for climate change and climate change adaptation in Central Coast First Nations could increase awareness and therefore adaptive capacity (e.g. Sheppard et al. 2011). Some of the First Nations we worked with for this project aim to incorporate climate change adaptation into their resource stewardship and management programs. For example, one of the consistent statements from the Heiltsuk community is that of adaptation, or 'We have always adapted'; one of the Heiltsuk Fundamental Truths is "Adapting to Change" (Fundamental Truth #7; Brown & Brown 2009). Stories and cultural history describe Indigenous resilience through periods of past environmental change, such as floods (Brown and Brown 2009b, Horne 2012), past climatic shifts (S. Brown pers. comm. 2018), and resource decline.

Indigenous communities have adapted to environmental, social, and cultural change for hundreds and thousands of years. Things are different now – change is much more rapid, and harvesting practices have become much more unpredictable (Turner and Clifton 2009, Fernández-Llamazares et al. 2015). The growing discourse around Indigenous peoples and climate change is uneven by geographic region and population, due to different political circumstances, the perceived level of risk posed by climate change (i.e. much focus on the Arctic), and the extent of involvement by Indigenous communities in climate change research and adaptation planning (Ford et al. 2016, Belfer et al. 2017). In a multi-year project across six regions in the southern hemisphere, sharing adaptation responses to shifting species ranges due to climate change revealed insights into cultural values of adaptation, and the value of participatory methods for developing adaptation strategies (Hobday et al. 2016). Modern management considers only the past several decades, thus obscuring long term social-ecological trends; in contrast, considering local knowledge, diverse knowledge systems and longer management time scales in coastal fisheries management may lead to better outcomes that are ecologically sustainable and socially just (Savo et al. 2017, Lee et al. 2018).

Limitations, caveats, & future directions

Our work is limited by several methodological and logistical challenges. Aiming to understand perspectives of climate change adaptation across a region meant that the lead author did not spend more than two weeks in each community to conduct interviews; ethnography approaches would doubtless reveal a more nuanced understanding of the issues and context (Lyons et al. 2016). While we focused on adaptation to climate change as a central stressor, we sought to encompass the more holistic perspective of Indigenous people (Atleo 2011, Huntington et al. 2019) to the extent possible. We asked participants to prioritize adaptation actions for their social-ecological system from a predetermined list of options; by narrowing the range of actions considered, we may have obscured or de-emphasized other strategies (Loring and Hinzman 2018). The list of strategies may also have been misconstrued by some participants, or some participants' meaning may have been mis-identified by the lead author. By engaging with the topic of environmental change, other topics that might seem separate from an outside perspective emerged. Traditional harvesting practices, trade relationships, identity, and place-based traditional knowledge of native species are all connected to the land and sea, and thus were seen as affected by contemporary or future climate change. This landscape of identity has been identified in research with Arctic Indigenous communities related to the social and cultural importance of sea ice to Inuit (Cameron 2012, Durkalec et al. 2015, Huntington et al. 2019). Since we framed this research on climate change adaptation, we may have unintentionally missed other contextual or historical elements of the implications of governance and environmental change.

Some of the management responses that First Nations already use and brought up as effective may be controversial. For example, salmon hatcheries are a common management tool used extensively across the north-east Pacific to supplement wild populations (Ruggerone and Irvine 2018). Each of the communities we worked with has an existing hatchery for salmon (coho, chum, chinook), and felt strongly that they were essential for ongoing food security: "*Without our hatchery, we wouldn't have a fishery"* (Peter Siwallace, Marine Use Planner, Nuxalk Nation). Hatchery salmon may compete with wild salmon at sea, potentially leading to decreased prey availability and changes in foraging behaviour linked to reduced growth, delayed maturation, and poor survival in wild populations (Poorten et al. 2011, Rogell et al. 2012, Ruggerone and Irvine 2018). Genetic risks may also increase through interbreeding depression (Kostow 2009). However, responsible hatchery management draws on principles of Indigenous stewardship and conservation hatcheries can potentially augment populations of conservation concern (Myers et al. 2004, Connors and Atnarko Sockeye Recovery Planning Committee 2016, Trushenski et al. 2018). Some participants also spoke of travelling further to access traditional fish and marine species; this adaptation has trade-offs in increased emissions and fuel consumption with associated climate change feedback loops, and may have transboundary governance implications for both First Nations and federal governments for marine species ranges that cross international boundaries (Jay et al. 2016, Gaines et al. 2018).

Future work can build on our results in several ways. First, given the key theme of communication that emerged across the four communities, we recommend developing information tools in the format preferred by each community. A potentially useful model developed and tested in Australia uses stepwise “adaptation pathways” to guide coastal communities through adaptation initiatives while including diverse perspectives, complexities, and uncertainties. A key applicable result of this project was that in order to be effectively implemented, adaptation strategies must consider the complete set of coastal community values (Lin et al. 2017). Second, many interviewees discussed the need to develop locally-driven climate change monitoring programmes; other communities in coastal BC (Gitga’at First Nation; Thompson 2018) and elsewhere have begun to pursue these types of initiatives (Thompson et al. n.d.) Since this interview work was completed, climate action coordinators are in the process of being hired across the Coastal First Nations (CFN) region, including within these four First Nations communities. We also found interest in developing local enforcement capacity and legislative power to enforce management restrictions (e.g. harvest limits for recreational and commercial fishers) as a tool to de-centralize governance and support reconciliation processes.

Finally, throughout this research we found a clear theme of self-governance and the need for transformative change in management practices. Challenges to accomplishing this large shift include funding, legislative support, and ongoing reconciliation with Indigenous peoples by provincial and federal governments. However, without that shift, climate change adaption actions may be inadequate. The onus is on the current federal and provincial governments to recognize the failures of the past and support Indigenous peoples in developing their own adaption actions that are culturally and socio-ecologically relevant, with support from other governance scales.

Chapter 7: Conclusions

The overarching objective of this dissertation was to link social and ecological adaptation theory with the specific needs and perspectives of coastal planners and communities to contribute to our understanding of how climate change adaptation options may be realized in coastal social ecological systems. To achieve this objective, I applied both theoretical and empirical methodologies from natural and social sciences to focus case studies of the coastal region of British Columbia (BC), Canada. The BC coast has already started to see climate-related changes, with examples including changing seasonality (Turner and Clifton 2009), decreasing fisheries abundance, and shifting species distribution (Healey 2011, Okey et al. 2012, Chandler 2017, Whitney and Conger 2019). Climate-related changes in habitat availability and ecosystem function, and the associated shifts in species range distributions, will have significant impacts on coastal communities. Since initiating this research in 2014, the impacts of climate change have become more evident, and the enormity of the adaptation challenge has risen drastically. When the Paris Accord was signed in 2014, international agreements were made to keep warming below 1.5ºC relative to pre-industrial levels (IPCC 2018). Yet greenhouse gas emissions have continued to rise and demand for some fossil fuels (e.g. coal) have *increased* (Global Energy Statistical Yearbook 2019). Subsidies for the fossil fuel industry have persisted across the globe, while subsidies and investments for renewable energy systems (wind, solar) in many places has dwindled (Coady et al. 2019, UNEP et al. 2019). This reality drives home the urgency of this research, and implementing adaptation strategies that are effective, realistic, and actionable in the context of coastal social-ecological systems.

Through my research, I answered five main research questions. Below I outline the main findings for each of these questions, followed by the limitations, methodological lessons learned, future directions for research, and some policy implications.

Research question 1: How is adaptive capacity assessed in social-ecological systems, and how can these assessments lead to actions to improve adaptive capacity for coastal communities to climate change?

Due to the complexity and speed of environmental, climatic, and socio-political change in coastal marine social-ecological systems, there continues to be significant academic and applied interest in assessing and fostering the adaptive capacity (the latent ability of a system to respond proactively and positively to stressors or opportunities) of coastal communities. A variety of qualitative, quantitative, and participatory approaches have been developed and applied to understand and assess adaptive capacity, each with different benefits, drawbacks, insights and implications. In Chapter 2, drawing on case studies of coastal communities from around the globe, I led a workshop and review to describe and compare 11 approaches that are often used to study adaptive capacity of social and/or ecological systems in the face of social, environmental, and/or climatic change. I synthesized lessons from this series of case studies to present important considerations to frame research and to choose an assessment approach in different contexts, key challenges to analyze adaptive capacity in linked social-ecological systems, and good practices to link results to action to foster adaptive capacity. For future research, I suggested more attention to integrated social-ecological assessments, and that greater effort be placed on evaluation and monitoring of adaptive capacity over time and across scales. Overall, I found that too few assessments seem to lead to tangible outcomes or actions to foster adaptive capacity in social-ecological systems. This research inspired and informed subsequent chapters applied to the specific geographical context of the BC coast (Chapters 5 & 6).

Research question 2: What is the current state of knowledge related to climate change impacts and recommendations for adaptation strategies within a coastal region?

Planning for adaptation to climate change requires regionally relevant information on air and ocean temperatures, sea levels, storm frequency, and other climate-related impacts. However, many regions lack constrained and focused reviews of the climate impacts, risks, and potential adaptation strategies for coastal marine areas and sectors. To fill this gap, I led a regional assessment of climate change impacts and recommendations for adaptation strategies in the NE BC coast, in collaboration with a regional planning and plan implementation partnership (Marine Plan Partnership for the North Pacific Coast), aimed at bridging the gaps between climate science and regional adaptation planning (Chapter 3). I looked into both social and ecological aspects of climate change impacts and adaptations, and the feedback mechanisms which may result in both increased risks and opportunities for the following sectors: ‘Ecosystems’, ‘Fisheries and Aquaculture’, ‘Communities’, and ‘Marine Infrastructure’. As next steps within the region I propose proactive planning measures including communication of the key impacts and projections and cross-sectoral assessments of climate vulnerability and risk to direct decision making.

Research question 3: How can projections of marine species range shifts be applied to marine spatial planning?

To build on these findings, I then used outputs of species distribution models fitted with biological and climate data as inputs in spatial prioritization tools to identify conservation priority regions for marine species in British Columbia, Canada (Chapter 4). I assessed and compared two examples of ways of incorporating climate change projections into marine protected area planning: 1) as overlay of 98 species with modeled distributions now and using a future climate projection scenario for existing BC marine parks, to ask which species are more or less likely to be protected in the future; and 2) a spatial prioritization analysis using Marxan with inputs as the projections of species ranges, to ask where priority regions exist for culturally and economically important marine species. Overall, I found that many BC marine parks will lose species (e.g. rockfishes, bivalves) as climate change continues, and that protecting 30% of important marine species will be very challenging (i.e. require larger areas) under the current climate change trajectory. Transboundary marine planning initiatives will be necessary to protect the current abundance of marine species in BC into the future. While challenges include the coarse resolution of the data, and the uncertainty in projecting species range shifts without incorporating biological interactions, these simple methods could be used by marine planners and managers to inform marine protected areas planning, and the results should inspire policy action on protected areas and climate change mitigation.

Research question 4: What are perceived climate change risks and adaptation strategies across the same region, from the perspective of regional planners and managers?

Climate change certainly poses novel and complex challenges to planning, management, and policies for marine and coastal social-ecological systems. Despite ongoing discussion of adopting interventions for improving adaptation and adaptive capacity to climate change, practitioners often continue to carry out conventional management strategies that do not effectively incorporate climate change impacts and projections. In Chapter 5, I used a web-based survey and semi-structured interviews to explore the perceptions of practitioners (coastal managers and planners) in BC relative to climate change risks, adaptation actions for social and ecological systems, and barriers for adaptation within the region. Overall, practitioners shared a concern that climate change is not currently well incorporated in management or policy in this region and noted significant implementation gaps. Practitioners expressed more support for ecological adaptation actions that are well suited to regional implementation, such as incorporating climate change projections into management and reducing fisheries overexploitation, than for actions such as protecting specific areas. Social adaptation actions were overall perceived as less useful than ecological adaptation actions, and actions that would support local management and monitoring efforts were viewed as more useful than developing alternative livelihoods. The main barriers and associated opportunities for climate change adaptation in marine management identified by participants included political action, reducing scientific uncertainty, improving communication, and increasing capacity (both funding and staff). Additional opportunities include supporting Indigenous co-governance and co-management, improving policies and funding for climate change adaptation including monitoring efforts, and focusing efforts on communication and education programs specific to practitioners and communities. This study demonstrates the necessity of collaboration across scales of management for effective climate change adaptation.

Research question 5: How do coastal First Nations perceive climate change impacts and adaptation strategies?

Rapidly developing and complex climate change impacts have profound implications for coastal communities, demanding adaptation actions for both social and ecological systems. Along the coast of BC, Indigenous peoples exhibit tightly coupled social-ecological system which was interrupted by the arrival of settler colonialism in the 1800s, and earlier in some cases. While both climate change adaptation and the socio-economic changes associated with colonization have been well studied, little research has examined how these themes interact, and the conditions that may support or prevent people's ability to adapt local livelihoods to the social-ecological changes that emerge. Through a collaborative partnership with four First Nations and their umbrella organization for technical support, I examined people's perceptions of social and ecological aspects of adaptation to climate change (Chapter 6). In an analysis of 50 semi-structured interviews, four key strategies emerged as critical for climate change adaptation: (1) strengthening Indigenous governance autonomy and authority, (2) promoting knowledge sharing for adaptation practices within and among communities, (3) promoting adaptive co-management among governance scales, and (4) developing learning platforms to disseminate climate impacts and adaptive strategies. I found diverse attitudes towards climate change impacts, indicating that people's perceptions of such an overarching issue – and adaptation strategies – are strongly influenced by exposure to observable impacts, the social-ecological context in which they live, and realities of governance and self-determination. Our study suggests that supporting Indigenous peoples' ability to adapt to climate change will require transforming the current governance model into one that acknowledges Indigenous social, cultural, and food needs and the fundamental linkages among these related to marine resources and territorial management rights.

Methodological lessons learned

Developing this research in relation to the ongoing reconciliation, management, and governance processes that are ongoing within BC and the Central Coast region provided me the opportunity to dive into my relationship to these lands and peoples. Previous work on adaptive capacity and marine conservation planning has built a strong case for integrative social-ecological, multi-stakeholder, participatory approaches to understanding climate change (and non-climate) impacts at the local scale (Adger 2001, Dolan and Walker 2006a, Furgal and Seguin 2006, Matthews and Sydneysmith 2010, Jacob et al. 2010, Abecasis et al. 2013). Understanding stressors at both the community level and the larger regional scale is important to better understand the integrated social-ecological system (Drew 2005, Pearce et al. 2009, Adams et al. 2014), and by working with communities, conservation outcomes are more likely to be successful (or not; e.g. Bennett & Dearden, 2014). Both this research and previous work in this area suggests that large-scale environmental change is already having an impact on natural resource abundance, seasonality, and resilience (Turner and Clifton 2009). This may affect households and communities in both an ecological and social sense, therefore affecting past, present, and future adaptive capacity.

Community led discussions can document perspectives on climate change response at a relevant scale for conservation managers and regional planners (Dolan and Walker 2006a). I documented both regional and local perspectives on marine protection and climate change effects on coastal communities. The insights from a regional survey (Chapter 5) helped to build relationships, increasing the potential of these results to inform management and suggest lessons for and from local stakeholders. This work built a greater understanding of the factors that lead to vulnerability across the region, but the framing and language of these regional factors did not always translate to the community level (Chapter 6). An important aspect of worldviews is language, and how it is used and interpreted to act in the present and plan for the future. In a ‘western’ worldview, the term ‘management’ has come to be ubiquitous with ‘resources’ and applied widely when thinking about natural systems; it was a term that I used in framing some of the adaptation actions in my community-based interview guide. In contrast, Indigenous worldviews tend to view humans and nature as interrelated and in balance, so that the term ‘management’ may not be meaningful. Other terms for the ways Indigenous communities see their relationship with the land and sea could be ‘stewardship’ (Des Lawson, pers. comm. 2018); for others, the term ‘ownership’ would more effectively describe the level of care that these communities tend to have for the land and sea, in the way that one tends to truly value something that is owned (Saul Brown, pers. comm. 2018). These nuances can make a world of difference when it comes to making joint and collaborative decisions for natural and human systems.

In developing the methodology for Chapter 6, I aimed to quantify certain responses using best-worst scaling approaches (Lee et al. 2008, Rudd 2011). In the context of Indigenous communities in BC, this was not a successful method. I therefore aimed, to the best of my ability, to code responses made through dialogue but may not always have exactly captured people’s opinions. In the context of the Central Coast of BC First Nations worldviews (Atleo 2011, Weiss et al. 2012) meant that people ranked all adaptive responses as equally important, which likely comes from seeing things as quite interconnected. In other areas and cultures, this approach has been quite successful (e.g. Chilean fishers; Davis et al., 2017); that methodologies are not always transferrable is in itself is a lesson. Indigenous epistemologies are typically inherently different than Western ways of knowing, in that they are experiential, holistic, and context specific rather than standardized and repeatable (Kovach 2009, Latulippe 2015). For non-Indigenous researchers who may be asked or invited to engage in partnerships and collaborative projects such as this one, it is important to prioritize participatory and decolonizing methodologies (Smith 1999, Irlbacher-Fox 2014, Simpson 2017). While I did not necessarily set out to wrestle with theories of decolonizing methodologies, by doing research in collaboration with Indigenous communities I humbly strive to be accountable, appreciative, and open-minded to the different ways of knowing and community-based visions that may emerge. One example of this is my decision to use semi-structured interviews as a research tool. By doing so I avoided boxing participants’ into an issue or evidence that I expected beforehand and allowed people’s perspectives to emerge naturally and without constraint. I highlight that this research is, as one participant noted “the first step in talking about climate change adaptation” in this context and building on these dialogues is necessary in order to build effective adaptations and transformations to climate impacts. People related to changes that have been, or may in the future, affect their daily lives – I learned to try to tell a human story, not a scientific one (Moser 2014, Herrando-Perez and Vieites 2018).

Limitations and research gaps

Adaptive capacity assessments are certainly useful for evaluating social-ecological system responses to change, and the diversity of assessment methods are useful for specific contexts and scales (Chapter 2). Considering the global threat of climate change and other rapid large scale changes, there is a need to increase strategic action in applying adaptive capacity assessments to action, and building broader system dynamics to support social change across scales (Westley et al. 2013). Scale is just as relevant for building adaptive capacity as it is for choosing an assessment method, and by successfully matching adaptive strategies, it may be possible to navigate change by seizing opportunities rather than avoiding threats (Westley et al. 2013). These efforts should be matched, or exceeded, by efforts to build a shared understanding of climate change adaptation responses. Evidence from the EU has illustrated the importance of compatible values and beliefs for effective climate policy and climate action (Rietig 2019).

Due to limitations of the scope of a dissertation, I looked at the potential effects of climate change on marine species, and separately investigated human perceptions of the indirect effects of those changes. Climate change impacts on natural and human systems are both direct (e.g. temperature change, causing species range shifts, or sea level rise, causing flooding hazards), and indirect (e.g. the likely response of humans to range shifts, which results in feedbacks to the already degraded or changed natural system) (Segan et al. 2015). The indirect effects of the human response to climate change have rarely been included in predictions or plans of climate impacts (Jones et al. 2016). If the indirect impacts of climate change outcomes are likely to have greater impacts on biodiversity than direct climate impacts (Paterson et al. 2008, Turner et al. 2010), failing to incorporate human responses is an obvious major shortcoming of climate change risk projections. For example, in some cases by looking only at the direct impacts of climate change (e.g. sea level rise), migration may be seen as a necessary adaptation strategy. However, migration can be maladaptive, and as exemplified in Chapter 6, if this strategy was applied in the context of coastal BC First Nations would lead to loss of culture, place, and traditional livelihoods (Jacobson et al. 2019). Second, approaches need to be developed that incorporate the discrete impacts of stochastic events, such as heat waves (Jones et al. 2016). These impacts are inherently difficult to predict or plan for, beyond the general prediction that they are likely to increase in intensity and frequency. As climate and non-climate impacts cannot be separated, the cumulative effects on biodiversity, ecosystems, and society will likely continue to increase (Crain et al. 2008, Okey et al. 2014c).

Similarly, my research suggests that adaptive capacity assessments should build on examples of integrated social-ecological adaptive capacity assessments (McClanahan et al. 2008, Cinner et al. 2013, Aguilera et al. 2015), and move towards an integrated approach across scales and foci (e.g. historical, community level, analyses of institutions). As well, building adaptive capacity research at multiple scales is a necessary part of operationalizing adaptive capacity frameworks to move these concepts from the literature to an integral part of adaptive management (Adger, Barnett, Brown, Marshall, & O'Brien, 2012; Marshall & Marshall, 2007; Pearce et al., 2009). It is time to move from single assessments, or 'snapshots' of adaptive capacity and vulnerability, to evaluations of adaptive capacity over time and change. If progress on adaptation and adaptive actions is rarely measured (Berrang-Ford et al. 2011), then it will continue to be difficult to convince governments to invest in building adaptive capacities and supporting adaptive or transformative interventions (Pielke 1998, Serrao-Neumann et al. 2013). Adaptive capacity assessments that incorporate change over time are more likely to be able to link to the mechanisms of change and draw on real life lessons from case study experiments (e.g. Cinner et al. 2015b). This remains a gap and opportunity for the field.

In Chapter 3, I looked at conservation planning as a tool to mitigate the implications of shifting species ranges in the coastal marine environment. While conservation planning is an essential part of managing biodiversity loss and anthropogenic impacts, it is only one option in the management toolbox. This is especially apparent when conservation planning fails to take into account the indirect human responses to global change. MPAs can support biodiversity by reducing the impacts of stressors such as overfishing and habitat loss within the protected area, but they cannot prevent the direct impacts of climate change. As global emissions continue to rise and climate impacts accelerate (Hansen et al. 2016), there is a rate mismatch between the causes and effects of climate change and the generally slow rate of MPA implementation. Certainly, a gap in marine conservation planning is the lack of implementation of protected areas and other sustainable management practices (Bennett and Dearden 2014b). Governance and policy is needed that incorporates the most recent science and management tools for conservation planning with climate change (Fox et al. 2012). Designing a portfolio of conservation planning approaches to manage the direct and indirect impacts of climate change would be appropriate for the socio-economic climate of coastal BC.

Overall, MPA networks should provide a framework for joint management of marine coastal areas that is based on adaptive ecosystem-based management, with shared decision making that is flexible and responsive to new information through time. In BC, the current MaPP marine plans are based on principles of ecosystem-based management, which integrates evaluation and re-design into plans as required due to ecosystem changes or other process changes (http://mappocean.org/). These spatial tools should also be integrated with fisheries co-management approaches (Gutiérrez et al. 2011) that prioritize traditional fisheries (Guénette et al. 2000), and a longer term shift away from the current fisheries license system that has lead more profits for fewer fishers and less local benefits (Haas et al. 2016). Considering spatial and temporal connectivity across a heterogeneous landscape would allow for species to move as climate impacts affect coastal regions, while providing a fail-safe of diverse habitats for species with low dispersal potential. Supporting the local social system through integrated management tools such as customary marine tenure agreements (Ruddle et al. 1992) would increase the long term sustainability of coastal communities through time and change.

Much of the later chapters of this dissertation focused on climate change adaptation actions and barriers to adaptation; more work needs to be done on focused opportunity generation for these First Nations. For example, as the forest and fishing industries have declined, and climate change impacts continue to affect wild species distributions and abundance, there have been many calls for expansion of the shellfish aquaculture industry in B.C. (Holden et al. 2019). This is one of potentially other opportunities for developing new marine-based food security and economic opportunities for Central Coast First Nations. I hope that these conversations develop into further research and, more importantly, action on climate change education and adaptation strategies. First Nations, as place-based peoples on the forefront of climate change, are invested, potentially adaptive stewards of the land and sea – and must be supported to be so.

Contributions and challenges for policy and management

This dissertation contributes to the adaptive capacity, adaptation planning, and conservation planning spheres. Much of the applied component of this dissertation was done in partnership with Indigenous communities and organizations, and I focus on these contributions and challenges here given the importance of acknowledging the context, as well as how much more work there is to do in this arena. With adaptation assessments and planning increasingly looking to engage and include Indigenous communities and knowledge, it is imperative that communities be involved and engaged in implementing those projects. Irrespective of our intentions, academic research is always haunted by the ghosts of settler colonialism (see Wolfe 2006). Territorial and cultural dispossession has left Indigenous communities with a long history of inequity and inappropriate state sovereignty which continues to this day. This project did not aim to catalogue Indigenous knowledge, but to address community perspectives on climate change impacts and adaptations that they could envision being suitable from the community level. While I sought to communicate perspectives and values of communities rather than interpreting or distorting them, this research is unlikely to achieve transformative change in longstanding racial tensions or radically improve decision-making processes within the settler state. It can, however, serve as a step in the process of developing better collaborative research partnerships with Indigenous communities and move beyond problematizing Indigenous communities to help support and follow the lead of First Nations in the process of reconciliation (Latulippe 2015). In this way I aimed to address knowledge gaps in governance, and the role of Indigenous knowledge in climate adaptations and decision-making (Wesche 2011, Veland et al. 2013, Ristroph 2017).

As Caucasian researchers invited into research partnerships with First Nations communities, it is our responsibility to consciously and consistently eschew extractive research practices. We must engage with TEK/LEK research in such a way that Indigenous and local knowledges remain rooted in the social, cultural, and political contexts that are all connected (Latulippe 2015). However, the challenge remains that the act of cataloging Indigenous perspectives and Indigenous knowledge systems could be interpreted as yet another example of colonial actions that continues to maintain uneven power relations, unless the research is valued, co-lead, and guided by Indigenous collaborators and communities (Latulippe 2015, Simpson 2017). Asking questions of community in regard to climate change brings up a lot of history around governance, management, colonization, and social issues. The historical context of colonization demands significant work be placed on reconciliation and restoration of decision making power to Indigenous communities in order for community adaptations and transformations to be generated and applied effectively (Irlbacher-Fox 2014, Simpson 2017).

There are also several practical outcomes that relate to this thesis in the context of adaptation planning on the BC coast. First, the Marine Plan Partnership (MaPP) – a partner on Chapter 3 – is working to share the key findings and adaptation recommendations within that chapter on an interactive HTML based web portal. In addition to the previous PDF report that was shared with sub-regional planners and managers, this web portal (https://northernshelf.docu.li/) will enable more individuals to engage with the issues and impacts associated with climate change on the marine and coastal environment and consider the implications for adaptation. Secondly, while this is not a direct outcome of my research, awareness of climate change impacts and adaptation actions has been increasing on the Central Coast, and Coastal First Nations/Great Bear Initiative (CFN/GBI) is now in the process of hiring climate action coordinators in each of the First Nations communities in the region. Specific to my dissertation work, I am preparing a lay report version of Chapter 6 to share with the Nations involved, whom I will continue to work with to publish the results and present them back to the community in person.

Many of the component parts of this thesis focused on adaptation actions as part of management, planning, or theory from a social-ecological lens. While adaptive management from the paradigm of resilience and adaptive capacity thinking may be more appropriate than ‘command and control’ style management methods (Holling and Meffe 1996), is still difficult to link these more holistic tools to policy and governance change (Lebel et al. 2006). Adaptive capacity assessments should be conducted with policy actions in mind, by engaging policy makers and managers in the process, and by incorporating evaluative processes into assessments. A recurrent theme of adaptive capacity research is that governance and institutional change is important for building adaptive capacity (Adger 2001, Hagerman 2016, Barnes et al. 2017). Policy action and political will is often lacking when it comes to proactive environmental management, especially when it comes to climate change.

In order to foster adaptive capacity across scales and support actions from community development to government interventions (Serrao-Neumann et al. 2016), I highlight five challenges for linking adaptive capacity to action based on the component parts of my thesis:

1. Consider scale for assessment and building adaptive capacity. Scalar mismatches lead to inaccurate or intangible relative measures and suggestions of adaptive actions (Chapter 2).
2. Build consistency in results. Adaptive capacity is and has been assessed in a diversity of ways, using a diversity of metric and principles. By mainstreaming a shorter set of assessment tools applicable to specific scales, and making those tools broadly accessible, the lessons from adaptive capacity evaluations may be more readily applied to governmental and non-governmental action (Chapter 2).
3. Consider framing assessments for policy needs: Integrate decision makers into the process. Rather than conducting adaptation or adaptive capacity assessments in isolation, work across sectors and with policy makers to frame assessments and lessons in actionable policy terms (Chapter 5).

4. Prioritize interdisciplinary assessments. Social-ecological systems management is more likely to successfully build adaptive capacity across natural and social systems if assessments are integrated. Tradeoffs and interactions exist across social ecological systems and considering these throughout the assessment process will enable actions that build adaptive capacity without surprise negative effects (Chapter 3 & 5).
5. Focus on collaborative governance and institutions which allow for stakeholder agency and transformative partnerships in order to foster adaptive responses to global threats (i.e. climate change) (Chapter 6).

Overall, these lessons and directions for applying adaptive capacity may improve the ability of communities and in particular, the social-ecological system in coastal BC, to prepare for global change. More work is certainly needed to test the implications of these tools for directing adaptive capacity research and development over time in a variety of contexts. Future research into implementing slow and rapid interventions to build adaptive capacity is also required to order to build a toolbox of reflexive adaptive actions for collaborative governance and potential transformations.

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Appendix A: Supplementary Material, Chapter 2

Table A.1: Comparison of 11 Approaches for Analyzing Adaptive Capacity: Strengths, weaknesses, insights, implications and applications. Key references are included of case study examples and reviews for each method, where available.

Approach	Description	Details	Strengths, Weaknesses	Insights, Implications, Application	Key References
Large scale social indicators	Studies of relative adaptive capacity (or inversely related indicators of vulnerability), based on existing socio-economic or social data across the system.	Key Methods: Relative community assessments of risk exposure (e.g. to climate change), system sensitivity (i.e. resource dependence), and adaptive capacity of the social system (wealth, governance, assets, learning, etc.). System focus: Social Scale of Analysis: Communities to state to cross-national Temporal Focus: Present	Strengths: Can provide rapid outcomes for decision makers, and be useful for communicating differences in vulnerability and adaptive capacity among different regions, populations and communities. Relatively easy to conduct - relies on simple surveys at community level (e.g. from focus groups and RRA type research) or on secondary data. Weakness: Indices are often generic, theoretical, and composite: Difficult to evaluate. Doesn't allow for evaluations of the effectiveness of responses; difficult to incorporate traditional or cultural knowledge. Relative measures only; difficult to apply to policy for building adaptive capacity in a particular place.	Insights: Allows a broad understanding of potential relative response to stress or opportunities, generally related to how the combination of hazard exposure, dependency (sensitivity) and adaptive capacity led to differential vulnerability. Implications & Applications: Local management is not very responsive at this scale. Useful for policy and governance insights across communities or regions.	(Himes-Cornell et al. 2016) (Himes-Cornell and Kasperski 2015) (Barange et al. 2014) (Hughes et al. 2012) (Allison et al. 2009) (Brooks et al. 2005) (Yohe and Tol 2002)

Large scale ecological indicators and models	Modeling of past and present ecological changes and future adaptation potential of species and fisheries along with projected environmental changes	Key Methods: Mean responses to changes in environmental conditions: species distribution shifts, species' adaptive capacity index, rate of evolutionary changes. Attention to: Ecological Scale of Analysis: Species, biological communities, and fisheries (e.g. Large Marine Ecosystem scale) Temporal Focus: Past, present and future.	Strengths: Reveal large-scale pattern of adaptive responses and capacity to adapt to ecological change from both the perspective of species, and the fishery response to that change. Weakness: Low resolution because of limitation of data or model, need downscaling to be directly usable for regional and local scale studies; confidence is limited by the state of knowledge on species' and fisheries' adaptive responses.	Insights: Understand how species are responding to changing conditions through distributional changes, and how some fisheries are adapting to that through changes in species composition of catches. Implications & Applications: The rate of evolutionary adaptation may not be fast enough under the current rate of warming, particularly for species that have a low adaptive capacity (e.g., low genetic variability, slow turn-over rate). This tool is policy relevant for larger regional/national governance, and can be applied to identify species/fisheries most vulnerable to climate change.	(Cheung et al. 2013) (Cheung et al. 2012) (Gattuso et al. 2015a) (Cheung et al. 2015) (Sumaila et al. 2011) (Lam et al. 2014)
Integrated social-ecological indicators	Studies of the adaptive capacity of social-ecological systems based on existing socio-economic and ecological data within or across systems	Key Methods: Assesses the adaptive capacity of social-ecological systems based on ecological and social data (e.g. time series of catches, biomass, ocean conditions, market price, participation). Uses existing data, key informant interviews. E.g. IMBER ADApT (Assessment of Responses based on Description, Appraisal and Typology): Vulnerability, Governability, Response and Appraisal. Attention to: Social-ecological Scale of Analysis: At all scales: Individual to multi-	Strengths: Combines multiple properties and characteristics of the system into a smaller number of variables with similar or greater descriptive power (similar to indicators of human health). E.g. The I-ADApT framework combines both quantitative and qualitative responses to enable more explanation of motivation, etc. The questionnaire format allows people involved in the event to express their opinions. Responses can be timely (e.g. as an event is happening) and does not necessarily rely on subsequent written/published reports. Weakness: Data intensive. Often considers relative measures:	Insights: Understanding of trade offs in fisheries adaptation: In times of rapid change (i.e. climate change), allowing for adaptability by fishers will be critical for the survival of their livelihoods. The I-ADApT framework provides insights which include both natural and social system attributes and responses, as well as how they were integrated. Practical solutions pertain to how scientists, managers, and communities involved in the event responded, at both short and longer time and spatial scales, across cases. Implications & Applications: Need more rapid and effective	(Aguilera et al. 2015) (Bundy et al. 2015) (Perry et al. 2011) (Barange et al. 2010) (Miller et al. 2010) (Cinner et al. 2013) (Cinner et al. 2012)

		communities to state to cross-national Temporal Focus: Past to present, with lessons for future integration of existing studies.	difficult to apply to local management. No evaluations of effectiveness of responses. Can be at an overly coarse scale with less application to local communities.	responses to marine social-ecological crises/events - relevant at a larger policy/governance level for management. IMBER-ADApT can be applied across cases based on a core set of indicators. This method has been applied to case studies (e.g., Monterey Bay, California), and is currently in development.	
Governance approaches	Approach to understand the role of institutions (rights, rules, norms) and governance dimensions of vulnerability and AC. Assessments not typically framed *a priori* by suites of indicators, but rather insights on institutional and governance dimensions of vulnerability and AC developed inductively from case experiences. Where the focus has been more directly oriented towards institutions/governance, some established attributes and indicators are available.	Key Methods: Assessment of governance often through conventional social science techniques (semi-structured interviews, focus groups, etc.); sometimes indicators used Attention to: Linked social-ecological systems and role of institutions and governance processes in mediating human interaction with the environment Scale of Analysis: Local (community-based institutions and governance arrangements) to macro (national, supra-national arrangements) Temporal Focus: Past, Present; Possible to use for future scenario planning.	Strengths: Opportunity to consider the role of existing institutions and governance arrangements in facilitating capacity of communities to adapt to change (i.e., as a dimensions of vulnerable and adaptive capacity); the importance of assessing the capacity of actors to modify institutions in response to change; and that governance is multi-faceted and requires assessments of daily practices of governance, issues of institutional design and its implications, and values and principles that frame governance Weakness: Limited attention to relations of power; emphasis is on governance as context, rather than an analytical lens with which to consider principles and values, institutional design, social practices (e.g. learning). Inadequate attention to the nature of change (i.e. incremental change versus thresholds of change or regime shifts).	Insights: Understand the role of networks and multilevel governance important attribute of adaptive capacity Institutions as pathways for knowledge co-production and social learning needed for adaptive capacity Understanding of community-based institutions (customary practices, norms) as sources of adaptive capacity, renewal. Implications & Applications: Enhanced understanding of the social and institutional (formal, non-formal) capacity of actors at multiple levels to make decisions about adaptation, and the linkages/feedbacks among decision making levels about adaptive capacity. Opportunity to apply governance and institutional assessments at multiple levels; contribute to bottom-up and top-down assessments of vulnerability and adaptive capacity.	(Dietz et al. 2003) (Gupta et al. 2010) (Pahl-Wostl 2009) (Brown et al. 2010) (Smit and Wandel 2006) (Armitage and Plummer 2010b)

Multiple community surveys	Studies between several communities where adaptive capacity is measured through assets and actions taken to respond to change. Indicators based on the 5 capitals (human, financial, physical, social, natural) and adaptive strategies.	Key Methods: Household surveys, semi-structured interviews, focus groups Attention to: Interactions between social and ecological stressors, livelihoods Scale of Analysis: Household to community Temporal Focus: Recent past (1 year) to present	Strengths: Allows for inclusion of cultural, historical, or traditional adaptive techniques. Leads to an understanding of potential barriers to adaptation (e.g., economic, cultural). Personal descriptions of adaptations show that strategies vary by socio-economic status (e.g. diversification vs. intensification for poor to wealthy fishers), with differentially impacts on the ecological system (e.g., diminishing vs. amplifying feedbacks). Weakness: Lower explanatory power and intervention actions as specific strategies are highly context specific	Insights: Insights into how social dynamics constrain or facilitate adaption and what the social/ecological consequences might be (e.g., intensification can increase pressure on resource), which provides better information for intervention depending on the goal of the intervention (e.g., interventions trying to reduce pressure on the resource by diversifying wealthy fishers' livelihoods may not work in this context). Implications & Applications: A more nuanced understanding of livelihood diversification as an adaptation strategy and of material wealth as for a potential barrier for adaptation. Methods can inform interventions to foster adaptive capacity or reduce vulnerability in communities or across sectors	(Blythe 2014) (Blythe et al. 2015) **(Blythe et al. 2014)** (Cinner et al. 2011)
Social experiments	Social: Field economic experiments where individuals make hypothetical decisions (for economic rewards) based on real-world daily decisions and behaviors relevant to their livelihoods and context.	Key Methods: Economic experiments: Individual choice behavior (Catch decisions). Attention to: Social Scale of Analysis: Local (individual and community) Temporal Focus: Fishers are using past experiences to make catch decisions in the present (which is what we are measuring), and are also reflecting on how these lessons are applicable for the future.	Strengths: Allows researcher to understand fisher decisions in response to different sources of uncertainty in a controlled and replicable way. May also have pedagogical value in providing a platform for reflection in an interactive environment about daily decisions and behavior. Weakness: Unless used with other approaches (i.e. interviews, surveys) does not answer questions about *why* some fishers respond and behave differently or have different levels of adaptive capacity.	Insights: Fishers (within this context) have agency to confront change and uncertainty by adjusting their fishing behaviors to counteract declines in fishery resources. It is a useful way to look at the social-ecological feedbacks of multiple drivers. Implications & Applications: Using this method provides an interactive space for reflection which could induce favorable (increased communication) or unfavorable (exacerbation of power asymmetries) changes in	(Camilo Cardenas and Carpenter 2005) (Castillo et al. 2011) (Gelcich et al. 2013). (Finkbeiner 2015)

				the community itself. No known applications of the results to action.	
Species level experiments	Lab or field based studies in which the responses of populations within a single species are assessed with respect to a particular stressor (e.g. temperature, water chemistry). The objective is to assess adaptive capacity (genotypic variation and/or phenotypic plasticity) to variation in environmental conditions.	Key Methods: Ecological experiments assess genotypic or phenotypic variation in observable traits (or loci) within species or populations exposed to different environmental conditions (e.g. temperature, different CO2 concentrations). E.g. Breeding designs, "common garden" experiments, molecular or genomics approaches, meta-analyses. Attention to: Ecological Scale of Analysis: Multiple populations/stocks (regional) Temporal Focus: Assess genetic adaptation or plasticity in traits to help explain current species distributions or predict future adaptive and evolutionary species responses.	Strengths: Conceptually simple experimental design (e.g. factorial breeding designs); Provides quantitative estimates of genetic variation, heritability or phenotypic plasticity for species and/or populations of species; Can provide evolutionary potential based on a single generation. Weakness: Logistical constraints on the number of species and/or populations that can be included in a single study; Controlled lab experiment does not account for natural variability in aquatic systems. Does not account for multiple interacting stressors (e.g. increased temperature and higher CO_2) or trait correlations; Experiments that target specific life-history stage or single generation do not capture multigenerational evolutionary potential. .	Insights: Provides species-specific quantitative assessment of evolutionary potential; quantitative estimates obtained can be combined with demographic information in model simulations to predict future species persistence and community dynamics; gain insight into what species and/or populations have more/less potential for future adaptation. Implications & Applications: Susceptibility to changing environmental conditions varies between species and between populations of the same species: implications for species management (e.g. managing to maintain stock diversity or standing genetic variation, fisheries targeting, and species conservation priorities and approaches). Can apply to selection of populations/stocks/species for aquaculture, hatchery breeding programs), changes to fisheries objectives.	(Bernhardt and Leslie 2011). (Jensen et al. 2008) (Reed et al. 2011) (Crozier et al. 2008) (Hutchings 2011b) (Whitney et al. 2013) (Munday et al. 2013) (Sunday et al. 2011c) (Muñoz et al. 2014)
Historical ethnographic approaches	Analysis of past adaptive responses within a community or among several communities; at a household or community level. Indicators are based on historical knowledge, traditional engagement with ecological community,	Key Methods: Understanding traditional knowledge systems and past adaptations; identifying times of change or stress in historical/archaeological record, oral histories, and personal experiences and analyzing responses to change	Strengths: Understanding of past types and scale of change, and what cultural/social/ ecological adaptations occurred in response; people can relate to changes experienced by ancestral peoples; can inspire adaptive capacity in contemporary circumstances	Insights: Knowledge transmission and sharing through stories and ceremonies contributes greatly to adaptive capacity of people and communities. Strong social structures really help communities adapt, along with access to resources. Knowing	(Alcorn et al. 2002) (Atleo 2011) (Berkes 2012) (Berkes et al. 2000) (Berkes et al. 2003)

	traditional ecological knowledge (TEK) holders	Attention to: Social-ecological (integration) Scale of Analysis: Local to regional Temporal Focus: Past, recent and distant	Weakness: Past changes and adaptations many not be relevant to modern circumstances; Takes time to gain community trust and acceptance; Not necessarily applicable at large scales.	how ancestors have responded to and overcome changes and difficulties can inspire people to face and adapt to change in their own lives Implications & Applications: Communities where strong ties between generations are apparent also benefit from adapting to change; access to traditional knowledge is important. Community leaders and others who are trained from a very young age provide knowledge bank to draw from. The use of stories, ceremony, art, to convey experiences of past adaptation can inspire and inform adaptation to changes today, and inform ecological restoration.	(Ford and Martinez 2000) (Menzies 2006) (Senos et al. 2006) (Turner 2014)
Participatory planning approaches	Urban and regional planning for resilience related to changing hydrological systems and risk assessments	Key Methods: Mixed methods: interviews, a regional survey and participant observation at key regional planning events over 3 years [and] participatory action research. Planning approaches to adaptive capacity have ranged from ‘participatory futures approaches’ to community-based climate change adaptation (by engaging and empowering community members to be active collaborators in re-visioning and developing scenarios about their communities that facilitates co-evolutionary	Strengths: Comprehensive, multiple streams of evidence, easy to triangulate evidence types. Participatory action research can foster new knowledge, learning, and action to support positive social/environmental change through reconfiguring the standard processes of knowledge production. An informal collaborative can be seen as a safe shadow space for learning more inclusive and less political that other regional forums where thinking out loud, revealing uncertainties, collectively troubleshooting and learning from neighbouring municipalities may not be doable or would be	Insights: Participatory vulnerability assessments can help identify adaptation strategies that are most feasible and practical in communities with a focus on risks that are already problematic; while climate stresses are reviewed along environmental and social stresses, allowing for integration and co-benefits with resource management, disaster preparedness and sustainable development initiatives. Implications & Applications: Allows for in-depth *understanding* and building of *adaptive capacity* which can serve as an effective link from assessment to action. This	(Pelling et al. 2008) (Folke et al. 2002) (Gidley et al. 2009) (Smit and Wandel 2006) (Ballard and Belsky 2010) (Tschakert and Dietrich 2010)

		adaptation to climate change rather than passive adaptation. Attention to: Socio-ecological system Scale of Analysis: Community (municipal), sub-regional, and regional Temporal Focus: Past (historical adaptations), present, and future	considered as inappropriate (less inclusive). Weakness: Very time consuming	methodology allows to identify and address specific hazards and risks while building a generalized capacity to address change. Study findings may inform local and metropolitan scale actions by partner organizations.	
Qualitative interview approaches	Inductive qualitative assessment within a community using local knowledge engagement. Indicators include various assets, organizations, and other supports that interviewees mentioned help or have helped them adapt to changes and their impacts.	Key Methods: Interviews and focus groups; unstructured and semi-structured interview format Attention to: Social and ecological components Scale of Analysis: Household to community Temporal Focus: Past and present impacts of change and drivers of adaptive capacity	Strengths: Gives an in-depth understanding of a community with household or individual responses to change. Builds a relationship with that community. Based on self-perception of adaptive capacity from the perspective of the community members themselves. Weakness: Very time intensive; requires community buy-in, often pre-existing relationships or understanding of the community are critical. Need to build trust to collect information.	Insights: Gain a greater range of the elements of adaptive capacity. Appreciate the nuance of limitations and opportunities at an individual or household level. Insights included: 1) types and trajectories of significant processes of change being experienced by community members, 2) the array of responses being taken to change and 3) the mechanisms that either inhibit or strengthen ability to adapt or cope with changes, including nuanced data around access to supports. Implications & Applications: Provides data for planners, decision makers, and communities on what types of policies, programs, and other supports might lead to improved adaptive capacity for groups at the local level. An increased understanding of barriers or limitations to accessing exiting supports is key to increasing successful responses across community groups.	(Bennett et al. 2015b) (Knapp et al. 2014) (McCubbin et al. 2015) (Ruiz-Mallén et al. 2015)

Mixed-methods approaches	A combination of social indicators, including interviews, surveys, focus groups, document reviews, and Photovoice processes in order to understand flexibility and diversity, the ability to self-organize, social knowledge and learning, and access to assets.	Key Methods: Mix of qualitative, quantitative and participatory approaches. Attention to: Primarily social, as well as ability to proactively respond to ecological change. Scale of Analysis: Household, Individual community to multiple community. Temporal Focus: Present	Strengths: Nuanced understanding of the factors that lead to adaptive capacity. Leads to abundant data. Differentiation of the factors that led to adaptive capacity to different changes – e.g., climate change, fisheries declines, and livelihood opportunities. Results are comprehensive, showing whether communities are able to adapt, cope or react. Produces lots of recommendations. Weakness: Very time consuming and expensive. Difficult to confirm the recommendations/outcomes with stakeholders.	Insights: Numerous insights about how to increase adaptive capacity to different changes that are occurring. Insights into some generic actions to build adaptive capacity e.g., improving relations, gender considerations, education. Research can provide insights into which factors helped communities to adapt, cope or react to changes that are occurring. Implications & Applications: Suggests actions that communities might take for policies or programs that might be implemented at higher levels to increase community adaptive capacity. No clear path to application of the results.	(Cinner et al. 2009) (McClanahan et al. 2009) (Bennett et al. 2015b) (Bennett and Dearden 2013) (Cinner et al. 2015b) (Marshall et al. 2010) (Marshall et al. 2013)

Appendix B: Supplementary Material, Chapter 3

Expert Elicitation Questions

1. Are you aware of new or work in process data/literature on these specific climate impacts for the MaPP region?
2. Are you aware of specific sectorial impacts in the MaPP region?
3. Are you aware of additional projects/literature on climate vulnerabilities in the MaPP region?
4. Are you aware of additional projects/literature on the adaptation actions or recommendations in the MaPP region?
5. In your opinion, what are the main gaps in projections and impacts in this region?
6. Do you have any recommendations to fill these gaps?
7. Do you have any recommendations on who else to talk to?

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Appendix C: Supplementary Material, Chapter 4

BC Parks analysis summary tables: Climate Change Projections and Inferred Species Presence/Absence Data for Individual BC MPAs

Anne Vallee (Triangle Island) Ecological Reserve	1
Banks Nii Luutiksm Conservancy	2
Beresford Island Ecological Reserve	3
Bishop Bay-Monkey Beach Conservancy	4
Brooks Peninsula Park (Muqqiwn Park)	5
Broughton Archipelago Marine Park	6
Byers/Conroy/Harvey/Sinnett Islands Ecological Reserve	7
Cape Scott Park	8
Codville Lagoon Marine Park	9
Cormorant Channel Marine Park	10
Daawuuxusda Conservancy	11
Dala-Kildala Rivers Estuaries Park	12
Duu Gusd Conservancy	13
Dzawadi/Klinaklini Estuary Conservancy	14
Ecstall Spoksuut Conservancy	16
Fiordland Conservancy	17
Foch-Gilttoyees Park	18
Gitxaala Nii Luutiksm/Kitkatla Conservancy	19
God’s Pocket Marine Park	20
Hakai Luxvbalis Conservancy	21
Homathko Estuary Park	22
Huchsduwachsdu Nuyem Jees/Kitlope Heritage Conservancy	24
Kamdis Conservancy	25
Kennedy Island Conservancy	26
Khutzeymateen Inlet Conservancy	27
Khutzeymateen Park (Khutzeymateen/K’Tzim-A-Deen Grizzly Sanctuary)	28
Kilbella Estuary Conservancy	29
Klewnuggit Inlet Marine Park	31
Ksgaxl/Stephens Island Group Conservancy	32
Kunxalas Conservancy	33
K’uuna Gwaay Conservancy	34
Lanz and Cox Islands Park	35
Lax Ka’Gass/Campania Conservancy	36
Lax Kul Nii Luutiksm/Bonilla Conservancy	37
Lax Kwaxl/Dundas-Melville Islands Conservancy	38
Lax Kwil Dziidz/Fin Conservancy	39
Lowe Inlet Marine Park	40
Lucy Islands Conservancy	41
Mahpahkum-Ahkwuna/Deserters-Walker Conservancy	42
Maxtaktsm’Aa/Union Passage Conservancy	43
Monckton Nii Luutiksm Conservancy	44
Naikoon Park	45
Nang Xaldangaas Conservancy	46
Negiy/Nekite Estuary Conservancy	47
Octopus Islands Marine Park	48
Penrose Island Marine Park	50
Qwiquallaaq/Boat Bay Conservancy	51
Raft Cove Park	52
Robson Bight (Michael Bigg) Ecological Reserve	53
Rock Bay Marine Park	54
Sartine Islands Ecological Reserve	56
Skeena Bank Conservancy	57
Small Inlet Marine Park	58
Ugwiwey/Cape Caution Conservancy	60
Union Passage Marine Park	62
Vladimir J. Krajina (Port Chanal) Ecological Reserve	63
Wakeman Estuary Conservancy	64
Wales Harbour Conservancy	65
Yaaguun Gandlaay Conservancy	66

Anne Vallee (Triangle Island) Ecological Reserve

Baseline number of modeled species of interest within MPA (2016)	84 species		
Species lost by 2060 within MPA (RCP 8.5)	Starry flounder Pacific halibut Lingcod Pacific sardine	Rougheye rockfish China rockfish Redbanded rockfish Red Irish lord	Pacific tomcod Pile perch Puget Sound sculpin Pink salmon
Species gained by 2060 within MPA (RCP 8.5)	Thatched barnacle Butter clam Pacific razor clam Nuttall cockle Varnish clam	Manila clam Humpback shrimp Purple shore crab Green shore crab	Pacific blue mussel Pacific cupped oyster Kelp perch Sidestriped shrimp

Banks Nii Luutiksm Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

Beresford Island Ecological Reserve

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Pile perch Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Varnish clam Humpback shrimp

Bishop Bay-Monkey Beach Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Pacific sardine

Brooks Peninsula Park (Muqqiwn Park)

Baseline number of modeled species of interest within MPA (2016)	92 species	
Species lost by 2060 within MPA (RCP 8.5)	Manila clam Pacific tomcod Pile perch	Rougheye rockfish Dusky sculpin Puget Sound sculpin
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Purple shore crab Sidestriped shrimp	Humpback shrimp Sablefish

Broughton Archipelago Marine Park

Baseline number of modeled species of interest within MPA (2016)	85 species		
Species lost by 2060 within MPA (RCP 8.5)	Manila clam Dungeness crab Pacific tomcod Pile perch	Red sea urchin Widow rockfish Yellowtail rockfish Chilipepper rockfish	Redstripe rockfish Chinook salmon Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Flathead sole Sidestriped shrimp Humpback shrimp	Longspine thornyhead Yellowmouth rockfish Shortraker rockfish Redbanded rockfish	Sablefish Pacific sardine Dusky sculpin

Byers/Conroy/Harvey/Sinnett Islands Ecological Reserve

Baseline number of modeled species of interest within MPA (2016)	96 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp

Cape Scott Park

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Pile perch Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Varnish clam Humpback shrimp

Codville Lagoon Marine Park

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

Cormorant Channel Marine Park

Baseline number of modeled species of interest within MPA (2016)	0 species

Daawuuxusda Conservancy

Baseline number of modeled species of interest within MPA (2016)	92 species	
Species lost by 2060 within MPA (RCP 8.5)	Kelp greenling Pacific tomcod Pile perch	Red sea urchin Rougheye rockfish Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Varnish clam Olympia oyster	Humpback shrimp Longspine thornyhead Pacific sardine

Dala-Kildala Rivers Estuaries Park

Baseline number of modeled species of interest within MPA (2016)	86 species		
Species lost by 2060 within MPA (RCP 8.5)	Manila clam Green sea urchin Kelp greenling Pacific tomcod	Pile perch Red sea urchin Yellowtail rockfish Yelloweye rockfish	Redstripe rockfish Chinook salmon Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Varnish clam Pacific halibut Olympia oyster	Humpback shrimp Chilipepper rockfish Longspine thornyhead Vermillion rockfish	Redbanded rockfish Pacific sardine Dusky sculpin

Duu Gusd Conservancy

Baseline number of modeled species of interest within MPA (2016)	93 species	
Species lost by 2060 within MPA (RCP 8.5)	Kelp greenling Pacific tomcod Red sea urchin	Rougheye rockfish Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Olympia oyster Humpback shrimp	Longspine thornyhead Pacific sardine

Dzawadi/Klinaklini Estuary Conservancy

Baseline number of modeled species of interest within MPA (2016)	21 species		
Species lost by 2060 within MPA (RCP 8.5)	Green sea urchin Eulachon Rex sole Rock sole Pacific herring Lingcod Pacific tomcod	Widow rockfish Yellowtail rockfish Black rockfish Bocaccio rockfish Canary rockfish Pink salmon	Sockeye salmon Chinook salmon Coho salmon Rock scallop Dolly Varden trout Albacore tuna
Species gained by 2060 within MPA (RCP 8.5)	Northern abalone Acorn barnacle Gooseneck barnacle Giant Pacific chiton Black chiton Butter clam Pacific razor clam	Nuttall cockle Pacific gaper Tanner crab Purple shore crab Red sea cucumber Longnose skate	Spiny dogfish Pacific sanddab English sole Olympia oyster Shortraker rockfish Spotfin sculpin

Ecstall Spoksuut Conservancy

Baseline number of modeled species of interest within MPA (2016)	92 species	
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Widow rockfish	Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Humpback shrimp Longspine thornyhead Yellowmouth rockfish	Sablefish Pacific sardine

Fiordland Conservancy

Baseline number of modeled species of interest within MPA (2016)	92 species		
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Widow rockfish	Rougheye rockfish Steelhead	
Species gained by 2060 within MPA (RCP 8.5)	Humpback shrimp Longspine thornyhead Yellowmouth rockfish	Sablefish Pacific sardine	

Foch-Gilttoyees Park

Baseline number of modeled species of interest within MPA (2016)	90 species		
Species lost by 2060 within MPA (RCP 8.5)	Manila clam Pacific tomcod Pile perch	Red sea urchin Redstripe rockfish Rougheye rockfish	Chinook salmon Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Varnish clam Pacific halibut	Humpback shrimp Longspine thornyhead Redbanded rockfish	Pacific sardine Dusky sculpin

Gitxaala Nii Luutiksm/Kitkatla Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

God's Pocket Marine Park

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Pile perch Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Varnish clam Humpback shrimp

Hakai Luxvbalis Conservancy

Baseline number of modeled species of interest within MPA (2016)	96 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp

Homathko Estuary Park

Baseline number of modeled species of interest within MPA (2016)	17 species		
Species lost by 2060 within MPA (RCP 8.5)	Giant acorn barnacle Eulachon Rex sole Pacific herring Lingcod Pacific tomcod	Widow rockfish Yellowtail rockfish Bocaccio rockfish Canary rockfish Pink salmon Sockeye salmon	Chinook salmon Rock scallop Steelhead White sturgeon Albacore tuna
Species gained by 2060 within MPA (RCP 8.5)	Northern abalone Acorn barnacle Gooseneck barnacle Giant Pacific chiton Butter clam Pacific razor clam	Nuttall cockle Pacific gaper Tanner crab Purple shore crab Green shore crab	Longnose skate Spiny dogfish Pacific sanddab Shortraker rockfish Spotfin sculpin

Huchsduwachsdu Nuyem Jees/Kitlope Heritage Conservancy

Baseline number of modeled species of interest within MPA (2016)	0 species

Kamdis Conservancy

Baseline number of modeled species of interest within MPA (2016)	92 species	
Species lost by 2060 within MPA (RCP 8.5)	Kelp greenling Pacific tomcod Red sea urchin	Widow rockfish Rougheye rockfish Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Humpback shrimp Longspine thornyhead Yellowmouth rockfish	Sablefish Pacific sardine

Kennedy Island Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

Khutzeymateen Inlet Conservancy

Baseline number of modeled species of interest within MPA (2016)	94 species	
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish	Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead	Pacific sardine

Khutzeymateen Park (Khutzeymateen/K'Tzim-A-Deen Grizzly Sanctuary)

Baseline number of modeled species of interest within MPA (2016)	93 species	
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish	Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Humpback shrimp Longspine thornyhead Sablefish	Pacific sardine

Kilbella Estuary Conservancy

Baseline number of modeled species of interest within MPA (2016)	62 species		
Species lost by 2060 within MPA (RCP 8.5)	Horse clam Red rock crab Eulachon Rex sole Pacific herring Northern horse mussel Pacific cupped oyster Pacific cod	Pacific tomcod Pile perch Spot shrimp/prawn Red sea urchin Widow rockfish Yellowtail rockfish Bocaccio rockfish	Canary rockfish Silvergray rockfish Chinook salmon Rock scallop Puget Sound sculpin Steelhead Albacore tuna
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Tanner crab Purple shore crab Longnose skate Spiny dogfish Arrowtooth flounder Pacific dover sole English sole	Kelp greenling Pacific halibut Prawn / northern shrimp Sidestriped shrimp Humpy shrimp Yellowmouth rockfish Copper rockfish China rockfish	Tiger rockfish Vermillion rockfish Redbanded rockfish Sablefish Pacific sardine Weathervane scallop Spotfin sculpin

Klewnuggit Inlet Marine Park

Baseline number of modeled species of interest within MPA (2016)	88 species		
Species lost by 2060 within MPA (RCP 8.5)	Manila clam Pacific cupped oyster Pacific tomcod	Red sea urchin Widow rockfish Redstripe rockfish	Rougheye rockfish Chinook salmon Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Pacific halibut Sidestriped shrimp Humpback shrimp	Longspine thornyhead Yellowmouth rockfish Redbanded rockfish	Sablefish Pacific sardine Dusky sculpin

Ksgaxl/Stephens Island Group Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

Kunxalas Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

K'uuna Gwaay Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

Lanz and Cox Islands Park

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Pile perch Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Varnish clam Humpback shrimp

Lax Ka'Gass/Campania Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Pacific sardine

Lax Kul Nii Luutiksm/Bonilla Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

Lax Kwaxl/Dundas-Melville Islands Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

Lax Kwil Dziidz/Fin Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Pacific sardine

Lowe Inlet Marine Park

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Pacific sardine

Lucy Islands Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish

Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

Mahpahkum-Ahkwuna/Deserters-Walker Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Pile perch Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Varnish clam Humpback shrimp

Maxtaktsm'Aa/Union Passage Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Pacific sardine

Monckton Nii Luutiksm Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Pacific sardine

Naikoon Park

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead

Nang Xaldangaas Conservancy

Baseline number of modeled species of interest within MPA (2016)	94 species		
Species lost by 2060 within MPA (RCP 8.5)	Kelp greenling Pacific tomcod Red sea urchin	Rougheye rockfish Steelhead	
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead	Pacific sardine	

Negiy/Nekite Estuary Conservancy

Baseline number of modeled species of interest within MPA (2016)	86 species		
Species lost by 2060 within MPA (RCP 8.5)	Manila clam Rex sole Pacific cupped oyster Pacific tomcod	Pile perch Red sea urchin Widow rockfish Redstripe rockfish	Rougheye rockfish Chinook salmon Rock scallop
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle English sole Pacific halibut Sidestriped shrimp	Humpback shrimp Longspine thornyhead Yellowmouth rockfish Redbanded rockfish	Sablefish Dusky sculpin Spotfin sculpin

Octopus Islands Marine Park

Baseline number of modeled species of interest within MPA (2016)	67 species		
Species lost by 2060 within MPA (RCP 8.5)	Manila clam Dungeness crab Green sea urchin Arrowtooth flounder Pacific dover sole Starry flounder Kelp greenling Pacific herring Pacific lamprey	Pacific blue mussel Pacific tomcod Prawn / northern shrimp Red sea urchin Yellowtail rockfish Canary rockfish Redstripe rockfish Longspine thornyhead Yellowmouth rockfish	Tiger rockfish Pink salmon Chinook salmon Coho salmon Weathervane scallop Spiny scallop Steelhead White sturgeon
Species gained by 2060 within MPA (RCP 8.5)	Northern abalone Nuttall cockle Pacific gaper Purple shore crab Green shore crab Yellowfin sole	Pacific sanddab Olympia oyster Sidestriped shrimp Humpback shrimp Spot shrimp/prawn Shortraker rockfish	Redbanded rockfish Cabezon Dusky sculpin Thornback sculpin Cutthroat trout

Penrose Island Marine Park

Baseline number of modeled species of interest within MPA (2016)	93 species	
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Pile perch Red sea urchin	Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Humpback shrimp Longspine thornyhead	Sablefish

Qwiquallaaq/Boat Bay Conservancy

Baseline number of modeled species of interest within MPA (2016)	0 species

Raft Cove Park

Baseline number of modeled species of interest within MPA (2016)	93 species	
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Pile perch Rougheye rockfish	Dusky sculpin Puget Sound sculpin
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Varnish clam Purple shore crab	Sidestriped shrimp Humpback shrimp

Robson Bight (Michael Bigg) Ecological Reserve

Baseline number of modeled species of interest within MPA (2016)	0 species		

Rock Bay Marine Park

Baseline number of modeled species of interest within MPA (2016)	67 species		
Species lost by 2060 within MPA (RCP 8.5)	Manila clam Dungeness crab Green sea urchin Arrowtooth flounder Pacific dover sole Starry flounder Kelp greenling Pacific herring Pacific lamprey	Pacific blue mussel Pacific tomcod Prawn / northern shrimp Red sea urchin Yellowtail rockfish Canary rockfish Redstripe rockfish Longspine thornyhead Yellowmouth rockfish	Tiger rockfish Pink salmon Chinook salmon Coho salmon Weathervane scallop Spiny scallop Steelhead White sturgeon
Species gained by 2060 within MPA (RCP 8.5)	Northern abalone Nuttall cockle Pacific gaper Purple shore crab Green shore crab Yellowfin sole	Pacific sanddab Olympia oyster Sidestriped shrimp Humpback shrimp Spot shrimp/prawn Shortraker rockfish	Redbanded rockfish Cabezon Dusky sculpin Thornback sculpin Cutthroat trout

Sartine Islands Ecological Reserve

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Pile perch Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Varnish clam Humpback shrimp

Skeena Bank Conservancy

Baseline number of modeled species of interest within MPA (2016)	92 species	
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Widow rockfish	Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Humpback shrimp Longspine thornyhead Yellowmouth rockfish	Sablefish Pacific sardine

Small Inlet Marine Park

Baseline number of modeled species of interest within MPA (2016)	67 species		
Species lost by 2060 within MPA (RCP 8.5)	Manila clam Dungeness crab Green sea urchin Arrowtooth flounder Pacific dover sole Starry flounder Kelp greenling Pacific herring Pacific lamprey	Pacific blue mussel Pacific tomcod Prawn / northern shrimp Red sea urchin Yellowtail rockfish Canary rockfish Redstripe rockfish Longspine thornyhead Yellowmouth rockfish	Tiger rockfish Pink salmon Chinook salmon Coho salmon Weathervane scallop Spiny scallop Steelhead White sturgeon
Species gained by 2060 within MPA (RCP 8.5)	Northern abalone Nuttall cockle Pacific gaper Purple shore crab Green shore crab Yellowfin sole	Pacific sanddab Olympia oyster Sidestriped shrimp Humpback shrimp Spot shrimp/prawn Shortraker rockfish	Redbanded rockfish Cabezon Dusky sculpin Thornback sculpin Cutthroat trout

Ugwiwey/Cape Caution Conservancy

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Pile perch Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle Humpback shrimp

Union Passage Marine Park

Baseline number of modeled species of interest within MPA (2016)	95 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Pacific sardine

Vladimir J. Krajina (Port Chanal) Ecological Reserve

Baseline number of modeled species of interest within MPA (2016)	89 species		
Species lost by 2060 within MPA (RCP 8.5)	Green sea urchin	Pile perch	Rougheye rockfish
	Kelp greenling	Red sea urchin	Steelhead
	Pacific tomcod	Yelloweye rockfish	
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle	Sidestriped shrimp	Longspine thornyhead
	Varnish clam	Humpback shrimp	Vermillion rockfish
	Olympia oyster	Chilipepper rockfish	Pacific sardine

Wakeman Estuary Conservancy

Baseline number of modeled species of interest within MPA (2016)	82 species		
Species lost by 2060 within MPA (RCP 8.5)	Manila clam	Red sea urchin	Redstripe rockfish
	Dungeness crab	Widow rockfish	Chinook salmon
	Pacific tomcod	Yellowtail rockfish	Puget Sound sculpin
	Pile perch	Chilipepper rockfish	Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Nuttall cockle	Sidestriped shrimp	Shortraker rockfish
	Tanner crab	Humpback shrimp	Redbanded rockfish
	Purple shore crab	Longspine thornyhead	Sablefish
	Flathead sole	Yellowmouth rockfish	Pacific sardine
	Pacific halibut		

Wales Harbour Conservancy

Baseline number of modeled species of interest within MPA (2016)	94 species
Species lost by 2060 within MPA (RCP 8.5)	Pacific tomcod Red sea urchin Rougheye rockfish
Species gained by 2060 within MPA (RCP 8.5)	Varnish clam Humpback shrimp Longspine thornyhead Pacific sardine

Yaaguun Gandlaay Conservancy

Baseline number of modeled species of interest within MPA (2016)	92 species	
Species lost by 2060 within MPA (RCP 8.5)	Kelp greenling Pacific tomcod Red sea urchin	Widow rockfish Rougheye rockfish Steelhead
Species gained by 2060 within MPA (RCP 8.5)	Humpback shrimp Longspine thornyhead Yellowmouth rockfish	Sablefish Pacific sardine

B: Marxan scenarios: Additional maps & spatial file

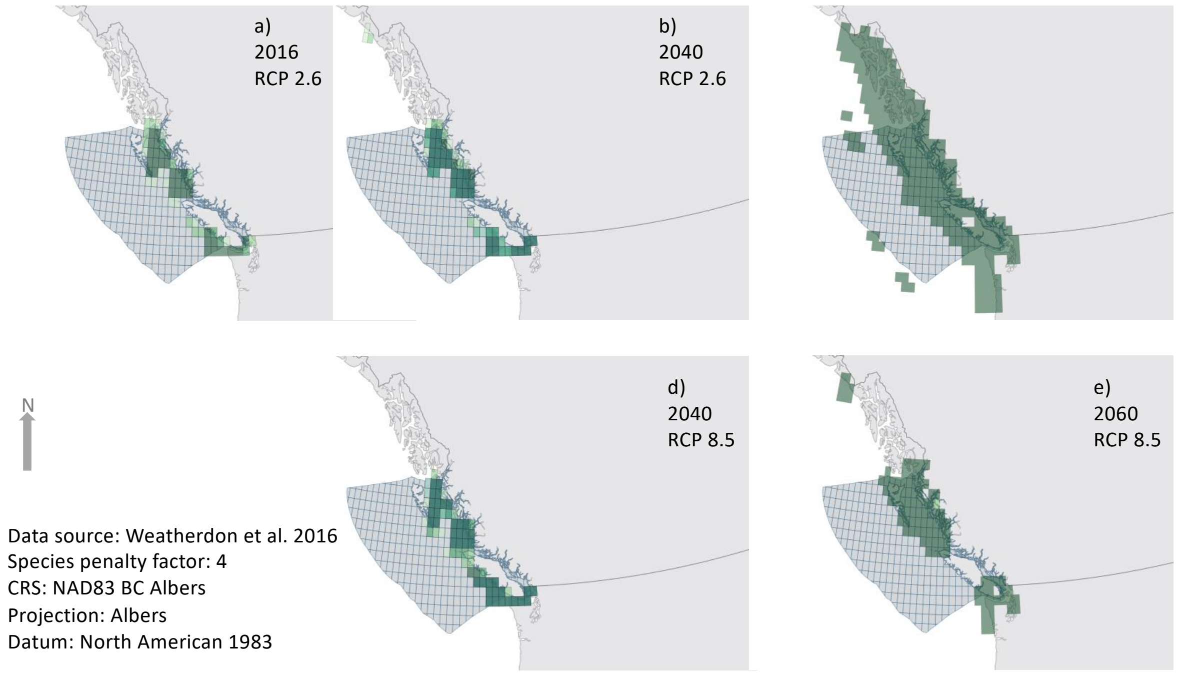

Figure B.1: Increasing and poleward shifting selection of priority planning units in the summed solution (green) over decades from 2016 (a), 2040(b, d), 2060 (c, e) at RCP 2.6 and 8.5. Grey planning unit grid represents the BC Exclusive Economic Zone.

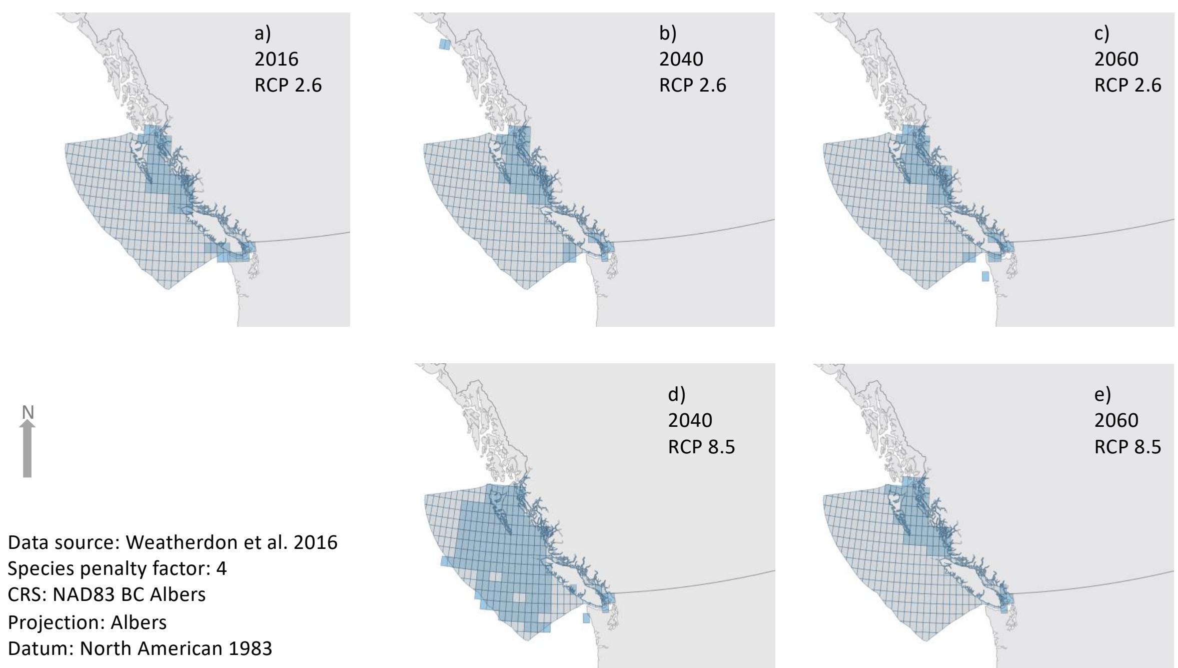

Figure B. 2: ‘Resilience’ scenarios where the target file was allowed to vary with the projection year and RCP pathway. Increasing and poleward shifting selection of priority planning units in the summed solution (green) over decades from 2016 (a), 2040 (b, d), to 2060 (c, e). Grey planning unit grid represents the BC EEZ.

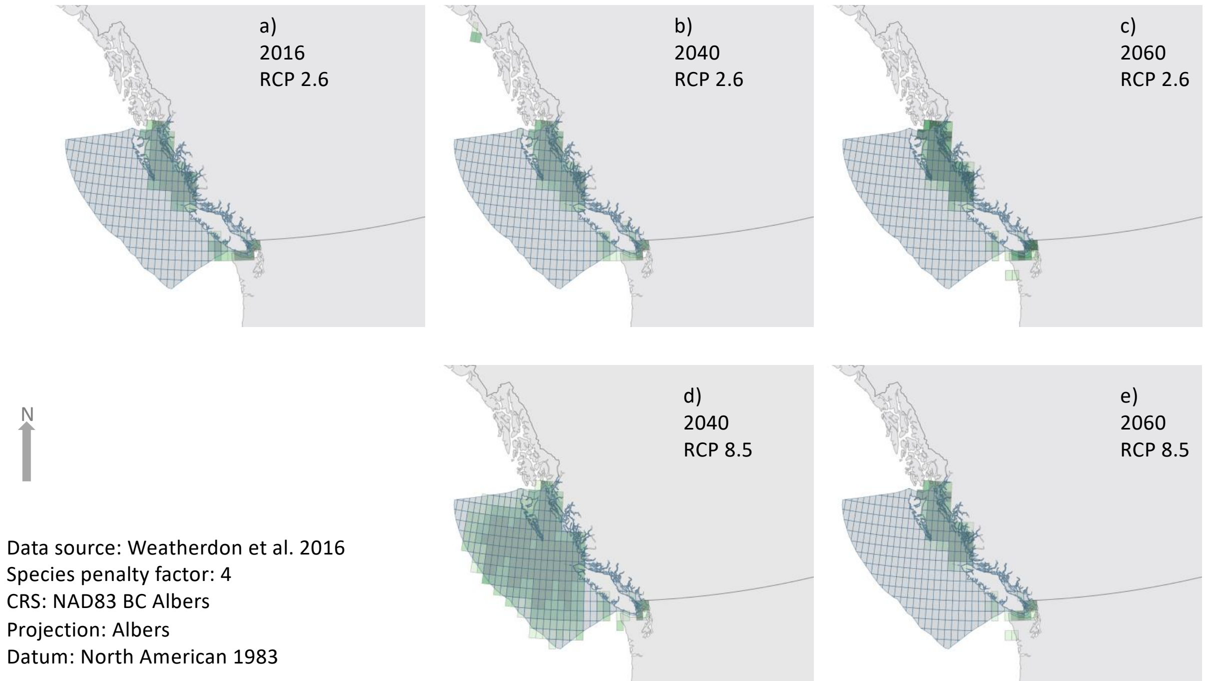

Figure B.3: 'Resilience' scenarios where the target file was allowed to vary with the projection year and RCP pathway. Increasing and poleward shifting selection of priority planning units in the summed solution (green) over decades from 2016 (a), 2040 (b, d), to 2060 (c, e). Grey planning unit grid represents the BC EEZ.

Table B.1: Species that did not meet targets, 2060, RCP 2.6. PU = planning unit.

Species ID	Taxon Key	Common Name	Occurrences Held (PUs)	Target Met
11	600503	Yellowtail rockfish	133	no
12	600509	Lingcod	166	no
26	604140	Cabezon	219	no
34	690064	Butter clam	258	no
37	690279	Olympia oyster	172	no
42	690287	Red rock crab	231	no
45	690615	Sidestriped shrimp	17	no
49	690664	Pacific gaper	207	no
53	700005	Yelloweye rockfish	71	no
56	700008	Yellowmouth rockfish	211	no
60	700012	Copper rockfish	174	no
69	700021	Rock scallop	210	no
73	700026	Cutthroat trout	181	no
77	700031	Pile perch	226	no
78	700032	Kelp perch	230	no
84	700038	Thornback sculpin	211	no
87	700041	Black chiton	184	no
92	700046	Acorn barnacle	0	no
98	700055	Spiny dogfish	0	no

Table B.2: Species included in the analysis, 2016-2060. Sp. 600142 was not included by 2060, RCP 8.5 due to projection uncertainty as reflected in Weatherdon et al. 2016.

id	TaxonKey	TaxonName	CommonName
1	600142	Thunnus alalunga	Albacore tuna
2	600239	Oncorhynchus mykiss	Steelhead
3	600240	Oncorhynchus gorbuscha	Pink salmon
4	600241	Oncorhynchus keta	Chum salmon
5	600243	Oncorhynchus nerka	Sockeye salmon
6	600244	Oncorhynchus tshawytscha	Chinook salmon
7	600245	Oncorhynchus kisutch	Coho salmon
8	*600256*	Thaleichthys pacificus	Eulachon
9	600308	Gadus macrocephalus	Pacific cod
10	600502	Sebastes entomelas	Widow rockfish
11	600503	Sebastes flavidus	Yellowtail rockfish
12	600509	Ophiodon elongatus	Lingcod
13	600512	Anoplopoma fimbria	Sablefish
14	600514	Hippoglossus stenolepis	Pacific halibut
15	600517	Atheresthes stomias	Arrowtooth flounder
16	600519	Hippoglossoides elassodon	Flathead sole
17	600520	Limanda aspera	Yellowfin sole
18	601520	Clupea pallasii pallasii	Pacific herring
19	601879	Microgadus proximus	Pacific tomcod
20	*602594*	*Acipenser transmontanus*	*White sturgeon*
21	603971	Sebastes goodei	Chilipepper rockfish
22	603979	Sebastes melanops	Black rockfish
23	603987	Sebastes paucispinis	Bocaccio rockfish
24	603989	Sebastes pinniger	Canary rockfish
25	604009	Sebastolobus alascanus	Shortspine thornyhead
26	604140	Scorpaenichthys marmoratus	Cabezon
27	604215	Citharichthys sordidus	Pacific sanddab
28	604237	Eopsetta jordani	Petrale sole
29	604238	Glyptocephalus zachirus	Rex sole
30	604247	Microstomus pacificus	Pacific dover sole
31	604248	Parophrys vetula	English sole

32	604249	Platichthys stellatus	Starry flounder
33	624237	Lepidopsetta bilineata	Rock sole
34	690064	Saxidomus giganteus	Butter clam
35	690115	Metacarcinus magister	Dungeness crab
36	690269	Pandalus borealis	Prawn / northern shrimp
37	690279	Ostrea lurida	Olympia oyster
38	690283	Crassostrea gigas	Pacific cupped oyster
39	690284	Panopea abrupta	Pacific geoduck
40	690285	Protothaca staminea	Pacific littleneck clam
41	690286	Siliqua patula	Pacific razor clam
42	690287	Cancer productus	Red rock crab
43	690429	Patinopecten caurinus	Weathervane scallop
44	690494	Strongylocentrotus droebachiensis	Green sea urchin
45	690615	Pandalopsis dispar	Sidestriped shrimp
46	690616	Pandalus goniurus	Humpy shrimp
47	690617	Pandalus hypsinotus	Humpback shrimp
48	690651	Clinocardium nuttallii	Nuttall cockle
49	690664	Tresus nuttallii	Pacific gaper
50	700001	Parastichopus californicus	Red sea cucumber
51	700002	Sebastes brevispinis	Silvergray rockfish

Appendix D: Supplementary Material, Chapter 5

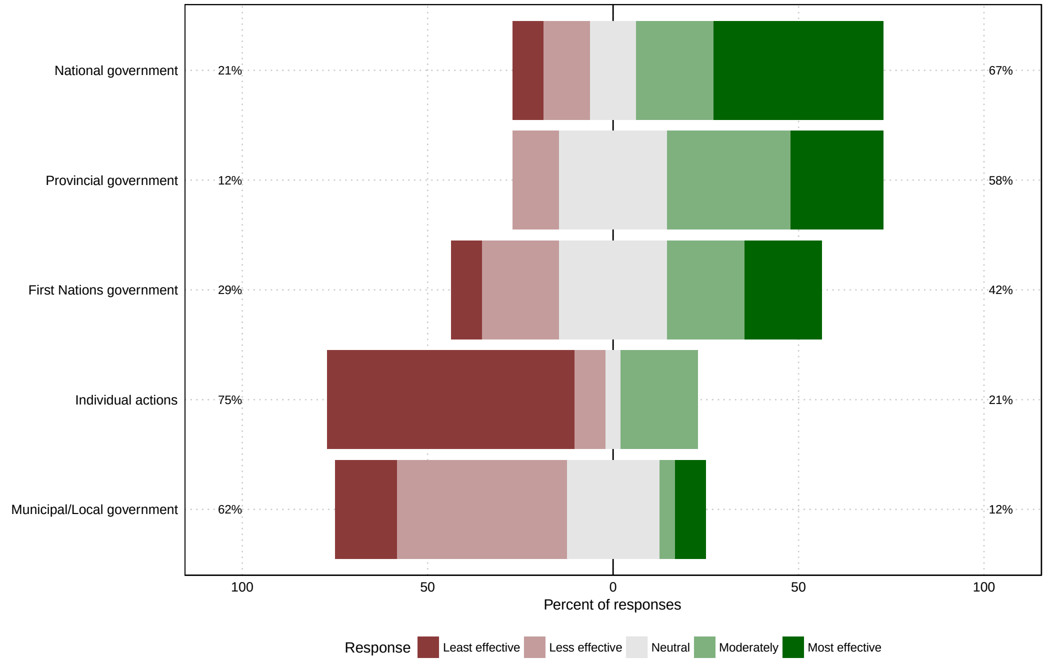

Figure D.1: Scales of decision-making thought to be most effective to achieve success in climate change adaptation (n=24).

Table D.1: Characteristics of interview participants (completed interviews, n=21)

Respondent #	Position	Scale/governance level	Interview? (n=8)
1	Planning	Other (no response)	
2	Management	First Nations	Y
3	Planning	Provincial	Y
4	Management	Federal	
5	Planning	First Nations	Y
6	Planning	First Nations	
7	Management	First Nations	
8	Planning	First Nations	
10	Management	First Nations	
11	Management	First Nations	
12	Management	First Nations	Y
13	Policy	Provincial	Y
14	Planning	Federal	
16	Planning	First Nations	Y
17	Research	Federal	
19	Planning/Policy/Management	Provincial	Y
20	Research	Federal	
21	Planning	First Nations	Y
22	Planning/Policy/Management	First Nations	

23	Management	First Nations (NGO)	
24	Planning	First Nations	

Table D.2: Thematic codes from open-ended questions

Topic	Codes
Observed environmental changes	Seasonality Seaweed Glaciers Freshwater Storms Ocean changes Species distribution changes Weather Erosion Invasive species Fish (changes in availability) Shellfish Berries
Consequences of failing to adapt to climate change	Social-ecological consequences Ecological loss Economic impact Infrastructure impact Conflict Cultural loss Food security Inappropriate management Inappropriate planning Community property impacts Social impacts Inability to adapt
Knowledge gaps to incorporate climate change	Action (policy) Capacity and training Data sharing and misinformation Uncertainty
Opportunities to incorporate climate change	Funding Education Research Policy leadership Capacity (time and staff)

Table D.3: The three most common responses to open-ended questions on adaptation planning, summarized by the governance scale at which practitioners work. Bolded text reflects issues that were identified by more than 2 levels.

	What are the consequences of failing to adapt to climate change?	***Are there knowledge gaps or areas of inefficiency that could be addressed in order to incorporate climate change in your work?***	***How would you acquire the resources to be able to incorporate climate change adaptation in marine planning & management?***
Group 1: First Nations staff	• Impacts and loss of access to historical cultural sites • Property damage to communities and **infrastructure** • Food insecurity due to diminished food resources	• Improve capacity • Improve access to clearly communicated information • Incorporate local and traditional knowledge into monitoring and management	• Education • **Funding** and resources to develop capacity • Policy development and support
Group 2: Provincial government staff	• **Loss of jobs** and economic opportunity • Impacts to marine **infrastructure** • Impacts to human property and well-being	• **Incorporate climate change impacts into management** • More funding to communicate the issues • Overcoming uncertainty and finding community support for adaptation efforts	• **Funding** • Research on the social-ecological side of climate change impacts and outcome • Partnerships with organization and other governance levels
Group 3: Federal government staff	• Economic **losses to jobs** and industry (fisheries) • Costs and impacts to coastal **infrastructure** • Ecological impacts due to poorly situated conservation/management measures	• Develop better projections of climate impacts that incorporate species interactions • Build improved geospatial datasets for marine planning and management • **Explicitly consider climate change in fisheries management**	• Tools and policies to engage communities and management • Time • Staff

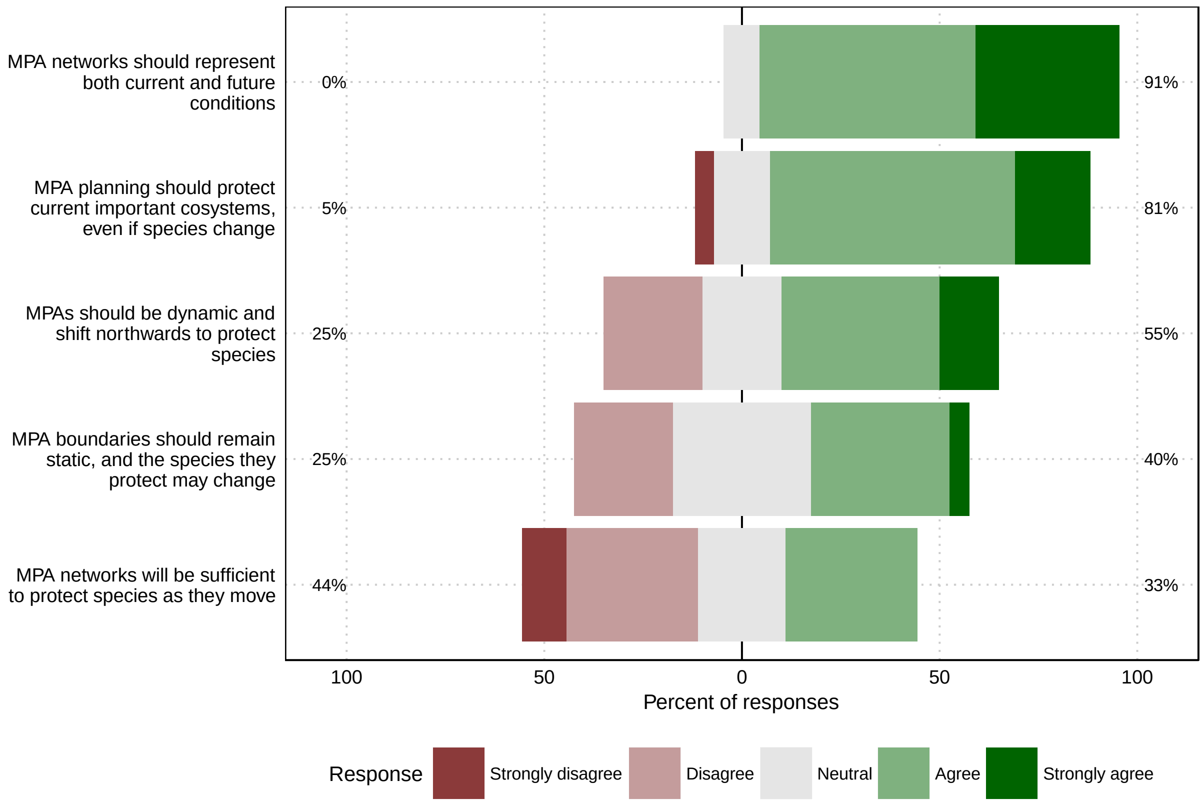

Figure D.2**:** Responses to climate change impacts and marine planning question: How should protected areas planning and management respond to shifting species ranges as environmental conditions change (n = 24)?

Survey consent form and interview questions

Survey: Perceptions of Climate Change Adaptations

You are invited to participate in a study being conducted by University of Victoria PhD Student Charlotte Whitney and Professor Natalie Ban. Charlotte and Natalie are members of the School of Environmental Studies at the University of Victoria. You may contact Charlotte by phone at (778) 839-3107 or email at ckw@uvic.ca or Natalie at nban@uvic.ca with questions or comments. You may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or *ethics@uvic.ca*).

Purpose of the project: Our purpose is to share and discuss the predicted impacts of climate change on marine species and gather information on how people living and working in coastal regions and communities might adapt to those changes. In particular, we ask: how can marine spatial planning, or other management tools, support adaptation to climate change for coastal communities? The answers will inform conservation planning scenarios that account for climate change, and give direction to further research on adaptation.

What is involved: In this survey, we seek input about climate change, adaptation to climate change, and conservation planning actions that could support local marine species, including those that are important for food resources, over time. If you choose to share your knowledge and opinions with us today, you are consenting to allow us to use that information. Your answers will remain anonymous unless you consent to the use of your name. The confidentiality of your information will be protected by password protected computers and the use of encrypted back-up files. Your participation is entirely voluntary, and you may stop participating at any time without any consequences or any need for explanation.

Participant Selection and Involvement: You have been invited to participate in this study because you work in a professional position that is connected to coastal marine management and conservation planning. If you agree to participate, the survey will require approximately 20-25 minutes of your time.

Risks and Benefits: There are no known or anticipated risks to you by participating in this research. This survey has the potential to provide an invaluable perspective on climate change impacts and adaptation actions that could help to support coastal BC communities and ecosystems. This research arrives at a critical moment because climate change impacts are worsening, increasing the need for coastal communities to adapt.

Dissemination of Results: It is anticipated that the results of this study will be shared with others in the following ways: directly to participants in writing, in Charlotte Whitney's Thesis project, scientific journal publications, scholarly presentations and meetings, presentations to policy-makers, social media, and potentially through community education materials. Funding: This research is supported by the Pacific Institute for Climate Solutions (PICS), the National Science and Engineering Research Council (NSERC), and the University of Victoria. By participating in this survey, YOUR FREE AND INFORMED CONSENT IS IMPLIED and indicates that you understand the above conditions of participation in this study.

Observed Climate Changes

These introductory questions ask you about your experiences the marine environment and your perceptions of climate change. They are meant to provide context to our research.

Have you noticed any climate change related changes in your area, or heard others describe such changes?
Examples may include shifting seasonality, changing weather patterns, different availability or abundance of local species
(Yes, in my area; Yes, in other areas; No)

Do you wish to add any details?

What type of climate related impacts have you seen or heard about?
(comment here)

Climate change adaptation

Climate changes will continue for at least the next 50-100 years, and likely several centuries, regardless of any actions we take now to mitigate the impacts (e.g. reducing emissions, etc.). Many local community members along the coast have noticed the impacts of climate change on the marine environment in their lifetimes, and recognize the impact this may have on marine resources in the future (L. Eckert 2017). Effective adaptation to climate change will require local and regional understanding, decision making, and adaptation actions. We are interested in how you see the region now and in the future, and actions that could improve regional marine planning for climate change adaptation. Throughout the survey, please keep your perspective on the impacts of climate change and adaptive responses for the coastal marine environment. This is the main focus of this research.

Climate change and adaptation

1. In your opinion, how important is climate change adaptation as part of a comprehensive approach to regional planning? (Rank, 1-10)

2. What scale of decision making do you think will be most effective to achieve success in climate change adaptation?

Please rank in order of most effective to least effective by moving the options in the left to the right:

Variable
What scale of decision making do you think will be most effective to achieve success in climate change adaptation?
National level government
Provincial level government
Municipal or local government
First Nations government
Individual or collective actions

Consequences of failing to adapt

3. When you think of the consequences of inaction, what comes to mind? (comment here)

Types of adaptation actions

4. Adaptation can refer to social, ecological, or social-ecological adaptation. For marine and coastal systems, which do you think is more important to focus on, in the next 10 years, in your region?

Variable	Response
Social adaptation actions (economic diversification, changes to regulation, policy improvements, etc.)	(respond, least important to most important)
Ecological adaptation actions (fisheries management, habitat protection, marine conservation planning)	(respond, least important to most important)
Adaptation actions that consider the coastal region as a linked human-natural system (planning for social-ecological resilience, incorporating human values into ecosystem based management)	(respond, least important to most important)

5. Do you think that the following social adaptation actions would be effective in your region?

(Social adaptation actions are management or policy actions that may support human communities to adapt to major environmental change.)

(Scale: 5-point Likert scale from very unlikely (1) to very likely (5), including neutral)

Variable	Response
Develop alternative livelihoods	(5-point scale)
Support local adaptive governance	(5-point scale)
Infrastructure improvements	(5-point scale)
Create supportive institutions (e.g. community organizations)	(5-point scale)
Invest in monitoring and early warning systems	(5-point scale)
Strengthen social networks and community groups	(5-point scale)
Support intergenerational knowledge sharing	(5-point scale)
Consider adaptive policies for economic diversity and occupational mobility (help people to change careers)	(5-point scale)
Encourage increased participation and engagement in management and decision making	(5-point scale)

6. Are there other types of social adaptation actions that you think would help your region to adapt to climate changes?

(comment here)

7. Do you think that the following ecological adaptation actions are likely to be effective in your region?

(Ecological adaptation actions are management actions that can be taken to support ecological function through major environmental change.)

(Scale: 5-point Likert scale from very unlikely (1) to very likely (5), including neutral)

Variable	Response
Prioritize conservation: develop better networks of marine protected areas	(5-point scale)
Avoid over-exploitation in fisheries	(5-point scale)
Take an ecosystem-based approach to fisheries management: manage for population, species, and ecosystem diversity	(5-point scale)
Incorporate climate modelling into management and resource allocation decisions	(5-point scale)
Develop regional forums to support ecological knowledge and sound management practices	(5-point scale)

Manage for ecological resilience where possible	(5-point scale)
Identify less degraded areas for 'hot spots' of ecological integrity, and protect them	(5-point scale)
Identify more degraded areas as critically important, and protect them	(5-point scale)
Develop education and training opportunities for maintaining ecological integrity	(5-point scale)
Improve connectivity among habitats	(5-point scale)

8. Are there other types of ecological adaptation actions that you think would help your region to adapt to climate changes?

(comment here)

Climate change and marine protected areas design

9. How important is climate change as part of a comprehensive approach to marine planning? (Scale, 1-10)

10. How important is it to include climate change projections into the design of marine protected areas? (Scale, 1-10)

Impacts of shifting species ranges and declining abundance

Species currently targeted by commercial or local fishers will change in abundance or be unavailable in the future. For example, some important marine fisheries species are expected to decline by up to 49% by 2050 in some regions, and many species are expected to move north by up to 10-15 km per decade (Weatherdon et al. 2016b). *In this figure, blue represents the impacts of a low emissions scenario, and the orange a high emissions scenario. Both show declining abundance for these species that are important to fisheries, coastal communities, and First Nations.*

Ecological adaptation actions

11. How much do you agree or disagree with the following statements about management options that contribute to adaptation?

(Scale: Strongly disagree to strongly agree, 5-point Likert response)

Variable	Response
Managing for community food security and well-bring is crucial, no matter the target species.	(5-point scale)
Communities and small-scale fishers need support to prepare for new and emerging fisheries.	(5-point scale)
Policy should change to allow for new permits/fisheries limits to adjust for new fisheries or changing fish availability	(5-point scale)
Communities should develop other sectors of the local economy that are not dependent on marine species (shift away from fishing)	(5-point scale)

Adaptation: Marine planning and protected areas

12. With climate change, many marine species will likely move northwards as the environmental conditions of their current habitats change. How do you think protected areas planning and management should respond?

(Scale: Strongly disagree to strongly agree, 5-point Likert response)

Variable	Response
Marine protected areas (MPAs) should be dynamic and shift northwards to protect species	(5-point scale)
MPA boundaries should remain static, and the species that they support and protect may change.	(5-point scale)
MPA planning should protect current important habitats and ecosystems, even if protected species move northwards or change.	(5-point scale)
MPA networks will be sufficient to protect species as they move out of some MPAs and into others	(5-point scale)
MPA networks should be designed to represent both current and future conditions wherever those areas overlap	(5-point scale)

Barriers to climate change adaptation in marine and coastal systems

13. What do you think are the knowledge gaps in incorporating climate change into marine protected areas planning? In other words, where are resources needed to improve the ability to incorporate climate change? Please rank these challenges by moving items in the left to the right.

Variable	Response
Scientific research	(rank)
Policy action (initiative)	(rank)
Management understanding	(rank)
Community acceptance	(rank)
Management action (initiative)	(rank)
Policy understanding	(rank)

14. In your opinion, are there knowledge gaps or areas of inefficiency that could be addressed in order to incorporate climate change in your work? (Yes, No, Maybe)

Please explain:
(comment here)

15. Do you feel that you have the resources available to successfully incorporate climate change into your work? (scale of 1-10, 1 being no, 10 being yes).

16. How would you acquire the resources to be able to incorporate climate change adaptation in marine planning & management? (comment here)

Demographics: We'd like to know a bit about you in the context of your work:

What sector do you work in?
(Provincial government, Federal government, First Nations government, Other)

What type of job do you typically do?
(Manager, Planner, Policy, Research, Other)

How many years have you worked in this field?
(comment here)

What is your age range?
(comment here)

Do you have any comments or additions you'd like to make at this time?
(comment here)

Can you suggest someone who would appreciate receiving this survey? Please add their name(s) and contact information below. Thank you!
(comment here)

Contact Information
Can we follow up with you for a short discussion on these topics? Please add your information below.

Variable
Contact Information | Name
Contact Information | Email
Contact Information | Organization
Contact Information | Role in organization

Thank you!

We appreciate your time and interest in climate change impacts and adaptation planning.

Semi-structured interview questions

Table D.4 Semi-structured interview themes and questions

Theme	Key questions
Adaptation actions	What do you think would be most feasible, or least feasible, adaptation actions in this region? If you could rank adaptation actions, what do you think is the greatest (or top three) priorities for ecological and social adaptation?
Barriers to adaptation	Do you feel that you have enough information to act (on adaptation planning, and conservation planning for climate change)? Do you think that your organization has the capacity to contribute to adaptation actions for the BC coast?
Opportunities for adaptation in their work	What do you think are the basic research gaps in terms of climate change adaptation in the region? What do you see as the specific science needs? How do you think other types of knowledge (other than scientific research) might fit or are needed to improve adaptation in the region?

Semi-structured interview script and questions:

If applicable, the ***online/phone introduction*** *may follow as (example):*

Hi. My name is Charlotte Whitney. I'm a researcher at the University of Victoria working to learn more about the impacts of climate change on the north coast of British Columbia to generate discussion marine use planning and fisheries management that can better support adaptation to climate change. My project seeks to generate knowledge about climate changes to marine species, and regionally relevant adaptation actions to climate change by speaking with regional planners and managers in the area. If you are willing, I am interested in interviewing you. In an interview, we would discuss your perception of climate changes to the marine environment, the predicted impacts from a regional level based on other research that I can share, and what you think would be effective regional responses to adapt to those impacts. The interview will take approximately ½ hour to 1 hour to complete. Participation is voluntary and, should you agree to participate, you will be free to refuse to answer particular questions and to withdraw from the study at any time.

1. What organization do you work with?
2. What area/region do you work in?
3. Is there anything else, related to this study that we should have talked about? Anything we missed?

4. What do you think are the basic research gaps in terms of climate change adaptation in the region?
5. What do you see as the specific science needs?
6. How do you think other types of knowledge (other than scientific research) might fit or are needed to improve adaptation in the region?
7. Do you feel that you have enough information to act (on adaptation planning, conservation planning for climate change).
8. Do you think that your organization has the capacity to contribute to adaptation actions for the BC coast?
9. In the survey, most people said that they supported all ecological adaptation actions, and that they would be effective. What do you think would be most feasible, or least feasible, in this region?
10. If you could rank adaptation actions, what do you think is the greatest (or top three) priorities for ecological adaptation?
11. How about for social adaptation? How do you feel the community will be able to adapt?
12. Is there anything else on your mind in regards to this issue?
13. Would you recommend anyone else I should try to speak to (from your organization or other)?
14. Is there anything we've talked about today, or that hasn't yet been mentioned, that is very important to the region? A priority?
15. How did you feel about today's interview? Do you have any ideas to improve the process or questions?
16. Would anyone like to add anything?
17. Is there anything else, related to this study that we should have talked about? Anything we missed?
18. Do you have any final comments that you would like to add about what we've talked about?
19. Is there anything else you would like to tell us, or feedback you would like to offer?

Appendix E: Supplementary Material, Chapter 6

Additional Quotes

Observations and impacts of climate change

Quote 1

"We have watched the numbers of some of the salmon decline to nothing… I think climate change has a lot to do with it, but I also think salmon farms…is that part of climate change or part of [fisheries]? or part of both? Who can you blame... Partially you can blame climate change, but I also think a lot of it has to do with the salmon farms that are all spread all over the place..." (Wally Webber, Hereditary and Elected Chief, Nuxalk Nation)

Quote 2

"Berries have been coming later too, not staying around as long. That's what I noticed... Later and they go faster." (Charles Saunders, Guardian Watchman, Nuxalk Nation)

Quote 3

"You talk to the fishermen here and they will tell you, all the species have started to come in together. It used to be the chinook, chum, and the pinks and then the sockeye and then the coho. Now it's the chum, no, it's the springs, chum, and pinks coming in all at once, with the sockeye. All at once. So it's...getting crazy. The coho, there's the odd coho coming in now, but it's usually a fall fish. Things are getting kinda wacky out there." (Wally Webber, Hereditary and Elected Chief, Nuxalk Nation)

Quote 4

"I remember when I first moved up here [from Bella Bella], I was able to fill up two boxes with about 30 fish in one morning. It's not like that anymore." (James Anderson, Fisher, Kitasoo-Xai-xais Nation)

Quote 5

*"In 2016, I'm trying to think of the percentage, maybe 2 percent came back [*Pyropia *seaweed], and that was in living memory. Nobody had ever recalled a time when seaweed didn't come back. You know the Blob is the first time ever, an event such as that was ever recorded. So, I think that's climate change." (Mike Reid, Fisheries manager, Heiltsuk Nation)*

Quote 6

"*You know, there's so much knowledge that people have about marine resources and the territory that comes from intergenerational knowledge that's been passed down to them because the rate of change was so slow that from one generation to the next you could pass on your knowledge of where a good fishing spot for certain species is or what time of year you can expect certain things in certain places. And it seems like at a really accelerated pace, that intergenerational knowledge is no longer true. And I think that really leaves people reeling. In a social sense it creates some challenges in terms of relationships with younger generations where you start to feel like you don't have the knowledge to pass down what was passed down to you, which is really hard for folks."* (Councillor, Heiltsuk Nation)

Quote 7
"Well, they say when you look after something for a long time, you take care of it. But look at Mother Earth now, she's withering. She's going downhill. Fast. The reason I'm saying that, is you look up north. The Arctic Circle, how fast it's melting. And even that's...You look at the polar bear, he's looking around, where's the ice? He's starving. Can't find that food, the seal anymore. No ice to go, the way he used to hunt it. That's why I say, you have to look after the economics of your territory. You don't look after that; you're going to be in trouble" (Cecil Moody, Elder, Nuxalk Nation)

Adaptation actions for ecological and social systems

Quote 8
"We should have a stronger say in the MPAs out there. Because the government themselves say, you can't go here, you can't go there. But they let the sport fishermen come in here and they take out so many fish, and then they come over here and say you can't go fishing here. They say that to First Nations people. So that doesn't work. Take a hike, politely." (Peter Johnson, Knowledge holder, Wuikinuxv Nation)

Priority actions

Quote 9
"And Indigenous knowledge will evolve and adapt as well. So I think that it's just two different ways of relating the world and they can go hand in hand and I think you've got to make space for ours. Inherently make space for ours because we've been pushed to the side and the margins for far too long. And it's on Canadians not Indigenous people to do that." (Saul Brown, Reconciliation coordinator, Heiltsuk Nation)

Quote 10
I don't think we need more data, to be honest, one of the best things to do is integrate not Indigenous knowledge into the decision-making system, but actually integrate Indigenous knowledge keepers into decision making... Yeah, at the governance level I think you've got to make space for... even before that, make space for Indigenous governance systems to be part of that revitalization, be part of the solution" (Saul Brown, Reconciliation coordinator, Heiltsuk Nation)

Quote 11
"Our people don't go up there [further north to go fishing. If there's no fishing we just stay home...Some, they follow the fish...Not too many though. We don't have good enough boats to go!" (Hrwana, Elder, Nuxalk).

Quote 12
"[As marine species shift north] No, [they'd] just go to the grocery store. It's just too far, expensive. Too far away, too much money in fuel. Believe it or not, our people have forgotten how to live on the ocean..." (Wally Webber, Hereditary and Elected Chief, Nuxalk Nation)

Quote 13

"*Well, there is a big understanding, quite an understanding between one band to the next, you don't go into their area, because if you do, they consider you're stealing their fish.*" (Anonymous, Elder, Heiltsuk Nation).

Quote 14
"*Hopefully I have enough family up north to send me fish!*" (Alex Chartrand, Wuikinuxv Nation).

Quote 15
"I mean, it absolutely would [affect trade]. I can't definitively pin any one thing on climate change necessarily but in years when we had bad herring seasons, or really low seaweed growth, it's definitely impacted trade relationships because the things that we have to offer, we suddenly don't have. It's not viable enough to maintain those relationships with what we can harvest. Which means that, for sure, relationships suffer. People diet changes. And for sure, relationships across communities suffer when that happens." (Anonymous, Councillor, Heiltsuk Nation)

Quote 16
"I mean, we've adapted to everything… We've lost our language, not 100%, we're revitalizing that… but how are we going to manage the resource that's going to leave here because of climate change. And what are our people going to do to shift their culture, their way of life, without… without herring? I mean that would be huge for us. Without salmon… without crab… without prawns… without shellfish? I mean, these things would be a detriment to the culture. So.. we're seeing that every day. We're trying to adapt… to figure out what we can do….if salmon continue to deplete… we have to do something." (Kelly Brown, Stewardship Director, Heiltsuk Nation)

Quote 17
"I see in our office now that they are really trying to help and come and support things that are going on now, that we should step up and do more. Like yourself coming in and actually talking about it and reminding our Nation about stuff like this. I think it gives them a big reminder for sure about what we should do to protect what we have left. I think they need a reminder; I think anyway. Sometimes they do talk about it, they put it back on the back burner and they forget about it because there are a lot of other projects going on. But this is, I think the main thing that they should be concentrating on." (Roger Harris, Nuxalk Guardian Watchman).

Quote 18
"Well we rely on salmon. This whole community does. As the temperatures rise, I think our salmon is going to move up north where it's cooler. And the species down south are gonna come this way. So, we'll probably have to adapt to whatever is coming in, start harvesting it…To what degree I don't know. They might not say they would, but they might..." (Peter Siwallace, Marine Use Planner, Nuxalk Nation).

Perceptions of climate change, adaptive capacity, and marine conservation planning in coastal communities

You are invited to participate in a study entitled "Perceptions of climate change, adaptive capacity, and marine conservation planning in coastal communities" that is being conducted by Charlotte Whitney. Charlotte is a PhD Student in the School of Environmental Studies at the University of Victoria and you may contact her at 778-839-3107 or ckw@uvic.ca if you have any questions or comments. Her project is being conducted under the supervision of Dr. Natalie Ban. You may contact her at ***nban@uvic.ca****.*

This research is being funded by the Social Science and Humanities Research Council (SSHRC), the Natural Sciences and Engineering Research Council (NSERC), and the Pacific Institute for Climate Solutions (PICS).

Purpose and Objectives

Increasing ocean temperatures are likely to affect where marine species live, which will affect local and traditional access to traditional food resources. First Nations, and other coastal communities, will have to plan proactively to adapt to these changes.

The project's main objectives are:

1) To explore the perceptions of local community members in regards to climate change impacts on the BC coast.
2) To explore the perceptions of community members to climate change impacts on local food security and access to traditional food resources.
3) To develop locally based adaptation actions that will support coastal community adaptive capacity to climate based change.

Importance of this Research

Sharing climate change projections that are relevant to the local level, along with scenarios for conservation planning that could support the abundance of traditional marine food species over time. Exploring how local community members perceive these changes, can lead to developing adaptive actions that would work for their community and region.

What is involved

If you consent to participate in this research, your participation will include a 30-60 minute interview in a location that is comfortable and convenient. The interview will inquire about your experience in the marine environment and your vision for marine conservation tools, and other adaptive actions that could benefit your region or community, based on your knowledge. You may also be asked about your observations of the state and changes of marine ecosystems and key harvest species. Audio recordings, written notes and observations will be taken; a transcription will be made. If requested, you may receive a copy of all notes, recordings and transcriptions.

Inconvenience, risks, and benefits

Participation in this study may cause some inconvenience to you, including the time committed to the interview. There are no known or anticipated risks to you by participating in this research. The potential benefits of your participation in this research include being able to share your knowledge to inform marine use planning in your region.

Compensation

As a way to compensate you for any inconvenience related to your participation, you will be given a financial honorarium of $25. If you consent to participate in this study, this form of compensation to you must not be coercive. It is unethical to provide undue compensation or inducements to research participants. If you would not participate if the compensation was not offered, then you should decline.

Voluntary Participation

Your participation in this research must be completely voluntary. If you do decide to participate, you may withdraw at **any time** without any consequences or any explanation. If you do withdraw from the study your data will be used only with permission and your compensation adjusted to match time contributed fairly.

Anonymity and Confidentiality
Your name will remain unlisted and data provided anonymous unless you otherwise consent to the use of your name in research outputs. Your confidentiality and the confidentiality of the data will be protected by password protected computers and the use of encrypted back-up files. Any hard-copy data (e.g. notes) will be stored in the filing cabinets in the Marine Ethnoecology Lab at the University of Victoria. Digital data will be stored in Charlotte Whitney's personal password protected computer files and archived by their supervisor Natalie Ban. Any data that is requested to be kept confidential will be kept in a locked filing cabinet or encrypted digital files, accessible only to the researcher.

Dissemination of Results
It is anticipated that the results of this study will be shared with others in the following ways: through community workshops, directly to participants, in Charlotte Whitney's Thesis project, scientific journal publications, scholarly presentations and meetings, community newsletter, presentations to policy-makers, social media, and potentially through community education materials.

Disposal of Data
Data from this study will be disposed through paper shredding and deletion of all digital data, should you ask to have your data disposed. If participants allow, data will be stored at the University of Victoria Marine Ethnoecology Lab under password protection or encryption.

Contacts
Individuals that may be contacted regarding this study include Charlotte Whitney, and Dr. Natalie Ban. In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).

Your signature below indicates that you understand the above conditions of participation in this study, that you have had the opportunity to have your questions answered by the researchers, and that you consent to participate in this research project.

______________________________	______________________________	________________
Name of Participant	*Signature*	*Date*

PLEASE SELECT STATEMENT only if you consent:

I consent to be identified by name / credited in the results of the study: ______________ (Participant to provide initials)

Future Use of Data *PLEASE SELECT STATEMENT:*
I consent to the use of my data in future research: ______________ (Participant to provide initials)

I **do not** consent to the use of my data in future research: ______________ (Participant to provide initials)

I consent to be contacted in the event my data is requested for future research: ______________ (Participant to provide initials)

Data sharing
I consent to having a copy of my data shared with the local community office (if requested)
______________ (Participant to provide initials)

A copy of this consent will be left with you, if requested, and a copy will be taken by the researcher.

Interview Guide: Semi-structured interview questions

1. What type of job(s) do you typically do?
2. How do you depend on the ocean? For fishing, income, food, other?
3. How much experience do you have in fishing/food gathering? How long have you done it for?
4. What do you value most about your way of life?
5. When you think of climate change, what comes to mind?
6. How do you think these changes are or will affect your way of life?
7. Can you think of some actions you think would be effective for you and your community to adapt to climate change?
8. Which of the following social adaptation actions would be more effective in your community?
    a. Develop alternative livelihoods (help people to change careers)
    b. Support stronger local governance
    c. Community infrastructure improvements
    d. Strengthen social networks and community groups; support intergenerational knowledge sharing
    e. More local participation in regional/higher level management and decision making
9. Which of the following ecological adaptation actions are likely to be effective in your community?
    a. Develop better networks of marine protected areas (MPAs)
    b. Avoid fisheries over-exploitation
    c. Use more climate change projections into stewardship decisions
    d. Develop regional forums, education, and training opportunities to support stewardship/monitoring practices among communities
    e. Applying ecosystem-based management (EBM) approaches to fisheries
10. How do you think you would respond if climate change were to significantly affect your way of life and access to marine resources?
11. How do you think fishers and food harvesters might respond or adapt to changes in marine resource availability?
12. Generally, how do you think climate change may affect trade between communities/First Nations?
13. Do you feel that your community has the resources to act on climate change/implement adaptation actions?
14. Do you see any barriers to climate change adaptation in your community?
15. What do you think are the knowledge gaps in incorporating climate change adaptation in your community?