THE ROLE OF CLOSED AREAS IN MARINE ECOSYSTEM BASED MANAGEMENT

By

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A Thesis submitted to the School of Graduate Studies

in partial fulfilment of the requirement for the degree of

Doctor of Philosophy

Department of Biology

Memorial University of Newfoundland

May 2017

St John’s, Newfoundland and Labrador

This thesis is dedicated to my daughter, Rose Cordelia Audrey. My free spirit, my heart: may you explore the world and follow your dreams.

Abstract

This thesis aims to advance knowledge on the role marine closed areas play in achieving marine conservation and fisheries benefits under an ecosystem based management (EBM) approach. The approach follows broad EBM principles that include a combination of conservation and fisheries objectives, a wider view of multiple species and ecosystems and people as a part of, not apart from, the ecosystem. First, a review provides insights into all types of closed areas that had fisher involvement with biodiversity conservation and fisheries management objectives. An indicator based scorecard approach is proposed as a means to evaluate management success of such closures. Research then focused on specific closed areas in tropical (Mafia Island marine park, Tanzania) and boreal regions (Hawke Box, Labrador, Canada); both areas featured restrictions on fisheries instigated largely by the local fishers and management. In these diverse fisheries and regions, several parallels were evident: fishermen (>90%) believed that fisheries sustainability was the major objective, and that their fishery and communities would be much poorer, or gone, without the implemented restrictions, despite self-imposed limitations on their own actions. In Tanzania, multiple-use zoning provided a means to identify and resolve conflicts and achieve what are likely universal objectives for fisheries sustainability and conservation. In the Hawke Box, Canada, respondents believed that protecting the area from trawling was the primary reason for a viable snow crab pot fishery, despite research indicating little improvement since the closure. Long term (20 years) multi-species abundance and biomass analysis from pre/post this closed area revealed increases inside the Hawke Box for many benthic fish species, in addition to increased crab productivity inside relative to outside the closure. The evidence suggests that the Hawke Box has benefited fisheries, communities, and biodiversity conservation, and provides a unique boreal area for the study of restrictions on trawling in an area with historically strong fisheries, strongly supported by local fishers and their communities. This thesis, through different angles, contributed to knowledge to better understand the role different types of closures play from fisheries aspects, conservation aspects, and within a wider EBM approach. I conclude that closed areas of many types are important for fisheries, conservation and local communities and, with local support, can meet multiple management goals.

Acknowledgements

I would like to thank George Rose for providing the opportunity to pursue a PhD and for full support, guidance, advice and patience over the years. I also greatly appreciate the support from my committee members Rodolphe Devillers and Jonathan Fisher who were always available throughout. I appreciate the guidance and straight talking from Rodolphe Devillers who kept me moving in the right direction all the way and the continued support and advice from Jonathan Fisher. I would additionally like to thank Ratana Chuenpagdee, who put up with my visits to her office and emails that helped me to focus my research combining biological aspects with social aspects, despite not being part of my committee; I truly appreciated these interesting and useful discussions. I would like to thank my examination committee that pushed me and challenged me throughout my defence.

The Canadian Fisheries Research Network (CFRN) and the Department of Fisheries and Aquaculture, Newfoundland and Labrador, provided the financial support for this work, but more than that they provided a platform for true research collaboration from academia, government, fisheries and non-governmental sectors. This provided many unique opportunities to share knowledge and gain support from many people and I had many interesting discussions from many people from across Canada during the annual meetings. The following also provided financial support, of which I am grateful: Natural Sciences and Engineering Research Council (NSERC) Fisheries Conservation Chair (FCC) [funded by the former Fisheries Products International, the Newfoundland and Labrador Department of Fisheries and Aquaculture (DFA)], and the Centre for Fisheries Ecosystems Research (CFER) at the Fisheries and Marine Institute, Memorial University [funded by the DFA and the Research and Development Corporation of Newfoundland], Memorial University International Office Going Global Grant and NSERC Discovery grants to G.A. Rose. I acknowledge the research assistance from the following colleagues at Memorial University and the Marine Institute: Kiley Best, Laura Wheeland, Susan Fudge, Wade Hiscock, Marlene Power, Kelly Moret.

I would like to acknowledge the many local fishers in Mafia, Tanzania and Labrador, Canada that gave their time to meet with me and have an interview about their fishing practices.

I would like to thank the Department of Fisheries and Oceans Canada (DFO) who provided data used in part of this thesis, but more than that, the staff across all departments were the friendliest and most helpful group of government workers I have ever met. In particular, I would like to acknowledge Jake Rice, Maxine Westhead, Darryl Mullowney and Corey Morris who put up with my many emails and questions and were always there to help. I am grateful to fishers and their communities in Tanzania and Labrador, Canada that gave their time, let and provided data towards this thesis.

I would like to thank everyone on “the rock” for making a Brit feel really welcome. This is a unique place, where everyone is friendly and truly welcoming. The CFER lab (especially Susan, Anna, Victoria, Ed, Laura and Riley) for always offering support in many ways including cups of tea, little outings, breaks in between work and sometimes a place to stay. The Biology Department, Ginny Ryan and the writing centre team, Ocean Quest and the Stanley’s all made my time in Newfoundland special and feel like a home away from home. I spent a large portion on my thesis writing at The Island School, Eleuthera, The Bahamas and I appreciate the space given to family, this allowed me to finish and be part of a unique community. My thanks go to everyone in this special place. I give special thanks to Rikka Wommack.

I would like to thank my husband, Jason for the continued support (and patience) through the years despite the extended time taken to finish. My parents (Pauline and Tony) who helped guide me, and have always supported and encouraged me to follow my dreams. My dad with his “you will disappoint me if you don’t finish” comment helped push me through the final hurdle. My daughter, Rose has become my inspiration and heart, I

appreciated the wonderful baby snuggles in the wrap on my chest as I carried on writing. I am thankful for the wonderful free spirited toddler she has become, may she explore, discover and learn wherever her heart takes her.

I am truly appreciative of all the support and advice from everyone, being British however, this section was quite difficult to write as often, the British are not the best at expressing feelings. A simple "great, thank you very much", really does mean a lot despite its brevity. Great, thank you very much.

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List of Abbreviations and Definitions

CBD	Convention on Biological Diversity
CPUE	Catch per unit effort
EAF	Ecosystem approach to fisheries
EAFM	Ecosystem approach to fisheries management
EBFM	Ecosystem based fisheries management
EBM	Ecosystem based management
FAO	Food and Agriculture Organisation of the United Nations
FMA	Fisheries Management Area
IUCN	International Union for Conservation of Nature
MPA	Marine protected area
SSF	Small scale fisheries
UNCED	UN Conference on Environment and Development
UNEP	United Nations Environment Programme

Biodiversity

"the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". 1992 U.N. Convention on Biological Diversity (CBD).

Marine Protected Area

The most widely accepted definition of an MPA is, "*A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*"(IUCN 2008).

Sustainable

"the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations". 1992 UN Conference on Environment and Development (UNCED)

List of Appendices

Co-authorship Statement

The initial idea to investigate the Hawke Channel closed area was proposed by Dr. George Rose in a response to a funding request from the Canadian Capture Fisheries Network (CFRN) for projects of interest to the fishing industry. The design of the chapters within this thesis was developed by the author, in consultation with George Rose and the CFRN stakeholder partners in academia, industry and government.

The chapters in this thesis have been prepared as separate manuscripts. Due to the nature of the thesis that collates papers prepared for individual publications, some repetition may occur within the chapters, for this I apologise to the reader.

This research was designed and conceptualised by K. Kincaid, with assistance from George Rose. I am the first author on all of the manuscripts produced from this thesis. I identified research questions, conducted research, data analysis and prepared the manuscripts. In addition, George Rose, Rodolphe Devillers and Jonathan Fisher provided editing assistance, creative input and assistance with thesis preparation. I was responsible for all data collection in Chapter 2. In Chapter 3, H. Mahudi assisted as a translator in data collection. I collected all data for Chapter 4 with field assistance from K. Best. Fisheries data and snow crab data used in Chapter 5 were provided by Fisheries and Oceans Canada, and by George Rose through research conducted during his tenure with the NSERC Fisheries Conservation Chair and The Centre for Fisheries Ecosystems Research, Memorial University. I participated in offshore research surveys in 2011 and 2012 to assist in collecting data off Newfoundland and Labrador.

List of Papers

The following chapters have been published in, or accepted to international peer-reviewed journals at the time of submission:

Chapter 2: Kincaid, K., Rose, G., and Devillers, R. How fisher-influenced marine closed areas contribute to ecosystem based management: a review and performance indicator scorecard. Accepted to: Fish and Fisheries, January 2017.

Chapter 3: Kincaid, K.B., Rose, G, and Mahudi, H. (2014) Fishers' perception of a multiple-use marine protected area: Why communities and gear users differ at Mafia Island, Tanzania. Marine Policy 43, 226-235.

Chapter 4: Kincaid, K.B. and Rose, G.A. (2014). Why fishers want a closed area in their fishing grounds: Exploring perceptions and attitudes to sustainable fisheries and conservation 10 years post closure in Labrador, Canada. Marine Policy 46, 84-90.

Chapter 5: Kincaid, K., and Rose, G. Effects of closing bottom trawling on fisheries, biodiversity and fishing communities in a boreal marine ecosystem: the Hawke Box off Labrador. Accepted to: Canadian Journal of Fisheries and Aquatic Science (CJFAS) Special Network Issue, January 2017.

Chapter 1 Introduction and Overview

1. General Introduction

1.1 Background

The marine environment presents unique challenges for research and management (Carr *et al.* 2003). The oceans are more interconnected than terrestrial environments. Interconnections and physical forcing influence many ecological processes with dispersal, migrations and biogeographical patterns spanning large vertical and horizontal spatial scales (Kaiser et al. 2011). The marine realm has some of the most highly productive, valuable and heavily used ecosystems (Costanza *et al.* 1998), particularly those in coastal regions (Millennium Ecosystem Assessment 2005).

Within the past 50 years, human impact on ecosystems has been expanded greatly with biodiversity loss and degradation of ecosystems as a consequence of increasing demands for food, water and fuel (Millennium Ecosystem Assessment 2005). Impacts include climate change, habitat loss, overexploitation, unsustainable extraction of resources, invasive species and disease (Crain *et al.* 2009). Declining species richness and abundance due to human impacts has been well documented, and the protection of biological diversity is integral to ecosystem stability (Sala and Knowlton 2006; Halpern *et al.* 2008; Selig *et al.* 2014). Sustainably managing marine resources to address threats to marine ecosystems became a priority at the 1992 United Nations Conference on Environment and Development (UNCED). This included the formation of the United Nations Convention on Biological Diversity (CBD), an international treaty to protect biological diversity, and Agenda 21, an international plan of action for sustainable development.

Fisheries are one of the biggest pressures on the marine ecosystem (Costello *et al.* 2010). They alter biodiversity (Costello and Ballantine 2015) and too often have not been sustainable (Pauly *et al.* 2002) particularly when poorly managed/unmanaged. Global fisheries are threatened by overexploitation with biomass declines and ecological changes (Worm *et al.* 2009; FAO 2010; Sumaila *et al.* 2012). Within the past 50 years, many fish stocks have been depleted, with fewer large fish (Worm *et al.* 2005; Link 2010). Target species today are some of the species thought of as bycatch species 30 years ago (Link 2007). However, evidence has shown that well managed fisheries are improving (Hilborn and Ovando 2014) and have shown recovery of biomass (see Rose and Rowe 2015 for recent documented increased northern cod biomass in the NW Atlantic). A further example are fisheries in Australia and New Zealand (Punt *et al.* 2016), where a key part involves wider ecosystem conservation Further, of 24 depleted fisheries that Murawski (2010) reviewed, all but one showed signs of recovery.

Achieving a sustainable fishery can be a complex concept to define, depending on perceptions and definition (Hilborn *et al.* 2015). Hilborn *et al.* (2015) states that a fishery that is harvested at or below MSY can be deemed to be sustainable. Ye *et al.* (2013) assessed the global status of fisheries stocks and found 68% to be at or above maximum sustainable yield (MSY). Under the CBD guidelines, all fisheries should be harvested by applying an ecosystem approach by 2020.

The importance of sustaining fisheries can hardly be overstated. Fisheries provide food security (Sumaila *et al.* 2012), economic returns, a protein source for over 4 billion people (HLPE 2014) and are vital to livelihoods, in particular to coastal communities (Grafton *et al.* 2009). Globally, fisheries generate over US $217.5 billion and provide 16.6% of the global human population's animal protein intake (Parsons *et al.* 2014; FAO 2012). Small scale fisheries (SSF) are important, contributing to approximately half of the global fish catch and employing over 90% of the world's fishers (FAO 2015). This represents a way of life for coastal communities that are dependent on productive ecosystems and biodiversity. SSF use a mixture of gear types, are often multi-species fisheries, and are an important contribution in global fisheries providing food security to coastal communities' worldwide (FAO 2015).

1.2 Fisheries and conservation

An increasing concern in fisheries management is the effect of fisheries on ecosystems and biodiversity (McClanahan *et al.* 2015). Fishing efforts often need to be reduced and conservation measures increased (McClanahan *et al.* 2015), however, fisheries need to be maintained. The goal and importance of achieving both fisheries and biodiversity conservation is being recognised (FAO 2011; Robb *et al.* 2015). Fishing activities often seem to misalign with conservation practices, however, they are linked with outcomes impacting each other (Roberts 2012). Further, what may initially appear to be incompatible goals may be overlapping and compatible goals (Arkema *et al.* 2006).

Traditionally, the conservation of biodiversity has been a separate goal outside of fisheries management (Halpern *et al.* 2010). Despite differences, fisheries managers and biodiversity conservation agencies have many similar objectives and common goals, namely of sustaining habitats and resources (Rice *et al.* 2012) and healthy ecosystems (Hilborn 2007). Maintaining biodiversity is a key component of sustainable fisheries management (FAO 2011). Common goals for fisheries and conservation are outlined within the Code of Conduct for Responsible Fisheries (FAO 1995); aiming for responsible fisheries alongside effective conservation management that considers the whole ecosystem (Garcia *et al.* 2003). Despite the concerns of Costello and Ballantine

(2015) that fisheries should not have a place within the conservation of biodiversity, there is a need to consider fisheries management within wider ecosystem aspects, and research increasingly combines fisheries and conservation (e.g. Green *et al*. 2014; Barner *et al.* 2015). Recent progress to do so has been encouraging (Salomon *et al.* 2011).

1.3 Marine ecosystem based management (EBM)

One management approach that combines fisheries and conservation objectives is ecosystem based management (EBM), a concept intended to ensure the sustainability of ecosystems and human well-being through the integration of biological, ecological, social and economic perspectives (Crowder and Norse 2008). This is an adaptive approach covering multiple spatial and temporal scales (Leslie and McLeod 2007) to improve ecosystem resilience and function (Levin and Lebchenco 2008; Ruckelshaus *et al*. 2008) with multiple goals and management objectives (Link 2010). Bigelow (1929) first raised concerns about single species focus without consideration of other ecosystem factors. International interest and focus predominantly came after the Rio Earth Summit in 1992 (Arkema *et al.* 2006) and the development of the CBD, where the term 'Ecosystem Approach' was adopted (Beaumont *et al.* 2007). Research and policy advocating for marine EBM has steadily increased, with varying strategies on how to implement it (Arkema *et al.* 2006). However, implementing EBM remains a challenge (Cogan *et al.* 2009) with adaptive, complex marine ecosystems (Levin and Lubchenco 2008) along with environmental variability (Botsford *et al*. 1997), leading to uncertainty in predicting how marine ecosystems will respond to human actions (Pikitch *et al*. 2004).

Recognising the impacts of fisheries on marine ecosystems (Grafton *et al.* 2009) has encouraged a precautionary approach that considers the wider ecosystem (Witherall *et al.* 2000; Pikitch *et al.* 2004; Ruckelshaus *et al.* 2008; FAO 2011). An ecosystem approach to fisheries (EAF) and ecosystem approaches to fisheries management (EAFM) expand on single species focus to include wider ecosystem factors (Patrick and Link 2015). Similarly, an ecosystem based fisheries management (EBFM) is an integrated approach to fisheries management that considers interactions among species in the environment, which includes climate, habitat, predator-prey and food chain impacts and dynamics (Link 2002; Pikitch *et al.* 2004; Link 2010; Patrick and Link 2015; Skern-Mauritzen *et al.* 2015).

The intent of governments to move towards an ecosystem approach in fisheries has been recognised (FAO 2011) and adopted by key international agreements over the past few decades. Despite the inclusion of the ecosystem approach in policy, uptake has been slow in fisheries management, with only 2% of global fisheries stocks reviewed by Skern-Mauritzen *et al.* (2015) including wider ecosystem components. Thus, EBFM is a constantly evolving concept (Brodziak and Link 2002), leading to doubts on the realistic application in fisheries management, despite research on how to implement it in practice

(Patrick and Link 2015). As discussed by Patrick and Link (2015), there are many myths surrounding EBFM but, despite doubts, it is feasible to implement it, and the data are available to do so. Rather than a complete change in fisheries management, EBFM can be an evolving change (Marasco *et al.* 2007), using all available data to improve understanding of fish stocks in a wider context.

Simply, aside from the nuances between these terms, the EBM concept is an all-inclusive approach to managing living marine resources including physical, biological, economic and social complexities as opposed to a focus on a single species (Brodziak *et al.* 2002; Pikitch *et al.* 2004; Patrick and Link 2015). Priority is combining ecological aspects with social aspects, namely that people are a part of the system. As a primary stakeholder, fishers are a central part of this approach. For the purposes of this thesis the term EBM is used as an umbrella term that includes EAF, EAFM and EBFM approaches.

1.4 Closed areas for fisheries and conservation

Closed areas that address both fisheries and conservation objectives (Abbott and Hayne 2012; Pita *et al.* 2011; FAO 2013) have become a spatial management tool of EBM (Halpern *et al.* 2010) and can be established for biodiversity protection and for fisheries management (Jones *et al.* 2007; Robb *et al.* 2015). However, there are still knowledge gaps on how closed areas, particularly MPAs, work within a fisheries context (FAO 2011). Strong opinions have been advanced both for and against closed areas to meet both fisheries and conservation needs. In most cases, a lack of pre-closure information on the ecosystem, or lack of suitable comparisons with fished areas, has limited any strong conclusions (Sweeting and Polunin 2005).

Closed areas are one of the oldest tools of fisheries management areas (FAO 2011), with various goals that can include protection of spawning or juvenile fish and sensitive habitats (Agardy 2000). They can be implemented for many different objectives including maintaining biodiversity and ecosystem health, rebuilding fisheries, protecting key areas, resilience and food security needs (FAO 2011). Centuries ago, tropical Pacific island communities used fisheries and conservation measures that were not yet conceived by Western civilisation (Johannes 1978). More recently, in the form of marine protected areas (MPAs), closed areas have become a main tool for signatory parties to meet CBD targets (CBD 2010; Day *et al.* 2012) for the conservation of biodiversity. Closures that meet the IUCN definition for an MPA (namely long term conservation) are included within international agreements through the CBD to protect 10% of marine and coastal areas by 2020 (CBD 2010; Rife *et al.* 2013). There are six categories for different management types from strict no-take to areas open to some forms of fishing (Day *et al.*

2012). Overall, closed areas come under a multitude of different names and management types (Table 1.1), focusing on fisheries, conservation, or a combination of the two. They can be fully or partially closed. Definitions are often used interchangeably, without clear definition (Agardy 2000), and their meanings differ between countries, policies and social groups (FAO 2011). While it is reasonable for research and management to separate and distinguish between these terms to attribute for the different objectives, within this thesis, the term ‘closed area’ is used as an all-encompassing term (Table 1.1) and casts a broader net over the varying types of closures.

1.5 Biological benefits of closed areas for fisheries and conservation

The biological benefits of well-designed, well-enforced, no-take closed areas for conservation have been well documented and include: increases of fish abundance and biomass (Aburto-Oropeza *et al*. 2011) thus benefiting fisheries (Roberts 2012), spillover effects such as larval and egg export to areas outside the closure (Harrison *et al.* 2012), and increased species richness (Russ and Alcala 2011). See Lester et al. (2009) for a global synthesis. Partially protected areas can still be ecologically valuable in comparison to open access areas (Sciberras *et al.* 2013), although few studies have examined their effectiveness (but see McClanahan *et al.* 2006) compared to no-take areas. However, in some areas, partial closures may be more likely to be supported by local fishers (Tyler *et al.* 2011). Such areas can be a balance between conservation and socio-economic needs (Sciberras *et al.* 2015). Regardless, for any type of closed area to be biologically successful, life history characteristics need to be considered for any target species (Auster and Shackell 2000).

Potential benefits of closed areas to fisheries activities include spillover and catch increases in adjacent fishing grounds; enhancing fish stocks, with some evidence of larval export (Gell and Roberts 2003; Aburto-Oropeza et al 2011); increased yield (after an initial decreased yield due to the closure); buffer against uncertainties in stock assessments; ecosystem protection (e.g. from fishing gear, by catch, protected species); often cost-effective for multispecies fisheries; and serving as a control area (fished vs unfished site) (Hilborn *et al.* 2004). Additionally, some closed areas for conservation (MPAs) have shown positive effects on fisheries (Halpern 2003). For example, the Cabo Pulmo National Park, in Mexico, had a large increase in absolute biomass ten years after implementation (Aburto-Oropeza *et al.* 2011). Success was attributed to biological factors and strong local support (Aburto-Oropeza *et al.* 2011).

1.6 Closed areas in temperate ecosystems

Temperate ecosystems are characterised by highly mobile fish species that have defined migratory and dispersal characteristics (e.g. Atlantic cod, herring (*Clupea harengus*) and tuna species) (Breen *et al.* 2015). Species distributions are heavily influenced by temperature, along with latitude and depth (Rose 2005). Many temperate and boreal marine species form large feeding and spawning aggregations that can be influenced by climate variability (Rose 2005). Fishery closures in temperate seas have shown mixed results; take for example the Georges Bank, USA and the Scotian Shelf, Canada. Georges Bank was a closure primarily for haddock (*Melanogrammus aeglefinus*), (Murawski *et al.* 2000; Gell and Roberts 2003) but led to increased abundance and biomass of other sedentary fish species and sea scallops (*Placopecten magellanicus*). Similarly, a closed area for juvenile haddock on the Scotian Shelf did not meet its objectives for haddock, but other groundfish species increased (American Plaice, *Hippoglossoides americanus* and winter flounder, *Pseudopleuronectes americanus*) (Frank *et al.* 2000). Nonetheless, a review by Lester *et al.* (2009) on biological effects in no-take marine reserves found that they can be equally effective in tropical and temperate ecosystems. However, the higher dispersal rates in higher latitudes suggest that such closures may need to be larger than their tropical counterparts (Laurel and Bradbury 2011).

1.7 Limitations

There is a tendency to think that once closures are implemented, then all will be well; but closures do not address all aspects of conserving marine ecosystems. For example, impacts of climate change, ocean acidification and pollution are not addressed at all by closures. They can serve a role (as a refuge for species or reduce pollution within the closure), but do not protect from these larger impacts. Although biodiversity and habitat benefits of closures are likely, closures may not always improve fisheries' productivity and yields, and do not address all aspects of fisheries management (e.g. institutional structures) (Hilborn *et al.* 2004). Further issues include unintended consequences (e.g. effort redistribution) and lack of consideration of potential alternative management strategies (catch, size limits) (Hilborn *et al.* 2004). In addition, fishing can reverse the positive effects of closures. In Iceland, area closures on demersal fish (Jaworski *et al.* 2006) led to abundance and size increases once the area was closed, but re-opening to fishing reversed the effects. Similarly, Thurstan and Roberts (2010) combined historical accounts with landings data to review fishing activity in the Firth of Clyde, Scotland; the closed areas that reopened to trawls suffered from high fishing effort and seabed damage, and demersal fin-fisheries collapsed. Further, fisheries spatial-temporal variability complicates the influence of closed areas on fisheries such that evidence to determine their true impact is lacking (Mesnildrey *et al*. 2013). Closed areas for both fisheries and biodiversity may have conflicting objectives.For example a no-take closure may protect biodiversity but increase fishing pressure outside through displacement of fishers, causing negative effects on the ecosystem (Jones *et al.* 2007). In all, closed areas present a diverse mix of success with intrinsic challenges, with the best type of closed area in much debate. Overall, there is conflicting evidence on fishery benefits and empirical evidence is limited (see Caveen *et al*. 2015 for a full critique of current evidence).

1.8 Bringing social perspectives into biological research

Some closed areas may be considered to be biological successes, having met certain objectives, but may be viewed as social failures (Thorpe *et al.* 2011). Evidence suggests that the human dimension is of primary importance in the success or failure of closures in meeting management objectives (Mascia 2003; Pollnac *et al.* 2010). As closed areas are considered on larger spatial scales, socioeconomic concerns and the involvement of local communities need to be considered (Halpern *et al.* 2010; Rosendo *et al.* 2011; Rife *et al.* 2013). Such social aspects have not always been a priority in management plans (Rosendo *et al.* 2011), but in recent years, with EBM based approaches, they are becoming so.

Research is needed that examines closed areas as social-ecological systems (Pollnac *et al*. 2010). Including a social component is relatively recent in ecological studies, but as Leenhardt *et al*. (2015) discusses, it is necessary within effective marine resource planning and management. While both biological and social research is important, social-ecological research that crosses the traditional discipline boundary is an increasing trend. As an example, *"linking social and ecological systems to sustain coral reef fisheries"* by Cinner *et al*. (2009) was published in the peer reviewed biological research journal *Current Biology*. Similarly, articles with social and ecological components have been published in *BioScience* (Österblom *et al.* 2013), *Conservation Letters* (Lopez-Angarita *et al.* 2013) and *Bulletin of Marine Science* (Steneck *et al.* 2010). Social aspects are increasingly present in large conferences and meetings (e.g. The International Marine Conservation Congress), illustrating the widening view of the discipline. As EBM is a relatively new approach within natural resource management, the human aspects are a new approach as a part of the EBM concepts (Leenhardt *et al.* 2015).

1.9 Fisher involvement in closed areas

In many cases, EBM encourages local fishers to be fully involved, as opposed to the traditional approach of fishers being apart from management decisions (Curtin and Prellezo 2010). The failure to understand fishers' needs will not benefit fisheries or conservation (Grafton *et al.* 2009). As primary stakeholders, there is a need to incorporate fishers' knowledge and perceptions into marine management (Heck *et al.* 2011). There has been notable success in many parts of the world with community-based management

(Johannes 1978; 2002; Mills *et al.* 2011). Additionally, in data-poor regions, local knowledge and natural history may be used in lieu of empirical data (Aswani and Hamilton 2004; Ban *et al*. 2009). It is important that fishers are involved from the beginning, also known as "step-zero" (Chuenpagdee and Jentoft 2007; Chuenpagdee *et al.* 2013). This is because engagement and direct involvement are often key to the success of a closed area (Coleman *et al.* 2004; Rossiter and Levine 2014); attaining such support for closures may determine whether or not closure goals will be met (Agardi 2000; Leleu *et al*. 2012; Mellado *et al.* 2014).

1.10 The Canadian Fisheries Research Network (CFRN): Collaborative fisheries research

This thesis was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) Canadian Fisheries Research Network. This was a unique collaboration of academic researchers, government and non-government researchers, managers and the fishing industry from across Canada. The overarching goal of this network was to broaden how fisheries research was done in Canada to bring in academia, governments, industry and fishers as essential components of collaborative research. More specific objectives included the use of fisheries industry information, ecological sustainability and improvement of the ecosystem approach in fisheries management. As the result of one project within a wider network of fisheries research in Canada, this thesis aimed to answer questions important not only in academia, but also of importance to the fishing industry and governmental policies. One major aspect was close collaboration with the fisheries sector, hence the inclusion of interviews with local fishers alongside biological data collection.

2. Thesis overview

The research presented here aims to advance knowledge on the role marine closed areas of various types play in achieving optimal benefits to marine conservation and fisheries under an ecosystem based management approach. The approach follows EBM principles that include a combination of conservation and fisheries objectives, a wider view of multiple species and ecosystems, and includes people as a part of, not apart from, the ecosystem. This thesis offers a novel contribution to the existing literature by addressing questions important to both the fisheries industry and the conservation community from a global to local context to help understand the impact closed areas have on marine ecosystems and their contribution towards an ecosystem based approach.

2.1 Research questions and objectives

The manuscript format of this thesis is divided into chapters that address the following research questions and related objectives:

1. *Question*: Where are closed areas that have fisheries and conservation-based objectives; how have fishers been involved; and how successful are such areas?
   Objective: To review closed areas from a fisheries perspective in EBM and develop a scorecard to judge their efficacy.

The following two objectives focus on different types of closed areas in different ecosystems: a marine protected area in Tanzania and a fishery closure in Canada:

2. *Question*: What are the drivers for fishers' support of a multiple use MPA? *Objective*: To investigate fishers' perceptions of an MPA in a traditional fisheries location in the tropics and consider the use of fisher knowledge in biological data collection.
3. *Question*: Why would fishers support a closed area that limits their fishing activity? *Objective*: To explore drivers for fishers' support for a boreal offshore fisheries closure.

The final objective focuses on biological aspects of a boreal fisheries closed area in Canada (from Objective 3):

4. *Question*: What spatial and temporal effects has a fishery closure had on marine species in a boreal ecosystem? *Objective*: To assess spatial and temporal species changes for a closed area within a boreal offshore ecosystem and consider the role with a wider EBM approach.

2.2 Overview and links between chapters

The chapters within this thesis address each of these objectives. The themes linking the chapters are the use of closed areas for fisheries and conservation in EBM, including a global (Chapter 2) to a local focus on a tropical (Chapter 3) and a boreal ecosystem (Chapter 4 and 5); the temporal and spatial biological effects of a closed area in a boreal ecosystem (Chapter 5); and finally, bringing social perspectives into biological research (Chapters 2, 3 and 4).

In this thesis, socio-cultural influences are directly relevant and an essential component to the ecological elements of fisheries and nature conservation. As such, this thesis presents a wide approach, incorporating concepts to include a broad view on closed areas. Within this approach, data from fishers' knowledge and perspectives were considered to be a necessary and integral part of this thesis in biology. In such, while there is value in understanding bio-ecological dynamics of closed areas apart from socio-economic dynamics, here the EBM focus for closed areas includes people and their use of and impacts on marine ecosystems. Thus, as primary stakeholders, understanding the role of closed areas without including the fishers' perspective would not have fulfilled this thesis topic potential. In essence, it is necessary to include all elements to gain a complete picture of what is happening, and why. Local small-scale fishers in particular are most affected by closed areas, yet in many circumstances they can be involved and included, and support such areas whether they are focused on conservation or fisheries-based priorities.

Due to the limited knowledge available of the performance of many types of closed areas from a fisheries perspective, the thesis begins with a review and scoring of closed areas that include fisheries and conservation based objectives and considers the involvement of local fishers (Chapter 2). Following this, social and biological survey data from two diverse study areas are presented: a tropical coral reef fishery in the Indian Ocean (Mafia Island, Tanzania), presented in Chapter 3; and the other, a boreal deep-sea fishery (Labrador, Canada), presented in Chapters 4 and 5. Despite different types of closed areas (MPA in Tanzania and fishery closure in Labrador), ecosystems and fisheries (multispecies in Tanzania and single species in Labrador), both areas feature restrictions on fisheries supported by local fishers in planning and management of the areas. To investigate further, Chapter 4 explores fishers' perceptions and knowledge, bringing together EBM principles to study a closed area within a boreal area (an ecosystem underrepresented in marine closed area research), while Chapter 5 investigates the effects of a closure on a major boreal fisheries ecosystem using data from before and after implementation. These closed areas cover opposite ends of the closed area spectrum and provide an opportunity to consider the role of closures in EBM under different yet similar concepts. I conclude with a final chapter (Chapter 6) highlighting main findings, a summary of the main results and discussing the wider applications of the research presented here.

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Tables

Table 1.1: The many names of marine closed areas

Artisanal restricted area	Marine protected area
Community fisheries management area	Marine replenishment area
Fish conservation area	Marine reserve
Fisheries closure	Marine sanctuary
Fisheries management area	Multiple use area
Fish nursery reserve	No take area
Fish replenishment area	No take zone
Fisheries reserve	No trawl area
Fish sanctuary	Real time closure
Locally managed marine area	Seasonal closure
Marine conservation zone	Special area of conservation
Marine management area	Special protection area
Marine park	World natural heritage area

Chapter 2 How fisher-influenced marine closed areas contribute to ecosystem based management: a review and performance indicator scorecard.

A version of this manuscript accepted in Fish and Fisheries journal as:

Kincaid, K., Rose, G., and Devillers, R. How fisher-influenced marine closed areas contribute to ecosystem based management: a review and performance indicator scorecard. Fish and Fisheries.

1. Introduction

Closing marine and freshwater areas to fishing activities is one of the oldest fisheries management tools (FAO 2011). Closures typically are intended to lower or remove fishing pressure, protect essential [fish] habitats (e.g. spawning grounds or juvenile areas), or sensitive habitats (e.g. unique or productive sites)(Agardy 2000). Closures can be permanent, seasonal, rotating, or episodic in timing, and may be gear-specific (Hall 2002; FAO 2011). They can contribute to fisheries, as they have historically, by protecting sensitive life stages from harvest, but also through spillover of catchable fish (Kaunda-Arara and Rose 2004a, b; Stobart et al. 2009), export of eggs and larvae (Gell and Roberts 2003) and enhancement of juvenile recruitment (Harrison *et al.* 2012). More recently, closed areas have become a key tool for biodiversity conservation through marine protected areas (MPAs) (Kelleher and Kenchington 1992; Kelleher and Phillips 1999). Through this, MPAs have been implemented in many jurisdictions to meet international conservation targets set by the Convention on Biological Diversity (CBD 2011). MPAs (with a main goal of long term biological conservation) currently cover about 2.2% of the world’s oceans, of which only 1% is completely closed to fishing (Marine Conservation Institute 2016).

In contrast to fisheries-based closures, conservation-based closures (e.g. marine reserves and MPAs) have been established primarily by non-fisheries entities, such as National Park agencies (e.g., Kenya in the 1960s, Kaunda-Arara and Rose 2004a), and originally designed to exclude fishing to support biodiversity conservation (Agardy 2000; Watson *et al.* 2014). More recently, however, the evolution of conservation-based closures has led to a broader range of objectives and goals that can include fisheries objectives (Day *et al.* 2012).

Engagement of local communities and fishers can contribute to the success of all types of closed areas (Rossiter and Levine 2014) and the strength of local support from the planning stages onward often determines if conservation goals will be met (Agardy 2000; Leleu *et al.* 2012; Mellado *et al.* 2014). Engagement of local communities in closed area planning is a key factor in the success of an area (IUCN 2007; Charles and Wilson 2009; Pollnac *et al.* 2011). Furthermore, understanding the impacts of closures on both ecological and human communities is an important part of planning (Agardy *et al.* 2003). Despite numerous calls to involve communities (Pomeroy and Douvere 2008; CBD 2011; FAO 2011) and fishers (Gaines *et al*. 2010; Mellado *et al.* 2014) in fisheries management, few studies have examined participation, primarily by fishers, in various types of closed areas (Pita *et al.* 2011). Fishers often have knowledge of the fisheries that complements, and in some cases exceeds, that of scientists and managers. Fishers' knowledge can help formulate key research questions (Arthur *et al.* 2013), but should always be judged in the context of their unique perspectives on the ecosystem, largely their catches, which can lead to misinterpretations of stock and ecosystem status (e.g., Rose and Kulka 1999; Ward *et al.* 2013). Despite these limitations, given that fishers typically are most affected by management and closures, their involvement will improve the likelihood of achieving management objectives (CBD 2011; Pita *et al*. 2011; Kincaid *et al.* 2014b; Mellado *et al.* 2014).

Closed areas can have many names (e.g., fishery closure, marine reserve, marine park, MPA, National Monument), objectives (focusing on fisheries, biodiversity conservation, or both) and management regimes. Names have been used interchangeably and without clear definition (Agardy 2000), resulting in situations in which approaches and objectives of closures with the same name differ but those with different names are similar. Taking a broader EBM approach, in this paper, the term ‘closed area’ or ‘closures’ is used in this paper to encompass all types of closures.

The name “MPA” in particular, often incites negative reactions from people that have historical and contemporary attachment to the area’s fisheries, despite most MPAs not excluding all fisheries (Pita *et al.* 2011). In some situations, closed areas implemented by fisheries management, with similar goals and regulations as MPAs, but under a different name, may be viewed more positively (Jentoft *et al.* 2012). Furthermore, fishery closures have been shown to provide biodiversity conservation benefits (Mc Clanahan *et al.* 2006) and may, in some cases be a conservation tool with impacts well beyond the fisheries

(Robb *et al.* 2015). In addition, although no-take marine reserves may have biological benefits (Edgar *et al.* 2014), partially closed areas may be more socially acceptable in some situations (Lester *et al.* 2008), leading to greater support among users (Chuenpagdee *et al.* 2013). Support in turn can lead to meeting management objectives and spurring new initiatives that will benefit both fisheries and biodiversity conservation (Murawski *et al*. 2000; Harris 2007).

Implementation of closed areas under ecosystem based management (EBM) can unify, or at least make compatible, the objectives of fisheries and biodiversity conservation. Although conservation of biodiversity has not traditionally been a central part of fisheries management (Halpern *et al.* 2010), the awareness that fishable stocks depend on ecosystem productivity has fostered the implementation of EBM (e.g., Link and Browman 2014). EBM recognises the dependence of the productivity of commercially harvested species on ecosystem dynamics and critical habitat (FAO 2005; Abbott and Hayne 2012; Pita *et al.* 2012) in a more holistic approach to single species management (Pikitch *et al.* 2004). In particular, EBM recognises that human societal well-being (McLeod *et al.* 2005) and participation (Espinoza-Tenorio *et al.* 2012) are legitimate objectives, in addition to long-term sustainability of marine ecosystems, their biodiversity and fisheries production. EBM also emphasises that biological and societal goals are compatible and mutually beneficial – for example, protection of critical habitat, life stages or keystone prey species may lead to higher fisheries production which in turn leads to societal benefits (Agardy *et al.* 2011). Despite these advantages and resulting recommendations for EBM of marine systems for more than a decade (Kelleher and Phillips 1999; Link 2002), implementation has been slow in part because of the complexity of implementing EBM principles (Long *et al.* 2015), and the lack of specific information on how to achieve optimum implementations and benefits (Link and Browman 2014).

The contribution of conservation-based closed areas to fisheries has been widely discussed and debated (Lindeman *et al.* 1998; Jamieson and Levings 2001; Hilborn *et al.* 2004; Kaiser 2005; Jones 2007; Botsford *et al.* 2009; Weigel *et al.* 2014). The contribution of fisheries-based closed areas to biodiversity conservation has yet to receive similar attention in the literature. We hypothesised that there may be considerable overlap in the outcomes of closures, and that all types of areas that feature some type of area based restriction should be considered as they influence fisheries and biodiversity conservation. Our approach is primarily from a fisheries perspective within EBM principles (that include biodiversity conservation), as despite reviews of the impacts of conservation-based closures (Lester *et al.* 2008; Sciberras *et al.* 2013), the fisheries perspective has, in comparison, often been overlooked (but see Caveen *et al.* 2015).

The main goal of this paper was to explore the performance of a wide range of marine closures under an EBM approach having fisheries and biodiversity conservation objectives and fisher involvement. We pose four working questions: 1) what types of closures under EBM are fishers involved in? 2) do closed areas with fisher engagement lead to positive outcomes? 3) how best to monitor and track the performance of closed areas under an EBM approach? and 4) do closures of different types have different outcomes? To address these questions, we first review the literature on closed areas that had fisheries and biodiversity conservation objectives, together with fisher involvement, describe how fishers were involved, and summarise the main findings. A set of indicators was developed based on input from stakeholders representing fishers, industry, governments and conservation interests, the literature, and EBM principles. These were used within an indicator based scorecard developed to assess the performance of the reviewed closed areas.

2. Methods

2.1 Systematic Review

A systematic rapid review based on the methods of Pita *et al.* (2011), employing guidelines recommended by Petticrew and Roberts (2006) and PRISMA best practice protocols (Moher *et al.* 2009), was undertaken to identify relevant studies from the peer-reviewed literature. Systematic reviews comprise a structured literature review used in evidence based decision making (Pita *et al.* 2011). Systematic rapid reviews aim to synthesise evidence more efficiently (Ganaan *et al.* 2010). A rapid review can limit searching by years, data type, data extraction or to online sources (Ganaan *et al.* 2010). For example, Pita *et al.* (2011) conducted a rapid review of commercial fishers' attitudes towards MPAs by limiting the search to peer reviewed studies found within six scientific databases and focused on commercial fishers only.

The literature was reviewed up to May 2013 by searching the ISI Web of Knowledge, the Aquatic Sciences and Fisheries Abstracts (ASFA), and the Google Scholar databases. The search was not restricted to any specific geographic region. In line with the rapid review method, literature was restricted to peer reviewed papers that were accessible in full text online. The following criteria were used for the web search: "marine AND fishers (and 3 derivatives: fishermen, fish harvester, fisherfolk) AND closed areas (and 47 derivatives of closed areas)", see supplementary material (S1) for full search terms. All references were imported into the Endnote referencing software (v. X6) to be read for inclusion. Criteria for inclusion in further analyses were (1) reporting on a specific marine closed area (of any type), (2) evidence of fisher involvement, (3) mention of both biodiversity conservation and fisheries (in any way, keeping this focus purposely broad), (4) reporting of empirical data on the specific closure (comparing either before vs. after, or inside vs. outside and/or reported fisher perception/knowledge data).

A total of 523 studies were identified and read at title and abstract levels for the inclusion criteria (Fig. 1). A repeat search with ‘fisher’ (and synonyms) removed, yielded 62,622 results, suggesting that most published studies on closures do not mention fisher involvement. This does not however suggest that fishers were excluded in those studies the absence of mention of fishers could be due to many reasons (e.g. fisheries may not be a threat to manage in some areas. A random sample of the 523 studies (20%) was checked against the inclusion criteria at the abstract level by an independent reader for quality assurance and no disagreements arose from this. Out of the remaining 156 studies that passed initial criteria, 44 were not available online in full text. The remaining 112 studies were read to check against inclusion criteria. Many studies were discarded at the full text level as they either reported models, or predictions, had no empirical data, discussed only that fishers should be involved or discussed fishing gears without consideration of impacts on biodiversity. Twenty-one studies describing 19 closed areas fulfilled all criteria and were subsequently used for further analyses. Data extracted from selected studies included methodology, type, size and age of closed area, type of fisher involvement, description of the closed area, main results and conclusions.

2.2 Indicator development and scorecard system

The review provided 19 closed areas in various regions of the world that had peer reviewed studies reporting fisher involvement and elements of biodiversity conservation and fisheries management. These provided a group of closed areas with similar characteristics to be evaluated with an indicator based scorecard. Performance indicators are often used to measure management effectiveness at meeting fisheries (FAO 1999) and biodiversity conservation (Garces *et al*. 2012) objectives. Here, a set of 24 performance indicators was chosen based on questions and concerns raised in stakeholder meetings (15 individuals representing the fishing industry, academia, government and non-governmental fisheries and conservation based organisations from the Canadian Fisheries Research Network), recommendations from the literature, and EBM principles. Indicators were grouped into four categories and designed to provide measurable targets to assess the performance of closed areas from an EBM approach: planning and management, design, fisheries based bio-ecological expectations, and fisheries based socio-economic expectations (Table 4).

The selection of performance indicators and scoring criteria was justified using the primary literature (see Table 4 for scoring system and justifications). Some indicators could be answered using ‘yes’ or ‘no’ while others allowed more detailed responses. Hence two rating scales were used: an ordinal four-point rating scale (low to high, 0-3) and a 0/3 score for dichotomous answers (yes/no). Scores were equally weighted and assessed as a total score per closed area (maximum score of 72) and as an overall percentage per indicator. The scoring system was designed to measure how each closed area met the selected indicators, based on the Management Effectiveness Tracking Tool (METT) methodology (Stolton *et al. 2007*). METT is a rapid assessment scorecard questionnaire used globally as a protected area management effectiveness tool. Such scoring systems can use colour-coded indices to describe status (Hyde *et al.* 2011), and numbered scoring systems (Stolton *et al.* 2007). Using this approach, a score of zero indicates either that the indicator has not been met, or there was no known information available to answer. Thus, a low score may indicate poor performance or a lack of data. In either case, for the scoring system designed here these two scenarios are treated as the same and receive a zero score. Following this, scorecards were then developed using the indicator framework to measure the outcomes of a closed area from a fisheries and biodiversity conservation perspective under an EBM approach. Scale based scoring was chosen when the indictor could be partially met, with certain circumstances and could be scored along a scale of low to high. In other cases, were a scale was not deemed to be appropriate, an indicator was best scored as a definitive yes/no response. In these cases, either a closure met the indicator or did not/unknown. This scorecard was designed to assess effectiveness thus it was deemed more appropriate to include no data available as a part of the scoring system and given a zero score. This method could be adjusted in future uses of this scorecard method to allow no data available responses to be separated from the scoring system.

To assist with scoring, managers of each of the 19 closed areas from the review received a survey by email based on the indicator framework to provide responses to questions that were used for each indicator. Managers were contacted because they were able to provide the most current information for a closed area and current management plans that may not be available online. In addition, surveys canvassed current unpublished information and any recent management plans and data sources. Surveys included each indicator and the available answers as detailed in Table 5. For the areas with responses from managers (n = 8), a wider literature search was undertaken to identify further research and data available (See S2 for extra references used to assist with scoring). The final score for each indicator was determined from the information provided by managers, published sources and current management plans. All available information was evaluated against each indicator to derive a score. For the majority of the indicator scoring, the final score was consistent with the managers' responses to the survey. However, managers often partially responded, or deferred to the management plan. In these cases, management plans and published literature and reports were consulted to provide a final score.

3. Results

3.1 Fisher involvement in closed areas

The selected studies (n=19) spanned a wide variety of closed areas from fishery closures to no-take MPAs (Fig. 2, Table 1). Their geography ranged from northern boreal (e.g., Gilbert Bay, Labrador, Canada) to tropical environments (e.g., coastal Kenya, Fiji and the Great Barrier Reef, Australia). The closed areas used 12 different names: marine protected area (n=5), seasonal closed area (n=3), marine national park/marine park (n=2), fisheries management area/zone (n=2), world natural heritage area (n=1), prohibited trawling area (n=1), national marine sanctuary (n=1), marine reserve (n=1), managed resource protected area (n=1), inshore potting agreement (n=1) and national monument (n=1). The average age of the closures was 25 years and their creation ranged from 1971-2005. Their size ranged from $5km^2$ for the Cap Roux MPA (France), to $345,000km^2$ for the Great Barrier Reef Marine Park (Australia). All data in the studies were collected between 1997-2010 and involved either industrial (large-scale), artisanal (small-scale) and/or recreational fishers (Table 2). Fishing regulations within the closed areas varied widely from no-take (n=5) to commercial fishing being allowed (Table 2). Regardless of the type of closed area and main purpose, the majority (74%) had some form of fishing allowed inside the closed area from gear restrictions, to seasonal restrictions and rights for artisanal fishers. While some studies did not specify the number of fishers involved, for those that did the number ranged widely from 16 to 1743 (Table 2).

The majority of studies involved fishers through individual interviews. Fishers provided fisheries information to researchers (e.g. catch data, landings information), were involved in planning and management and reported fisher involvement in active enforcement of the area (Table 3). Fishers' knowledge was used in a variety of ways, to assess changes in fish stocks (Galal *et al.* 2012), to compare fishing data (McClanahan and Mangi 2001) and define the fisheries taking place (Forcada *et al.* 2010) and to implement closures (Seytre and Francour 2009). Many studies described additional aspects including fishers perceptions on restrictions (Tonioli and Agar 2009), the extension of an area (Sutton and Tobin 2009; Lédée *et al.* 2012; Sutton and Tobin 2012), effectiveness (Karras and Agar 2009), and differences before-after implementation (Milon *et al.* 1997; Shivlani *et al.* 2008).

There were notable differences among fisher groups that were involved in the case studies. Three studies on the Great Barrier Reef Marine Park, Australia focused on interviews with recreational fishers (Sutton and Tobin 2009) and commercial and charter fishers (Lédée *et al.* 2012; Sutton and Tobin 2012) about rezoning plans to increase no-take areas. Recreational fishers had positive attitudes towards rezoning (Sutton and Tobin 2009). For the commercial and charter fishers, 5 years after implementation, the more resilient fishers (defined by level of agreement on their perceived ability to cope with change in the fisheries industry), were more supportive of the rezoning plan (Sutton and Tobin 2012). However, despite a very small impact on their fishing grounds (i.e. decrease of 4.8% of trawlable area; Grech and Coles 2011) and significant compensation packages, the majority of commercial fishers believed that rezoning was a bad idea. In this case, fishers did not feel engaged in public consultations, were dissatisfied with the process and thought zoning locations were politically influenced (Lédée *et al.* 2012).

Gear conflicts often influence the type of closures imposed. A study on Prohibited Trawling Areas (PTAs) in the UK (Bloomfield *et al.* 2012) discussed conflict resolutions between mobile and static gear fishers, similar to Blyth *et al.* (2004) on the Inshore Potting Agreement (IPA). In both studies, static gear fishers were allowed to fish inside the closed areas, while mobile gear users were not. In Bloomfield *et al*. (2012), 54% of the trawl fishers interviewed thought PTAs achieved their objectives. Fishers were generally positive about the closed areas for conflict resolution and stock protection. However, few perceived any benefit from the closed area with regards to increased abundance or size of mobile fish.

3.2 Type of fisher engagement and outcomes

Fishers had mixed views of the outcomes of closures. In interviews at seasonal closures in Thailand, Aujimangkul *et al*. (2000) reported that 59% said that the abundance of fishery resources had improved since the establishment of the closed area and 67% said the closed area had a positive impact on them. Fishers perceived a value in the closed area with 92% strongly agreeing to spawning and nursery area closures. Similarly, Leleu *et al*. (2012) reported a high social acceptance with general outcomes of the closure on fisheries thought to be positive (88%) in the *Parc Marin de la Côte Bleue* MPA in France. Here, most fishers said the MPA benefited the fishery and ecosystem, despite scientific evidence against this. However, the effect on fishers' activities received a neutral opinion (50%) and fishers did not perceive any spillover effect from the closed area. Similar observations were reported by Tonioli and Agar (2009) in the *Bajo de Sico* seasonal closed area in Puerto Rico, where fishers acknowledged that the current closed area had protected spawning aggregations but were unwilling to support further or longer closures due to the socio-economic impact on their livelihoods. Karras and Agar (2009) reported similar results in the Buck Island Reef national monument, USA with 55% of fishers believing that fish abundance had increased inside the reserve area but that the closure had adverse effects on their livelihoods and the local community. Fishers were involved within decision making in a few of the studies. For example, Guidetti *et al* (2010) described how in the Torre Guaceto MPA in Italy fishing regulations were supported by local fishers as they were part of the decision making process. Galal *et al*. (2012) concluded that participation of the fishing community in meetings and consultations was key to improving both support for the area and compliance with regulations. In Shiretoko World Natural Heritage area in Japan, fishers were not only part of the decision making process, they were the primary decision makers on fisheries management (Makino *et al.* 2009). In contrast, Milon *et al*. (1997) reported that fishers did not believe that the Florida Keys National Marine Sanctuary, USA was effective in restoring reefs, even though many had been involved in developing the management plan (Shivlani *et al*. 2008).

In recent cases, fishers provided a variety of biological and ecological data relevant to closures (Galal *et al.* 2002; Blyth *et al.* 2004; Seytre and Francour 2009; Forcada *et al.* 2010; Guidetti *et al.* 2010; Jupiter *et al.* 2010; Bloomfield *et al.* 2012). For example, fishers provided information on fishing locations and habitat information to help select study sites for biomass sampling at the South Devon Inshore Potting Agreement (IPA), UK (Blyth *et al*. (2004). It is important to note that data from fishers were diverse, some supporting positive outcomes from a biological perspective, but negative and sometimes indicating unintended outcomes for fisheries. For example, based on data from fishers in the Nabq managed resource protected area in Egypt, Galal *et al*. (2012) reported that mean fish abundance was 94% higher inside the area than outside and overall higher 15 years post closure. Karras and Agar (2009) reported that fishers expressed a need for their ecological knowledge to be incorporated into management. Most studies suggested that utilising the ecological knowledge of fishers in management yields positive biological results (Pita *et al*. 2011; Arthur *et al.* 2013).

3.3 Indicator based scoring system

The performance indicator framework (Table 4) and scoring system (Table 5) outline the full scoring process including the type of scoring and justification for each indicator selected. The indicator scorecard was used for 8 out of the 19 closed area sites from the review as detailed in the method (Fig 1) and displayed within the scorecard (Table 6). The scorecard shows scores for each indicator and total scores per site and per indicator. Scores were colour coded (green-excellent, orange-room for improvement and red-poor) for easier identification. The total score from each indicator category (%)are highlighted in Fig. 3.

The closed areas used in the scorecard (n=8) represented a range of geographic regions including tropical, temperate and boreal areas, and varied in their closed area type (Table 6). The closed areas represented multiple use areas (n=5) and fishery closures (n=3). Within these closed area categories, areas covered many types including marine reserve, world natural heritage area and prohibited trawl area. In regards to the performance of individual closed areas, the highest scoring areas were the Kubulau fisheries management area/MPA and the Florida Keys National Marine Sanctuary with a score of 69 (out of 72), 95.6%. These areas scored well in all categories and across all indicators (Table 6).

For individual closed areas, all scored well across a number of indicators. The indicators that scored highly across all 8 closed areas included: local support (100%), bottom habitat protection (100%), conservation and fisheries objectives (100%), monitoring (91.7%) and fishers' concerns (91.7%) (Fig. 5). In addition, it was expected that fishers would be supportive of these closed areas and that conservation/fisheries would score highly (100% had biodiversity conservation and fisheries in the management plan, one of the criteria used to select the studies). In contrast, many other indicators within the bio-ecological and socio-economic expectations categories had low scores. In particular, low scores were obtained for indicators monitoring spillover (37.5%), fish populations (62.5%), catch levels (50%), levels of fishing effort (62.5%) and management involvement level (58.3%) (Fig 5). The relationship between the indicator types differed (Fig 6). The socio-economic indicators had a stronger relationship to planning, management and design based indicators ($R^2 = 0.77$) than did the bio-ecological indicators ($R^2 = 0.25$).

4. Discussion

The main objective of this paper was to explore how a wide range of marine closures have contributed to EBM through their potential to provide both biological and social benefits. This was explored through four research questions directed towards fisher involvement in closures (through the review method) and performance of such closures (through an indicator scorecard method). In addition, this paper outlines the indicator scorecard approach as a performance tracking tool that can be modified to track progress and effectiveness of closed areas under a variety of conditions.

The review demonstrated that fishers were involved in a broad range of closed areas and in several ways. Fishers were involved in knowledge acquisition (through interviews, meetings, providing fisheries data and mapping) and in planning and decision making (establishment, area selections). Unsurprisingly, fishers saw a value for a closed area when they perceived a direct benefit to their livelihoods (e.g. fisheries resources improved), and were supportive of closed areas to protect nursery and spawning areas. Fishers provided biological information and acknowledged the biological based benefits of a closed area (Seytre and Francour 2009; Jupiter and Egli 2011). However, they were often cautious about benefits to themselves and often unwilling to support further protection efforts citing the impact on their livelihoods. Views varied, consistent with different fisher groups having widely divergent views about closures (Kincaid and Rose 2014b). .

The generally positive assessment of the contributions of closures to both fisheries and biodiversity conservation reported here may have resulted in part because all had fisher involvement. Our results are consistent with such involvement and inclusion serving to engage and create stronger support and more effective management (FAO 2011). Given repeated calls for the integration of fisheries and conservation under an EBM approach (FAO 2005; Abbott and Hayne 2012) and for fisher involvement in closed areas (Gaines et al. 2010; Mellado et al. 2014), the small number of closed areas globally (19 of 562 studies initially considered) that met all the review criteria was surprising, and suggests that the majority of closed area studies have not focused on fisheries impacts. We believe that this needs to change if closed areas are to achieve management objectives. It is acknowledged that the review process used here concentrated on published papers and may not have captured all evidence of fisher involvement but even so the results are striking.

The indicator-based scorecard advanced in this study is a rapid assessment method that can provide a snapshot to track the performance of closed areas under an EBM approach. Many indicators under the planning/management and the design categories rated highly. Perhaps predictably, the responses of managers were generally positive (indicators #1-14). Nonetheless, most matched independent responses from the other sources, and allow insight into how effective an area is relative to objectives, and as a repeated monitoring measure to assess performance changes over time. Similarly, design-based indicators of size of the area, zonation plan and no-take areas and connectivity generally rated highly. Another finding of this study was that there was a lack of availability of data to adequately score some of the indicators. For example, the scoring for indicator 4 may be biased towards areas with many stakeholders, and indicator 15 (fish populations) and 16 (spillover) scorings were likely biased by the few areas where these results were available. In general, the socio-economic indicators were more strongly evidence-based, although in some cases somewhat subjective, than were the eco-biological indicators. The dearth of biological data on the fisheries was in some cases problematic in judging performance against management objectives. Despite these issues, we believe that the scorecard provided a reasonable performance based assessment of closed areas.

An important conclusion of this study is that a broad range of closures may be able to meet fisheries needs and biodiversity conservation commitments (Gaines et al. 2009) within an EBM approach. We recommend that management and fisheries and oceans conservation interests recognize that a diversity of closures is likely to be most successful through wider marine spatial planning (Agardy et al. 2003; 2016). As examples, many of the closed areas not classified as MPAs (see Day et al. 2012 for a description of MPA categories) had highly rated bio-ecological indicators. In addition, fishery closures gained substantial local support in Madagascar which resulted in the implementation of conservation focused MPAs (Harris 2007). Fishery closures were a stepping stone towards enhanced fisheries and biodiversity at Mafia Island, Tanzania, involving a wide and diverse set of staged fishing and conservation focussed management (Kincaid and Rose 2014a). Of note, one of the highest scoring closed areas was the Kubulau District fisheries management area and MPA (KFMA), Fiji (Table 6). The KFMA amalgamates traditional fisheries management and MPA biodiversity closures (WCS 2012; Clarke and Jupiter 2010). Several factors led to the high score. The management model starts with the community and their fishers (Johannes 1978; 2002). Importantly, local fishers asked for assistance and wanted marine protection for this area. This, with early involvement, can be key to the success of an area (Chuenpagdee et al. 2013). Possibly as important, management strategies were adaptive (Weeks and Jupiter 2013), and aspects important to communities and fishers were addressed, such as traditional fishing rights being recognised and alternatives available for displaced fishers (Jupiter and Egli 2011). Although it might be argued that such a model is not easily transported to other regions and fisheries, it is equally likely that the application of many of its elements could lead to parallel successful fisheries and biodiversity outcomes in many regions.

The rapid assessment method used to identify relevant studies has advantages, but also limitations. Some areas or studies may have been overlooked either because of biases caused by the lens (search engine) used (see Valiela and Martinetto 2005), the search strategy, under-reporting of fisher involvement, or because the search was limited to the academic literature and documents accessible online. Indicator selection and scoring also imposed certain limitations; indicators are simplified representations of a more complex reality and should be used as a guide, not as rules, for decision making and further analysis. We believe that the indicator framework should be flexible and adaptable to the context and objectives of specific closures. For instance, some indicators may not apply to some closures (e.g., many conservation-based closures do not have, and should not necessarily have, an objective to increase fish populations). Another example is with closure size. Although the literature provided evidence that larger closures tend to provide more benefits than smaller ones (e.g. Edgar *et al*. 2004), it does not mean that specific small closures cannot be effective in some contexts. In addition, the scoring system designated a 0 score for unreported indicators/missing data. This could be adapted to provide some differentiation to an area having not met the indicator and missing data. Finally, scores were collected from management plans, the primary literature and from area managers. All may contain some bias, including those of individual managers in evaluating the success of their closure (e.g., Hockings *et al.* 2003*;* Stolton *et al.* 2007). However, scoring and monitoring targets should be used with caution, and performance based goals need to work within a broader framework that consider wider contexts (e.g. marine spatial planning) and collaboration as recommended in Agardy *et al*. 2016). Marine spatial planning is an essential step towards EBM (Douvere 2008).Future developments of this approach should include a detailed look at how fishing activities are displaced by closures, the levels of illegal, unreported fishing within no-take areas, and conduct further comparisons of areas with and without fisher involvement. Our method using a mixture of published literature with management plans and surveys to managers in the scorecard allowed us to use as much up to date information as possible. The lack of availability of data to adequately score some of the indicators is a major concern and needs to be addressed in future studies. We found that data and analyses may be available, nonetheless, but not yet published, an important point raised by Westhead *et al.* (2012) in their response to Agardy *et al.* (2013), which suggests direct contact with managers is important to ongoing assessments of closure impacts. The importance of independent scientific study cannot be overstated - most of the successes reported here had strong scientific support.

In conclusion, we believe that the present findings are valid globally in terms of meeting the objectives of EBM. In response to our working questions, it was evident that fishers are involved in only a small percentage of closed areas, but their involvement appears to benefit the achievement of both biological conservation and fisheries management objectives. It was also evident that fisheries and biodiversity conservation outcomes are not exclusive to any one type of management closure, under any name, and many can serve the interests of both fisheries and biodiversity conservation. The scorecard provided a reasonable means to evaluate management success in light of often qualitative or non-existent data. It is important to note that all of these closures, and likely their successes, benefited from fishers' involvement, consistent with the findings of Agardy et al. (2016). Our analyses support the notion that addressing the interests and utilizing the knowledge of those most affected by closures and most familiar with the area, most often local fishers, is key to achieving management objectives. Future research should compare areas with and without fisher involvement to gain more insight. Finally, bio-ecological data and monitoring of the impacts of closures is often lacking, making evaluation of the key elements of biological production problematic. With the proliferation of closures under many names worldwide, it is essential that research on their impact both on fisheries and biodiversity does not get lost in a race to close areas.

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Tables

Table 2.1: Studies and closed areas identified for detailed analyses from the literature review.

Continent	Country	ID	Name of area	Year first implemented/ actively managed	Size (km^2)	Studies selected from the review
Africa	Egypt	1	Nabq Managed Resource Protected Area	1992	35	Galal *et al*. (2012)
	Kenya	2	Mombasa Marine National Park	1991	35	McClanahan and Mangi (2001)
Asia	Indonesia	3	Berau Marine Protected Area	2005	2,852	Gunawan and Visser (2012)
	Thailand	4	Seasonal Closed areas in the Gulf of Thailand	1984	unknown	Aujimangkul *et al.* (2000)
	Japan	5	Shiretoko World Natural Heritage Area	2005	617	Makino *et al*. (2009)
Europe	UK	6	South Devon Inshore Potting Agreement (IPA)	1978, current size 1993	478	Blyth *et al.* (2004)
	UK	7	Prohibited Trawling Areas (PTA)	1930	95	Bloomfield *et al*. (2012)
	Malta	8	The Maltese Fisheries Management Zone	1971	11,980	Dimech (2009)
	France	9	Cap Roux MPA	2003	5	Seytre and Francour (2009)
	France	10	Parc Marin de la Côte Bleue MPA	1983, 1996	98	Leleu *et al*. (2012)
	Italy	11	Torre Guaceto MPA	2001	22	Guidetti *et al* (2010)
	Spain	12	Tabarca Marine Reserve	1986	14	Forcada *et al.* (2010)

N. America	Puerto Rico	13	Bajo de Sico seasonal Closed Area	2005	31	Tonioli and Agar (2009)
	Canada	14	Gilbert Bay Marine Protected Area	2005	60	Wroblewski *et al*. (2009)
	USA	15	Buck Island Reef National Monument	1961, expanded 2001	77	Karras and Agar (2009)
	USA	16	Red Hind Seasonal Closure	1993	41	Karras and Agar (2009)
	USA	17	Florida Keys National Marine Sanctuary	1990, implemente d 2007	9,946	Shivlani *et al.* (2008), Milon *et al*. (1997)
Oceania	Fiji	18	Kubulau District Fisheries Management Area and MPA	2005	80	Jupiter and Egli. (2011)
	Australia	19	Great Barrier Reef Marine Park	1981	345,000	Sutton and Tobin (2009), (2012), Lédée *et al.* (2012)

Table 2.2: Summary of fishing regulations and fisher types involved for the closed area studies from the review. ID relates to the closed area studies (see Table 1). ?: the number of fishers involved was not reported in the study.

ID	Any fishing allowed inside the closed area? Yes/ No	Regulation in place	Fishers involved in study Type^	Number
1	Y	Traditional fishing rights	S	?
2	N	No fishing but due to conflicts, size reduced in 1995	S	?
3	Y	Artisanal fishing allowed	S	?
4	N	No fishing allowed	S, I	305
5	Y	Controlled quota for certain species	S,I	?
6	Y	Restrictions on gear and seasons	S	?
7	Y	No trawling	S	?
8	Y	Some trawling allowed	S,I, R	241
9	N	No fishing allowed	S	?
10	N	No fishing allowed	S	16
11	Y	Artisanal fishing in buffer zone allowed	S	?
12	Y	Zones and gear restrictions	S	32
13	Y	No bottom trawling and fishing restrictions	S	65
14	Y	Some fishing allowed	I	?
15	N	No fishing allowed	S	95
16	Y	Gear restrictions	S	95
17	Y	Zone restrictions	S	294,337
18	Y	Fishing determined by local village chiefs	S	?
19	Y	Zoned, commercial fishing allowed, others no-take	R, I	1743, 114

^ Categories of fishers follow the FAO broad level capture fishery types. S: Small-scale artisanal (labour intensive, small vessels, usually family owned, includes traditional fisheries), I: Industrial (capital intensive fisheries with large vessels, company owned) and R: Recreational (sport fisheries for personal leisure). ? = Unknown, the number of fishers involved was not specified within the study.

Table 2.3: Overview of closed area types and how fishers were involved.

Closure Type*	**How fishers were involved.**			**Corresponding studies from the rapid review**
	Decision making*	**Fisheries information^**	**Interviews/ meetings**	
Fishery Closures	1	3	7	Aujimangkul et al. (2000); Bloomfield et al. (2012); Blyth *et al.* (2004); Dimech (2009); Garcia (2005); Karras and Agar (2009);Tonioli and Agar (2009)
Multiple use/ Zoned area>	3	3	8	Forcada et al. (2010); Galal et al. (2002); Guidetti (2010); Gunawan & Visser (2012); Jupiter et al. (2010); Makino et al. (2009)Milon et al. (1997); Shivlani et al. (2008); Sutton and Tobin (2009); Wroblewski et al. (2009)
Marine Reserve (no-take area)>	1	1	4	Karras and Agar (2009); Leleu et al. (2012); McClanahan and Mangi (2001); Seytre and Francour (2009)

* Closed areas were grouped into categories based on classifications described in Agardy (2000), * Decision making Includes choosing site location, implementing gear type and size allowance for closure. ^ Fisheries information Includes recording catch data, landings, catch per unit effort and providing fisheries and habitat information. > may or may not be classified as an MPA under IUCN guidelines.

Table 2.4: Performance indicator framework.

	Indicator	type*	Max.
Planning and management			
1	Is there a management plan in place?	scale	3
2	Are there conservation and fisheries objectives in the management plan?	Y/N	3
3	Does the area follow an ecosystem-based management approach?	Y/N	3
4	Who is involved in management?	scale	3
5	Have the goals and objectives been achieved?	scale	3
6	Does the management plan allow for adaptation and change?	Y/N	3
7	Are local fishers concerns being acknowledged and/or addressed?	scale	3
8	What is the fishers' involvement level?	scale	3
9	How has the level of protection changed over time?	scale	3
10	Is there regular monitoring of the area?	scale	3
	Maximum possible score		30
Design			
11	What size is the area?	scale	3
12	Does the area have a zoning system that includes fishing areas?	Y/N	3
13	Are there no-take areas?	Y/N	3
14	Is there any connectivity to other areas?	Y/N	3
	Maximum possible score		12
Fisheries based bio-ecological expectations			
15	Have fish populations increased over time?	Y/N	3
16	Is there evidence of spillover effects?	Y/N	3
17	How many species are protected?	scale	3
18	Is the bottom habitat protected?	Y/N	3
19	Productivity: Are spawning areas protected?	Y/N	3
	Maximum possible score		15
Fisheries based socio-economic expectations			
20	Has fishing effort changed inside/outside the area over time?	Y/N	3
21	What fishing gears are allowed inside?	scale	3
22	Have fish catches increased in/around the area?	Y/N	3
23	Displacement: are there alternatives for lost fishing areas?	Y/N	3
24	Does the area have local fishers' support?	Y/N	3
	Maximum possible score planning and management		15
	Total maximum possible score, all categories combined		72

* Scoring type: Scale = 0-3, 4 point rating scale bad (0)to excellent (3). YN = Yes, met the indictor (3), No, did not meet indicator/ no data available (0).

Table 2.5: Indicator scorecard scoring system. Scores use either an ordinal scale from 0-3 or a 0/3 score for dichotomous answers. Scoring was justified using the literature where possible based on the METT model (Stolton et al. 2007).

	Indicator	**Scoring Criteria**	**Justification for indicator and scoring**
Planning and Management			
1	Management plan	0- No management plan in place 1- Being prepared/not implemented 2- Exists but only partially implemented 3 -Exists and is being implemented	A well-defined management plan is needed with specific, measureable goals (Stolton *et al*. 2007)
2	Conservation and fisheries objectives	Has both in the management plan, 3	Maintaining biodiversity and the wider ecosystem to provide goods and services for future generations (Lubchenko *et al.* 2003)
3	Ecosystem-based management approach	An EBM approach is mentioned in the management plan, 3	For human and ecosystem wellbeing (Garcia *et al*. 2003)
4	Management Involvement	0- Government manages completely 1- Government plus 1 other stakeholder group involved 2- Government plus 2 others involved 3-Government plus 3 or more involved	Need a balance between top down and bottom up management, need a wide range of stakeholders to be involved in the management (McCay and Jones 2011)
5	Goals and Objectives	0- None in place 1- Yes but not been met 2- Yes, partially met 3- Yes and met/ on track to meet them	Effectiveness can be measured against how an area is meeting goals and objectives (Pomeroy *et al*. 2005)

6	Area uses adaptive management	Management plan allows for changes to area boundaries, rules, and/or regulations, 3	Adaptive management should be included in management plans (Morris and Green 2014)
7	Fishers concerns	0- Fishers concerns have not been acknowledged or addressed. 1- Fishers concerns have been discussed in an ad hoc manner 2- The concerns of fishers is acknowledged but not being addressed 3- Concerns are acknowledged and are actively being addressed	This was an important factor among local fishers in stakeholder meetings
8	Fisher involvement level	0- None: No input into management decisions. 1- Low: Some input but no direct role in management 2- Medium: Directly contribute to some relevant decisions 3- High: Directly participate in all relevant decisions and can influence management plan (co-management)	"The decision of MPA design requires close collaboration with local fishermen communities for it to be accepted and respected." (Mellado *et al*. 2014)
9	Protection level change over time	Protection level has…. 0- Reduced 1- Stayed the same 2- Increased a little 3- Increased substantially over time	More protection is better if an area starts small but gets local support. It could expand, thus protecting more habitat and species (Harris 2007)
10	Regular monitoring/ evaluation	0- No monitoring/evaluation 1- Some, but not put into management 2- Agreed and implemented system but not put into management 3- Good and well implemented	How effective an area is can be evaluated against the areas targets and objectives (Day *et al.* 2002)
Design			
11	Size of area	0- Very small (<3km^2) 1- Small(4-10km^2) 2- Medium (11-30km^2)	Larger the area that eggs and larvae survive within boundaries, greater benefit

		3-Large (>30km^2)	(FAO 2011)
12	Zones	Area has a zoning system of fishing and non-fishing areas, 3	Balance between biodiversity protection and sustainable fishing, high socio-economic success (McCook *et al*. 2010)
13	No fishing areas	Area has no-fishing/ no-take areas, 3	No-fishing areas benefit fish stocks (McCook *et al*. 2010) and increase conservation benefits in MPAs (Edgar *et al*. 2014)
14	Connectivity to other areas	Other closed areas are in proximity to allow fish movements between them, 3	Adult and larval connectivity to other areas may allow an ecosystem-wide supply to fish stocks (McCook *et al*. 2010)
Fisheries bio-ecological expectations			
15	Fish populations over time	Biomass and/or population density has increased in the area, 3	Effective MPAs have increased biomass (Edgar *et al*. 2014)
16	Evidence of spillover	Evidence that adult fish migrate across boundaries, 3	Increased abundance in one protected area had increased yields for the adjacent fishery (Stobart *et al*. 2009)
17	Protected species	0- No species protection 1- Single species protected 2- A few key species for fisheries/conservation are protected 3- Whole ecosystem protection	Move towards EBM, to protect whole ecosystem
18	Habitat protection	Habitat protection is included in management plan, 3	Important for EBM as above, protects fisheries and conservation interests
19	Spawning areas protected	Area provides protection to spawning aggregations/ areas, 3	Important for fisheries and conservation interests, including spawning areas increases biomass (Aburto-Oropeza *et al*. 2011)
Fisheries socio-economic expectations			

20	Fishing effort	Effort (hours fished, or number of days fished) has reduced in the area, 3	Decreased fishing effort will allow fish to recover faster
21	Sustainable fishing gear/ what is allowed inside area	0- No regulations or restrictions on gears used inside 1- All gear types are allowed, with regulations 2- Some gear types are allowed, seasonal allowance 3- Sustainable/ artisanal fishing gears	Fishers and conservation can compromise with sustainable fishing gears used over unsustainable ones
22	Fish catches increased	Any increase in fish catch, 3	Increased fish catches improves local livelihoods
23	Displacement	There are alternative incomes or opportunities for displaced fishers, 3	Many fishers concerned with this, have to fish somewhere or have an alternative
24	Have local support	Local fishers actively support area, 3	Ecological effectiveness depends on the compliance of an area (McCook *et al*. 2010). Success due to local support, leadership and self-enforcement (Aburtot-Oropeza *et al*. 2011)

Table 2.6: Review performance indicator scorecard for selected closed areas that had enough data to be included. Scores were derived from peer-reviewed

	Indicator	Score range	Kubulau FMA[1], Fiji	Florida Keys NMS, USA	Tabarca MR, Spain	Shiretoko WNHA ,Japan	Devon IPA, UK	Gilbert MPA, Canada	Flamborough PTA, UK	Bajo de Sico SC, PR	Overall score (%)
	Planning and Management										
1	Management Plan in place	0-3	3	3	2	3	3	3	3	2	92
2	Conservation & fisheries	0/3	3	3	3	3	3	3	3	3	100
3	EBM approach	0/3	3	3	3	3	0	3	3	0	75
4	Management Involvement	0-3	3	1	0	2	2	3	0	3	58
5	Meeting goals objectives	0-3	3	3	3	3	3	2	3	0	83
6	Adaptive management	0/3	3	3	3	3	3	0	3	3	88
7	Fishers concerns	0-3	3	3	2	3	3	3	3	2	92
8	Fisher involvement level	0-3	3	3	3	3	3	3	1	1	83
9	Protection level change	0-3	3	3	3	3	1	1	1	3	75
10	Regular monitoring	0-3	3	3	3	3	3	3	3	1	92
	Design										
11	Size of area	0-3	3	3	3	3	3	3	2	1	88
12	Zones	0/3	3	3	3	3	3	3	3	0	88
13	No take areas	0/3	3	3	3	3	3	3	0	3	88
14	Connectivity to other areas	0/3	3	3	3	3	3	0	0	3	75
	Fisheries based Bio-Ecological expectations										
15	Fish populations over time	0/3	3	3	3	3	3	0	0	0	63
16	Evidence of spillover	0/3	0	3	3	0	0	0	0	3	38
17	Protected species	0-3	3	3	2	2	2	1	3	2	75
18	Bottom habitat protection	0/3	3	3	3	3	3	3	3	3	100
19	Spawning/nursery areas	0/3	3	3	3	3	0	3	0	3	75
	Fisheries based Socio-Economic expectations										
20	Fishing effort	0/3	3	3	3	3	3	0	0	0	63
21	Sustainable fishing gear	0-3	3	2	3	1	2	2	2	2	71
22	Increased catch	0/3	3	3	3	3	0	0	0	0	50
23	Displacement	0/3	3	3	3	3	0	3	3	0	75
24	Have local support	0/3	3	3	3	3	3	3	3	3	100
	Overall score	**72**	69	69	66	65	52	48	42	41	
	% total		96	96	92	90	72	67	58	57	

Figures

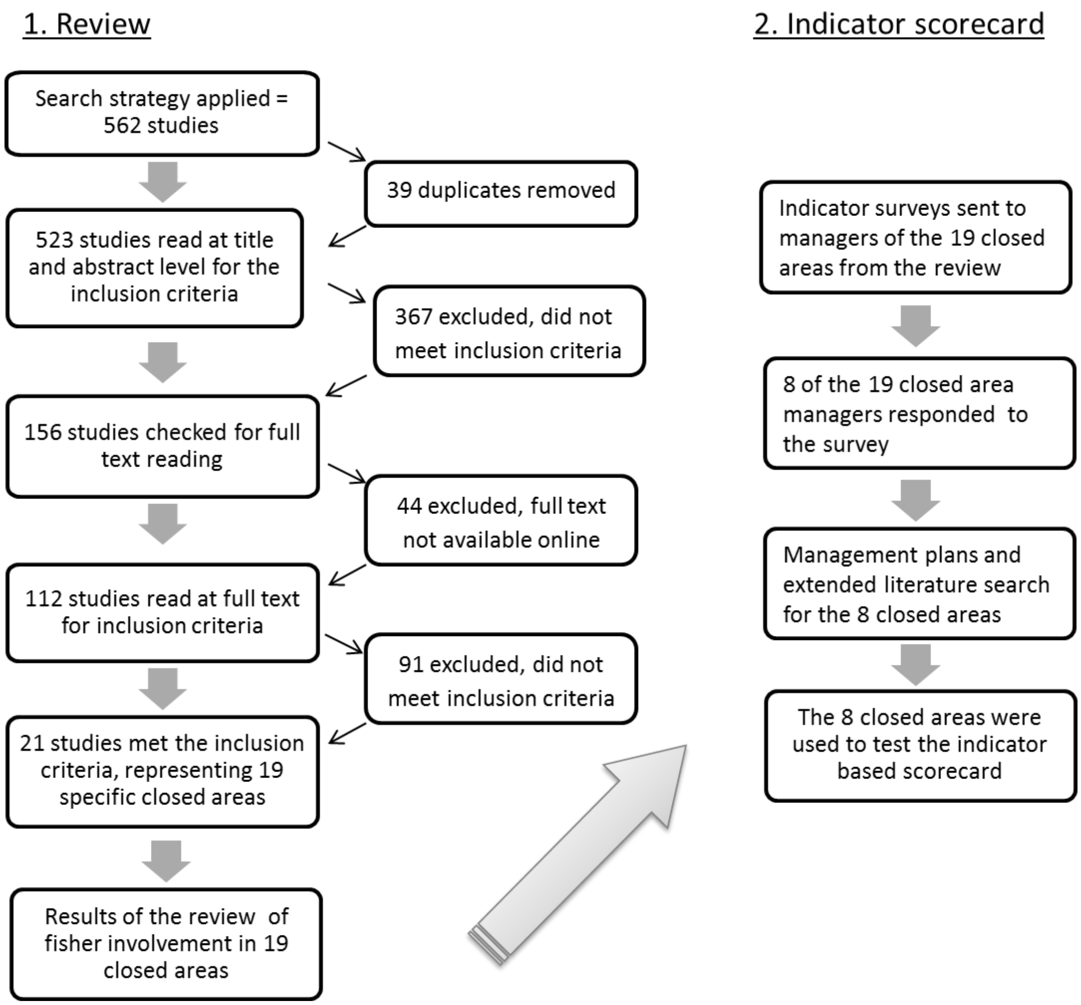

Figure 2.1: Steps used for the review and scorecard.

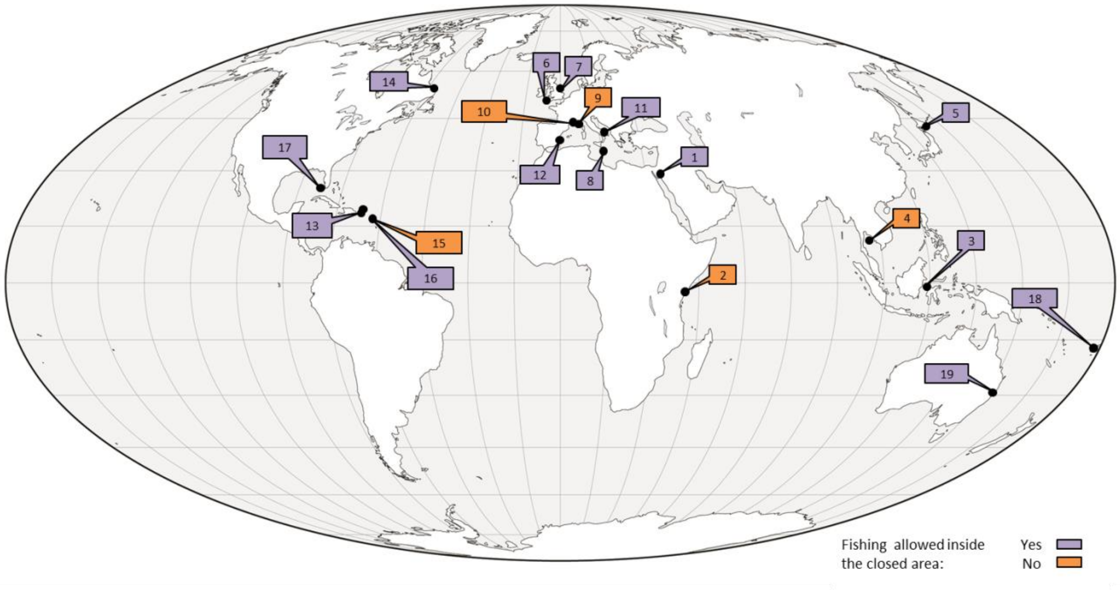

Figure 2.2: Locations of the 19 closed areas selected from the review process that had fisher involvement alongside fisheries and conservation aspects. Numbers represent the closed areas from the accepted studies in the review that are listed in Table 1.

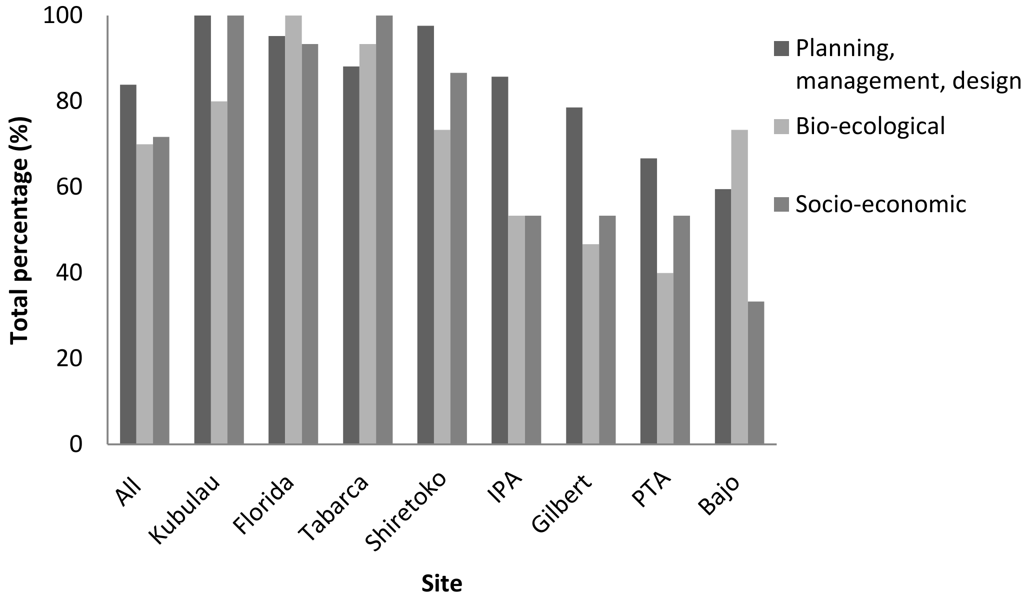

Figure 2.3: The total percentage per indicator category for the 8 closed areas used in the scorecard.

*Site names: Tabarca- Tabarca Marine Reserve; Kubulau - Kubulau District fisheries management area and MPA; Florida - Florida Keys National Marine Sanctuary; Shiretok – Shiretoko World Natural Heritage area; IPA- South Devon Inshore Potting Agreement; Gilbert – Gilbert Bay MPA; PTA - Prohibited Trawling Areas; Bajo – Bajo de Sico seasonal closure.

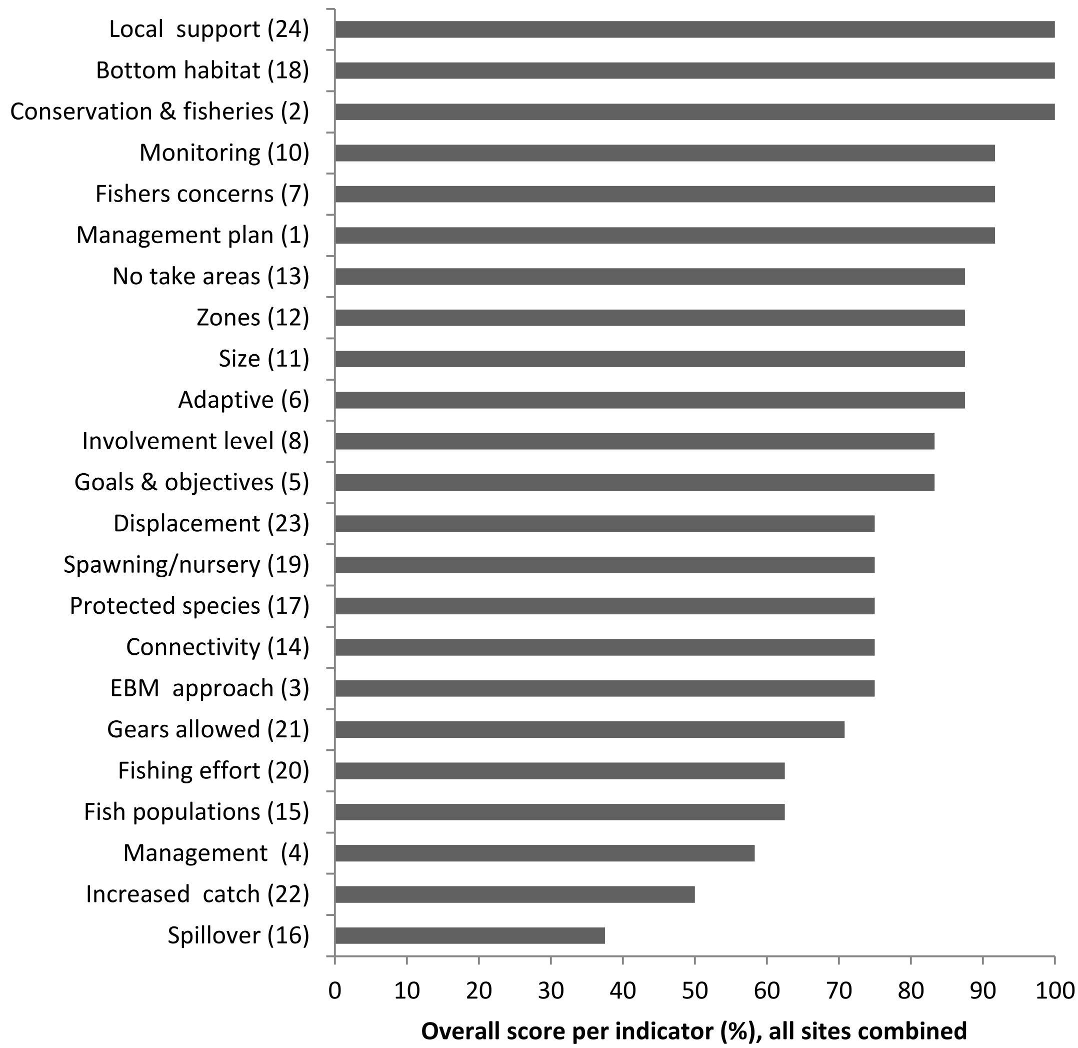

Figure 2.4: Total indicator scores in order from highest to lowest ranked indicators from the scorecard (n=8).

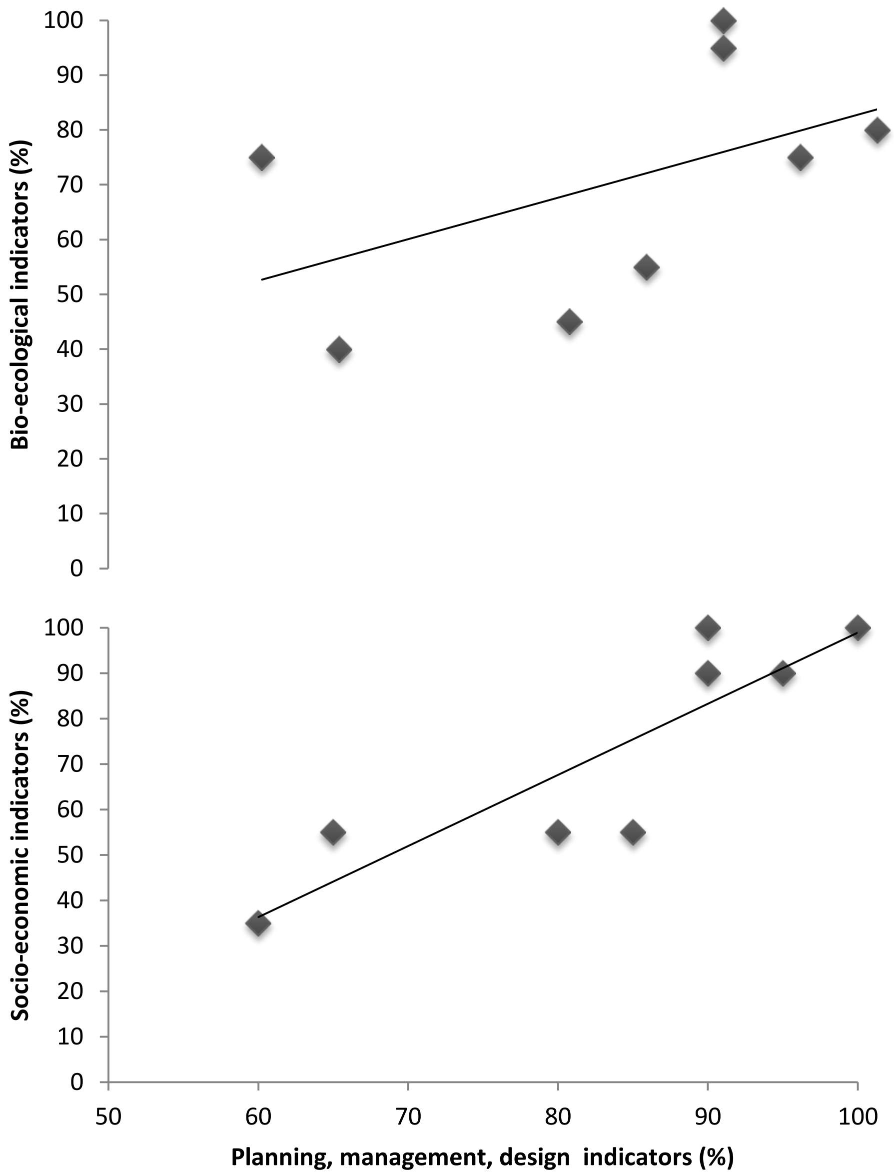

Figure 2.5: The relationship between the planning, management and design indicator scores and the bio-ecological (r2 = 25) and socio-economic scores (r2 = 0.77).

Chapter 3 The perceptions of small-scale fishers and their involvement in biological surveys in a multiple-use marine park: A case study from Mafia Island, Tanzania.

A version of this manuscript published in Marine Policy as:

Kincaid, K. B., Rose, G., and Mahudi, H. (2014) Fishers' perception of a multiple-use marine protected area: Why communities and gear users differ at Mafia Island, Tanzania. Marine Policy, 43, 226-235

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1. Introduction

Fishery closures are among the oldest tools of management (Agardy 2000) and can be employed alone or incorporated into multiple-use marine protected areas (MPAs). Closures vary in approach; they can be complete, allowing certain types of fishing but restricting others, and may be permanent or temporary. Fisheries closures are at times overlooked as a tool in marine conservation, due in part to the management priorities of increasing fisheries yields/fisheries sustainability rather than biodiversity or more general conservation interests (Salomon *et al.* 2011). The effects of closures may be complex and are often poorly understood. On the one hand, a fishery closure can provide a refuge from destructive fishing practices and protect spawning fish and juveniles, and may have a positive spillover effect for fisheries. Closures can become incorporated into multiple-use MPAs, with different areas for different uses, in attempts to balance conservation with small-scale fisheries. On the other hand, closures may lead to increases in fisheries effort near boundaries or in other sensitive areas (Forcada *et al.* 2010).

It is near axiomatic that all types of MPAs will be problematic without local support. Such support typically requires that fishers are involved in the process (Chuenpagdee and Jentoft 2007), with their knowledge (including habitat, fish species caught etc.) and perceptions (how fishers perceive something) forming a basis for design, management, and planning, with harvest considered a part of the mortality that occurs within all ecosystems (Johannes 2002; Rochet *et al.* 2008; Dimech *et al.* 2009; Pita *et al.* 2010; Culis-Suzuki *et al.* 2012; Leleu *et al.* 2012). Failure to take these steps has typically resulted in failed closures and fisheries (Pita *et al.* 2012). In many jurisdictions where science is scarce, the so-called “data-poor” fisheries, fisher knowledge may be the major available source of information (Haggan *et al.* 2007; Charles and Wilson 2009). Fishers often know about relative abundance of species over various spatial and temporal scales that are unknown to scientists and managers (Johannes *et al.* 2000; Hamilton *et al.* 2012; Johnson and Wilson 2012; Silvano and Begossi 2012). Additionally, fishers can be trained to collect biological data (Heck *et al.* 2011) and provide valuable input towards evaluating MPA performance indicators (Himes 2007; Heck *et al.* 2011). Their knowledge may assist in re-constructing historic baselines (Eddy *et al.* 2010) and yield early warning signs of ecosystem change from whatever cause (Haggan *et al.* 2007). Recent studies have shown that by interviewing fishers, information can be gathered to track resource changes over space and time (Moseby *et al.* 2012) that is useful for both marine conservation (Johannes *et al.* 2000) and fisheries management (Stead *et al.* 2006). Such an approach may also encourage fishers’ willingness to engage in marine conservation (Versleijen and Hoorweg 2006).

Despite the advantages or necessity of having local support for fisheries closures and MPAs, it may be unclear why support is sometimes forthcoming and sometimes not

(McClanahan *et al.* 2009). Complications may include level of involvement, proximity to fishing grounds, different gear types and restrictions and fishing management regimes.

The overall objective of this study was to evaluate fisher knowledge and perceptions of a relatively long-standing multiple-use MPA that included various levels of fisheries closures. A question was posed of why attitudes to the closures might vary between communities that use the same grounds, but have differing fisheries histories, involvement with policy and management and utilize different gear types. Specifically, under working null hypotheses of no difference between these communities, the use of zoned areas, changes over time, and attitudes to conservation are tested. Finally, of interest is to assess how fisher knowledge can complement biological data collection in areas with a paucity of biological data available. The Mafia Island Marine Park, in the western Indian Ocean, Tanzania, was chosen for study as it includes several levels of closure, has a traditional fishery, and was implemented with a varied degree of local and fisher participation from several communities in 1996 (McClanahan *et al.* 2009). Two adjacent communities within the Park that utilize the same fishing grounds, but differ in their involvement, history and gear, were chosen for study.

2. Material and methods

2.1 Site Description

In Tanzania, the demand for fish is high with 27% of animal protein intake derived from fish (FAO 2007). Tanzanian Marine Parks utilize a management strategy that attempts to co-enhance conservation, biodiversity and the sustainable use of marine resources. Their policy is to consider that fishers are a valid and important part of the ecosystem and marine parks are zoned for multiple-use. Such parks may include core zones that are closed to extractive use, specified use zones with gear restrictions and general use zones (McClanahan *et al.* 2009) in attempts to recognise traditional/ local community fishing grounds and provide continued but controlled sustainable use (MIMP 2000,2011)

Mafia Island Marine Park (MIMP) is the largest MPA in Tanzania (882km^2) and was established under the Tanzanian Marine Parks and Reserves Act after a stakeholder workshop in 1991 (Fig. 3.1). Boundaries and zones that were determined by the stakeholder process were officially published in September 1996 and classified as IUCN category VI (Defined as a Protected Area with sustainable use of natural resources). Atypically, MIMP is a governmental department with headquarters inside the Park and was the first marine park in Tanzania to allow local residents to live within it (Jones 2011). There are 13 communities with an estimated population of 23,000 within the MIMP and all residents are highly dependent on the resources of the area (MIMP 2007).

The MIMP is a collaborative process with knowledge transmitted through community liaison committee members and the community Chairman to the local community.

Despite community involvement in park planning, there are some conflicts among gear users, communities, and between fishers and the Marine Park staff (McClanahan *et al.* 2009). Some of the current issues are increasing pressure on resources and destructive fishing practices. The MIMP also attracts fishers from other parts of Tanzania, thus increasing fishing pressure. Since MIMP has been in place, dynamite fishing and beach seining has been eradicated, but, despite efforts to remove all destructive fishing practices, pull nets (bottom dragging nets that are hand pulled over the seabed/reef) are still responsible for the majority of catches within MIMP, accounting for 70-80% of catches (MIMP 2000).

2.2 Community background and fishing history

Utende: This community is the site of the MIMP headquarters and has a population of 2,160 (2012). Most fishers traditionally use gears that are considered sustainable in MIMP such as hand lines and fish traps; therefore, these fishers have been able to retain their traditional fishing methods since MIMP has been in place. These fishing practices were significantly impaired, however, by the escalated numbers of pull net fishing in the

Chole bay general use zone; this can destroy their fish traps. Apart from fishing, most residents in Utende have various opportunities for generating alternative income such as cultivation, employment in hotels, other tourist related activities and small-scale farms.

Chole: This community is on an island across from Utende and has a population of 1,009 (2012); a regular water taxi transports people and goods between Utende and Chole. Before and after the establishment of the Marine Park a major fishing practice at Chole Island was pull net fishing locally known as "*Mtando*" which may result in greater landed catch in the short term but is thought to be destructive of the reef environment. This type of fishing was practiced long before the establishment of Marine Park and despite initial success to restrict pull net fishing, the number of nets has recently escalated as foreign fish vendors invest in the Island (MIMP 2000). In operation, each pull net can employ 15- 30 fishers at one time. Despite high catchability, the gear drags the seabed, uses a "bunt" net locally known as "*tandio"* and has mesh size of less than 1 inch (2.54 cm) and is not allowed within MIMP. MIMP regulations require nets to have a mesh size more than 2.5 inches (6.35 cm) to be used only within the general use zone (Table 3.4). Fishers in Chole have been reluctant to support the MIMP's sustainable fishing practices despite the fact that more than Tsh 63 million (ca. 63,000 US dollars) has been provided to the community through a MIMP fishing gear exchange and environmental benefit program (MIMP). Through the program, more than 24 fishing groups, including 80 fishers, benefited by receiving equipment and other income generating activities to replace pull nets. Chole Island has good soil and local residents also farm, which complements their income. Nevertheless Chole residents are mainly dependent on marine resources.

These communities were selected as they both have access to, and use the same areas to fish and are close to each of the zoned areas. Their fishing histories however, are very different and as a result, Chole residents have had to change their fishing methods to comply with MIMP regulations more than Utende residents.

2.3 Interviews

Overall, 30 individual interviews were conducted during April 2012 in Utende and Chole using a set questionnaire (Appendix A). Before beginning research, all documents were sent to each community chairman to ask permission to interview fishers within their community. Interview questions were designed and phrased with input from MIMP officials and based upon the MIMP objectives in addition to survey designs from relevant published studies (Innes 2005; Williams 2002; DFO 2006; Himes 2007; Charles and Wilson 2009; McClanahan *et al.* 2009; Sutton 2009; Marshall *et al.* 2010; Carruthers *et al.* 2011; Heck *et al.* 2011; Cullis-Suzuki *et al.* 2012; Tokotch *et al.* 2012). MIMP staff assisted in the wording and phrasing for local context. Questions were designed to be a mixture of quantitative and qualitative open-ended questions. This research was reviewed by the interdisciplinary Committee on Ethics in Human Research and is in compliance with Memorial University's ethics policy (ICEHR Number: 2012-314-SC). All approved English language documents were subsequently translated by a native Kiswahili speaker with expert knowledge of Tanzanian coastal peoples and marine parks.

The chairman of each community in Utende and Chole was interviewed first for context, and then fishers were selected for interview by approaching fishers haphazardly when returning from fishing, or through fishers arriving at the chairman's office after hearing about the interviews in the community. Some fishers were also recruited from community members' suggestions of specific fishers that used certain gear types, or had position and knowledge within the community. Interviews were conducted in the community centre, on the beach, at fish landing sites, or outside fishers' homes.

Before starting interviews, copies of all documents were provided to fishers and explained verbally in Kiswahili. All interviews began with an exchange on gear type, main species fished, habitat, area and experience in the fishery. Questions then focused on perceptions and knowledge of the Marine Park, zones, fisheries management methods and overall conservation knowledge. Each respondent was interviewed individually; questions and answers were translated between fisher and researcher and responses were written down as they were translated. The same translator (H. Mahudi) was used throughout. Discussions with marine park government officials were conducted in English; interviews with fishers were conducted in Kiswahili.

2.4 Data analysis

Quantitative survey data and open-ended questions that were appropriate to be grouped were tested and analysed using non-parametric tests in SPSS (IBM SPSS Statistics Version 20). Categorised variables followed a yes/no format or Likert-type scale (measures the level of agreement or disagreement with the question). Qualitative responses from open-ended questions were explored, captured in quote form, and set into relevant categories in tables, and within text using methodology similar to Heyman & Granados-Dieseldorff (2012). Quantitative trend indices for qualitative questions were established by grouping open-ended qualitative responses into related categories. Responses that had theme areas and definite response areas were categorised accordingly. Trend indices were grouped after questioning, rather than providing categories to the respondent to allow for an unrestricted range of answers.

To test for significance between variables, chi-square tests for independence were used or Fisher's exact test if assumptions were not met (cell frequency <5). Significance was determined at alpha = 0.05. For the purpose of the chi-square test, some questions with Likert scales were grouped from a 5-point to a 3-point scale. Gear users were grouped into two categories: net fishers and static gear fishers (dema trap, hook and line, hand and fence trap). Relationships were also explored between gear types, fishing experience, and years lived on Mafia. Hierarchical Multiple Regression Analysis was performed to examine the most important predictors of the perception that fisheries production and broader conservation are compatible goals. ANOVA results indicated that the model as a whole was significant.

The sample sizes used here are a small representation of the fisher population, but include the wide variety of fishing gear types used, and provide adequate statistical power to address the questions of interest. Any language bias was minimised as much as possible by using local interpreters.

2.5 Underwater Surveys

This part of the study aimed to conduct underwater visual census surveys based on information provided by fishers. Following fisher interviews, rapid snapshot underwater visual census surveys were conducted to assess the abundance and diversity of fishery indicator species. Surveys focused on two sites inside Chole Bay, one in the specified use zone, Milimani, at a site regularly used by tourist boats and some fishers, and one in the general use zone (S 07 55 732, E 039 46 787) at a site used by fishers. Both sites were similar habitat of coral reef, with sand and seagrass areas, and similar depths (3-7m).

Fisher information on the most commonly caught fish species was used to select species for underwater assessments. (Species were grouped by family, due to the uncertainty in species-specific identification translated between fishers and the interviewer). Thus, the most commonly caught fish families by the fishers interviewed became the indicator species for surveys, referred to herein as fishery indicators. Fisher knowledge was used for a comparable habitat type-site within the nearby general use zone. Fisher knowledge was the only information available for this area in terms of habitat type, depths, and locations. Additionally, a local fisher acted as a guide to this location.

At each site, surveys were conducted using a Roving Diver Transect (RDT). To get an even coverage, a 7-minute line was swum at a steady and constant pace in each direction (N, S, E and W) from the boat anchor. This gave a total survey time of 28 minutes per site. For each indicator species, an abundance estimate was counted along each transect within a 5x5m box to quantify the diversity and abundance of fishery indicators within each zone. An abundance index was used that groups sighting frequency into the following abundance categories: 1= single (1); 2= few (2-10), 3= many (11-100), and 4= abundant (>100) following a rapid visual census survey methodology (Hill and Wilkinson 2004). Percentage abundance was from all surveys combined per site. Swimming speeds for visual census surveys average at 10 meters per minute (aims.gov.au). Surveys were conducted by KK.

3. Results

3.1 Fisher profile

Of the 30-fisher respondents, half were from Utende, (n=15) and half from Chole (n=15). An effort was made to interview as many women as possible (n=4) all women interviewed were from Chloe. All fishers interviewed said that they go out and fish every day that they can, the only barrier being weather. Regardless of their main income type all respondents described themselves as primarily being a fisher, thus despite some respondents having a non-fishing based income, they were included as fishers (Table 3.1).

Fishing was the main source of income for 63% of fishers but many fishers had additional income from small-scale farming, crafts, carpentry, and/or boatbuilding. Many respondents had lived on Mafia their entire life, with many fishing for all, or most of their working life (Table 3.1). Fishers used a variety of methods, gears, and vessels (Table 3.2, Fig. 3.2), all fished both for subsistence and commercially. Fishing areas were mainly in Chole Bay (n=21) general and specified use zones (Fig. 3.1), followed by the Jibondo/Juani area (n=4) general and specified use zones, Kifinge Bay area (n=3) specified use zone, and Mange Reef (n=2) specified use zone.

3.2 Fisher knowledge

3.2.1. On management regulations

Questions about what the different zones are for generated a wide variety of responses. Generally, respondents said that core zones (those closed to fishing) were for tourism (40%). The specified use zones were reported to be for fishers (23.3%), tourism (20%), and government (13.3%), and the general use zone for fishers (23.3%) and tourism (20%). When asked for their opinion on each zone as it related to their fishery on a scale from very good to very bad, the majority of respondents were positive about the core zones (67% positive, $p < 0.01$), but less positive the general use zones (36.7% positive, $p < 0.05$). To illustrate this further, Table 3.3 lists some of the reasons fishers gave for their opinions on the different zones. Many were concerned with increasing fishing pressure within the general use zone. One fisher commented that *"Fish increased* (since MIMP), *but because fishing pressure increased, competition is high"* and another commented that *"fishing pressure has increased and therefore I cannot say if fish have increased or not".*

Several different management tools are used within the MIMP (Table 3.4) in addition to zoned areas, in particular restrictions on mesh size and fishing gears. Respondents were asked about these types of management regulations and if they agreed or disagreed with them. Respondents preferred mesh size restrictions (76.7% agreed, 6.7% strongly agreed), and gear restrictions (70% agreed, 10% strongly agreed), over permanent closures (46.7% agreed, 10% strongly agreed) (Fig. 3.3-5, separated by community). Respondents were asked about what else could be done to improve MIMP management and provided many suggestions that were divided into categories.

3.2.2 On changes over time

Most respondents (60%) said that the size of fish had increased since MIMP has been in place (Fig. 3. 6). When asked if they had caught more fish since the establishment of the MIMP (Fig. 3.7), significantly more fishers from Utende (53.3%) than Chole (13.3%) believed that an increase had occurred (see section 4.3). Fishers that reported increased sizes of fish were also more likely to agree with where the zones are located ($p < 0.05$).

Generally, respondents had mixed views on changes to fishing effort. Of the fishers that said their fishing effort had increased, 86% (n=21) had been fishing in the park for more than 10 years. Many respondents said that their increase in fishing effort was a response to increased fishing pressure, as more fishers are coming from outside areas, *"there may* *be 100 fishers out there, this is not good",* and, *"before MIMP lots of fish, now less because* [there are] *many fishers now".*

3.2.3. On fishing location and perceived increased catches

Fishers were asked why do you fish where you fish. This question was based from a report on the social dimensions in the MIMP, where a fisher had asked, "Why don't they first ask us why we fish where we fish" (Nyigulia Mwaipopo 2008). 40% of respondents fish in their location because of fish/habitat reasons, 40% stated gear restrictions/regulations as their reason, and 20% stated that their choice of location was close to home or accessible with their vessel. Fishers that chose a location based on fish/habitat reasons were more likely to comment that they had increased catches (60% yes). Those fishing in a location because either they could not go anywhere else and had to stay close to home, or fished where the MIMP wanted them to fish for regulation reasons, were less likely to report increased catches (25% no, or do not know).

3.2.4 On attitudes to conservation

The majority (70%) of fishers agreed that fisheries and conservation are inseparable. Fishers that reported increased catches were more positive about fisheries and conservation ($p < 0.01$). The majority of fishers stated that if there was no MIMP, the marine environment would have dynamite use, no fish, poor habitats, or highly depleted resources (Fig 3.8).

3.3 Evaluating differences between communities

There were significant differences in responses between fishers from Utende and Chole. Fishers from Utende were significantly more positive about fisheries and conservation being inseparable than were fishers from Chole (Table 3.6). Additionally, Utende fishers reported more frequently that the MIMP had increased the size and abundance of fish than did Chole respondents. Utende fishers were generally more positive about the MIMP. More fishers from Chole fished within the Chole Bay area (93.3%) than did Utende fishers (46.7%) who fished a wider area (Table 3.6). In terms of the zones used, fishers from Chole fished more in the General use zone (86.7%) than in the specified use zone (13.3%), whereas fishers from Utende fished in the specified use zone (60%) over the general use zone (40%). Gear types also differed between communities with fishers from Utende using more static gears (73.3%) than net gears; in contrast Chole fishers used more net (53.3%) than static gears.

3.3.1 Gear users

Overall, there were significant differences between fishers who fished with static gears, and fishers who fish with nets (Table 3.7). Static gear fishers were generally more supportive of fisheries and conservation working together than were net fishers, and more positive about the specified use zone. A majority of static gear fishers felt that the zones and regulations were good. Net fishers however, were far less supportive and commented how they cannot net fish in all the zones. Others commented that the sustainable gears from the MIMP are less efficient than gears used before MIMP regulations. *"Fishing practice has changed, it takes a lot of time to set the net, wait, and haul it, and it is hard and takes a long time. Pull nets are quick; previously fishing time was less, now it takes longer".*

3.3.2 Involvement vs. Support

Seventy percent of respondents said that they had been, or are currently involved in, the development of the MIMP General Management Plan (GMP). Involvement was in many forms ranging from attending community meetings to training and workshops. Net fishers (40%) were more involved in the MIMP management plan and more fishers from Chole (86.7%) had been involved than fishers from Utende (53.3%). The main involvements at Chole were training in alternative livelihoods to fishing (e.g. bee keeping, retail trade, crop cultivation), sustainable fishing, or oyster and seaweed farming. In contrast, at Utende, involvement was more at community meetings and in developing the GMP, thus having input in the location of the MIMP zones. Fishers said they had benefited from the MIMP by a fishing gear exchange scheme and through training on either sustainable fishing methods or alternative livelihoods. Fishers from Chole were less likely to feel that they have benefited from the MIMP than fishers from Utende that had less involvement.

The Hierarchal Multiple Regression Model (Table 3.8) explored the influence of a set of variables on fisher's perception that fisheries and conservation go together. In step 1, community and gear type explained 46% of the variation in the indicator ($R^2 = 0.46$). In step 2 perceived increased catches only explained 9% of the variation ($\Delta R^2 = .009$) and the addition of involvement in step 3 explained 18% of the variation ($\Delta R^2 = .018$). The influences of community, gear type and increased catches were positive, but overall involvement had a negative relationship with the perception of how fisheries and conservation work together.

3.4. Fisher knowledge and biological data collection

Fish families were grouped into the percentage mentioned by fishers overall, and for each gear type (static or net). Overall, fishers targeted snappers and emperors the most, with general reef fish, trevally, parrots, sharks and rays also highly targeted (Fig. 3.9).

Generally, hook/trap fishers targeted reef fish including snappers, parrots, groupers, and wrasse. Net fishers targeted larger, pelagic-based fish, barracuda, sharks, kingfish, and trevally (Fig. 3.9). Some fishers mentioned that they targeted specific species; most said they target anything they can catch. Snapper, emperor, trevally, jacks and reef fish are the most commonly mentioned fish families mentioned. The next group consists of large bodied fish, followed by the last group, the smaller bodied, elongate shaped fish families (Fig. 3.10**).** An independent-samples t-test revealed no statistical significance between net fisher and hook/trap (static) gear fishers and the frequency of fishery indictors mentioned. This snapshot survey allowed for a comparison between the specified use and the general use zone. The specified use zone had more diversity (11 families) than the general use zone (7 families). 82% of fish abundance identified in the general use zone comprised of *Acanthuridae* and *Chaetodontidae* (Table 3.9).

4. Discussion

The main objective of this study was to evaluate fisher knowledge and perception of a relatively long-standing multiple-use MPA in communities that varied in their involvement with policy and management, history and gear use.

Fishers in this study provided information on changes in fishing effort, size, and abundance of fish over time and mentioned conservation related indicators (Table 3.3).

Results here indicate that the primary factors that impact support for the MIMP goals of conservation and sustainable fisheries were community and gear type, with minimal influences of fishing success and involvement. As there was interaction between communities and gear types, it is difficult to separate these influences. The data suggest that the community that used fixed gear and were able to exploit the multiple zones were more supportive of the zoning as being effective to sustain their fishery. Fixed gear has also been less restricted than were nets. It was surprising that involvement had little impact on support for the joint management goals of conservation and fishing sustainability. Chole fishers had more involvement yet were less supportive of fisheries and conservation together and in the location of the zones (Table 3.6). Similarly, net gear fishers were more involved in MIMP planning, yet were less supportive than static gear fishers (Table 3.7). It is likely that a more detailed set of questions might have shown that it was the type of involvement that was important, and not involvement *per se*. For example, fishers at Utende were more involved in planning and execution of the management plans, whereas those at Chole were more recipients of attempts to replace gear and retraining to replace fisheries. Unfortunately, the questionnaire was not sufficiently detailed to probe those differences.

The differences in perception between communities may be partly attributed to Utende and Chole having different fishing histories. Most Chole fishers used the immediate area of Chole Bay to fish, an area reported by both communities as having high fishing pressure. Thus, unequal restrictions to fishing grounds may be one reason for Chole fishers had more negative views of the MIMP. Static gears are allowed into a wider area of the park (general use and specified use zones) than nets (general use zone only, see Table 3.4). Additionally, it is acknowledged that there may be a potential gender bias as women interviewed were only from Chole and fished by hand.

It was not surprising that users of different gears had different opinions about closed areas (Pita *et al.* 2010; Pita *et al.* 2013). Our data suggest that the MIMP regulations affected net fishers more than static gear fishers, and this translated into less support from Chole residents, with their fishing history of using nets. Fishers tend to support closures to gears used by others, and not the gear they operate (Pita *et al.* 2013). For example, static gear users were more positive about closed areas on the South Coast of England than towed gear users that would be more severely impacted (Blyth *et al.* 2002). The attitudes of fishers from different fishing syndicates in Chile were mainly due to socio-demographic variables (Gelcich *et al.* 2005). The present research reinforces the conclusions of recent studies (Blyth *et al.* 2002; Pita *et al.* 2010; Pita 2013) that fisher groups are very different, and their reactions to fisheries closures, be they intended for marine conservation or fisheries production, or both, will depend on their history and gear usage.

MIMP fishers frequently supported size and gear restrictions over permanent closures; however, the majority of respondents were more positive about the core zones that restricted all fishing than they were about general use zones. The reason, stated many times, was increased fishing pressure in the general use areas. Not surprisingly, fishers were more positive about management zones if they had experienced increased catches. In Madagascar, community support for larger closed areas occurred after communities experienced increased catches from temporary fishery closures (Benbow and Harris 2011). Of primary importance, notwithstanding that not all fishers have directly benefited from the MIMP, the majority stated that the environment is better than if there was no MIMP and that there would be little or no fishery without it. Many provided suggestions to improve current management (Table 3.5). Multiple use MPAs that incorporate fishing closures and fishing areas may offer a bridge between fisheries and conservation in highly used areas such as the MIMP.

4.1. Fisher knowledge and biological surveys

A secondary objective of this study was to include fishers and fisher knowledge in biological data collection within an area that has limited bio-ecological data available and knowledge to collect it. Fishers had knowledge about changes in size and abundance of fish over time and provided information on habitats and fish for underwater surveys. Biological surveys using the fishery indicators would provide diversity and abundance estimates of the most commonly fished species, and could be conducted by trained Marine Park staff or fishers. The zoned areas in and around Chole Bay have research and monitoring programs in place (Jones 2011), however, a large proportion of MIMP has limited biological data collection and limited funds and personnel to conduct surveys. Thus, fisher knowledge is the only source of data for many areas. For fish surveys, this was a snapshot study, thus any strong conclusions cannot be drawn from this at it is beyond scope of this study, but the method of combining fisher information and assistance with visual surveys demonstrates a way to conduct biological surveys in specific areas.

This is appropriate as the extent of resources within MIMP is limited (MIMP 2011). Training and incorporating local fisher knowledge into biological surveys is vital for collecting information over space and time. Extensive fisheries surveys are labour and data intensive and often, key economic species, common species, or indicator species, can be targeted for underwater assessments. Fishers in this study were able to identify key economic fish species and highlighted locations of reef habitats in areas. This technique allows a focused underwater assessment of key species and habitat types. Additionally, some fishers in MIMP are trained to collect fisheries landings data, this provides additional income and valuable information that otherwise may not be collected. Combining fisher, fisheries and ecological data, allows more data and information be captured, and has value in fisheries science (Nenadovic *et al.* 2012).

5. Summary and conclusions

Determining the success of MPAs and fishery closures is complex; this study illustrates an interaction between community history and policy that directly affects management outcomes for multiple use MPAs. Fishing pressure, pull net usage and disagreements among communities and gear users all contribute to a complex web of social issues that need to be resolved to meet the goals of both increasing fisheries and marine conservation (McClanahan *et al.* 2009). It is possible that the fisheries and conservation benefits of the multi-use MIMP may be restricted by these conflicts (McClanahan *et al.* 2009). But it is equally likely that multi-use management such as implemented at the MIMP over the past 16 years is the best way forward to resolve conflicts and achieve what are likely universal objectives. The notion that all fishers or communities will respond similarly to management initiatives is false, hence marine planning needs to recognise impending differences and their potential impact on management outcomes.

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Tables

Table 3.1: Demographics of all respondents interviewed in Utende and Chole.

Demographics	Village (n)	
	Utende	Chole
Gender		
Male	15	11
Female	0	4
Total fishers interviewed	15	15
Main Income Source		
Fishing	9	10
Farming	3	1
Both	3	0
Other[a]	0	4
Fishing Experience (yrs)		
min	0.4	4
max	60	50
average	26.7	24.8
Lived on Mafia (Yrs)		
min	0.4	23
max	58	60
average	27.5	42.3

[a] other = own business (boat building, local store), seaweed collecting

Table 3.2: Number of respondents by fishing gear type, boat, and the fishing zone they use.

	Village Chole	Utende	Total
Fishing Gear Type			
Hand	5	0	5
Hook and Line	1	7	8
Fence Trap[a]	1	0	1
Dema Trap[b]	0	4	4
Set Net[c]	5	1	6
Shark Net[d]	3	3	6
Boat			
None	5	0	5
Dugout canoe	0	5	5
Out-rigger canoe	3	7	10
Dhow[e]	7	3	10
Zone used			
General use	13	7	20
Specified use	0	8	8
Both	2	2	2

[a] Traditional fishing method using local wood to make a fence, a passive fishing gear.

[b] Traditional fishing method using local wood and coconut palms to make passive trap.

[c] " Nyavu za kupweleza" < 4 inches; these are operated during the tidal range and are set in intertidal areas

[d] " jarife" mesh size > 4 inches; set for 24 hours and aim for large fish and sharks and operated in deeper water than intertidal set nets.

[e] Traditional sailing vessel

Table 3.3: Fishers perspectives to what they thought about the different zoned areas. Quotes represent the variation among responses.

1. Core zone

    a. A place for fish breeding and research

    b. Good for spillover

    c. Important because most people cannot reach these areas, some complain that this area is closed yet fish come to him from this area so this is good

    d. Important because breeding habitat, good place where fish are recruited to another zone

2. Specified use zone

    a. Important but not good as everyone is allowed to be there, everyone fishes here therefore not as important and useful as core zone

    b. Important because residents are allowed to fish for their livelihoods

3. General use zone

    a. Not as good as everyone is in these areas fishing

    b. Not as good as too many fishers

    c. No fish, take all until gone and not enough money

    d. Not good because all the good places to fish are restricted

    e. This is where seaweed farms are yet fishers also come here as there is high fishing pressure and this causes conflicts as they are destroying seaweed farms

Table 3.4: Summary of permitted fisheries activities in the Mafia Island Marine Park by zone (MIMP 2011).

Activity	Core Zone All users	Specified-use zone Residents	Specified-use zone Others	General-use zone Residents	General-use zone Others
Hand-lines, box-traps, fence-traps	X	LRUC	X	LRUC	P
Long-lines	X	X	X	LRUC	P
Pull nets (2.5” or more mesh-size)[a]	X	X	X	LRUC	X
Set-nets / shark nets 2.5 – 7” mesh	X	LRUC	X	LRUC	P
Shark nets > 7” mesh	X	X	X	LRUC	P
Sport-fishing	X	X	X	LRUC	P
Octopus collection	X	LRUC	X	LRUC	P
Sea cucumber, lobster, crab, shells (food)	X	LRUC	X	LRUC	P
Collection of shells for the curio trade	X	X	X	P	X
Aquarium collection (all organisms inc. corals)	X	X	X	P	X

X = Not permitted, LRUC = Local Resident User Certificate required, P = MIMP Permit required

[a] pull nets are allowed in general use areas, but are discouraged by MIMP and are not considered sustainable fishing gears [28] Prohibited items: Beach-seines, pull nets with stretched-mesh size less than 2.5 inches, trawling, damage to corals and other benthic habitats or organisms, killing turtles and dugong, and removing turtle eggs, propelled spear-guns and harpoons, chemicals and poisons for fishing, SCUBA to collect any marine organism other than for research purposes and mangrove cutting for commercial sale.

Table 3.5: Responses to the question “"anything else that you think should be done at MIMP for fisheries and for conservation?” Responses have been divided into categories for ease (table design adapted from Heyman, Granados-Dieseldorff 2012).

1. Fishing gears	
1.1	*Fishers should be equipped with sustainable fishing gears*
1.2	*Be supported with fishing gear*
1.3	*Fishers should be equipped with modern gears*
1.4	*Small scale fishers should get gear to go deeper, and not fish close to shore*
1.5	*Fishers should be given more support so they can fish sustainably*
1.6	*Support for dema trap fishers*
1.7	*Should be more training to use set nets*
1.8	*More fishers should take part in gear exchange scheme*
1.9	*More training for fishers and more loans for fishers*
2. Alternative livelihoods	
2.1	*MIMP should support more alternative livelihoods*
2.2	*Provide alternatives and other jobs, not fishing*
	More effort on alternative livelihoods, and have to be trained on good farming practices,
2.3	*to learn other incomes that are not fishing*
3. Education/revenue	
3.1	*More communication needed, more infrastructure*
3.2	*More education to local community and more revenue has to be given to support secondary students*
3.3	*More revenue to focus on health*
3.4	*More education and also people have to be facilitated so they can fish*
3.5	*Need business training, fishers should be shown how to use gears they get from MIMP, and how to use their training.*

3.6	*Elders and leaders should be the ambassadors, also people need more environmental training*
3.7	*Younger generation have to be given good education to know conservation, and should be given other means not fishing*
4. Laws/Surveillance	
4.1	*More surveillance, this is the only thing that can keep control*
4.2	*More surveillance is needed*
4.3	*Stronger laws and more punishments needed for illegal fishers*
4.4	*Government has to play key role in restricting fishing gears. Fishers buy gear regardless if restricted or not. Why can you buy it if it is illegal? Government should ban restricted gears from being sold by industry.*
4.5	*Stopping destructive fishing, already done this so all is good*
4.6	*MIMP should work harder to stop illegal pull net fishing*
5. On benefits and strengthening agreements	
5.1	*Have to sort out conflict between fishers and seaweed farmers*
5.2	*Although Jibondo residents do not want MIMP, they should still benefit from revenue and profit, and then they will see a benefit to MIMP.*
5.3	*MIMP and fishers should sit together and have a mutual agreement*
6. Zoning	
6.1	*Core zones should be reduced when younger generation get big as more fishing will mean limited space*
6.2	*MIMP should still be here, but regulations should be reduced*
6.3	*Should be allowed to use all restricted places*
6.4	*Should be allowed to pull net fish in the general use zone*
7. Closed seasons	
7.1	*There should be a closed season for octopus to allow them to recover, for 3 months a year*

Table 3.6: Chi Square crosstabulation results of significant differences between variables and communities.

Variables	Community		
	Utende (n=15)	Chole (n=15)	Chi-Square Statistical test results
Higher abundance of fish since MIMP (%)	60	13.3	X^2 (2) = 8.43, p = 0.04
Have had increased catches since MIMP (%)	53.3	13.3	X^2 (2) = 5.40, p = 0.02
Agree with the locations of the MIMP zones (%)	80	40	X^2 (2) = 5.00, p = 0.03
Fisheries and Conservation work well together (%)	93.3	46.7	Fisher's Exact = 0.02
Agree with use of permanent closures (%)	80	46.7	X^2 (2) = 3.59, p = 0.05
Have been involved in the management plan (%)	53.3	86.7	X^2 (2) = 3.97, p = 0.05
Fish close to home, inside the Chole Bay Area (%)	46.7	93.3	X^2 (2) = 8.33, p = 0.04

Table 3.7: Chi Square crosstabulation results of significant differences between variables and gear users, all communities combined.

Variables	Fishing Gear users		
	Static[a]	Nets[b]	Chi-Square Statistical test results
Fisheries and Conservation work well together (%)	88.9	41.7	Fisher's Exact = 0.01
Positive/neutral about the specified use zone (%)	100	58.4	X^2 (2) = 9.79, p = 0.01
Involved in the management plan (%)	55.6	91.7	Fisher's Exact = 0.04

[a] Static methods include: hook and line, dema trap, fence trap and by hand.

[b] Nets include shark nets and set nets.

Table 3.8: Hierarchical Multiple Regression analysis coefficient for each predictor to explore the influence of community, gear, increased catches, and involvement on fishers' perceptions of how much fisheries and conservation go together (constant).

		b	SE *b*	β
Step 1				
	Constant	-0.51	0.62	
	Community	1.31	0.34	0.57*
	Gear	0.58	0.35	0.25
Step 2				
	Constant	-0.77	0.73	
	Community	1.28	0.35	0.55*
	Gear	0.6	0.35	0.26
	Increased catches	0.14	0.21	0.1
Step 3				
	Constant	-0.03	1.09	
	Community	1.17	0.37	0.51*
	Gear	0.5	0.37	0.21
	Increased catches	0.17	0.21	0.12
	Involvement	0.38	0.41	-0.15

Note. R^2 = .46 for Step 1 (p= .000) : ΔR^2 = .009 for Step 2: ΔR^2 = .018 for Step 3. *p < .005

(b), Std. Error (SE b), and Standardised coefficients (β)

Table 3.9: Abundance index (A.I) and % abundance of families identified from the visual census survey in the general use, and specified use zones.

Specified use zone			General use zone		
Family	A.I	% Abundance	Family	A.I	% Abundance
Chaetodontidae	3	20.63	*Acanthuridae*	4	59.12
Acanthuridae	3	18.13	*Chaetodontidae*	3	22.65
Atherinidae	3	13.75	*Mullidae*	3	9.71
Mullidae	3	13.13	*Pomacanthidae*	3	3.82
Scaridae	3	10.62	*Lutjanidae*	2	1.76
Lethrinidae	2	6.25	*Scaridae*	2	1.76
Pomacanthidae	2	6.24	*Balistidae*	2	1.18
Serranidae	2	5.00			
Lutjanidae	2	3.75			
Balistidae	2	1.87			
Siganidiae	1	0.63			

Abundance index groups sighting frequency into the following abundance categories: 1= single (1); 2= few (2-10), 3= many (11-100), and 4= abundant (>100).

Figures

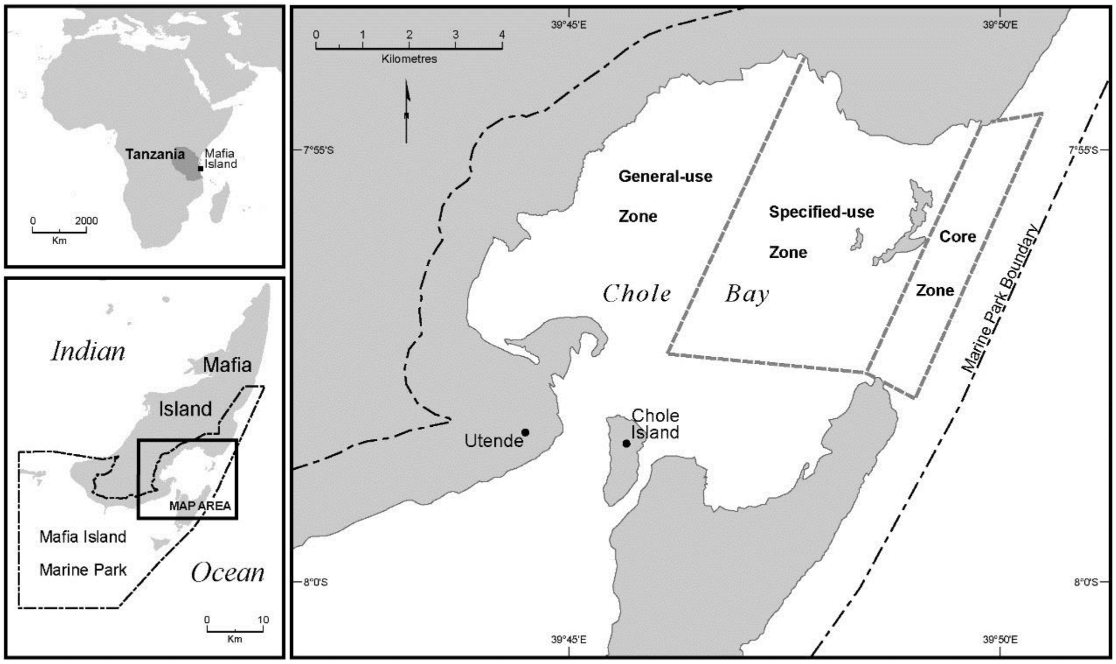

Figure 3.1: Mafia Island Marine Park, one of the largest MPAs in the western Indian Ocean (822 km2). Utende and Chole sit within the Chole Bay area and both have access to, and use the general-use, and specified-use areas to fish.

Figure 3.2: Fishers from Utende and Chole use variety of vessel types from Dugout canoes (front), to sailing dhows (middle) and outrigger canoes (rear).

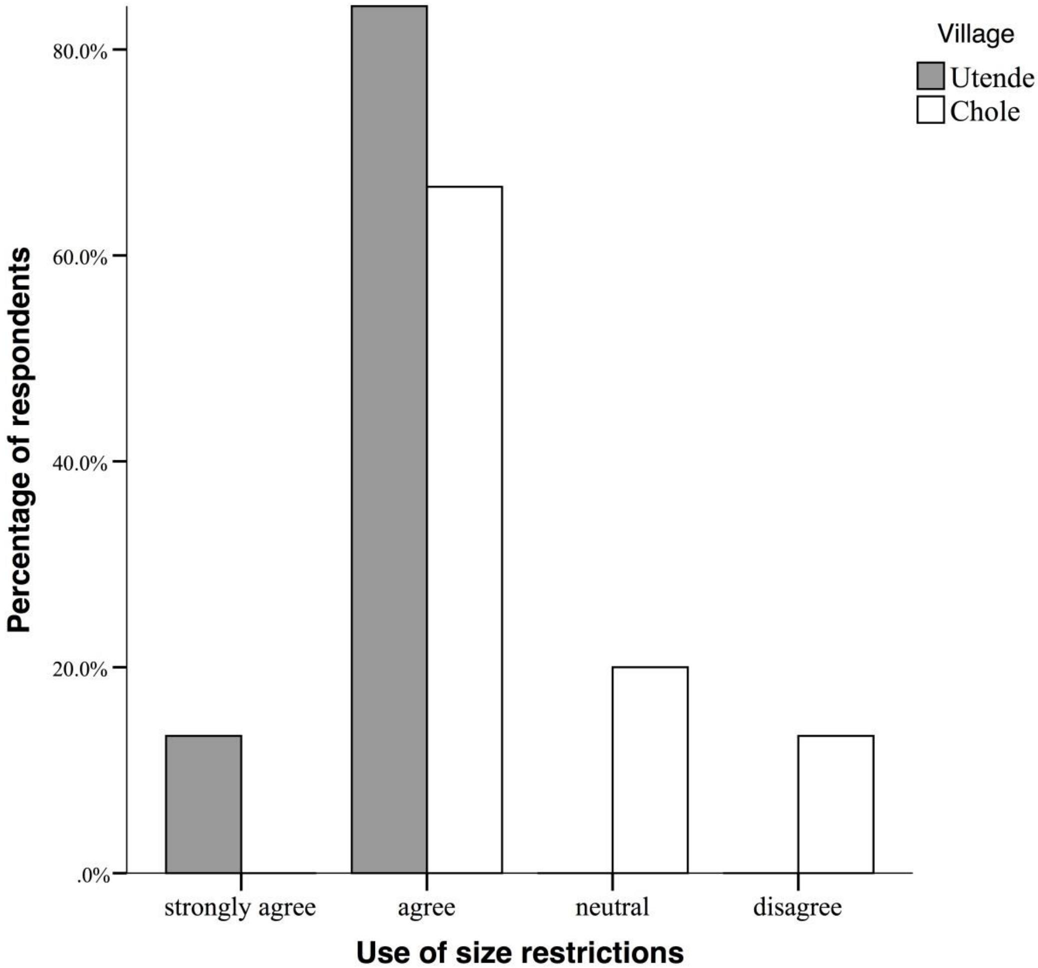

Figure 3.3: Responses to the question “How much do agree with the use of size restrictions”.

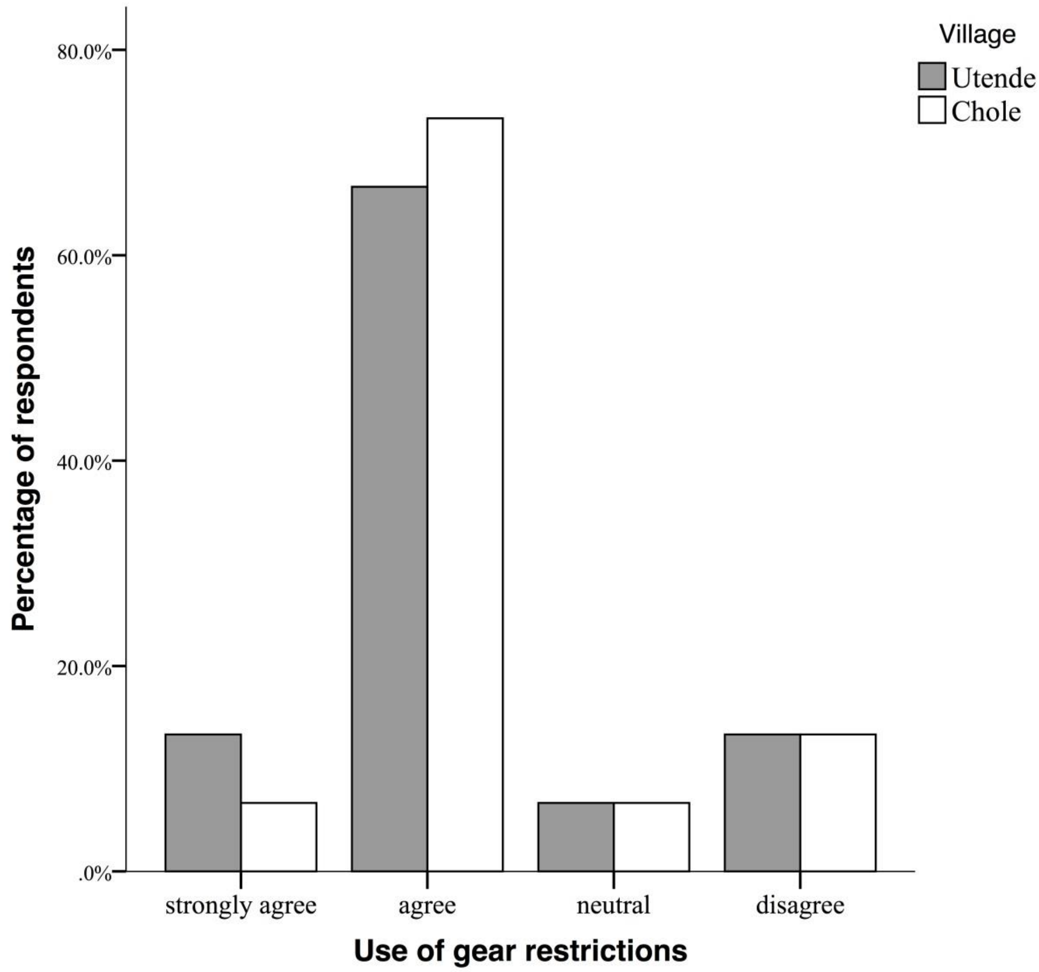

Figure 3.4: Responses to the question “How much do agree with the use of gear restrictions”.

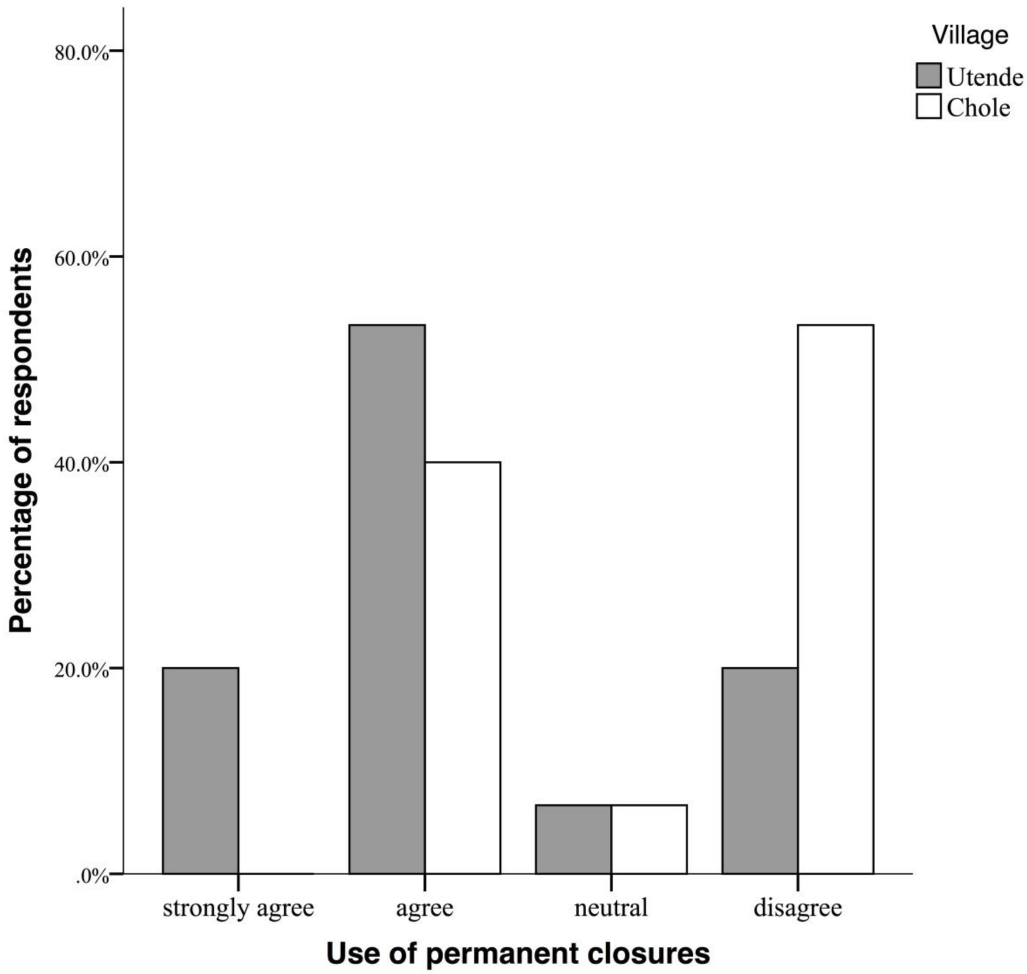

Figure 3.5: Responses to the question "How much do agree with the use of permanent closures".

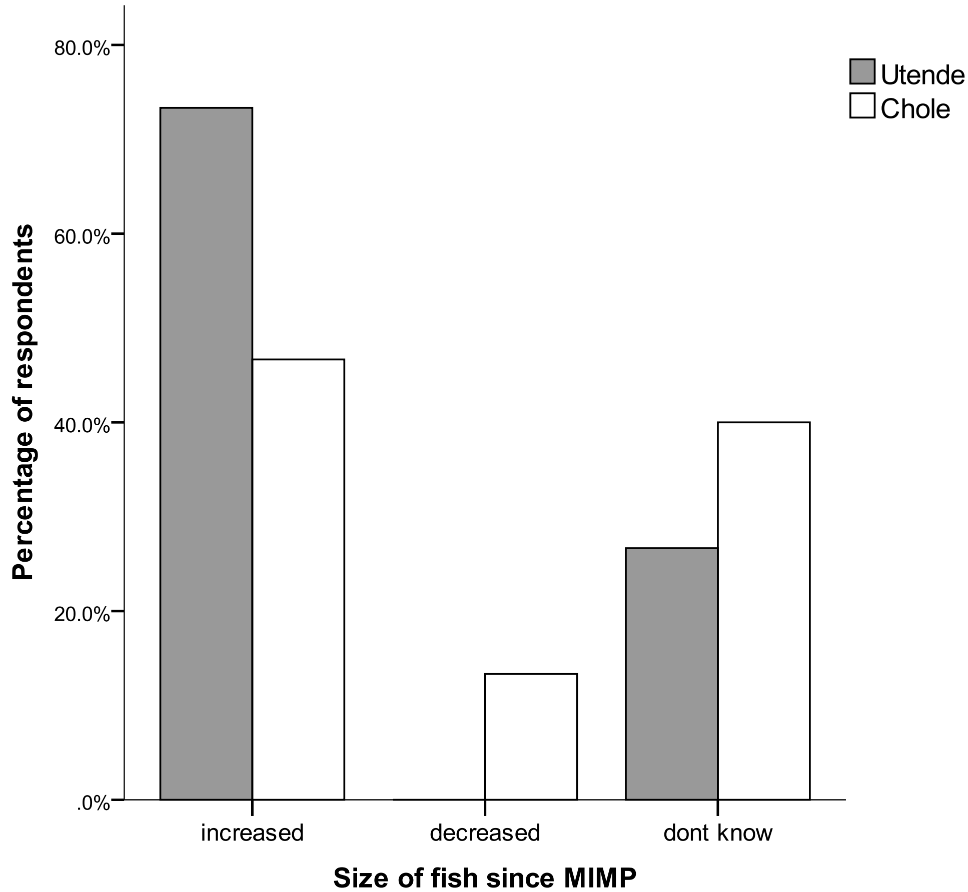

Figure 3.6: Responses to the question “What has happened to the size of fish since MIMP”.

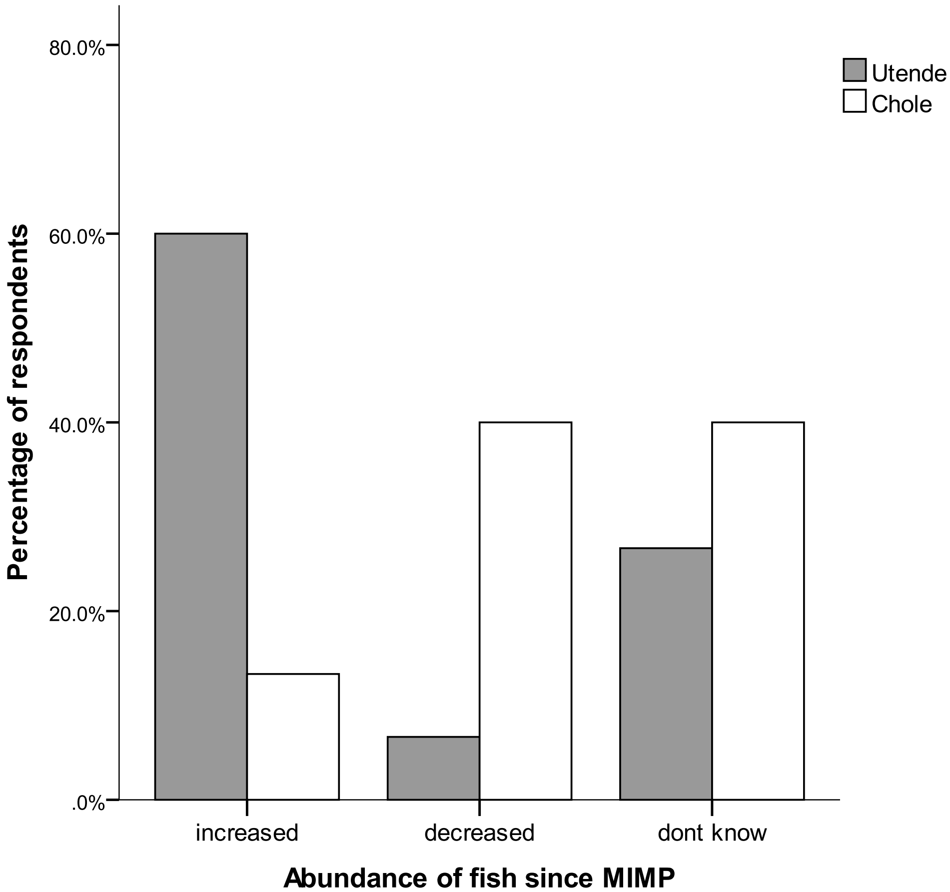

Figure 3.7: Response to the question "What has happened to the abundance of fish since MIMP".

Figure 3.8: Responses to the question "What do you think it would be like today if there was no MIMP", divided by fishing gear type.

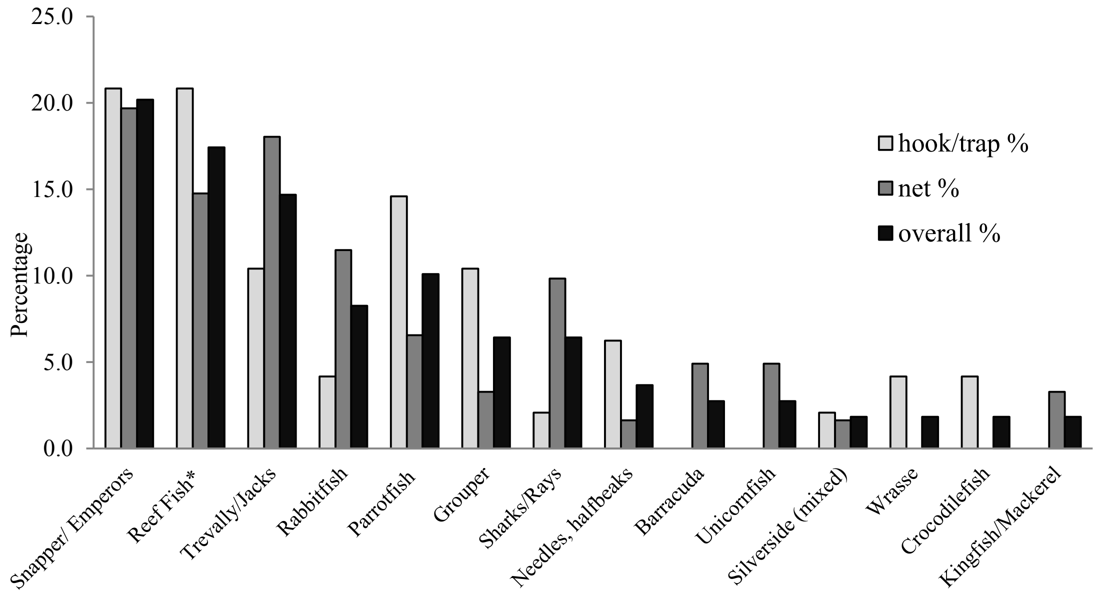

Figure 3.9: Economically important species as identified by fishers. Groups of target finfish, % they were mentioned by fishers and separated by gear type.

*Reef Fish was a term used by many respondents. When asked for more detail, along with observations of catches, reef fish comprised mainly of butterflyfish, angelfish and surgeonfish, triggerfish and goatfish. Fishery indicator families are: Snappers (*Lutjanidae*), Emperors (*Lethrinidae*), Reef fish comprising of: Surgeonfishes (*Acanthuridae*), Butterflyfishes (*Chaetodontidae*), Angelfishes (*Pomacanthidae*), Triggerfishes (*Balistidae*)and goatfishes (*Mullidae*), Jacks/Trevally (*Carangidae*), Rabbitfishes (*Siganidiae*), Parrotfishes (*Scaridae*), Grouper (*Serranidae*), Sharks (*Carcharhinidae*) and Rays (*Batoidea*), Needlefishes (*Belonidae*), Halfbeaks (*Hemirhamphidae)*, Barracuda (*Sphyraenidae*), Unicornfish (*Naso*), Silversides (*Atherinidae*), Wrasses (*Labridae*), Crocodilefish (*Platycephalidae*).

Chapter 4 Why fishers want a closed area in their fishing grounds: Exploring perceptions and attitudes to sustainable fisheries and conservation 10 years post closure in Labrador, Canada.

Manuscript published in Marine Policy as:

Kincaid, K. B., and Rose, G. A. (2014). Why fishers want a closed area in their fishing grounds: Exploring perceptions and attitudes to sustainable fisheries and conservation 10 years post closure in Labrador, Canada. Marine Policy 46, 84-90.

1. Introduction

Many fisheries closures and marine protected areas might be judged successful from a biological perspective, resulting in enhanced biodiversity (Russ and Alcala 2011), connectivity (Christie *et al.* 2010) and species abundance (Carilia *et al.* 2013) but nevertheless fail to generate local support. In general, fishers that initially support closures are more likely to support further marine protection efforts (Epps and Benbow 2007). Thus it is important to understand why and how such support can be garnered in attempts to conserve fisheries and biodiversity. The importance of community involvement has been recognised in the Convention on Biological Diversity (CBD) 2011-2020 Aichi Biodiversity Targets for signatory countries to achieve by 2020 (CBD 2013; VanderZwagg *et al.* 2012). These targets include sustainable fisheries, protection of at least 10% of coastal and marine areas by 2020 with participation of local communities and respecting and integrating traditional and local knowledge. Thus, understanding how fishers are involved in these types of areas and may be supportive (or not) is imperative towards achieving such targets.

In 2003, the Department of Fisheries and Oceans Canada (DFO) established the Hawke Channel trawling and gillnetting exclusion zone (herein referred to as “Hawke Box”) following calls for the closure from local fishers. An initial 10 by 10 nautical mile closure was expanded the following year to 50 by 50 nautical miles (8610 km^2) (Fig 1).

The Hawke Box was instigated and fully supported by the local community (Mullowney *et al.* 2007) with the strong sense of ownership often documented in near shore tropical areas (Johannes *et al.* 2000; Elliott *et al.* 2001; Pollnac *et al.* 2001; Govan *et al.* 2009), but seldom for temperate continental shelf regions (Auster and Shackell 2000), (but see Haliday (1988) where fishers supported seasonal spawning closures in the northwest Atlantic). The Hawke Box is unique as a community initiated closed area in a boreal offshore environment; there are few, if any, examples in the literature of fishers instigating and supporting a closure in their own fishing grounds in a boreal environment.

The present research aimed to explore why the Hawke Box was initiated by local fishers and their perceptions of its benefits or liabilities and to sustainable fisheries and conservation a decade after the initial closure. The primary objective was to assess why fishers that use trawls would ask for and support a trawling closure on a central portion of their own fishing grounds. Secondary objectives were to assess fishers' perceptions of the successes or failures of the closure thus far, and to determine perceptions of conservation, if they would support additional protection in the form of specially designated marine protected areas in the Hawke Channel and other adjacent areas that would allow some types of fishing but not others. Such information will be of use to marine management within Canada, and all countries that have made commitments towards marine protection, sustainable fisheries, and an ecosystem based management approach. This paper includes a history and overview of the Hawke Channel closed area and the local fishery, followed by an overview of the survey methodology used to interview local fishers. A combined results and discussion section discusses the topic of why fishers had asked for a closure in their fishing grounds, and discusses the results in context of the knowledge and perceptions of fisheries and conservation in general.

1.1 The Hawke Channel and Box

The Hawke Channel is a deep offshore soft mud bottom environment located off southern Labrador (Fig. 4.1) in the Northwest Atlantic Fisheries Organisation (NAFO), Division 2J. The Channel is characterised by low species diversity, and has habitat utilised by both resident and highly migratory species. The surface waters are dominated by the cold Labrador Current (to -1.5 °C) that is undercut in the Channel by much warmer Atlantic Ocean waters (to 4.5 °C) (Colbourne *et al.* 2010). The region is covered with sea ice for several months of the year and crab pot fishing is seasonal (Table 4.1). In the 1990s, following the collapse of the cod stock that frequented this region (Rose 2007) increases in pandalid shrimp (*Pandalus* spp.) led to the area being heavily trawled. The area also became a centre for a snow crab (*Chionocetes opilio*) fishery utilising passive pot gear, in part by the same fishers and communities. A key difference in the two fisheries was that the crab fishery was prosecuted entirely by Labrador fishers from communities adjacent to the Channel, whereas the shrimp fishery had a local component that utilizes smaller (65 ft. and smaller) trawlers, but also a non-local fishery that utilizes large (ca. 65 m) trawlers. By 2001, strong concerns were expressed by local fishers about the potential effects of the intensive trawling on the lucrative snow crab fishery and 2J crab fishers submitted a proposal for a no-trawl zone to DFO. Initial requests were rejected, but the 2J crab fishers persisted (DFO 2007). After consultations with stakeholders, and with support from the former Fisheries Resource Conservation Council, who also perceived some benefits to juvenile groundfish, in particular Atlantic cod (*Gadus morhua*), recommendations were made to close the area to all trawling. DFO implemented a no-trawl-no gillnetting zone in 2002. The Hawke Channel thus became a year-round offshore closed area that excluded all trawling and gill netting (Mullowney *et al.* 2012). Fishing for crab with pots was allowed to continue by the fleet in the region. This closed area is similar to an area in NAFO division 3K, Funk Island Deep, south of Hawke (Fig 1), but differs in that shrimp and crab fisheries do not overlap in 3K as they do in 2J. This was another reason why the Hawke Box was closed, to allow for an un-trawled zone within this division (DFO 2007).

1.2 The Hawke Box fishery

The crab fishery in the Hawke Box opens for approximately three months of the year with fishers using fleets of conical baited traps (DFO 2013a). Crab pots are a passive fishing gear that are set on the bottom, and are highly selective for snow crab (Fig. 4.2). In this crab fishery, only males are kept, but other management measures include the mandatory release of soft shell and undersized crabs. Fisheries regulations for the region include a minimum size (95mm carapace width), management areas, trap limits, quotas, seasonal fishery to limit soft-shelled crabs, closures when the percentage of soft shelled crabs exceed 20% of catch, and a total allowable catch (DFO 2013a). Additionally, stock assessments are assessed annually from multispecies trawl surveys, trap surveys, fisher's logbooks and observer data. Local fishers are included and consulted through regional advisory meetings.

Annual snow crab landings in the Hawke Box increased between 2003 and 2007; since 2008 landings have decreased (Mullowney *et al.* 2012) (Fig. 4.3). Fishing effort, calculated as the number of trap hauls per year, peaked in 2004, post closure with 218,005 traps and had a mean of 115,953 traps pre 2004, and 113,096 post 2004 (Fig. 4.4). Catch per unit effort (CPUE) peaked at 16.25 kg/trap in 1999. This then decreased steadily to a low of 3.99 kg/trap in 2004 (Mullowney *et al.* 2012). Post closure, CPUE has been increasing (Fig. 4.5) within the box.

2. Methods

A survey amenable to quantification was developed based upon designs from recent literature (Marshall *et al.* 2010; Heck *et al.* 2011; Cullis-Suzuki *et al.* 2012; Tokotch *et* *al.* 2012) and through talks with fishing industry representatives. Ethics were approved by the NunatuKavut Research Review Committee, and Memorial University Interdisciplinary Committee on Ethics in Human Research (2012-298-SC). Local fishers (n=85, from 28 vessels) from southeast Labrador communities that fish for crab within the Hawke Box region were contacted through phone and of these, 19 were available and agreed to be interviewed in their own homes during March 2012. The fishers interviewed were mainly owners of fishing vessels (15 different vessels) and part of the initial discussions to close the Hawke Box. Participants were asked a series of questions intended to capture knowledge and perceptions of the area and why they wanted or did not want the area closed to trawling. Answers to categorical questions were scored along Likert type scales, and open-ended responses that could be categorised were explored using descriptive statistics in SPSS (IBM SPSS Statistics Version 20). Open-ended responses were also explored, with responses that had theme areas and definite response areas categorised accordingly. The advantage of grouping into trend indices post-questioning, rather than providing categories to the respondent, allowed for more independent and non-biased answers. Quotes have been included within text where appropriate, or set in quote form into relevant categories, using methodology similar to Heyman and Dieseldorff (2012).

3. Results and Discussion

Nineteen fishermen with an average of 29 years fishing experience were interviewed from communities in south-eastern Labrador. Most were owner-operators of fishing enterprises ranging from 35-65 feet. Fishing was the main source of income of all fishers interviewed, with snow crab using pots as the main fishery, followed by shrimp trawling. Most were directly involved in the establishment of the closed area (78.9 %, n=15).

3.1 Why a closure in their fishing grounds?

Local fishers that instigated this closure fish within the Hawke Box for snow crab and must travel further to trawl for shrimp as a direct consequence of the closure. This extra time and travel has a cost, but most fishers believe that leaving this area free from bottom trawling and gillnetting will keep their snow crab fishery sustainable for the future. One fisher said, "If that box wasn't closed for the crab we wouldn't have a fishery today, that's all that's keeping us going today", a sentiment expressed by the majority of respondents. 73.7% said that without the closure, there would be no fishery today, and 26.3% said the fishery would be in worse shape without it (Table 4.2). A strong sense of ownership was evident among all fishers interviewed. One respondent put it as *"if we don't help ourselves right now, then we can forget about the future";* another said "*it's the only thing that's saving us. If you go outside* (the Hawke Box) *you don't get any crab, that's where they're doing all the dragging".* In three separate questions, 100%

interviewed said that the closure was beneficial to them, their community, and to marine life.

As a baseline for judging the opinions of fishers as to the outcome of the 10 year closure, each was asked why, in their view, the Hawke Box was established (Table 4.3). A positive engagement of fishers from the pre-implementation stage is an important step towards successful stakeholder involvement (Chuenpagdee and Jentoft 2007). Individual responses were themed around three categories; fishers discussed how the Hawke Box was established to protect the snow crab fishery, because of potential damage caused by fishing gears, and as a nursery/moulting area (Table 4. 3). The main reasons for wanting the closure related to protecting the snow crab, and eliminating fishing gear that can damage crab (gill nets and trawls). Fishers said that the Hawke Box was established to enhance both marine life and fishing opportunities for crab (84.2%), to solely conserve crab (10.3%), or just for the benefit of people (5.3%). The majority of fishers wanted this closure to be kept as it is (Table 4.2).

Recent evidence has shown little or no gain in snow crab in the Hawke Box since the closure, with little evidence of positive effects from the Hawke Box (Mullowney *et al.* 2012); yet, despite this, fishers said that without the closure, there would be nothing left, no fishery, or the fishery would have declined (Table 4.2). One fisher said, *"If this wasn't protected there wouldn't be anything in the Hawke Channel and I'm saying that from the* *bottom of my heart".* Despite not seeing a significant improvement in the fishery, fishers valued the closure as a buffer against not having any fishery at all. A concentration of fishing effort within the closure has been documented in temperate fishery closed areas (Murawski *et al.* 2005) and has likely contributed to the lack of increase in snow crab in the Hawke Box (Mullowney *et al.* 2012). It is important to note, however, that the lack of increase in snow crab in the Hawke Box over the past decade does not mean that there has been no increase in crab productivity; CPUE has increased over the past 10 years (Fig. 4.5). This aspect is beyond the scope of this paper but will be addressed in future research. In addition, high crab mortality from discarding of soft-shelled crabs may have occurred before the closure was implemented (Mullowney *et al.* 2012).

Fishers were well aware of the potential for effort concentration and that restricting gear was not a guarantee of improvements in fisheries. One fisher said, *"I'm all for protecting species but you need to be careful when you do that because it concentrates the fisherman in areas and they fish those harder, before the closure those boats were spread all over, now they have to come back inside the box".* There was near universal agreement that with high quotas for crab, and recognition of the area as a nursery ground for crustaceans and groundfish, other management measures are needed, especially reducing fishing effort. In 2013, under recommendations by DFO at the regional advisory meeting, 2J fishers agreed to reduce their quota for crab further; quotas for 2013 have been reduced by 10% (DFO 2013b). Local fishers believed that the closure, with reduced fishing effort would protect their fishery for the future. Restrictions on the level of effort on snow crab inside the box, in addition to the closure is a reasonable biological management approach (Mullowney *et al.* 2012). It was evident, and important, that these fishers and the science and management institution, here the Canadian DFO, have a good working relationship in a co-management approach. In agreement with Mullowney *et al*. (2012) one respondent said "*I think that the quota* (for crab) *is too high for what is there and it's being overfished"*.

Fishers were also asked what factors had attributed to changes (good or bad) inside the Hawke Box since the closure in the abundance and size of cod, crab, and shrimp (Table 4.2). Responses were divided into categories and topics (Table 4.4). Categories included fishing gears, temperature changes, and the presence of predators (Table 4.4). Some respondents said the seasonal nature of the fishery, and the lack of trawling in the box contributed towards changes seen in the numbers of crab since the closure. The majority of respondents commented on the temperature increase (DFO 2007) in the area for the main reason on changes seen, one fisher said this is because they get more crab when the water is colder (Table 4.4). Such knowledge on changes to species and habitat can be valuable towards marine management decisions; fishers often know about relative abundance of species over various spatial and temporal scales that may be unknown to scientists and managers (Johannes 2000; Hamilton *et al.* 2012; Johnson *et al.* 2012; Silvano *et al.* 2012).

3.2 Perceptions and attitudes to sustainable fisheries and conservation

Fishers mentioned conservation related indicators including spillover effects and habitat protection, and discussed the importance of the area as a nursery, moulting and spawning ground (Table 4.3). 42% of respondents said they would consider the Hawke Box fishery closure as a type of MPA (Table 4.5). Many fishers expressed their perceptions on the impacts of trawling on the soft mud bottom of Hawke Channel: "It's *a prime spot for spawning and juvenile fish* (fish in Newfoundland and Labrador are generally cod, but the Hawke Channel is a known juvenile area for cod, Greenland Halibut and Redfish, Brown and Anderson 1999), *and if you have this dragging over the bottom you're not only damaging the young fish but the environment".*

Further questions explored fishers' perceptions and attitudes to other conservation measures. Fishers expressed concern that this area could be reopened at any time by DFO. A fishery closure can be reopened easily, however a designated Marine Protected Area (MPA) would give more permanent protection to the area. Despite this, fishers were more supportive of size and gear restrictions, as practiced at present within the Hawke Box, than of full MPAs (Table 4.6) and almost all (94.7%) agreed that fisheries and conservation are compatible goals (Table 4.5).

The Hawke Box fishers' support and positive perception of conservation and sustainable fisheries, coupled with their concern about this area being reopened at any time, suggests further conservation measures might be required, and supported. The near universal local support for the closure provides a strong basis from which to consider this area for permanent protection (Chuenpagdee and Jentoft 2007) which under the Aichi Biodiversity Target 11 (CBD 2013) encourages community-supported protected areas and includes areas that allow sustainable fishing while restricting impacts to biodiversity provided that there is adequate protection of species, habitat and ecosystem processes. At present, many of Canada's international and national commitments to marine protection, ecosystem based approaches and restoration of fish stocks remain unfulfilled (VanderZwagg *et al.* 2012). Utilising areas such as the Hawke Box that already have the support of communities and fishers could assist in fulfilling these commitments.

As a final point, there is a unique scientific opportunity with the Hawke Box. It is the only large deep and boreal-sub-Arctic continental shelf area that has not been commercially trawled for a decade, in the middle of important and highly trawled fishing grounds. There are many calls in the recent literature for empirical evidence on the impacts of closures in temperate, boreal and sub-Arctic regions such as this (Caveen *et al.* 2012). Most evidence to date comes from tropical systems whose results may not be applicable to colder and higher latitude marine ecosystems. Moreover, although trawling has been shown to have a negative impact on mud seafloor communities in stable mud habitats (Hixon and Tissot *et al.* 2007), the impacts of trawling in a deep, soft muddy bottom habitat such as exists in Hawke Channel is uncertain. This lack of reference areas (those free from fisheries disturbances) in boreal and sub-Arctic seas is of particular concern considering the heavy fishing effort these areas may receive in future with climate change elevating access to northern seas.

4. Conclusions

The Hawke Box was implemented solely as a fishery management tool. Over the past 10 years, a strong sense of ownership among local fishers has developed. This, coupled with their willingness to reduce effort, and concerns about biodiversity (e.g., nursery area, habitat protection) linked to scientific interest in a large no-trawled area, make this closed area a strong candidate as a community based marine protected area that allows sustainable fishing and precludes re-opening. Such candidate areas could become building blocks towards achieving ecosystem based management approaches and conservation based targets. From the standpoint of communities and fishers, the Hawke Box has been a large success, despite its implementation leading to increased costs in effort and fuel to fish for shrimp with trawls outside the area. Hence this is not solely a case of excluding competitors, as the majority of excluded effort is their own. This demonstrated commitment, based on adjacency and dependence, linked with an intimate spatial and temporal knowledge of the area and 10 years of experience with the closure, has led fishers to believe that the future of their communities and livelihoods depends on the existence of this closure. This type of commitment is vital to fisheries conservation, is not universal, and should be a basis for implementation of fisheries closures both here and worldwide.

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Tables

Table 4.1: The Hawke Channel Trawling Exclusion Zone.

Size of closure (km2)	Year established	Initiated by:	Main habitat	Species of interest	Depth Range	Fishing allowed	No. of vessels inside	Vessel size range	Fishing activity
8610	2003	Local Fishers and Government	Soft mud bottom, channel	Snowcrab, Atlantic cod, Shrimp, All juveniles	200-500m	crab pots when season open	28	34-89 feet	May-July

Table 4.2: Fisher responses about the Hawke Box and species changes since the closure (%).

	responses %		
Should the Hawke Box be….			
Kept as it is			84.2
Expanded			10.5
Reduced			0
Don't know/ unsure			5.3
What would it be like today if there was no closure			
nothing left/no fishery			73.7
fishery would be in worse shape			26.3
Before vs. after closure changes	cod	crab	shrimp
increased	63.2	42.1	57.9
stayed the same	0	26.3	10.5
decreased	10.5	10.5	5.3
do not know	26.3	21.1	26.3

Table 4.3: Responses to the question: "Why was the Hawke Channel established in the first place?"

Responses have been separated into categories for ease of reference.

1. Protect fishery	
1.1.	The main place for crab and wanted it trawl free
1.2.	We figured the box would be our survival
1.3.	To protect the crab stocks
1.4.	For cod and we knew it would benefit the crab fishery and all species
1.5.	We didn't want the species we had left to go the same way the cod went.
1.6.	We were losing our right to go fishing; big companies were dragging in there.
2. Fishing Gear	
2.1.	Scrapping over with draggers not good. It's the best help for the fishery yet.
2.2.	Closed for the shrimp dragging and gill nets because that's where the crab moulted and it was tearing up the habitat as well as the crab
2.3.	Closed to shrimp dragging, have heavy metal doors
2.4.	Because of the dragging and the gill nets
2.5.	We felt that the shrimp dragging and gill netting was affecting our crab stocks
2.6.	Before, lots of nets left in there, all full of crab and they would cut it and let it go to the bottom because it's too much trouble to clean it
2.7.	Gill nets was a big one on top of the dragging
2.8.	When turbot nets came in they were full of crab, those draggers were in there too.
2.9.	To stop the dragging that was damaging the bottom and the crab
2.10.	But I know first-hand that it is doing damage when I saw what was coming in with the shrimp in the plant.
2.11.	On account of the shrimp boats coming in the area. I was in there one year and I found a spot of crab, swarming when I went back to that same spot the next Spring there was hardly anything there and then what I did get was all broke up.
3. Nursery/Moulting area	
3.1.	The biggest nursery for fish and lets protect that area for fish to grow. It's a nursery for everything
3.2.	The area is a moulting area and it makes no sense to go in there. It's where the crab spawn and the juveniles are, so protecting the bottom is important. A lot of things spawn there too like shrimp. They (shrimp) have a chance to grow up in the box and swim to other places.

Table 4.4: Responses to the question: What do you think is the main reason for the changes in stocks since the Hawke Channel Closure has been in place?

1. Fishing gear restrictions

1.1. Stopping the trawling and nets in the area.

1.2. Because there is no (fishing) pressure on there in the winter time.

1.3. Because there is no dragging,

2. Fishing gear problems

2.1. Left nets, they fish forever.

2.2. I think it's too big of a (crab) quota for the damage that's done.

2.3. The bycatch with the shrimp nets.

3. Temperature

3.1. Temperature increase, temp hasn't been good for crab especially in the spawning stages, I think that's some of the reason for changes in the stocks.

3.2. I do know that shrimp does tend to stay in water of a particular temperature

3.3. Temperature and ice changes.

3.4. The temperature got something to do with it for sure with the warmer waters. We get good crab when the water is cold and the ice is around longer.

3.5. When the water is warmer I know the groundfish breed more and the crab breed less.

3.6. Temperature's a big thing, according to the science.

3.7. Temperature changes.

3.8. I think that all of those factors combined (temperature and
3.9. overfishing etc.)
I think temperature is the reason they (crab) haven't come back.

4. Predators

4.1. Cod: is our next big problem, meaning they're going to eat everything out there

4.2. Cod are increasing and I think they are eating a lot of the crab because they are a bottom dweller and one of the food they eat is small crab and shrimp too.

Table 4.5: Fisher responses from conservation related indicators (%), including: marine protected areas, conservation, and further protection.

	Responses (%)	
Do you consider a fishery closure to be a type of Marine Protected Area?		
yes		42.1
no		15.8
unsure/ do not know		42.1
Do fisheries and conservation go together?		
yes		94.7
no		0
unsure/ do not know		5.3
Would you consider closing more areas to protect…	fisheries	habitat
yes	26.3	31.6
no	15.8	15.8
unsure/ do not know	57.9	52.6

Table 4.6: Mean fishers agreement level for fisheries and conservation tools from most to least agreement. Table design adapted from (Chen 2012).

Do you agree with the use of the following management tools for fisheries and conservation?	Mean[a]	S.D.[b]
Size Restrictions	4.32	0.478
Gear Restrictions	4.21	0.478
No-trawl areas	3.89	0.658
Temporary Closures	3.58	0.692
Seasonal Closures	3.53	0.772
Permanent Closures	3.47	0.964
Marine Protected Areas (MPAs)	3.42	1.017

[a] Mean of 5-point likert scale of agreement ranging from 1 (strongly disagree) to 5 (strongly agree).
[c] Standard deviation

Figures

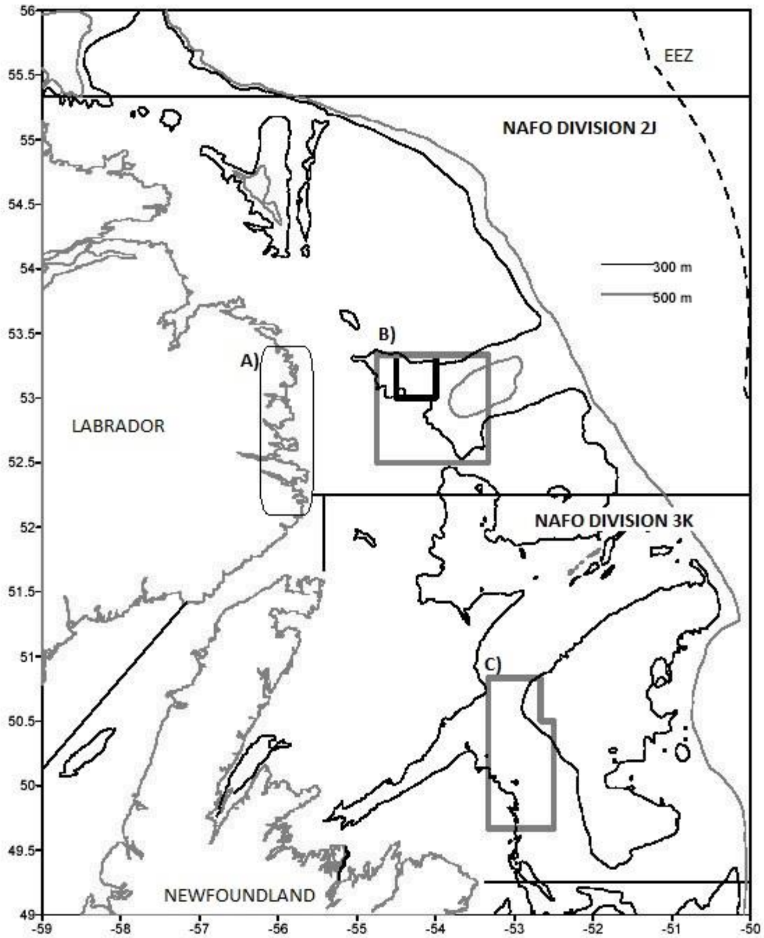

Figure 4.1: Map of SE Labrador with NAFO divisions 2J and 3K.

A) Location of fisher respondents in communities along the SE Labrador coast. B) The Hawke Box offshore shrimp trawling and gillnet closed area. The small black box indicates the original 2002 closed area, while the larger grey box indicates the present closed area and includes the deeper 500m channel. C) Funk Island Deep closed area in 3K, closed to small vessel trawling, but only voluntary closed to large vessel shrimp fishing fleet. Map adapted from DFO (2007).

Figure 4.2: Crab pot with snow crab inside (Photo with permission from Alton Rumbolt).

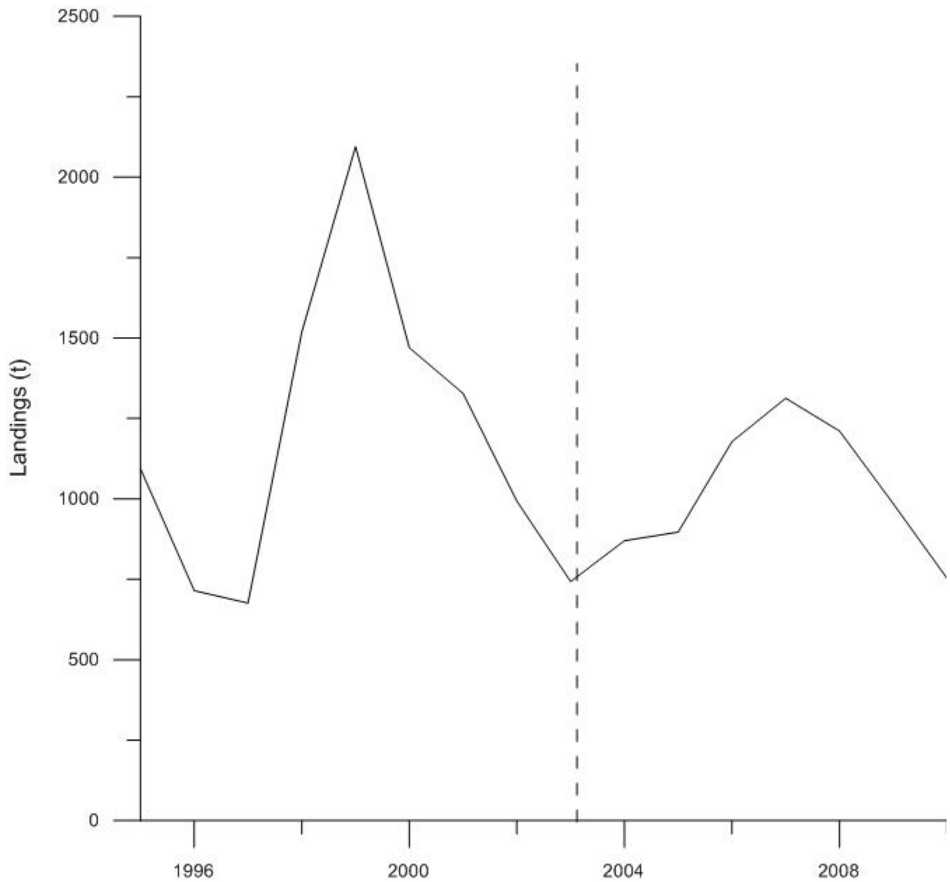

Figure 4.3: Annual Snow Crab landings (t) from the Hawke Box. The dashed line intercepted at 2003 represents the start of the Hawke Box closed area. (CPUE kg/trap data extracted from Mullowney *et al.* 2012).

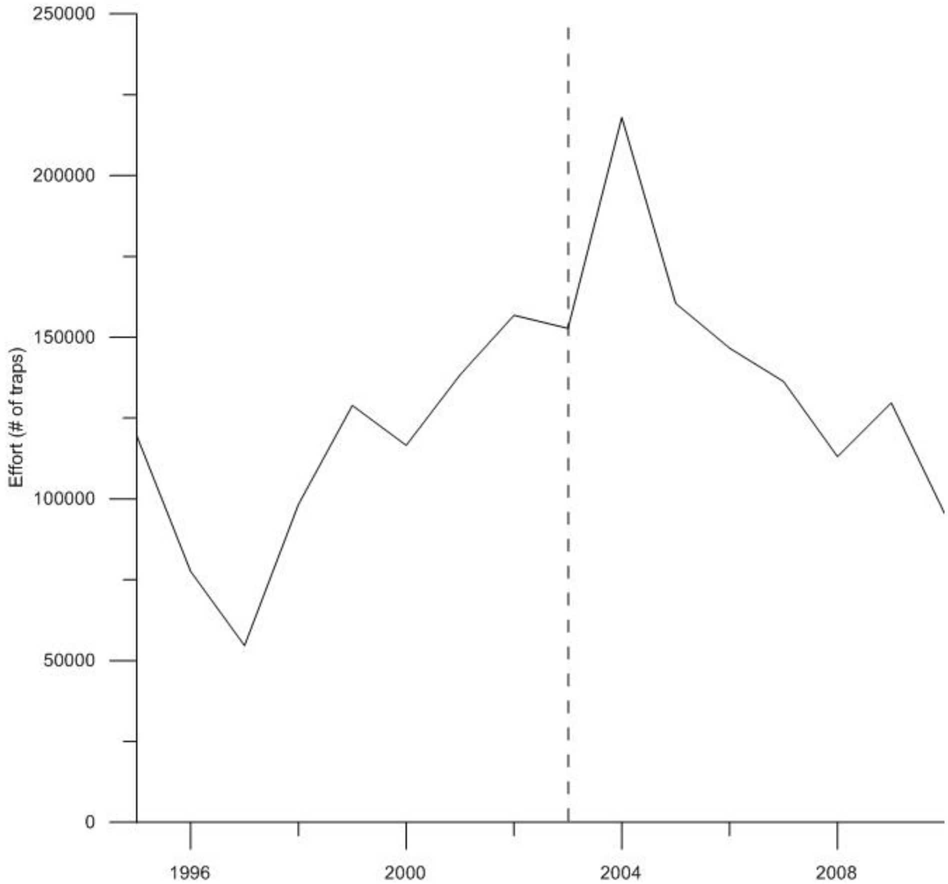

Figure 4.4: Annual Snow Crab effort for the Hawke Box. Dashed line intercepted at 2003 represents the start of the Hawke Box closed area. (Effort as # of trap hauls per year, data extracted from Mullowney *et al.* 2012)

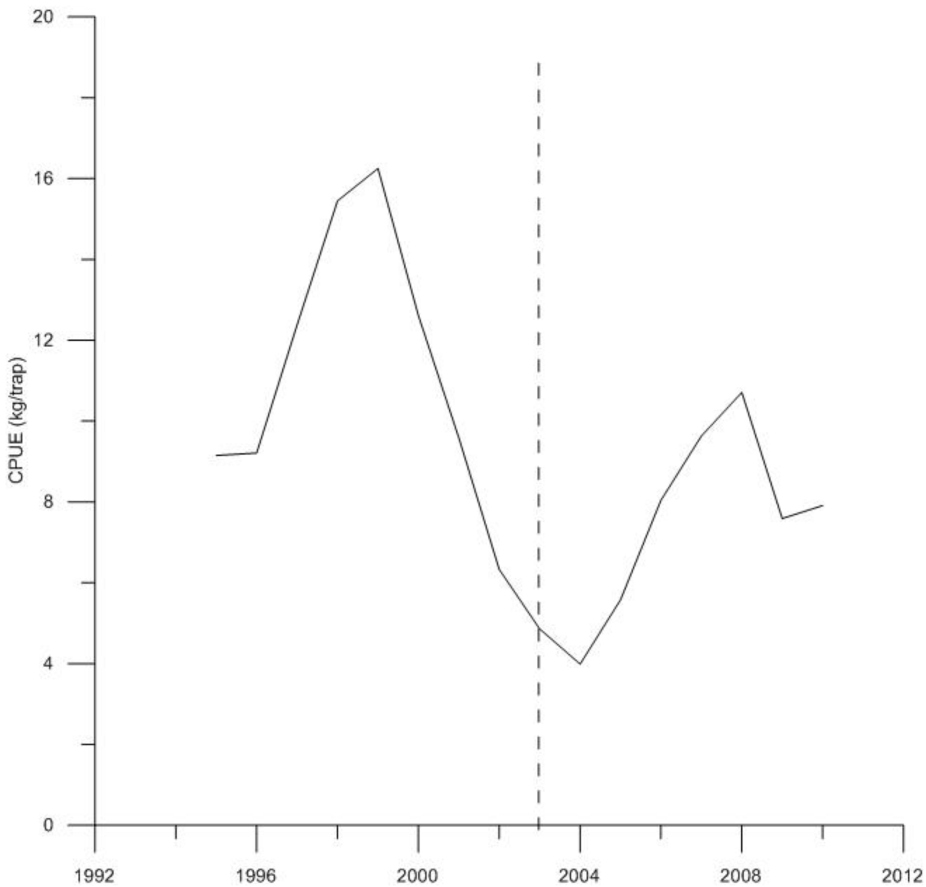

Figure 4.5: Annual catch-per-unit-effort (CPUE) rates of Snow Crab in the Hawke Box, calculated at kg/trap. Dashed line represents the start of the Hawke Box closed area. (CPUE kg/trap data extracted from Mullowney et al. 2012).

Chapter 5 Effects of closing bottom trawling on fisheries, biodiversity and fishing communities in a boreal marine ecosystem: the Hawke Box off Labrador, Canada.

Manuscript accepted to Canadian Journal of Fisheries and Aquatic Science (CJFAS)

Special Network Issue Perspective as:

Kincaid, K., Rose, G. Effects of closing bottom trawling on fisheries, biodiversity and fishing communities in a boreal marine ecosystem: the Hawke Box off Labrador, Canada.

1 Introduction

Closures to fisheries have been a management tool for centuries (Johannes 1978; Johannes 2002; Cinner et al. 2005), typically to protect spawning or juvenile fish and in some cases to benefit broader conservation concerns (Gell and Roberts 2002; Kaunda-Arara and Rose 2004; McClanahan 2010). Closures have also become a tool to conserve biodiversity, often as marine protected areas (MPAs). More recently, conservation and fisheries management goals have been converging (Gaines et al. 2010; Rice et al. 2012) under more inclusive ecosystem-based management (EBM) regimes (Salomon et al. 2011). Implementing such closed areas remains controversial (Gell and Roberts 2003; Abbott and Hayne 2012), particularly in temperate seas where evidence of their effectiveness in meeting management objectives is often lacking (Auster and Shackell 2000).

Closures in temperate seas may be less effective than in tropical reef systems. Temperate regions tend to have wider ranging and migratory species which limits spatial coverage of entire life cycles (Le Quesne and Codling 2008; Link et al. 2011; Breen et al. 2015). In addition, response times to closures may be longer (Fisher and Frank 2002) as a consequence of relatively slow individual and population growth rates. Some positive outcomes of closures have been documented in temperate ecosystems (Murawaki et al. 2000), but there are few examples in higher latitude boreal regions where many of the world’s largest fisheries occur (Caveen et al. 2012).

Analyses of the potential impacts of fishery closures are made complex by several factors. Control areas are often problematic to assign, and in particular, untrawled areas in trawlable habitat are rare (Atkinson et al. 2011), perhaps absent in boreal seas. In addition, few studies have long term multi-species data from before – after the closure needed to examine spatial and temporal ecosystem changes (Sweeting and Polunin 2005; Horta e Costa et al. 2013). Moreover, information is scarce on heavily fished boreal regions with soft sediments, and studies on similar areas in temperate seas have tended to focus on invertebrates and not on species assemblages or mobile species (Caveen et al. 2012). Adding to the complexity, fisheries and biodiversity studies often ignore the impacts of closures on fishing communities, which must occur if the tenets of EBM are to be followed (FAO 2005).

The boreal marine ecosystem of the Labrador continental shelf has supported major fisheries for hundreds of years (Rose 2007). Numerous coastal communities are highly dependent on these adjacent fisheries. In early 2000s, the local fishing industry requested that the federal regulatory authority, the Department of Fisheries and Oceans Canada (DFO), implement an area closed to bottom trawling and gill netting within the Hawke Channel fishing area with the objective of the conservation of snow crab fishing grounds (Chionocetes opilio), (DFO 2007; Kincaid and Rose 2014) (Fig. 1). Many of the fishermen advocating the closure fished snow crab in the Hawke Channel, but also bottom-trawled for shrimp (primarily Pandalus borealis), thus were requesting to exclude themselves. This advocacy was supported by the then Fisheries Resource Conservation

Council (FRCC), which advised the Minister of Fisheries on groundfish, as it was thought that such a closure might also assist the rebuilding of highly depleted spawning and juvenile cod (Gadus morhua) and other groundfish (Anderson and Rose 2001; FRCC 2003; DFO 2007). Following recommendations from the Labrador fishing industry, a small area (1370km2) was closed to bottom trawling and gillnets by DFO management in 2002 and expanded to 8610km2 in 2003 (Mullowney et al. 2012)(Fig 1). This area is referred to as the "Hawke Box". Since the closure, trap fishing for snow crab is the primary fishery and is permitted seasonally inside the Hawke Box, under license and quotas (approximately May-Sept depending on ice conditions) (Mullowney et al. 2012). In 2013, the crab fishery was certified by the MSC (Marine Stewardship Council). The fishery is based on catches of larger male crabs (legal size limit 95 mm, MSC 2016).

The Hawke Box is the only known relatively long-term (14 years) closure of large area of an Atlantic boreal continental shelf within a heavily fished area. Analyses of the impacts of the Hawke Box since the closure have been limited to stock assessments of shrimp and snow crab (DFO 2013a, 2014). Mullowney et al. (2012) conducted a Before-After-Control-Impact design, using fisheries data, concluding that the partial closure had limited benefits for snow crab, largely as an unintended consequence of increased snow crab fishing effort within the Hawke Box. Nonetheless, local fishers and communities remained supportive of the closure as the basis for their fishery (Kincaid and Rose 2014) that takes place inside and outside (mainly shrimp fishing) the Hawke Box. Thus, guidance on the broader effectiveness of the closure was needed for management. The present study was the first to address the effects of the closure on fishing communities, fisheries and biodiversity beyond the commercial crustaceans.

As a direct consequence of differing views on the effectiveness of Hawke Box management, this study was advocated for and supported by the DFO, the Newfoundland Department of Fisheries and Aquaculture (DFA), industry, communities and fishers to address the impacts of closed areas within a wider EBM approach as part of the Natural Sciences and Engineering Research Council of Canada (NSERC) Canadian Fisheries Research Network (CFRN). The study embodied the CFRN focus on integrating and utilizing cross-institutional expertise and knowledge with that of industry, fishers and communities, with the objective of enhancing ocean management in terms of both fisheries production and Canadian commitments to conserve biodiversity (Government of Canada 2011; Link et al. 2011).

The overall objectives of this study were to examine spatial and temporal changes in the communities and abundance of a range of fish and crustacean species after closure of the Hawke Box to bottom trawling and gill netting. To address the initial goals of protecting snow crab and cod and ongoing concerns of both industry and management, particular attention is paid to changes in the production and abundance of these species. In keeping with EBM policies, we discuss the impacts of the closure on adjacent fishing communities (Kincaid and Rose 2014).

2. Materials and methods

2.1 Hawke Channel

Hawke Channel is located on the boreal northern Newfoundland-Labrador shelf (NAFO Subdivision 2J) (Fig. 5.1). The Channel reaches depths of over 500m but shallows to a basin with depths of 200-400m as it approaches the Labrador coast (Brown and Anderson 1999). The oceanography of the region is complex, but is dominated by the southward flowing cold and relatively fresh Labrador Current (to -2C and 35 psu) that is seasonally variable but blankets the Channel and closed area to depths of over 100m year-round (Colbourne 1994). There is seasonal heating of near-surface waters. The Channel depths contain warmer and more saline Atlantic Ocean waters contiguous with the Labrador Sea year-round (2-4.5C and 32-33 psu) that reach shoreward to the interception of the Labrador Current with the seafloor providing a biologically rich area (Rose 1993).

The biota of the region is characterized by relatively few species that can reach high abundance but have the slow growth rates typical of boreal ecosystems (Rose 2007). Post-1950, this region was one of the most important cod fishing grounds in the world (Rose 2007), but since the decline of cod in the early 1990s the region has supported large fisheries for shrimp and snow crab (DFO 2013*a*, 2014). Also of economic and ecological importance in this region are redfish (*Sebastes* spp), Greenland halibut (also known as Turbot in this region) (*Reinhardtius hippoglossoides*) and capelin (*Mallotus* *villosus*). Little was known of other species. The importance of the snow crab fishery in the Hawke Channel led directly to local fishing industry advocating closing the area to bottom trawling, primarily targeted at shrimp. In the Hawke Channel region, shrimp are trawled commercially year-round (except in the closure). Within the Hawke Box, prior to the closure, 500-2,500 shrimp trawls of varying duration occurred each year; post-closure crab pot fishing occurred for 3 months each year (Mullowney *et al.* 2012). Outside the closure, commercial bottom trawling for shrimp and gillnetting for Greenland halibut has continued, in addition to crab fisheries.

2.2 Data

Multispecies bottom trawl data from NAFO Subdivision 2J were compiled from the Department for Fisheries and Oceans (DFO) annual fall surveys from 1996-2013 ("fall surveys"). Surveys followed standardised protocols using a Campelen 1800 Shrimp trawl and random-stratified survey design (Walsh et al. 2009; Chadwick et al. 2007). All catches were standardised to 15-minute tows. Catch data from the Hawke Box (inside) and a reference area (outside) that surrounds the Hawke Box were used, following a similar method to Jaworski et al (2006) to identify the outside area. The "outside" area sets were limited to NAFO 2J below 54 degrees latitude, within similar depths (150-550m) and habitat types (soft mud and sand) as the Hawke Box (NL Seabed Atlas 2016). Survey indices were: biomass (calculated as kg per tow, per species) and abundance (calculated as number per tow, per species).

In addition, targeted acoustic-trawl fishing sets using the same vessel and gear as the DFO fall surveys have been conducted in the spring (“spring surveys”) (between March-June) by the NSERC Industrial Chair in Fisheries Conservation, Memorial University of Newfoundland, Canada (1996-2003) and the same gear and sample methodology but different vessel in 2015. These previously unpublished data were part of research to locate the distribution of cod overwintering and spawning in and around the Hawke Channel, and provided information of potential seasonality of changes in the area (Fig.5.2) (see Anderson and Rose 2001 and Rose and Rowe 2015 for additional detail). Sets were targeted at areas identified using a scientific echosounder (EK500 or EK60; 38 kHz) where the acoustic signal indicated that cod and other species were present. Catches were disaggregated by species and weighed. Not all species were sampled across all years therefore the main species sampled (n=10) were retained for multispecies analysis. Spring survey analyses were based on 123 individual targeted fishing sets between 1996-2015 (Table 5.1). No sets were included in the analysis from 2004 - 2014 (a few sets conducted in 2007 and 2008 had inadequate coverage for a comparison inside-outside). For temporal comparisons, surveys were separated into 3 groups: B1 – before closure, n=60 (1996-1999), B2 – before closure, n=47 (2000-2003) and A – after closure, n=16 (2015).

Snow crab fisheries data for the 2J region between 1995-2014, including catch per unit effort from the trap fisheries (kg/trap) and landings, were available from DFO. Scaled landings data were used (logbook captured landings to dockside monitored landings for totals) because logbooks were incomplete (Darrell Mullowney, DFO Newfoundland, personal communication). Capture efficiency of snow crab in the multispecies trawl surveys is unknown, but is thought to be higher, and possibly more consistent, in soft mud habitat (Dawe et al. 2010; DFO 2014). For snow crab analyses, although the study nominally covers the NAFO 2J region, snow crab and their fisheries are concentrated in the Hawke and the Cartwright Channels (Fig. 5.1) therefore inside-outside comparisons are essentially between two similar channels with soft sediments, one with a trawl and gillnet closure, and one without a closure.

2.3 Analysis

Multivariate analysis for fall and spring survey data were performed separately using PRIMER (Plymouth Routines in Multivariate Ecological Research v6, Clarke and Gorley 2006) with the PERMANOVA (permutational multivariate analysis of variance) + add on (Anderson et al. 2008) on species level data. PERMANOVA uses a Pseudo-F test statistic, a multivariate analogue of Fishers F ratio (Martin et al. 2012). Data from the spring and fall surveys were not directly comparable due to potential seasonal differences and different survey designs, random (fall) and targeted (spring). Multivariate techniques were deemed appropriate for ecological data at this scale; PRIMER uses permutation techniques that do not require parametric assumptions and are able to handle unbalanced designs (Clarke and Warwick, 2001).

Mean abundance and biomass for each species per year inside and outside the closed area were treated as individual samples and used to create a Bray-Curtis similarity matrix, with the coefficient used to define similarity/dissimilarity. Abundances and biomass for each year was 4th root transformed prior to analysis to down-weight highly abundant species in the samples and increase the relative influence of rare species. The effects of year (before-after) and location (inside-outside) were considered as factors.

To test for relationships between community structure and the environmental variables of temperature and depth, a RELATE test (comparative test on similarity matrices) and PERMANOVA distLM (regression) tests were performed (Anderson et al. 2008). RELATE tests for relationships between the abundance/biomass of the taxa and environmental variables, based on Spearmans rank correlation. A PERMANOVA distLM distance-based linear model was used to assess the amount of variation in abundance-biomass explained by temperature and depth.

Hypotheses about differences in community structure were analysed at the species level using PERMANOVA. A three-way PERMANOVA was used to test for spatial and temporal differences. This allows analysis of a wide range of data distributions and factors to be tested using permutations (Anderson et al. 2008). PERMANOVA was used to test for significance of the following factors: Before_After = BA, In_Out = IO, Year = YR (nested in BA). Abundance and biomass were modelled as functions of the factors.

Canonical analysis of principal coordinates (CAP) was applied to visualise the groupings from PERMANOVA as a measure of the distinctiveness amongst the groups in multivariate space, to characterise the groups and assess how distinct they are from one another (Anderson et al. 2008). To identify characteristic species within the assemblage, significant differences in the assemblage structure were analysed using similarity of percentages (PRIMER SIMPER). The SIMPER routine determines the contribution of each species in the assemblage by computing the average Bray-Curtis similarities and dissimilarities between each sample before and after the closure. A one-way design was conducted with before-after closure as the factor inside and outside the closed area.

Species abundance (fall surveys only) and biomass changes over time were represented as the percent change post-closure relative to pre-closure: (Fall surveys: 2004-2013) (Spring surveys: 2015) and represented as a fold change.

For snow crab analysis, a normalized index of relative annual production (0-1 scale) was estimated from the sum of annual landings and change in trawl exploitable biomass estimates after completion of annual crab fisheries:

$$X\ new = \frac{X - X\ min}{X\ max - X\ min}$$

These indices represent comparable and bounded trends in total biomass of exploitable crab in the respective areas. The index does not account for the source of recruits.

2.4 Multivariate analysis

Mean abundance and biomass for each species per year inside and outside the closed area were treated as individual samples and used to create a Bray-Curtis similarity matrix, with the coefficient used to define similarity/dissimilarity. Abundances and biomass for each year was 4^{th} root transformed prior to analysis to down-weight highly abundant species in the samples and increase the relative influence of rare species. The effects of year (before/after) and location (inside/outside) were considered as factors. To test for relationships between community structure and the environmental variables of temperature and depth, a RELATE test (comparative test on similarity matrices) and PERMANOVA distLM (regression) tests were performed (Anderson *et al.* 2008).

Hypotheses about differences in community structure were analysed at the species level using PERMANOVA. A three-way PERMANOVA was used to test for spatial and temporal differences. This allows analysis of a wide range of data distributions and effects factors to be tested using permutations (Anderson *et al.* 2008). PERMANOVA was used to test for significance of the following factors: Before_After = BA, In_Out = IO, Year = YR (nested in BA). Abundance and biomass were modelled as functions of the factors. Canonical analysis of principal coordinates (CAP) was applied to visualise the groupings from PERMANOVA as a measure of the distinctiveness amongst the groups in multivariate space, to characterise the groups and assess how distinct they are from one another (Anderson *et al*. 2008). To identify characteristic species within the assemblage, significant differences in the assemblage structure were analysed using similarity of percentages (PRIMER SIMPER). The SIMPER routine determines the contribution of each species in the assemblage by computing the average Bray-Curtis similarities and dissimilarities between each sample before and after the closure. A one-way design was conducted with before-after closure as the factor inside and outside the closed area.

3. Results

3.1 Environmental variables: temperature and depth

Biological community composition and environmental variables temperature and depth were related in both spring and fall surveys (RELATE test), with depth and temperature explaining 23% (fall) and 24% (spring) of the variation in the data (PERMANOVA distLM distance based linear model). Nonetheless, neither variable explained a significant portion of the inter-annual variability, and hence were deemed to be constant over time for the purposes of this study.

3.2 Fall surveys

Analysis was based on 914 fishing sets (Table 5.1). The species level assemblage was comprised of 32 species from 24 genera, 16 families, 9 orders, 6 superorders, 3 subclasses and 3 classes (see Appendix B for a full taxonomic list of the species assemblage). Species assemblages differed before and after and inside and outside the Hawke Box closure and by year (Permanovas, $P<0.0001$; Table 5.2A). Inside the Hawke Box, abundance increased significantly 6-10 years post-closure ($P<0.0077$) (Table 5.2c, Fig 5.2). Outside the Hawke Box, overall biomass increased 6-10 years post-closure ($P<0.0228$), and abundance increased both 1-5 years ($P<0.0087$) and 6-10 years post-closure ($P<0.008$). There were notable differences inside and outside and before and after closure across 2 axes (CAP analysis, Fig 5.3).

Changes in abundance and biomass post-closure show mostly increasing and some decreasing trends (SIMPER analysis; Fig 5.2). The main species that were the most dissimilar before-after were capelin (*Mallotus villosus*) with increased biomass 6-fold inside (+622%) and 0.9-fold outside (+94%) and redfish with a 0.5 fold increased biomass inside (+50%) and a 2-fold increase outside (+284%) (SIMPER analysis, Table 5.3). Abundance changes were similar inside and outside the Hawke Box, but biomass changes varied inside-outside with some species having increased biomass within the closure: smooth skate (*Raja senta*) (+531% in, +167% out), capelin, American plaice (*Hippoglossoides platessoides*) (+39% in, +8% out), thorny skate (*Raja raidata*) (+35% in, +14% out) and turbot (*Reinhardtius hippoglossoides*) (+31% in, -28% out), and others having decreased biomass: northern wolfish (*Anarhichas denticulatus*) (-21% in, +214% out), redfish and marlin-spike grenadier (*Nezumia bairdii*) (+48% in, +124% out) inside the closed area (Fig 5.2). Biomass declined across the region for snow crab (-36% inside,

-71% outside) and shrimp spp. (northern shrimp -11% inside, -24% outside; striped -28% inside, -25% outside). Atlantic cod (fall season to 2013) increased in abundance 2-fold both inside (+244.55%) and outside (+217.91%) and in biomass with a 0.1-fold increase inside (+14.53%) and 0.6-fold increase outside (+61.44%) the closed area.

3.3 Spring surveys

Species assemblages assessed during the spring surveys differed before and after and inside and outside the Hawke Box and by year (Permanovas, P<0.001; Table 5.4). There were some noticeable separations in assemblages before and after the closure (CAP analysis, Fig.5.5). Inside-outside the closure patterns were less distinct. Overall, 7 species were responsible for the changes in community structure (SIMPER analysis). Species with the highest similarity and the principle contributor's before-closure were turbot, snow crab and shrimp. Post-closure the principle contributor was Atlantic cod (Table 5.5). The differences between inside and outside the closed area detected in the PERMANOVA test are represented in the biomass change plot (Fig. 5.6) with higher increases in biomass inside relative to outside the closed area. Atlantic cod displayed the largest biomass change with higher biomass inside than outside (see next section for further results). In addition, redfish increased 5-fold (+551.97%) inside relative to 0.08-fold (+8.57%) outside, American plaice increased 4-fold (+474.31%) inside and declined outside (-2.67%), thorny skate increased inside (+139.92%) more than outside (+5.46%), and roughhead grenadier (Macrourus berglax) increased inside 9-fold (+928.07%), but decreased outside the closed area (-99.32%). The 5 other species all had declining biomass (turbot, shrimp, capelin, arctic cod and snow crab) and this pattern was similar both inside and outside the closed area.

3.4 Cod changes

Spring surveys indicate that Atlantic cod underwent a dramatic 110-fold increase in biomass (+10,909%) in the 2J region, in 2015, after the closure (Fig. 5.6, 5.7). Mean biomass was 13.4 kg (Std.Dev. 14.7; 95% CI. 3.71) in 1996-1999 increasing to 25.9 kg (Std.Dev. 30.4; 95% CI. 4.4) in 2000-2003. Mean biomass increased to 2065.7 kg (Std.Dev. 4319.55; 95% CI. 2116.54) in 2015, 12 years after the closure. Biomass increase was slightly greater inside the closed area with a 139 –fold increase (+13,908%) than outside with a 117-fold increase (+11,703%).

3.5 Snow crab fishery

Snow crab landings fluctuated between 1995-2014 with decreased landings post closure. Prior to the closure (1995-2003) landings were higher outside (22,576t) than inside the closure (9,998t); post-closure (2004-2014) total landings were higher inside the closed area (11,010t outside; 10,870t inside). In general, despite fluctuations, landings are relatively stable inside the closed area but show a decreasing trend outside (Fig. 5.8a). Post closure, fishing effort remained relatively stable in the closed area, but decreased outside (Fig. 5.8b). CPUE remained similar inside and outside the closed area over the entire period of study with a decreasing trend pre-closure, and an increasing trend post closure (Fig.5.8c). The annual index of production was similar inside and outside prior to the closure, but beginning in 2005 became higher inside than outside the closed area in each year, on average by a factor of 2 (Fig. 5.8d).

4. Discussion

The primary objective of the Hawke Box was to enhance the likelihood of a sustainable snow crab fishery by eliminating what were thought by local fishers to be detrimental fishing practices for other species. Despite evidence that the density of snow crab of exploitable size had not increased within the closed area, nor had CPUE (Mullowney et al. 2012); local fishers believed that this objective had been met (Kincaid and Rose 2014). The present analyses indicate that although landings and relative production have declined throughout the region post-closure, largely as a consequence of a warming oceanographic trend (DFO 2014), they have not declined nearly as much inside the box as outside. This suggests that the removal of trawling and gillnetting has resulted in an increase in the relative production of snow crab. Increased production is consistent with the lesser decline in landings despite an increase in effort within the closure relative to a decline outside. Of note here, our CPUE and landings data do not include what could be substantial discards of soft-shell crabs (Mullowney et al. 2012), The impact of discarding, if diverse among areas, could bias the present results although it is not clear in what direction. For example, if discarding was relatively higher within the Hawke Box, as suggested by one reviewer, it would lead to even higher production estimates within the closure relative to outside. With further data the impacts of discarding could be addressed in future studies. The mechanism by which trawling or gill-netting may have led to a decrease in relative production is not known, but Nguyen et al. (2014) reported that 54% of snow crabs had a direct encounter with an experimental shrimp trawl. Whether or not such encounters result in increased mortality is unclear but it is likely that moulting and soft-shelled crabs may be particularly susceptible. We note, however, that several studies have concluded that there is no significant impact of trawling on snow crab (FDP 2002; Dawe et al. 2007; Mullowney et al. 2014). There is little information on the impacts of gillnets on snow crab, but there is little doubt that they will be entangled if gillnets are encountered (G.A. Rose, personal observations).

A secondary objective of the Hawke Box closure was to enhance the survival of juvenile and spawning cod known to utilize this area (Anderson and Rose 2001; Rose 2007). Spring surveys in 2015 in the Hawke Channel region recorded a dramatic increase in cod biomass over the past decade (Rose and Rowe 2015). This biomass increase was slightly greater inside than outside the Hawke Box but the sparse data and wide ranging migratory nature of cod in the region (Rose 1993) impose difficulties in determining the impact of the closed area on this increase (Breen et al. 2015), and may be insufficient to have impact at the population level (Laurel and Bradbury 2006; Le Quesne and Codling 2008). Nonetheless, an impact of the Hawke Box on cod should not be dismissed out of hand (Lester et al. 2009). The abundance of cod increased post-closure in both surveys, but the fall survey showed increased abundance post-closure but declines in biomass, which is consistent with an increase in younger juveniles (DFO 2015), while the increase in the spring survey represented an increase in the spawning population (Rose and Rowe 2015). The Hawke Box closure could have enhanced the survival of juvenile cod spawned in that region (Anderson and Rose 2001) that would be expected to increase their range as they matured (Anderson and Dalley 1997) and perhaps home back to their natal grounds (Robichaud and Rose 2001). Such behaviour could have led to an increase in spawning biomass inside the closure and nearby. Closed areas (in the right locations) have been shown to protect juvenile cod (Schopka et al. 2009), and even relatively small area closures (Jaworski et al. 2006) can protecting spawning sites, migration routes and potential nursery and productive areas like the Hawke Channel (Gell and Roberts 2003). We note that relatively small closures have been used as a management tool to protect spawning cod populations in Maine, USA (Armstrong et al 2013) and gear restrictions banning trawling have been in place on cod spawning areas in Norway for many years (Nakken 2008). Overall, although it is uncertain if the Hawke Box has played a role in the rebuilding of the northern cod, the evidence is that at a minimum it has done no harm.

Data from the fall surveys show abundance increases in 11 species inside and 10 species outside the Box post-closure (8 species increased in biomass in both areas). Data from spring surveys detected a large biomass increase in the 2015 survey inside and outside the box 12 years post-closure but this was largely a function of the increase in cod. It is important that several species declined across the region, as evident in both spring and fall surveys. These included snow crab, shrimp, and arctic cod, all species expected to decline with the warming oceanographic conditions (Mullowney et al. 2014). On the other hand, increases in redfish, American plaice, roughhead grenadier and thorny skate evident in the spring surveys within the closure relative to outside may have resulted from the elimination of bottom trawling and gillnetting, although the fall data did not show these trends as strongly.

All assessments of the changes observed in marine ecosystems and fishes, including those of closed areas, should be made in light of the ecological and climate dynamics that influence distributions and abundances. In effect, all measures are made against what is essentially a moving background that is independent of closures. In terms of the biological community under study here, it was expected that cod and perhaps other demersal fishes would increase, and crustaceans decline, over the period under study (Mullowney et al. 2014; Rose and Rowe 2015), independent of the closure, largely as a result of changing production (e.g., Pastoors et al. 2000). Both changes were observed, and against that background we measured significant differences in response between the closed and open areas. Of note, temperature and depth as expected explained some of the variability in the overall biological community data, because Atlantic cod, shrimp and snow crab occur within known temperature and depth ranges at the times of both surveys (the designs of both are based on this (e.g., Walsh et al. 2009, Rose and Rowe 2015, and references therein). Consistent with this, depth and temperature did not contribute significantly to inter-annual variation in the inside-onside comparisons made in this study, although statistical power is acknowledged to be limited.

The use of a quasi-control area, with similar oceanographic conditions, bathymetry and seafloor characteristics was thought to provide a measure against which to judge any changes attributable to the closure in Hawke Channel. Shrimp trawling and gillnetting occurred in the outside area, not inside, allowing the comparison for this and other studies in temperate environments (e.g., Deehr et al. 2014; Sherwood and Grabowski 2015). In our study, compared areas had similar temperatures, depths and oceanographic conditions. Nonetheless, we acknowledge that no oceanic control area for such studies can be perfect and it would be beneficial in future studies to make comparisons with additional areas. For example, the outside area did not have the same crab fishing effort (Mullowney et al., 2012), and the Hawke box could be more naturally productive than the control (Hilborn 2002; Halpern et al 2004). Siting the closure in a productive area likely increases the likelihood of increased abundance, and this factor may have impacted some of the present results, but for snow crab at least, this appears unlikely, as the bulk of the control data came from the Cartwright Channel, which although not as well studied at the Hawke Channel, may be similarly productive, and furthermore, the landings, effort and production data pre-closure offer no support that the Hawke is naturally more productive than the Cartwright Channel. That our data using a quasi-control (e.g., Edgar and Barrett 1997) suggest that differences did occur against that moving background is evidence that the closure did influence both commercial and non-fished species. Perhaps the most important dynamics were the maintenance of catches and relative production of snow crab against a background of decline outside the closure – meeting the primary objective of the closure.

The Hawke Box was implemented solely as a fishery management tool. Over the past 14 years, a strong sense of ownership among local fishers has developed. Fishers asked for the closure to protect the snow crab fishery through eliminating bottom trawl and gill net fishing gears, thus eliminating themselves from fishing for shrimp and turbot within the closure. Doing so resulted in increased travel time and costs, particularly in their shrimp fishery; increases that fishers believed were worthwhile to ensure a sustainable crab fishery. Despite evidence that the crab fishery (particularly CPUE) had not improved (Mullowney et al. 2012), fishers continued to value the closure as a management tool and understood that increased effort within the closure had negated some potential gains. A sentiment expressed one respondent was "If that box wasn't closed for the crab we wouldn't have a fishery today, that's all that's keeping us going" (Kincaid and Rose 2014). Local fishers were aware of the need to reduce their fishing effort and collectively agreed to reduce their crab quota under advice from DFO (DFO 2013b). Fishers were also aware of conservation related indicators including spillover effects and habitat protection for all species, and discussed the importance of the area as a nursery, moulting and spawning ground. Overall, from the standpoint of the local community and fishers, the Hawke Box has been a large success and thought to be fundamental to the future of their communities and livelihoods.

One of the often understated goals of fisheries management is to contribute to the viability and sustainability not only of the fish but of the fisheries and fishing communities. This goal is particularly important in EBM. The commitment of local fishers and communities has only increased recently with the overall decline in snow crab and shrimp primarily as a result of oceanographic warming (DFO 2014; Mullowney et al. 2014). An important aspect of this commitment is the ownership taken not only of the area but also of inevitable changes that are necessary for management, including reducing their own quotas and effort to maintain a sustainable fishery. The Hawke Box in many ways exemplifies how closures can and should be implemented in prime fishing areas, based on the knowledge and involvement of local fishing communities. Such implementations will almost certainly be more effective in achieving both fisheries and biodiversity conservation goals – they will be better supported, with higher rates of compliance, than those that do not have such characteristics (Agardy et al. 2011; Arias et al. 2015)

The Hawke Channel provides a unique reference site of no trawling (or gillnetting) in the boreal northwest Atlantic. Globally, there is a lack of representative unfished areas to compare with trawled fishing grounds and untrawled areas in trawlable habitat for comparative studies are rare (Kaiser and Spencer 1996; Atkinson et al. 2011). Although positive results have been reported from closures in the temperate North Atlantic (Murawski et al. 2000; Fisher and Frank 2002), the Hawke Box provides a rare boreal closure with soft mud sediments, a seafloor type for which the impacts of trawling are contentious (Kaiser et al. 2003; Caveen et al. 2012). In the Gulf of Maine, seasonal shrimp trawling on mud bottom fishing areas created only short-term changes (Simpson and Waitling 2006). However, in the Mediterranean, meiofauna biodiversity, abundance and biomass decreased by 80% in deep trawled vs. untrawled soft mud bottom areas (Pusceddu et al. 2014). This conflicting evidence supports the importance of the Hawke Box as a reference site for an "untrawled" area in a region of highly trawled fishing grounds.

5. Conclusion

The Hawke Box closure was closed as a precautionary management measure for the conservation of snow crab fishing grounds and to conserve cod concentrations (DFO 2007). Although changing oceanic regimes and increased effort led to declines in crab landings, there is evidence that production has been maintained relative to trawled and gillnetted areas outside the closure. There has also been a dramatic increase in cod, although it is more difficult to relate this directly to the closure. Nonetheless, other demersal species appear to have benefitted and this may apply to cod. Perhaps of importance, the Hawke Box provides a unique boreal area for the study of restrictions on trawling and gillnetting in an area with historically strong finfish and crustacean fisheries, restrictions that are strongly supported by local fishers and their communities. The overall evidence suggests that within a decade of closure the Hawke Box has benefited fisheries communities, fisheries production and biodiversity conservation.

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Tables

Table 5.1: Number of sets inside and outside the Hawke Box closed area for fall and spring data.

	Fall data				Spring data			
	Year	Out	In	Total	Year	Out	In	Total
Before closure	1996	48	14	62	1996	9	9	18
	1997	42	9	51	1997	0	0	0
	1998	40	10	50	1998	15	16	31
	1999	37	9	46	1999	5	6	11
	2000	39	1	40	2000	4	9	13
	2001	38	10	48	2001	3	12	15
	2002	18	8	26	2002	2	7	9
	2003	56	9	65	2003	2	8	10
Total		318	70	388		40	67	107
After closure	2004	41	7	48				
	2005	40	5	45				
	2006	41	8	49				
	2007	40	6	46				
	2008	34	7	41				
	2009	36	6	42				
	2010	39	11	50				
	2011	50	12	62				
	2012	65	9	74				
	2013	59	10	69				
					2015	11	5	16
Total		445	81	526		11	5	16
Total sets (all years)		763	151	914		51	72	123

Table 5.2: Fall survey PERMANOVA models.

A)All	Abundance				Biomass			
Factor	df	MS	Pseudo-F	*P*(MC)	df	MS	Pseudo-F	*P*(MC)
Before_After = BA	1	1037.4	13.877	0.0001	1	1184.1	9.216	0.0001
In_Out = IO	1	1591.5	21.288	0.0001	1	2524.9	19.652	0.0001
Year = YR (BA)	16	244.29	3.267	0.0001	16	569.02	4.428	0.0001
BA X IO	1	34.559	0.462	ns	1	42.494	0.331	ns
Residual	16	74.76			16	128.48		
Total	35				35			

B)Pair-wise comparisons	Temporal effects (Abundance)					
	a) All		b)Inside		c)Outside	
	t	P (MC)	*t*	P (MC)	*t*	P (MC)
Before-after 1 (2004-08)	1.6747	0.027	1.2926	ns	1.8382	0.0087
Before-after 2 (2009-13)	2.6663	0.0002	2.0508	0.0077	2.2597	0.008
After 1-after 2	1.8912	0.0162	1.5145	0.0403	1.4644	ns

C)Pair-wise comparisons	Temporal effects (Biomass)					
	a) All		b)Inside		c)Outside	
	t	P (MC)	*t*	P (MC)	*t*	P (MC)
Before-after 1 (2004-08)	1.3927	ns	1.1095	ns	1.4923	ns
Before-after 2 (2009-13)	2.2366	0.0027	1.5406	ns	1.9379	0.0228
After 1-after 2	1.8141	0.0258	1.236	ns	1.4311	ns

A) Three-way PERMANOVA analysis of spatial-temporal variation in community structure for all species. Factors were fixed (before-after closure, inside-outside closure and year) with year nested within Before_After. All analyses were carried out on abundance and biomass data using permutations of residuals under a reduced model on normalised, fourth root transformed data and 9999 permutations and type III sums of squares. df, degrees of freedom; MS, mean square; P(MC), probability level after Monte Carlo tests; pseudo-F, statistic F. * ns = not significant. PERMANOVA Pair-wise comparisons of temporal effects before-after closure on the whole area, inside only and outside only, unrestricted permutation of raw data for abundance (B) and biomass (C).

Table 5.3: A) Fall survey SIMPER routines on Bray-Curtis similarity, standardised and 4th root transformed abundance and biomass data inside the HC closed area.

		Inside HC closure					
		Abundance			Biomass		
		% Similarity		Before-After % dissimilarity	% Similarity		Before-After % dissimilarity
		Before	After		Before	After	
Average Similarity		83.43	80.91	19.73	79.97	67.74	27.28
Species	**Common name**						
Pandalus borealis	Northern shrimp	35	31.7	5.7	19.9	17.6	14.6
Pandalus montagui	Striped shrimp	11.7	12.7	6.8	6.7	7.5	3.1
R. hippoglossoides	Turbot	10.2	8.8	3.6	15.1	13.3	6
Sebastes mentella	Redfish (beaked)	5.8	8.4	6.6	7.4	8.5	5.4
Mallotus villosus	Capelin	5.7	4.9	13.2	5.3	4.6	7.4
Boreogadus saida	Polar/Arctic cod	5.7	3	10	4.6		5.9
Chionoecetes opilio	Snow crab	4.7	5.2	*	6.4	7.3	4.2
H. platessoides	American plaice	4.6	4.9	*	7	5.9	3.2
Gadus morhua	Atlantic cod	3.4	3.8	*	6.5	5.6	4
Nezumia bairdii	Marlin-spike grenadier	3	*	4.7	3.1	3.1	3.6
Raja radiata	Thorny skate	3	3.1	*	5.6	5.6	*
Icelus spatula	Spatulate sculpin			3.8			
Anarhicas minor	Spotted Wolffish			3.7		*	5
Raja senta	Smooth skate			3.4			
Lycodes reticulatus	Arctic eelpout			3.2			3.9
Cyclopterus lumpus	Lumpfish				*	3.5	3.8
Anarhicas lupus	Atlantic Wolffish					3	*
Glyptocephalus cynoglossus	Witch flounder					3	4
Anarchicas denticulatus	Northern Wolffish						3.9
Macrourus berlax	Roughhead grenadier						3.6
Coryphaenoides rupestris	Roundnose grenadier						
Antimora rostrata	Blue hake						

Species with the highest contribution to the similarity per year and % dissimilarity before and after the closed area. * = <3% similarity. Before: data collected before closure; after: data collected post-closure.

		Outside HC closure					
		Abundance			Biomass		
		% Similarity		Before-After % dissimilarity	% Similarity		Before-After % dissimilarity
		Before	After		Before	After	
Average Similarity					86.21	76.12	20.86
Species	**Common name**						
Pandalus borealis	Northern shrimp	25	25.2	5.8	13.3	11.7	6.6
Pandalus montagui	Striped shrimp	10.8	11.7	6.2	5.7	5.7	*
R. hippoglossoides	Turbot	7.1	6.5	*	8.9	8.8	3.5
Sebastes mentella	Redfish (beaked)	5.8	8.8	7	6.7	8	7.8
Mallotus villosus	Capelin	5.4	4.1	9	4.1	3.3	5.5
Boreogadus saida	Polar/Arctic cod	7.1	3.5	8	5.4	*	5.9
Chionoecetes opilio	Snow crab	4.5	3.8	*	5.2	4.1	3.8
H. platessoides	American plaice	3.2	3.9	*	4.3	3.8	*
Gadus morhua	Atlantic cod	*	3.5	*	4.8	5.2	*
Nezumia bairdii	Marlin-spike grenadier						*
Raja radiata	Thorny skate				4	4.2	*
Icelus spatula	Spatulate sculpin						
Anarhicas minor	Spotted Wolffish					4.23	3.3
Raja senta	Smooth skate						*
Lycodes reticulatus	Arctic eelpout				3.5	*	3.2
Cyclopterus lumpus	Lumpfish				4.1	3.2	3.2
Anarhicas lupus	Atlantic Wolffish				3.1	4.3	
Glyptocephalus cynoglossus	Witch flounder						*
Anarchicas denticulatus	Northern Wolffish				*	5.4	3.7
Macrourus berlax	Roughhead grenadier				3.7	3.7	*
Coryphaenoides rupestris	Roundnose grenadier						4.09
Antimora rostrata	Blue hake						3.9

Species with the highest contribution to the similarity per year and % dissimilarity before and after the closed area. * = <3% similarity. Before: data collected before closure; after: data collected post-closure.

Table 5.4: Spring surveys. Three-way PERMANOVA analysis of spatial-temporal variation in community structure for species (n=10) from spring surveys (targeted cod acoustic-trawls sets.

A) All	Biomass			
Factor	df	MS	Pseudo-F	*P*(MC)
Before_After = BA	2	10470	9.436	0.0001
In_Out = IO	1	5532	4.985	0.0007
Year = YR (BA)	5	5715.4	5.151	0.0001
BA X IO	2	2748.2	2.477	0.0082
Residual	107	1109.6		
Total	122			

B)Pair-wise comparisons	All		Inside		Outside	
	t	*P*(MC)	t	*P*(MC)	t	*P*(MC)
Before 1 - Before 2	1.816	ns	1.2634	ns	1.6009	ns
Before 1-After	3.9539	0.0001	2.4366	0.001	3.8928	0.001
Before 2- After	3.7383	0.0001	2.448	0.004	2.9546	0.001

(A). Temporal pair-wise comparisons (B). Factors were fixed (before-after closure, inside-outside closure and year) with year nested within Before_After. All analyses were carried out on biomass data using permutations of residuals under a reduced model on normalised, fourth root transformed data and 9999 permutations and type III sums of squares. df, degrees of freedom; MS, mean square; pseudo-F, statistic F; P(MC), probability level after Monte Carlo tests.

Table 5.5: Spring survey SIMPER routines on Bray-Curtis similarity, standardised and 4th root transformed biomass data for the 2J area showing species with the highest contribution to the similarity per year and % dissimilarity before and after the closed area.

ALL 2J	Before 1		Before 2		After		Before 1- After
Species	Mean biomass per tow (kg)	% Similarity	Mean biomass per tow (kg)	% Similarity	Mean biomass per tow (kg)	% Similarity	closure difference % dissimilarity
Turbot	48.48	**24.28**	47.18	**18.65**	10.53	15.82	11.6
Snow crab	11.63	**16.11**	13.40	13.17	0.19		**12.39**
Northern shrimp	61.43	15.00	77.65	**23.13**	2.91		**15.06**
Atlantic cod	13.17	12.95	25.90	15.05	2065.65	**43.35**	**26.24**
American plaice	3.43	11.83	3.64	12.24	8.87	9.69	7.36
Redfish	4.40	9.23	11.63	9.35	21.73	22.80	8.71
Thorny skate	1.50	5.70	2.61		2.89		8.42

Figures

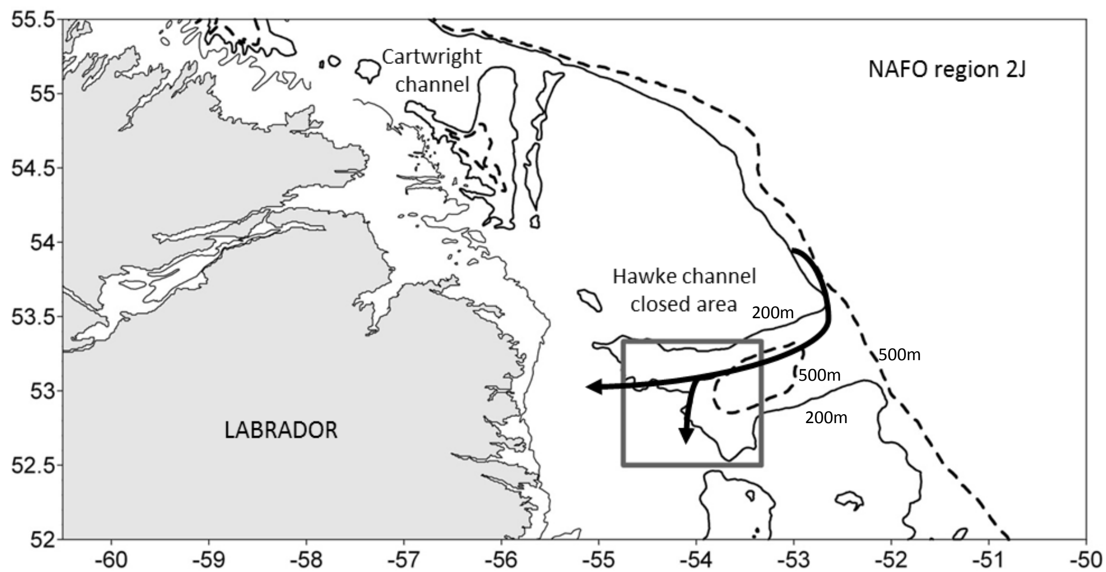


Figure 5.1a: Map of SE Labrador and NAFO 2J area showing the location of the Hawke Box closed area. To the north is the Cartwright channel, this and the Hawke Channel are the main fishing areas for snow crab pot fishery. All shelf area is commercial shrimp trawling areas. Arrows show predicted migration pathway for northern cod from offshore spawning areas to inshore feeding areas (Rose 1993). Map reproduced and re-annotated from DFO.

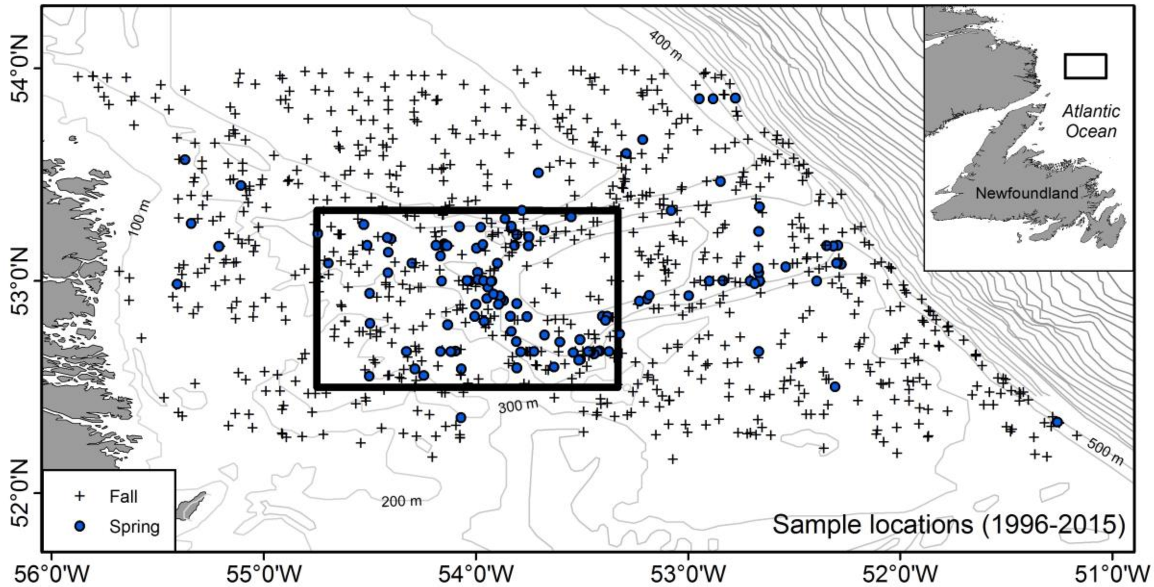


Figure 5.2b: Map of spring and fall survey sampling sites inside and outside the Hawke Box closed area.

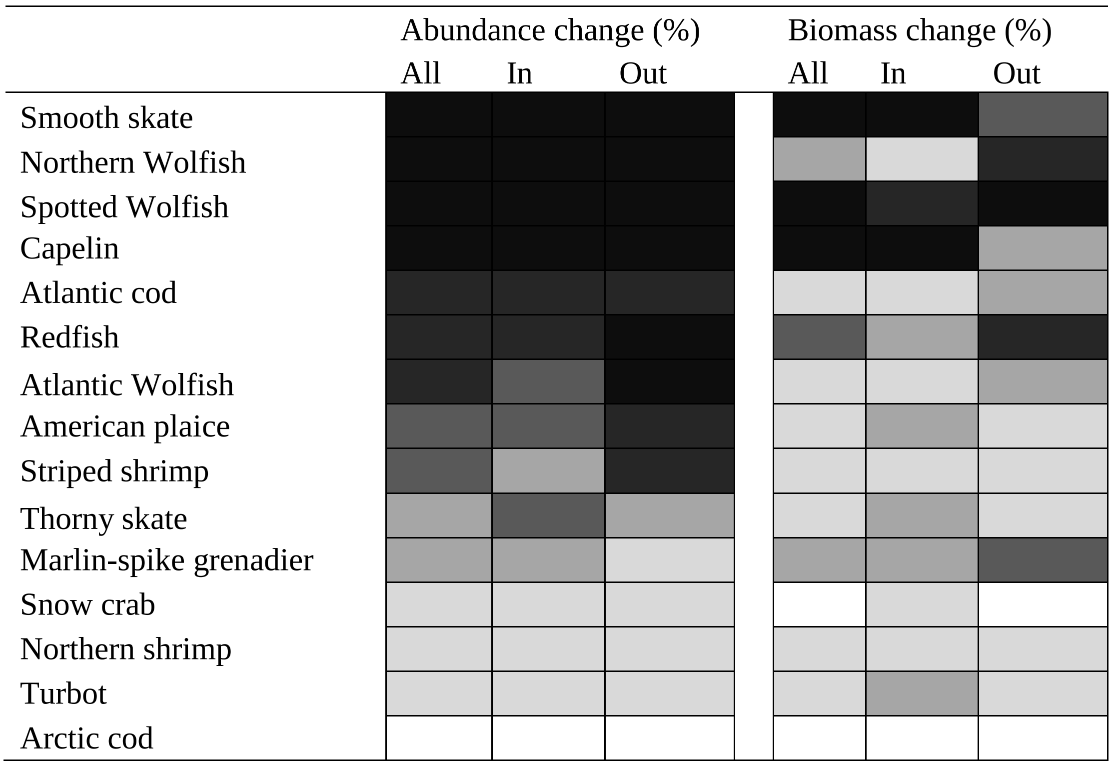
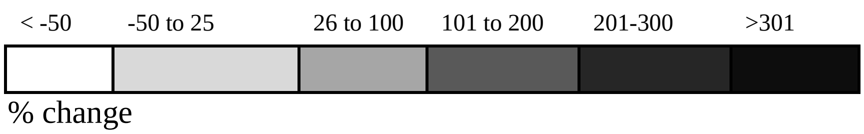


Figure 5.3: Fall survey post-closure mean abundance and biomass change (relative to the mean abundance and biomass pre-closure) for the whole area and inside and outside the Hawke Box for key species and species of conservation interest.



Method adapted from Fisher and Frank (2002).

a)

b)

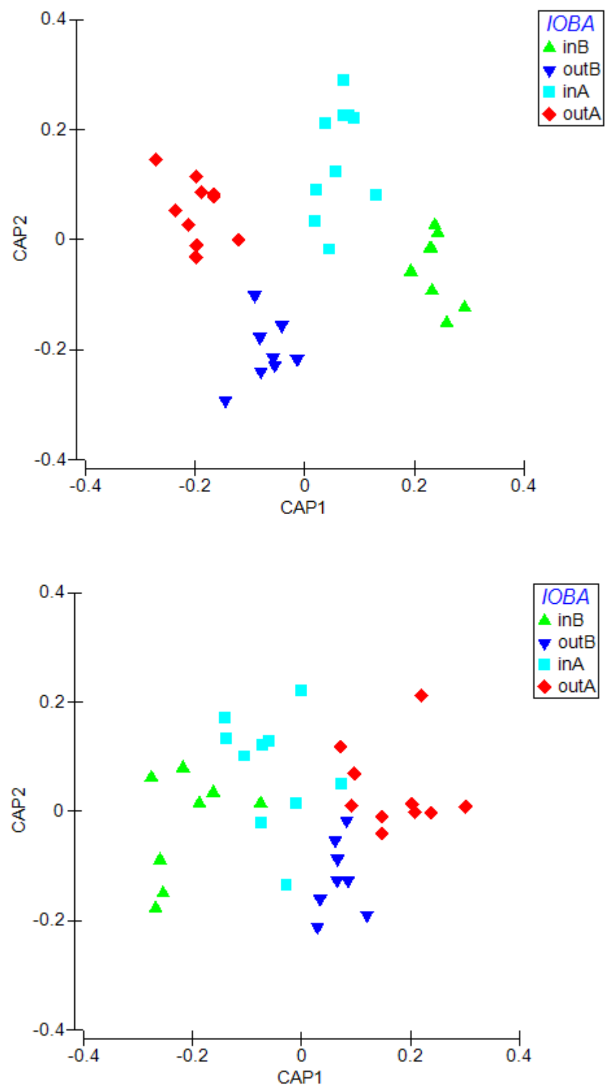


Figure 5.4: Fall survey canonical CAP analysis of the principal coordinates for mean abundance (a) and biomass (b) per year, all species, for inside-outside, before-after the closed area.

Analysis on fourth root transformed, Bray-Curtis similarity resemblance data. Symbols: in: inside the closed area; out: outside the closure; B: data collected before closure; A: data collected post-closure. A miss-classification error of 2.78% (abundance) and 19.44% (biomass) indicated a strong association. In addition, the permutation test in CAP of no difference was significant ($p<0.001$).

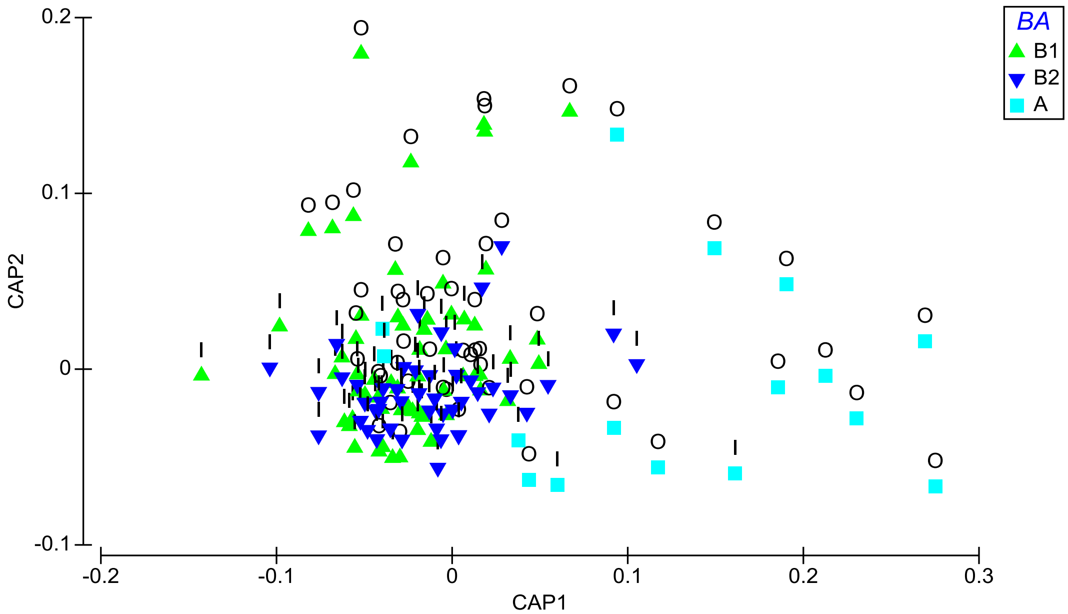


Figure 5.5: Spring survey canonical CAP analysis of the principal coordinates for targeted sets.

Analysis on fourth root transformed, Bray-Curtis similarity resemblance data. Groups were defined by the ordination P<0.001 based on the trace statistic. B1 - n=60 (1996-1999), B2 – before closure, n=47 (2000-2003) and A – after closure, n=16 (2015). I: Inside, O: outside the closed area.

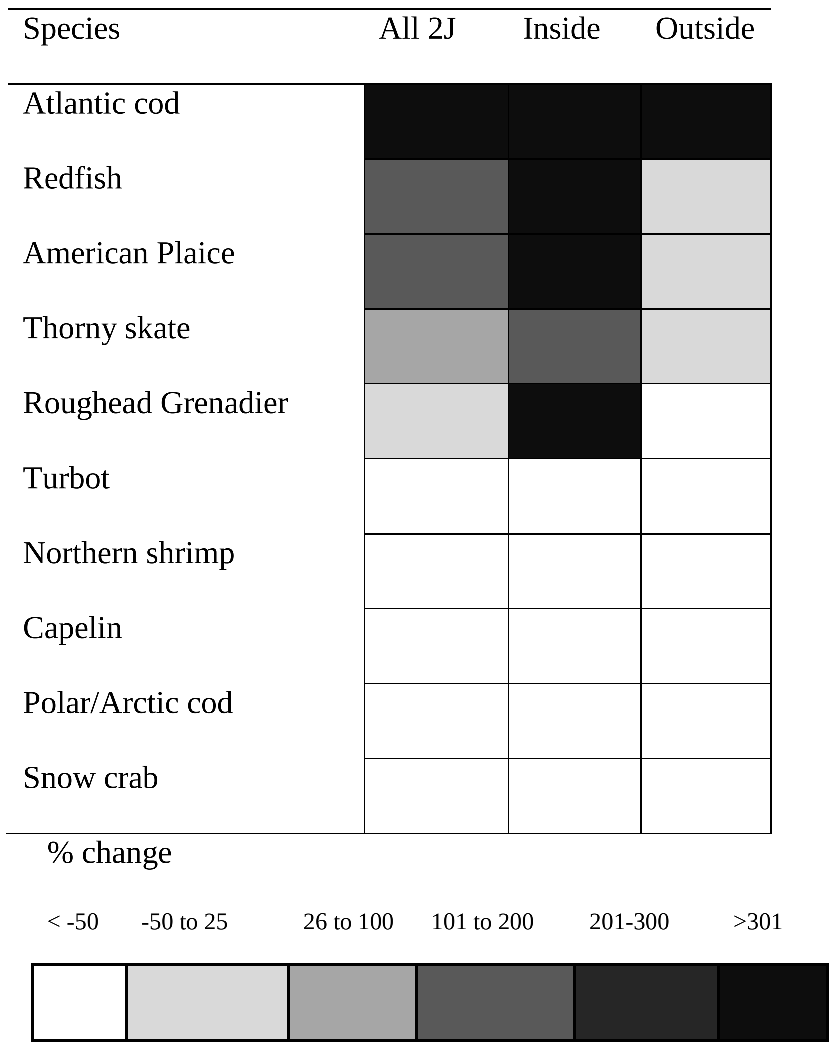


Figure 5.6: Spring survey species biomass changes (relative to pre-closure biomass) for all of the area, inside the Hawke closure only, and outside the Hawke closure only for 2015 data, 12 years post-closure.

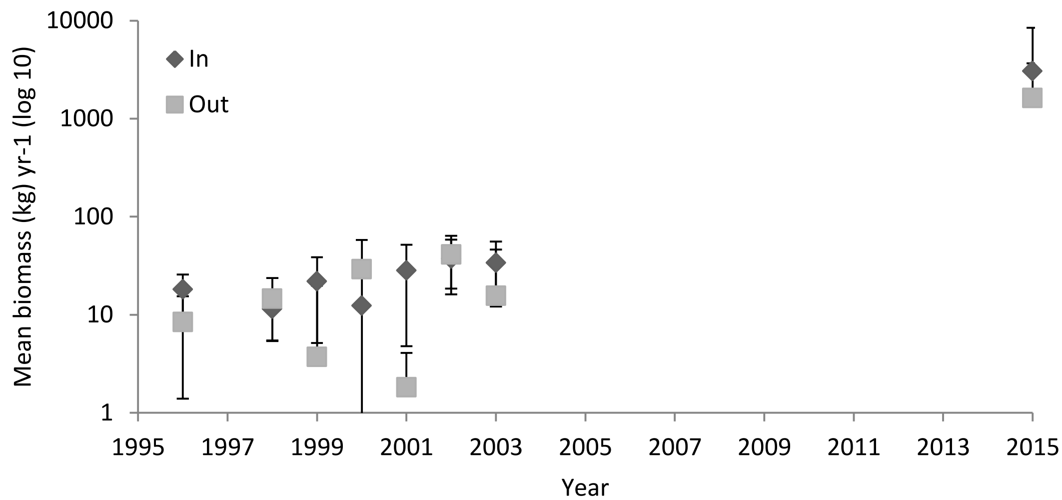


Figure 5.7: Spring survey mean annual cod catch per standardized 15 minute fishing set before-after, inside-outside the Hawke Channel closed area. Cod biomass increased 110-fold from 2003 to 2015 (no surveys in between).

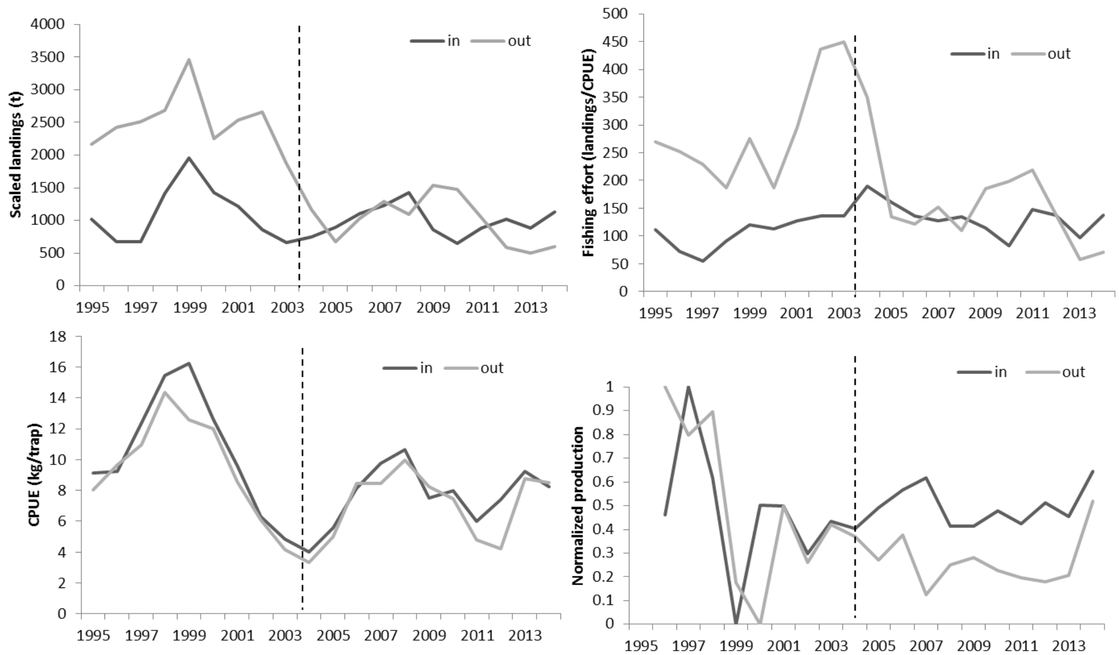


Figure 5.8: Snow Crab fishery data inside and outside the Hawke Box (NAFO 2J), pre (1995-2003) and post (2004-2014) closure. a) normalised landings, b) fishing effort, c) catch per unit effort, CPUE (kg/trap) and d) normalized relative production. * Due to incomplete logbook data scaled landings capture landings to dockside monitored landings. Scaled landings provided by DFO. Note that data for CPUE and landings excludes discard data.

Chapter 6 Conclusion

This study set out to explore the role of marine closed areas in achieving optimal benefits to marine conservation and fisheries under an ecosystem based management approach. Primary objectives were based around EBM principles that included a wider view of multiple species (in contrast to a single species focus) and ecosystems (tropical and temperate examples), including people (local fishers in particular) as a part of the ecosystem. This study also sought to investigate the impact of closures in areas important to both the fisheries industry and for conservation of biological diversity. The increasing calls within policy and literature for the need to meet conservation targets and for fisheries management to consider a wider ecosystem based approach prompts research needs on the role closed areas play and their relative effectiveness within such situations. This thesis provides a contribution towards this research gap. It is no coincidence that this gap was identified not only in the literature but by federal and provincial government scientists and managers, industry and fishers that collaborated under the Canadian Fisheries Research Network (CFRN).

The main findings were summarised within the respective chapters. This section synthesises the main findings for each research question and follows with a discussion of the results and future research applications. The four questions and their related findings are:

1. What closed areas have fisheries and conservation based objectives; how have fishers been involved; and how successful are such areas? (Chapter 2)

    a. Closures of diverse management types and names shared many common traits and outcomes for fisheries and biodiversity conservation.
    b. Fishers were involved in research on many types of closures in a variety of ways, with their involvement often resulting in positive outcomes.
    c. Fishers have been involved in only a small percentage of closed areas, but their involvement appears to have benefitted the achievement of both biological conservation and fisheries management objectives.
    d. The indicator-based scorecard provides an assessment method that can be used as a performance-based assessment of closed areas.
    e. In general, socio-economic indicators were stronger and more evidence-based than were bio-ecological indicators.
    f. A broad range of closures may be able to meet fisheries needs and biodiversity conservation commitments within EBM.

2. What are the drivers for fishers' support of a multiple use MPA? (Chapter 3)
    a. The majority of fishers were supportive of the MPA studied: The majority believed the environment would be worse off without any protection.
    b. An increase in fishing pressure was one driver in fisher support: The majority of fishers were more positive about core zones (no-take fishery closures) than general use zones (areas allowing selective fishing) due to higher fishing

pressures in the general use zones resulting in a higher competition for resources.

c. Fishers that saw a benefit to their livelihood were more supportive of the MPA: Those who reported increased catches and sizes of fish were more likely to agree with present zone locations and more positive in general about fisheries and conservation planning.

d. Different fishing histories played a part in support: Perceptions differed among communities and gear users. This may be partly attributed to different fishing histories.

e. Fisher involvement can lead to more support and fishers often have in-depth ecological knowledge of their fishing area: Fishers provided knowledge on fishery indicators and habitat information for biological surveys, and this method could provide cost-effective data collection in areas with a paucity of biological data and limited capacity to collect it.

3. Why would fishers support a closed area that limits their fishing activity? (Chapter 4)

   a. Local fishers had concerns about biodiversity protection and displayed willingness to reduce their fishing effort: Fishers understood that this could enhance long-term sustainability of livelihoods.

   b. From the perspective of communities and fishers, the Hawke Box closure has been a large success, despite its implementation leading to increased costs in effort and fuel to fish with trawls outside the area: Respondents believed that protecting the area from trawling was the primary reason they still had a viable fishery, despite little improvement in snow crab catches since the closure and their own partial exclusion.

c. All respondents indicated that the closure was beneficial to them, their community, and marine life: This demonstrated commitment, with an intimate spatial and temporal knowledge of the area. 10 years of experience with the closure has led fishers to believe that the future of their communities and livelihoods depends on the existence of this closure. This strong commitment is uncommon, and understanding the aspects leading to such support is vital towards successful fisheries conservation.

4. What spatial and temporal effects has a fishery closure had on marine species in a boreal ecosystem? (Chapter 5)
    a. There have been spatial and temporal changes in species assemblage inside-outside: Likely factors include the removal of trawling and wider ecosystem changes.
    b. Snow crab productivity declined more in the trawling area than inside the closure.
    c. The period of study coincided with a large increase in Atlantic cod throughout the region. As a potential spawning and nursery area, the Hawke Box may be an important site in protecting cod.

d. Benthic species (redfish, American plaice, roughhead grenadier and thorny skate) showed increases inside the closure relative to outside (spring surveys) that may have resulted from the elimination of bottom trawling.
e. The Hawke Box provides a unique reference site as a long-term area closed to trawling within a heavily fished area of the northwest boreal Atlantic.
f. Combined with the strong local support, this fisheries closure would be a worthy candidate for wider EBM that includes wider ecosystem based objectives and management.

An important result of this thesis is that despite the divergent paths fisheries closures and marine protected areas often seem to take, these closures share many common traits (Chapter 2). In addition, fisher involvement can lead to positive outcomes and assist in the collection of biological data that can improve research efficiency and knowledge and reduce costs. Lastly, such involvement can benefit future conservation and fisheries focused research (Chapters 3, 4).

Recommendations from this research are in line with those of Jentoft *et al.* (2012) that the name of an MPA, or any type of closure, can determine what local stakeholders may think about the area. Thus, I recommend that, alongside a widened focus that includes all closed area types as having potential for conservation and fisheries management under

EBM, further clarity be sought among all stakeholders about how the name assigned to a closure relates to its actual objectives.

The addition of the indicator based scorecard to a traditional review method in Chapter 2 provided a basis to assess and systematically track the effectiveness of individual closed areas under EBM. Similar scoring systems are already in place for conservation based MPAs (e.g. Hatziolos 2004) and the use of indicators within marine conservation is well established (e.g. Pomeroy *et al.* 2004). In addition, there was a gap within the literature for such scoring systems that could be applied to a wider spectrum of closure types. With this, and the increasing calls for an EBM approach to closures, the scorecard system developed here provides a contribution to evaluation and indicator based methods that could be useful within closed area management. One issue, raised by Stem *et al.* (2005), is the subjective nature of such scoring systems. Here, this issue was addressed through the use of a rapid systematic review methodology and a full justification system for the scorecard. The methods used here were designed to provide answers to the numerous questions raised about closures from an EBM perspective, fishing industry concerns and areas of importance identified in the literature. Following this wider review, Chapters 3-5 explored different types of closures in different ecosystems that had local fisher involvement to investigate further their role within EBM.

Social and biological survey data were collected from two diverse study areas: one a tropical coral reef fishery in the Indian Ocean (Chapter 3), and the other a boreal deep-sea fishery off Labrador, Canada (Chapters 4 and 5). Both areas featured restrictions on fisheries instigated to a large extent by the local fishers and local management. In these diverse fisheries and regions, several parallels were evident. In both regions, fishers (>90%) believed that sustainability was the major objective, and that their fishery, and their communities, would be much poorer, or gone, without the implemented restrictions they asked for, despite self-imposed limitations on their own actions. Perceived ownership was important. These perceptions were held despite “unintended consequences” of management intervention, such as concentration of fishing effort and lack of significant short-term biological responses. Fishers viewed sustainable fisheries as more than a bio-ecological concept – it was also about sustaining themselves and their communities – and they saw the link very clearly. Support or non-support for particular management measures was also strong but not as unified (e.g. temporal and spatial closures and gear restrictions) depending on social and economic factors related to proximity to fishing grounds, fishing history and gear usage. The perceptions of fishers in these diverse regions have enhanced the effectiveness of management measures intended to result in sustainable fisheries.

Chapter 3 provides an addition to the literature on fishers' perception of a multiple use marine protected area in a traditional fisheries location in the tropics. It is notable that differences in perception between the two communities studied can be partly attributed to different fishing histories and highlights the importance of understanding conditions at local level. In the Mafia Island Marine Park (MIMP) in Tanzania, it was initially a surprise that the majority of fishers were more positive about core zones than general use zones. Further discussions revealed that increased fishing pressure in the general use zones resulted in a higher competition for resources within these areas, thus making them less desirable. Fishers understood that core zones were important to the future of their fisheries. This level of support for higher protection despite the limitations to their own fishing was also present in the local fishing communities that utilize the Hawke Channel (Chapters 4-5). Fishers who saw a benefit to their livelihood were more supportive of the MIMP, a pattern consistent with those reported by Bennett and Dearden (2014) that fishers were unsupportive of MPAs in Thailand due to their perceived lack of benefit from the areas. This information and the acknowledgement of differences in perceptions between groups of fishers will benefit closed area planning and management (e.g. Chuenpagdee *et al.* 2013). Fishers that are more involved and supportive of closed areas are more likely to work together with fisheries managers (as the Hawke Channel fisher groups did in Canada) and conservation management (as fishers in the MIMP did in Tanzania). This is particularly important in areas like the MIMP that have limited capacity for active enforcement. Thus, I conclude that the inclusion of local fishers and their communities in design and implementation of closures whose goals span fisheries management and biological conservation is likely to lead not only to a higher level of compliance but also to greater likelihood of achieving closure goals. McClanahan *et al.* (2006) arrived at similar conclusions based on their work in Indonesia and Papua New Guinea.

In the Hawke Channel closed area, Canada, fishers understood that reducing their own fishing effort could likely enhance long-term sustainability of livelihoods, and the majority believed that fisheries and conservation are compatible goals**.** Further, fishers expressed concern that this area, being a fisheries closure, could be reopened at any time. This fisheries closure plays an important role within an EBM context in this area with local support and evidence that it has wider biological benefits, more than its primary fisheries goal (Chapter 5). Similar to the fishers in Tanzania preferring core closures over general use fishing areas, Hawke Channel fishers believed that protecting the area from trawling and restricting their own fishing grounds were the primary reasons they still had a viable fishery and closure. While research has often concluded that without local stakeholder support, many closures fail to meet their fisheries and biodiversity conservation objectives (Mascia 2003; Klein *et al.* 2008; Pollnac *et al.* 2010), and that closures are indeed complex social-ecological systems (Charles and Wilson 2009), fostering this level of support should be one basis for implementation of fisheries closures.

Despite local support for the Hawke Channel closure, the lack of early biological evidence for success had placed doubt on the effectiveness of the closure to achieve its primary objective of enhancing the sustainability of the snow crab fishery. This and the lack of before-after closed area comparison studies in the region was an important factor in the preparation of Chapter 5. The results presented here highlight the importance of a long-term closed area set within historical and highly used fishing grounds on a boreal continental shelf to identify impacts. This may be especially true in boreal and cold water ecosystems, where reaction times are likely slower than in the better studied tropics. The data and analyses presented here indicate that fish abundance and biomass increased inside the area for many species. The effectiveness of closures on highly migratory commercial species remains controversial (Sweeting & Polunin 2005). However, there are some indications, although speculative, that the Hawke Channel closed area may have benefited the rebuilding of the highly migratory and depleted groups of Atlantic cod in this region.

It is uncertain how closed areas may impact sustainability of fisheries. Largely, this may depend on the definition of sustainability. There is interaction between sustainability of fish and sustainability of fisheries. For example, fisheries will close if biomass is less than the limit, but if a growth strategy (productivity) were used this would not necessarily occur. Closed areas could impact one strategy more than another. For example, in terms of their buffering capacity: do they impact biomass or production (growth)? In these terms, ecological sustainability and fisheries sustainability are hard to separate. Overall, it is recommended that the Hawke Box area remain in place due to its importance from fisheries, biological, scientific and social perspectives. Further, this area could be a starter for wider EBM within the region to meet Canada's goals in sustainable fisheries and long-term conservation through the use of closures. Finally, this thesis has shown that fisheries closures can benefit fisheries and productivity of key commercial species, and in addition assist in meeting the wider goals of biological conservation under EBM.

6.1 Future research

Following from the results in this thesis, future work is needed to better understand how the diverse types of closures and their fisheries can contribute to conservation, and conversely, how MPAs can contribute to fisheries. In addition, further clarity is needed among stakeholders about how the name assigned to a closure relates to its actual objectives. Further work on the scorecard system in chapter 2 could aid in the management of closed areas under EBM. Additional research is recommended that investigates complementary management schemes and how they can be brought together to achieve both the sustainability of fisheries and the conservation of biological diversity.

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Appendix A:

Chapter 2 supplementary material: How fisher-influenced marine closed areas contribute to ecosystem based management: a review and performance indicator scorecard

S1) Search strategy (all years)

Topic=marine, AND fisher or fishermen or "fish harvester" or fisherfolk AND Title=“closed area*”or “real time” or seasonal or temporary or partial or gear or restricted or “multiple-use” or “multiple use” or zones or ”no-take” or “no take” or “no take zone” or park or “marine protected area” or LMMA or “locally managed marine area” or “area closed area” or “fishery closed area” or “marine sanctuary” or “fish conservation area” or “artisanal restricted” or “community fisheries management” or “fish habitat area” or “fishery reserve” or “fish sanctuary” or “fisheries resources protected area” or “fish nursery reserve” or “groundfish clos” or “fishery management zone” or “protected area” or “no take area” or “fishing ban” or “nature reserve” or “fishery restriction” or “marine management area” or “offshore marine protected area” or “special areas of conservation” or “special protection area*” or “marine conservation zone” or “natura 2000” or “live closed areas” or box or MPA or “no trawl” OR “ecosystem-based management” OR “ecosystem approach fisheries”

S2) Extended references

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Appendix B

Chapter 3: Mafia Island Marine Park Fisher Perception Survey

(Note: All questions also allowed comments and discussion)

Background questions: Main Species, Fishery purpose, Gear type used, Area fished, Depth/habitat fished, Period fished (timeframe), Number of years a fisher, Main source of income.

Core Questions:

Q1) Do you think the core zone is…Do you think the specified use zone is…Do you think the general use zone is…

A) Very good, Good, Ok, Bad, Very bad

Q2) What are the closed areas in the MIMP for?

A) Fish, everything, tourism, bottom habitat, government/officials, other

Q3) Have you ever been or are you involved in the MIMP management plan? Have you had any training from MIMP? Have you benefited from the MIMP (received gears, boats etc.)?

A) Y / N

Q4) Have you caught more fish since the MIMP?

A) Y / N/Unsure

Q5) Do you agree with where the zones are?

A) Y / N

Q6) Do you think that the zones should be…

A) Bigger, Stay the same, Smaller, Stopped, Unsure

Q7) What has happened to the ……..… since the MIMP? Size of fish? Numbers of fish? Your Time spent fishing?

A) Increased decreased the same don't know

Q9) How do you agree with…1. permanent closures2. gear restrictions3. size restrictions

A) strongly agree agree neutral disagree strongly disagree

Q10) Why do you fish where you fish?

Q11) Do you think fisheries and marine conservation (marine parks, protecting habitats and fish etc.) go well together?

A) Y / N

Q12) What do you think it would be like today if there was no MIMP?

Appendix C

Chapter 4: Hawke Box fisher perception survey

Fishery closures, fisheries, and marine conservation in Southern Labrador, Canada: The fishers' story.

Contact information: Principle Investigator, Kate Barley (kate.barley@mun.ca)

Date	time	location
Name:		Contact number:
Species fished:		
Fishery:	commercial ☐ recreational ☐ bait ☐ Artisinal ☐	
By-Catch (other species)		
Gear used:		
Depth fished		
Period fished (timeframe)	start end	
Number of years a fisher:		
Main source of income	fishing ☐ other☐	

I am interested in your personal opinions to the following questions, from your experience at sea in the 2J region. I want to know what you think. The first questions will be about the Hawke Channel Closed Area; I will also show you some maps of the area. The second part is about marine conservation and fisheries in general.

HAWKE CHANNEL (HC) CLOSED AREA biological-ecological, step zero, social-economic, change over time)		
1	How much do you know about the Hawke Channel Closure?	Nothing ☐ not much ☐ a little bit ☐ a lot ☐
2	Why do you think the Hawke channel closure was established in the first place?	
3	What is it for?	Cod ☐ all species ☐ Crab ☐ bottom habitat ☐ shrimp, ☐ people ☐ other ☐
"The Hawke Channel box was closed in 2004 (show on map), it was closed to trawling, but remains open to crab fishing".		
4	Were you involved in the establishment of the closed area?	Y☐ N☐
5	Has the closure affected your overall profit?	Y☐ no comment ☐ N☐
6	Do you think that this closed area should be…	Expanded ☐ stay the same ☐ Reduced ☐ unsure ☐ Stopped ☐

7	Can you think back to before the closure in 2004, what do you think has happened to the following stocks (in 2J):	Cod Crab Shrimp	Increased☐ decreased☐ the same☐ don't know☐ Increased☐ decreased☐ the same☐ don't know☐ Increased☐ decreased☐ the same☐ don't know☐
8	What do you think is the main reason of these changes in stocks?		
9	Would you say the HC closure is beneficial…	To you? To the community? To marine life?	Y☐ N☐ Unsure☐ Y☐ N☐ Unsure☐ Y☐ N☐ Unsure☐
MARINE CONSERVATION AND FISHERIES SUSTAINABILITY			
10	Would you consider closing more of your fishing grounds to help protect	Fishing stocks? The habitat?	Y☐ N☐ Unsure☐ Y☐ N☐ Unsure☐
11	Do you think fisheries and marine conservation go together?	Y☐ N☐ Comment:	
12	Do you think of a fishery closure as a type of Marine protected Area (MPA)	Y☐ N☐	
13	For increasing fisheries and for conservation for the future, do you agree on the following management tools?	1.Permanent closures 2.temporary closures 3.seasonal closures 4.gear restrictions 5.catch/size restrictions 6.no trawl areas 7.marine protected areas 8.none	1strongly agree☐ agree☐ neutral☐ disagree☐ strongly disagree☐ 2strongly agree☐ agree☐ neutral☐ disagree☐ strongly disagree☐ 3strongly agree☐ agree☐ neutral☐ disagree☐ strongly disagree☐ 4strongly agree☐ agree☐ neutral☐ disagree☐ strongly disagree☐ 5strongly agree☐ agree☐ neutral☐ disagree☐ strongly disagree☐ 6strongly agree☐ agree☐ neutral☐ disagree☐ strongly disagree☐ 7strongly agree☐ agree☐ neutral☐ disagree☐ strongly disagree☐ 8strongly agree☐ agree☐ neutral☐ disagree☐ strongly disagree☐

		comment	
14	Are there any areas within your fishing grounds that you would consider unique, rare, or significant? (These may be areas that are spawning areas, nursery areas, have high numbers of fish, have lots of different types of fish, pristine, should be protected etc).		
15	What is your proposed solution to sustaining fisheries, marine life, and the habitat for your community? (Video response if willing)		

Debriefing statement

Thank you for taking the time to take part in this survey. The information you have provided will be very helpful in this research. If you would like to withdraw from this research, you can do this now. If there are any specific questions that you would like to withdraw from you can do this now. If there is anything you would like to check or clarify, you can also do this now. If you need to contact me at any time, my information is on your copy of the consent form. Thank you for your time

Appendix D

Chapter 5: Taxonomy for Hawke Channel species

Common name	Species	Genus	Family	Order	Superorder	Subclass	Class
Phylum: Arthropoda; Subphylum: Crustacea							
Snow Crab	*Chionoecetes opilio*	Chionoecetes	Oregoniidae	Decapoda	Eucarida	Eumalacostraca	Malacostraca
Northern shrimp	*Pandalus borealis*	Pandalus	Pandaloidea	Decapoda	Eucarida	Eumalacostraca	Malacostraca
Striped shrimp	*Pandalus montagui*	Pandalus	Pandaloidea	Decapoda	Eucarida	Eumalacostraca	Malacostraca
	Pandalus propinquus	Pandalus	Pandaloidea	Decapoda	Eucarida	Eumalacostraca	Malacostraca
Phylum: Chordata; Subphylum: Vertebrata							
Northern Wolffish	*Anarhichas denticulatus*	Anarhichas	Anarhichadidae	Perciformes	Acanthopterygii	Neopterygii	Actinopterygii
Atlantic Wolffish	*Anarhichas lupus*	Anarhichas	Anarhichadidae	Perciformes	Acanthopterygii	Neopterygii	Actinopterygii
Spotted Wolffish	*Anarhichas minor*	Anarhichas	Anarhichadidae	Perciformes	Acanthopterygii	Neopterygii	Actinopterygii
Blue Antimora, blue hake	*Antimora rostrata*	Antimora	Moridae	Gadiformes	Paracanthopterygii	Neopterygii	Actinopterygii
Polar cod/Arctic cod	*Boreogadus saida*	Boreogadus	Gadidae	Gadiformes	Paracanthopterygii	Neopterygii	Actinopterygii
Atlantic Herring	*Clupea harengus*	Clupea	Clupeidae	Clupeiformes	Clupeomorpha	Neopterygii	Actinopterygii
Roundnose Grenadier	*Coryphaenoides rupestris*	Coryphaenoides	Macrouridae	Gadiformes	Paracanthopterygii	Neopterygii	Actinopterygii
Polar sculpin	*Cottunculus microps*	Cottunculus	Cottidae	Scorpaeniformes	Acanthopterygii	Neopterygii	Actinopterygii
Lumpfish	*Cyclopterus lumpus*	Cyclopterus	Cyclopteridae	Scorpaeniformes	Acanthopterygii	Neopterygii	Actinopterygii
Fouline snakeblenny	*Eumesogrammus praecisus*	Eumeogrammus	Stichaedae	Perciformes	Acanthopterygii	Neopterygii	Actinopterygii
Atlantic cod	*Gadus morhua*	Gadus	Gadidae	Gadiformes	Paracanthopterygii	Neopterygii	Actinopterygii
Greenland cod	*Gadus ogac*	Gadus	Gadidae	Gadiformes	Paracanthopterygii	Neopterygii	Actinopterygii
Witch flounder	*Glyptocephalus cynoglossus*	Glyptocephalus	Pleuronectidae	Pleuronectiformes	Acanthopterygii	Neopterygii	Actinopterygii
Fish doctor	*Gymnelis viridis*	Gymnelis	Zoarcidae	Perciformes	Acanthopterygii	Neopterygii	Actinopterygii
Arctic staghorn sculpin	*Gymnocanthus tricuspis*	Gymnocanthus	Cottidae	Scorpaeniformes	Acanthopterygii	Neopterygii	Actinopterygii
American plaice/dab	*Hoppoglossoides platessoides*	Hippoglossoides	Pleuronectidae	Pleuronectiformes	Acanthopterygii	Neopterygii	Actinopterygii
Spatulate sculpin	*Icelus spatula*	Icelus	Cottidae	Scorpaeniformes	Acanthopterygii	Neopterygii	Actinopterygii
Greater eelpout	*Lycodes esmarki*	Lycodes	Zoarcidae	Perciformes	Acanthopterygii	Neopterygii	Actinopterygii
Arctic eelpout	*Lycodes reticulatus*	Lycodes	Zoarcidae	Perciformes	Acanthopterygii	Neopterygii	Actinopterygii
Roughhead grenadier	*Macrourus berglax*	Macrourus	Macrouidae	Gadiformes	Paracanthopterygii	Neopterygii	Actinopterygii

Capelin	*Mallotus villosus*	Mallotus	Osmeridae	Osmeriformes	Protacanthopterygii	Neopterygii	Actinopterygii
Shorthorn sculpin	*Myoxocephalus scorpius*	Myoxocephalus	Cottidae	Scorpaeniformes	Acanthopterygii	Neopterygii	Actinopterygii
Marlin-spike grenadier	*Nezumia bairdii*	Nezumia	Macrouidae	Gadiformes	Paracanthopterygii	Neopterygii	Actinopterygii
Thorny skate	*Raja radiata*	Raja	Rajidae	Rajiformes	Euselachii	Elasmobranchii	Chondrichthyes
Smooth skate	*Raja senta*	Raja	Rajidae	Rajiformes	Euselachii	Elasmobranchii	Chondrichthyes
Turbot/Greenland halibut	*Reinhardtius hippoglossoides*	Reinharditus	Pleuronectidae	Pleuronectiformes	Acanthopterygii	Neopterygii	Actinopterygii
Golden redfish	*Sebastes marinus*	Sebastes	Sebastidae	Scorpaeniformes	Acanthopterygii	Neopterygii	Actinopterygii
Beaked redfish	*Sebastes mentella*	Sebastes	Sebastidae	Scorpaeniformes	Acanthopterygii	Neopterygii	Actinopterygii
Boa dragonfish	*Stomias boa ferox*	Stomias	Stromiidae	Stomiiformes	Stenopterygii	Neopterygii	Actinopterygii