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Canada's pacific groundfish trawl habitat agreement: A global first in an ecosystem approach to bottom trawl impacts

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ABSTRACT

The impact of bottom trawling to seafloor habitat has been one of the major marine conservation issues over the last two decades. This paper describes the pre-conditions, process, and the first two years of results of a precedent setting ecosystem based management plan to address the habitat impacts of bottom trawling in Canada's Pacific waters. In British Columbia, Canada, industry and conservation organizations worked collaboratively over a period of three years outside of government to develop measures which formally took effect on April 2, 2012. The measures include four main components: (1) ecosystem based trawling boundaries; (2) the world's first habitat quota; (3) an encounter protocol; and (4) formation of a habitat review committee. It is demonstrated that measures implemented have resulted in reduced impacts to sensitive benthic habitat features such as coral and sponge complexes. It is concluded that the conditions required to produce this agreement are not unique to British Columbia, yet that the potential to develop a similar agreement and management reform elsewhere does require a unique set of conditions involving seafood markets, an effective ENGO sector, a strong regulatory environment, intra-industry cooperation, and the proper incentives.

1. Introduction

The peaking of global wild capture fisheries in the mid-1990s brought with it the recognition that many of the world's fisheries were either fully or overfished [42]. Along with the increasing concern about fisheries overexploitation came growing awareness of the impacts of fishing on other aspects of the ecosystem, such as non-targeted species and habitat damage [43]. In the past, fishery regulators had, with few exceptions, given little attention to by-catch and habitat issues.

After the mid-1990s, conservation and research organizations focused increased attention upon fisheries related marine conservation issues, including the development of market based seafood sustainability programs (e.g., Seafood Watch and the Marine Stewardship Council). Environmental non-government organizations (ENGOs) involvement in fisheries related issues led to polarized positions with respect to how, if, and where, fisheries should be conducted.

The impact of bottom trawling to seafloor habitat has been one of the major marine conservation issues over the last two decades. The scientific community has generally agreed that the severity of the impact varies by habitat type and fishing gear being used, with biogenic habitats combined with mobile fishing gears being the most vulnerable [31]. In fishery jurisdictions where habitat protection has been given some consideration, the primary management measure has been to close vulnerable habitats to fishing effort through the use of spatial closures (e.g., [24]. While spatial closures for vulnerable habitats result in direct protection, it also comes with a suite of associated challenges: the full extent of habitats vulnerable to fishing are often not identified, costly to identify, widespread, and variable in size. Enforcement of closed areas can be difficult and their establishment is often opposed to by fishing interests, resulting in a political outcome to a conservation issue.

In British Columbia, Canada, industry and conservation organizations worked collaboratively over a period of three years to

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develop a unique habitat management plan for the groundfish bottom trawl fishery operating in Canada's Pacific waters. The result of this collaboration is the *British Columbia Groundfish Trawl.*

Habitat Conservation Collaboration Agreement, which formally took effect on April 2, 2012. The agreement includes four main components: (1) ecosystem based trawling boundaries; (2) a habitat conservation bycatch limit (HCBL); (3) an encounter protocol; and (4) formation of a habitat review committee. These measures have been implemented through Fisheries and Oceans Canada (DFO) via the fishery's Integrated Fisheries Management Plan [12].

The agreement, at the time of writing, had passed the second anniversary of its implementation, and is now into its third year. Sufficient time has passed since the agreement's inception to allow us to assess the effectiveness of the new measures in achieving the ecological objectives, and to address additional fundamental questions regarding its development, such as how this agreement was possible and whether the agreement is replicable in other parts of the world. This paper describes the development and implementation of this comprehensive habitat management plan, and evaluates the effectiveness after two years of implementation.

1.1. Description of the issue and the regulatory environment

1.1.1. British Columbia's corals and sponges

Corals (Class Anthozoa) and sponges (Phylum Porifera) are abundant throughout the deep and cold waters of the northeastern Pacific. While these sponges and “deep sea” or “cold water” corals may not be as well known as their warm-water counterparts, they are important components of the marine ecosystem.

In the northeastern Pacific, cold water corals stretch from Hawaii to California [14] and northward to the Aleutian Islands [22] and Bering Sea [28]. Canada’s Pacific waters are home to a minimum of 60 [25], and likely over 80 [10] species of cold water coral, including some that form substantial structures, such as those in the families Primnoidae, Paragorgiidae, and Isididae [1]. With rare exceptions, the corals found in British Columbia's waters are ahermatypic (i.e., they do not form reefs), but their colonies may be found growing in close proximity to one another in dense coral “groves” or “forests” [1]. Unlike corals found in warmer and shallower waters, most cold water corals of the northeast Pacific lack symbiotic zooxanthellae [25] and thus may be found well beyond the photic zone, at depths of hundreds to thousands of meters [14].

While there are over 300 species of sponges found in or near Canada's Pacific waters [18], the primary structure-forming taxa are the glass sponges of class Hexactinellida. Among British Columbia's hexactinellid taxa are three that are primarily responsible for building British Columbia's glass sponge reefs (*Aphrocallistes vastus*, *Heterochone calyx*, and *Farrea occa*; [26]), and several others that do not build reefs, but which may develop into large, highly complex individual structures [27].

Much of the ecological importance of corals and sponges is associated with their capacity to create three-dimensional structure. Such structure can modify hydrodynamics near the seafloor and thus affect flows of food and larvae [40], harbor invertebrates that are preyed upon by other invertebrates and fish [28], and provide substrate for egg cases, attachment platforms for sedentary invertebrates, shelter from predators, and energy-conserving refuge from water currents [7]. Recent research from Dixon Entrance [13], the Gulf of Alaska [17], the Aleutian Islands [37], and the Bering Sea [28] highlights the close associations between certain fish species (in these cases, *Sebastes* spp.) and corals and/or sponges.

Bottom-tending fishing gears can damage and destroy cold water corals and sponges and consequently the habitat associations. While fixed gears such as longlines and pots can cause damage [21], it is broadly acknowledged that mobile gears, and in particular bottom trawls and dredges, have the greatest impact [7]. The role of bottom trawling as a primary threat to corals and sponges has been supported through direct observations of trawled areas (e.g., [13,21]), and indirectly, via surveys of fisheries experts’ knowledge [6].

1.1.2. The fishery, the ENGOs, and the issue

Canada's Pacific multispecies groundfish bottom trawl fishery (hereafter referred to as “the fishery”) is a complex fishery, comprising approximately 70 active vessels that target a variety of flatfishes, rockfish (*Sebastes* spp.), thornyheads (*Sebastolobus* spp.), lingcod, pollock, sablefish, dogfish, skate, and Pacific cod [12]. Since 1997, the fleet has operated under a system of Individual Transferrable Quotas (ITQs), which are currently broken down into 58 species/area quota combinations [10]. In 2014 there as a total of 151,000 t of allocation covering most of the marketable species captured in the fishery. In addition there are also allocations for non-marketable species as a means of controlling bycatch (e.g., bocaccio rockfish and Pacific halibut). The fleet receives 100% at-sea observer coverage combined with 100% dockside monitoring of off-loaded catch [12].

Prior to the turn of the 21st century, British Columbia's structure-forming sponges and cold water corals had received relatively scant attention from scientists [1], but research efforts and general awareness of their ecological importance began to increase in the early 2000s. As awareness increased, Canadian ENGOs began criticizing the trawl fishery and its management for the fishery's impacts on corals and sponges in part due to comprehensive at sea observer data recording the capture of habitat forming corals and sponges. The ENGOs’ campaigns included the publication of reports that called attention to the issue, direct research efforts, and a variety of other media and outreach actions [5]. Areas containing three large glass sponge reefs were closed to bottom trawling in 2002, but no further management measures were taken to address the fishery's impacts on corals and sponges [5].

A factor that was likely a significant hindrance to improved management was the lack of a legal or policy mandate for fisheries managers to manage fishing gear impacts on habitat. Canada's *Fisheries Act* is the country's guiding piece of fisheries legislation. In 2004, a federal court ruled that the *Act's* prohibitions against the harmful alteration, disturbance, or destruction of fish habitat did not apply to commercial fisheries [15].

Without the impetus provided by a legal mandate, management of habitat impacts from Canadian fisheries has only recently been considered within a national policy framework. In response to the 2006 United Nations’ Sustainable Fisheries Resolution, DFO released its Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas in 2009 [9], and in 2013 released an accompanying Ecological Risk Assessment Framework (ERAF) *for Cold-water Corals and Sponge Dominated Communities* [10,11]. At the time of this publication, however, the policy, framework, and strategy have yet to be applied to any fishery in Canada.

In 2010, with this science, policy, and advocacy context in the background, and without any signs of immediate government action on the issue, the trawl fishery represented by the Canadian Groundfish Research and Conservation Society (CGRCS) and the Deepsea Trawlers Association, and the ENGOs, represented by the David Suzuki Foundation and Living Oceans Society, initiated informal discussions regarding a mutually acceptable path forward on the issue of trawl damage to corals and sponges.

1.2. Theory: internalizing externalities

Economists are fond of talking about negative “externalities”, where such externalities are costs arising from the activities of given individuals, firms, or industries that are born by others. The catch of corals and sponges by this fishery was a clear example of a negative externality. The damage and destruction of coral and sponges imposed a cost upon society at large, but imposed no recognized costs upon the industry.

The problem, when confronted with negative externalities, is to find ways of "internalizing" them, i.e. of ensuring that these costs do come to be borne by the relevant individuals, firms, or industries. In the case at hand, the solution lay in the fact that the primary market for bottom trawl caught fish from Canada's Pacific waters is along the west coast of North America, and in the policies of most large fish retailers along this corridor. The large retailers have committed themselves to sustainable seafood procurement policies, including the phasing out of seafood products not verified to be from a sustainable source [19]. The threat of lost markets internalized the externality. As a member of the industry commented, "——— we know that in order to maintain and expand market opportunities, we need to provide assurances to environmental organizations, retailers and consumers that we are serious about managing and reducing our impact on ocean ecosystems" [7].

This internalizing of the externality provided the motivation for the industry to engage directly with the relevant ENGOs. The new measures were designed to improve the performance of the fishery against the Seafood Watch methodology for assessing habitat impacts from wild capture fisheries.

The internalizing of the externality, while providing the essential motivation, must be seen as a necessary, but not sufficient, condition for effective collaboration between the CGRCS (representing the groundfish trawl industry participants) and the ENGOs. The CGRCS is not a single corporation, but is rather a collection of independent fishers and processors. Moreover, the 70 vessels in the fleet operate throughout the length and breadth of the waters off British Columbia. In order for there to have been effective collaboration between the CGRCS and the ENGOs, there had to be effective cooperation among the members of the industry. How was this cooperation achieved? The existence of an ITQ scheme, it can be argued, facilitated such cooperation [2]. There is, however, ample evidence that ITQ schemes alone offer no guarantee of effective cooperation in an industry as large as that represented by the CGRCS [2,41]. What is also required is the DFO mandated 100% at-sea observer coverage plus 100% dockside monitoring. The DFO mandated monitoring and enforcement have been, and are, of critical importance for the achievement of stable intra-industry cooperation as each individual's activity is accountable.[1]

[1] To provide support for the assertion, one has to turn to the widely used theory of strategic interaction, more popularly referred to as the theory of games. The intra-industry cooperation can be seen as a cooperative game. It is well known that the larger the number of "agents" in such a game, the more difficult it is to achieve stable cooperation, because of the chronic threat of "free riding" – "agents" who defect and enjoy, free of charge, the benefits arising from the efforts of those who continue to cooperate [4]. This is a major issue in international fisheries, in attempts, for example, to achieve resource management cooperation through RFMOs. A key reason for this difficulty is that international cooperative fisheries management arrangements have to be self-enforcing [4,36]. That is to say, there exists no "third party" to which the "agents" can turn for assistance in suppressing free riding. In the case of intra-EEZ fisheries cooperative games, by way of stark contrast, there do exists potential "third parties" in the form of resource managers. With respect to the cooperative game, DFO acts as a very effective "third party". For an in-depth discussion of this issue, as it pertains to the CGRCS [30].

2. Process for negotiating measures

2.1. Creating a collaborative environment

The conservation measures were developed outside any formal government process. Therefore clear conservation and industry objectives and ground rules for structuring the process were needed. The primary shared conservation objective was to achieve a "yellow" habitat score, or better, under the Monterey Bay Aquarium's Seafood Watch methodology [38] for the fleet's entire operations. The Seafood Watch habitat ranking is developed by evaluating the combination of gear type (i.e., bottom trawl) with habitat sensitivity and mitigation measures. Under this methodology a fleet is "guilty until proven innocent"; therefore, a bottom trawl operating in a fishing area encompassing sensitive habitats starts off in a default "red" position and needs to have demonstrable mitigation measures in order to ascend to a higher ranking. Potential mitigation measures include spatial protection of vulnerable habitats with effective ecosystem representation in closed areas, effort reduction, and gear modification.

There was a shared socio-economic objective, in that new measures could not cause a severe disproportionate impact any single individual in the fleet. As the fleet has evolved through 15 years of transferrable quotas, certain license holders have traded their multispecies quota holding to specialize in an area, depth strata, or a particular assemblage of species. Consequently, negotiated mitigation measures had to take this into consideration.

Additionally, the process had to be based on reliable information and data. To achieve this objective, the information needs were coordinated through DFO, which acted as an information broker, supplying data requests in a timely manner. This included catch data, spatial data, and a variety of other requests.

2.2. Developing the habitat conservation measures

2.2.1. Ecosystem-based trawling boundaries

The first component of the collaboration was to establish ecosystem-based spatial boundaries for the bottom trawl fleet. Mapping and analysis were crucial to this effort. As the work needed to be transparent and trusted by both parties, spatial data were made available to the ENGOs by DFO, and analyses were undertaken by both DFO and the ENGOs. All results were shared and discussed with all parties.

Data depicting the spatial extent of fishing effort were provided by DFO; these data were based on an accepted model that represents the tow location with a vector between the start and end positions and a grid size of 1 km^2 [39]. In recent years, tow midpoints have also been included in the analyses. Habitat types were identified based on surficial geology, marine ecosections [29], and 200 m depth classes to 1500 m for a total of 206 habitat combinations.

The initial objectives for the boundaries were to prevent further spatial expansion of the fishery, exclude areas of historically high coral and sponge bycatch, ensure that the area opened to bottom trawling did not disproportionately impact any single habitat type with an objective of having $\geq 50\%$ of the area of each identified habitat type closed to bottom trawling, and reduce to the extent possible trawling in waters deeper than 800 m. The 50% representative habitat goal was based on the Seafood Watch methodology, which defines strong habitat mitigation as protecting $\geq 50\%$ of the representative habitat from the gear type used in the fishery under assessment [38]; this standard is based on Auster [3]. Statistics quantifying the overlap of historical bottom trawl locations and alternate boundaries with numerous data layers were repeatedly generated throughout the iterative boundary development process. ModelBuilder in ArcMAP 9.3 was used to facilitate the analyses.

It was decided that habitat types smaller than 100 km^2 would be excluded from the analyses, as the spatial resolution of the data for the habitat data sets was larger than 100 km^2; this reduced the number of habitat types to 78. The historical (1996–2011) spatial trawl effort (or "footprint") was overlaid with these 78 habitat combinations, and further compared to a variety of additional data layers including: habitat complexity (rugosity), areas of known coral and sponge catch from fishery data and fisheries independent survey data (DFO), and modeled coral habitat [16]. For data layers that overlapped with the trawl footprint (i.e., depth classes, ecosections, benthic classes, and rugosity), the area in km^2 of each benthic class or "habitat type" that coincided with the historic trawl footprint and area outside the footprint was quantified. In addition, two types of areas at risk to future habitat damage were identified and mapped where they remained within the allowable trawling boundary. These two types of areas include (1) 12 indentified sub-areas of historical high rates of coral and sponge encounters ("high risk" areas), and (2) previously untrawled areas remaining within the allowable trawling boundary.

The development of the allowable trawling area boundary was an iterative process that included multiple rounds of in-depth consultations within and between the negotiating organizations, and subsequent revision and re-analysis of proposed boundaries.

2.2.2. Habitat conservation bycatch limit

The second measure was the establishment of the "Habitat Conservation Bycatch Limit" (HCBL), which places fleet-wide and individual vessel limits on coral and sponge catch. The fishery's existing quota management system and 100% at-sea observer program provided both the data needed to develop the HCBL and the operational infrastructure by which the HCBL could be implemented.

Since 1997, the bottom trawl fleet has operated under a system of individual transferrable quotas, which now totals 58 species-area combinations [12]. At-sea observers are present for 100% of all trawl trips and are responsible for enumerating the catch of all species, including all retained and released catch of both directed (quota species) and non-directed species. Non-directed catch has always included estimates of coral and sponge catch, and therefore DFO was able to provide detailed historical coral and sponge catch statistics. Between 1997 and 2009, the annual fleet-wide catches of corals and sponges combined ranged from 0.9 to 102 t, with an average of 25.4 t. The lowest year was in 2009, at 884 kg. This value was adopted as the management target level for maximum coral and sponge catch, and the HCBL was then developed with this management target in mind.

For operational reasons, it was not possible to derive the individual allocation simply divide up the management target of 884 kg via the existing quota vessel allocation formula; each vessel would have received a prohibitively small amount of HCBL, with the smallest quota holder starting with 1 kg of HCBL and the largest quota holder (who would hold approximately 2000 t of bottom trawl groundfish quota) receiving only 30 kg of HCBL. In such a situation, there would be insufficient HCBL made available by others in the fleet to cover even a moderate encounter, and a single unforeseen large catch of corals and sponges could even exceed the total fleet-wide HCBL (i.e., 884 kg). This latter example was within the realm of possibility; for example, in the year prior to these new measures, there was a single tow which caught 1100 kg of coral. For these reasons, the risks to industry that would have existed if the management target had simply been divided by the existing quota allocation formula were too significant for this option to be considered.

The habitat quota was thus designed to balance the need for a disincentive to capture corals and sponges with the requirement of the fleet to have some flexibility in the event of a mistake. Ultimately it was agreed to by both parties that a combined coral and sponge HCBL of 4500 kg would meet this objective, while the management target (884 kg) remained the upper limit that the measures strived to achieve.

2.2.3. Encounter protocol

The third measure was the development of an encounter protocol. An encounter protocol is a set of defined management steps that are followed when a fishing vessel encounters pre-established indicators of a vulnerable marine ecosystem [8]. Encounter protocols have been identified as important tools for the management of fisheries' interactions with vulnerable marine ecosystems, and are a component of Canada's international commitments [8]. Thus, for this effort, an encounter protocol was developed for the event of a large catch of corals and sponges in a single tow. The purpose of the protocol is to both inform the fleet of a potential high-risk area within the boundary and to identify areas for potential removal from the allowable trawl boundary.

Based on historical coral and sponge catch frequencies binned into 20 kg classes, it was found that only 7% of all sponge encounters and 5.5% of coral encounters from 2005 to 2009 were greater than 20 kg (data provided by DFO). A catch level of 20 kg of coral and sponge combined caught in one tow was adopted as the threshold amount that would trigger a series of actions, including enhanced data collection by the on-board observer and an alert sent to notify the fleet of the location of the encounter.

2.2.4. Implementation

The measures that were developed in this process were implemented via the fishery's official management plan on April 2, 2012. Sufficient time has passed since implementation to analyze their effect on the spatial distribution of fishing effort, and to evaluate the efficacy of these measures relative to stated management objectives.

3. Methods for evaluating the measures

3.1. Effect of trawl boundary and habitat quota on trawling effort

To characterize the effect of the trawl boundaries and the habitat quota on the spatial distribution of fishing effort, the location of all individual bottom trawl tows between April 2, 2012 and Feb. 21, 2014 were mapped using methods described in Section 2.2.1. The trawl tow locations were mapped to examine boundary infractions, effort by representative habitat type, and changes in behavior based on historical patterns of trawling. Fishing effort during this period relative to or overlapping with the 12 "high risk" areas was mapped (see Section 2.2 above). It should be noted that the high risk areas (Fig. 1) are based on catches recorded from trawl tows which may be many kilometers long and therefore the precise location of the coral and sponge interaction along these tows cannot be identified through the data.

3.2. Interaction with coral and sponges

Aggregated observer data on the interactions of coral and sponges on a tow by tow basis were provided by DFO from 1997 to 2014 to examine whether the total coral and sponge catch, mean catch weight of a coral and sponge interaction (kg/tow), and frequency of large tows (> 20 kg) had changed with the implementation of the HCBL.

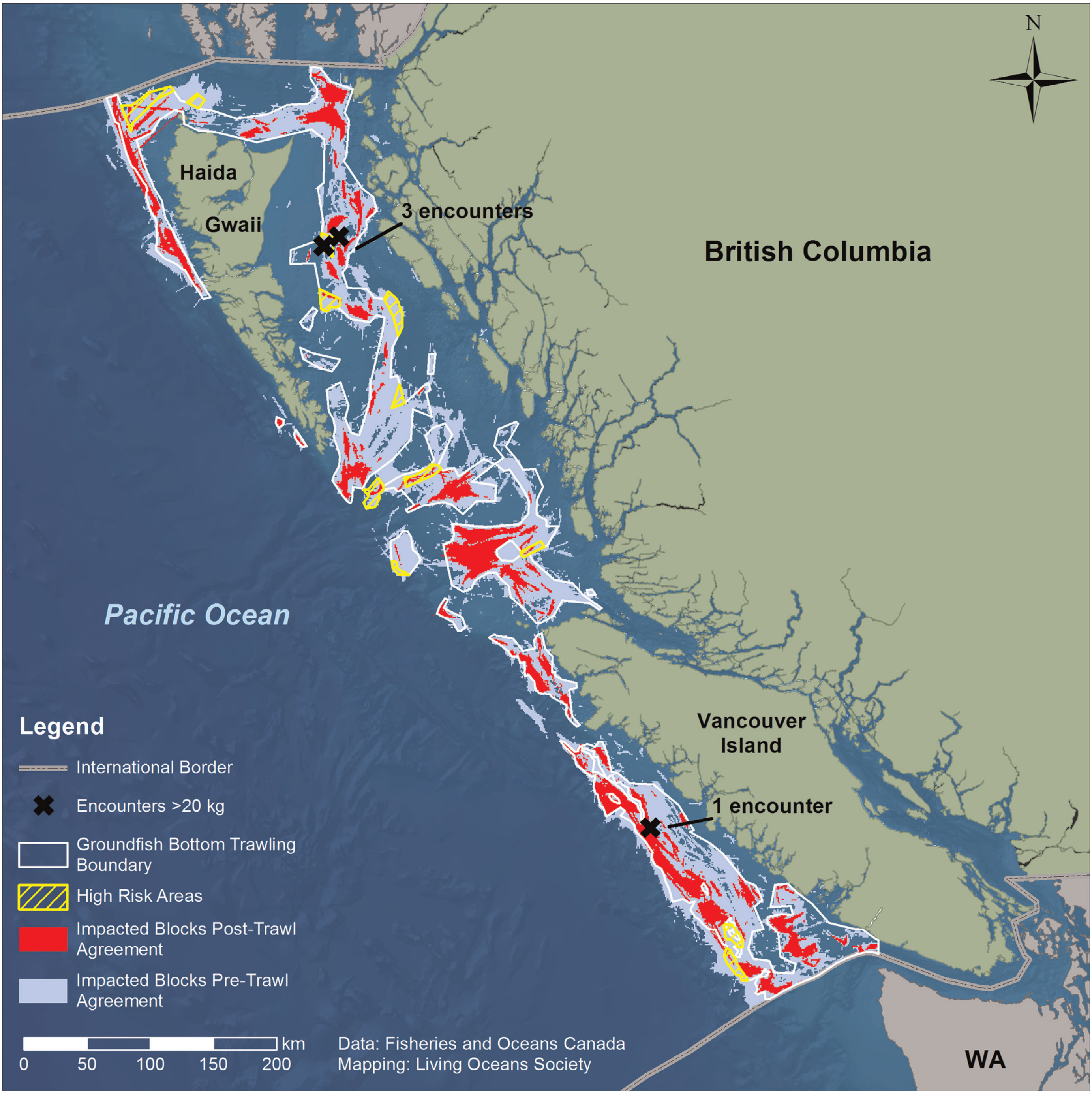

Fig. 1. Map showing historical area trawled from 1996 to 2011 (light blue), negotiated groundfish bottom trawling boundary, area bottom trawled in the two fishing years since the agreement, location of encounters greater than 20 kg (**x**), and identified high coral and sponge areas (yellow) (Source: Living Oceans Society). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. Results

4.1. Allowable trawling area boundary and habitat representation in closed vs. open area

The negotiated allowable trawling area comprises 19 polygons made up of 537 coordinates. The resulting area open to bottom trawling (31,628 km^2) is 21.9% (8846 km^2) less than the historically trawled area (Fig. 1).

To understand the historical distribution of trawling relative to the 78 identified habitat types an analysis of the total trawled area from 1996 to 2011 (i.e., before the agreement) found that trawling historically occurred in $>50\%$ of the area for 32 of 78 identified habitat types. The negotiated boundary resulting from the agreement removed some previously trawled areas from the allowable trawling area, to reduce the number of habitat types exceeding the 50% trawled threshold to 22 of 78 habitat types. The focus of the negotiated boundary was on habitat types that are considered less resilient to trawling impacts. Of the 22 habitat types demonstrated to have an area more than 50% accessible to bottom trawling remaining within the negotiated allowable trawling area, most were found to be (i) very close to the 50% goal, (ii) were considered to be a resilient habitat type as defined by [38], and/or (iii) had received very little or no trawling effort in the five years prior to

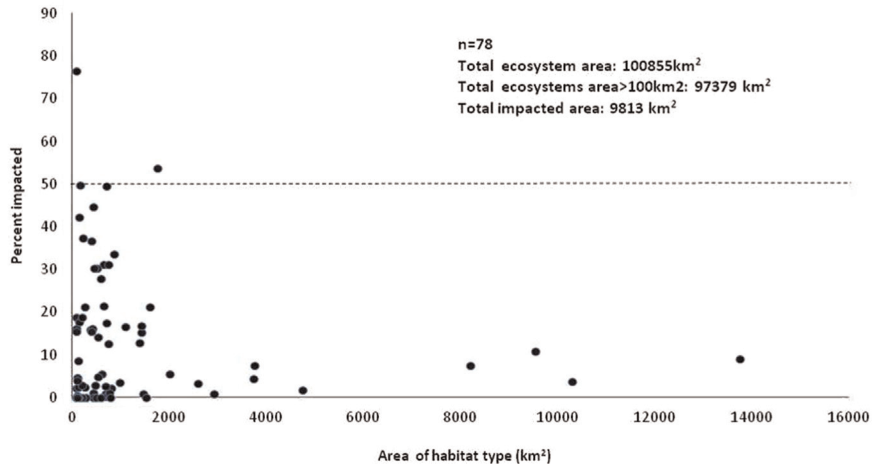

Fig. 2. Proportion trawled and total coastwide area of the 78 representative habitat types impacted by the BC groundfish bottom trawl fleet April 2, 2012–February 22, 2014. The dashed line represents the target protection level.

establishing the boundary.

Additional effort was made to protect much more than 50% of the deep sea habitat types that are believed to be particularly sensitive to trawl impacts. These habitats are found between 800 and 1500 m and in total comprise 9289 km^2 coast-wide. Analysis showed that 37% (3437 km^2) of this area had historically been bottom trawled. The final boundary resulted in the removal of 2368 km^2 of previously trawled deep-sea habitat from the allowable trawling area, which left 88% of the total coast-wide 800–1500 m depth stratum being permanently placed outside of the allowable trawling boundary.

From the implementation of these measures on April 2, 2012 through February 2014, the total area trawled was 9813 km^2. An analysis of the area trawled by habitat type has identified 2 remaining habitat types (out of 78 total habitat types) that continue to have trawling effort covering more than 50% of their total coast-wide areal extent (Fig. 2). These two habitat types are found at depths of 200–600 m on substrates representative of sandy flat continental slope habitat, which historically has been the most trawled habitat type. During the negotiation of the boundary, industry agreed to the removal of approximately 1000 km^2 of additional continental slope habitat from the allowable trawl area in order to come closer to the 50% objective. Although 64% of the total continental slope habitat (which includes all substrate types not just sandy bottoms) between the depths of 200 and 600 m remains within the trawling boundary, the actual proportion trawled since 2012 has only been 36%. Effort in these habitat types continue to be monitored.

4.2. Coral and sponge interactions in the fishery

In the three years since the inception of the HCBL (the fishing years for 2012, 2013, and 2014), total fleet-wide at-sea observed catches of corals and sponges have been 500 kg, 280 kg, and 270 kg, respectively (at the time of writing, data for 2014 are preliminary). These values are the lowest recorded in the 17-year data set, and are well below the management maximum target level (884 kg). Over this period, the maximum single tow catch of combined coral/sponge was 45 kg, and the mean weight of corals and sponges per interaction was 1.3 kg/interaction, with the second year having a mean of 0.9 kg/interaction (note that the vast majority of tows do not have a coral or sponge interaction). The encounter protocol (i.e., tows > 20 kg) has been triggered four times over these two years; all of these occurrences happened within the first two months of the program, and three of these events occurred in a single day due to three tows with excessive coral and sponge catch by one vessel at the same location. During the second year of fishing under the new measures (2013), the largest recorded catch of combined corals and sponges in one tow was 6.7 kg.

4.3. Change in fleet behavior post-agreement

Despite the awkward shape, compliance to the trawl fishery boundary has not been a problem, with only four boundary infractions over 21,925 tows, all incurred by one vessel on one trip. Not enough time has passed to verify whether the HCBL has changed fishing practices in relation to the 12 ‘high-risk’ zones. The total area of all 12 high-risk zones is 1245 km^2 (see Section 2.2A above). In the years before the measures were put in place (1996–2011), trawling occurred in all 12 of these zones and over 91% of the available area. Since the measures have been in place, the total area trawled within these zones is 14% of the total area; five of the 12 areas have not been trawled at all, two areas have been trawled but have not resulted in any coral or sponge catch, and five areas have continued to be fished and have encountered small quantities of coral and sponges in 37% of the tows. If this pattern of fishing effort continues, then it is likely that the HCBL is modifying the behavior of the fleet.

5. Discussion

5.1. Discussion of conservation outcomes

The joint ENGO/industry effort defined in this paper resulted in the implementation of a suite of management measures meant to reduce and manage the trawl fishery's impacts on corals, sponges, and other sensitive benthic habitats. These measures consist of fleet-wide and individual vessel limits on coral and sponge catch, the definition and enforcement of the area allowed to be fished with bottom trawl gear, and the implementation of an encounter protocol that is followed when a trawl tow catches more than 20 kg of combined coral and sponge. Results from the first two years of this program suggest that a co-created solution for habitat protection offers an effective approach for achieving conservation outcomes. In this discussion the results to date are reviewed and the questions of how this agreement was achieved, and whether it is replicable in other jurisdictions, are addressed.

While the freezing and shrinking of the British Columbia trawl fishery's footprint is a key aspect of an overall strategy to manage and reduce habitat impacts both outside and inside of traditionally trawled areas, it is not a unique management measure by itself. On the Pacific coast of North America, trawl closures are used to protect areas of seafloor from bottom trawling and/or to prevent expansion of trawling in Alaska [32–35] and the U.S. west coast [35], for example. These jurisdictions also have measures to reduce some impacts of trawling within open areas, as well, in the form of limitations on footrope diameter in the U.S. west coast [35] and mandatory gear modifications in Alaskan flatfish trawl fisheries [32,35].

Conversely, at the time of this writing, the authors are unaware of any other fishery jurisdiction that has implemented individual vessel quotas as a tool to manage habitat impacts. The idea has been proposed in the literature: Holland and Schnier [23] modeled the use of individual transferable quotas, derived from a proxy for marginal habitat damage (e.g., the area contacted by the gear), to achieve habitat management objectives. Their model suggested that quota-based approaches may achieve habitat management objectives with greater cost-effectiveness than permanent closures, but that this result is sensitive to the characteristics of the targeted fish species [23].

The HCBL was implemented with the goal of reducing coral and sponge interactions within the allowable trawling area. However, this was not the first management action to reduce sponge catch. In 2003 the DFO implemented large closures encompassing known sponge reefs that drastically reduced the mean catch weight of coral and sponge interactions and the frequency of such interactions. Prior to the closure of these reefs, permissible fishing in those areas resulted in enormous catches of combined sponges and corals, with a single maximum interaction of 11,250 kg and a coastwide mean of 73.8 kg of corals and sponges per interaction. Between 2003 and 2012 (i.e., prior to the 2012 habitat conservation measures discussed in this paper, and after the sponge reef closures), coral and sponge interactions were characterized by several moderate to large interactions and many smaller interactions, with a maximum single-tow recorded catch of 2085 kg and a mean interaction of 9.2 kg/interaction. Since the new measures, the maximum single tow catch of combined coral/sponge has been 45 kg and the mean is 1.3 kg/interaction, with the second year having a mean of 0.9 kg/interaction. The mean and maximum catch/interaction have thus decreased by roughly two orders of magnitude relative to pre-2003 levels.

5.2. Discussion of economic factors

Although there was no indication of any significant spatial expansion by the British Columbia fleet in the decade prior to the agreement, establishing boundaries and reducing the area open to trawling achieved the important function of “freezing the footprint” to ensure that previously unfished areas would not be accessed in the future due to either technological innovation or market opportunities. Freezing the footprint for the British Columbia trawl fishery also helped with the goal of managing bottom trawling based on representative habitats. As the boundary was developed areas of recent low effort were taken out of the allowable trawling area, thereby assisting in achieving the ecological representivity goals.

Although fishing within a boundary was a new concept for the fishing industry, in reality it did not change much on the ground since the fleet had not been expanding in recent years and the most valuable areas for fishing were maintained in the boundary. In addition, the deep sea fishery was increasingly less profitable in the years prior to the agreement resulting in much less effort and consequently no immediate economic impact. In total 22% of the historically trawled area, primarily economically less important to the fleet or well known sensitive areas, were removed from the footprint, which helped achieve the ecosystem representation targets.

Despite the fleet being restricted to a defined area, the allowable trawling area still includes several known sensitive coral and sponge habitats, and likely unknown ones as well. During the negotiation of the agreement, the ENGO parties argued for these known areas to be removed from the allowable area, but the trawl industry was concerned that the identified high risk areas, such as the 12 shown in Fig. 1, were much larger than the actual habitat attribute due to the fact that the indentified location was based on observed catch information and research trawl surveys that only had the resolution of an entire trawl tow (which are sometimes up to 15 km in length). Agreeing not to remove these areas from the footprint required alternative mitigation measures. Mitigating impact to these areas and other unidentified sensitive habitats was achieved through the HCBL and encounter protocol. The creation of the HCBL was designed to give the industry the flexibility they needed to fish in the proximity of coral and sponge features but also restrictive enough to entrench a concern amongst the skippers to be cognizant of these habitat types on a tow by tow basis. The risk presented by encountering these habitats and exceeding their individual allocation is significant, as it could possibly prevent them from fishing their target species, or, if they used their entire HCBL quota, result in their vessel being tied to the dock until they could acquire sufficient quota, through purchasing or annual reallocations to address their overage. In this way, the HCBL is a tool by which individual captains’ extensive knowledge of coral and sponge locations and their individual abilities to maneuver the fishing gear have been mobilized on a tow-by-tow basis, due to the self-interest-based incentive to avoid coral and sponge catch. The analysis presented here suggests that such self-interest-driven avoidance of coral and sponge can lead to significant reductions in total coral and sponge catch for the entire fleet.

However, a risk inherent in the use of quotas to protect corals and sponges is the theoretical possibility that a situation-specific cost-benefit comparison for an individual vessel may, under certain circumstances, support trawling in an area known to present a high risk of coral and sponge catch. This is a risk that is not present in a well enforced closure-based approach to coral and sponge protection. As new data become available, additional analysis of the consistency of high-risk area avoidance will be necessary to ascertain the degree to which the disincentive posed by the HCBL is constant over time and across multiple fishing trips undertaken by multiple actors.

The fleet-wide 4500 kg annual HCBL is now allocated annually in a manner similar to targeted fish species quotas, where 90% of the overall TAC is divided amongst the license holders and 10% (450 kg) is kept in reserve by the Groundfish Development Authority, a structure within the management system that addresses overall industry objectives related to processing and coastal community stability through maintaining some unallocated quota. The 90% is allocated annually amongst licensees such that in year one of the program, the largest holder was allocated 141 kg and the mean starting HCBL allocation was 74 kg/vessel. A carry-forward of up to 10% of the unused quota into the subsequent fishing year is permitted, which is less than the 30% typically allowed for marketable species. During the period of the negotiation of the HCBL a vessel encountered a single tow of 1100 kg of sponges, an amount that would result in a vessel being unlikely to acquire enough quota from other holders to cover their overage and get back out on the water if it occurred today. It was these types of large encounters that both industry and the ENGOs wanted to prevent through the use of the bycatch limit. With the exception of four encounters over 20 kg near the beginning of the program, the fleet has not had any large tows of corals and sponges.

For the BC trawl fishery, the management cost of implementing another quota species was almost negligible as there were already 56 area-species quotas at the time of negotiating the agreement (now at 58). Whether there has been an economic cost (e.g., decreased CPUE) or benefit (e.g., improved market access or healthier stocks) to individual vessels is not yet possible to ascertain due to the complex interaction of ecological and economic variables influencing each vessel's operation. It is worth reiterating that the measures were designed with economic viability of all participants as an objective. Costs associated with the quota management system are borne by the fleet itself. This includes the full cost of on-board observers, the potential costs associated with avoiding sensitive areas, and absorbing the risk of making a mistake. This is therefore an example of an industry internalizing what had previously been a particularly notable environmental externality.

5.3. How repeatable is this approach?

The success of the agreement in achieving the conservation objectives provokes the question of whether this approach is repeatable elsewhere, or whether the necessary conditions were unique to the British Columbia context.

In addition to data requirements described throughout this paper that provided the information basis for co-creating a solution, the next requirement is that there are ENGOs or other external organizations capable of bringing effective pressure upon the relevant fishing industry. The second requirement is that the industry be capable of entering into serious negotiations with the ENGO(s). That second requirement will not be met unless there is, in turn, effective and stable intra-industry cooperation and the leadership to harness that cooperation.

The ability of ENGOs to bring effective pressure upon the fishing industry has been enhanced in recent years through widespread North American and European seafood retailer commitments to procure seafood that have addressed the primary conservation concerns. In the present example of the BC bottom trawl fleet, they receive the best value for their products as a fresh product into markets along the west coast of the United States an area of regionally high consumer awareness and demand for sustainable seafood products [Monterey Bay Aquarium, unpublished results]. When many of the major buyers of BC trawl caught seafood committed to time-bound procurement policies, the industry had no option but to resolve remaining conservation issues.

The retailers' policies often commit to some form of third party evaluation using established criteria such as those used by Seafood Watch or the Marine Stewardship Council. These criteria carry the function of coordinating a common a goal that both ENGOs and industry can figure out the most effective way to reach it. In this particular case, the habitat criteria of the Seafood Watch criteria played this critical role.

The second requirement of an industry capable of entering into negotiations requires conditions that are not a given for all fisheries. Similar experiences of bycatch avoidance schemes, based on intra-industry cooperation, are not unknown in other parts of the world.[2] Having said this, no by-catch avoidance scheme exists that matches that in British Columbia, in terms of magnitude. In many ways the BC trawl industry is an 'avoidance' fishery designed around individual vessels trying to maintain their 58 species-area quota allocations through avoiding the capture of allocations given in very small amounts designed to primarily limit the capture.

It must be re-emphasized that the British Columbia groundfish trawl industry is not a single corporation, but is rather a collection of a large number of fishermen, with vessels operating throughout the extensive waters off Canada's Pacific coast. Based on historical examples, under these circumstances, attempts to achieve stable intra-fishing industry cooperation should have been doomed to failure.[3]

Experience with attempted fisheries cooperation at the international level points to the ongoing and chronic threat of free riding as proximate cause for failure in these situations. At the international level, curbing free riding is made difficult by virtue of the fact that such cooperative arrangements must be self-enforcing, in that there exists no "third party" to provide support and assistance.[4]

What the British Columbia groundfish trawl experience reveals is the fact that in intra-EEZ fisheries cooperative fisheries arrangements among industry members do not have to be self-enforcing. There exists a potential "third party" in the form of the resource manager.[5] In the British Columbia groundfish trawl fishery, DFO plays the "third party" role with great effectiveness through in part the requirement of at-sea observers aboard all vessels and the information collected from this arrangement. Globally, only a small fraction of fisheries have created the management and data infrastructure to manage based on individual accountability.

From this the following can be inferred with regards to attempts to replicate the British Columbia groundfish trawl fishery agreement. If the relationship between the resource manager and the fishing industry is such that the cooperative arrangements among the members of the industry must be self-enforcing, then, even with the presence of influential ENGOs attempts to replicate the agreement in full will have limited success. The resource manager must be capable of taking, and must be willing to take, the critical "third party" role and have the appropriate infrastructure backing it up.[6]

It is interesting to explore what elements of this co-created solution are essential in order to understand the possibility for similar arrangements in data poor situations. It is the opinion of the authors that in data poor situations, the critical requirement is self-enforcement among cooperating fishermen in turn leading to cooperation between the industry and ENGOs. For this to occur, strong leadership and a level of social cohesion would need to exist [20]. It is unlikely that self-enforcement could occur over large geographical scales such as the British Columbia coastline. Providing that some form of self-enforcing cooperative arrangement is achieved, processes leading to better information gathering and subsequent conservation measures may be possible.

6. Conclusions

This paper describes the pre-conditions, process, and results of a precedent setting ecosystem based management plan to address the habitat impacts of bottom trawling in Canada's Pacific waters. This plan was developed through a negotiated agreement between the fishing industry and ENGOs in British Columbia and then brought to the regulator, the DFO, to implement through the

[2] One example is provided, the yellowtail flounder bycatch avoidance scheme in the New England scallop fishery [34].

[3] See for example [41].

[4] See: n. 1.

[5] While this fact is obvious upon stating, one searches in vain in the published literature for references to it.

[6] In the case of the New England scallop fishery, the resource manager does not, apparently, fill this "third party" role effectively (Daniel Georgianna, personal communication). The area covered by the yellowtail flounder by catch avoidance scheme is small, in comparison with the British Columbia scheme, small enough that the industry members can effectively monitor one another.

Integrated Fisheries Management Plan. In this paper it is demonstrated that the Agreement brought about habitat measures leading to strong conservation outcomes in a timely manner that met the conservation objectives of the ENGOs, the management and policy goals of DFO, and the criteria of Seafood Watch for market recognition. This collaborative model provides an alternative to more traditional approaches such as lobbying for policy development and implementation. It is shown that measures implemented have resulted in an immediate change to fishers' behaviors and consequently reduced impacts to sensitive benthic habitat features such as coral and sponge complexes. It is concluded that the conditions required to produce this agreement are not unique to British Columbia, yet that the potential to develop a similar agreement and management reform elsewhere does require a set of conditions involving seafood markets, an effective ENGO sector, a strong regulatory environment, intra-industry cooperation, and the proper incentives.

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References

[1] J.A. Ardron, G.S. Jamieson. Reducing Bycatch of Corals and Sponges in British Columbia's Groundfish Trawl Fishery Through Trawl Fishery Closures (Research Document No. 2006/061). Canadian Science Advisory Secretariat, 2006.
[2] R. Arnason, Property rights in fisheries: How much can individual transferable quotas accomplish? Review of Environmental Economics and Policy 6 (2012) 217–236.
[3] P. Auster, Defining thresholds for precautionary habitat management actions in a fisheries context, N. Am. J. Fish. Manag. 21 (2001) 1–9.
[4] M. Bailey, U.R. Sumaila, M. Lindroos, Application of game theory to fisheries over three decades, Fisheries Research 46 (2010) 804–878.
[5] J.S. Campbell, J.M. Simms, Status report on coral and sponge conservation in Canada, Fish. Oceans Can. (2009).
[6] R. Chuenpagdee, L.E. Morgan, S.A. Maxwell, E.A. Norse, D. Pauly, Shifting gears: assesing collateral impacts of fishing methods in US waters, Front. Ecol. Environ. 1 (10) (2003) 517–524.
[7] CSAS, Occurrence, Sensitivity to Fishing, and Ecological Function of Corals, Sponges, and Hydrothermal Vents in Canadian Waters (Science Advisory Report No. 2010/041). Canadian Science Advisory Secretariat, 2010.
[8] CSAS, Science-Based Encounter Protocol Framework for Corals and Sponges (Science Advisory Report No. 2011/048). Canadian Science Advisory Secretariat, 2011. Retrieved from: ⟨http://www.dfo-mpo.gc.ca/Library/344555.pdf⟩.
[9] DFO, Policy for Managing the Impact of Fishing on Sensitive Benthic Areas, 2009. Available from: ⟨http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/benthi-back-fiche-eng.htm⟩ (retrieved 06.05.14).
[10] DFO, Pacific Region Cold-water Coral and Sponge Conservation Strategy. Oceans Program, Fisheries and Oceans Canada, 2010.
[11] DFO, Ecological Risk Assessment Framework (ERAF) for Coldwater Corals and Sponge Dominated Communities, 2013. Available from: ⟨http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/risk-ecolo-risque-eng.htm⟩ (retrieved 06.05.14).
[12] DFO, Pacific Region Integrated Fisheries Management Plan: Groundfish, 2014 (effective 21.02.14).
[13] C. Du Preez, V. Tunnicliffe, Shortspine thornyhead and rockfish (Scorpaenidae) distribution in response to substratum, biogenic structures and trawling, Mar. Ecol. Prog. Ser. 425 (2011) 217–231.
[14] P. Etnoyer, L.E. Morgan, Habitat-forming deep-sea corals in the Northeast Pacific Ocean, Cold-water Corals and Ecosystems, Springer-Verlag, Berlin Heidelberg (2005), p. 331–343.
[15] FCD, Federal Court-Ecology Action Centre Society v. Canada (Attorney General), 2004. Available from: ⟨http://decisions.fct-cf.gc.ca/fc-cf/decisions/en/item/38235/index.do⟩ (retrieved 09.05.14).
[16] J.L. Finney, Overlap of Predicted Cold-water Coral Habitat and Bottom-contact Fisheries in British Columbia (Research Document No. 2010/067). Canadian Science Advisory Secretariat, 2010.
[17] J.L. Freese, B.L. Wing, Juvenile red rockfish, Sebastes sp., associations with sponges in the Gulf of Alaska, Mar. Fish. Rev. 65 (3) (2003) 38–42.
[18] J. Gardner, Coldwater Corals and Sponge Conservation on Canada's Pacific coast: Perspectives on Issues and Options. Background Paper to Support Discussions Toward a Conservation Strategy. Submitted to the Organizing Committee for the Workshop, Developing a Conservation Strategy for Coldwater Corals and Sponges on the Pacific Coast, 2006. DFO, Vancouver, BC. 49 pp.
[19] Greenpeace, Carting Away the Oceans VIII: 2014 Rankings of Seafood Sustainability in U.S. Supermarkets. 702H Street NW Suite 300 Washington, DC 2000: Greenpeace, 2014. Retrieved from: ⟨http://www.greenpeace.org/usa/Global/usa/planet3/PDFs/oceans/Carting-Away-the-Oceans-VIII.pdf⟩.
[20] N.L. Gutierrez, R. Hilborn, O.Defeo, Leadership, social capital and incentives promote successful fisheries, 2011, http://dx.doi.org/10.1038/nature09689.
[21] J. Heifetz, R.P. Stone, S.K. Shotwell, Damage and disturbance to coral and sponge habitat of the Aleutian Archipelago, Mar. Ecol. Prog. Ser. 397 (2009) 295–303.
[22] J. Heifetz, B.L. Wing, R.P. Stone, P.W. Malecha, D.L. Courtney, Corals of the Aleutian Islands, Fish. Oceanogr. 14 (Suppl. 1) (2005) S131–S138.
[23] D. Holland, K.E. Schnier, Individual habitat quotas for fisheries, J. Environ. Econ. Manag. 51 (2006) 72–92.
[24] T.F. Hourigan, Managing fishery impacts on deep-waer coral ecosystems of the USA: emerging best practices, Mar. Ecol. Prog. Ser. 397 (2009) 333–340.
[25] G.S. Jamieson, N. Pellegrin, S. Jessen, Taxonomy and Zoogeography of Cold Water Corals in Explored Areas of Coastal British Columbia (Research Document No. 2006/062). Canadian Science Advisory Secretariat, 2006.
[26] M. Krautter, K.W. Conway, J.V. Barrie, M. Neuweiler, Discovery of a "living dinosaur": globally unique modern hexactinellid sponge reefs off British Columbia, Canada, Facies 44 (1) (2001) 265–282.
[27] S.P. Leys, K. Wilson, C. Holeton, H.M. Reiswig, W.C. Austin, V. Tunnicliffe, Patterns of glass sponge (Porifera, Hexactinellida) distribution in coastal waters of British Columbia, Canada, Mar. Ecol. Prog. Ser. 283 (2004) 133–149.
[28] R.J. Miller, J. Hocevar, R.P. Stone, D.V. Fedorov, Structure-forming corals and sponges and their use as fish habitat in Bering Sea submarine canyons, PLoS ONE 7 (3) (2012).
[29] British Columbia Marine Ecological Classification Marine Ecosections and Ecounits, Version 2.0. Report prepared for Coastal Task Force, Resources Information Standards Committee. 2002.
[30] Munro, G., Turris ,B., Kronbak, L., Lindroos, M., Sumaila, U.R. Catch share schemes, the theory of dynamic coalition games and the groundfish trawl fishery of British Columbia 2013, in North American Association of Fisheries Economists Forum 2013, 21-24 May 2013, St. Petersburg ,Florida, USA.
[31] NEFMC, Essential fish habitat (EFH) omnibus amendment. The swept area seabed impact (SASI) model: A tool for analyzing the effects of fishing on essential fish habitat. Part 1: literature review and vulnerability assessment. Newburyport, MA. 160 pp., 2010.
[32] NPFMC, Fishery Management Plan for Groundfish of the Gulf of Alaska. North Pacific Fishery Management Council, 2014a.
[33] NPFMC, Fishery Management Plan for the Groundfish of the Bering Sea and Aleutian Islands Management Area. North Pacific Fishery Management Council, 2014b.
[34] C.E. O'Keefe, G.R. DeCelles, Forming a partnership to avoid bycatch, Fisheries 38 (2013) 434–444.
[35] PFMC, Fishery Management Plan and Amendments: Fishery Management Plan Appendices. Appendix C. Map of EFH Conservation Areas. Pacific Fishery Management Council, 2014.
[36] P. Pintassilgo, M. Finus, M. Lindroos, G. Munro, Stability and success of Regional Fisheries Management Organizations, Environmental and Resource Economics 46 (2010) 377–402.
[37] C.N. Rooper, J.L. Boldt, Distribution of juvenile Pacific ocean perch (*Sebastes alutus*) in the Aleutian Islands in relation to benthic habitat, Alaska Fish. Res. Bull. 11 (2) (2005) 102–112.
[38] Seafood Watch. Seafood Watch Criteria for Fisheries. Monterey Bay Aquarium Seafood Watch, 2014. Retrieved from: ⟨http://www.seafoodwatch.org/-/m/sfw/pdf/criteria/mba-seafoodwatch-capture-fisheries-methodology.pdf?la=en⟩.
[39] Sinclair, A. 2007. Trends in groundfish bottom trawl fishing activity in B.C. CSAS Research Document 2007/006.
[40] S.F. Thrush, P.K. Dayton, Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity, Ann. Rev. Ecol. Syst. 33 (2002) 449–473.
[41] R. Townsend, Corporate governance of jointly owned fisheries rights, in: R. Q. Grafton, Hilborn R., Squires D., Tait M., Williams M. (Eds.), Handbook of Marine Fisheries Conservation and Management, Oxford University Press, Oxford, 2010, pp. 520–531.
[42] UNFAO, The state of world fisheries and aquaculture: opportunities and challenges. Rome: FAO Fisheries and Aquaculture Department Food and Agriculture Organization of the United Nations, 2014.
[43] L. Watling, E.A. Norse, Disturbance of the seabed by mobile fishing gear: A comparison to forest clearcutting, Cons. Bio. 12 (6) (1998) 1180–1197.