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Historical abundance of juvenile commercial fish in coastal habitats: Implications for fish habitat management in Canada

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ABSTRACT

An important component of science-based fisheries policy is the provision of habitat adequate for population renewal. In Canada, the Fisheries Act pays little attention to managing fish habitat, and was further weakened by changes enacted in 2012. Specifically, determining the role of fish habitat in contributing to fisheries and fish stock recovery is challenging when many stocks have severely declined and no longer occupy former habitats. This study compared the abundance of juvenile fish in coastal vegetated habitats before and after collapse or decline of groundfish stocks in Atlantic Canada. This comparison was done by compiling past studies that surveyed juvenile Atlantic cod (*Gadus morhua*) and pollock (*Pollachius virens*) in vegetated habitats across three provinces. Two studies were repeated, and one that already had post-collapse data was analyzed to quantify long-term changes in juvenile abundance. In all three cases substantial reduction in juvenile abundance coincided with declines in adult stocks. However, juvenile fish still occur in coastal habitats and could aid in adult stock recovery. The current version of the Canadian Fisheries Act requires presence of an ongoing fishery to trigger habitat protection. This is problematic as low fish abundance may lead to lowered habitat protection and potentially habitat degradation, with less or lesser-quality habitat for fish in the future. Thus, recommendations are made to repeal the 2012 Fisheries Act changes and enhance current fish habitat legislation. Using a precautionary approach for coastal fish habitat management, particularly in valuing its potential for fish stock recovery, would strengthen Canadian fisheries management.

1. Introduction

Fisheries have shaped global economies and vastly influenced marine ecosystems for centuries. Fisheries are also vital for food security, as fish provides more than 2.9 billion people with ~20% of their average per capita intake of animal-based protein, with the majority coming from marine capture fisheries [1]. Rebuilding overfished stocks could increase capture fisheries production and associated annual value by US$32 billion [2]. Effective fisheries management is therefore imperative. Habitat management is not traditionally seen as an important component of fisheries management, despite the known importance of habitat at various stages of fish life history [3,4]. Specifically, complex habitats mediate mortality of juvenile fish, and therefore play a role in supporting fisheries [5–11]. The protection and management of coastal ecosystems and complex habitats is an integral component of ecosystem-based fisheries management [12].

At a time when many commercially important fish stocks have been depleted [13], protection and restoration of juvenile habitats may be contributing factors for recovery. For example, population recovery of goliath grouper (*Epinephelus itajara*) in the southeastern United States stemmed directly from their nursery habitat – mangroves [14]. Mangroves functioning as nursery habitat have also been shown to increase local fishery yield in the Gulf of California [11]. Nursery and juvenile habitat conservation can even exceed the effects of no-take reserves in coral reef fisheries [15]. Nursery habitat availability may limit the adult stock size and recruitment for some fish species [16–18], and nursery habitat degradation has been related to population decline of European flounder (*Platichthys flesus*) in the northern Baltic Sea [19]. While there is a wealth of evidence supporting nursery habitat function, directly quantifying the contribution of juveniles to an adult population continues to be challenging [20]. Furthermore, measuring the value of a nursery habitat solely by contribution to adult fish stocks has recently been criticized as an oversimplification [20,21]. Due to the challenges associated with directly quantifying contributions of nursery habitats to fisheries, the value of coastal nurseries in Canada for sustaining fish populations, as well as

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aiding recovery, is largely unknown.

In Atlantic Canada, there have been strong declines of major groundfish stocks, namely Atlantic cod (*Gadus morhua*) and pollock (*Pollachius virens*) [22–24]. Due to the substantial depletion of adult stocks, juvenile abundance may also be low, such that the current value of coastal habitat as important juvenile habitat may be underestimated. This issue was addressed by using a historical approach, which is increasingly important for setting baselines of healthy ecosystems and fisheries for marine management [25–27]. The principal objective of this study was to quantify change of juvenile fish abundance in coastal vegetated habitats during periods of stock decline. Three historical surveys that quantified juvenile commercial fish abundance in vegetated habitats were identified, across three provinces in Atlantic Canada. These studies were then repeated using the same methodology, or analyzed from already available data from post-collapse surveys. The results are discussed in relation to concomitant declines in adult fish stocks and the effectiveness of Canadian fisheries management to protect fish habitat. Canadian fish habitat management is then compared with best practices for managing coastal nursery habitats in the United States, and recommendations are made for how to strengthen management of coastal zones and fish habitat in Canada.

2. Methods

Published studies were identified that quantified juvenile fish abundance of commercially important species in vegetated habitats in Atlantic Canada before the major collapse of groundfish stocks in the early 1990s. Because the goal was to compare juvenile abundances between time periods in which stock collapse or declines occurred, published data on both periods were needed or available past studies had to be repeated. To achieve the latter, detailed descriptions of the methods and results (i.e. raw abundance, or mean and standard deviation) were required. Three possible studies were identified: firstly, a highly resolved data set from beach seine surveys of juvenile cod in coastal habitats along the east coast of Newfoundland in the 1959–1964 and again 1992–1996 (Fig. 1) [28]. Two suitable dive survey studies were identified, one quantifying juvenile pollock in Brandy Cove, New Brunswick in 1989–1990 [29], and a second measuring juvenile Atlantic cod in vegetated habitats in St. Margaret's Bay, Nova Scotia in 1992 (Fig. 1) [30]. These case studies are all possible coastal nurseries (e.g. the Newfoundland coast, in which strong year classes in the coastal nursery matched those in the offshore commercial fishery) [31], despite a lack of quantification of their contribution to fish stocks. In the following, there are details for each of the three case studies as well as the statistical analyses required for comparing past and contemporary abundances. A type I error rate of 5% was set as the criterion for statistical significance.

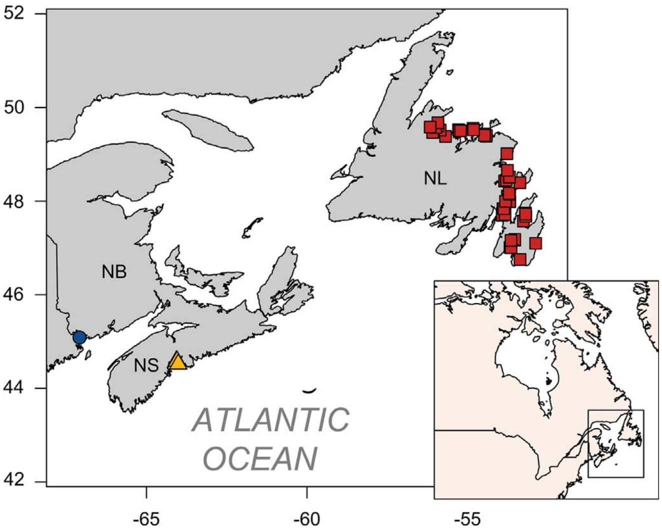

Fig. 1. Sites for case studies in Atlantic Canada: (1) juvenile cod along the east coast of Newfoundland (NL; squares), (2) juvenile pollock in Brandy Cove, New Brunswick (NB; circle), (3) juvenile cod in St. Margaret's Bay, Nova Scotia (NS; triangles).

2.1. *Case Study 1: Eastern Newfoundland – Atlantic Cod*

A systematic series of beach-seine surveys was done along the east coast of Newfoundland from 1959 to 1964, and repeated after the collapse of Atlantic cod from 1992 to 1996 [28]. 84 different sites were surveyed from mid-September to late-October examining juvenile Atlantic cod abundance in coastal bays in the first series, known as the “Fleming survey”. Of the 84 sites sampled, 42 were sufficiently sampled to allow year to year comparisons (this eliminated the first year of the data series, 1959), and in any one year between 17 and 41 sites were sampled depending on weather and ocean conditions. For the purpose of this study, only sites with vegetation (described as “kelp” or “eelgrass” in the field notes) were analyzed, which totaled 35 sites (Fig. 1).

A 25 m bottom seine was used, where one person on land stands holding one hauling rope while the seine is let out 55 m from shore. Then, the seine is let out parallel to shore, and then the other hauling rope is towed into shore. This second hauling rope is received by another person on shore, with 16 m between individuals, and the ropes are simultaneously pulled in. The seine thus censuses 880 m^2 from the shore and the water column up to $\sim$2 m above the bottom. Full specifications, including mesh size, detailed dimensions, and slight modifications between time periods, are described in [32].

In the 1960 s, the number of sets at each site varied; therefore, the data were reduced to 42 sites where there were consecutive sets in many years, removing those years at sites where there were not two consecutive sets. Thus, the comparison of juvenile cod abundance was restricted to the first two sets of beach seines performed at each site. Abundances of cod in the two sets were summed, which represents an index of density. This seining method has high catchability [33], with higher than 95% retention of all fish in the path of the net. Once hauled in, all fish were counted and identified. Here, only the abundances of juvenile cod are used, classified into three age bins: age 0 ($<$97 mm), age 1 (97–192 mm) or age 2 ($>$192 mm), based on annually repeatable modes in the catch curves [28].

The “Resurrected Fleming Survey” (1992–1996) was initiated after the collapse of the Northwest Atlantic cod stocks. The seasonal timing, location of sampling, gear specifications, gear deployment, sampling design, and time of day sampled were all given attention to ensure comparability between the two periods [28,34,35]. Sampling bias was held constant between time periods by close matching of the sampling protocols. Sites that had direct habitat degradation due to development (e.g. wharf building) were not sampled in the “Resurrected Fleming Survey”. It is therefore unlikely that vegetation and habitat within the sites used in this analysis had changed dramatically due to anthropogenic causes.

Generalized linear models (GLMs) [36] were used to analyze changes in juvenile cod abundance. Every GLM used had a common set of categorical explanatory variables: time period (1960–1964 and 1992–1996), and year nested within time period. Year was set as a categorical variable; as temporal autocorrelation of cod abundance counts between years was negligible. Every age group of cod had overdispersed counts, with ages 1 and 2 also exhibiting zero inflated counts. Thus, for age 0 cod, a GLM with negative binomial error structure and a log link function was used.

For age 1 and age 2 cod, a two-stage model was more appropriate, with the first stage examining presence and absence of a count (a binomial error structure with a logit link function) and the second stage examining the counts themselves, a GLM with negative binomial error structure and a log link function. Sequential analysis of deviance tables were used to assess significance of the observed contrasts among means, which test the reduction in residual deviance from the null model.

2.2. Case study 2: Brandy Cove, Passamaquoddy Bay, New Brunswick – Pollock

Rangeley and Kramer examined tidal impacts on habitat selection in juvenile pollock [29]. They used seven fixed 140 m dive transects that were set at random intervals perpendicular to shore along 200 m of coastline in Brandy Cove, Passamaquoddy Bay, New Brunswick (Fig. 1). Transects reached a depth of 4–6 m, and the habitat consisted mainly of rocky macroalgal reef, mostly rockweed (*Ascophyllum nodosum*) with interspersed mud flats. At different tidal stages (low rising, low falling, high rising, and high falling), two divers counted juvenile pollock along 1 m wide transects from late May to the end of August in 1989 and 1990. They then reported the mean, standard error, and sample size (number of transects) of juvenile pollock density (m^{-2}) for each tidal stage and for spring (May-June) and summer (July-August) separately (Table 2 within [29]), however raw data were no longer

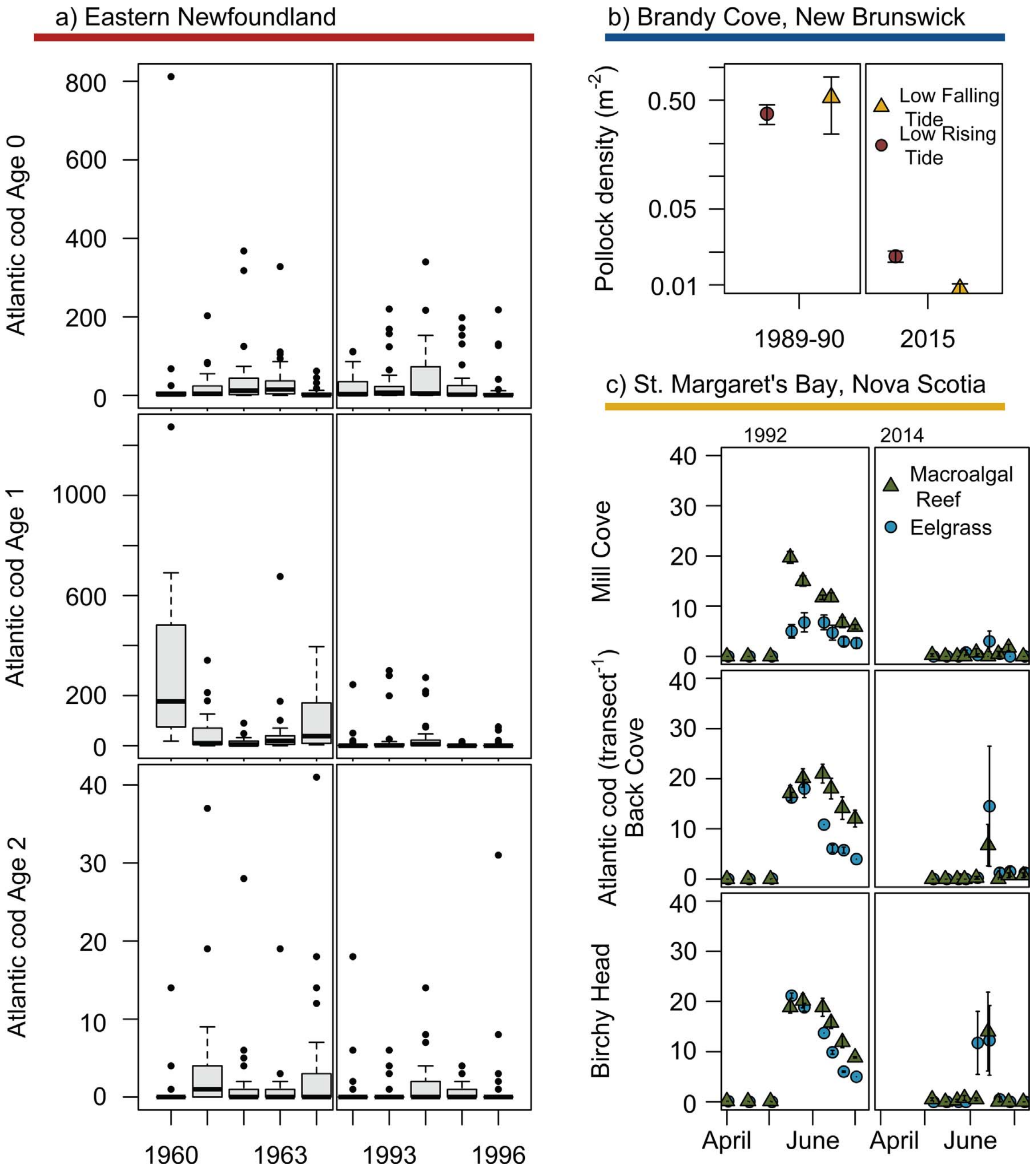

Fig. 2. Summary of case study results: (a) Juvenile Atlantic cod abundance for age 0, 1 and 2 in vegetated habitats across 35 study sites in eastern Newfoundland. Abundances are an index of density given as a sum of counts in two consecutive beach seines per site (described in Methods). Boxplots show the median, the first and third quartiles, and outliers (points) are 1.5x the interquartile range above or below the upper and lower quartiles, respectively. (b) Changes in juvenile pollock density (mean ± SE, n=277, 311, 70, and 72 from left to right) from 1989 to 90-2015, at the low-rising and low-falling tide. (c) Time series of juvenile Atlantic cod abundance at three sites in St. Margaret's Bay, Nova Scotia, comparing abundances (±SE, n=4 for every point) in 1992 and 2014. Data are jittered to visualize error bars.

available. Simulating historical datasets and consequently comparing raw data was also explored, however the assumptions required for these simulations were not met. A related study found no significant site differences in juvenile pollock density between Brandy Cove and three other sites in Passamaquoddy Bay [37], allowing us to generalize to pollock abundance in the region.

In 2015, the diver surveys described above in Brandy Cove were repeated [29]. The highest densities reported were compared, specifically those in the spring period, from the end of May until the end of June, and at the low rising and low falling tide [29]. Instead of using transect lines, divers swam along a compass bearing perpendicular to shore, diving to a maximum depth of 5 m, and measured the dive transect length retroactively using a surface-towed Global Positioning System (GPS). As in the original study, two divers counted juvenile pollock and other organisms within a 1 m wide transect, which were then converted to pollock density. Divers completed a total of 142 transects, 72 for the low rising and 70 for the low falling tidal stage. Eight transects were completed for each sampling day, with a total of 9 sampling days. These transects had a total length of 15.79 km when summed through the entire season, so the sampling coverage was very high. A two-sample *t*-test with unpooled standard errors was used to compare mean densities. Degrees of freedom were calculated assuming unpooled independent means with unequal variances [38].

2.3. *Case Study 3: St. Margaret's Bay, Nova Scotia – Atlantic Cod*

Tupper and Boutilier (1995) used visual dive surveys to examine the effect of habitat on settlement, growth and survival of juvenile Atlantic cod [30]. They completed four, 15 m long transects in four different habitat types (rocky reef with macroalgae, small cobble bottom, eelgrass *Zostera marina* beds, and sandy bottom), within three separate study sites in St. Margaret's Bay, Nova Scotia (Birchy Head, Back Cove, and Mill Cove). They counted juvenile Atlantic cod (age 0) within 1 m of each side the transect line, with a total planar area of 30 m^2, sampling every 10 days from May 1st until July 1st in 1992. They report the mean density of cod (m^{-2}) and the SD for each sampling time (Fig. 2 within [30]); the raw data were not available anymore.

The same survey methods were repeated at the same three study sites in 2014. Divers anchored floats at 15 m intervals within two of the habitats (rocky reef with macroalgae and eelgrass beds), which had the highest survivability of juvenile cod reported in 1992, and similarly used dive transects to count juvenile Atlantic cod (age 0). One diver completed all surveys to ensure comparable estimates. Counts were restricted to within 1 m of each side of the transect to also ensure the same sampling intensity, again with a total planar area of 30 m^2. Divers similarly sampled from May 6th to July 7th, on average every 8 days (varying due to weather constraints) with a total of 9 sets, with four transects in each habitat at each site.

In order to statistically compare abundances between 1992 and 2014, the time series of mean number of individuals per transect and standard deviations were extracted from [30]. Because the goal of our study was to compare overall abundances, the maximum reported abundances were statistically compared. As with the previous case study, a two-sample *t*-test with unpooled standard errors, comparing independent means was used [38]. Standard errors were calculated from the extracted standard deviation and sample size ($n=4$ transects). Our analysis was constrained because raw data from the original study were not available, so the entire time series from May-July in 1992 and 2014 was visually compared, emphasizing effect sizes rather than significance levels [39].

3. Results

Juvenile fish abundances decreased in the latter time periods in each of the three case studies. Within vegetated habitats across Newfoundland, abundance of juvenile Atlantic cod declined strongly in different age groups, with high variability within time periods (Fig. 2a). For age 0 cod, the high variability within time period was evident with a significant year nested within time period effect (Table 1). However, there was no statistically significant change in overall age 0 cod abundance between the two time periods. For both ages 1 and 2 cod, the log-odds ratios for the presence/absence of a count (fewer sites occupied) declined significantly, as did the abundances from the 1960s to the 1990s, with an overall 5.4-fold decline in mean abundance of age 1 and 2.4-fold in age 2. There was also significant variability within time periods for age 1 cod, but not for age 2 cod (Table 1).

In the rockweed beds in Brandy Cove, New Brunswick, there was significantly lower juvenile pollock density in 2015 compared with 1989–90. Mean pollock density declined more than one order

Table 1

Analysis of deviance tables for juvenile Atlantic cod (ages 0, 1, and 2). For Age 0 cod, a negative binomial GLM was used, while for ages 1 and 2 a two-stage model (binomial for the presence/absence and negative binomial for counts) was used. The table contains test statistics and associated p-values comparing the reduction in deviance for the row to the residuals. χ^2 tests for models with known dispersion are used, the raw deviance is reported (synonymous with the χ^2 value). Period and year nested in period ("/") are the explanatory variables. Significant results ($p < 0.05$) are bolded.

Response	Variable	DF	Deviance	Residual DF	Residual Deviance	*p* value
Cod 0	Null			276	338.0085	
	Period	1	1.6776	275	336.3308	0.1952
	Period/Year	**8**	**19.1662**	**267**	**317.1646**	**0.0140**
Cod 1 Presence/Absence	Null			276	334.7840	
	Period	**1**	**55.4307**	**275**	**279.3533**	**< 0.0001**
	Period/Year	**8**	**21.2964**	**267**	**258.0569**	**0.0064**
Cod 1 Counts	Null			195	324.8323	
	Period	**1**	**33.6390**	**194**	**291.1934**	**< 0.0001**
	Period/Year	**8**	**58.6867**	**186**	**232.5066**	**< 0.0001**
Cod 2 Presence/Absence	Null			276	343.1895	
	Period	**1**	**4.6980**	**275**	**338.4915**	**0.0302**
	Period/Year	**8**	**21.3814**	**267**	**317.1101**	**0.0062**
Cod 2 Counts	Null			85	100.2846	
	Period	**1**	**4.6884**	**84**	**95.5962**	**0.0304**
	Period/Year	8	11.5308	76	84.0654	0.1734

of magnitude from 0.376 to 0.018 individuals m^{-2} (d.f.$=$310.5, $t=4.64$, $p<0.001$) at the low-rising tide, and from 0.531 to 0.009 individuals m^{-2} (d.f.$=$276, $t=1.82$, $p=0.035$) at the low-falling tide (Fig. 2b).

In St. Margaret's Bay, Nova Scotia, there was reduced overall abundance of juvenile cod in both rocky reefs with macroalgae and eelgrass beds at all three study sites (Fig. 2c). However, statistically significant lower abundance maxima were only detected in two of the six surveys, namely in rocky reefs at Mill Cove and Back Cove (d.f.$=$4.6, $t=13.45$, $p\lll0.001$ and d.f.$=$4.2, $t=3.13$, $p=0.016$, respectively; Fig. 2c). Yet there was also much higher variability in peak abundance in 2014 compared with 1992, evident in the larger standard deviations (Fig. 2c). In addition, across both habitats at all three sites, the pulse of juvenile cod was much shorter, only evident in one week in 2014 compared to six weeks in 1992. In all other weeks, the abundance of juvenile cod in 2014 was near zero. We also examined the sum of individuals along each time series, and found significantly lowered abundance in 2014, at every site and habitat.

4. Discussion

Our three case studies confirm the expected reduction in abundance of juvenile cod and pollock in coastal vegetated habitats in Atlantic Canada over periods of severe adult stock decline. Yet despite collapsed or depleted adult stocks, juvenile fish of commercially important species persisted in coastal habitats. This highlights the potential importance of juvenile fish from these habitats to supply adult stocks and aid in stock recovery. Our findings have important implications for the protection of coastal fish habitats and for enabling policy and regulatory improvements in Canadian federal and provincial coastal and habitat management.

4.1. Juvenile fish decline coupled with adult stock decline

The decline in juvenile Atlantic cod in Newfoundland shown in the first case study, specifically ages 1 and 2, is the expected outcome of the substantial reduction of the Northwest Atlantic cod stocks that reduced adult stocks to <1–3% of former abundance [23,24]. High inter-annual variability may explain why the observed decrease in age 0 juvenile cod was not statistically significant despite the magnitude of adult decline [40]. Another potential explanation is community changes and altered predator dynamics [41]. Specifically, reduction in juvenile numbers may have been offset by reduced cannibalism, which is a substantial source of juvenile mortality [42–44]. Reduced cannibalism may also explain why observed declines in juveniles ages 1 and 2 are less severe than those reported for adult stocks. The large spatial scale and long temporal coverage of the Newfoundland surveys allows inference of the relationship between stock abundance and juvenile fish abundance [31].

Our second and third case studies were much smaller scale, but also confirm the expected decrease in juvenile abundance after stock decline. These case studies are therefore used as generalizations of the first case study reported. The decreased juvenile pollock abundance coincided with a 6-fold decline in pollock biomass index (3-year geometric mean) from over 60 kg/tow in 1990 to under 10 kg/tow in 2015 in the management area adjacent to Passamaquoddy Bay, New Brunswick (NAFO Areas 4XOPQRS5; DFO, 2015a). Lowered juvenile pollock abundance in our surveys was anticipated, as pollock juveniles recruit to coastal habitats and have not been found in deeper waters [45]. Similarly, the Atlantic cod biomass index in the adjacent management area to St. Margaret's Bay, Nova Scotia (NAFO Area 4 × 5Yb) declined 6.5-fold from 1992 to 2014 [46], which may explain the lower juvenile cod abundance found in coastal vegetated habitats across three different study sites. Unfortunately, changes in habitat for the case studies presented could not be measured. However due to the relatively low development of coastal zones near these sites and the exclusion of developed sites in the “Resurrected Fleming” surveys, these results are likely not confounded by anthropogenic changes in habitat. Sampling over multiple years would have provided better estimates of coastal juvenile abundance in the second and third case studies, given high juvenile recruitment variability in marine fishes [40].

Overall, results from these last two case studies support our conclusion from the Newfoundland case study, that juvenile fish abundance is linked to stock size. Such declines in adult stocks and consequently juvenile fish abundance in coastal ecosystems have also been observed in the Skagerrak [47,48]. These concomitant declines in adult and juvenile abundance, in case after case, highlight the connectivity between coastal habitats and offshore fish stocks [49]. While concomitant declines may reflect connectivity, it is important to note that the presence of fish alone does not indicate their importance for contributing to fish populations. In order to establish the contribution of these habitats to fish populations, further research aimed at quantifying the proportion of fish that use coastal ecosystems in a population is required. Despite this research gap, there is extensive evidence that commercially important fish use coastal ecosystems in Atlantic Canada [31,33,37,45,50–54], warranting the use of coastal habitat management as a tool for fisheries management in Canada.

4.2. Fish habitat management in Canada

Management of coastal fish habitat encompasses three different legislative avenues in Canada: fish habitat management through the Fisheries Act [55,56], coastal zone management through the Oceans Act [57], and biodiversity conservation through international and national commitments (e.g. the Aichi Biodiversity Targets, the Species At Risk Act of Canada; [58,59]). Each of these avenues requires significant improvements, and some of their weaknesses have been previously addressed [57–64]. Here, the focus is on the management of coastal fish habitat in light of our case studies' results.

Canadian fish habitat management began with the guiding principle of “no net loss of productive capacity” of fish habitat, where productive capacity is defined as “the maximum natural capability of habitats to produce healthy fish” [55]. Fish habitat management significantly shifted with changes made to the Fisheries Act of Canada with Bill C-38, in particular the re-naming of Section 34, formerly “Fish Habitat Protection and Pollution Prevention” into “Fisheries Protection and Pollution Prevention”. Prior to 2012, Section 35(1) stated that: “No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat.” The changes made in 2012 then mandated that: “No person shall carry on any work, undertaking or activity that results in serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or to fish that support such a fishery.” In essence, the Fisheries Act as it stands in 2012 no longer protects fish habitat per se but instead focuses on the protection of fish that are part of a fishery, or fish that support such a fishery. It also protects habitats of commercial, recreational, or aboriginal (CRA) fisheries, as the definition of “serious harm to fish” includes both the “death of fish” or “any permanent alteration to, or destruction of, fish habitat”. Furthermore, the Fisheries Act as of 2012 allows for alteration and disruption of fish habitat, but does not allow for permanent destruction. The changes outlined above were scrutinized due to the potential negative impacts on freshwater fish species and aquatic conservation [61], as well as the reasoning for implementing these changes [65]. A repeal would re-establish and enable the need for habitat-based research and management. Repealing these changes would be enabling but not sufficient to protect fish habitat as there has been a long-standing deficiency of management action [57].

Under current legislation, evaluation of fish habitat by different CRA fishery species can only be done when there is an active fishery. Specifically, the 2012 Fisheries Act changes were justified by "shift[ing] the focus of protection from habitat per se to the sustainability and ongoing productivity of CRA fisheries" [66]. At a time when many fish populations have been severely depleted and are no longer experiencing "ongoing productivity", such as those focused on in our case studies, this potentially results in a self-reinforcing downward trend for fish habitat protection. That is, fewer fish due to population reduction leads to lowered habitat protection and potentially degradation, with less or lesser-quality habitat for fish in the future. However, habitat protection is particularly important because of the connection between commercial fish populations and coastal ecosystems, discussed above. Accordingly, there have been calls that these habitats should be protected to maintain their function and services, as habitat may aid in the potential recovery of adult stocks [54,67–69]. In Atlantic Canada, the importance of eelgrass beds has been recognized by listing eelgrass as an ecologically significant species in 2009 by Fisheries and Oceans Canada (formerly the Department of Fisheries and Oceans; DFO) [70]. However, there is no legal protection associated with this listing. In contrast, despite also being recognized as important coastal habitat to juvenile fish and other species [37,54,67], rockweed beds are commercially harvested with currently increasing harvest pressure and under provincial jurisdiction [71]. Underestimation of the value of coastal ecosystems as juvenile fish habitat could be a critical gap in Canadian fisheries management due to poor protective legislation. This gap brings with it an opportunity for significant improvement in the legislation to increase conservation-oriented habitat management [61].

4.3. Comparison of Canadian and American fish habitat management

In contrast to Canada, effective protection of all life history stages of commercially important species as well as ecologically and biologically significant coastal zone habitats is required under the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) in the United States [72]. This Act recognizes areas and habitats that are important for fisheries productivity and recovery. The National Oceanic and Atmospheric Administration (NOAA) in the United States manages fish habitat by assessing what constitutes "Essential Fish Habitat" (EFH) for every managed species. For example, eelgrass meadows in our case studies would very likely be considered EFH for Atlantic cod. Via the MSFCMA, NOAA then works with regional fishery management councils to identify EFH and habitat areas of particular concern (HAPCs), and to assess the largest threats to EFH. For example, the New England Fishery Management Council designated a large inshore area an HAPC for juvenile Atlantic cod, specifically from 0 to 20 m depth in the Gulf of Maine and southern New England in order to "focus attention on coastal and nearshore development activities" [73]. Importantly, American federal agencies (e.g. U.S. Army Corps of Engineers) are required to consult with NOAA if they carry out any activities which may adversely affect EFH [72]. EFH and particularly HAPCs are therefore protected to some degree. The MSFCMA is fundamentally different from its Canadian counterpart in that it explicitly mandates fish habitat management.

Another important difference is that the MSFCMA also requires that management councils adhere to binding scientific advice, thereby effectively eliminating the discretionary decision-making authority of the American equivalent to the Fisheries Minister in Canada [59]. Strengthening accountability and the links between policy and science in fisheries management would go a long way to ensuring coastal fish habitats get the protection that they require [59].

4.4. Moving habitat management forward in Canada

Marine conservation, coastal zone management, and fish habitat management are all connected, so moving management forward can be done through any combination of these three avenues. The critical missing tool for fishery managers in Canada is one that enables directed, specific management actions that safeguard areas of high-quality juvenile habitat – those areas which maximize growth and reduce predation risk for juveniles. Ecologically and Biologically Significant Area (EBSA) designation is a potential tool which could be enhanced for this purpose, however it currently provides no legal protection once implemented [74]. In that way they are similar to HAPCs in the United States, as they are used as a tool for increasing risk adverse management [74]. An important difference is that EFH in the United States is legally protected under the MSFCMA, and HAPCs are used to concentrate management effort. Whether it be through EBSA designation or another avenue, Canadian fisheries managers require an effective tool for protecting fish habitat, which potentially enables recovery.

Improvements in habitat management have been made in recent years by the DFO, including formalizing "offsetting policies" that theoretically compensate habitat destruction with habitat creation [75]. Furthermore, the DFO has begun analyzing habitat in terms of "adult equivalents", which attempts to quantify how many adults may be produced by a habitat [76]. Both of these are steps in the right direction towards adequate fish habitat assessments, although implementation of habitat offsets ("compensation" prior to 2012) is largely deficient in Canada and in general [77,78] and estimation of adult equivalents is still challenging in practice for any nursery habitat [20]. The key missing component is protection of fish habitat in a proactive manner, potentially contributing to fisheries recovery.

Uncertainty around the value of fish habitat remains because direct quantification of fish habitat impacts for fish stocks is challenging [8,20,79]. Despite this challenge, recent work in Australian seagrass meadows estimated that commercial juvenile fish were enhanced via reduced predation and increased growth, thus valuing seagrass beds $\sim$\$A230,000 ha^{-1} year^{-1} [80]. This estimate demonstrates the potentially high value of coastal fish habitat in Canada. Estimates of fish habitat contributions to fisheries may be more challenging in Canadian temperate waters where many juvenile fish use coastal ecosystems opportunistically, while others settle into complex habitat offshore [81]. Alongside the challenges of quantifying habitat contributions, human impacts are persistent throughout many coastal ecosystems [82] and continued threats are sometimes even concentrated in important fish habitats (e.g. reproduction areas; [83]). For example, aquaculture development was identified as one of three main threats to Canadian marine biodiversity [59]. It is also extremely difficult to restore degraded or destroyed habitats in coastal marine ecosystems [84–86], which highlights using a precautionary approach for habitat management. A precautionary approach for valuing coastal fish habitat is important, and protection of fish habitat should not wait until adequate quantification of fish habitat contribution to fish stocks [59].

Evaluating essential fish habitat for fish populations that have collapsed or declined is a critical challenge. Coastal ecosystems differ fundamentally in larval supply, which is a key determinant of the value of a nursery habitat [8]. For some species (e.g. Atlantic cod), oceanographic circulation models are a valuable tool for modeling larval supply to nurseries [87,88]. Alongside identifying areas of high larval supply, looking at factors of juvenile success (e.g. survival and growth) as a function of habitat variables is critical to determine differential habitat quality [89]. Examining juvenile survival and growth explicitly as a function of habitat, or habitat characteristics, would establish the biological processes that relate juvenile abundance to habitat. This would allow fish habitat importance to be characterized during periods with low fish abundance.

Another key component to effective fisheries management is implementation of the legislation itself. In Canada, various provisions in the Oceans Act recommend the use of “integrated management of activities in estuaries, [and] coastal waters” as well as the precautionary approach [90]. While improving the legislation itself is important, which is a principal recommendation, implementation of existing legislation still needs to be improved.

Given the weaknesses addressed above concerning Canadian fish habitat management, the following recommendations are made:

1) Canada should use directed coastal management (e.g. coastal MPAs, EBSAs, or restricted development zones) to safeguard areas of high quality juvenile habitat. To do this, Canadian fishery managers therefore require a tool for protecting fish habitat, which could be through EBSA designation if it were enhanced with legal authority. Development of a management tool with an intermediate level of protection, below that of a Marine Protected Area (MPA) but above no-management, would be appropriate.
2) Canada should broadly approach fish habitat management with a precautionary approach, valuing its contribution to fish stock recovery.
3) Canada should focus research efforts to describe mechanistically the relationship between harvested fish species and their habitats, which would enable habitat evaluation during low stock abundance periods.
4) Quantifying the link between coastal habitats and fish stocks in Canada should be of primary interest. This has been done with some success in other regions, such as the Gulf of California, the Baltic Sea, and in Western Patagonia [11,16,19,91]. Novel techniques such as natural tags (e.g. otolith microchemistry [91]) could be used to quantify contribution of juveniles settling in specific habitats. In addition, identifying regions that have higher larval supply could prioritize habitat management.

5. Conclusion

Evaluation of fish habitat use is challenging when fish populations are severely depleted. These difficulties are partially overcome by using a historical approach. By quantifying change in juvenile fish abundance with historical reference points, our results suggest that coastal vegetated habitats have been heavily used by commercially important fish in the past and are still used today, albeit in much reduced numbers. Therefore, these coastal vegetated habitats should be managed as important fish habitat. Precautionary approaches are integral for managing fish habitat, as restoring destroyed eelgrass meadows or other biogenic structures is extremely difficult. Strengthening fish habitat management will move Canada towards ecosystem-based fisheries management.

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