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Sea-cage aquaculture impacts market and berried lobster (*Homarus americanus*) catches

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ABSTRACT: Sea-cage finfish aquaculture frequently spatially overlaps and competes with traditional fisheries and ecologically important habitats in the coastal zone. Yet only few empirical studies exist on the effects of sea-cage aquaculture on commercially important fish and shellfish species, due to the lack of data. We present results from a unique collaboration between scientists and lobster fishers in Port Mouton Bay, Atlantic Canada, providing 11 yr of market (market-sized) lobster catches and berried (ovigerous) lobster counts in 5 spatially resolved areas adjacent to a sea-cage finfish farm. The time series covered 2 stocked (feed) and 2 non-stocked (fallow) periods, allowing us to test for the effects of feed versus fallow periods. Our results indicate that average market lobster catch per unit effort (CPUE) was significantly reduced by 42% and berried lobster counts by 56% in feed compared to fallow periods. Moreover, both market and berried lobster CPUE tended to be lower in fishing region 2, which included the fish farm, and higher in region 5, furthest away from the farm. Bottom temperature measurements in one region suggest that differences in CPUE between feed and fallow periods were not driven by temperature, and that berried lobsters may be more sensitive to both aquaculture and temperature than market lobster. We discuss possible mechanisms of how finfish farms as well as other abiotic and biotic factors such as habitat quality and temperature could affect lobster catch. Our results provide critical information for the management of multiple human uses in the coastal zone and the conservation of shellfish habitats that sustain traditional fisheries.

KEY WORDS: Finfish farming · Environmental impacts · Traditional fishery · Lobster habitat · Coastal zone · Atlantic Canada

INTRODUCTION

Sea-cage finfish aquaculture commonly takes place in the sheltered bays, coves, inlets and fjords of the coastal zone. These areas provide protection from heavy seas, suitable year-round temperature and, depending on the location, some tidal flushing (Saunders 1995). Coastal sites also provide growers with convenient and inexpensive access to their grow-out sites. However, space limitations and environmental problems, such as disease outbreaks and waste build-up, have forced some producers into new coastal areas that may be marginal for sea-cage farming, ecologically sensitive, or in conflict with traditional uses such as inshore fisheries (Holmer 2010, Wiber et al. 2012).

The coastal zone also contains some of the world's most ecologically and economically important habitats such as estuaries, seagrass and rockweed beds, kelp forests and oyster reefs (Barbier et al. 2011, Seitz

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et al. 2014). These serve as temporary or permanent habitat for a wide range of commercial and non-commercial fish, shellfish and plant species, providing nursery areas and protection against predation for early-life stages, spawning and breeding grounds for adults, migration routes and feeding areas (Seitz et al. 2014). Coastal ecosystems are vulnerable to anthropogenic factors such as coastal construction, dredging, fishing, wastewater discharges and aquaculture, which have altered, fragmented, polluted and sometimes destroyed coastal habitats (Lotze et al. 2006, Halpern et al. 2008).

A long list of potential impacts of sea-cage aquaculture on coastal environments have been identified. These range from impacts associated with released nutrients, chemicals, pathogens and escaped fish to changes in habitat quality and migratory routes as well as effects on human health, traditional fisheries and world fish supplies (see reviews in Holmer et al. 2008, Sapkota et al. 2008, Naylor et al. 2009). To date, most research has focused on a narrow range of impacts such as near-field impacts of organic waste discharges (see review by Giles 2008), release of pathogens, pesticides and antibiotics (see reviews by Burridge et al. 2010, Johansen et al. 2011), and genetic interactions of escaped fish on wild populations (see review by Cross et al. 2008). Several studies have also examined the potential physiological and ecological impacts of sea-cage fish farms on wild commercial and non-commercial fish populations (see review by Uglem et al. 2014). However, except for some studies on the impacts of farmed salmon on wild Atlantic salmon *Salmo salar* (Carr et al. 1997, Carr & Whoriskey 2006) and one study on escaped farmed cod on wild cod *Gadus morhua* (Zimmermann et al. 2013), no other studies have been done in Atlantic Canada on the impacts of sea-cage aquaculture on wild commercial fish or shellfish populations.

In Atlantic Canada, sea-cage aquaculture (primarily Atlantic salmon) began in the 1970s (Saunders 1995), first in Nova Scotia and New Brunswick, and eventually expanded to Newfoundland. In 2014, 30 266 metric tonnes (mt) of sea-cage finfish valued at $216.3 million was produced in Atlantic Canada (DFO 2014). Within 10 yr of the industry's development and expansion in New Brunswick, herring *Alosa harengus* weir fishers were raising concerns that sea cages were blocking or diverting herring migration routes and interfering with the ability of the weirs to catch fish (Stephenson 1990). Early research by Lawton et al. (2001) reported the displacement of a population of lobsters *Homarus americanus* from their historic seasonal spawning habitat in New Brunswick (Canada) during the operation of a sea-cage salmon farm (1989–1991) and their re-establishment several years after the farm ceased operation; however, no explanation was offered for their results. Subsequent qualitative studies using social science approaches (e.g. interviews and surveys with fishers) further elaborated on the impacts sea-cage salmon farms were believed to have on commercial fisheries (Walters 2007, Wiber et al. 2012). In addition to the degradation and loss of important spawning, feeding and nursery grounds for commercial fish and shellfish stocks, including lobster, fishers also reported changes in smell, texture and shell quality of sea urchins *Strongylocentrotus droebachiensis* and scallops *Placopecten magellanicus* and changes in the overall ecology (e.g. predator–prey relationships) within their traditional fishing grounds (Wiber et al. 2012). To date, none of these observations have been examined using empirical methods.

The lobster fishery is the highest commercial value fishery in Atlantic Canada, with overall landings valued at $1.179 billion in 2015 (DFO 2017a). Declines in groundfish stocks such as cod have resulted in an almost complete reliance of coastal communities on this high-value fishery (Steneck et al. 2011). The lobster fishers of Port Mouton Bay on the Atlantic coast of Nova Scotia are part of a larger lobster fishing management area referred to as Lobster Fishing Area 33 (LFA 33; as defined by the federal Department of Fisheries and Oceans [DFO]) (our Fig. 1a), which has reported significant increased landings over the past decade (see our Fig. 2) (DFO 2017b). Port Mouton Bay, particularly the inner bay, has been the preferred area to fish for local fishers because of the short distance from wharves, less cost of fuel, fewer fishing days lost to poor weather, less gear loss and less safety risk. In 2006, lobster fishers in Port Mouton Bay began a collaboration with local scientists to initiate the present study to investigate the impacts of a sea-cage finfish farm on market-sized lobster catches and the distribution of female berried (ovigerous) lobster. At the time, fishers reported abandoning their historical lobster fishing 'territories' within the bay because of low catches, forcing them to move further offshore. In addition to potential impacts from aquaculture activities, our study also examined the possible effects of temperature on lobster catches. This 11 yr lobster study represents a unique long-term dataset to examine the impacts of sea-cage finfish aquaculture on market and berried lobster.

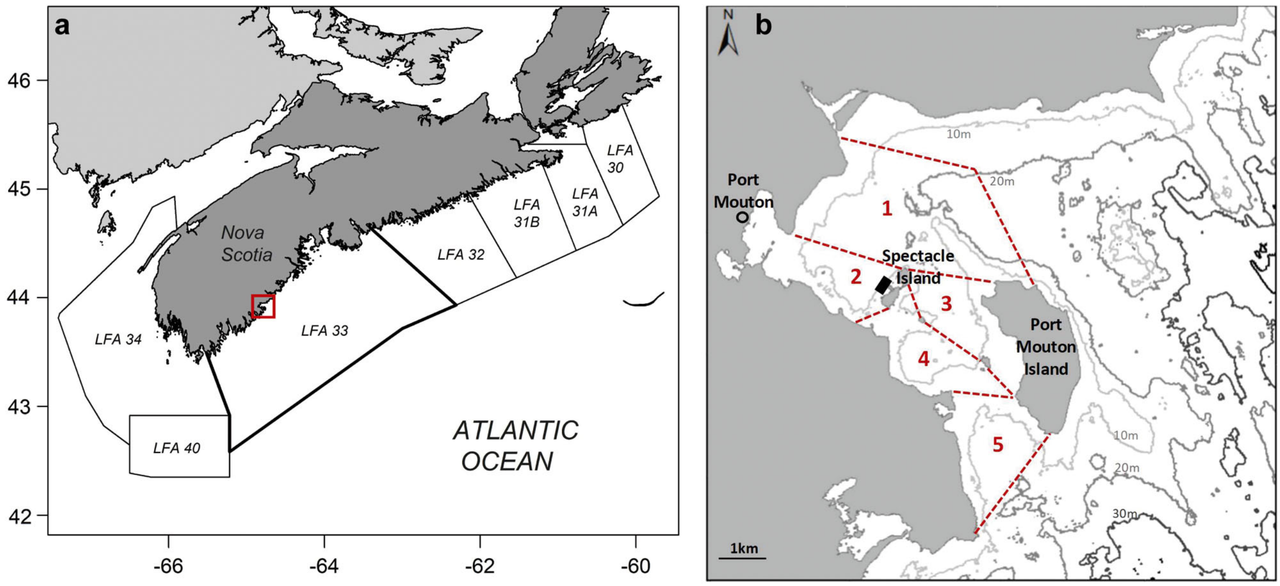

Fig. 1. (a) Lobster Fishing Areas (LFAs) of Nova Scotia, including the study area Port Mouton Bay (red square) in LFA 33. (b) The 5 traditional lobster fishing regions (1–5, red dashed lines) in Port Mouton Bay and the finfish farm (black filled rectangle) near Spectacle Island

MATERIALS AND METHODS

Study area

Port Mouton Bay, located on the Atlantic coast of Nova Scotia (Canada), is a partially sheltered bay covering an area of approximately 55.6 km^2 (Fig. 1b). Tides, averaging 1.5 m, are semi-diurnal and water depth throughout the bay ranges from 8 to 18 m. Tidal currents tend to be low (2–3 cm s^{-1}, Gregory et al. 1993) and surface currents are strongly influenced by winds (DFO 2007, 2009). In general, the bay is ice-free in the winter months but ice conditions do occur, with the most recent event in 2015. Bedrock morphology indicates that Port Mouton Bay is characterized by rocky ledges trending southeast and a series of small basins and shallow sills (Piper et al. 1986). Surficial sediment distribution indicates that the entire bay is a heterogeneous mix of sandy, gravelly sand and muddy areas (Piper et al. 1986). These features combine to make Port Mouton Bay a suitable habitat for lobster *Homarus americanus* and as lobster fishing grounds (Tremblay & Smith 2001, Tremblay et al. 2009). Both market-sized (carapace length >82.5 mm) and berried lobsters utilize these habitats which allow them to hide from predators. In soft-bottom habitat, berried female lobsters have been observed excavating bowl-shaped depressions where they extrude, brood and hatch their eggs under their abdomen (Campbell 1990). Lobster catch rates are known to be higher on low relief or unstructured sediments such as sand and gravel (Tremblay & Smith 2001, Geraldi et al. 2009).

In 1995, a sea-cage fish farm began operating in the inner portion of Port Mouton Bay near Spectacle Island (Fig. 1b). The current farm lease (43° 54′ 54.11″ N, 64° 48′ 43.62″ W) occupies an area of 8 ha and the sea cages occupy ~0.58 ha of the lease area. The farm site was stocked with Atlantic salmon *Salmo salar* from 2007 to 2009, fallowed from approximately June 2009 to August 2012, stocked with rainbow trout *Oncorhynchus mykiss* in 2012–2014, and fallowed from approximately March 2015 to the end of 2017. The typical grow-out period in sea cages for Atlantic salmon and rainbow trout is 24 and 9 mo respectively (FAO 2018); however, both species can spend more time in sea cages depending on the desired market size. Information on stocking numbers and monthly feed usage, mortalities, fish harvested, and potential pesticide treatments is viewed as proprietary and therefore was not publicly available for the Spectacle Island fish farm. As a result, it was not possible to estimate or track waste discharges during fish production on a monthly basis. Therefore, stages of aquaculture production were identified and based on direct observation of fish farming activity (feed period) and inactivity (fallow period). The farm site has been re-licensed for Atlantic salmon and rainbow trout for the period of March 2015 to March 2020 (NSDFA 2017a). Water depth at the farm site is 10 to 12 m. Current-meter data recorded 10 m from the northwest corner of the fish farm over a 2 wk period (June 18 to July 3, 2008) by the Nova Scotia Department of Fisheries and Aquaculture indicated mean current speeds of 3.4 cm s^{-1} for surface layer (0–4 m) and 3.1 cm s^{-1} for bottom layer (4–8 m) waters (McIver et al. 2018).

Study design

Lobster fishing is a seasonal activity in Atlantic Canada, and in LFA 33, which includes Port Mouton Bay, the fishery operates from the last Monday in November to May 31 of each year (DFO 2017b). During the spring portion of the fishery (last 2 wk of May), lobsters are known to migrate into Port Mouton Bay as water temperatures increase. Historical lobster trap surveys conducted by the DFO (Miller et al. 1989, D. G. Wilder unpubl. data) support local fishers' knowledge that Port Mouton Bay had been a destination for lobster migration.

The sampling design for the study was based on extensive discussions with local fishers, whose fishing history in Port Mouton Bay extends over several generations (>100 yr). Approximately 40 boats, with a crew of 2–3 fishers per boat, land lobster in Port Mouton Bay. We recruited up to 15 boats and ~30 fishers (depending on the year) who had fished full- or part-time in the bay to participate in this study. These fishers agreed to provide their market-sized lobster landings and berried lobster counts for the last 2 wk of May. In a fishing area with otherwise little published scientific information, their knowledge of historical lobster landings, population distribution and movement, bathymetry and oceanographic conditions and physical habitat characteristics was key to the study design.

For the purpose of this study, Port Mouton Bay lobster fishers partitioned their traditional lobster territories (~2600 ha) within the bay into 5 contiguous regions (Fig. 1b). Each region represents traditional fishing areas where, year to year, the same fishers occupy the same region with which they are most familiar. Overall, the spatial areas of regions 2–5 were similar (382.6 ± 41.1 ha), while region 1 was more than double (1073.7 ha) in area (Fig. 1b). However, according to the fishers, each region has approximately the same amount of suitable and fishable lobster habitat (as defined above in 'Study area') despite the difference in overall spatial area of region 1. The depth profiles in all fishing regions are also similar and range from 4 to 16 m (B. Fisher pers. obs., Canadian Hydrographic Chart 4240).

Trap design

Port Mouton Bay fishers typically use wooden traps baited with rock crab *Cancer irroratus*, green crab *Carcinus maenas*, frozen redfish *Sebastes marinus* heads, or fresh herring *Clupea harengus* in the spring lobster fishery. Fishers participating in this study consistently used wooden traps in all regions throughout the 11 yr study, with the exception of one fisher who consistently used wire traps in region 5. Catch rates for wire or wooden traps are the same (Miller 1990), and both trap designs are 115 cm × 55 cm (base) × 36 cm (height) with an offset mesh funnel to allow lobster to enter the trap into the first compartment known as the 'kitchen' where the bait is contained. Another mesh funnel leads to a second compartment known as the 'parlour' that retains the lobster and where there is a plastic escape vent containing two 6 cm holes that allow undersized lobsters to escape. This trap design allows fishers to catch lobsters >82.5 mm, the minimum legal carapace length prescribed for lobster in LFA 33 for Port Mouton Bay (DFO 2017b).

Catch data

Fishers recorded catches of market and berried lobster for each trap hauled on log sheets during the last 2 wk of May in Port Mouton Bay since 2007. We used the 2007–2013 data as reported in Loucks et al. (2014) and added the 2014–2017 data for an 11 yr time period (2007–2017). Fishers returned both berried lobster and undersized lobsters to the water, but retained market-sized lobsters. Empty trap hauls were recorded as 0 catch. Log sheets were submitted to the scientists for data analysis; fishers provided their data on an individual and confidential basis. Catch data were aggregated by region (1–5) and year (2007–2017) and standardized to determine (1) the mean number of berried lobster counts per 1000 trap hauls and (2) the catch per unit effort (CPUE, kg per trap haul) of market lobsters. These standardized catch rates thus account for differences in effort (number of trap hauls) between regions and years, as well as differences in spatial extent among the 5 fishing regions.

Temperature measurement

Each year, a temperature recording instrument (Vemco Minilog) is supplied to fishers by the Fishermen and Scientists Research Society (FSRS) as part of the Nearshore Temperature Monitoring Project (FSRS 2018). The device was attached to a lobster trap and placed on the seabed at a depth of 7 m approximately 3 km south of Spectacle Island in region 4 (Fig. 1b). Bottom temperature data were recorded every 60 min for the duration of the lobster fishing season (December–May). At the end of the season, temperature data were off-loaded using a Vemco field reader and software to provide minimum, maximum and average daily temperature data (J. Cosham, FSRS, pers. comm.). For this study, temperature data were aggregated to produce a mean and standard error (SE) as well as minimum and maximum for each annual 15 d survey period (last 2 wk of May). Temperature data were not available for 2007 due to loss of instrument.

Statistical analysis

As a first step, we tested whether lobster catch in one year influences catch data in the next year (temporal autocorrelation) in the time series of berried and market lobsters for each of the 5 regions (R Core Team 2016). Because there was negligible temporal autocorrelation in all time series (see Fig. S1 in the Supplement at www.int-res.com/articles/suppl/m598p085_supp.pdf), each year was used as an independent sample in subsequent analyses. We then classified lobster data by years that belonged to feed (n = 5) or fallow (n = 6) periods.

Next, we used generalized linear models (GLMs) to test for the effects of sea-cage culture (feed vs. fallow), region (1–5), and their interaction on berried and market lobster CPUE. For berried lobster, where residuals were not normally distributed, we used a GLM with a Poisson error distribution and a log link function. For market lobster, residuals were normally distributed and we used a GLM with a Gaussian error distribution and the identity link function. Residual versus fit plots were examined to ensure model assumptions were met and a significance level of $p < 0.05$ was set to test for Type I errors throughout. All statistical analyses were done in R version 3.2.1 (R Core Team 2016). To test for differences in bottom water temperature in feed versus fallow years, we used single-factor ANOVA and an *F*-test of equality of variances, which indicated that the untransformed data met the assumption of homogeneity. Finally, we used linear regression analysis to examine the relationship between lobster CPUE and temperature during feed and fallow periods in region 4, where temperature was recorded.

RESULTS

Between 7 and 15 boats and approximately 30 fishers participated in this 11 yr study, and their trap hauls varied depending on the year (Table 1). The year-to-year variation in participants reflects the variation in lobster *Homarus americanus* catchability in each region. Fishers will follow the lobster to optimize their catch. If lobster abundance is poor, fishers will abandon fishing in the region.

Annual landings of lobster in the greater LFA 33 showed a continuous increase over the study period from 2007 to 2016 (Fig. 2; 2017 data were not yet available), and the same trend was reported for CPUE (DFO 2017b). In Port Mouton Bay, however, CPUE results for both berried and market lobster showed highly variable trends over time (Fig. 3), with a tendency of higher CPUE during fallow compared to feed periods, particularly in regions 1, 3 and 4. In region 2, where the fish farm is located (Fig. 1b), CPUE was on average often lower, particularly during fallow periods, while in region 5, which is furthest away from the fish farm, CPUE was on average often higher, particularly during feed periods. The last 3 yr of the time series (2015–2017) was a fallow period and all regions showed increasing CPUE (Fig. 3).

When averaging over feed and fallow years, CPUE of both berried and market lobster was lower during feed compared to fallow years in all regions (Fig. 4).

Table 1. Number of boats and trap hauls for each survey year

Year	Boats	Trap hauls	Fish farm production stage
2007	7	5779	Feed
2008	12	5238	Feed
2009	15	10 230	Feed
2010	14	13 045	Fallow
2011	12	11 597	Fallow
2012	13	11 717	Fallow
2013	11	8558	Feed
2014	10	6957	Feed
2015	7	3914	Fallow
2016	8	5868	Fallow
2017	8	5865	Fallow

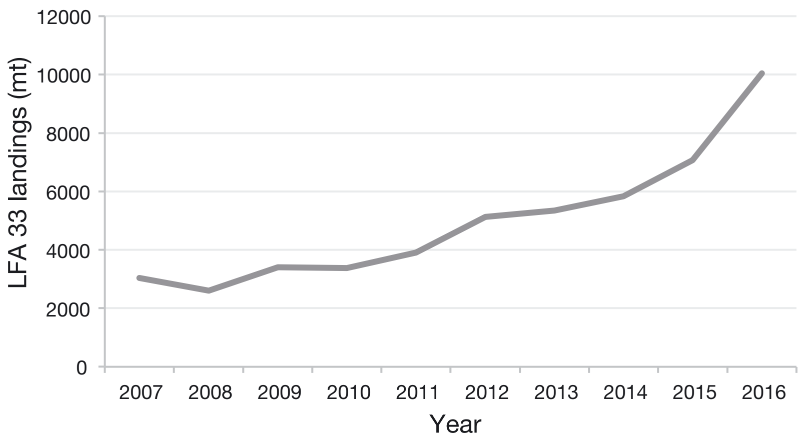

Fig. 2. Landings of lobster *Homarus americanus* in the overall Lobster Fishing Area (LFA) 33 over the study period as reported to the federal Department of Fisheries and Oceans (DFO 2017b)

In fallow years, average CPUE was lowest in region 2, while in feed years, average CPUE was highest in region 5 (Fig. 4). Averaging across all regions, berried lobster counts per 1000 trap hauls were 64.3 (±14.7 SE) during fallow but only 29.4 (±4.9 SE) during feed periods, a 56.4% reduction. For market lobster, average CPUE was 0.96 (±0.09 SE) kg per trap haul during fallow and 0.55 (±0.06 SE) kg per trap haul during feed periods, a 42.3% reduction.

Results of GLMs indicated significant effects of both region and aquaculture for berried and market lobster (Table 2). For market lobster, overall CPUE was significantly ($p < 0.01$)

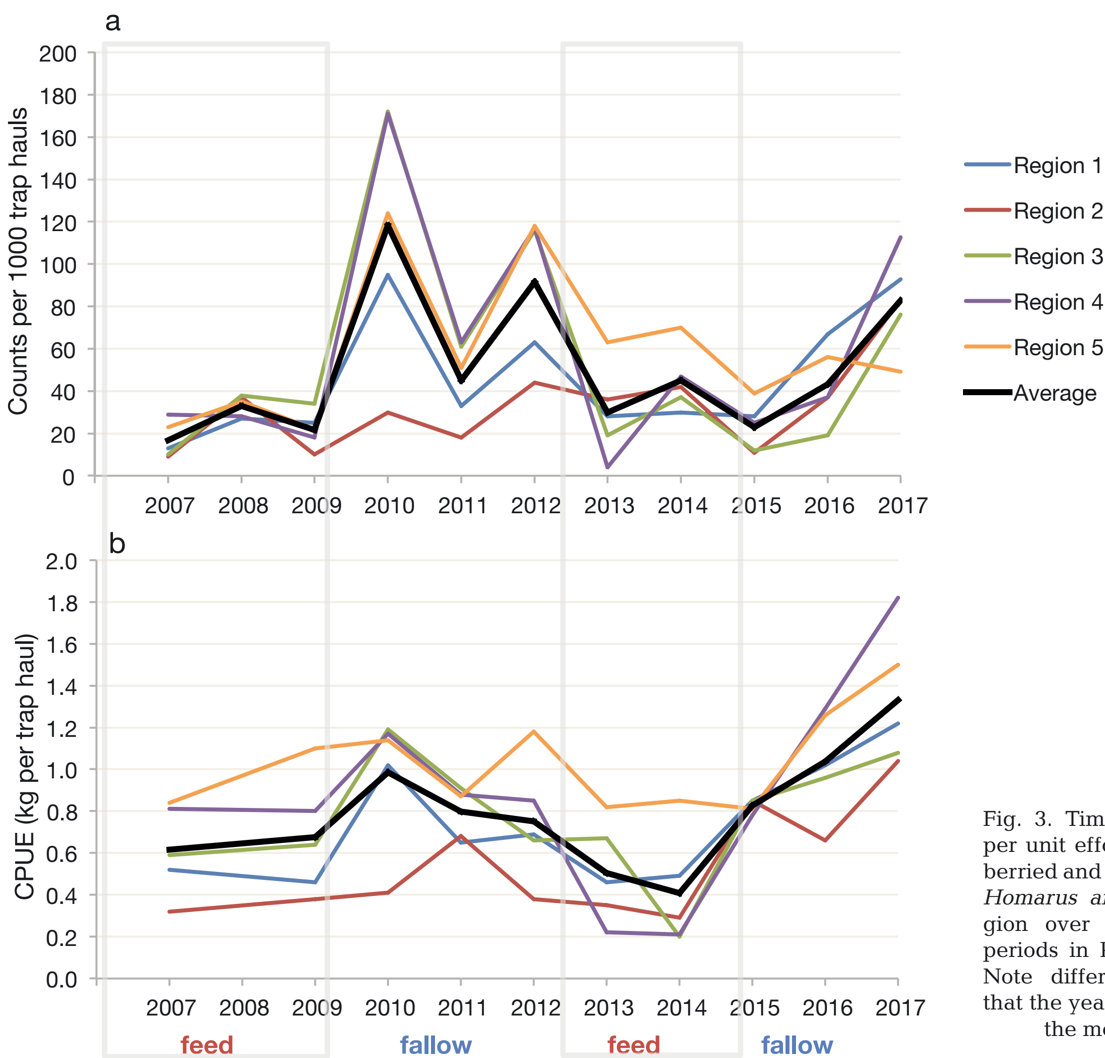

Fig. 3. Time series of catch per unit effort (CPUE) for (a) berried and (b) market lobster *Homarus americanus* by region over feed and fallow periods in Port Mouton Bay. Note different *y*-axes, and that the year marks represent the month of May

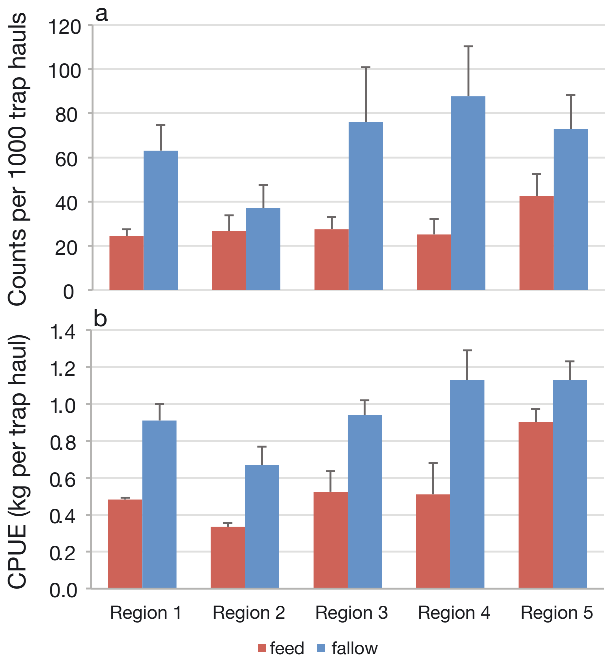

Fig. 4. Catch per unit effort (CPUE) of (a) berried and (b) market lobster *Homarus americanus* by region averaged over feed (n = 5) and fallow (n = 6) years. Note different *y*-axes. Error bars: SE

Table 2. Generalized linear models (GLMs) testing for the effects of region (1–5) and aquaculture (fallow compared to feed periods) for berried and market lobsters *Homarus americanus*. For berried lobster, the GLM was done with a Poisson error distribution and a log link function, and for market lobster with a Gaussian error distribution and the identity link function

Factor	Estimate	SE	*z*	p
Berried lobster				
Intercept	3.203	0.090	35.520	<0.001
Region 2	0.086	0.125	0.686	0.493
Region 3	0.115	0.124	0.928	0.353
Region 4	0.024	0.127	0.190	0.849
Region 5	0.549	0.113	4.849	<0.001
Fallow	0.943	0.108	9.087	<0.001
Region 2 × Fallow	−0.616	0.162	−4.087	<0.001
Region 3 × Fallow	0.070	0.147	0.492	0.622
Region 4 × Fallow	0.304	0.148	2.115	0.034
Region 5 × Fallow	−0.407	0.137	−3.053	0.002
Market lobster				
Intercept	0.483	0.122	3.960	<0.001
Region 2	−0.148	0.172	−0.856	0.397
Region 3	0.043	0.172	0.247	0.806
Region 4	0.028	0.172	0.160	0.874
Region 5	0.420	0.172	2.437	0.019
Fallow	0.426	0.157	2.707	0.010
Region 2 × Fallow	−0.091	0.222	−0.408	0.685
Region 3 × Fallow	−0.009	0.222	−0.041	0.967
Region 4 × Fallow	0.196	0.222	0.880	0.384
Region 5 × Fallow	−0.202	0.222	−0.906	0.370

higher in fallow than in feed periods, and CPUE in region 5 was significantly higher than in region 1, to which all others are compared in the GLM. Similarly, berried lobster counts were significantly higher ($p < 0.001$) in fallow compared to feed periods, and counts in fishing region 5 were significantly higher than in region 1. There were also some significant interactions for berried lobsters, suggesting that the difference in fallow versus feed periods was smaller in regions 2 and 5 than in region 1, and higher in region 4 (Table 2). These effects can be explained by the relatively low berried lobster counts in region 2 in both feed and fallow periods (Fig. 4a), whereas counts in region 5 were higher during feed periods compared to all other regions.

Bottom water temperature measured in region 4 during the 11 yr study period (last 2 wk of May) was on average 5.55°C (±0.78°C SE) during fallow periods and 5.92°C (±0.55°C SE) during feed periods, and thus not significantly different between feed and fallow years (ANOVA; $F_{1,8} = 0.122$, $p = 0.7$). The lowest temperature (1.5°C) was recorded in 2015, a fallow year, and the highest temperature (11.9°C) in 2012, also a fallow year, while temperatures during feed periods were more intermediate, with minimum and maximum values between 3.9 and 7.8°C (Table 3). Correlations between catch rates and water temperature indicated that berried lobster counts were positively related with increasing temperature in region 4 (Fig. 5), particularly during fallow periods (ANOVA; $R^2 = 0.75$, $p = 0.025$). For market lobster, CPUE was more variable during fallow periods, but tended to decrease during feed periods (Fig. 5). These patterns were consistent for berried and market lobsters in all other fishing regions (see Fig. S2 in the Supplement).

Table 3. Bottom water temperature (°C) by year in fishing region 4 during the study period (last 2 wk of May); 2007 data are missing due to loss of temperature recorder. na: not available

Year	Mean	Minimum	Maximum	SE
2007	na	na	na	na
2008	4.97	4.20	5.90	0.15
2009	5.03	3.93	6.53	0.21
2010	7.79	5.72	9.80	0.33
2011	5.98	5.40	6.69	0.18
2012	6.89	4.44	11.29	0.63
2013	6.55	4.97	7.75	0.22
2014	7.14	5.29	7.78	0.19
2015	2.30	1.48	3.82	0.19
2016	4.47	3.90	5.59	0.17
2017	5.6	4.02	7.72	0.30

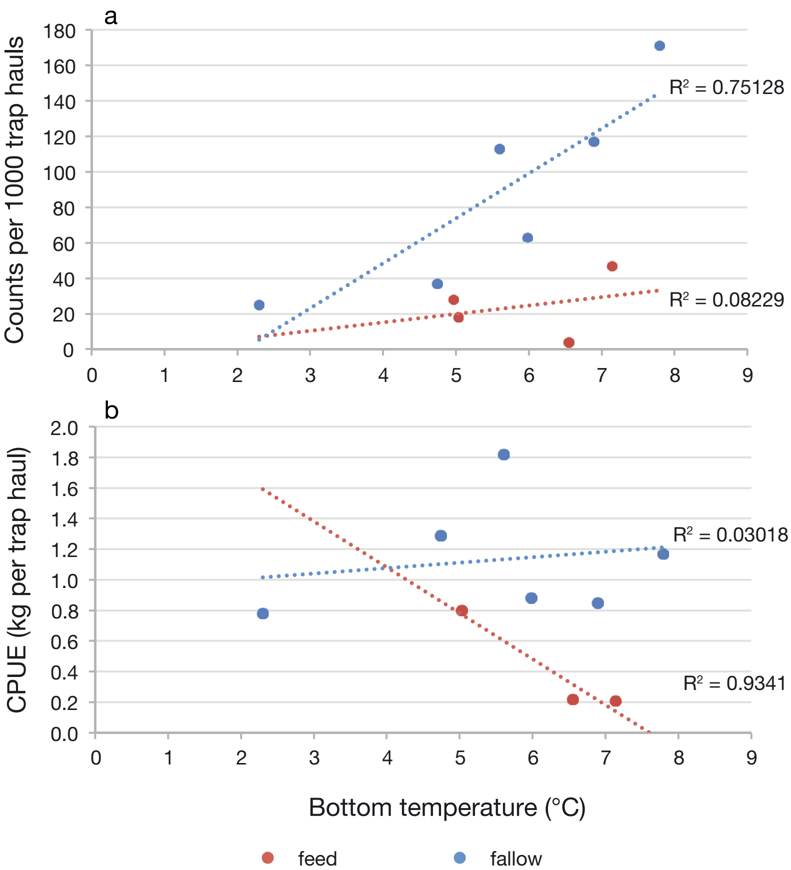

Fig. 5. Correlations of catch per unit effort (CPUE) for (a) berried and (b) market lobster *Homarus americanus* with bottom water temperature in region 4. Note different *y*-axes. For the other regions, see Fig. S2 in the Supplement

rates between feed and fallow years were not confounded by temperature. Although berried lobster counts were positively influenced by temperature, this effect was much stronger during fallow than feed periods, and we found no temperature effect on market lobsters. Our results confirm previous observations from Port Mouton Bay (Loucks et al. 2014) and other regions in Atlantic Canada (Wiber et al. 2012) that lobster catches in the vicinity of sea-cage finfish farms can be reduced during feed periods.

DISCUSSION

Aquaculture impacts lobster catches in Port Mouton Bay

Our study presents results of a unique long-term collaboration between fishers and scientists to examine lobster *Homarus americanus* catches in 5 traditional fishing regions around a sea-cage finfish farm in Port Mouton Bay, Atlantic Canada. Over the 11 yr study period (2007–2017), our analyses show that average catch rates of market lobsters (kg per trap haul) and berried lobsters (counts per 1000 trap hauls) were consistently lower during fish farm production (feed) periods compared to fallow years. In fishing region 2, where the fish farm is located, both market and berried lobster catch rates remained lower during fallow years than in other regions, while in feed periods, they remained higher in region 5, which is furthest from the fish farm. The differences in catch rates between feed and fallow years were not confounded by temperature. Although berried lobster counts were positively influenced by temperature, this effect was much stronger during fallow than feed periods, and we found no temperature effect on market lobsters. Our results confirm previous observations from Port Mouton Bay (Loucks et al. 2014) and other regions in Atlantic Canada (Wiber et al. 2012) that lobster catches in the vicinity of sea-cage finfish farms can be reduced during feed periods.

Lobster catch rates

Port Mouton Bay has traditionally been an important habitat for lobsters and a destination for lobster migration in the spring and has thus supported generations of local lobster fishers. Yet despite lobster stocks in Nova Scotia being at high abundance and overall catches and catch rates in LFA 33 significantly increasing over the past decade (our Fig. 2, DFO 2017b), Port Mouton Bay lobster fishers began abandoning their historical fishing territories within the bay 2–3 yr after a sea-cage finfish farm began operating in 1995. Unfortunately, the modern aggregation of fisheries statistics (e.g. catch, effort) and monitoring data (abundance, size) into larger management units (e.g. LFA 33) hampers investigations on smaller spatial scales.

In Port Mouton Bay, lobster fishers agreed to engage in a smaller bay-scale study. From 2007 to 2017, they reported variable catch rates, with overall 42% lower catch rates of market lobster and 56% lower catch rates of berried lobster during feed compared to fallow periods. Interestingly, during feed periods, catch rates remained highest in the region furthest away from the farm and most connected to the open Atlantic (region 5, Figs. 1 & 4). Moreover, although catch rates tended to increase again during fallow periods in most regions, they remained low in the region closest to the fish farm (region 2, Figs. 1 & 4). These results corroborate similar observations from New Brunswick, where lobsters disappeared from their historic habitat during operation of a salmon farm and re-established themselves several years after the farm's closure (Lawton et al. 2001). Generally, fishers are concerned about negative impacts of sea-cage aquaculture on important spawning, feeding and nursery grounds for commercial fish and shellfish stocks, including lobster, as well as changes in predator–prey relationships and the general ecology within their traditional fishing grounds (Walters 2007, Wiber et al. 2012).

Lobster fishers have detailed knowledge of their resource and the environment it lives in, which is highly valuable to science and management (Galparsoro et al. 2009, Boudreau & Worm 2010, Kay et al. 2012). For example, Kay et al. (2012) utilized fishers' knowledge about California spiny lobster *Panulirus interruptus* to identify reefs with similar historical (i.e. pre-reserve) catch dynamics and physical/biological habitat characteristics within and outside marine reserve areas. Galparsoro et al. (2009) coupled fishers' knowledge and a habitat distribution model to predict suitable habitat for European lobster *H. gammarus* in the Bay of Biscay and Boudreau & Worm (2010) used lobster *H. americanus* fishers' ecological knowledge to investigate ecosystem effects of fishing. Our study adds to these examples by using fisher-collected data in their traditional fishing areas to investigate the impacts of sea-cage aquaculture.

Potential temperature effects

One potential confounding factor on lobster catches can be water temperature. Lobster catch rates have been generally viewed as being temperature-dependent (McLeese & Wilder 1958, Miller 1990, Green et al. 2014). Several studies have identified positive correlations between temperature and market lobster catch rates at large spatial scales (>50 km^2) or temporal scales (e.g. months, years) (Hudon 1994, Koeller 1999, Drinkwater et al. 2006). Yet at shorter temporal (e.g. days, weeks) and smaller spatial (<25 km^2) scales, the temperature correlation was weak or even negative (Tremblay & Drinkwater 1997, Koeller 1999, Pickering et al. 2010, Jury & Watson 2013). Few studies have examined temperature effects on mature female or berried lobsters. Jury & Watson (2013) reported highest catches of both male and female American lobster in Great Bay Estuary (New Hampshire, USA) near their preferred temperature, between 12 and 18°C. In northern Nova Scotia (Canada), Ugarte (1994) reported highest berried lobster catch rates at temperature >5°C as well as increasing catches of mature non-ovigerous female lobsters with increasing temperature; however, this relationship only held for berried females throughout the entire fishing season.

In Port Mouton Bay, lobsters historically migrate into the bay in spring when water temperatures increase, and we found a strong positive effect of temperature on berried lobster catch rates, but only during fallow periods. This effect was much reduced during feed periods, suggesting an overriding negative impact of the fish farm. For market lobsters, there was no relationship between temperature and catch rates during fallow periods, yet the relationship turned negative during feed periods, again suggesting an overriding negative impact of the fish farm. Unfortunately, we were limited by only one bottom temperature recorder in one fishing region, which precluded a more rigorous statistical test of the potential temperature effect on catches during feed versus fallow periods. However, previous studies have reported that temperature loggers distributed at intervals of 10 km along a coastline (Koeller 1999) or a single logger in a 25 km^2 fishing area (Pickering et al. 2010) were sufficient to measure the effects of temperature on lobster catches. Both these sampling conditions are similar to our study (Fig. 1b). Our data suggest that berried lobsters were more sensitive to and more strongly affected by both aquaculture and temperature than market lobsters. Moreover, both berried and market lobster catches were significantly reduced during feed compared to fallow periods, which did not coincide with lower compared to higher temperatures.

In general, adult lobsters have relatively wide thermal preferences (Lawton & Lavalli 1995). Lobsters are able to detect small changes (~1°C) in temperature (Jury & Watson 2000) and berried lobsters may be more responsive to small temperature fluctuation and move more to optimize thermal conditions for egg development and larval release (Ugarte 1994, Cowan et al. 2007, Goldstein & Watson 2015). However, once lobster move into habitats that are at or near their thermal niche or envelope, many other ecological factors (e.g. moulting, reproductive status, predation pressure, food availability, habitat type) or environmental impacts may override small temperature fluctuations and influence differences in movement and catches (Jury & Watson 2013).

Other factors influencing lobster catch

Numerous factors other than temperature (e.g. wind, season, habitat type, fishing effort, bait type, odour) are known to affect lobster catches depending on temporal and spatial scales (Miller 1990, Tremblay & Smith 2001, Drinkwater et al. 2006). In our study, moulting is an unlikely factor, as the lobster fishing season in Port Mouton Bay ends, before their moulting period. We did not examine the impact of wind; however, any correlation between wind and catch could be a function of fishing effort where fishers alter (reduce) their fishing activity because they know winds of a certain direction and force could affect lobster activity and catches (Koeller 1999). Fishing effort in our study is embedded in CPUE estimates which standardize the CPUE (number of traps) in each fishing region. When catches are low or negligible in a particular fishing region due to wind, effort will be limited and reflected in the CPUE data.

Odour of the bait can influence catch (Miller 1990), and odour plumes in general play a significant role in the behaviour and ecology of aquatic animals, including lobsters (see review by Atema & Voigt 1995). They contain chemical cues used to locate food, detect predators, find conspecifics and mates, select habitats, and detect environmental stressors (e.g. hypoxia, sulphides, ammonium). Dissolved sulphides, ammonium and hypoxic conditions known to be produced from organically enriched environments such as sea-cage fish farms (Hargrave 2010) can have behavioural and toxic effects on lobsters (Draxler et al. 2005, Van Son & Thiel 2007). Common behavioural responses in lobsters to hypoxia and sulphides include a reduction in movement to conserve energy and movement to oxic areas of >3.0 ml l^{-1} dissolved oxygen (DO), which can be reflected in decreased catch rates (Diaz & Rosenberg 1995, Riedel et al. 2014). Increased irrigation behaviour (pleopod activity) during hypoxic (30% oxygen saturation) events have been reported in berried female Norway lobsters *Nephrops norvegicus* (Eriksson et al. 2006), and Butterworth et al. (2004) found Norway lobster exhibited retreat behaviour at 50 µM sulphides.

Environmental monitoring data collected at the Port Mouton Bay sea-cage operation during finfish production periods (2007–2009; 2013–2014) indicated numerous individual sampling stations ranged from 5000 to 10 000 µM sulphides (S^{2-}) depending on the production year; in 2007 and 2014, mean sediment sulphides were >4000 µM (NSDFA 2007, 2014a). During the 2010 fallow period, mean sediment sulphides were 2205 µM, with several stations reporting levels >3000 µM (J. Grant unpubl. data). At the end of the 3 yr fallow period in 2012, mean sediment sulphides were 725 µM (J. Grant unpubl. data), but within 1 yr of re-stocking, mean sediment sulphides were up to 4028 µM (NSDFA 2014b). Given what is known about the behaviour and sensitivity of lobster to very low levels of sulphides and the odour-generating potential of sediments associated with the fish farm (see previous paragraph), it is possible that lobsters in fishing regions surrounding the fish farm could encounter sulphide odour plumes that caused them to decrease their movement or to relocate, hence decreasing their catchability during feed periods, as reflected in lower catch and count data. Moreover, the apparent slow return to oxic benthic status (sediment sulphide levels <1500 µM) during fallow years at the Port Mouton Bay farm site (J. Grant unpubl. data) and the increased sensitivity of berried lobster to sulphide odours could potentially explain why, regardless of feed or fallow periods, we found that berried lobster counts were lower in region 2, which includes the fish farm. Although fishers (Wiber et al. 2012) and researchers (Black et al. 1996, Holmer et al. 2005) have reported 'sewage' or hydrogen sulphide odours emanating from waters and sediments in the vicinity of fish farms, virtually nothing is known about the odour seascape around farms. To date, no studies at sea-cage aquaculture operations have modelled the areal extent or horizontal transport of dissolved sulphides and ammonium along the benthic boundary layer (5–10 cm above the sediments), where lobster and other mobile benthic organisms live.

Sea-cage finfish operations are also point sources of fine and coarse particulate matter (uneaten feed pellets, faeces, metabolic products), which can combine with natural fine-grained sediment to form loosely packed aggregates of particulate material called floc (Milligan & Law 2005). This material can settle and become part of a loose and mobile near-bottom turbid layer sometimes referred to as a nepheloid layer (Belias et al. 2007). Increased turbidity is believed to affect lobster catches (Drinkwater et al. 2006, Lewis et al. 2009). To our knowledge, no studies have been done to assess lobster behaviour or catch rates in turbid conditions around sea-cage finfish farms.

Management implications

Until recently, the environmental impacts from sea-cage finfish aquaculture were thought to be mostly limited to the near-field areas under and adjacent to net pens (Giles 2008). Within the last 5–10 yr, there has been a growing acknowledgement of the potential significant spread and persistence of aquaculture waste over large areas and their potential impacts on the environment and traditional fisheries (Uglem et al. 2014, Price et al. 2015). Our study examined only the impact of sea-cage aquaculture on lobster fishing in one small bay. We found that the spatial footprint of this impact extends several kilometres beyond the farm site and suggest these impacts, particularly on berried lobsters, may be associated with changes in habitat quality associated with sea-cage finfish activities. Crustaceans, in particular decapods, are known to be vulnerable to hypoxia and sulphides (see reviews in Diaz & Rosenberg 1995, Vaquer-Sunyer & Duarte 2010), and numerous studies have examined their periodic or short-term individual-level effect on behaviour, physiology, mortality and predation (see reviews in Van Son & Thiel 2007, Riedel et al. 2014). Few, if any, studies have examined the potential longer-term population-level consequences (e.g. recruitment, fecundity, density and sex structure) of hypoxia or sulphides. For example, survival of crustacean egg stages in the presence of hypoxia and sulphides is much lower than in adult and juvenile stages, suggesting decreased hatching success that could affect local population dynamics (Vaquer-Sunyer & Duarte 2010). A potential recruitment failure in one small bay is unlikely to have an impact on overall population size, but recruitment failures in many small bays could result in a population collapse (Hughes et al. 2005). In addition, currently most net-pen finfish aquaculture takes place in the same nearshore coastal ecosystems (Holmer et al. 2008) that also serve as important nursery habitat for lobster (Wahle & Steneck 1991). Not only is habitat quantity important for nursery areas, but so is habitat quality (e.g. food availability, water quality, habitat connectivity) (Beck et al. 2001). We are not suggesting there has been or will be a lobster recruitment failure in Port Mouton Bay as a result of sea-cage aquaculture. However, there are ~100 active sea-cage fish farms in Atlantic Canada (NBDELG 2014, NLDFA 2015, NSDFA 2017b), and >60% operate within the Bay of Fundy/southwest Nova Scotia lobster fishery management areas. Lobsters within these management areas are also subject to several other environmental stressors, such as ocean acidification (Waller et al. 2017) and climate change (Steneck & Wahle 2013). It will be important for fisheries managers to integrate multiple environmental stressors, including those associated with sea-cage aquaculture, into management frameworks to ensure the health of future lobster populations and the conservation of their habitat.

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LITERATURE CITED

Atema J, Voigt R (1995) Behavior and sensory biology. In: Factor JR (ed) Biology of the lobster *Homarus americanus.* Academic Press, San Diego, CA, p 313–348

Barbier EB, Hacker SD, Kennedy C, Koch EW, Stier AC, Silliman IR (2011) The value of estuarine and coastal ecosystem services. Ecol Monogr 81:169–193

Beck MW, Heck KL, Able KW, Childers DL and others (2001) The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51:633–641

Belias C, Dassenakis M, Scoullos M (2007) Study of the N, P and Si fluxes between fish farm sediment and seawater. Results of simulation experiments employing a benthic chamber under various redox conditions. Mar Chem 103: 266–275

Black KD, Kiemer MCB, Ezzi IA (1996) The relationships between hydrodynamics, the concentration of hydrogen sulphide produced by polluted sediments and fish health at several marine cage farms in Scotland and Ireland. J Appl Ichthyol 12:15–20

Boudreau SA, Worm B (2010) Top-down control of lobster in the Gulf of Maine: insights from local ecological knowledge and research surveys. Mar Ecol Prog Ser 403: 181–191

Burridge L, Weis JS, Cabello F, Pizarro J, Bostick K (2010) Chemical use in salmon aquaculture: a review of current practices and possible environmental effects. Aquaculture 306:7–23

Butterworth KG, Grieshaber MK, Taylor AC (2004) Behavioral and physiological responses of the Norway lobster, *Nephrops norvegicus* (Crustacea: Decapoda), to sulphide exposure. Mar Biol 144:1087–1095

Campbell A (1990) Aggregations of berried lobsters (*Homarus americanus*) in shallow waters off Grand Manan, eastern Canada. Can J Fish Aquat Sci 47:520–523

Carr JW, Whoriskey FG (2006) The escape of juvenile farmed Atlantic salmon from hatcheries into freshwater streams in New Brunswick, Canada. ICES J Mar Sci 63: 1263–1268

Carr JW, Anderson JM, Whoriskey FG, Dilworth T (1997) The occurrence and spawning of cultured Atlantic salmon (*Salmo salar*) in a Canadian river. ICES J Mar Sci 54: 1064–1073

Cowan DF, Watson WH III, Solow AR, Mountcastle AM (2007) Thermal histories of brooding lobsters, *Homarus americanus*, in the Gulf of Maine. J Mar Biol 179:70–78

Cross TF, Burnell G, Coughlan J, Culloty S, Dillane E, McGinnity P, Rogan E (2008) Detrimental genetic effects of interactions between reared strains and wild populations of marine and anadromous fish and invertebrate species. In: Holmer M, Black K, Duarte CM, Marbà N, Karakassis I (eds) Aquaculture in the ecosystem. Springer, Dordrecht, p 117–154

DFO (Department of Fisheries and Oceans Canada) (2007) Port Mouton site review. DFO Can Sci Advis Sec Sci Response 2007/009

DFO (2009) Review of cumulative effects report for Port Mouton, Nova Scotia. DFO Can Sci Advis Sec Sci Response 2008/015

DFO (2014) Aquaculture: production quantities and values. DFO, Ottawa. www.dfo-mpo.gc.ca/stats/aqua/aqua14-eng.htm (accessed 27 Oct 2017)

DFO (2017a) Fisheries statistics: seafisheries. DFO, Ottawa. www.dfo-mpo.gc.ca/stats/commercial/land-debarq/sea-maritimes/s2015av-eng.htm (accessed 27 Oct 2017)

DFO (2017b) Lobster (*Homarus americanus*) off the Atlantic coast of Nova Scotia (Lobster Fishing Areas 27-33): 2017 stock status update. DFO Can Sci Advis Sec Sci Rep 2017/026

Diaz RJ, Rosenberg R (1995) Marine benthic hypoxia: a review of its ecological effects and the behavioral responses of benthic macrofauna. Oceanogr Mar Biol Annu Rev 33:245–303

Draxler AFJ, Robohm RA, Wieczorek D, Kapareiko D, Pitchford S (2005) Effects of habitat biogeochemicals on survival of lobsters (*Homarus americanus*). J Shellfish Res 24:821–824

Drinkwater KF, Tremblay MJ, Comeau M (2006) The influence of wind and temperature on the catch rate of the American lobster (*Homarus americanus*) during spring fisheries off eastern Canada. Fish Oceanogr 15:150–165

Eriksson SP, Nabbing M, Sjöman E (2006) Is brood care in *Nephrops norvegicus* during hypoxia adaptive or a waste of energy? Funct Ecol 20:1097–1104

FAO (Food and Agriculture Organization of the United Nations) (2018) Cultured Aquatic Species Information Programme. Fisheries and Aquaculture Department, FAO, Rome. www.fao.org/fishery/collection/cultured-species/en (accessed 21 Mar 2018)

FSRS (Fishermen & Scientists Research Society) (2018) Nearshore temperature monitoring project. FSRS, Halifax. www.fsrs.ns.ca/temperature.html (accessed 21 Mar 2018)

Galparsoro I, Borja Á, Bald J, Liria P, Chust G (2009) Predicting suitable habitat for the European lobster (*Homarus gammarus*), on the Basque continental shelf (Bay of Biscay), using Ecological-Niche-Factor analysis. Ecol Modell 220:556–576

Geraldi NR, Wahle RA, Dunnington M (2009) Habitat effects on American lobster (*Homarus americanus*) movement and density: insights from georeferenced trap arrays, seabed mapping, and tagging. Can J Fish Aquat Sci 66: 460–470

Giles H (2008) Using Bayesian networks to examine consistent trends in fish farm benthic impact studies. Aquaculture 274:181–195

Goldstein JS, Watson WH III (2015) Seasonal movements of American lobsters in southern Gulf of Maine coastal waters: patterns, environmental triggers, and implications for larval release. Mar Ecol Prog Ser 524:197–211

Green BS, Gardner C, Hochmuth JD, Linnane A (2014) Environmental effects on fished lobsters and crabs. Rev Fish Biol Fish 24:613–638

Gregory D, Petrie B, Jordan F, Langille P (1993) Oceanographic, geographic and hydrographical parameters of Scotia-Fundy and southern Gulf of St. Lawrence inlets. Can Tech Rep Hydrogr Ocean Sci 143

Halpern BS, Walbridge S, Selkoe KA, Kappel CV and others (2008) A global map of human impacts on marine ecosystems. Science 319:948–952

Hargrave BT (2010) Empirical relationships describing benthic impacts of salmon aquaculture. Aquacult Environ Interact 1:33–46

Holmer M (2010) Environmental issues of fish farming in offshore waters: perspectives, concerns and research needs. Aquacult Environ Interact 1:57–70

Holmer M, Wildish D, Hargrave B (2005) Organic enrichment from marine finfish aquaculture and effects on sediment processes. In: Hargrave BT (ed) Environmental effects of marine finfish aquaculture, Vol 5M. Springer, Berlin, p 181–206

Holmer M, Black K, Duarte CM, Marba N, Karakassis I (eds) (2008) Aquaculture in the ecosystem. Springer, Dordrecht

Hudon C (1994) Large-scale analysis of Atlantic Nova Scotia American lobster (*Homarus americanus*) landings with respect to habitat, temperature, and wind conditions. Can J Fish Aquat Sci 51:1308–1321

Hughes TP, Bellwood DR, Folke C, Steneck RS, Wilson J (2005) New paradigms for supporting resilience of marine ecosystems. Trends Ecol Evol 20:380–386

Johansen LH, Jensen I, Mikkelsen H, Bjørn PA, Jansen PA, Bergh Ø (2011) Disease interaction and pathogens exchange between wild and farmed fish populations with special reference to Norway. Aquaculture 315: 167–186

Jury SH, Watson WH III (2000) Thermosensitivity of the lobster, *Homarus americanus*, as determined by cardiac assay. Biol Bull 199:257–264

Jury SH, Watson WH III (2013) Seasonal and sexual differences in the thermal preferences and movements of American lobsters. Can J Fish Aquat Sci 70:1650–1657

Kay MC, Lenihan HS, Guenther CM, Wilson JR, Miller CJ, Shrout SW (2012) Collaborative assessment of California spiny lobster population and fishery responses to a marine reserve network. Ecol Appl 22:322–335

Koeller P (1999) Influence of temperature and effort on lobster catches at different temporal and spatial scales and the implications for stock assessments. Fish Bull 97: 62–70

Lawton P, Lavalli KL (1995) Postlarval, juvenile, adolescent, and adult ecology. In: Factor JR (ed) Biology of the lobster *Homarus americanus*. Academic Press, New York, NY, p 47–81

Lawton P, Robichaud DA, Rangeley RW, Strong MB (2001) American lobster (*Homarus americanus*) population characteristics in the lower Bay of Fundy (Lobster Fishing Areas 36 and 39) based on fisheries independent sampling. DFO Can Sci Advis Sec Sci Res Doc 2001/093

Lewis CF, Slade SL, Maxwell KE, Mathews TR (2009) Lobster trap impact on coral reefs: effects of wind driven trap movement. NZ J Mar Freshw Res 43:271–282

Lotze HK, Lenihan HS, Bourque BJ, Bradbury RH and others (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312:1806–1809

Loucks RH, Smith RE, Fisher EB (2014) Interactions between finfish aquaculture and lobster catches in a sheltered bay. Mar Pollut Bull 88:255–259

McIver R, Milewski I, Loucks R, Smith R (2018) Estimating nitrogen loading and far-field dispersal potential from

background sources and coastal finfish aquaculture: a simple framework and case study in Atlantic Canada. Estuar Coast Shelf Sci 205:46–57
McLeese DW, Wilder DG (1958) The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. J Fish Res Board Can 15:1345–1354
Miller RJ (1990) Effectiveness of crab and lobster traps. Can J Fish Aquat Sci 47:1228–1251
Miller RJ, Duggan RE, Robinson DG, Zheng Z (1989) Growth and movement of *Homarus americanus* on the outer coast of Nova Scotia. Can Tech Rep Fish Aquat Sci 1716
Milligan TG, Law BA (2005) The effect of marine aquaculture on fine sediment dynamics in coastal inlets. In: Hargrave BT (ed) Environmental effects of marine finfish aquaculture, Vol 5M. Springer, Berlin, p 239251
Naylor RL, Hardy RW, Bureau DP, Chiu A and others (2009) Feeding aquaculture in an era of finite resources. Proc Natl Acad Sci USA 106:15103–15110
NBDELG (New Brunswick Department of Environment and Local Government) (2014) Fall 2014 annual monitoring summary for the environmental management program for marine finfish cage aquaculture. NBDELG, Fredericton. www2.gnb.ca/content/dam/gnb/Departments/env/pdf/MarineAquaculture-AquacoleMarin/Results-Resultats/2014EMPResults.pdf (accessed 3 Nov 2017)
NLDFA (Newfoundland and Labrador Department of Fisheries and Aquaculture) (2015) Number of active and non-active licensed salmonid aquaculture cage sites. NLDFA, St. John's. www.fishaq.gov.nl.ca/aquaculture/public_reporting/pdf/sites.pdf (accessed 3 Nov 2017)
NSDFA (Nova Scotia Department of Fisheries and Aquaculture) (2007) Environmental monitoring program. Level II monitoring results for Port Mouton lease #0835 July 01, 2007. NSDFA, Halifax
NSDFA (2014a) Environmental monitoring program. Level II monitoring results for Port Mouton lease #0835 July 16, 2014. NSDFA, Halifax
NSDFA (2014b) Standard operating procedures for the environmental monitoring of marine aquaculture in Nova Scotia. July 2014. NSDFA, Halifax
NSDFA (2017a) Public information. NSDFA, Halifax. https://novascotia.ca/fish/aquaculture/public-information/ (accessed 19 Sep 2017)
NSDFA (2017b) Environmental monitoring program summary 2015. NSDFA, Halifax. https://novascotia.ca/fish/documents/EMP_Summary_2015.pdf (accessed 3 Nov 2017)
Pickering T, Williams J, Apaloo J (2010) Catch variation among traps in an American lobster (*Homarus americanus*) trawl. Fish Res 106:555–559
Piper DJW, Mudie PJ, Letson JRJ, Barnes NE, Iuliucci RJ (1986) The marine geology of the inner Scotian Shelf off the south shore, Nova Scotia. Paper 85-19. Geological Survey of Canada, Ottawa
Price C, Black KD, Hargrave BT, Morris JA Jr (2015) Marine cage culture and the environment: effects on water quality and primary production. Aquacult Environ Interact 6: 151–174
R Core Team (2016) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. www.R-project.org
Riedel B, Pados T, Pretterebner K, Schiemer L and others (2014) Effect of hypoxia and anoxia on invertebrate behaviour: ecological perspectives from species to community level. Biogeosciences 11:1491–1518
Sapkota A, Sapkota AR, Kucharski M, Burke J, McKenzie S, Walker P, Lawrence R (2008) Aquaculture practices and potential human health risks: current knowledge and future priorities. Environ Int 34:1215–1226
Saunders R (1995) Salmon aquaculture: present status and prospects for the future. In: Boghen AD (ed) Cold-water aquaculture in Atlantic Canada. Canadian Institute for Research on Regional Development, Moncton, p 35–82
Seitz RD, Wennhage H, Bergström U, Lipcius RN, Ysebaert T (2014) Ecological value of coastal habitats for commercially and ecologically important species. ICES J Mar Sci 71:648–665
Steneck RS, Wahle RA (2013) American lobster dynamics in a brave new ocean. Can J Fish Aquat Sci 70:1612–1624
Steneck RS, Hughes TP, Cinner JE, Adger WN and others (2011) Creation of a gilded trap by the high economic value of the Maine lobster fishery. Conserv Biol 25: 904–912
Stephenson RL (1990) Multiuse conflict: aquaculture collides with traditional fisheries in Canada's Bay of Fundy. World Aquacult 21:34–45
Tremblay MJ, Drinkwater KF (1997) Temperature, catch rate, and catchability during the spring lobster fishery off eastern Cape Breton. DFO Can Stock Assess Sec Res Doc 97/119
Tremblay MJ, Smith SJ (2001) Lobster (*Homarus americanus*) catchability in different habitats in late spring and early fall. Mar Freshw Res 52:1321–1331
Tremblay MJ, Smith SJ, Todd BJ, Clement PM, McKeown DL (2009) Associations of lobsters (*Homarus americanus*) off southwestern Nova Scotia with bottom type from images and geophysical maps. ICES J Mar Sci 66: 2060–2067
Ugarte RA (1994) Temperature and distribution of mature female lobsters (*Homarus americanus*, Milne Edwards) off Casco, N.S. PhD dissertation, Dalhousie University, Halifax
Uglem I, Karlsen O, Sanchez-Jerez P, Sæther B (2014) Impacts of wild fishes attracted to open-cage salmonid farms in Norway. Aquacult Environ Interact 6:91–103
Van Son TC, Thiel M (2007) Anthropogenic stressors and their effects on the behavior of aquatic crustaceans. In: Duffy JE, Thiel M (eds) Evolutionary ecology of social and sexual systems: crustaceans as model organisms. Oxford University Press, New York, NY, p 413–441
Vaquer-Sunyer R, Duarte CM (2010) Sulphide exposure accelerates hypoxia-driven mortality. Limnol Oceanogr 55:1075–1082
Wahle RA, Steneck RS (1991) Recruitment habitats and nursery grounds of the American lobster *Homarus americanus*: a demographic bottleneck? Mar Ecol Prog Ser 69: 231–243
Waller JD, Wahle RA, McVeigh H, Fields DM (2017) Linking rising pCO2 and temperature to the larval development and physiology of the American lobster (*Homarus americanus*). ICES J Mar Sci 74:1210–1219
Walters B (2007) Competing use of marine space in a modernizing fishery: salmon farming meets lobster fishing in the Bay of Fundy. Can Geogr 51:139–159
Wiber M, Wilson L, Young S (2012) Impact of aquaculture on commercial fisheries: fishermen's local ecological knowledge. Hum Ecol 40:29–40
Zimmermann EW, Purchase CF, Fleming IA, Brattey J (2013) Dispersal of wild and escapee farmed Atlantic cod (*Gadus morhua*) in Newfoundland. Can J Fish Aquat Sci 70:747–755

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