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ARTICLE

Long-term studies of lobster abundance at a salmon aquaculture site, eastern Canada

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Abstract: Wild lobster (*Homarus americanus*) abundance was monitored before, during, and after salmon (*Salmo salar*) aquaculture production in a bay on Grand Manan Island, New Brunswick, Canada, in an 8-year survey, 2008 to 2015. Diver transects and free-area spot-dives were used to measure the carapace length and determine sex (including berried state) of each lobster encountered both inside (farm) and outside (reference) the lease boundaries. In pairwise comparisons of each sampling date, there was no significant difference between the number of lobsters inside the salmon farming area versus a nearby reference site and no significant difference in the number of berried females inside or out of the farm lease area. Combining data from all lobster surveys (farm and reference sites) indicated an increase over 8 years, similar in slope to the increase of the trap fishery in Lobster Fishing Area (LFA) 38. These results indicate that the fish farm had no obvious impact on lobster density at any point in the salmon production cycle and that inshore lobster abundance followed trends similar to those of the general fishery of LFA 38.

Résumé : L'abondance des homards (*Homarus americanus*) sauvages a été mesurée avant, durant et après le début de la production aquacole de saumons (*Salmo salar*) dans une baie de l'île Grand Manan (Nouveau-Brunswick, Canada) dans le cadre d'une étude sur huit ans, de 2008 à 2015. Des plongées le long de transects et des plongées ponctuelles ont été utilisées pour mesurer la longueur de la carapace et déterminer le sexe (et l'état œuvé) de chaque homard rencontré à l'intérieur (pisciculture) et à l'extérieur (référence) des limites de la concession. Des comparaisons par paire de chaque date d'échantillonnage n'ont révélé aucune différence significative entre le nombre de homards à l'intérieur de la pisciculture de saumons et le site extérieur de référence avoisinant, ni aucune différence significative du nombre de femelles œuvées entre l'intérieur et l'extérieur de la concession piscicole. Les données combinées de tous les relevés de homards (sites de pisciculture et de référence) indiquent une augmentation sur huit ans de pente semblable à celle de l'augmentation de la pêche au casier dans la zone de pêche au homard (ZPH) 38. Ces résultats indiquent que la pisciculture n'a pas eu d'impact évident sur la densité de homards à quelque moment que ce soit du cycle de production des saumons et que l'abondance de homards dans les eaux côtières a suivi des tendances semblables à celles de la pêche en général dans la ZPH 38. [Traduit par la Rédaction]

Introduction

The sustainability of coastal aquaculture is in part dependent on its fit with other coastal zone activities, including commercial fisheries, recreational use, resource extraction, and conservation. Fish farming in net-pens or cages occurs in discrete, well-defined areas, but two concerns of farm siting are its boundaries that may exclude other activities and its ecological footprint, including solid and dissolved waste dispersion. In Atlantic Canada net-pen culture of Atlantic salmon (*Salmo salar*) is a major economic activity. The lobster (*Homarus americanus*) fishery takes place in the same coastal environments as fish farming and is among the most valuable of commercial species. Designated Lobster Fishing Areas (LFAs) in the Bay of Fundy are the most prolific of *H. americanus* fisheries (Serdynska and Coffen-Smout 2017). Landings have shown huge increases over the last 10 years (DFO 2015), but conflicts between lobster fishing and fish farming remain for several reasons. For example, the availability of space for deployment of lobster traps is suggested to be compromised by space occupied by fish farms. However, stronger interactions have been suggested regarding the waste stream from the farm. First, organic loading of sediments due to deposition of waste food and feces in some cases produces hypoxic sediments beneath fish pens (Chang et al. 2014). Lobsters occupy a variety of substrates from mud to rock, with a preference for gravel in the early benthic phase (Pottle and Elner 1982). Fish farms are also sited on many bottom types, and locations with dispersive flows are less likely to accumulate waste and alter bottom habitat (Keeley et al. 2013). Second, some pesticide treatments specifically for sea lice, applied either in feed or in bath treatments (tarps surrounding pens or in well boats) may be harmful to crustaceans (Burridge et al. 2010), and there have been lobster mortality events due to pesticide dispersion (Wiber et al. 2012).

Grand Manan Island, a large Canadian island in the Gulf of Maine off New Brunswick, is home to multiple salmon farming sites and to a lucrative lobster fishery (Campbell 1992). The island is part of LFA 38, in which the fishery is conducted from about mid-November to the end of June via 136 trap licenses. According to DFO (2015, page 1), "Landings in LFAs 35–38 began a long-term increase in the mid-1990s and current landings are at record highs." Grand Manan is characterized by typically large regional tides (5 m) and is also the site of documented conflicts between these industries (Walters 2007).

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In the 1980s, salmon aquaculture was active on the northeast coast of Grand Manan in Flagg's Cove and Dark Harbour. As a result of originally unregulated farming practices, the seafloor experienced benthic degradation (Rosenthal and Rangeley 1989), reducing lobster habitat quality in Flagg's Cove. Lobster abundance recovered after the site was removed. This failed attempt to sustainably culture salmon was a result of suboptimal practices, which are now monitored and regulated with government involvement through New Brunswick's Aquaculture Environmental Monitoring Program (EMP), via their Department of Environment and Local Government (NBDELG 2018). Regardless of the development of best management practices in aquaculture, when a new salmon aquaculture lease was approved in 2007, 12 km south of Flagg's Cove on the northeast coast of Cheney Head Island (Duck Island Sound), surveys of lobster abundance became a condition of the lease. The goal of the surveys was to track the occurrence of lobster inside and outside the lease area, before, during, and after production. The following study presents the findings of the mandated surveys to determine how aquaculture practices might affect lobster populations in the immediate vicinity (within lease boundaries) and at the scale of a portion of Duck Island Sound.

In the following study, we undertook diver-based lobster surveys over an 8-year survey in a before–after, control–impact design experiment (Underwood 1991). We hypothesize (*i*) trends in lobster abundance at a salmon aquaculture site, including pre-aquaculture cycles and cycles into production, are identical to trends at a reference site of similar depth and bottom type, and (*ii*) both sites follow a trend similar to the larger regional fishery of LFA 38.

Methods

Lobster surveys over 8 years were conducted via diver transects and free-area spot-dives during the summer–fall months of August and September, 2008 to 2015. The timing of the surveys targeted the first 2 weeks in each of those months to capture summer lobster populations before their fall migration to deeper waters; however, in 2008 only one survey took place, 20–21 August. The August 2011 survey was delayed until the third week of the month due to weather. No aquaculture activities took place on the site in preproduction years 2008 and 2009. Within the remaining 6 years there were two production cycles, 2010–2011 and 2013–2014, where Atlantic salmon were grown on site, and two fallow periods, 2012 and 2015, where all production stopped.

Study site

All surveys were conducted in and around lease area MF-0503 at Cheney Head (26.51 ha) located on the northeast side of Cheney Island, off Grand Manan Island, New Brunswick (Fig. 1). Water depth in the area ranges from ~5 to 15 m, while the center of the Cheney Head site sits in ~14 to 16 m of water at low tide. Location in the Bay of Fundy signifies large semidiurnal tidal currents ($>0.5\ \mathrm{m{\cdot}s^{-1}}$) with a range of 6 m. The general direction of flow is north–south; however, direction and speed are influenced by rocks and ledges. The Cheney Head site is typical for a salmon farm off Grand Manan, employing plastic circular cages and standard husbandry methods. The Cheney Head site started with 100 000 fish, which is small in comparison with other farms in the area of southwestern New Brunswick. For the second production cycle, the number of fish increased to ~336 000. Other farms in the area were stocked at 380 000 to 490 000 fish during that time.

Transect dives

A total of six diver transects were established off the coast of Cheney Island based on the transect locations from a previous lobster survey conducted in the same area by Fisheries and Oceans Canada in 2007 (Robichaud 2007), with three transects inside (farm) and three outside the lease boundaries (reference) (Fig. 1A). Location of transects at the farm were constrained by the farm boundaries and avoidance of net-pen infrastructure. Reference transects were along similar depths and substrate as the farm. Georeferenced coordinates were used to position the transect lines in approximately the same locations each year. However, after the grid system and cages were placed on site in 2010, positions for transects 1, 2, and 3 were altered somewhat to avoid the cage array. For instance, transect 2 was broken into two segments as a result of cage interference with the original transect line. Additional adjustments to transects 1 and 2 were required in 2013 when a larger cage array was installed.

Each transect was 300 m long and was marked every 25 m, yielding 12 sections per line. A weighted sinking rope was used to position and anchor the line on the bottom during diver surveys. Lines were marked with floats at each end and at the 150 m mark to facilitate line retrieval and to aid in diver orientation. Each survey consisted of two divers swimming the length of the transect, and for each of the 12 sections, observations within 1 m on either side of the line were recorded. One diver captured lobsters while the second measured the carapace length (CL) with stainless steel calipers (scale in 1 mm increments) and determined the sex of each lobster, including the egg stage of berried females. All lobsters <50 mm CL were considered juvenile due to the difficulty in accurately sexing small lobsters underwater.

Spot-dives

Two free-area dive searches were also included in each survey period: one just inside the northwest corner of the lease area and the second 1.1 km outside the lease to the southwest (Fig. 1A). The starting coordinates of the spot-dives were the same for each survey; divers then swam in a haphazard manner and searched for lobsters for approximately 30 min. The same CL and lobster sex data were recorded during the spot-dives as the transect dives.

Benthic conditions

Bottom sediment type was defined using video footage collected during each of the transect and spot-dives. Videos were recorded with a SONY Handycam camcorder housed in an Amphibico Dive Buddy or a GoPro Hero (2, 3, or 3+) with GoPro dive camera housing case. Battery time constraints limited video collection to ~15 min of each dive. The provincially mandated EMP that classifies the level of benthic health using the concentration of dissolved sulfide in undisturbed surface sediments coincided with the survey dates and was used to characterize further the substrate. EMPs were conducted within 1 week of the September lobster survey each year.

LFA 38 data

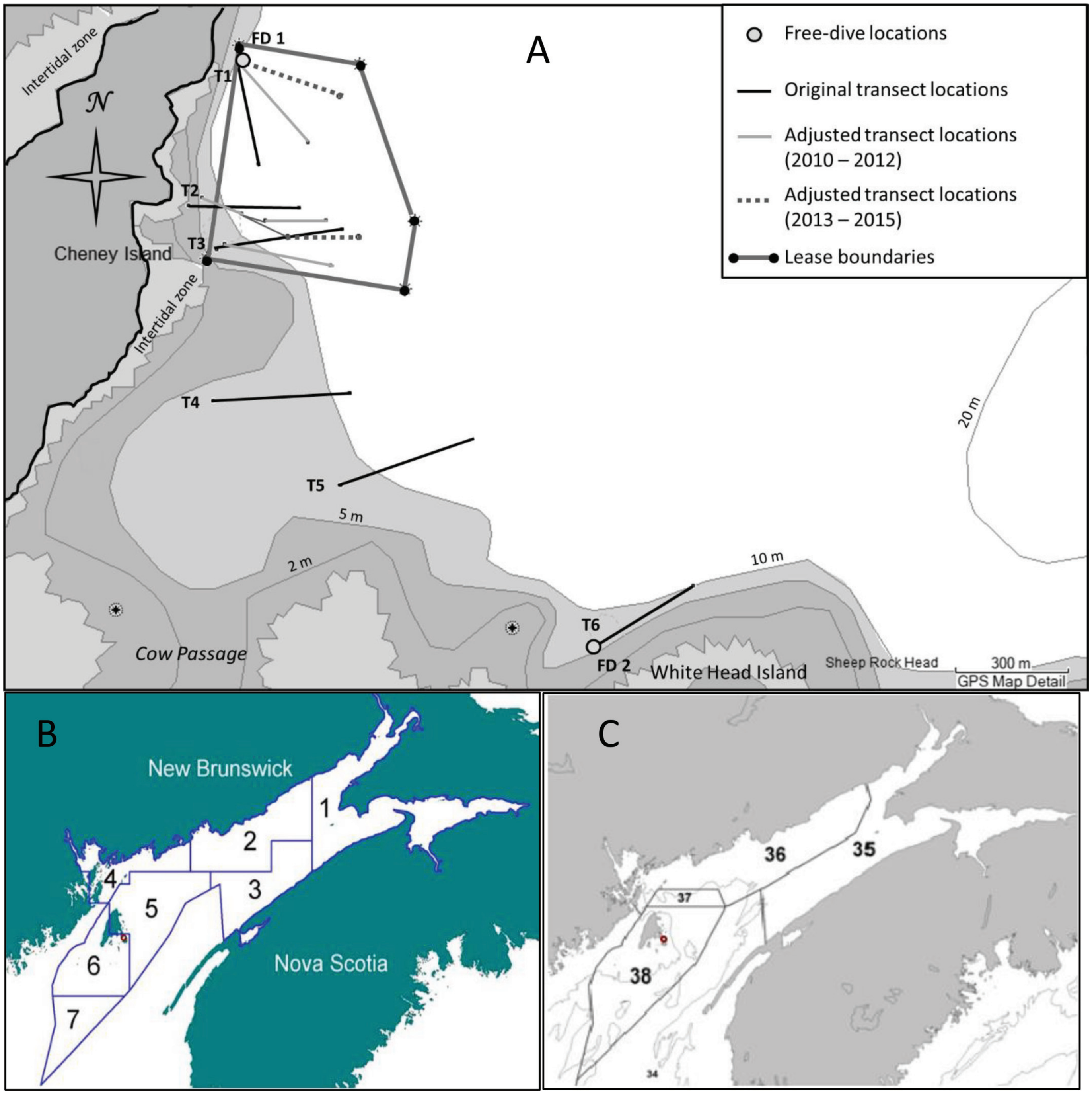
Aquaculture lease boundaries and the larger bay fall within LFA 38 (Fig. 1C) and in grid group 6 (GG-6; Fig. 1B) as defined by Fisheries and Oceans Canada (DFO 2013). To compare lobster abundance trends in the study area with the greater LFA, aggregated landings from fisher logbooks and the corresponding effort data spanning from the 2007–2008 to the 2014–2015 season were collated. Data were provided directly by DFO (2016). We found no difference in fishery statistics by analysing GG-6 separately from LFA 38 and consider only the latter, which is the more commonly known management unit.

Results

Benthic conditions

A mixture of bottom types ranging from coarse sand to gravel and cobble characterized the sedimentary environment of the study area. No changes were apparent over the 8 years. This bottom type is typical of most salmon farms on Grand Manan Island. Among 20 farms on Grand Manan, only one has sediments categorized as mud, the rest being sand, gravel, and shell debris (T. Daggett, personal observations). At Cheney Head, there were

Fig. 1. (A) Cheney Head bathymetry, salmon farm lease boundaries, sampling transects, and free dive locations. Farm transects are inside the lease polygon; reference transects are outside. White areas are >10 m depth. Map was created with Garmin MapSource software using BlueChart Americas v9.5. (B) Grid groups (GGs) from 10 min grids in LFA 35–38 logbooks (bottom left). (C) Lobster Fishing Areas (LFAs) 35–38. The red circle in GG-6 and LFA 38 is the location of the Cheney Head lease area on Grand Manan Island. Panels B and C are modified from DFO (2013). [Colour online.]



increases in farm production in the second production cycle (2013–2014) compared with the first production cycle (2010–2011) and changes to the provincial EMP standard operating procedures in 2013 and 2014. Regardless, the Cheney Head lease site was consistently classified as Oxic A (<750 μmol·L^{-1} of dissolved sediment sulfide, which indicates normal–oxic sediment) from 2010 to 2015 (Table 1). Prior to production, EMP monitoring was not required, but it is a condition of the government-issued Approval to Operate certificate. When an aquaculture site is fallow (i.e., not under production), this certificate is not required.

Survey data

Lobsters were numerous in all the survey areas, and a total of 1255 individuals were sampled inside the lease (farm area) and 1171 outside the lease (reference area) during the study period. The aggregate population was dominated by individuals of commercial size (>82.5 mm CL). Over 50% of the lobsters observed during the 8-year survey were within the 61–100 mm CL size range (Fig. 2). This mean size range was smaller than that found off Flagg's Cove on Grand Manan Island by Tremblay et al. (2006) in 2001–2002, where most lobsters fell in the 100–130 mm CL range.

Table 1. New Brunswick Environmental Monitoring Program results for the Cheney Head salmon farm (lease area MF-0503).

Cheney Head	Sulphide (μmol·L^{-1})
2015	4
2014	160
2013	144
2012	0
2011	705
2010	349

Note: Free dissolved sulfide determined by ion-specific electrode. The Cheney Head lease site was consistently classified as Oxic A (<750 μmol·L^{-1} of dissolved sediment sulfide). Source: produced from data in NBDELG 2018.

Fig. 2. Numbers of lobsters from all sites in 10 mm carapace length bins. Vertical lines represent the upper and lower quartiles.

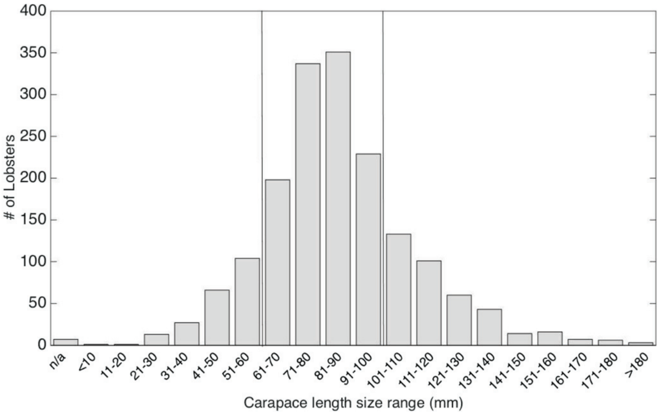
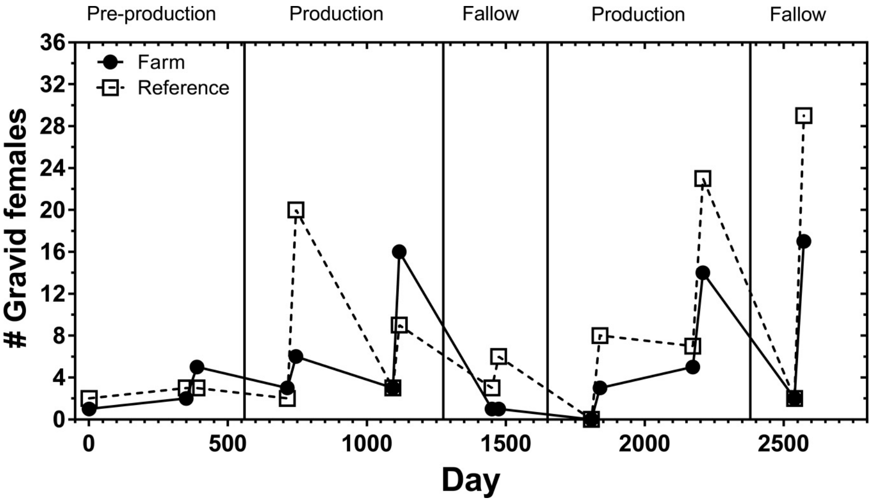


Fig. 3. Numbers of berried (gravid) female lobsters during the study period at the fish farm site versus the reference site.



Sex ratio (male:female) was usually >1 with a maximum ~1.6 and no significant difference in numbers of either sex in comparisons in the farm area versus the reference (paired Wilcoxon ranked sign test, $p = 0.097$ males; $p = 0.416$ females, $n = 15$ pairs; data were non-normal; $\alpha = 0.05$ here and following). The percentage of berried females ranged from 0% to 38% over all the sampling, with about half of the values ≤15%. There was no significant difference in the number of berried females in the farm versus reference areas (paired Wilcoxon ranked sign test, $p = 0.071$, $n =$ –15 pairs). However, on 7 of 15 comparison dates, there were three or fewer berried lobsters at both reference and farm sites (Fig. 3). Numbers of berried females were correlated in the farm and reference areas (Pearson $r = 0.797$, $p < 0.001$, $n = 15$).

The mean lobster density calculated from all transect dives during the study (600 m^2·transect^{-1}) was 0.035 individual·m^{-2} inside the lease (farm) and 0.028 individual·m^{-2} outside the lease (reference). Lower densities were found at farm and reference areas by Robichaud (2007) in the year prior to our starting date, 0.016 and 0.01 individual·m^{-2}, respectively. Robichaud's (2007) data did, however, fall within the minimum and maximum densities observed during the time of the current study (farm range = 0.009–0.079 individual·m^{-2}; reference range = 0.08–0.062 individual·m^{-2}).

The total number of lobsters (transects and spot-dives) were summed for each sampling date, separately at farm and reference areas. There was no significant difference between the number of lobsters in comparisons of farm versus reference totals, paired at each sampling date (paired t test, $p = 0.79$; D'Agostino and Pearson normality test, $p = 0.371$ and 0.227, respectively, $n = 15$).

Mean numbers of lobsters shown for each sampling date indicate that both farm and reference locations had increasing trends in lobster density during the study period (Fig. 4). In the reference area, this trend was significant through time (Fig. 4). Within the farm, the trend was not significant due to the generally greater spatial variation in lobster density found there (Fig. 4). Part of the variance is due to an increase in numbers consistently occurring from August to September in each of the sampling years. We emphasize that these trends were independent of production phases of the farm and that lowest lobster density occurred before the farm was established. It is apparent from Fig. 4 that the trajectories of increase in lobster abundance converged on similar density at the farm and reference sites. The ranges of density overlapped in every comparison between farm and reference sites, reinforcing the results of the paired t test for total abundance, which indicate no significant location difference. In summary, these data provide no statistical evidence of an effect of the fish farm location on lobster density. However, it is important to interpret these results in the context of the regional lobster fishery in LFA 38.

Comparison with LFA data

The landings from LFA 38 were standardized by effort (trap hauls) to derive catch per unit effort (CPUE) and expressed as

Fig. 4. Mean number of lobsters observed per dive at the farm site and reference site ($n = 4$; 3 transects + 1 spot-dive for each site) during each survey from August 2008 (day 0) to September 2015 (day 2571). Every year except 2008 has both an August and September sampling date. Error bars represent standard deviation of each mean. Linear regression, farm site: $y = 0.0065x + 12.028$, $R^2 = 0.252$, $p = 0.0567$; reference site: $y = 0.0077x + 9.0074$, $R^2 = 0.572$, $p = 0.001$.

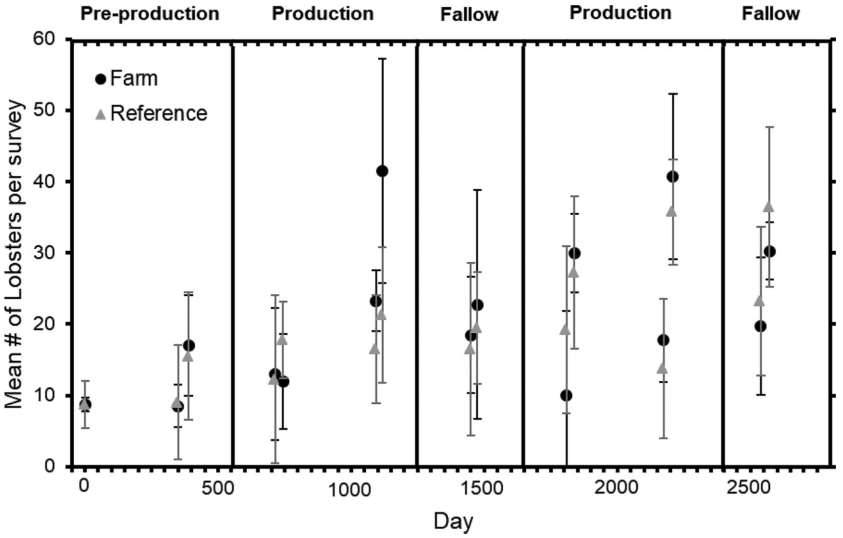
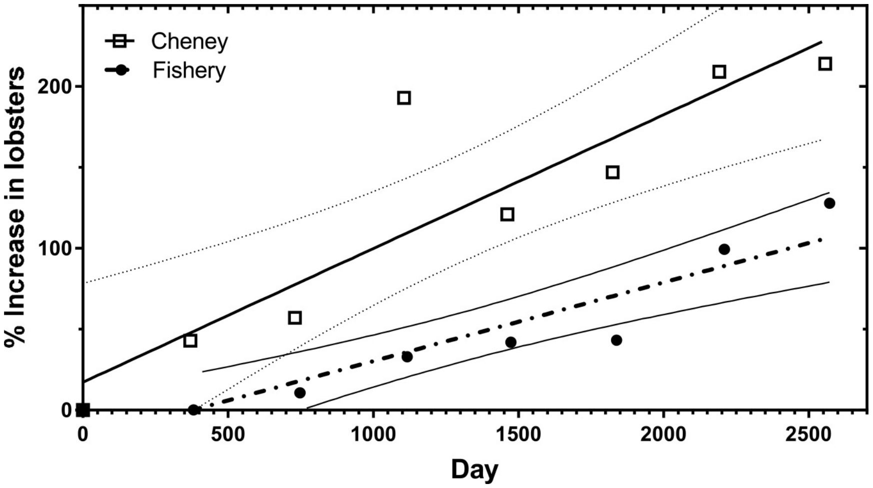


Fig. 5. Seasonal catch per unit effort data (pounds per haul; 1 lb = 0.453 kg) for LFA 38 (Fishery) and annual August–September mean of total number of lobsters observed in combined farm and reference surveys (Cheney Head) from 2008 to 2015. Both data sets have been normalized as percent increases from the initial value. Cheney regression: $y = 0.083x + 17.27$, $R^2 = 0.81$, $p = 0.002$; Fishery regression: $y = 0.043x - 18.31$, $R^2 = 0.878$, $p < 0.001$.



percent increase from the starting value in 2008. To compare the Cheney Head survey data to the regional abundance in LFA 38, we summed the farm and reference data on each sampling date to produce a single estimate of total lobster density for the entire sampling area. Lack of significant differences between these samples justifies their summation. The August and September survey dates were then averaged per year (see August–September variation in Fig. 4) and compared with the DFO lobster fishery season that had just ended. In LFA 38, the fishery is conducted from the second Tuesday in November to 29 June. Because each data set produced a single annual value, we made the date consistent between them.

LFA 38 displayed significant increases in lobster abundance (estimated as CPUE) over the eight seasons (Fig. 5). Cheney Head (farm + reference) also showed a significant increase in abundance (Fig. 5). An F test of the slopes indicated no significant difference between them ($F = 3.608$; $p = 0.0818$). However, the intercepts were significantly different ($F = 23.33$; $p = 0.0003$) indicating that although similar in slope, the regression lines were displaced in elevation. Variation in the regressions is obvious, each with a single substantial outlier beyond 95% confidence interval (Fig. 5). Differences in intercept between the lines are not surprising since the data are from very different sources. Beyond their location difference, CPUE data are a cumulative total over the fishing season, while the Cheney Head data are from averaged August and September samples outside of the fishing season. Despite the difference in data sources, LFA 38 and Cheney Head show a similar temporal trend, suggesting that over this multiyear time series, inshore lobsters reflect the abundance of the regional (LFA 38) population.

Discussion

Our results show that the salmon farming cycle at Cheney Head, including fallow periods, had no obvious influence on lobster abundance. It is important, however, to examine the applicability of this finding to other fish farming sites, the modes by which lobster populations could be affected by salmon farming, and the extent to which they apply to the present study.

The farm site and reference area transects are ideal gravel–cobble habitats for lobster (Pottle and Elner 1982). Density values as much as 0.1 individual·m^{-2} are typical for Grand Manan shallow waters (Tremblay et al. 2006), but higher densities (1 individual·m^{-2}) have been observed in Maine (Steneck and Wilson 2001). Coarse sediments are often nondepositional, and it is obvious that there is not local accumulation of farm waste in the sediment, since regulatory monitoring indicates a consistent classification of Oxic A, the least impacted category (NBDELG 2018). Using available provincial EMP data for the 20 salmon farms on Grand Manan, 11 had sulfides exceeding 750 μmol·L^{-1} (limit of Oxic A classification) in EMP years 2012–2014, but none in more than one of those years. Collectively, these are largely nondepositional sites at similar depths with few near-field eutrophication impacts, and our results should be widely applicable to Grand Manan. Although a similar lobster study would be of interest in depositional soft sediments, such conditions are not typical lobster habitat, and substrate suitability for lobsters might confound fish farm effects in interpretation of results. The Cheney Head farm is an example of a well-managed, well-sited fish farm and as such stands as an example that fish farms can have no apparent negative impact on local lobster abundance.

The topic of far-field effects often arises in consideration of organic deposition dispersing away from fish farms. The literature has limited documentation of far-field impacts (Grant 2010) and typically involves small inlets with closely spaced fish farms (Wildish 2005), a situation that is avoided in modern husbandry. In the highly dispersive macrotidal environment of the Cheney Head salmon farm, it is unlikely that there are regional (farm + reference) impacts of organic deposition in the benthos, confirmed by the EMP data, which includes reference sites. Trace metals from either food waste or antifouling treatments (e.g., Zn, Cu) have also been associated with sediments near salmon farms (Chou et al. 2002), but in nondepositional environments we expect lack of accumulation as with organic matter.

The risk to lobster populations from pesticide exposure applied to treat sea lice is difficult to assess under field conditions. Our limited data for the Cheney Head farm indicate that bath (well boat and tarp) and in-feed treatments were used for sea lice. Exposure to water-borne therapeutants studied via brief exposure in laboratory experiments indicates variable toxicity (Burridge et al. 2014), depending on which product is applied. Recent studies by Ernst et al. (2014) in the Bay of Fundy examined the scope for pesticide dispersion in a series of dye experiments simulating tarp treatments. Their results suggest that potentially deleterious pesticide concentrations could occur up to several hundred metres from a treated cage, but this is dependent on the specific pesticide applied, exposure time, nontarget species- and life-stage-specific toxicity, and hydrodynamic regime. Although in-feed treatments might be expected to provide a direct route for pesticide exposure (since lobsters could ingest waste feed beneath cages), laboratory studies suggest that the dose in feed pellets is not necessarily harmful to adult lobsters (Burridge et al. 2004). In addition, salmon food pellets are not a preferred food source for *H. americanus* (Waddy et al. 2007). In-feed treatments may persist in sediments for long periods (Benskin et al. 2016), but we would not expect this mode of exposure at a nondepositional site like Cheney Head.

Pesticides used for sea lice have also been shown to impact lobster spawning (Burridge et al. 2008). Our data suggest that gravid females on the farm follow a similar temporal pattern compared with the reference site, but this trend was not obviously related to the farm production–fallow cycle, and the highest number of gravid females occurred at the end of the time series. Correlation between the dynamics of farm and reference sites indicates that application of sea lice treatments on the farm is not decoupling these patterns. In describing the preliminary results of a field study, Maillet et al. (2017) suggest that gravid females avoid farms undergoing pesticide treatment. Laboratory experiments on female lobster behavior relative to pesticides either in sediments or in water-borne application would be fruitful in addressing this question (see also Abgrall et al. 2000).

Our second hypothesis was that lobster abundance at the fish farm–reference site followed the temporal pattern shown in the wider population. This is demonstrated in the similarity of slope in trends at the combined farm–reference site and LFA 38. If the fish farm affected lobster abundance, either positively or negatively, the trend demonstrated in the LFA 38 fishery would not be observed at the 1–10 km scale of our sampling (farm and reference). Owing to seasonal migrations (see below), inshore–offshore lobsters may be viewed as effectively the same populations. In an investigation of indices used for assessing lobster populations, research trawl data demonstrated the same large increase in abundance as fishery statistics (DFO 2015). Our diver surveys indicate similar agreement with fishery data, providing confidence that the temporal trends documented for the fish farm and reference area accurately capture dynamics of local abundance.

There are clearly ecosystem-level factors affecting increased lobster abundance in eastern Canada, and our results suggest that they are reflected in the nearshore as well. The loss of groundfish due to overfishing in continental shelf ecosystems in parts of eastern Canada is a major alteration to these systems, including a shift from a demersal to a pelagic food chain (Bundy 2005). Among other observed effects, large increases in lobster abundance in recent decades have not been easy to relate to apparent regime shifts occurring from fishing down the food web. It has been suggested that increased lobster abundance is due to release from predation pressure by the decline in demersal fish (Boudreau and Worm 2010). Wahle et al. (2013) suggest that overfishing of larger predatory fish in the Gulf of Maine has given lobsters a size refuge from predation, contributing to their increasing numbers. If there is any local impact of fish farming on lobster populations at Cheney Island, it is obscured by the larger trend of increasing abundance.

Lobsters are known to be attracted to food resources and shelter (Karnofsky et al. 1989), these attractants being the basis of the trap fishery. Lobster fishers on Grand Manan have in the past trapped close to salmon cages to take advantage of potentially higher abundance (Walters 2007). However, our data do not indicate increased abundance on the farm site compared with reference areas. Moreover, lobster abundance at the farm site continues to increase even through fallow periods.

It has been suggested that lobsters seek warmer water to enhance temperature-dependent processes such as molting and egg development. Campbell (1986) conducted mark–recapture studies of lobsters off Grand Manan and confirmed that they undertake two seasonal migrations, entering shallow waters in summer and retreating to deeper, colder waters in fall. This might lead to higher densities in August compared with September if fall migrations to deeper water occurred during the study period. However, we usually saw higher densities in September than in August, and water temperatures are similar between these months (Campbell 1986), confirmed in our data collected during this study (data not shown).

There are few studies that specifically consider the interaction between lobster fisheries and fish farming. Loucks et al. (2014) suggested that a steelhead (*Oncorhynchus mykiss*) farm in coastal Nova Scotia caused baywide reduction in lobster catches. The methods and results of this research were subsequently called into question (Grant et al. 2016). Trapping locations by fishers were estimated in their study rather than documented by GPS, and the designated spatial sampling regions for lobster overlapped in their distances from the farm. Moreover, sampling involving only the final 2 weeks on the fishing season was potentially influenced by the prior months of catches (see also Loucks et al. 2016). We consider our study to be a comprehensive work on lobster–fish farm interactions because it contained a multiyear time series and a repeated spatial sampling plan, it included all aspects of the salmon production cycle, and it compared data with wild fishery dynamics. The timing of our annual sampling timing predates the start of the annual lobster fishing season in LFA 38, so we anticipate that our survey results were not influenced by trapping pressures.

It is likely that potential conflicts between lobster fishing and fish farming will persist. Conflict resolution in coastal resource use is managed via marine spatial planning, an approach previously applied to aquaculture (Filgueira et al. 2014). Although scientific studies are essential in this process, consultation among stakeholders is key to decision making. Mapping of fishing areas and lobster habitat is important in this planning, as demonstrated for lobsters by Serdynska and Coffen-Smout (2017). Initial efforts at marine spatial planning were promoted for Grand Manan in a study by Lane et al. (2008). An ecosystem approach to aquaculture requires an assessment of zones of impact surrounding coastal activities and an understanding of far-field effects. Continued dialog in the framework of a structured planning process among coastal resource industries, coastal residents, and regulators is key to avoiding conflict and pursuit of sustainability in shared use of the ocean.

Acknowledgements

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