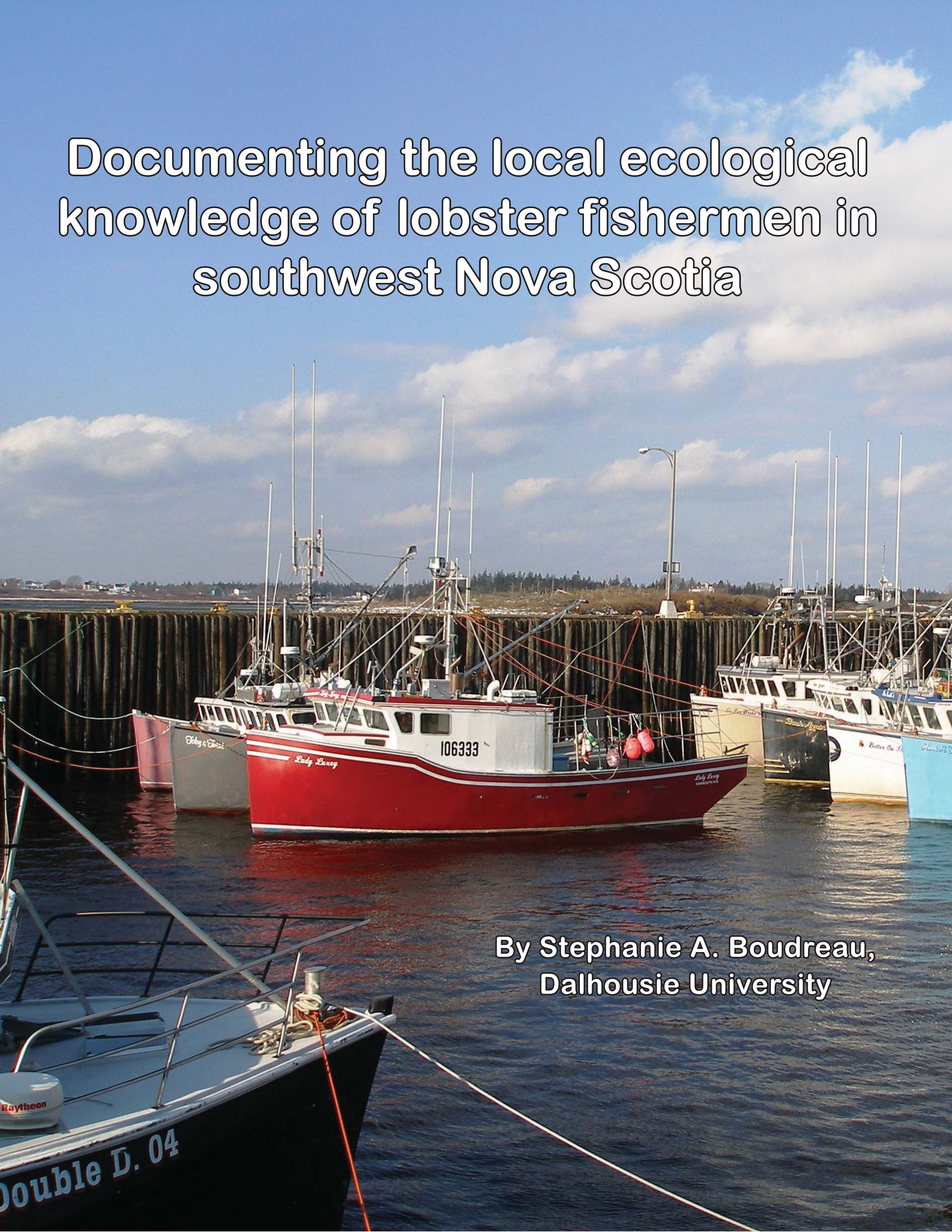
Documenting the local ecological knowledge of lobster fishermen in southwest Nova Scotia



By Stephanie A. Boudreau,
Dalhousie University

Contents

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Study written and conducted by Stephanie A. Boudreau as part of her PhD thesis research in the Biology Department at Dalhousie University. Report edited by Catherine Muir.

COVER PHOTO: Boats in harbour at the Yarmouth Public Wharf, by Stephanie A. Boudreau

BACK COVER PHOTO: Gear at the Little River Harbour Wharf, by Christopher A. Boudreau

Acknowledgements

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Scientific survey

The results from the survey of fishermen in LFA 34 are published in an article in the scientific journal Marine Ecology Progress Series (Vol 403: pages 181-191, 2010, titled "Top-down control of lobster in the Gulf of Maine: insights from local ecological knowledge and research surveys"). The article is attached and is also available for free online at http://www.int-res.com/articles/meps_oa/m403p181.pdf. Please contact Stephanie Boudreau at 902-494-2478, or s.boudreau@dal.ca, or care of the Biology Department, Dalhousie University, 1459 Oxford Street, Halifax, N.S., B3H 4R2 if you have any questions or comments.

Detailed answers to survey questions

PHOTO: VERNA A. DEVILLER

The Pinkney's Point fleet is ready to go on Dumping Day.

From June to October 2007, 42 lobster fishermen were interviewed in Shelburne, Yarmouth and Digby counties of Southwest Nova Scotia to learn about changes in the inshore region in recent decades. Here are the answers to the survey questions, and, whenever possible, evidence from scientific studies.

Structure of survey:
The survey was structured around research questions about the observed increase in the American lobster population and landings (see Figure 1) in the Gulf of Maine, specifically Lobster Fishing Area (LFA) 34. It was based on six different themes: predation, conservation, climate, prey abundance, disease and fishing effort.

Note:
The percentage total for each answer does not always equal 100. Sometimes it is higher if the fishermen had more than one answer to a question. If the percentage is less than 100, some fishermen did not have an answer or did not want to reply.

Demographics of fishers interviewed (Table 1):
Forty-two experienced fishermen, including 40 owner/operators (4 of whom were retired) and 2 crew, were interviewed in the tri-counties (7 in Shelburne Co., 26 in Yarmouth Co., and 9 in Digby Co.) of LFA 34. Fishermen from a total of 20 harbours were surveyed. The highest number of people interviewed who fished from the same wharf was 9.

	Minimum (lowest)	Maximum (highest)	Average
Year born (age when interviewed)	1973 (34)	1923 (84, retired) 1939 (68, active)	1951.6 (55.4)
First year fishing for livelihood (years fished when interviewed)	1991 (16)	1936 (51)	1970.6 (35.3)
Number of licences/fisheries	2	8	4.7
Percent of income from lobsters	30% (retired) 50% (active)	100%	90.8%

Table 1: Demographics of fishers interviewed.

PHOTO: LISA M. SURETTE

Berried lobsters are returned to sea.

Research Topic 1: Is temperature affecting lobster catches?

1) *In your experience, has the time of year when water temperature turns warm or cold changed over the years that you have been fishing in these waters?*

Interviews: Over half of the fishermen (55%) reported that water temperature stays colder longer in spring, while only 2% thought it stays warmer longer in spring. 76% observed that the water now stays warmer longer in fall than it used to, with 2% saying it gets colder sooner in fall. 17% said the water temperature varies from year to year.

One person reported no change in water temperature over his career.

Science: In the scientific community, water temperature has often been suggested to be a major reason for the increased lobster landings in Maine and Nova Scotia. There is some evidence to support this idea but no clear relationship has been found just yet. A study in Nova Scotia using data from 1929 to 1970 was able to connect lobster landings to sea surface temperature. However, other studies during the mid-1990s were not able to connect sea surface temperature with the increase in lobster landings during the 1980s and early 1990s. Temperature likely plays a role but the scientific jury is still out on exactly how much and at what life stages it is the most important.

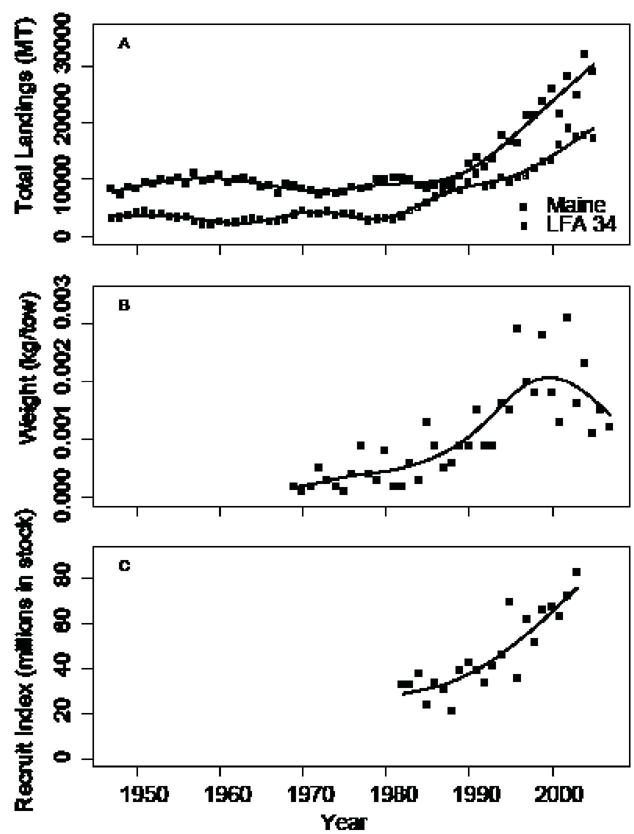

Figure 1. American lobster trends in the Gulf of Maine: (A) from 1947 to 2005, lobster landings (mt) in Maine from Maine's Department of Marine Resources (grey points) and lobster fishing area (LFA) 34 from the Canadian Department of Fisheries and Oceans (black points), (B) from 1969 to 2007, lobster abundance (kg/tow) from the United States' National Marine Fisheries Service research trawl (dragger) surveys, and (C) from 1983 to 2003, lobster recruit abundance (millions in stock) from the Atlantic States Marine Fisheries Commission.

Research Topic 2: Does the weather influence lobster abundance / catches?

2A) *In your experience, do wind direction and strength have an effect on lobster catches?*

Most (79%) reported that their catch decreases with high winds, while only one fisherman reported his catch increasing with offshore winds. 19% of the fishermen said wind direction and strength have no effect on their lobster catches. Of those who did say direction has an effect, the westerly winds seemed to be the most favourable for lobster catches as "you don't catch much with the easterly wind." "Winds from the W/SW cause big swell" reported another fisherman, and according to another, "North, NW wind or light SW are best for lobster catches."

"There's fishing now 24 hours a day, 7 days a week."

2B) *In years where there are a lot of storms, do you a notice a change in lobster catches?*

Over half (59%) reported that storms caused catches to decrease, while 36% said stormy weather had no effect on the catch. Only one person reported an increase in years with a lot of storms. The general feeling was that average catch remains the same regardless of the weather. "Price makes the season," but when storms "make the water turbid, catches go down."

2C) *Do you think Hurricane Juan (2003) had an effect on the lobster population?*

The majority (60%) did not notice a change. About one-fifth (19%) of those interviewed noticed an increase in the lobster population, in comparison to less than a tenth who reported a decrease (7%). Approximately 2% felt that Hurricane Juan had an effect other than simple changes in abundance, such as bringing in warmer water.

Research Topic 3: Is disease affecting lobster catches?

3A) *Are you concerned about disease affecting lobsters in the wild?*

The answers were split here, with half (50%) saying no and 41% saying yes.

PHOTO: STEPHANIE A. BOUDREAU

The gear soaks while the boats rest at the Yarmouth Public Wharf.

3B) *Have you seen evidence of disease in lobsters coming fresh out of the ocean?*

The majority of fishermen (64%) said that they have never seen evidence of disease in fresh lobsters. However, about one-third (31%) have seen instances of lobster disease very rarely, while 5% have more frequently seen this.

Most people had only seen diseased lobsters when they've been kept in close quarters, like in the lobster pound. Some mentioned healthy but heavily barnacled lobsters. Many felt that the cold waters protect the lobsters from most diseases.

PHOTO: STEPHANIE A. BOUDREAU

Lobster crates waiting to be filled.

> "Expectations are too high, young people keep trying to make the fishery into what they want it to be instead of what it is."

Research Topic 4: Are changes in groundfish or invertebrate abundance affecting lobster catches?

4A) *Are you concerned that lobsters may be running out of food?*

Half (50%) of the fishermen interviewed were worried that lobsters were running out of food, while almost as many (43%) were not. Of those who said that food becoming scarce is a concern, they felt that the rock crab, Jonah crab, "wrinkles" (sea snails) and hermit crab being harvested and used as bait could be a major reason. Fishermen report that herring and mackerel eggs are a source of food for lobsters, and so they were concerned because there is now less of these fish (see Figure 2). "There is more lobster on the bottom than food sources" said one fisherman.

4B) *Do you think that the amount of bait used in the fishery has subsidized the lobster population and could be a reason why there are more lobsters? Scientists in Maine refer to this as "farming" lobsters.*

Interviews: About half (48%) said that they don't think they are "farming" lobsters with bait, and almost the same number (40%) said they do think they are feeding lobsters with bait, while 12% were not sure or did not give an answer. Of those who said yes, nearly all did not think that the amount of bait used was a reason for the high lobster landings in southwest NS and felt that lobsters eat bait when it is available during the fishing season, depending on the time of year. For example, their landings are generally slow in the winter even though there are baited traps in the water. Additionally, many other animals, such as slime eels and sand fleas, may eat the bait.

Most mentioned that the idea of "farming with bait" was new to them (it is more common in Maine) but said that it is likely that lobsters eat bait when it's available during the 6-month fishing season. "It's just like fertilizing the garden" said one fisherman. However, they noted that they have been using baited traps for a very long time and fishermen move their gear around so the effect on lobsters is likely reduced.

Science: Some scientists think that the lobster bait in the Gulf of Maine has been subsidizing the lobster population. This is based on a study that noticed that many lobsters are able to exit

PHOTO: STEPHANIE A. BOUDREAU

Life raft and spare buoys.

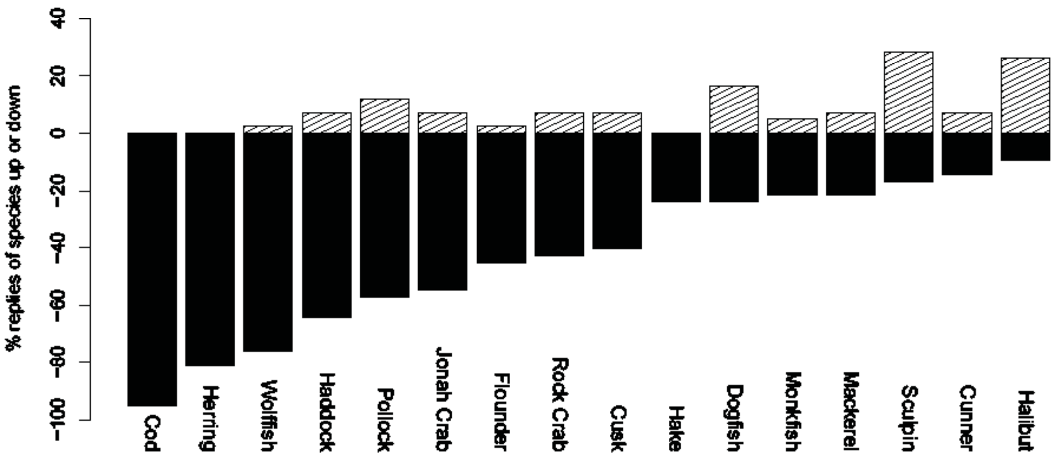

Figure 2. The percentage of fishermen who reported that a species has decreased (solid bars, going down) or increased (striped bars, going up) in the inshore ecosystem throughout their careers, from left to right: Atlantic cod, herring, wolffish (or catfish), haddock, pollock, Jonah crab, flounders, rock crab, cusk, hake, spiny dogfish, monkfish, mackerel, sculpin, cunner, and halibut.

the trap after having fed on bait. The amount of bait used is probably higher on the United States' side of the Gulf of Maine because they fish many more traps than in LFA 34 and the fishery operates year-round. It is pretty likely that lobsters eating bait helps their growth and increases their body size, however; in the eastern portions of the Gulf of Maine (New Brunswick), bait is not believed to be boosting the number of lobsters.

4C) *In your experience, when did you observe cod populations starting to decline in the inshore areas?*

There wasn't a clear consensus for this question. One-fifth (19%) said the early 1980s, one-quarter (29%) said the late 1980s, one-fifth (19%) said the early 90s, about another fifth (17%) said the late 90s, and one fisher said early 70s or before. Most replies mentioned draggers as a reason for declining cod populations.

4D) *Have you observed any other changes in species abundance in the inshore since 1980?*

Interviews: Overall, most species were reported to have decreased in abundance (see Figure 2). Almost all (95%) of respondents observed a decline in cod. The other large declines were seen in herring (81% of fishermen surveyed), wolffish (also called catfish, 76%), haddock (64%), pollock (57%), and Jonah crab (55%), while over 40% of respondents also saw decreases in the populations of flounder, rock crab, and cusk. When asked about species

PHOTO: STEPHANIE A. BOUDREAU

Jumbo lobster on board the CCGS Wilfred Templeman.

other than lobster, only sculpin and Atlantic halibut were reported to be increasing rather than decreasing. For complete details of responses to this question listed by species, see the Survey Response Summary (page 14).

Science: Examining data from USA dragger research surveys (see Figure 3) shows that when groundfish abundance was compared with lobster, their numbers went in opposite directions, which means that as the numbers of groundfish went down, lobster was going up.

However, there is one example from the USA data showing that as lobster numbers went up, so did longhorn sculpin (the ones

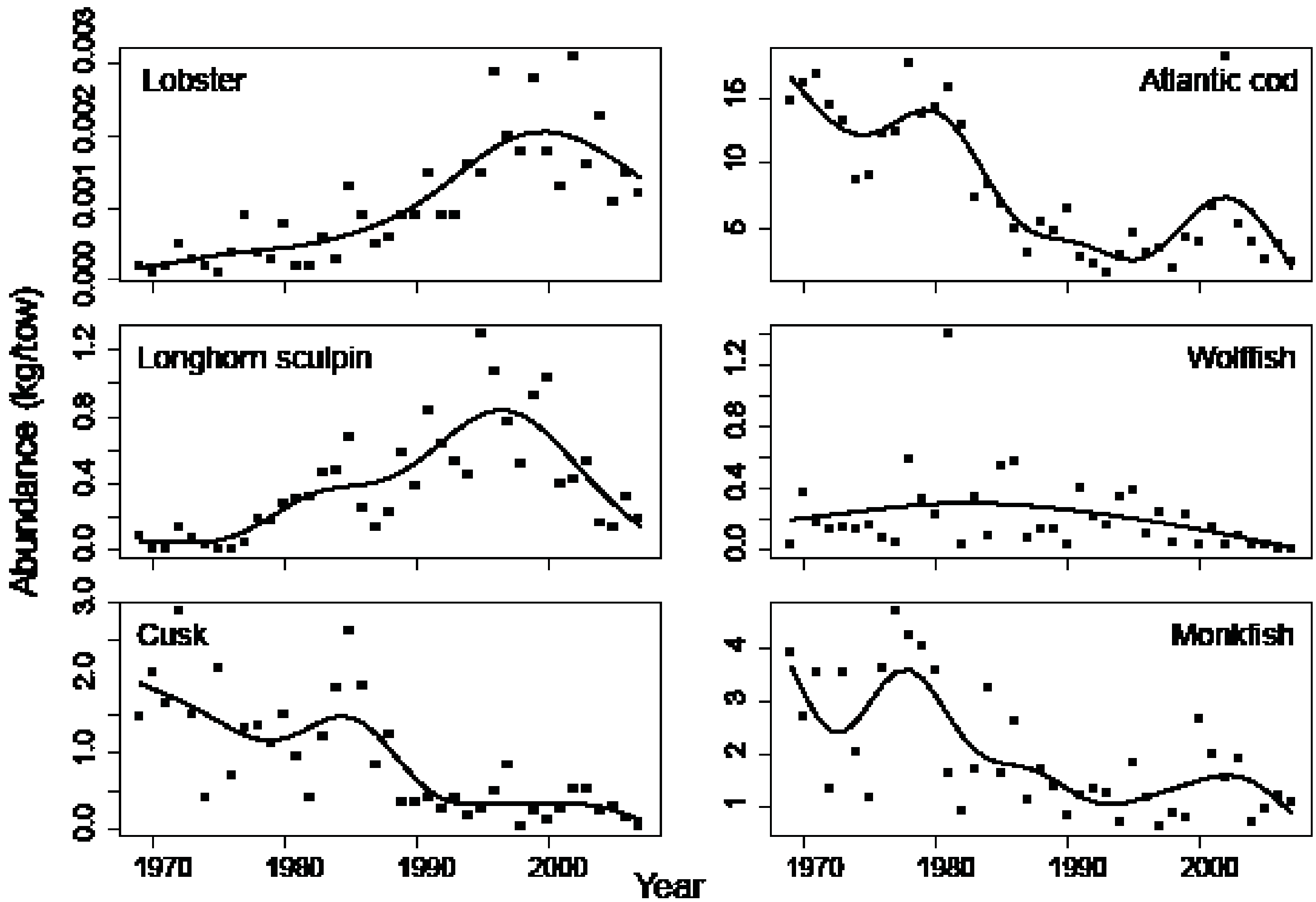

Figure 3. The abundance trends (kg/tow) of American lobster and five of their groundfish predators; Atlantic cod, longhorn sculpin, wolffish (also called catfish), cusk, and monkfish in the Gulf of Maine from the United States' National Marine Fisheries Service research trawl (dragger) surveys from 1969 to 2007.

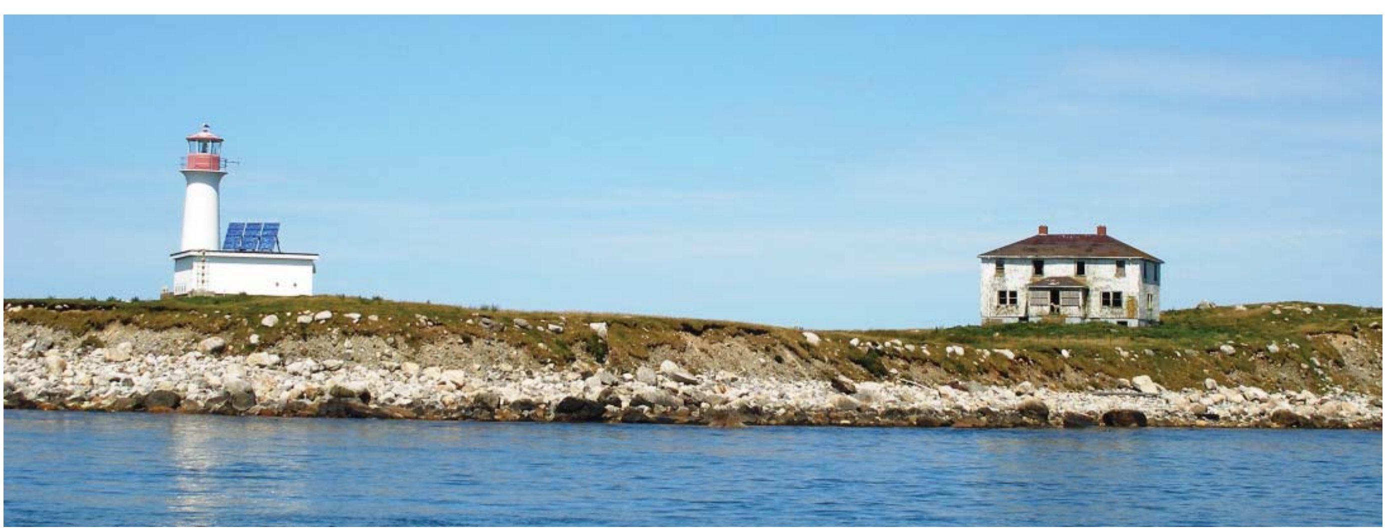

PHOTO: STEPHANIE A. BOUDREAU

Pease Island and lighthouse.

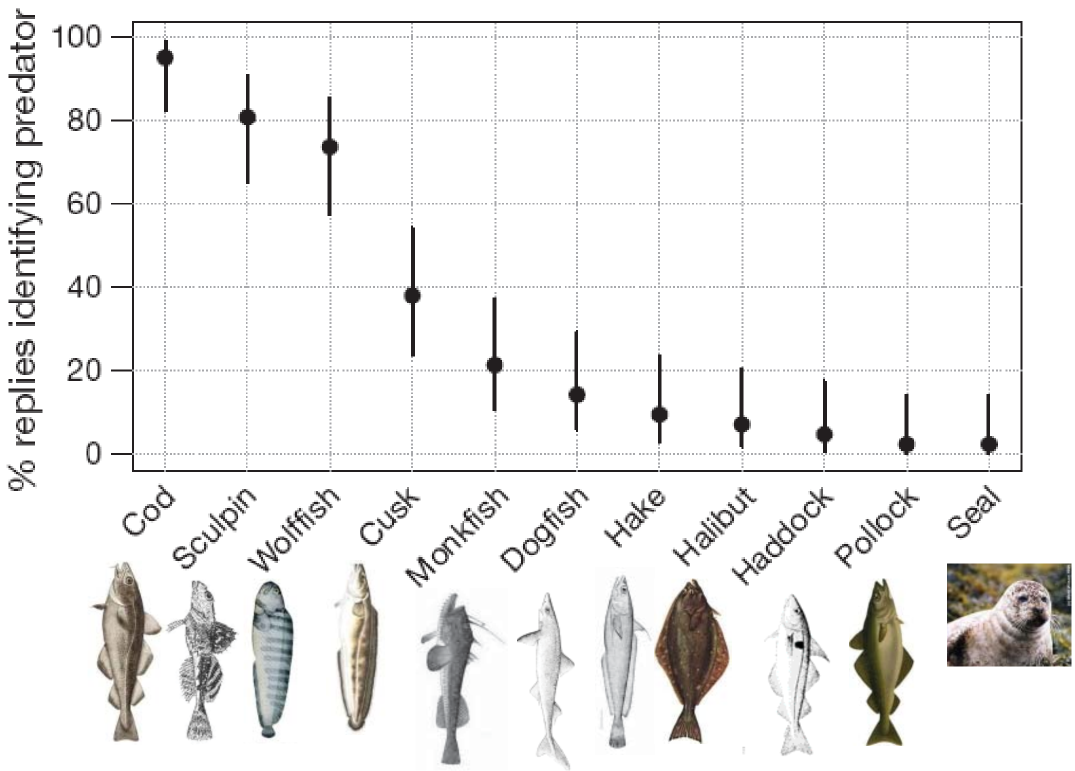

Figure 4. The percentage of fishermen who identified particular predators of lobsters from their own sampling of stomach contents: Atlantic cod, sculpin, wolffish (or catfish), cusk, monkfish, spiny dogfish, hake, Atlantic halibut, haddock, pollock and grey seal. The solid lines around the black circle (the percentage) are 95% confidence intervals (please see A Guide to Reading a Scientific Paper, page 18, for an explanation).

that buzz). This is what the fishermen also reported (see Figure 2).

This is explained a bit more in the Guide to Reading a Scientific Paper (see page 18) if you're interested in learning more.

4E) *In your experience, what species are caught with lobsters the most often? Which season?*

The survey responses reported that cod (98%), sculpin (88%), Jonah crab (86%), rock crab (83%), and cusk (64%) were caught the most often with lobster. The species caught the least were smaller invertebrates such as sea cucumber, shrimps, and mussels. See the Survey Response Summary (page 15) for a table of complete responses listed by species.

4F) *In your experience, what fish have you dressed and found a lobster in its stomach?*

Interviews: Almost all (98%) of the fishermen surveyed have found lobster in the stomach of cod (see Figure 4). Sculpin (83%) and wolffish (called catfish, 76%) were also found to have consumed lobster by the majority of fishermen. See the Survey Response Summary (page 15) for a table of complete responses listed by species. A few fishermen noted that seals have been seen eating the lobster that are thrown back.

PHOTO: STEPHANIE A. BOUDREAU

Monkfish are a predator of lobster (CCGS Wilfred Templeman).

"Taking away the big breeders will hurt the fishery."

Predator	Lobsters	Stomachs	%
Smooth Dogfish	25	7145	0.35
Atlantic Cod	58	18818	0.31
Atlantic Halibut	1	365	0.27
Thorny Skate	5	3279	0.15
Smooth Skate	1	869	0.12
Longhorn Sculpin	9	11116	0.08
Haddock	6	8132	0.07
Spiny Dogfish	43	63837	0.07
Little Skate	16	25818	0.06
Sea Raven	4	6693	0.06
Red Hake	8	16802	0.05
White Hake	5	13883	0.04
Monkfish	3	9573	0.03
Winter Skate	4	16358	0.02
Winter Flounder	1	7966	0.01
Spotted Hake	1	12084	0.01
Silver Hake	1	45646	0.00

Table 2: Percentage of lobsters found in groundfish, dogfish and skate stomachs from the Northeast Fisheries Science Centre (Woods Hole, Massachusetts) stomach contents database (North Carolina to Nova Scotia, from 1973 to 2005). The column named "Lobsters" is the number of lobsters identified and "Stomachs" is the number of stomachs examined.

(4F continued) Science: The interview results are similar to what is found in the stomach contents database (1973 to 2005) by the Northeast Fishery Science Center in the USA (see Table 2). The database reports which species have been found with lobster in their stomachs from North Carolina to Nova Scotia. Except for smooth dogfish, which is rarely seen as far north as the Gulf of Maine, many of the fish, such as cod, halibut, sculpin, haddock, and various hake species were all found in both regions with lobster as stomach content.

PHOTO: LISA M. SURETTE

Hauling gear.

Research Topic 5: Are changes in fishing effort influencing lobster catches?

5A) *In the past 10 years have you been routinely fishing lobsters in deeper water?*

More than three-quarters (79%) of the fishermen surveyed have been heading out farther from shore than they used to in order to fish for lobsters, while the rest – less than one quarter (21%) – have not.

5B) *In the past 10 years have you been finding and fishing lobster on new bottom types?*

Interviews: The majority (71%) of fishermen have been finding/fishing lobster on new bottom types. Of these, most (60%) have been fishing on mud or soft bottom, a quarter (23%) have been fishing on sandy bottoms and a quarter (24%) on rocky bottoms, with a few fishermen finding lobsters on cobble or gravel bottoms.

Science: This observation that lobsters are venturing from hard bottoms (rock and cobble) onto soft sediments has also been recorded by scientists in both Maine and Nova Scotia.

5C) *If your distribution of fishing effort has changed, what is the reason?*

Many different reasons were given as things

PHOTO: CHRISTOPHER A. BOUDREAU

Lobster vessel coming into Little River Harbour.

influencing changes in fishing effort, such as weather (21%), more lobsters being found midshore than inshore (43%), moving to find less fishing competition (29%), following the lobsters (24%), fishing large lobsters (7%), and experimenting (7%).

5D) *How much time do you spend fishing nearshore? If you fish midshore, when did you start?*

Over half of the fishermen interviewed (60%) still fish nearshore some of the time, while about one-fifth (19%) still fish mostly or entirely in the nearshore.

Almost one-quarter (24%) started fishing deeper than 30 fathoms in the early 2000s. 12% started in the late 1990s, 10% in the early 1990s, 10% in the late 1980s, 5% in the early 1980s, 10% in the early 1970s, 7% in the late 1960s, 2% in the early 1960s, and 2% a longer time ago.

Research Topic 6: Do all of the above have something to do with the increase in lobster catches?

6A) *Are you concerned that the lobster population may decline?*

About three-quarters (74%) of the lobster fishermen interviewed were concerned about a possible decline of the lobster population and 26% were not.

6B) *Why do you think that there are so many more lobsters in the last 20 years in LFA 34 than there have been since the 1950s?*

The number of lobsters has increased over the last 20 years in LFA 34, and the population is much higher than in the 1950s (See Figure 1A). The most-considered reason for this is that there are now fewer predators, a fact mentioned by more than four-fifths (83%) of fishermen. Other reasons for the increase were successful conservation regulations (21%), high fishing effort (33%), and other things such as climate, tides, natural cycles, etc. (19%).

"Lobster fishing was a living and now it's a business like any other."

PHOTO: CHRISTOPHER A. BOUDREAU

Familiar scene at the Little River Harbour Wharf.

What's on your mind?

We asked the fishermen what stood out in their minds as affecting the lobster population either positively or negatively.

Overall, there was a real feeling of nostalgia for a way of life that has become a business among the lobster fishermen. There was also a wish that fishing in general was more diverse, as it had been in the past with the groundfisheries. Many fishermen mentioned that there is more corruption and greed and less co-operation and support in the fishing community today compared to when they began fishing. Most were not in support of the currently discussed possibility of the lobster fishery adopting a quota system, and were concerned about lobster quality and health.

About half (52%) of the fishermen were also concerned about fishing effort. They cited concerns such as increased effort for the same result compared to a number of years/decades ago and the fact that the fishery is too mobile, and there are too many traps. Some commented on how the areas fished have expanded over time. "Five years ago only one-quarter of the fleet was fishing outside but now three-quarters is fishing outside" said one fisherman. "Most people start inside for a week and then go deeper and deeper." Also of concern is the allowed schedule of lobster fishing – "there is now fishing 24 hours/day-7 days/week." Whereas Sunday used to be a day to check gear, now it's a productive fishing day. According to one fisherman, "only 10% of the boats are tied to the wharf on Sunday", compared to 100% in days past. Another fisherman remembered fishing 7 to 9 days in December, comparing it to the norm now, fishing 20 to 25 days in December. Bigger boats and more efficient traps mean that the fishermen are fishing harder than they used to for the same landings.

Suggestions for improving/resolving the issues about fishing effort included splitting the season, closing the fishery one day per week (Sunday, for example), and making a rule that would allow fishing only during daylight hours. A limit of 300 to 350 for the number of lobster traps allowed was also suggested by a few fishermen. One fisherman rightly pointed out, "you can't catch them twice; if you catch them in the spring you can't catch them in the fall."

PHOTO: LISA M. SURETTE

Great day to be at work on the water.

Illegal fishing is a concern for more than three-quarters (79%) of the fishermen surveyed. Issues such as extra pots and fishing gear out in the water because of falsely obtained replacement tags, a "summer fishery" being observed during the closed season for the fishery, and the selling of these illegally obtained lobsters on the black market were of specific concern to many fishermen. One fisherman observed that some of his fellow fishermen have "up to 900 pots split between inshore and offshore and no one bothers them". One suggestion was that since the fines are small for those caught illegally fishing, the fines should be raised or the licenses should be taken away from these fishermen.

About half (52%) of the fishermen were also concerned that there is not a maximum allowable size for lobsters caught. The largest issue was the targeting of certain lobster sizes, especially large lobsters. "Taking away the big breeders will hurt the fishery" commented one fisherman. There were also questions about how long "the big recruitment" would keep up if the large breeding lobsters are allowed to be caught. Support for implementing a maximum legal size was strong, to create a "window" of size allowed between the minimum (82.5

mm) and a proposed maximum (127 mm, like in Maine).

Several fishermen mentioned concerns about scallop fisheries being allowed in traditional lobster fishing grounds in Southwest NS, expressing worry about scallop fishing gear harming both lobsters and their habitat.

The possible introduction of fishing quotas by DFO as a method for keeping lobster populations healthy was brought up by a number of those surveyed. Most of the fishermen would rather that this measure not be implemented. They felt that their livelihoods might be compromised by using a quota system and that the current methods of control, including gear restrictions, protection of egg-bearing females, and minimum legal size, are working, so the need for time-consuming and limiting factors is not necessary. One fisherman noted that the introduction of quotas might cause the lobster fishery to “go the way of the groundfishery”.

Other concerns about compromised fishing included a proposed quarry in the Digby Neck area, as run-off from the mining operations could pollute the lobster-fishing waters. Government over-management was mentioned by a few fishermen, plus the fact that government “just doesn’t listen [to us]. They only listen to big business.” Some fishermen wanted the fishery to be less dependant on the buyers. “We should be investing in the market, throughout the whole district 34. We shouldn’t be so dependant on the buyers but should help them find markets instead.”

Being on the water almost every day gives fishermen a chance to observe the marine ecosystem and notice changes in local ecology. For example, many of those surveyed noted an increase in “short seeders” and small lobsters in their catches in recent years. One fisherman commented that “there are more lobsters just under the measure being seen now than ever.” A few expressed support for the mandatory implementation of the V-notching system in Nova Scotian waters, to be able to quickly identify the females with eggs and release them if caught in the traps. “Soft lobsters” were also mentioned by several respondents, as a possible sign of lobster disease or ill-health.

Experienced fishermen remember the simpler lobster fishing days of past decades. Not only are fishing conditions, fishing effort, population size, and regulations different than what they used to be, there is also a general feeling among the older fishermen that “lobster fishing was a living and now it’s a business like any other” with the young fishermen “going for the dollar because they can.” Although living season to season was always a necessity of the life of a lobster fisherman, “it was never with this amount of money.” “The young want it all now” and “own the motto ‘you can’t make money without spending it’. They’ve over-stretched their means and need more money and so they fish harder.” Says another fisherman, “Expectations are too high, young people keep trying to make the fishery into what they want it to be instead of what it is.”

PHOTO: STEPHANIE A. BOUDREAU

Yarmouth Public Wharf.

Survey response summary

From June to October 2007, 42 fishermen were interviewed in Shelburne, Yarmouth and Digby counties of Southwest Nova Scotia to learn about ecosystem changes in the local inshore lobster fishing area in recent decades. Following is a summary of the results found from this survey.

The survey was structured around research questions about the observed increase in the American lobster population and landings in the Gulf of Maine, specifically Lobster Fishing Area (LFA) 34. It was based on six different themes: predation, conservation, climate, prey abundance, disease and fishing effort.

PHOTO: CHRISTOPHER A. BOUDREAU

Colourful vessels at the Little River Harbour Wharf.

	Minimum (lowest)	**Maximum** (highest)	**Median** (middle)	**Mode** (most common)	**Average**
Year born (age when interviewed)	1973 (34)	1923 (84, retired) 1939 (68, active)	1951.1 (55.5)	1956 (51)	1951.6 (55.4)
First year fishing for livelihood (years fished when interviewed)	1991 (16)	1936 (51)	1972 (35)	1975 (32)	1970.6 (35.3)
Number of licences/fisheries	2	8	5	5	4.7
Percent of income from lobsters	30% (retired) 50% (active)	100%	95%	100%	90.8%

Table of Demographics (Information about the fishermen interviewed): 42 fishermen (including 2 crew and 40 owner/operators, 4 of whom were retired) were interviewed in the tri-counties (7 in Shelburne Co., 26 in Yarmouth Co., and 9 in Digby Co., from a total of 20 harbours) of LFA 34. Age, years, or status at the time of the interview (June-Oct 2007) is in brackets.

Research Topic 1: Is temperature affecting lobster catches?

1) *In your experience has the time of year when water temperature turns warm or cold changed?*
76.2% stays warmer longer in fall
54.8% stays colder longer in spring
16.7% varies from year to year
2.4% stays warmer in spring
2.4% gets colder sooner in fall
2.4% no change
2.4% unpredictable

PHOTO: STEPHANIE A. BOUDREAU

Jumbo lobsters on board the CCGS Alfred Needler.

"The government just doesn't listen [to us]. They only listen to big business."

Research Topic 2: Does the weather influence lobster abundance / catches?

2A) *In your experience, does wind direction and strength have an effect on lobster catches?*
78.6% catch decreases with high winds
19.0% no effect
2.4% catch increases with offshore winds

PHOTO: STEPHANIE A. BOUDREAU

Cod on board the CCGS Alfred Needler.

2.4% no answer or don't know

2B) *In years where there are a lot of storms, do you a notice a change in lobster catches?*
59.0% they decrease
35.7% no effect
2.4% they increase
2.4% no answer or don't know

2C) *Do you think Hurricane Juan (2003) had an effect on the lobster population?*
59.5% no change
19.0% yes it increased
7.1% decreased
2.4% influenced in some way not mentioned
11.9% no answer or don't know

Research Topic 3: Is disease affecting lobster catches?

3A) *Are you concerned about disease affecting lobsters in the wild?*
50.0% no
40.5% yes
9.5% no answer or don't know

3B) *Have you seen evidence of disease in lobsters coming fresh out of the ocean?*
64.3% never
31.0% very rarely
4.8% sometimes

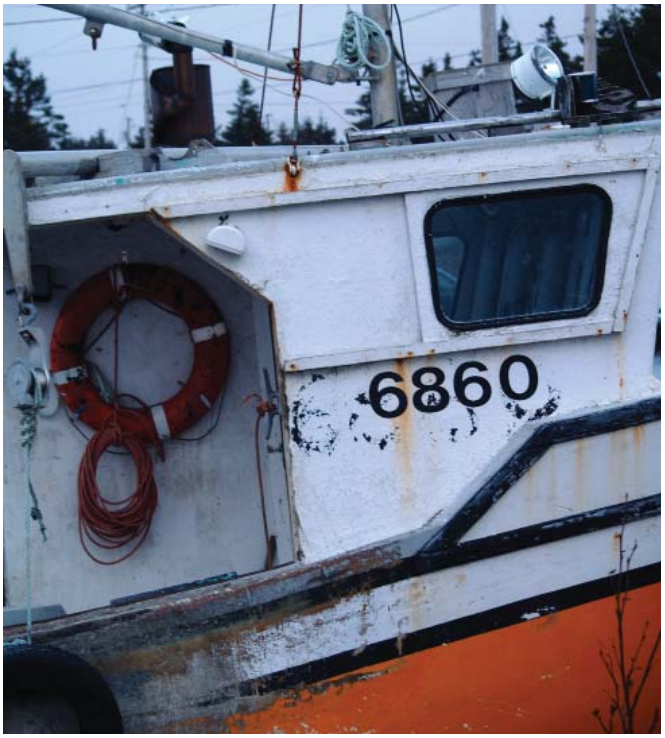

PHOTO: CHRISTOPHER A. BOUDREAU

Little River Harbour Wharf.

Research Topic 4: Are changes in groundfish or invertebrate abundance affecting lobster catches?

4A) *Are you concerned that lobsters may be running out of food?*
50.0% yes
42.9% no
7.1% no answer or don't know

4B) *Do you think that the amount of bait used in the fishery has subsidized the lobster population and could be a reason why there are more lobsters? Scientists in Maine refer to this as "farming" lobsters.*
47.6% no
40.5% yes
11.9% were not sure or no answer

4C) *In your experience, when did you observe cod populations start to decline in the inshore areas?*
19.0% early 80s
28.6% late 80s
19.0% early 90s
16.7% late 90s
2.4% early 70s or before
14.3% no answer or don't know

4D) *Have you observed any other changes in species abundance in the inshore since 1980?* (See table below.)

Species	Replies of a decrease	Replies of an increase	Replies of no change	No answer	% Decrease	% Increase	% No change	% NA
Cod	40	0	0	2	95.2	0.0	0.0	4.8
Herring	34	0	1	7	81.0	0.0	2.4	16.7
Wolffish (Catfish)	32	1	2	7	76.2	2.4	4.8	16.7
Haddock	27	3	2	10	64.3	7.1	4.8	23.8
Pollock	24	5	2	11	57.1	11.9	4.8	26.2
Jonah	23	3	13	3	54.8	7.1	31.0	7.1
Flounders	19	1	6	16	45.2	2.4	14.3	38.1
Rock	18	3	13	8	42.9	7.1	31.0	19.1
Cusk	17	3	11	11	40.5	7.1	26.2	26.2
Hake	10	0	3	29	23.8	0.0	7.1	69.1
Dogfish	10	7	7	18	23.8	16.7	16.7	42.9
Monkfish	9	2	7	24	21.4	4.8	16.7	57.1
Mackerel	9	3	12	18	21.4	7.1	28.6	42.9
Sculpin	7	12	20	3	16.7	28.6	47.6	7.1
Cunner	6	3	19	14	14.3	7.1	45.2	33.3
Halibut	4	11	5	22	9.5	26.2	11.9	52.4

(4D continued) There was also mention of changes in the smaller benthic invertebrates such as toad, hermit, Jonah and rock crabs, periwinkles, and whelks.

4E) *In your experience, what species are caught as bycatch in your traps with lobsters the most often?*

Species	Replies	%
Cod	41	97.6
Sculpin (buzzers)	37	88.1
Jonah Crab	36	85.7
Rock Crab	35	83.3
Cusk	27	64.3
Mackerel	17	40.5
Cunner	16	38.1
Flounder	15	35.7
Wolffish (Catfish)	13	31.0
Haddock	11	26.2
Dogfish	10	23.8
Sea Urchin	9	21.4
Hermit crab	9	21.4
Red fish	7	16.7
Wrinkles	7	16.7
Conger Eel	7	16.7
Skate	7	16.7
Scallops	6	14.3
Herring	5	11.9
Hake	5	11.9
N. Stone Crab	5	11.9
Pollock	4	9.5
Halibut	4	9.5
Seastar	4	9.5
Hagfish	3	7.1
Garbage	3	7.1
Whelk	3	7.1
Green Crab	2	4.8
Jellyfish	2	4.8
Snails	2	4.8
Rock Eel	2	4.8
Crab (unidentified)	1	2.4
Shrimp	1	2.4
Poule de Mer	1	2.4
Mussel	1	2.4
Dulse	1	2.4
Toad Crab	1	2.4
Sponge	1	2.4
Sea Cucumber	1	2.4
Ling	1	2.4

PHOTO: LISA M. SURETTE

Jonah crab are commonly caught with lobsters.

4F) *In your experience, what fish have you dressed and found a lobster in its stomach?*

Species	Replies	%
Cod	40	98
Sculpin	34	83
Wolffish (Catfish)	31	76
Cusk	16	39
Monkfish	9	22
Dogfish	6	15
Hake	4	10
Halibut	3	7
Haddock	2	5
Pollock	1	2
Seal	1	2

Research Topic 5: Are changes in fishing effort influencing lobster catches?

5A) *In the past 10 years have you been routinely fishing lobsters in deeper water?*
78.6% yes
21.4% no

5B) *In the past 10 years have you been finding and fishing lobster on new bottom types?*
71.4% yes
28.6% no

If yes, what kind?
59.5% mud (or soft)
23.8% rocky
23.0% sandy

16.7% cobble
9.5% gravel
2.4% other

5C) *If your distribution of fishing effort has changed, what is the reason?*
42.9% more lobsters outside than in
28.6% less competition/fishing pressure
23.8% following the lobsters
21.4% weather
7.1% experimenting
7.1% larger lobsters

PHOTO: STEPHANIE A. BOUDREAU

Preparing for a lobster supper.

5D) *How much time do you spend fishing nearshore? If you fish midshore, when did you start?*
59.5% still fish nearshore some of the time, 19% still fish mostly or entirely nearshore

When did you first start fishing deeper than 30 fathoms?
23.8% early 2000s
11.9% late 1990s
9.5% early 1970s
9.5% early 1990s
9.5% late 1980s
7.1% late 1960s
4.8% early 1980s
2.4% early 1960s
2.4% a long time ago
19.1% no answer or don't know

Research Topic 6: Do all of the above have something to do with the increase in lobster catches?

6A) *Are you concerned that the lobster population may decline?*
73.8% yes
26.2% no

6B) *Why do you think that there are so many more lobsters in the last 20 years in LFA 34 than there has been since the 1950s?*
83.3% less predators
33.3% high fishing effort
21.4% conservation regulations work
19.1% other

"Other" included many reasons; for example, climate, tides, natural cycles, luck, increased egg/larval survival due to a decrease in sea ice, benefitting from the USA's v-notching program and God.

A summary of concerns or insights brought up during the interviews:

Insight or Concern	Respondents	%
Scallop draggers	7	16.7
Increased fishing effort	32	76.2
Split the fishing season	4	9.5
Close on Sunday (or one day per week)	9	21.4
Fishery is too mobile	5	11.9
Fish only in daylight hours	2	4.8
Too many traps	7	16.7
Don't want quotas	8	19.0
Illegal fishing (in general)	14	33.3
Extra pots (above limit)	6	14.3
Summer fishery	4	9.5
Replacement tags = extra traps fishing	6	14.3
Black market	3	7.1
Lobsters are starving	2	4.8
Jumbo conservation	20	47.6
Window measure	2	4.8
Digby quarry	3	7.1
More short seeders	2	4.8
Many small lobsters	6	14.3
Water temperature is currently good for lobsters	1	2.4
Water temperature is currently bad for lobsters	2	4.8
Soft lobster	6	14.3
V-notching is positive	4	9.5
V-notching is negative (creates a wound)	1	2.4

A guide to reading a scientific paper

Scientists communicate their research by writing papers for scientific journals. If you've never read a scientific paper before, the language can be confusing and may be difficult to understand. Scientific articles are often full of numbers and graphs (and long descriptive paragraphs), but they can also contain interesting and useful information. Here are some definitions and explanations to help navigate the following paper, which includes results from the survey:

A scientific paper has 6 major sections:

1) **Abstract:** a summary of the study's findings.
2) **Introduction:** gives background information and the reasons why the study is necessary, and the research questions and predictions.
3) **Methods:** how the research was carried out, including how data were collected and analysed.
4) **Results:** reports the results from the statistical tests (analyses) described in the Methods, often with tables and figures (graphs).
5) **Discussion:** the conclusion of the study, which puts the results into perspective using other published studies. It also talks about how the results could be used in the future (next steps).
6) **Literature cited:** the references (other studies, text books, etc…) used to write the paper, consisting of other published studies, books, and reports.

Top-down control – An ecosystem is a natural community including living and non-living elements. Top-down control means that predators control and structure the ecosystem. The classic example is sea otters in the Pacific Ocean, they prey on sea urchins which eat kelp. When otters (the top predator) are removed from the ecosystem, the sea urchin populations grow and eat the kelp forests, which then creates urchin barrens. Removing the large predators, in our case Atlantic cod (through fishing), can change the structure of the ecosystem, in our case by increasing some of their prey species like lobsters and crabs.

Acronyms (abbreviations) – The first time that an important term or phrase is mentioned in the paper we follow it with an acronym, usually inside brackets. From that point on we use this abbreviation because it saves space (and lowers the word count in the published report). So for example, Gulf of Maine becomes "GOM" for the rest of the paper, and Lobster Fishing Area 34 becomes "LFA 34".

Species names – The first time a species is mentioned in the text, the Latin species name is given in italics in addition to the more commonly known English name. Just as human beings are also called *Homo sapiens* and the grey wolf is named *Canis lupus*, in this study *Homarus americanus* refers to American lobster, and *Gadus morhua* are Atlantic cod.

Hypothesis testing – Scientists begin a study with a general statement called a hypothesis. This hypothesis is a "default" statement that says there is no pattern or relationship in the data that we have collected. Though it may be contrary to what you would expect, the general hypothesis for this study would be, "There is NO relationship between the decline of groundfish stocks and the increase of lobsters in the Gulf of Maine". We want to use our data to test whether this statement is likely to be true.

To do this, we use statistics to tell us that the data we have collected either, 1) supports this general hypothesis or, 2) does not support this general hypothesis, in which case it is more likely that there is a relationship between the decline of groundfish and the increase of lobster in the Gulf of Maine.

P-value (probability) – We use statistics to give us a probability-value (p-value), which tells us how likely it is that there is no relationship between groundfish declines and lobster increases. The p-value is a number between 0 and 1, but we can think of it as the percent chance that the general hypothesis is true. If we get a p-value of 0.9, then we can think of it as a 90% chance that there is no relationship between the decline of groundfish stocks and the increase of lobster. The higher the p-value, the stronger the evidence that there is no relationship between the abundance of groundfish and lobster.

Because scientists set out to explain patterns (not show that there isn't one), what we actually hope to see is that there IS a relationship between groundfish declines and lobster increases in the Gulf of Maine. We want really small p-values to tell us that the general hypothesis of "no relationship" is not likely to be true. The researcher decides what p-value will be the cut-off used to determine whether the general hypothesis is likely to be true. Any p-value lower than this cut-off point would mean that there is a relationship between groundfish and lobster, and scientists refers to this as "statistical significance".

Statistically significant means that it is unlikely that chance is responsible for a pattern that we see in the data. The most commonly used level of significance is 0.05, as is the case in this study. We usually set the cut-off at this low number to be really certain that any relationship we see is real. If we get a p-value of less than (<) 0.05, we can reject the general hypothesis. This means that there is a 5% (or less) chance that there is no relationship between groundfish and lobster. When the p-value is less than 0.05 it is considered "statistically significant" and we can conclude that, "There IS a relationship between the decline of groundfish stocks and the increase of lobsters in the Gulf of Maine".

Negative/positive relationships (correlations) – Correlation determines the type of relationship between two variables. In this case our variables are: 1) groundfish abundance and, 2) lobster abundance. Sometimes changes in one variable (for example, cod) will correspond with changes in another variable (lobster). In this case we say that there is a correlation between the two variables.

For example, our study has found a correlation between lobster abundance and groundfish abundance from research dragger surveys. This is a negative correlation (meaning the abundance goes in opposite directions). In this case, as groundfish abundance goes down, lobster abundance goes up.

If the two variables are changing in the same direction, for example both are increasing or decreasing at the same time, we say that there is a positive correlation. This sort of relationship was found for longhorn sculpin and lobster abundance, meaning as one increased, so did the other.

kg tow^{-1} means "kilogram per tow" (used in Figures 1 and 3).

N refers to the number of individuals in a study. For example, on page 186 "N = 668 stomachs examined" means that in the Maine research trawl survey discussed here, 668 cod stomachs were examined in total.

CI (confidence interval) is an upper and lower boundary that gives us an idea of how sure we are that the statistical model is correct, in this case the model which is looking for correlations or relationships between lobster and its predators. In the case of a 95% confidence interval we can say that if we repeated the experiment many times, 95% of the time the result (or true value) is found within the upper and lower boundaries. It's the same idea as saying "I'll be there at 3 o'clock give or take 10 minutes". So most of the time (95%) when you say you'll be there at 3 o'clock you'll arrive somewhere between 2:50 pm and 3:10 pm, but occasionally (5% of the time) you would be earlier or later.

R^2 (R-squared) is a value which tells us how much of the variability (how far the numbers in the dataset are spread from each other) in a dataset is accounted for by the statistical model. So for example, on Figure 3, panel A on page 187, the R^2 is 0.36, which we can interpret by saying that 36% of the variance in lobster abundance can be explained by the abundance of groundfish.

Time lags – An interval of time between two events. We use a time lag when an event that happens at one point in time is likely to affect an event that happens later on. In this case, we're trying to account for whether the groundfish abundance at one point in time affects the lobster population in the future. Because the groundfish can only eat lobster as big as their mouth allows, they tend to eat young, small lobster that are not legal-sized. It is believed that it takes approximately 7 to 8 years for lobster to reach legal-size so we would only expect to see an impact on the fishery somewhere around 7 to 8 years AFTER many small lobsters were eaten by the groundfish. This is a "time lag" because the recruitment of legal-sized, older lobster "lags" behind the time when the young, small lobster were actually eaten and gone from the fishery.

Figure 3 on page 187, panels A, C, and E do not have a time lag but show that, year for year, when lobster abundance (on the left hand side, y-axis) is high, the groundfish abundance (on the bottom, x-axis) is low and vice versa. Panels B, D and F use the time lags (years), and because all of the vertical (up and down) solid lines (illustrating the statistic correlation value) are below the 0 line they are "negative" (or opposite) correlations (lobster abundance is high, groundfish abundance is low). The horizontal (side to side) dashed lines show the 95% confidence intervals and when the solid lines cross the dashed line it means that the correlation (relationship) is statistically significant.

Putting all these terms together helps to understand a main concept in the **Abstract** (or summary) of the paper: "We further show that the proposed **top-down control** mechanism is independently supported by USA research trawl surveys, which revealed a **negative correlation ($p < 0.05$)** between the summed abundance indices of 5 groundfish predators of lobster and lobster abundance **(kg tow^{-1})** at **time lags** ranging from 0 to 9 years..." We can break this sentence down into parts.

First it tells us that "the proposed top-down control mechanism is independently supported by USA research trawl surveys". This means that the theory that the decrease of large groundfish populations resulted in an increase in lobster abundance in the Gulf of Maine, which is supported by information from the USA dragger surveys. This could be because groundfish eating the lobster could control the lobster population ("top-down control"), and as groundfish became scarce, lobsters were not preyed on as often and have increased.

Next it tells us that these dragger surveys "revealed a negative correlation ($p < 0.05$) between the summed abundance indices of 5 groundfish predators of lobster and lobster abundance (kg tow^{-1}) at time lags ranging from 0 to 9 years". This means that there is a negative relationship (as groundfish abundance goes down, lobster abundance goes up) that is statistically significant (because of the p-value less than our 0.05 cut-off), and that this is true for many years into the future (time lags).

References – When reading through the text, you may notice brackets with last names and years. These are references to published scientific material, supporting the information found in the statement with the brackets. For example, at the bottom of page 182, the bracketed information at the end of the sentence, "Prior to the mid-1970s, lobster fishing in LFA 34 occurred in nearshore waters of <55 m depth, and then began to expand to midshore waters, a trend which continued through the 1990s (Pezzack *et al.* 2001)" indicates that this information was published by a researcher with the last name Pezzack (Dr. Doug Pezzack at the DFO) and others ("*et al.*" is a Latin abbreviation meaning "and others") in 2001. Similarly, at the top of page 188 of the paper, "Lobsters in the northeastern USA have also shown an increase in the incidence of shell disease in recent years, which largely causes deformations in lobsters being held for market, but is occasionally fatal (ASMFC 2006)" indicates that the information came from a document published by the ASMFC (Atlantic States Marine Fisheries Commission) in 2006. More details about these documents, including their full names, are found in the Literature Cited section at the end of the scientific paper (beginning on page 190).

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Top-down control of lobster in the Gulf of Maine: insights from local ecological knowledge and research surveys

Stephanie A. Boudreau*, Boris Worm

Biology Department, Dalhousie University, Halifax, Nova Scotia B3H 4J1, Canada

ABSTRACT: American lobster *Homarus americanus* landings in the Gulf of Maine have been steadily increasing since the 1980s. As a result, lobsters now support one of the most important fisheries in the USA and Canada. One hypothesis for this pattern is that lobsters have been released from predation as groundfish stocks declined, expanding both in abundance and habitat. Lobster habitat is typically rocky substrate of the inshore region, which is difficult to sample. Some long-term fisheries-independent abundance indices for lobsters and their predators are available for the Gulf of Maine in the USA, but not in Canada. To try and fill those research gaps, we designed a local ecological knowledge (LEK) survey. Semi-structured interviews of 42 fishermen in southwest Nova Scotia, Canada, revealed consistent trends of the depletion of large groundfish, particularly Atlantic cod *Gadus morhua*. Eighty-three percent of fishermen concluded this depletion was the main reason for an observed increase in lobster abundance. They also reported the expansion of lobsters to new habitats and depths. We further show that the proposed top-down control mechanism is independently supported by USA research trawl surveys, which revealed a negative correlation ($p < 0.05$) between the summed abundance indices of 5 groundfish predators of lobster and lobster abundance (kg tow^{-1}) at time lags ranging from 0 to 9 yr. Survey-based diet data also corroborated direct observations by fishermen on lobster predation by groundfish. These results suggest that LEK may be a useful supplementary tool to investigate the ecosystem effects of fishing, particularly in data-poor situations.

KEY WORDS: Local ecological knowledge · American lobster · Gulf of Maine · Ecosystem effects of fishing · Atlantic cod

INTRODUCTION

Commercially harvested invertebrate populations often exhibit abrupt declines under intense fishing pressure and can be slow to recover. Alaskan red king crab *Paralithodes camtschaticus* (Orensanz et al. 1998), abalones *Haliotis* spp. (Tegner & Dayton 2000), green sea urchins *Strongylocentrotus droebachiensis* (Berkes et al. 2006) and oysters (e.g. *Crassostrea virginica*, Kirby 2004) are well-documented examples of this phenomenon. American lobster *Homarus americanus* in the Gulf of Maine (GOM) of the NW Atlantic Ocean, however, shows a different trend characterized by long-term sustainability and recent increases in reported landings (ASMFC 2006, Steneck 2006).

In the present study we focus on lobster fishing area (LFA) 34 in SW Nova Scotia, which is part of the Canadian GOM. It is one of the most productive lobster fishing areas in the world, accounting for approximately 40% of Canadian lobster landings every year. The annual lobster fishing season in LFA 34 lasts from late November to the end of May, with an estimated 70 to 90% of fishable biomass removed every year with baited traps. The fishery is managed by limiting licences, gear and vessel regulations, minimum carapace size and protection of egg-bearing females (DFO 2006a).

Despite intense fishing pressure, the lobster population in the GOM has been increasing since the 1980s, and in the 2004/2005 fishing season, LFA 34 landings were approximately 5 times higher than in 1980/1981

*Email: s.boudreau@dal.ca

(Fig. 1A). Likewise, increases have been documented in landings, abundance indices and recruitment of lobster in the United States' part of the GOM (Fig. 1B,C). Observed increases in landings, abundance and recruitment are unique to this region, as an observed decline of lobster landings has been observed in areas south of the GOM, as well as in the Northumberland Straight (LFA 25) and parts of Newfoundland (ASMFC 2006, DFO 2006b, 2007), Canada. The reason for this increase is not well understood; one hypothesis is that the increase in lobster landings is partially explained by the rapid decline in predatory groundfish stocks, such as Atlantic cod *Gadus morhua*, in the NW Atlantic, leading to a predatory release (Frank et al. 2005, Steneck 2006, Zhang & Chen 2007, Collie et al. 2008). For example, while cod spawning stock biomass in the Canadian GOM decreased from 65 000 t in 1980 to 9000 t in 2008 (Clark & Emberley 2009), the lobster population increased.

The NW Atlantic is assumed to have been a top-down dominated ecosystem before being subjected to exploitation (Worm & Myers 2003, Steneck et al. 2004, Frank et al. 2007). Fishing has altered this by removing most of the larger predators, which in turn has led to significant ecological change (Lotze & Milewski 2004, Steneck et al. 2004). For example, the GOM is thought to have gone through 3 phase shifts in nearshore habitats, from a dominance of predatory groundfish (e.g. Atlantic cod, haddock *Melanogrammus aeglefinus*, Atlantic halibut *Hippoglossus hippoglossus* and wolffish *Anarhichas lupus*) to herbivorous invertebrates (sea urchins) and then to predatory invertebrates (*Cancer* spp., lobster) (Steneck et al. 2004). Another study documented a trophic cascade from large groundfish to pelagic forage fish, plankton, marine mammals and benthic invertebrates on the Scotian Shelf (Frank et al. 2005); it was thought to be a consequence of overfishing, possibly mediated by changes in temperature and stratification. An example of an invertebrate population being released from predation is provided by a meta-analysis of cod and shrimp *Pandalus borealis* biomass in the North Atlantic Ocean (Worm & Myers 2003). Cod and shrimp biomass, as estimated by research trawl surveys, were found to be inversely correlated, leading to large increases in shrimp abundance as cod stocks declined. Collectively, these results lead to interesting questions about ecosystem-based management and the number of predators that can be removed from a system before forcing it into another ecological state (Frank et al. 2007).

A second hypothesis for the observed increase in lobster landings is the advancement of effective fishing effort. The nominal fishing effort in LFA 34 has remained relatively constant over the last few decades; there has been an established fishing season since the 1900s, trap limits have remained between 375 and 400 per fisherman and no new licences have been issued since 1968 (Pezzack et al. 2001). However, there have been changes in the effective fishing effort, in terms of improvements in fishing technology, vessels and expansion of the area fished (FRCC 1995, 2007, DFO 2006a). Prior to the mid-1970s, lobster fishing in LFA 34 occurred in nearshore waters of <55 m depth, and then began to expand to midshore waters, a trend which continued through the 1990s (Pezzack et al. 2001). These changes are not unique to LFA 34; in the Magdalen Islands in the northern Gulf of St. Lawrence, Canada, fishing capacity expansion coincided with an in-

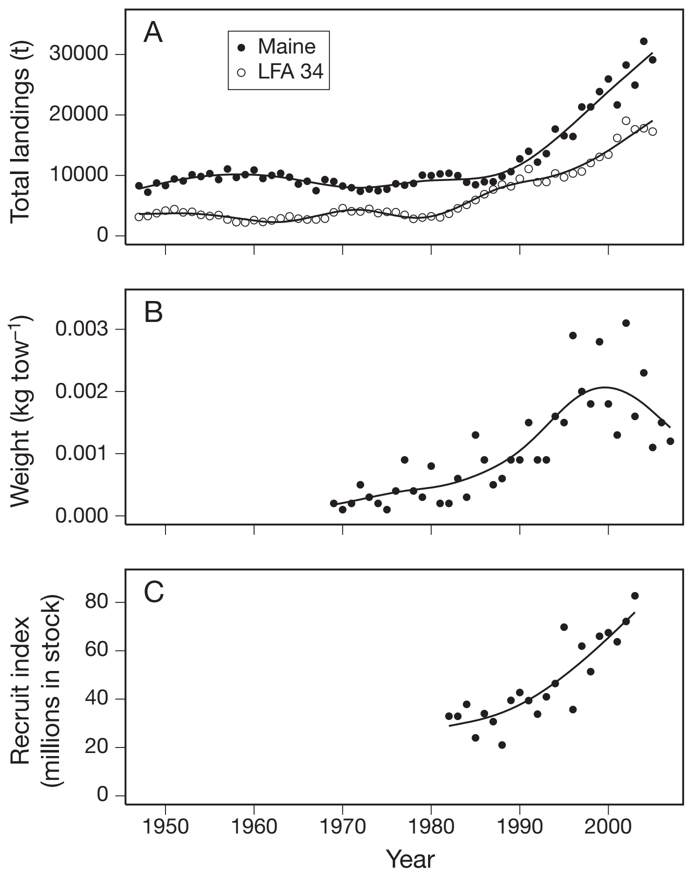

Fig. 1. *Homarus americanus*. American lobster trends in the Gulf of Maine: (A) from 1947 to 2005, lobster landings (t) in Maine from Maine's Department of Marine Resources (solid circles) and lobster fishing area (LFA) 34 from the Canadian Department of Fisheries and Oceans (open circles), (B) from 1969 to 2007, lobster abundance indices (kg tow^{-1}) from the National Marine Fisheries Service research surveys, and (C) from 1983 to 2003, lobster recruit abundance index (millions in stock) from the Atlantic States Marine Fisheries Commission. Trend lines on all panels were derived from a general additive model

crease in lobster landings (Gendron & Archambault 1997, Gendron et al. 2000). In addition, interviews of fishermen documented an increase in vessel size and width to facilitate the transport of more traps (Gendron & Archambault 1997). Advanced technologies for navigation and depth sounding have been quickly adopted and have spurred the discovery of new lobster grounds. The results from the study suggested that the increase in catch per unit effort in the Magdalen Islands resulted both from an increase in lobster biomass and improved fishing technology (Gendron et al. 2000).

Here we were interested in learning how interactions among predatory groundfish and lobsters may have played out in the inshore region of SW Nova Scotia. Recent recruitment of lobsters in this region has been strong (ASMFC 2006), implying that environmental conditions have been favourable for early lobster life stages. However, currently there are no long-term fisheries-independent estimates of lobster abundance in LFA 34, and lobsters have only recently been recorded in the Canadian Department of Fisheries and Oceans (DFO) research trawl surveys. The research surveys typically cover offshore regions, but most lobster habitat is located inshore at depths of <55 m. In order to fill some of the knowledge gaps for this inshore ecosystem, we designed a local ecological knowledge (LEK) survey for the fishermen of LFA 34. The goals of the survey were to record the LEK of fishermen of the coastal LFA 34 ecosystem, with respect to lobsters and groundfish, and compare available fisheries-independent data from the United States to the survey results. We were further interested in the possible effects of climate, disease, changes in prey abundance and fishing effort on lobster abundance and catches, as recorded by these local experts.

MATERIALS AND METHODS

LEK is 'the knowledge held by a group about their local ecosystem' (Olsson & Folke 2001) and considers humans as part of the ecological system (Murray et al. 2006). Trends from LEK interviews can be quantified on an ordinal scale and may be used to complement scientific information for resource management (Neis et al. 1999b).

LFA 34 was selected for the interviews as it is commercially important to Atlantic Canada and has shown a striking increase in landings since the 1980s (Fig. 1A; DFO 2006a). Forty-two lobster fishermen, 4 of whom were retired, out of approximately 937 lobster fishing licence holders in LFA 34 (DFO 2006a) were interviewed from June to October 2007 during the LFA's seasonal closure.

Survey design and questions. A consent form and semi-structured interview were designed and approved by Dalhousie University's Social Sciences Research Ethics Board. Questions were formulated from ecological hypotheses linked to the fluctuations in the American lobster *Homarus americanus* population in the NW Atlantic. Specifically, the survey addressed the observed increase of lobster abundance and landings in LFA 34. It was structured around 6 different variables: predation, conservation, climate, prey abundance, disease and fishing effort. Several recent studies (Neis et al. 1999a,b, Hutchings & Ferguson 2000, Davis & Wagner 2003, Sáenz-Arroyo et al. 2005a,b) were used as references for the design. Further advice on design and execution was sought from a number of experts in ecological knowledge surveys. The fishermen were contacted first by telephone, and arrangements were made to be interviewed in person. The interview began with the fisherman signing the consent form, then an explanation of the research, leading into the interview questions. The survey ended with a free-form discussion in which the interviewee could mention any topics not previously covered. There were 2 versions of the respondent's consent form, the first mentioned our interest in the loss of groundfish as a potential mechanism for the increased lobster landings and the second did not.

The 3 main questions of interest about the inshore ecosystem were:

(1) Why do you think there are so many more lobsters in the last 20 yr in LFA 34 than there were in the 1950s?

(2) In your experience, what fish have you cut open and found lobster in its stomach?

(3) Have you observed any other changes in fish or invertebrate species abundance since 1980 in the inshore region?

Participants. The goal was to target a certain demographic of the licence holders, predominantly middle-aged fishermen with a relatively long history of fishing in the inshore region of LFA 34. To create an initial list of potential participants we consulted the LFA 34 fishermen's representative, community members and the DFO, who identified local experts for the inshore ecosystem. However, the majority of participants were identified by their peers through recommendations at the end of the interviews (Davis & Wagner 2003). Such snowball sampling schemes (also called chain referral or reputational sampling; Neuman 2000) are useful in situations where the information desired is perceived as 'sensitive' and finding individuals willing to participate in the survey is a challenge (Lopes et al. 1996). This non-random sampling methodology is used in the social sciences (Neuman 2000) and has been used successfully in similar marine LEK studies (e.g. Neis et al. 1999a,b, Hutchings & Ferguson 2000).

Data analysis. The various responses to each question were tallied and percentages with 95% confidence intervals (CIs) were calculated. The prop.test command in R was used to create proportions, and CIs were calculated using a modified Wilson's method, correcting for the assumption of normality, with the Yates correction for continuity, which is appropriate for discrete data (Newcombe 1998, R Development Core Team 2008). This method also allows for asymmetrical CIs bounded between 0 and 1.

To test for possible age-related biases among the respondents' answers, a series of logistic regression analyses were performed with 'years of fishing experience' as the explanatory variable. Answers that were not originally recorded binomially were grouped and converted. For example, if the fisherman reported first starting to fish midshore waters in the 1980s or before (i.e. before the observed increase in landings), the answer was assigned 0, if it was in the 1990s or after, it was assigned 1.

Data from research trawl surveys were compared with average responses from our LEK survey, if available. For predator diet data, we compiled occurrences of lobster from the stomach content databases of the Northeast Fishery Science Center (NEFSC) in Woods Hole, Massachusetts (Table 1) and the Maine and New Hampshire inshore research trawl survey (Maine Department of Marine Resources, DMR); these data were tallied and converted to proportions, with 95% CIs calculated as above. We selected 5 groundfish species with available abundance indices that were identified as predators of lobster from both the LEK survey results and stomach contents database: Atlantic cod, longhorn sculpin *Myoxocephalus octodecemspinosus*, wolffish, cusk *Brosme brosme* and monkfish *Lophius americanus*. The groundfish and lobster abundance indices (kg tow^{-1}) in the GOM from the National Marine Fisheries Service (NMFS) research trawl survey were log-transformed for normality and correlated using linear regression (see Fig. 3). Conventionally, these data are analyzed with time lags to reflect the average time of recruitment of GOM lobster to the fishery and the predation of groundfish on various life-stages of lobster. It takes lobsters in LFA 34 from 7 to 8 yr to grow to minimum legal size (DFO 1997). To address this, correlograms were constructed with lags from 0 to 10 yr. Lobster landings for Maine were accessed from the DMR website (www.maine.gov/dmr/rm/lobster/lobdata.htm).

RESULTS

Interviewed fishermen were thoughtful in their replies, had an average of 35 yr of fishing experience (range: 16 to 51 yr), were on average 55 yr old (range: 34 to 84 yr old) and 91% of their income came from the lobster fishing industry (range: 30 to 100%). The average fisherman interviewed possessed 5 different fishing licences or permits (range: 2 to 8). The majority of the fishermen interviewed were from Yarmouth County (26), followed by Digby County (9) and Shelburne County (7). Fishermen from a total of 20 harbours were surveyed, with between 1 and 9 of the fishermen interviewed fishing from a particular harbour. Contact with fishermen was initiated in Yarmouth County, and, as a result, it was more difficult to snowball-sample fishermen in the other 2 counties. The

Table 1. *Homarus americanus*. Species found with lobster in their stomachs from the stomach contents database (1973 to 2005) of the Northeast Fishery Science Center, ordered by percentage with 95% confidence intervals (CI)

Predator	Species name	Lobsters	Stomachs	Percent	95% CI
Smooth dogfish	*Mustelus canis*	25	7145	0.35	0.23–0.52
Atlantic cod	*Gadus morhua*	58	18818	0.31	0.23–0.40
Atlantic halibut	*Hippoglossus hippoglossus*	1	365	0.27	0.01–1.52
Thorny skate	*Raja radiata*	5	3279	0.15	0.05–0.36
Smooth skate	*Raja senta*	1	869	0.12	0.00–0.64
Longhorn sculpin	*Myoxocephalus octodecemspinosus*	9	11116	0.08	0.04–0.15
Haddock	*Melanogrammus aeglefinus*	6	8132	0.07	0.03–0.16
Spiny dogfish	*Squalus acanthias*	43	63837	0.07	0.05–0.09
Little skate	*Raja erinacea*	16	25818	0.06	0.04–0.10
Sea raven	*Hemitripterus americanus*	4	6693	0.06	0.02–0.15
Red hake	*Urophycis chuss*	8	16802	0.05	0.02–0.09
White hake	*Urophycis tenuis*	5	13883	0.04	0.01–0.08
Monkfish	*Lophius americanus*	3	9573	0.03	0.01–0.09
Winter skate	*Raja ocellata*	4	16358	0.02	0.01–0.06
Winter flounder	*Pseudopleuronectes americanus*	1	7966	0.01	0.00–0.07
Spotted hake	*Urophycis regia*	1	12084	0.01	0.00–0.05
Silver hake	*Merluccius bilinearis*	1	45646	0.00	0.00–0.01

location of the interviewee's home harbour did not necessarily reflect where they lived.

When asked why lobster landings had increased over the last 20 yr, 83% of respondents said that the loss of predators was the major reason, 33% also attributed increased landings to recent increases in fishing effort and the expansion to deeper waters and 21% thought that conservation measures, such as gear restrictions and the protection of egg-bearing females, were helping to increase the population (Fig. 2A). Finally, 19% identified a different factor that may have influenced the increase, such as changes in climate or water temperatures. Seventy-four percent were concerned that the population may eventually decline due to increasing fishing effort, the targeting of large lobster and the depletion of brood stock. Fifty-two percent mentioned that they would be supportive of a maximum legal size limit to preserve the large individuals.

Of the 17 fishermen that received the first version mentioning our interest in the decline of groundfish abundance as a mechanism for the increase in lobster landings, 82% mentioned that the 'loss of predators' was, in their view, a mechanism for increased lobster landings. Of the 25 individuals that received the second version, 84% gave the same reply. Fisher's exact test for count data revealed no significant difference (p = 1).

Predator diet

To examine the potential mechanism of the hypothesized predator release effect, fishermen were asked which fish they had dressed in their careers and found a lobster in its stomach contents (Fig. 2B). Large-bodied predators, such as cod (95% reported finding a lobster in stomach contents), wolffish (74%) and cusk (38%), were listed, in addition to sculpin (most likely longhorn sculpin, 81%). To complement the fisher-

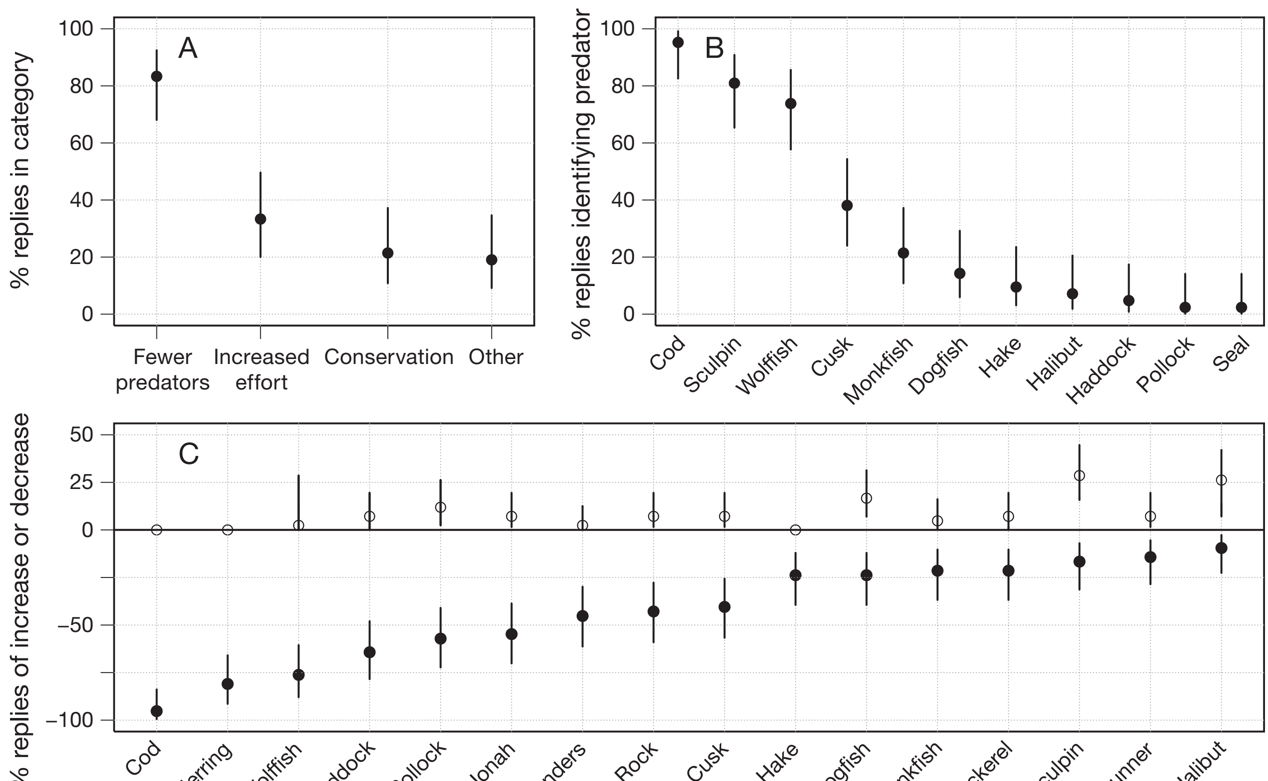

Fig. 2. Average responses, with 95% CI, to the 3 main survey questions (see 'Materials and methods'): (A) reasons given by the fishermen for the increase in lobster landings since 1980, (B) the percentage of fishermen who identified particular predators of lobsters based on their own sampling of stomach contents: Atlantic cod *Gadus morhua*, sculpin (Cottoidea), wolffish *Anarhichas lupus*, cusk *Brosme brosme*, monkfish *Lophius americanus*, spiny dogfish *Squalus acanthias*, hake *Urophysis* spp. and *Merluccius bilinearis*, Atlantic halibut *Hippoglossus hippoglossus*, haddock *Melanogrammus aeglefinus*, pollock *Pollachius virens* and grey seal *Halichoerus grypus* and (C) the percentage of fishermen who reported that a species has decreased (solid circles) or increased (open circles) in the inshore ecosystem throughout their careers; species not mentioned above: Atlantic herring *Clupea harengus*, Jonah crab *Cancer borealis*, flounders (Pleuronectidae), rock crab *Cancer irroratus*, Atlantic mackerel *Scomber scombrus* and cunner *Tautogolabrus adspersus*

men's observations of lobster predators, 2 stomach content databases derived from trawl surveys were examined. The NEFSC stomach contents database (North Carolina to Nova Scotia, from 1973 to 2005, Table 1) revealed that smooth dogfish *Mustelus canis*, which is rarely observed in the GOM (Branstetter 2002), and cod had the highest proportions of lobster found in their stomachs. Longhorn sculpin, haddock and various hakes (e.g. *Urophycis* spp., *Merluccius bilinearis*) also preyed upon lobster. A much smaller inshore research trawl survey, conducted by the Maine DMR (2005 to 2007, not shown), found 1 lobster in a cod (N = 668 stomachs examined) and another in a monkfish (N = 289).

Predator abundance

The fishermen were asked to reflect on any population, besides lobster, that had undergone an increase or decrease in the inshore fishing grounds during their careers. Consistently, large-bodied fish, such as cod (95%), wolffish (76%) and haddock (64%) were reported to have declined (Fig. 2C). There was no consensus, however, as to when precisely the cod populations had started to decline in nearshore areas: 2% thought that the decline began in the 1970s or before, 19% found this had happened in the early 1980s and 29% answered in the late 1980s. Similarly, in the 1990s, 19% observed cod abundance declining in nearshore waters early in the decade, and 17%, late in the decade. Only sculpins and Atlantic halibut were identified more commonly as increasing, rather than as decreasing (Fig. 2C).

Trawl survey estimates

Regression analyses between the NMFS trawl surveys for combined groundfish predators (R^2 = 0.3615, $p < 0.0001$; Fig. 3A), cod (R^2 = 0.3616, $p < 0.0001$; Fig. 3C) and groundfish without cod (R^2 = 0.1996, p = 0.0026; Fig. 3E) with lobster abundance indices all revealed negative and significant correlations. These negative correlations were largely driven by cod, with lobster increasing as cod abundance indices decreased in the trawl surveys. This negative correlation is also evident at time lags of 6 to 10 yr and is usually strongest at around 0 to 4 yr (Fig. 3). When predators other than cod were examined individually with lobster, longhorn sculpin correlated positively (R^2 = 0.4742, $p < 0.0001$), monkfish (R^2 = 0.1929, p = 0.0030) and cusk (R^2 = 0.2731, p = 0.0004) negatively, and wolffish trended negatively, but without statistical significance (R^2 = 0.0251, p = 0.1708).

Changes in fishing effort

The increase in landings in LFA 34 could in part be due to changes in fishing effort, such as expansion into deeper waters (FRCC 1995, Pezzack et al. 2001, DFO 2006a). The region referred to as the 'inshore' is composed of the nearshore and midshore areas. The traditional 'nearshore' grounds are <55 m deep, with the expansion in fishing effort, documented since the 1980s, taking place in the deeper waters of the 'midshore'. The midshore ends at the boundary with LFA 41, which is considered the 'offshore' (DFO 2006a). Accordingly, 79% of interviewed fishermen have recently been fishing in deeper waters, with 60% of them starting to fish in these areas between the early 1980s and the early 2000s. However, 60% still spend some time fishing nearshore, and 19% spend their entire season there. There have been several reasons for this redistribution in fishing effort: 43% report more lobsters in deeper water, 29% prefer to avoid competition in nearshore waters and 24% follow the lobsters as they migrate seasonally from shallow to deeper water. Seventy-six percent were concerned that the increase in effective fishing effort would eventually cause the lobster population to decline, and 33% mentioned illegal fishing practices. The fishermen identified several ways to reduce fishing effort, such as lower trap limits, restricting fishing to daylight hours, closing the fishery for part of the season or 1 d each week. Traditionally lobster were found mostly on highly structured hard substrates, such as boulder fields, but over the past 10 yr, 71% of the interviewed fishermen recorded that lobsters are now being found on other bottom types, such as soft sediments or mud (60%).

There was no evidence for respondents' answers being biased in any way by their age or experience. The only exception was that their years of fishing experience correlated with when they started fishing in midshore waters (p = 0.0194). This result is intuitive, as the more years of experience a fisherman had at the time of the interview, the earlier they could have started fishing midshore.

Other factors

Temperature plays a major role throughout the lobster's life cycle (Aiken & Waddy 1986). Fifty-five percent of the fishermen surveyed replied that the water temperature stays colder for longer into the spring, and 76% said that it is warmer into the fall. Nineteen percent felt that wind direction and strength had no effect on lobster landings, while 79% said that catch decreases with high winds.

In 1999, a parasitic paramoeba caused a massive lobster mortality event in Long Island Sound, USA

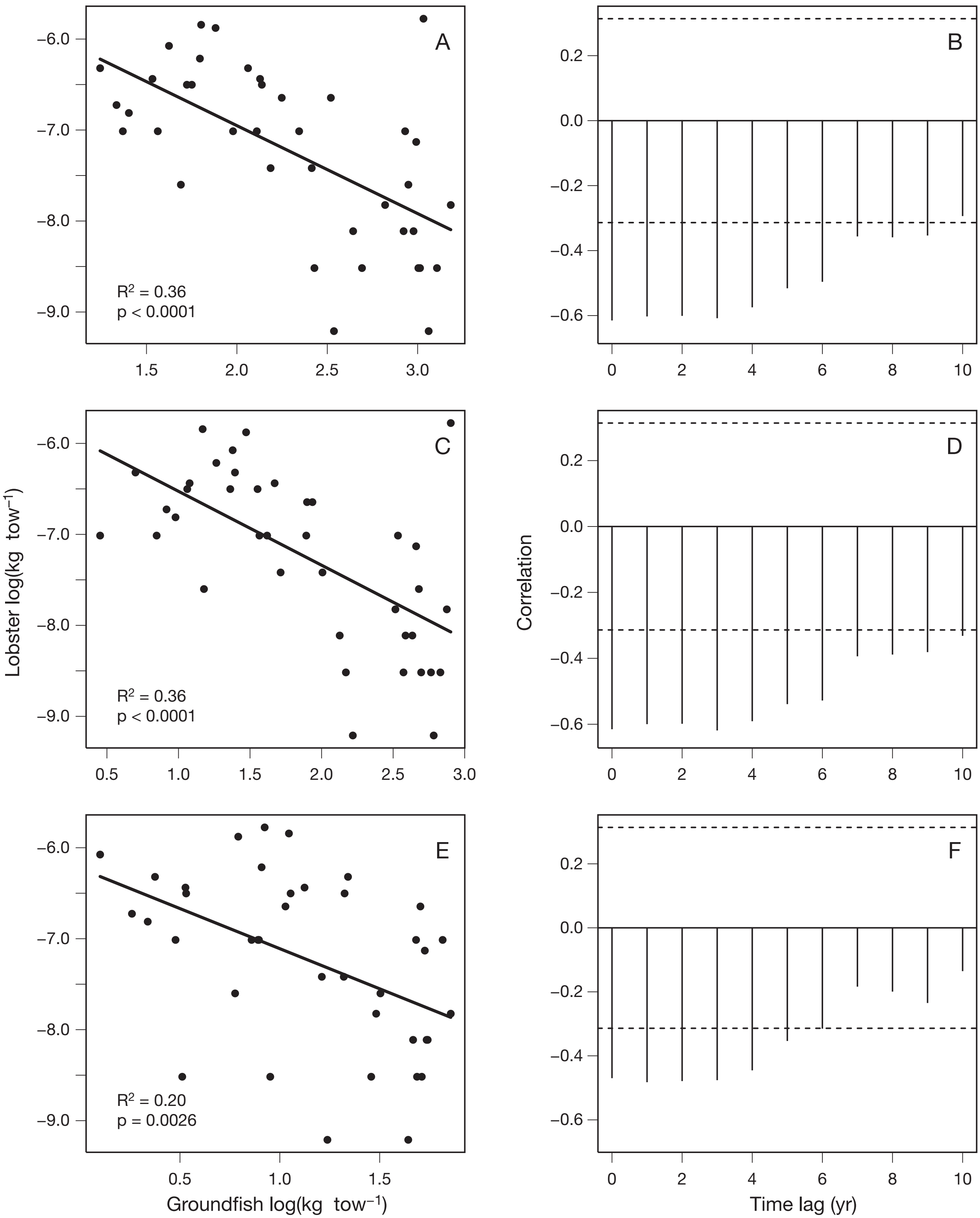

Fig. 3. Negative correlations between research trawl survey estimates of Gulf of Maine groundfish and lobster. National Marine Fisheries Service abundance indices (kg tow^{-1}) were log-transformed, and correlations were tested at time lags from 0 to 10 yr. (A,B) Lobster abundance versus combined survey estimates of Atlantic cod, cusk, longhorn sculpin, monkfish and wolffish, (C,D) Atlantic cod and lobster, and (E,F) 4 groundfish predators of lobster, as above, but without cod. Dashed lines indicate 95% confidence intervals. Trendline and test statistics are from a linear regression on log-transformed data

(Mullen et al. 2004). The effects of this disease were likely exacerbated by hypoxia and higher water temperatures (ASMFC 2006). Lobsters in the northeastern USA have also shown an increase in the incidence of shell disease in recent years, which largely causes deformations in lobsters being held for market, but is occasionally fatal (ASMFC 2006). Forty percent of the interviewed fishermen voiced a general concern about disease affecting the lobster population; however, 95% had never or very rarely seen evidence of a diseased animal in their catch.

As for changes in prey abundance, 2 species of *Cancer* crab are known prey of juvenile and adult lobsters (Elner & Campbell 1987, Lawton & Lavalli 1995). Fifty percent of the fishermen surveyed were concerned that lobsters in LFA 34 were becoming food limited due to their high population density and to commercial catches of Jonah crab *Cancer borealis* by those with permits and for use as bait (DFO 2000). *Cancer* spp. were 2 of the top 5 species mentioned as being captured most commonly with lobster: cod (98%), sculpin (88%), Jonah crab (86%), rock crab *Cancer irroratus* (83%) and cusk (64%).

It has been suggested that the large input of lobster bait (mostly the herring *Clupea harengus*) into the GOM has been subsidizing high lobster abundances (Saila et al. 2002). This argument is based on the fact that many lobsters exit the trap after feeding on bait (Karnofsky & Price 1989, Jury et al. 2001). The average herring bait to lobster ratio in adjacent LFA 33 has been estimated to be as high as 1:1.9 (Harnish & Willison 2009). While 40% of the fishermen in the present study felt that they were to some extent feeding lobsters with bait during the fishing season, for the majority of those interviewed it was not considered as a principal reason for the increase of lobsters in LFA 34.

DISCUSSION

This LEK survey provided evidence in support of the hypothesis that inshore lobster populations in the GOM have been released from predation, which may in part explain their high recruitment, abundance and landings. Despite high exploitation rates, whereby most of the new recruits are being caught every year, landings continue to be high. According to the fishermen interviewed, this may be explained partially by the extraordinary peak in lobster abundance and recruitment (Fig. 1) and partially by increased effort, conservation measures and possibly other factors (Fig. 2A). Fishermen's observations of predator diet and changes in abundance (Fig. 2B,C), as well as the observed decline in cod abundance and increase in lobster abundance, are all consistent with the hypothesized top-down mechanism (Fig. 3, Table 1).

These results add further support to the notion that the collapse of demersal predator populations, such as NW Atlantic cod, has released a suite of species from predation and contributed to a reorganization of the NW Atlantic inshore and shelf ecosystems (Worm & Myers 2003, Steneck et al. 2004, Frank et al. 2005). More broadly, there is increasing evidence that top-down interactions and cascading ecosystem effects of fishing may be quite important both in nearshore and oceanic food webs (Heithaus et al. 2008, Baum & Worm 2009). These interactions are typically mediated both by changes in prey density and behaviour (Heithaus et al. 2008). In this case, there is some evidence for both mechanisms leading to increased abundance of lobster and the reported expansion towards previously risk-prone habitats. The observation that lobsters are venturing from structured hard substrates onto soft sediments has been independently confirmed by scientific studies which report that catch rates of lobster in trap surveys were higher on soft sediments than on hard substrates; however, lobster densities from diver surveys were higher on hard- than on soft-bottom types (Tremblay & Smith 2001, Geraldi et al. 2009). Lobsters originally caught and released on soft substrates travelled significantly farther than those caught on hard substrates, indicating that the animals move faster over sediment in order to find more suitable habitat (Geraldi et al. 2009).

According to this survey, factors other than predation and fishing may play a limited role in regulating lobster populations in the GOM. Only 19% of fishermen observed that climate, disease, or changes in prey abundance were influential. Water temperature is often hypothesized to play a major role in the increased lobster landings in Maine and Nova Scotia. In Maine (1946 to 1986), 54% of the variance in lobster landings could be explained by the sea-surface temperature (SST) at the time of larval settlement (Steneck & Wilson 2001). In Nova Scotia (1929 to 1970), 68% of the variance in landings was explained by the SST in St. Andrews, New Brunswick, in addition to the previous year's catch (Flowers & Saila 1972). Drinkwater et al. (1996), on the other hand, were not able to link SST with the increase in lobster landings throughout the American lobster's range in the 1980s and early 1990s, although they acknowledged a potential role of SST in the past. From the present LEK survey, it is evident that the fishermen pay close attention to changes in water temperature, which affects lobster movement, moulting and spawning, and they are keenly aware of environmental cycles. However, water temperature did not emerge in the replies as a main driver of the increase in lobster.

Likewise, bait inputs were not considered as a major mechanism to boost lobster populations in LFA 34, though 40% agreed that lobsters were likely eating bait during the fishing season from late November to the end of May. Bait inputs may be more substantial on the United States' side of the GOM, where trap density is higher and the fishery operates year-round (Myers et al. 2007, Grabowski et al. 2009). Despite the higher bait input, however, the relative increase in lobster landings has been less pronounced in the United States compared with Canadian waters (Myers et al. 2007), and, in the eastern portions of the GOM, bait is not believed to subsidize lobster populations (Grabowski et al. 2009).

Ecological knowledge surveys may best be used in combination with other data sources, so that fishermen's observations can be verified independently. One contrasting example comes from the southern Gulf of Saint Lawrence (sGSL; Davis et al. 2004), where fishermen were concerned that research survey protocols were insufficient to document the predation of white hake *Urophycis tenuis* on juvenile lobster. Fishermen did provide accurate details of hake distribution, yet stomach sampling revealed that, contrary to the belief of fishermen, white hake did not ingest lobster (N = 3080). In our study, the fishermen revealed detailed insights into potential predators of lobsters and other aspects of the coastal ecosystem, such as shifts in species composition, water temperatures, habitat expansion and the incidence of disease. By comparing their replies with the trawl survey-derived stomach content and abundance data, it seems evident that the LEK for LFA 34 reflects some of the ecosystem changes in the GOM. Interviewees consistently reported that large fish had declined in abundance and that those same large fish were predators of lobster. Atlantic cod stood out as the species that was most consistently reported as having declined and as being a predator of lobster. While the proportion of lobsters found in fish stomachs is small overall (Table 1), the predation of a large cod stock upon lobsters could still have had a significant effect, particularly when considering the historical biomass of cod in the GOM and Scotian Shelf area (Steneck 1997, Rosenberg et al. 2005).

In a study of the sGSL, Atlantic cod reportedly ingested lobster at a much lower rate than those in the present study, with lobster being found in 0.05% of cod stomachs between 1990 and 1996. Most size classes of cod, however, overlapped spatially with lobsters in the sGSL only during June and October. There were no significant relationships between cod and lobster abundance indices (1950 to 1996) for time lags of 0 to 7 yr, indicating that cod did not control lobster abundance in the sGSL. However, the study identified shorthorn sculpin *Myoxocephalus scorpius*, cunner *Tautogolabrus adspersus* and white hake as potential predators of lobster (Hanson & Lanteigne 2000). A second study in the northeastern USA collected >15 000 cod stomachs from the NEFSC seasonal bottom trawl survey between Cape Hatteras, North Carolina, and SW Nova Scotia from 1973 to 1998. Commercially valuable decapods were determined to be an important component of the diet of Atlantic cod; however, American lobster was not identified as a major prey item. The study concluded that cod were opportunistic generalists and that it was not likely that cod exerted predatory control on all of its prey populations in the United States' northwestern Atlantic (Link & Garrison 2002).

One of the key challenges of LEK surveys is determining whether or not the respondent is giving a reply that they think the interviewer wants to hear, potentially by being led by the interviewer. To address this, there were 2 versions of the respondent's consent form, the first mentioned the loss of groundfish as a potential mechanism for the increased lobster landings and the second did not. No differences were found between responses to the 2 versions, indicating respondents were not led by the consent form. Another potential challenge in the present study was our relatively small sample size; roughly 4.5% of the license owners were interviewed, coming close to our goal of 5%. As a comparison, Hutchings & Ferguson (2000) interviewed 47 fishermen of a similar demographic in 2 sectors of Newfoundland's fixed-gear cod fishery. Their sample represented 1% of 4677 fishermen, yet they were able to establish patterns in the harvesting of cod from 1980 to 1991 that were consistent with the hypothesis that the decline in Newfoundland's inshore cod stock was gradual. We targeted fishermen with decades of experience who were viewed as local experts by their peers. The considerable agreement between respondents for most answers indicated that a higher sample size would not likely have changed the results.

It is possible for a respondent to reply in such a way that serves personal motives, particularly if the interviewee has a high stake in the outcome (Gendron et al. 2000). We note, however, that this survey did not question fishermen about the abundance of lobsters (which was assumed to be high) or their personal catches and that the ecological hypotheses we explored would not necessarily influence lobster management. In an effort to minimize any further potential for personal biases we targeted experienced fishermen, some of whom would be near retirement. These fishermen were often very candid and forthcoming, and there was little sense of hesitation, bias, or staged answers.

In conclusion, we suggest that LEK surveys are a useful method to learn more about how fisheries may affect ecosystems, especially when they can complement independently collected scientific data. Canadian fisheries are now largely dependent on lower trophic levels (Pauly et al. 2001), with a heavy emphasis on benthic invertebrates. Unfortunately, the knowledge base for many of these fisheries is slim, and fisheries-independent data or proper assessments are often not available (Anderson et al. 2008). It seems prudent in this case to use all of the available information, including fishermen's expert knowledge as one possible line of evidence, to evaluate ecological interactions and to inform the management process.

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