Ecological Role of Adult and Juvenile Anadromous Forage Fish in Maine Estuaries: Sea-Run Alewife and Groundfish Predators

Contract number PZ07007

30 Sept 2009

Submitted by

Dr. Karen A. Wilson, PI

Assistant Research Professor,

Dept. of Environmental Science, University of Southern Maine

37 College Ave.

Gorham, ME 04038

In association with

Dr. Theodore Willis, Aquatic Systems Group, Portland, ME

David Turner, Perry, Maine

Mike Myrick, Cushing, Maine

John Stotz, Round Pond, Maine

Christopher Taylor, South Bristol, Maine

Abstract

Historically, river herring (composed of alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) were an extremely abundant seasonal resource in the nearshore Gulf of Maine, originally as a subsistence food and trade item for both Native Americans and European settlers, and later as a commercial commodity. River herring link marine and freshwater systems through the transfer of marine- and freshwater-derived nutrients up and downstream. Historical evidence suggests that river herring were an important forage fish for nearshore groundfish stocks; we contend that without prey fish restoration, the rebuilding of commercial fish stocks will be an incomplete, and likely unsuccessful process. This project addresses what we think is a key component of this system– the role of river herring in estuarine food webs before, during and after spawning runs. Our objectives were to (a) assess the ecological role of river herring as prey in Maine estuarine food webs, and (b) to assess the relationship between spatial distribution, seasonal timing and densities of river herring in estuaries

relative to their movement between freshwater and saltwater habitats. We sampled 4 estuaries in with low and high river herring returns and quantified predation on alewife by nearshore groundfish caught using hook and line. We analyzed diets from cod, pollock, sculpin and mackerel, developing a somewhat unique nearshore record of diets of these species. The most important results of this work were that (1) that, in contrast to historical reports, few to any large fish predators were present inshore during the time in which adult river herring would be moving up rivers to spawn (May/June), and (2) young-of-year (YOY) river herring were readily consumed by a variety of fish species and sizes when YOY river herring were present in the system in late summer or fall. We conclude that that river herring have the potential to provide important late summer forage for juvenile groundfish and other predators, and that, until large groundfish recover in the nearshore region, the most important predators of adult river herring are humans, seals and waterfowl.

Final Technical Report to the Northeast Consortium: Ecological Role of Adult and Juvenile Anadromous Forage Fish in Maine Estuaries: Sea-Run Alewife and Groundfish Predators

K. Wilson, Dept. of Environmental Science, University of Southern Maine, Gorham, Maine

____

Signature *Date*

T. Willis, Aquatic Systems Group, University of Southern Maine, Portland, Maine

Introduction

Historically, river herring (alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis)*) were an extremely abundant seasonal resource in the nearshore Gulf of Maine (GOM), functioning originally as a subsistence food and trade item for both Native Americans and European settlers, and later as a commercial commodity. Prior to 1825 hundreds of tons of river herring were harvested from the St. Croix River, Washington County, Maine, salted and barreled for export to southern New England and the West India market (Perley 1852). The availability and importance of river herring as a commercial and ecological resource plummeted coast-wide in the late 1800s, first as a result of the damming of rivers and streams (Baird 1883), and later with the introduction of more efficient open water fishing gear. The connection between loss of spawning habitat and decrease in alewife numbers was often obvious within a few years of dam installation; for example, on the St. Croix River, local residents wrote letters of protest to the Maine state government as early as 1821 describing the loss of food and revenue and imploring that fish ladders be installed (MSA 1821). More recently, east coast landings of alewife have decreased since the 1970s, dropping from 40-65 million pounds to 1.4 million pounds by 1996 (U.S.D.C. 1999).

Today, river herring are a resource whose diminished numbers have substantial ramifications for the ecology of the GOM and associated rivers and lakes in which they spawn. River herring link marine and freshwater systems by transferring marine-derived nutrients upstream in the form of eggs, excretion and the approximate 50% of adults who die during the spawning run. In oligotrophic freshwater systems these nutrients may have bolstered benthic productivity (e.g., Durbin et al. 1979), possibly augmenting prey availability for other anadromous fishes such as Atlantic salmon. In addition, alewife young-of-year (YOY) can have a transitory effect on zooplankton community composition in lakes (Durbin et al. 1979, Yako et al. 2000) and are prey for freshwater fish species (e.g., large- and smallmouth bass, Yako et al. 2000, Hanson and Curry 2005). River herring YOY export freshwater nutrients to marine systems where they are consumed by a variety of predators. In the nearshore marine environment, commercially important predatory fishes would have benefited from both the spawning run and YOY escapement, as well as seabirds and marine mammals. Adult stripped bass are voracious predators of both adult and YOY alewife in estuaries and rivers (Walter et al. 2003) and cod commonly eat clupeids in the GOM (Link and Garrison 2002). In 1883, a report by the U.S. Commissioner of Fish and Fisheries describe the co-migration of spawning cod and alewife along the coast, and implicates the loss of alewife runs as the cause for the loss of cod spawning aggregations near rivers (Baird 1883; Ames 2004). Remaining populations of nearshore cod and other predators now compete with commercial river herring fisheries for a shrinking resource.

Currently, river herring are taken by several fisheries that operate both in rivers and offshore in the GOM. Spawning river herring are harvested by municipalities and fishermen in early spring as an inexpensive commercial and recreational fishing bait. For example, the alewife fishery at Damariscotta Mills generated revenues of $16,000 for the towns of Newcastle/ Nobleborro, Maine, in 2004 from license fees and bushel sales of alewife to lobster fisherman (D. Wright, pers. comm.). The local nature of river herring runs can also reduce bait costs of fishers by eliminating middle-men, fuel, and handling charges. River herring are also taken offshore by gillnet, purse-seine and trawl during yearly migrations to and from spawning rivers. Competition for river herring may become more fierce with recent amendments to the Atlantic States Marine Fisheries Commissions (ASMFC) Fisheries Management Plan by tightening regulations on the American shad, river herring (alewife and blueback herring) and the Atlantic herring fisheries. The ASMFC recognized the duel commercial and ecological roles of river herring, but lacks the data required to make management suggestions that would ensure the sustainability of river herring resources (ASMFC 1999, 2009).

River herring are particularly desirable as a forage fish for nearshore food webs because alewife, at least, respond quickly to habitat restoration efforts and therefore have the potential to meet the demands of commercial harvesters while fulfilling the ecological needs of freshwater and estuarine systems. For example, when the head-of-tide fishway was improved on the St. Croix River, New Brunswick, alewife spawning escapement climbed from 170,000 in 1981 to 2 million by 1986 (St. Croix International Waterway Commission, unpublished data). Closing the fishways in later years had the reverse effect. Restoration efforts in the Kennebec watershed, including removal of the Edwards Dam and initial stocking of alewife, resulted in estimated returns between one and two million alewife by 2004 which have been maintained since (MDMR 2004). Both state and federal agencies have demonstrated the political and financial will to pursue localized habitat restoration for anadromous fishes (i.e., by supplying funds for fish passage improvements). Increases in sheer numbers appear to be a real possibility for alewife and likely blueback herring.

This project attempted to address what we contend is a key component in understanding consequences of reestablishing links between freshwater and marine ecosystems of the GOM through the restoration of alewife spawning runs: the ecological role of alewife in estuarine food webs, both as predators and prey and densities and spatial distribution of alewife in estuaries before, during and after spawning runs. This information will assist in quantifying the transfer of nutrients and materials from the ocean to the uplands in the form of adult excretion, adult mortality, and egg production, and the return of some of those materials to the estuaries as YOY escapement. In concentrating on estuaries, we highlight river herring interactions with many juvenile fishes that use the estuaries as nursery grounds, increase our ability to relate river herring density and location to spawning activities, and compliment existing large-scale data on alewife distribution along the coast of Maine collected by Maine Dept. of Marine Resources nearshore trawl survey (http://www.maine.gov/dmr/rm/trawl/). We feel a better understanding of the freshwater – marine connection will help inform public discussions and decisions in a way that will be broadly beneficial for the people of the state.

Project objectives and scientific hypotheses

Our original objectives were to compare the diets of potential predators in one high alewife estuary to one low alewife estuary per summer, with a total of four estuaries in the experimental design. After near zero catches of potential alewife predators in Denny's Bay (Cobscook/ Passamaquoddy Bay) in 2006 and no available means to count alewives in the Denny's River that same spring, in 2007 we added two midcoast Maine estuaries with larger, monitored alewife runs and larger potential predator populations. This effectively increased the chance of observing alewife predation in the nearshore marine environment and we maintained this sample regime in 2008 (Table 1).

Our second original objective was to quantify the distribution of river herring in estuaries before, during and after spawning runs; we were unable to pursue this objective because (1) fisherman, upon further reflection, were unable, or unwilling, to tow nets in the nearshore region (Passamaquoddy Bay) because of currents or obstructions, (2), in the midcoast estuaries (Damariscotta & St. George) the proliferation of fixed gear (i.e., lobster gear) made trawling or purse seining impossible, and (3) it was difficult to schedule days at sea when river herring out-migrations are unpredictable in advance.

Participants

David Turner (2006, 2007, 2008), South Meadow Road, Perry, Maine

Mike Myrick (2007), P.O. Box 36, Cushing, Maine

John Stotz (2007), P.O. Box 131, Round Pond, Maine

Christopher Taylor (2007, 2008), P.O. Box 38, South Bristol, Maine

Six undergraduate or recently graduated students from the University of Southern Maine, University of Maine and McGill University have assisted in diet analyses, data entry and fieldwork (Kyle Moulton, Shannon Prescott, Mike Rautenberg, Abby Pearson, Spencer Blair-Glantz, Robin Tiller).

We received additional help from the Maine Department of Marine Resources, Damariscotta/Newcastle Fish (Alewife) Committee, the Warren (St. George River) Fish Committee and Town of Warren, The Passamaquoddy Tribe (Pleasant Point), and Maine SeaGrant.

Methods

Sampling sites

We chose sample sites along a water temperature gradient in the Gulf of Maine. The Eastern Maine Coastal Current (EMCC) creates what is arguably a dynamic thermal boundary near Owl's Head in Penobscot Bay as the current veers offshore into deeper water (Pettigrew et al. 2005, Manning et al. 2009). The Western Maine Coastal Current (WMCC) becomes apparent inshore just south of Penobscot Bay. Years with high rainfall totals can shift the EMCC north and east and in dry years ocean conditions can push the EMCC further south and west. Consequently, our most southern site, Damariscotta River and Estuary, was within the WMCC and thus considered our "warm" water site, our northernmost site, Western Passage, Passamaquoddy Bay, was considered our "cold" water site, and our site in the St. George River and Estuary was our transition zone site (Fig. 1). Average 2007 August water temperature in Harpswell Sound (25 km E. of the Damariscotta site) was 16.6^{o}C (2m depth), compared to 11.1^{o}C (1 m depth) in Western Passage Passamaquoddy Bay during the same period.

Figure 1: Map of estuaries sampled. Outlined and shaded areas encompass the (1) inner, (2) middle and (3) outer angling sites.

Initially we were focused entirely on the Passamaquoddy region. However, in 2006 we caught very few fish and no cod using a variety of sampling methods. Methods that used mobile gear were not an option at that time because of the strong currents and potential endangered species impact in the area. Consequently we greatly expanded our sampling in the following two years of the study. One of the reviewers of the original proposal suggested we expand our sampling further south into the midcoast Maine, which resulted in the three estuary study.

We used hook and line angling as the primary method for capturing fish. Each trip was populated by two to five people, usually three, including the ship captain. Each crew member used a deep sea jigging rod with one to five hooks. Hook size varied from #4 to 3/0, usually in combinations of 2 - 3 small hooks and a large hook at the bottom of a 3 - 5 hook rig. Hooks were either baited or were a variety of jig types with no bait or both, depending upon fisher-preference or what hooks were catching fish that day. An angling area was chosen first based on bottom topography; we targeted humps or bottom features where the sea floor shoaled from 25 - 36 m up to 12 - 18 m. A "drift" would begin on the up-current or up-wind side of the feature (depending up which was stronger) with the boat parallel to the direction of travel. Each drift was expected to go over the top of the feature; fish tended to be caught on the incline and decline slopes. All rigs were actively jigged. If no fish were caught after two to three passes a new feature was selected. If fish were caught the drift path would be repeated until no fish were caught after one to two times over the feature. Start and end time of the drift and number of hooks used, including changes in hook number part way through a drift period were recorded. Increasing hook size was not necessarily associated with increasing fish size; in some cases the largest fish were caught on the smallest hooks, though commenting on whether choice of hook size skewed the size distribution of our catch is not within the scope of this study.

Additional fishing methods used included trammel nets, baited lobster traps, baited fish traps, beach seine, and multiple 25 hook tub trawls. None of these methods proved to be particularly productive, and some were simply too difficult to use in the high tides in the Gulf of Maine, or the method produced too much bycatch. For example, trammel nets may have been a promising method but the urchin and crab bycatch in Passamaquoddy Bay made the method impractical. Tub trawls, a string of 25 baited hooks spaced six feet apart on 2.5 ft gangions, also proved very ineffective. Tub trawls were set for three hours and generally were retrieved with no fish and no bait. We added a video drop camera in 2007 with two baited hooks to determine what was happening to the bait. We discovered that invertebrates, usually lobster or crab, were attacking the baited lines almost as soon as they reached the bottom in the spring. In the summer and fall baited hooks were mobbed by cunner (*Tautogolabrus adspersus*), which effectively crowded out other fish that might take the hooks. Consequently, tub trawls were abandoned in 2008 and we focused on angling.

Diet collection and processing

Captured fish were held in a flow-through live well until processed. Fish were processed between major location transitions, e.g., fish caught on drifts in the middle location were processed before conducting drifts in the outer or inner locations. We obtained diet samples from fish > 150 mm in length using gastric lavage to flush the fish's stomach (Hartleb and Moring 1995). Fish were anesthetized by immersion into a five gallon bucket (1/3 full) of sea water and MS-222 or other approved anesthetic until the fish lost equilibrium. The stomach was flushed using a one gallon garden sprayer with the spray nozzle replaced by thin-walled tygon tubing. The tubing was inserted through the mouth into the gut. The operator gently squeezed the fish's stomach while filling the gut with water. Regurgitated diet items were captured on a 500 μm sieve. Fish were then fin-clipped, allowed to recover in the live well, then released alive. Gastric lavage produced a high quality diet sample because it stopped the digestive process, and allowed us to minimize the number of fish euthanized to make diet collections.

The effectiveness of gastric lavage on commonly caught species ranged from 85-100% (Table 1). We found that harder and larger items, e.g., whole urchins or large crabs, would not necessarily be dislodged from the stomach with standard effort. However, the operator could feel these large items in the stomach after the initial lavage attempt and, with additional effort, flush or remove these items. The presence of these items was also evident from crab legs and urchin spines that flushed out more easily. We concluded that this method was effective for flushing fish stomachs of the marine species tested. Diets were preserved in a solution of 70% ethanol, 10 % methanol, 5% PEG-300, and 15 % distilled water.

Table 1. Effectiveness of gastric lavage (stomach flush). To test the efficacy of the stomach flush method 20-25 specimens from commonly caught fish species were flushed according to our normal procedure and then euthanized. If possible, the stomach was excised immediately after flushing or the whole fish was put on ice for transport back to the lab. Collected stomachs and whole fish were dissected within six hours of capture and checked for residual food items. Gastic lavage was not 100% effective in only 8 of 87 fish sampled.

Species	Number sampled	Empty after flushing	Not empty after flushing	% Effectiveness
sculpin	21	18	3	86
mackerel	23	21	2	91
dogfish	3	3	0	100
cod	20	17	3	85
pollock	20	20	0	100

Diet items were identified to the lowest taxonomic level possible (usually family), counted and total wet weight for each type of diet item was recorded. In order to preserve as much data in the analysis as possible, most major diet items were collapsed into large categories for analysis (e.g., crab, amphipod, etc) because digestion levels, and therefore levels of taxonomic identification, varied from fish to fish. See Appendix A for a full list of species, genera and families that constituted these larger diet categories.

We collapsed diet information into an Index of Relative Importance for each estuary – species combination. The IRI combines frequency of occurrence as percent occurrence (% O), diet category weight as percent weight (% W) and diet category numerical occurrence as percent of number (% N), with the final value expressed as a percent relative importance (% IRI) (Liao et al. 2002). IRI values for all diet taxa were arrayed into a sample x species matrix (in this case estuary-species x diet items) for multivariate analysis. We used non-metric multidimensional scaling (NMDS) to ordinate the IRI matrix. NMDS requires first calculating a similarity matrix from the sample x species matrix and then assigning rank order values to the similarity values in that matrix. Ranks are plotted along two or more non-scalar axes. In this case, each point represents the assemblage of diets items consumed, on average, by a fish species stratified by estuary; the closer two points are located in a NMDS plot, the more similar they are in attributes. Stress value is a goodness-of-fit calculation that measures how well the non-parametric regression upon which NMDS is based matches the rank order from the similarity matrix. The lower the stress value, the better the model fit; stress < 0.1 is a good two dimensional fit to the data.

River herring spawning run count

River herring spawning run numbers for each estuary were estimated in a variety of ways. Our assumption was that, at a minimum, the number of return adult spawners harvested or counted in a river must pass through the estuary on their way to spawn in the spring. Available spawning and harvest numbers are presented in Appendix B.

a. Damariscotta Dr. Willis installed video counting equipment at the Damariscotta Mills fish ladder in 2007 as part of a separate project to estimate spawning escapement into the lake. Video numbers were compared with 10 minute on the hour hand counts (conducted by the dam owners) and found to be greater than, but within the error estimate of, the hand count data (T. Willis, unpublished data) so we used the hand counts which were available for many years. When combined with harvest data, these data give an unusually complete account of how many alewives reached the harvest point at Damariscotta Mills, and therefore traversed the estuary during their migration.

b. St. George River In 2007 and 2008, Dr. Willis led a NOAA-funded project that constructed and installed an experimental counting weir in the St. George River. The proposal called for installation of the counting weir in Warren, but this activity was not supported by the town or the town-sanctioned harvester. Consequently, the weir was installed at a rehabilitated dam site at the inlet of Sennebec Pond (7 miles upstream) in association with a different project. We assume that Sennebec Pond received a small proportion of the total run because considerable spawning habitat exists downstream, but the data do give a relative sense of the run escapement in 2007 and 2008. In addition, we received adult river herring catch data from the St. George River harvest operation in Warren, ME from the town fish committee.

c. Little River (Passamaquoddy) Counting alewives on the Little River proved to be more difficult than anticipated because of poor cooperation between the stakeholders of that harvestable run. No data estimating harvest or run size were available for 2006 – 2008, although we know that small runs occurred each year.

d. Dennys River We were not able to obtain counts of river herring in the Dennys River for the 2006 season when we fished Dennys Bay. However, in 2008 the run was counted in its entirety for the first time, with ~almost 70,000 adults moving up the river to spawn (Maine Dept of Marine Resources, personal comment).

Results

Catch

We found that the angling catch was distinctly seasonal in all estuaries . In general, more fish were caught in the fall than in the spring or summer fishing periods. Notably, we fished roughly the same locations in spring, summer and fall with markedly different catches between the seasons at the same locations (Table 2). We found weak statistical significance in catch per unit effort (CPUE: fish catch per number hooks deployed per hours fished) based on the results of a full factorial ANOVA analysis that included year, season, location and estuary ($p < 0.001$, $F = 1.8$, $df = 1054$). Significant terms were season and year. Tukey's Post-hoc test identified significant differences in year ($p = 0.009$) with 2008 average CPUE higher than 2007, and season with spring catches lower than summer ($p < 0.01$) or fall ($p < 0.001$). Higher catches in 2008 than in 2007 likely reflected an experience curve on the part of the samplers as we and the boat captains learned what features to target and under what conditions, e.g., there appeared to be a difference in species caught and catch rate related to tide stage, however, our sampling activity did not account for this observation until year two of the study. Please note that testing this observation with specific data is beyond the scope of this study. Seasonal differences in CPUE are likely a reflection of seasonal changes in water temperature. Because of the overall latitude at which the study was conducted water temperatures tend to be cool to cold for more of the year, i.e., a maximum water temperature of 17.2^{o}C on the Central Maine Shelf in 2007 and 18.2^{o}C in 2008, average April to November temperature was below 12^{o}C in both years. Peak water temperatures occur late in the summer and persist into early fall (Pettigrew et al. 2005).

Table 2: 2007 and 2008 catches from Damariscotta, Passamaquoddy Bay (Little River, Perry) and St. George Estuaries. The Passamaquoddy site was not fished in the spring of 2007 as a result of insurance issues for our collaborating fisherman.

	Damariscotta						Passamaquoddy						St. George					
	2007			2008			2007			2008			2007			2008		
Fish Species	spring	summer	fall	spring	summer	fall	spring	summer	fall	spring	summer	fall	spring	summer	fall	spring	summer	fall
Cod	3	22	46	3	43	76	.	1	14			3	1	17	18		17	56
Cunner	8	4	10	3	6	51	.							7	7		8	18
Cusk	3						.											

Dogfish							.	1	1		5							
Herring							.	4		2		1		1				4
longhorn sculpin	2	4	14		13	18	.	34	17	35	55	86	1	6	3	2	2	8
mackerel		15	106		58	155	.	63	80		200	237		40	137		57	244
pollock		30	60	14	23	147	.	1	4		1	27		13	20		33	78
redfish	3	15	5	3	19	21	.				1			10	6		6	3
sea raven				1	1	6	.	7	1		4	15		1	1		1	5
shorthorn sculpin	2	10	4	7	3	2	.	35	20	45	20	97	1	6	2			7
silver hake							.	1	1						1			
rainbow smelt							.	1				1						

To assess differences in catch at the species level we conducted full factorial ANOVA analyses for each species by estuary with CPUE as the response term. Only 48% of the analyses produced a significant model (Table 3). Of the non-significant models, shorthorn sculpin and mackerel from Passamaquoddy Bay were surprises; there was no pattern in the catch of these species, which were the most common species caught from the Passamaquoddy Bay sites. Several species were caught infrequently during the two years of the study, including sea raven, redfish and cunner, and although they produced a significant ANOVA result it is doubtful that enough fish were collected for a meaningful comparison between years and locations. Longhorn and shorthorn sculpin were relatively rare in Damariscotta and St. George estuaries and cod were rare in Passamaquoddy Bay.

Table 3: Anova table of statistically significant ($p < 0.05$) catch results for most frequently caught species. We used a full factorial design for eight species. There were no significant interactions terms for year x sampling period or year x sampling period x location, and there were no significant models for shorthorn sculpin. Value in parentheses is the F-ration of significant ANOVA terms. There were 44 sampling events in the Damariscotta estuary (n = 44), 42 in the St. George estuary, and 46 in Passamaquoddy Bay. Dam = Damariscotta, St.G = St. George, Pass = Passamaquoddy, NS = not significant ($p > 0.05$).

Species	Estuary	Year	Location	Season	Year x Location	Location x Season
Cod	Dam	p = 0.013 (5.1)	NS	p = 0.050 (3.4)	NS	NS
	St.G	p = 0.037	p < 0.001	p = 0.002	NS	p = 0.011 (4.2)

		(4.9)	(17.6)	(7.9)		
Cunner	St.G	p = 0.024 (5.8)	p = 0.000 (13.1)	p = 0.01 (5.6)	NS	p = 0.036 (3.1)
Longhorn sculpin	Pass	p = 0.036 (4.8)	p = 0.002 (11.9)	NS	NS	p = 0.037 (4.7)
	St.G	p = 0.002 (8.6)	NS	NS	NS	NS
Mackerel	Dam	NS	NS	p = 0.004 (6.7)	p = 0.036 (3.8)	NS
	St.G	NS	NS	p = 0.008 (5.9)	NS	NS
Pollock	Dam	NS	p = 0.004 (6.9)	p = 0.005 (6.6)	NS	p = 0.005 (4.8)
Redfish	Dam	NS	NS	p = 0.015 (4.9)	NS	NS
	St.G	NS	p = 0.002 (7.9)	NS	NS	NS
Sea raven	Dam	p = 0.044 (4.5)	NS	NS	NS	NS

Cod were generally most abundant in the outer locations, and could be more readily caught in the fall than in any other season (Table 3). Cod caught in the Damariscotta outer site averaged 36 cm in length and 35.5 cm from the middle site (Table 4). There were a few individuals present in the spring, though they tended to be quite rare. We found a significant difference in CPUE between season and year in the Damariscotta estuary where summer catches were highest in 2008, followed by fall catches in both years (Fig. 2a). Cod CPUE in the St. George River estuary were significantly different by year, location and season and there was a significant interaction between location and season (Fig. 2b). Outer sites had a significantly higher CPUE for all seasons except spring. Cod were never caught in the inner sites of any estuary sampled. However, cod did occur in the middle sites in lower abundances.

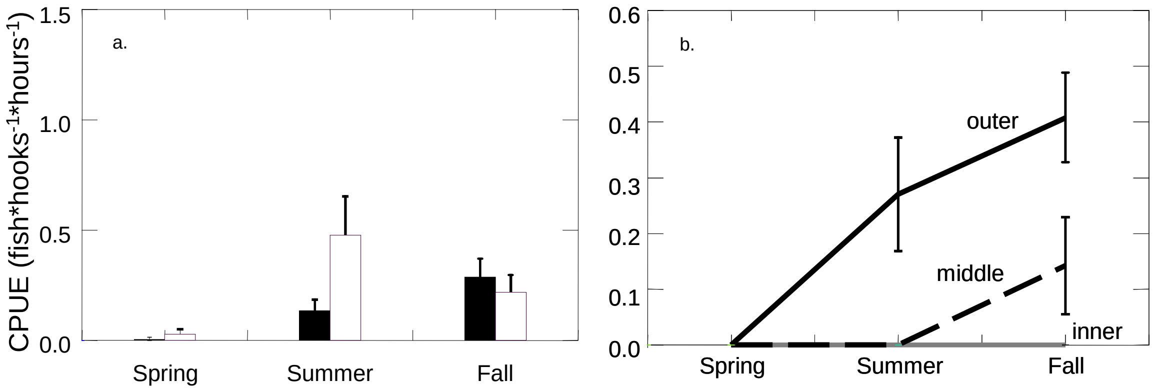

Figure 2: Catch per unit effort for cod showing significant patterns based on the ANOVA results. Panel a shows CPUE for the Damariscotta Estuary in 2007 (black bars) and 2008 (white bars) by season. Panel b shows CPUE for the St. George Estuary separated by season and location. Error bars = ± 1 SE, inner = gray, middle = black dash, outer = black.

Table 4: Average length of cod caught, separated by season and location within each estuary. Lengths are in cm. Parentheses show ± 1 S.D. and number of fish.

Estuary	Location	Spring	Summer	Fall
Damariscotta	middle	43.2 (± 9.4, 5)	33.1 (±11.3, 21)	36.4 (± 9.7, 59)
	outer	35.1	34.8 (± 9.8, 36)	37 (± 9.5, 34)
Passamaquoddy	middle			38.1 (± 4.2, 12)
	outer		29.0	34.3 (± 1.5, 4)
St. George	middle	57		39.6 (± 13.9, 14)
	outer		35.2 (± 10.6, 31)	39.5 (± 10.9, 55)

Although cunner were caught most frequently in the Damariscotta River estuary, there was no statistically significant pattern as far as when or where they occurred. There was a significant pattern in the St. George estuary. Cunner were significantly more abundant with increasing distance from the river mouth and season, i.e., there were more in the outer site and more were caught in fall and summer than spring (Fig. 3).

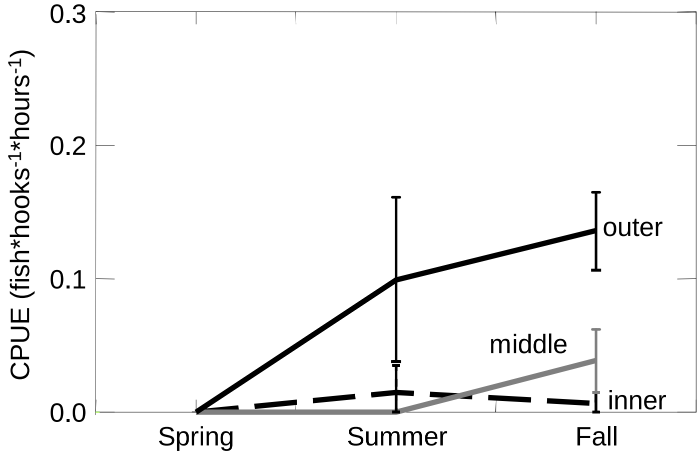

Figure 3: Catch per unit effort for cunner caught in the St. George estuary, separated by season and location. Error bars = ± 1 SE, inner = gray, middle = black dash, outer = black.

Longhorn sculpin were present in all three estuaries, but were most abundant in the Passamaquoddy Bay locations. They were caught in the second highest numbers after mackerel. There was a significant difference in catch by year, with more longhorn caught in 2008 (Fig. 4a), and a significant difference by season and location. Unlike most other species caught in all three estuaries, longhorn were caught most frequently in the “inner sites,” but not in the Little River itself. Also, longhorn CPUE was numerically highest in spring and statistically highest in summer (Fig. 4b). For the St. George Estuary longhorn catch was significantly higher in 2008 vs. 2007.

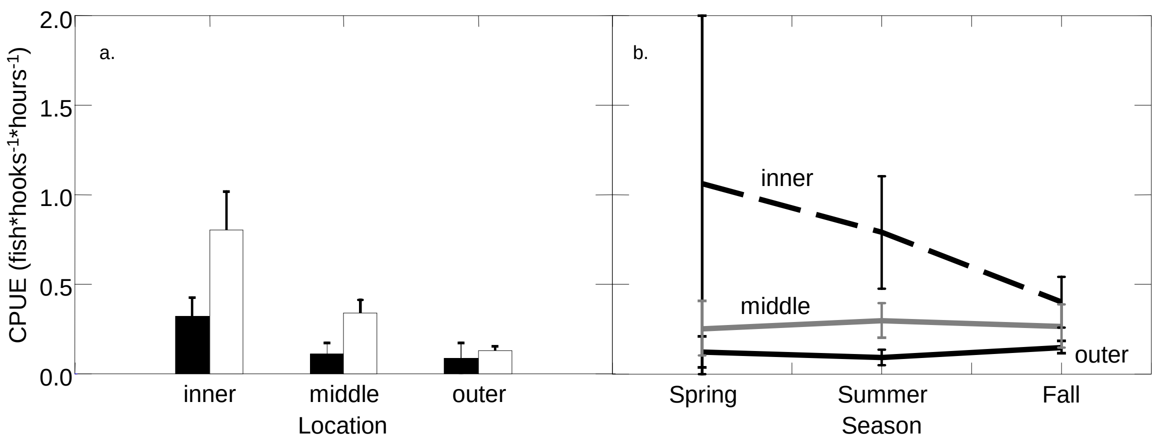

Figure 4: Catch per unit effort for longhorn sculpin caught in Passamaquoddy Bay. (a) CPUE separated by location and year (2007 = black, 2008 = white). (b) CPUE separated by location and season (inner = gray, middle = black dash, outer = black). Error bars = ± 1 SE.

Mackerel were the most ubiquitous species of any found during this project. Mackerel occurred in all three estuaries and in summer and fall. They also occurred in all three locations. There was no statistically significant pattern to mackerel CPUE in the Passamaquoddy sites. CPUE in both the Damariscotta and St. George estuaries differed by season; although there was no statistically significant difference between summer and fall, there was a difference between fall and spring (Fig 5a). No mackerel were caught in spring in any estuary. Mackerel in Damariscotta also had a significant interaction term of year x location. CPUE in outer sites was lower than inner and middle sites in 2008; CPUE was highest in the outer sites in 2007 (Fig. 5b).

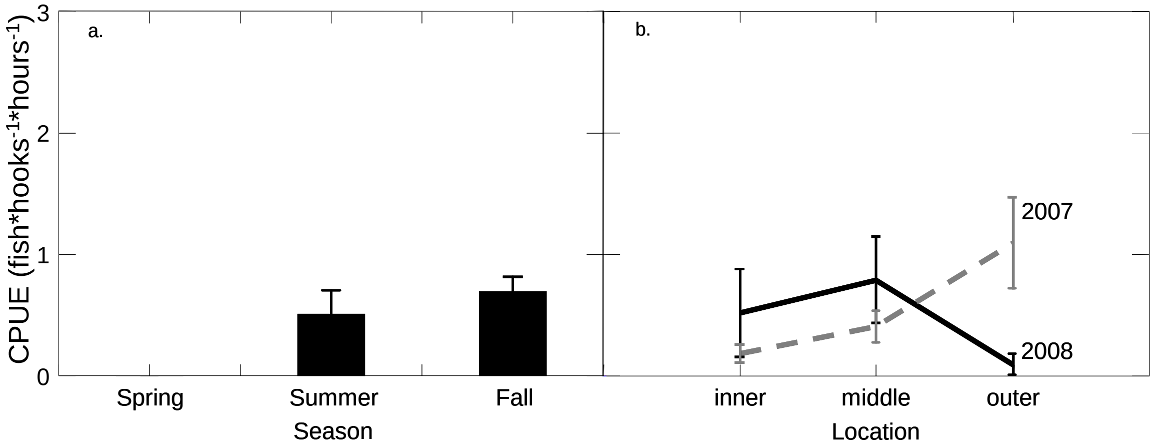

Figure 5: Catch per unit effort for mackerel caught in the Damariscotta estuary. (a) CPUE separated by location and year. (b) CPUE by season. Error bars = ± 1 SE.

Pollock were present in all three estuaries, though they were largely absent from Passamaquoddy Bay until fall of 2008. Pollock CPUE was highest in the fall for all estuaries, though this pattern was not statistically significant for the St. George. Pollock CPUE in the Damariscotta estuary was significantly different by location and season and there was a significant interaction between location and season. Pollock catch increased throughout the season in the outer sites and declined to near zero in the inner sites by fall (Fig 6). Pollock were one of the few species caught in the inner site in the spring, and then only in 2008.

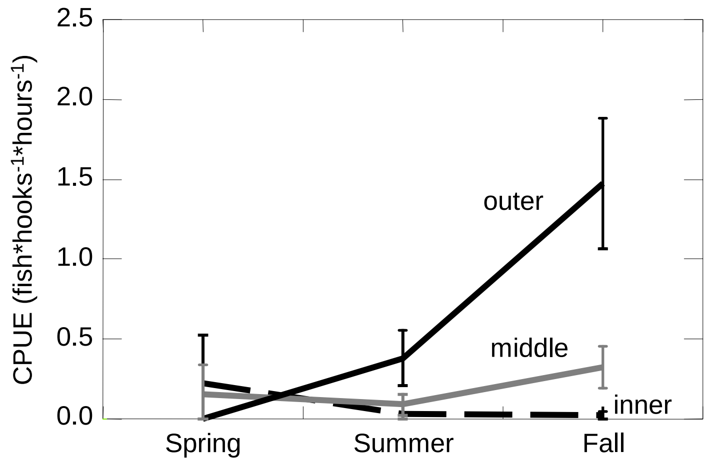

Figure 6: Catch per unit effort for pollock caught in the Damariscotta estuary, separated by season and location. Error bars = ± 1 SE, inner = gray, middle = black dash, outer = black.

Diets

We caught approximately 3000 fish in 2007 and 2008 (Table 2); from that catch approximately 1200 diets were sampled, identified and enumerated. Our goal was to collect at least 25 diets from each target species for each location from each estuary. Twenty-five diets provide a reasonable snap-shot of diet preference for a period of time, as defined by the propensity of a species to switch to new diet items or the seasonal availability of new diet items. Because the catch of species was not evenly distributed across any of the aforementioned categories our diet sampling was uneven. Diet analysis was most strongly skewed towards cod and mackerel in the Damariscotta and the St. George and longhorn and mackerel from Passamaquoddy Bay (Table 5). All available cod diets were enumerated; of those only three cod were completely empty. Mackerel were placed in two size classes greater and less than 25 cm, and 25 diets from each of those size categories, for each estuary, location and season were enumerated.

Table 5: Total number of diets analyzed for each estuary.

Species	Damariscotta	Passamaquoddy	St. George
cod	152	17	101
longhorn sculpin	33	125	16
mackerel	170	183	166
pollock	62	3	22
shorthorn sculpin	6	88	5

Diet preference could be divided into two basic categories, fish with a benthic preference and fish with a pelagic preference. Not surprisingly, mackerel showed a strong preference for pelagic diet items, and the preference was relatively consistent between small (< 24.9 cm) and large size classes, with both size classes preying upon zooplankton more than other food items in all three estuaries (Table 6). Damariscotta and St. George mackerel, both small and large, ate more fish prey than small Malcostraca, including Mysidacae, Euphausiacea, and shrimp-like decapods. Passamaquoddy small and large mackerel preferred small malacostraca over fish prey. Amphipods were also relatively common in Passamaquoddy mackerel diets.

Large cod (> 29.9 cm), caught only in the Damariscotta and St. George estuaries, showed slightly different prey preferences. St. George cod ate crab and small Malcostraca in nearly equal proportion, where as Damariscotta cod preferred small Malcostraca followed by fish then crab (Table 6). Small cod diets differed from those of large cod. Small cod from Passamaquoddy preferred amphipods, with small Malcostraca as a distant second in preference, followed by fish third. Damariscotta small cod also seemed to prefer amphipods above other prey items, followed by polychaetes. St. George cod ate small Malcostraca as their first preference, followed by roughly equal scores for amphipods and polychaetes.

Longhorn sculpin diets processed from the more southerly estuaries showed a strong preference for crab as a diet item, where as the Passamaquoddy longhorn showed a strong preference for amphipods (Table 6).

Pollock appeared to be generalist feeders, often having high scores for four or more items that were a mix of benthic and pelagic organisms. St. George pollock ate amphipods, fish and gastropods in nearly equal proportions. Damariscotta pollock showed a nearly equal preference for amphipods and zooplankton; bivalves and fish were also of nearly the same importance, though both lower than previously mentioned diet categories.

Amphipods were the most important prey item for shorthorn sculpin from Passamaquoddy, like pollock, longhorn and cod (Table 6). The few shorthorn sculpin diets collected from St. George and Damariscotta showed a preference for crab. Lobster were a second preferred item for Damariscotta shorthorn and third for St. George shorthorn. Amphipod were the second most important diet item for shorthorn sculpin in the St. George estuary.

Table 6: Index of relative importance diet proportions for the most common diet item categories, separated by estuary and species. A diet item was not found from diets of that species for that estuary when "a" is present. The code column identifies estuary and species with estuary as the 1st letter, species as the 2nd letter, and, for species split into small and large

size classes, a small (S) or large (L) designation as the third letter. D = Damariscotta, P = Passamaquoddy, S = St. George, C = cod, L = longhorn sculpin, M = mackerel, P = pollock, S = shorthorn, S (3rd position) = small, L (3rd position) = large.

Code	zooplankton	amphipod	crab	shrimp/krill/mysid	fish	bivalve	polychaete	lobster	gastropod
SS	<0.01	0.18	0.21	<0.01	0.01	<0.01	a	0.13	a
PS	a	0.63	0.09	0.01	0.02	<0.01	0.17	<0.01	<0.01
DS	0.02	0.01	0.44	0.01	a	0.01	a	0.27	a
SP	0.03	0.40	<0.001	0.02	0.39	0.04	0.01	a	0.32
PP	0.01	1.16	a	a	<0.01	0.52	<0.01	a	<0.01
DP	0.31	0.32	<0.001	<0.01	0.12	0.12	<0.01	a	0.08
SMS	0.87	<0.01	a	0.15	0.23	a	<0.01	a	<0.01
SML	1.04	<0.01	<0.001	0.03	0.16	<0.01	<0.01	a	<0.01
PMS	1.09	<0.01	a	0.56	<0.01	a	a	a	a
PML	0.63	0.15	a	0.27	0.07	<0.01	<0.01	a	<0.01
DMS	0.65	<0.001	a	<0.01	0.33	<0.01	<0.01	a	<0.01
DML	0.87	<0.01	0.00	0.01	0.37	0.01	<0.01	a	<0.01
SL	<0.01	<0.01	1.16	0.03	<0.01	0.04	<0.01	0.01	a
PL	<0.001	1.06	0.00	<0.01	0.06	<0.01	0.05	a	<0.0
DL	<0.01	a	0.77	<0.01	0.01	<0.01	0.01	0.10	a
SCS	<0.01	0.29	0.08	0.41	<0.01	0.01	0.27	<0.01	<0.0
SCL	<0.01	0.12	0.39	0.37	0.11	0.01	0.03	0.04	<0.0
PCS	<0.01	0.55	0.03	0.22	0.16	0.05	0.04	a	a
DCS	<0.01	0.44	0.10	0.19	0.08	0.03	0.24	<0.01	<0.01
DCL	<0.01	0.04	0.16	0.38	0.26	<0.01	0.03	0.05	<0.01

We used NMDS ordination to determine which fish species across estuaries had the most similar diet preferences. Data were 4th root transformed to conform more closely to the assumptions of multivariate normality. Similarities are based on cluster analysis overlays within the program Primer. All categories were at least 25% similar, and most were at least 50% similar in their diet preference (Fig. 7). Passamaquoddy pollock were dissimilar from most other categories, however the low number of samples analyzed likely influenced the IRI calculation. Overall, the estuary-species categories split into a fish with more pelagic diet preferences and more benthic diet preferences. Mackerel and pollock (except for Passamaquoddy pollock) grouped together, largely distributing along axis 1. Cod, longhorn and shorthorn grouped together and distributed largely along axis 2. Within the mackerel-pollock group, Damariscotta and St. George pollock diet preference were 75% similar and large and small mackerel from the southerly estuaries were also 75% similar. Passamaquoddy small mackerel were more dissimilar in diet preference from the larger mackerel group as were the southerly pollock. In the cod-longhorn-shorthorn group, Passamaquoddy fish diet preference was more similar within that estuary than individual species were to the same species from the more southerly estuaries. That is, cod, shorthorn and longhorn diet item importance was 75% similar, while Damariscotta vs. Passamaquoddy cod diet item importance was only 50% similar. Shorthorn and longhorn from the southerly estuaries were no more than 50% similar to each other or any other category in the benthic diet group.

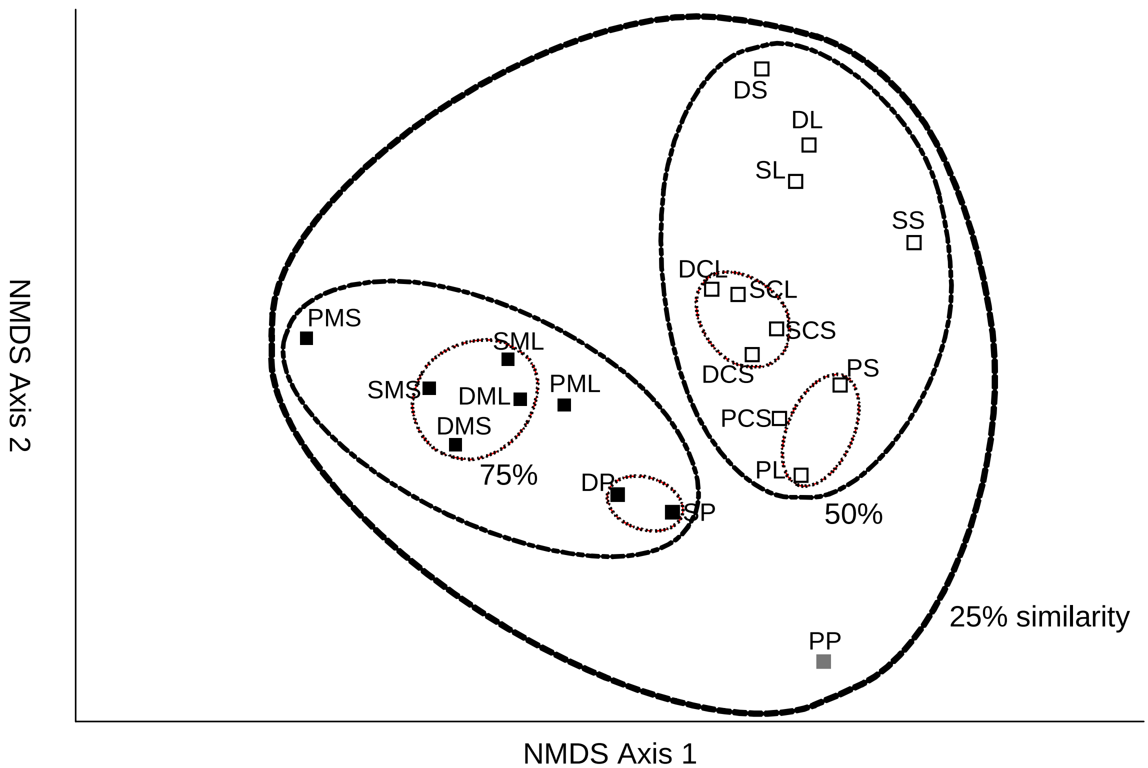

Figure 7: Non-metric multi-dimensional scaling representation of diet contents. Data are Index of Relative Importance values 4th root transformed to bring the data closer to assuming a multivariate normal distribution. The ordination is based on a Bray-Curtis similarity matrix. Circles indicate the % similarity of points within or intersecting the circle based on single linkage cluster analysis. Points represent an estuary (1st letter), a species (2nd letter) and if necessary, a size class (small or large). D = Damariscotta, P = Passamaquoddy, S = St. George, C = cod, L = longhorn sculpin, M = mackerel, P = pollock, S = shorthorn, S (3rd position) = small, L (3rd position) = large. Stress = 0.1.

We used spearman rank correlations, a non-parametric correlation procedure, to determine which diet items loaded the ordination axes, i.e., drove the separation between estuary-fish samples. Crab, lobster and isopods had a strong positive correlation with the first NMDS axis, while zooplankton, zoea and larvae, all largely pelagic life stages of various organisms, had a strong negative correlation. Barnacles and lobster had a positive correlation with NMDS axis 2, and amphipods and gastropods had a strong negative correlation.

Table 7: Spearman rank correlation results for diet item categories versus NMDS axis. Only diet items categories with -0.5 > ρ > 0.5 on at least one axis are shown.

Diet category	NMDS Axis 1	NMDS Axis 2
crab	0.88	0.33
lobster	0.82	0.46
isopod	0.64	-0.05
bivalve	0.41	-0.42
amphipod	0.26	-0.86
barnacle	0.23	0.58
gastropod	-0.43	-0.61
larvae	-0.6	0.09
zooplankton	-0.71	0.30
zoea	-0.76	0.29

River herring in diets

Our original hypothesis was that alewife, as a super abundant prey item available in the spring, would concentrate predators, particularly cod, in the mouths of Maine rivers. We also expected alewife to be an important seasonal prey item. Although we could not quantify the size of spawning alewife runs in 2007 and 2008 for Passamaquoddy, we did verify their presence through observation (Appendix B). Counts or harvest data were available for the southerly estuaries so we know the fish were present roughly at the same time we were angling in the spring.

We found little evidence of cod aggregations in the river mouths we sampled. Cod abundance close to shore increased as our sampling move south and west along the Maine coast, but overall we encountered relatively few large predatory groundfish in our spring sampling. Initially, we used a wide array of gear, including angling, tub trawls and two types of traps but no method resulted in a cod catch useful to the study for the spring season. Indeed, catch rates for all species was low in the spring. We even tried alternate locations that our fishermen insisted were better fishing grounds, i.e., the Kettle, south of Seguin Island and near Monhegan Island. Catch rates in these locations were also very low in the spring.

One disturbing observation was that our baited tub trawls, used in 2007 with the hope of increasing our catch rate, were retrieved with many hooks devoid of bait after three hour sets. In most cases, less than 10% of the hooks still had bait when retrieved. In summer 2007 we added a Baited

Video Observation Station (BVOS) to our sampling efforts to determine if bait was being lost to demersal scavengers, groundfish that were not being hooked, or if the bait was simply falling off the hooks. The BVOS was a low-cost underwater video camera system available to us through another project. In the midcoast (Damariscotta, St. George) we found that a baited hook was often denuded of bait within 15 minutes by lobster, crabs, or, particularly in summer, swarms of small cunner (*Tautogolabrus adspersus*) (see published resources, below, for links to videos). Besides cunner, pollock were the only other fish species we generally saw on the BVOS. In fall 2007 we went so far as to try rubber scented bait, just to see if we could keep bait on the tub trawl hooks, but the cunner also stripped the scented rubber bait. We abandoned tub trawls and concentrated on angling in light of the video results.

We did find that catches of target species increased significantly in the summer and fall sampling periods, suggesting that groundfish are rare inshore in the spring, and that groundfish large enough to prey upon spawning alewife over 20 cm in length were likely absent from nearshore waters. Our observations and inquiries lead us to conclude that birds, marine mammals, and humans are the major predators of spawning alewife.

We found evidence of alewife as an important diet item in October 2007 diet samples, but the diet item consumed was young of year (YOY) river herring. September 2007 was a dry period, ending in early October with heavy rains on the 12th (Fig.8). This coincided with the appearance of YOY river herring in the diets we sampled (Fig. 9), as well as sightings of schools of YOY river herring in harbors and along the coast. River herring in these schools ranged from 54 – 94 mm (Fig. 10). Groundfish (cod and pollock) and mackerel were captured in the Damariscotta estuary, and mackerel in the St. George estuary, that had been feeding on YOY river herring emigrants. Cod were caught near the northern edge of the Damariscotta middle location, in less than 30 m of water, within 150 m of land on either side. In particular, mackerel as small as small as 20 cm, weighing around 50 g had at least one YOY river herring in their gut. Larger mackerel contained multiple YOY river herring, as did cod and pollock.

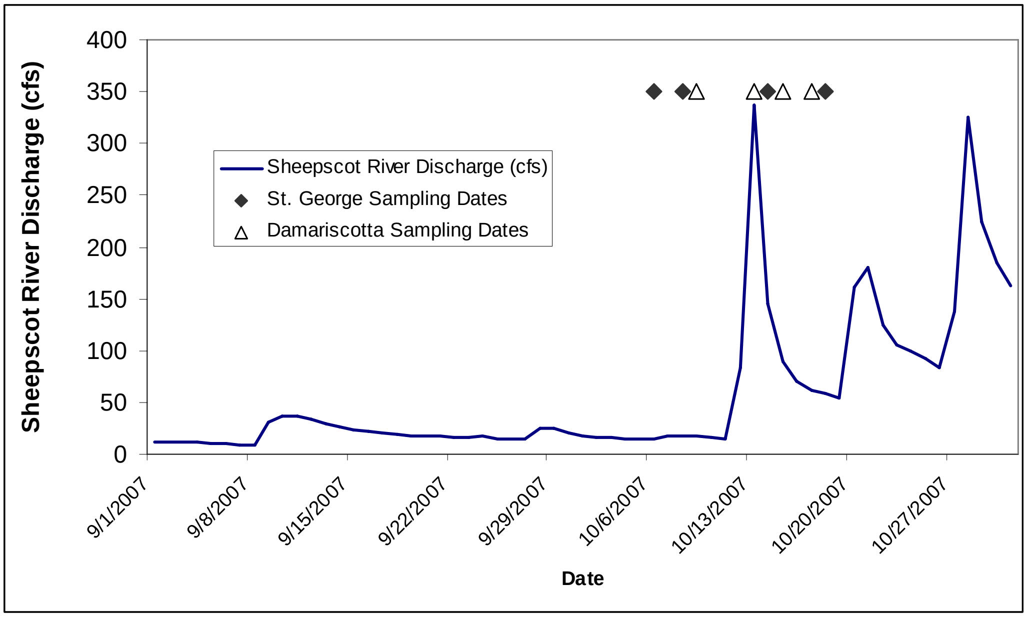

Figure 8. Sheepscot River discharge in cubic feet per second (cfs), 2007. Sampling dates for the St. George and Damariscotta estuaries are indicated. We first observed schools of YOY river herring on the 13th of October, one day after heavy rains. Discharge data from USGS.

Numerically, there were 82 YOY river herring found in fish diets in 2007 in the Damariscotta estuary, out of a total 199 fish or fish remains counted in diets across all species. River herring made up 41% of that total. It is unusual to have so many diet items be identifiable, and have such a high proportion be the same diet item. By way of comparison, only 46 crabs were counted in fall 2007 from Damariscotta, 27 of which could only be identified as generic crabs or crab parts due to the state of digestion.

Figure 9. Fresh YOY river herring in the diet of a mackerel caught off the mouth of the Damariscotta River. October 2007.

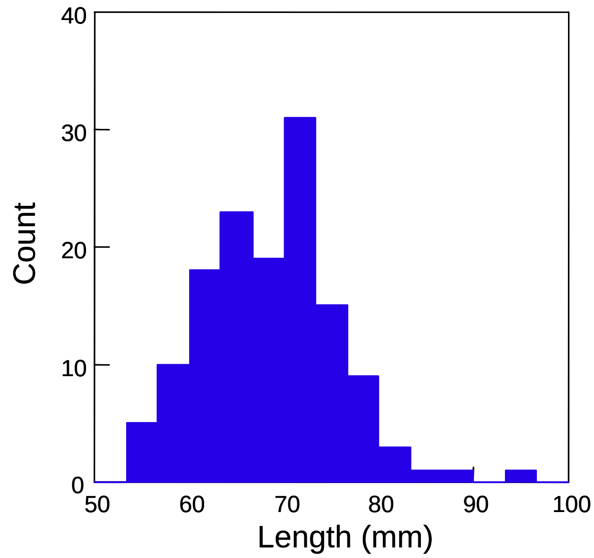

Figure 10. Length distribution of YOY river herring caught using a cast net in Damariscotta River, October, 2007. These fish were later dissected and identified as blueback herring (*Alosa aestivalis*).

Discussion

The Gulf of Maine food web persists in an ecosystem that has and continues to experience enormous anthropogenic pressure (Jackson 2001, Steneck et al. 2004). Historical accounts of a food web dominated by "hen cod," large cod 1 - 2 m in length are well known (Duncan 1992, Kurlansky 1997, Rosenberg et al. 2005). Several accounts discuss the relationship between hen cod, other groundfish, and river herring, wherein the groundfish "followed" the river herring inshore to grounds easily reached by early colonists (Field 1914, Ames 2004). Indeed, the southern area where we conducted this study, between Popham Beach, ME, and Pemaquid, ME, was once known as the "cod square" and was famous for providing cod of market size within 20 km or less of the mainland (Duncan 1992, Ames 2004, Alexander et al. 2009). Passamaquoddy Bay was more famous for its pollock and herring fisheries, but a respectable cod fishery also existed in this area (Atkins 1887).

In 2007 and 2008 we found that cod were largely absent from the Damariscotta and St. George estuaries in spring, and that cod were largely absent year round from Passamaquoddy Bay. River herring were abundant in the two southern estuaries we sampled. Although their estimated abundance was an order of magnitude lower than the historical estimates of carrying capacity of each stream (C. Hall; *in press*), there were over 175,000 migrating adult alewife in the Damariscotta estuary and 350,000 in the St. George estuary in each of 2007 and 2008. River herring were much less abundant in the Little River estuary, Passamaquoddy Bay. In all three estuaries, there were few if any other bait fish present in June.

We concluded that adult river herring are currently not an important diet item for fish, especially cod, in the estuaries sampled for this study. Not necessarily because of cod diet preference, but because cod of sufficient size to prey on river herring do not occupy our sampling area in the spring when the river herring spawning migration is under way. However, cod are present in the nearshore along with other pelagic and demersal fish species in the fall, and, when present, river herring juveniles are a prevalent food item in not only cod diets, but also mackerel and pollock diets.

The absence of cod large enough to eat an adult river herring in the spring is likely related cod migratory habits and overfishing in the nearshore area. Cod populations in the NW Atlantic appear to have retracted in geographic area and the population center has moved south and into deeper waters (Nye et al. 2009b). These observations are probably linked to a long history of heavy fishing pressure, and, to a lesser extent, ocean warming due to climate change. In effect, cod are more prevalent offshore and in the George's Bank - Massachusetts Bay area (Witman and Sebens 1992). The net effect in midcoast Maine is that most cod appear to be migrants from locations further south and offshore (Howell et al. 2008).

Several studies have indicated that cod have two primary life history strategies, a migrant lifestyle and a resident lifestyle (Rose 1993, Robichaud and Rose 2004). While we might not expect migrant cod to be present in our study estuaries in May and June when adult river herring are on their spawning migrations, resident cod should be able to take advantage of the ample food resource that spawning river herring represent. However, overfishing likely eliminated these resident nearshore cod subpopulations in the 1940s and 1950s (Jackson 2001, Ames 2004, Steneck et al. 2004). Ames (2004) estimated that of 92 historical nearshore spawning grounds, 40 are extinct, with no evidence of reproduction as of the mid 1990s. Adaptation of diesel technology to fishing at the end of WWII neutralized the advantage that probably kept cod population viable despite heavy fishing pressure from stationary gear (hook, gillnet, etc.): spawning cod are less likely to take a hook than a post or pre-spawn cod (Ames et al. 2000, Smith et al. 2007). Other lines of evidence also suggest that suppressed groundfish abundance, including cod, is still a problem in nearshore habitats, including Federal and state sponsored fish surveys (Overholtz et al. 2008, Auster and Link 2009, Link et al. 2009, Nye et al. 2009a), experimental observations (Witman and Sebens 1992), diet analysis of fish eating birds (Blackwell et al. 1995) and fish surveys in the Damariscotta area (Hacunda 1981).

The Gulf of Maine ecosystem has undergone radical changes in the constituents of the ecosystem. The system has evolved, under anthropogenic pressure, from a finfish dominated food web, to a habitat barren of complex kelp habitat, to an ecosystem dominated by small crustaceans and macro-algae (Steneck et al. 2004). However, despite the noticeable changes in the Gulf of Maine habitat and food web, the biomass of most feeding guilds has not changed significantly(Garrison and Link 2000, Auster and Link 2009). The piscivore guild, of which cod is a member, remained steady in terms of biomass, presumably compensating for the declines in cod with increases in dogfish and longhorn sculpin. Indeed, Hacunda (1981) found longhorn sculpin to be the most abundant species found in John's Bay, an area adjacent to our Damariscotta sample site. The nearshore region is now dominated by small gaped fishes, like cunner, juvenile pollock and mackerel (Steneck et al. 2004). Witman & Sebens (1992) observed that cunner were 12 times more likely than cod to initiate an attack on tethered brittle stars in Massachusetts Bay. The prevalence of planktivores and small gaped predators have initiated a size structured interaction (Olson et al. 1995) which enables prey species, like Atlantic herring, to control the abundance of their predator, i.e., cod, through larval predation (Garrison and Link 2000, Link et al. 2009). Low predation pressure experienced by crabs, because large gaped finfish are rare in the nearshore, may prevent the removal of marco-algae by urchins, which in turn might encourage the growth of complex kelp habitat that would favor juvenile cod (Steneck et al. 2004).

Similar to previous studies in the Gulf of Maine, we found a significant overlap in diet between groundfish species in the same area. Cod, shorthorn, and longhorn shared a 50% commonality in diet. Mackerel and most pollock also shared 50% of their diet items. Hacunda (1981) also found a high degree of trophic similarity amongst predators from John's Bay, ME. Within foraging guilds found on the Northeast US shelf it is not unusual for five prey species or less to account for over 50% of diets and for overlap between guilds to be low (Garrison and Link 2000). We also found diet overlap to be low between guilds, groundfish vs. pelagics, with 25% diet commonality.

Surprisingly, fish as prey items did not load significantly onto the NMS ordination axes, indicating that although present in many diets, fish prey explained little of the variation in diets between species or size classes within species among our sample sites. Rather, crab, lobster and isopods pulled benthic shorthorn and longhorn sculpin away from pelagic mackerel and that species' preference for zooplankton and other pelagic prey along the first NMS axis. The second NMS axis loaded fish species with a preference for amphipods, gastropods and bivalves on one end and loaded species with a preference for lobster and crab at the other end of the axis. Fish were present in diets, but had an IRI score greater than 0.25 in only five species-site-size classes, notably large cod from Damariscotta. In contrast, large cod from St. George had IRI scores for crab of 0.39 and 0.37 for the shrimp/krill/mysid category. Although cod less than 40 cm can be more dependent on macroinvertebrates, a prevalence of crustaceans is often seen as a stop-gap measure between periods when higher quality food is available (Sherwood et al. 2007, Smith et al. 2007), suggesting that nearshore cod found at our sample sites are not finding the high-quality food.

Diet composition has a strong influence on the completion of life history stages, particularly spawning. Large cod with diets consisting mostly of invertebrates may have lower gonad weight and poor condition (Sherwood et al. 2007, Link et al. 2009). Smith et al. (2007) demonstrated that cod switched their prey preference from invertebrates to higher quality fish prey when that prey was present and abundant. Cod are opportunist generalists and may require that prey abundance exceed some threshold to force concentration on single diet items. What we documented in the Damariscotta estuary in 2007, a fish predation event focused on juvenile river herring, may have occurred only because there were was an overabundance of fish prey items available. All fish caught during that three day sampling period had fish in their diets. That that event occurred only once during two years of sampling is informative about the depauperate state of the nearshore food web in coast Maine.

From a present-day food web standpoint, the emigration of juvenile river herring in the late summer and early fall may be more important than the immigration of adult river herring in the spring. If cod are eating the most abundant prey, and their diet is primarily lacking fish, then it is conceivable that cod in nearshore Maine are in poor condition. Historically, juvenile river herring would have provided a high quality, abundant resource for nearshore cod beginning as early as July and continuing through late September (Kosa and Mather 2001, Yako et al. 2002). The Damariscotta River alone has the capacity to produce $18x10^6$ juvenile river herring in one year (Walton 1987). The nearby Kennebec River, with an estimated pre-colonial annual adult return of $18x10^6$ alewife, had a juvenile production potential of $54x10^9$ (C. Hall, in press; Collette and Klein-MacPhee 2002). The net result of orders of magnitude decreases in river herring due to anthropogenic activity has likely reduced the overall quality of forage for nearshore cod. Ultimately, recovery of nearshore cod stocks may depend on increased availability of high quality forage that positively influences production potential by individual cod.

Partnerships with fishermen

Although our collaborating fishermen were not involved with the initial design of this project, they contributed greatly to the day to day operations, helping us find historical fishing areas and imparting invaluable local knowledge. When your livelihood depends on catching fish, it is rare to have the ‘luxury’ of catching zeros (e.g., spring sampling for groundfish), which spawned some interesting conversations with the captains, particularly in the spring. Through this project we were introduced to several river herring harvesters contracted to harvest river herring from Damariscotta, the

St. George and the Little River, as well as the fish committees for Newcastle/Damariscotta and Warren that oversee the harvests. Over the course of this study we found a sea-change in interest in our work; initially river herring harvesters were concerned that collaboration with us would bring on more regulation and oversight. However, by the end of the project, independent rulings by the Atlantic States Marine Fisheries Commission made it clear that harvesters would need to provide more information on their runs in order to continue harvesting. Since the start of the project attitudes have relaxed and we have found it easier to collaborate with river herring harvesters on this and subsequent projects.

Impacts and applications

Thus far, our largest impact on the fishing community is one of raising awareness of river herring runs and their potential impact on marine fisheries resources. The process of arranging to count river herring runs has brought us, as scientists, in contact with many members of the local community. We have worked with and conferred with fish committees from local towns, harvesters licensed by the towns to harvest and sell alewives, and local lobstermen who buy alewives for early spring bait. The river herring fishery in Maine has proven to be a foray into a politically charged fishery with many competing interests.

Alewives and blueback herring were thrust into the spotlight with the declaration of Species of Concern status in 2006 by National Marine Fisheries Commission, and the introduction of Amendment 2 to the Shad and River Herring Fisheries Management Plan by the Atlantic States Marine Fisheries Commission in January 2008. The possible action of closure of all directed fisheries took towns and harvesters by surprise.

In March, 2008, we (K. Wilson, T. Willis) organized a Maine Fisherman's Forum symposium on the Amendment 2 plan, which included a presentation by a representative of ASMFC. At this forum the four (at the time) proposed management options were discussed (see pg 19, ASMFC Shad and River Herring Public Information Document for Amendment 2, http://www.asmfc.org/), as well as two new management options, one of which was a proposal for river specific management requiring documentation of spawning escapement as well as harvest. Video and weir techniques developed and field tested in association with this project will be useful for towns interested in assessing alewife numbers in the rivers to which they have licensing rights.

The work we have been doing through this NEC project has lead to additional opportunities to work with the alewife fishery. For example, Dr. Willis is the *de facto* scientific advisor for the newly formed Alewife Harvesters of Maine. AHoM is bringing a new industry voice to alewife issues in Maine, including feedback on the proposed changes to the Shad and River Herring Management Plan and other issues, such as the St. Croix River fishway closures. We have worked with a river herring harvester in Maine to track river herring returns to his system, and we have begun work using a variety of methods to quantify river herring stock structure such that the origin of river herring caught at-sea can be ascertained.

Our second largest impact was with the fishermen we work with directly. During the June sampling both boat captains and their crew members recounted stories of fishing in the areas where we were working and catching fish. They were surprised that as far out as 6 miles from the mainland they could not catch any fish, let alone a cod or other large predator. In these same areas a decade earlier a 24 hr. tub trawl/groundline would have caught at least some desirable species.

We have also created opportunities for collaboration with municipalities in Nobleboro, Newcastle, Warren, and Waldoboro, and community groups with a resource focus (e.g., Quebec Labrador Foundation/Atlantic Center for the Environment, Trout Unlimited, Georges River Land Trust, Damariscotta River Association).

Related projects

Work on counting alewives in the St. George River was funded through a Gulf of Maine Council/NOAA habitat restoration partnership grant to Dr. Willis. Work on counting alewives in the Damariscotta River was funded through a Davis Conservation Grant to Dr. Willis. Alewife spawning run counts in the Little River (Gleason Cove, Passamaquoddy Bay site) were attempted in spring 2007 by collaborators associated with the Passamaquoddy Tribe with advice based on our experiences in the summer of 2006. Our work on river herring in the nearshore marine environment has led to several related efforts, including several dam-removal projects, a tagging project to assess river herring returns in collaboration with a river herring harvester, and, most recently, a project focused on developing methods to assess the origin of river herring when caught at sea.

Presentations

K.A. Wilson and Theodore Willis. Alewives as Groundfish Forage in Maine Estuaries. Northeast Consortium Participants Meeting, Dec 2007. (Invited)

Workshop presentation: River Herring Management & Biology. Maine Fisherman's Forum, March 2008. Organizers: K. Wilson and T. Willis.

K. Wilson and T. Willis. River Herring in the Gulf of Maine: challenges for management and research. Invited talk as part of the Gulf of Maine Research Institute's Sea State 3.1 Public Lecture Series. April 2008.

T. Willis. River Herring in the Gulf of Maine: challenges for management and research. St. George River Land Trust. May 2008. (Invited)

K. Wilson, T. Willis and K. Robbins. Freshwater-marine linkages: the role of small coastal Maine rivers as spawning habitat for a marine forage fish. 9th Biannual River Management Society Symposium, Portland, Maine. May 2008.

K. Wilson and T. Willis. River Herring in Maine: Challenges for Management and Research. Sheepscot River Watershed Council. June 2008. (Invited)

K. Wilson and T. Willis. Freshwater – marine subsidies: The role of small coastal river systems as a source of fall forage fish (*Alosa* spp.) in the nearshore Gulf of Maine. Ecological Society of America. Aug 2008.

K. Wilson and T. Willis. Freshwater – marine linkages: the role of small coastal river systems as a source of fall forage fish (river herring) in the nearshore marine environment in Maine. Maine Water Conference, Portland, Maine, 2009.

Published reports

Several videos were posted during the course of this project to illustrate bottom conditions around baited hooks from drop camera and alewives and their predators at the Damariscotta Fish ladder (App. 1).

Appendix 1. Videos of cunner, lobsters and pollock swarming baited hooks, and footage from the Damariscotta fish ladder video counting work posted on YouTube.

Video subject	Link
"Cunners and pollock"	http://youtube.com/watch?v=J47YXs8xyGA
"Lobster on drop camera"	http://youtube.com/watch?v=kPqH9DxvKSg
"Alewives in the Damariscotta Mills"	http://youtube.com/watch?v=PTkxoYtxkuM
"Largemouth bass eating alewives"	http://youtube.com/watch?v=VdtKc2LQ0Pg
"Cormorant eating alewives"	http://youtube.com/watch?v=EibZRfGfwjo

References

Alexander, K. E., W. B. Leavenworth, J. Cournane, A. B. Cooper, S. Claesson, S. Brennan, G. Smith, L. Rains, K. Magness, R. Dunn, T. K. Law, R. Gee, W. J. Bolster, and A. A. Rosenberg. 2009. Gulf of Maine cod in 1861: historical analysis of fishery logbooks, with ecosystem implications. Fish And Fisheries **10**:428-449.

Ames, E. P. 2004. Atlantic cod stock structure in the Gulf of Maine. Fisheries **29**:10-28.

Ames, E. P., S. Watson, and J. Wilson. 2000. Rethinking overfishing: insights from oral histories of retired groundfishermen. Pages 153-164 *in* B. N. Neis and F. L., editors. Finding our sea legs. Institute of Social and Economic Research, St. Johns, Newfoundland.

Atkins, C. G. 1887. The River Fisheries of Maine. Pages 673-728 *in* G. B. Goode, editor. Fisheries and Fishery Industries of the United States.

Atlantic States Marine Fisheries Commission (ASMFC). 1999. Fishery Management Report No. 35 of the Atlantic States Marine Fisheries Commission: Amendment 1 to the Interstate Fishery Management Plan for Shad & River Herring. Government Printing Office, Washington.

Atlantic States Marine Fisheries Commission (ASMFC). 2009. Amendment 2 to the Interstate Fishery Management Plan For Shad and River Herring For Public Comment (River Herring Management). Government Printing Office, Washington. http://www.asmfc.org/speciesDocuments/shad/fmps/draftAmendment2PublicComment.pdf.

Auster, P. J., and J. S. Link. 2009. Compensation and recovery of feeding guilds in a northwest Atlantic shelf fish community. Marine Ecology-Progress Series **382**:163-172.

Baird, S. 1883. U.S. Commissioner of Fish and Fisheries Report of 1883. Washington, DC.

Blackwell, B. F., W. B. Krohn, and R. B. Allen. 1995. Foods of nestling double-crested cormorants in Penobscot Bay, Maine, USA: Temporal and spatial comparisons. Colonial Waterbirds **18**:199-208.

Collette, B. B., and G. Klein-MacPhee. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine, Third edition. Smithsonian Institution Press, Washington, D.C.

Duncan, R. F. 1992. Coastal Maine: A Maritime History. W.W. Norton & Company, Inc., New York, NY.

Durbin, A. G., S. W. Nixon, and C. A. Oviatt. 1979. Effects of the Spawning Migration of the Alewife, Alosa-Pseudoharengus, on Freshwater Ecosystems. Ecology **60**:8-17.

Field, G. W. 1914. Alewife Fishery of Massachusetts. Transactions of the American Fisheries Society **43**:143-151.

Garrison, L. P., and J. S. Link. 2000. Dietary guild structure of the fish community in the Northeast United States continental shelf ecosystem. Marine Ecology-Progress Series **202**:231-240.

Hacunda, J. S. 1981. Trophic relationships among demersal fishes in a coastal area of the Gulf of Maine. Fishery Bulletin **79**:775-788.

Hanson, S. D., and R. A. Curry. 2005. Effects of size structure on trophic interactions between age-0 smallmouth bass and juvenile anadromous alewives. Transactions of the American Fisheries Society **134**:356-368.

Hartleb, C. F., and J. R. Moring. 1995. An improved gastric lavage device for removing stomach contents from live fish. Fisheries Research **24**:261-265.

Howell, W. H., M. Morin, N. Rennels, and D. Goethel. 2008. Residency of adult Atlantic cod (Gadus morhua) in the western Gulf of Maine. Fisheries Research **91**:123-132.

Jackson, J. B. C. 2001. What was natural in the coastal oceans? Proceedings Of The National Academy Of Sciences Of The United States Of America **98**:5411-5418.

Kosa, J. T., and M. E. Mather. 2001. Processes contributing to variability in regional patterns of juvenile river herring abundance across small coastal systems. Transactions of the American Fisheries Society **130**:600-619.

Kurlansky, M. 1997. Cod: A Biography of the Fish That Changed the World. Penguin Group, New York, NY.

Liao, H., C. L. Pierce, and J. G. Larscheid. 2002. Diet dynamics of the adult piscivorous fish community in Spirit Lake, Iowa, USA 1995-1997. Ecology of Freshwater Fish **11**:178-189.

Link, J. S., B. Bogstad, H. Sparholt, and G. R. Lilly. 2009. Trophic role of Atlantic cod in the ecosystem. Fish And Fisheries **10**:58-87.

Link, J. S., and L. P. Garrison. 2002. Trophic ecology of Atlantic cod Gadus morhua on the northeast US continental shelf. Marine Ecology-Progress Series **227**:109-123.

Maine Department of Marine Resources (MDMR). 2004. Status of the Kennebec River Watershed Anadromous Fish Restoration Program: Prepared for the Joint Standing Committee. Augusta, Maine.

Maine State Archives (MSA). 1821. For an act to regulate the taking of fish in St. Croix River and its branches., Legislative Graveyard.

Manning, J. P., D. J. McGillicuddy, N. R. Pettigrew, J. H. Churchill, and L. S. Incze. 2009. Drifter observations of the Gulf of Maine Coastal Current. Continental Shelf Research **29**:835-845.

Nye, J. A., A. Bundy, N. Shackell, K. D. Friedland, and J. S. Link. 2009a. Coherent trends in contiguous survey time-series of major ecological and commercial fish species in the Gulf of Maine ecosystem. Ices Journal Of Marine Science **67**:26-40.

Nye, J. A., J. S. Link, J. A. Hare, and W. J. Overholtz. 2009b. Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. Marine Ecology-Progress Series **393**:111-129.

Olson, M. H., G. G. Mittelbach, and C. W. Osenberg. 1995. Competition between predator and prey - Resource-based mechanisms and implications for stage-structured dynamics. Ecology **76**:1758-1771.

Overholtz, W. J., L. D. Jacobson, and J. S. Link. 2008. An ecosystem approach for assessment advice and biological reference points for the Gulf of Maine-Georges Bank Atlantic herring complex. North American Journal Of Fisheries Management **28**:247-257.

Perley, M. 1852. Reports on the Sea and River Fisheries of New Brunswick, 2 edition, Fredericton.

Pettigrew, N. R., J. H. Churchill, C. D. Janzen, L. J. Mangum, R. P. Signell, A. C. Thomas, D. W. Townsend, J. P. Wallinga, and H. J. Xue. 2005. The kinematic and hydrographic structure of the Gulf of Maine Coastal Current. Deep-Sea Research Part Ii-Topical Studies In Oceanography **52**:2369-2391.

Robichaud, D., and G. A. Rose. 2004. Migratory behaviour and range in Atlantic cod: inference from a century of tagging. Fish And Fisheries **5**:185-214.

Rose, G. A. 1993. Cod spawning on a migration highway in the north-west Atlantic. Nature (London) **366**:458-461.

Rosenberg, A. A., W. J. Bolster, K. E. Alexander, W. B. Leavenworth, A. B. Cooper, and M. G. McKenzie. 2005. The history of ocean resources: modeling cod biomass using historical records. Frontiers In Ecology And The Environment **3**:84-90.

Sherwood, G. D., R. M. Rideout, S. B. Fudge, and G. A. Rose. 2007. Influence of diet on growth, condition and reproductive capacity in Newfoundland and Labrador cod (Gadus morhua): Insights from stable carbon isotopes (delta C-13). Deep-Sea Research Part Ii-Topical Studies In Oceanography **54**:2794-2809.

Smith, B. E., T. J. Ligenza, F. P. Almeida, and J. S. Link. 2007. The trophic ecology of Atlantic cod: insights from tri-monthly, localized scales of sampling. Journal Of Fish Biology **71**:749-762.

Steneck, R. S., J. Vavrinec, and A. V. Leland. 2004. Accelerating trophic-level dysfunction in kelp forest ecosystems of the western North Atlantic. Ecosystems **7**:323-332.

Walter, J. F., A. S. Overton, K. H. Ferry, and M. E. Mather. 2003. Atlantic coast feeding habits of striped bass: a synthesis supporting a coast-wide understanding of trophic biology. Fisheries Management and Ecology **10**:349-360.

Walton, C. 1987. Parent-progeny relationship for an established population of anadromous alewives in a Maine lake. Pages 451-454 *in* M. Dadswell, R. Klauda, C. Moffitt, R. Saunders, R. Rulifson, and J. Cooper, editors. Int. Symp. on Common Strategies of Anadromous and Catadromous Fishes. American Fisheries Soc., Boston, MA (USA).

Witman, J. D., and K. P. Sebens. 1992. Regional Variation In Fish Predation Intensity A Historical Perspective In The Gulf Of Maine. Oecologia (Berlin) **90**:305-315.

Yako, L. A., M. E. Mather, and F. Juanes. 2000. Assessing the contribution of anadromous herring to largemouth bass growth. Transactions of the American Fisheries Society **129**:77-88.

Yako, L. A., M. E. Mather, and F. Juanes. 2002. Mechanisms for migration of anadromous herring: An ecological basis for effective conservation. Ecological Applications **12**:521-534.

Appendix A: Presence/ absence of species, genera, families and orders of organisms found in diet contents, sorted by location with indication of whether that type of organism was present (p) or absent (a) in that estuary. Group Name is the category into which diet items were lumped for the diet analyses. D = Damariscotta, P = Passamaquoddy, SG = St. George

Group Name	Order	Family	Genus	Species	D	P	SG
amphipod	Amphipoda	Stenothoidae			a	p	a
amphipod	Amphipoda	Podoceridae			p	p	a
amphipod	Amphipoda	Phoxocephalidae			a	a	p
amphipod	Amphipoda	Melitidae	Maera	danae	p	p	a
amphipod	Amphipoda	Lysianassidae			p	p	p
amphipod	Amphipoda	Lysianassidae	Orchomenella	minuta	a	a	p
amphipod	Amphipoda	Lafystiidae			p	a	a
amphipod	Amphipoda	Hyperiidea			p	p	p
amphipod	Amphipoda	Hyalidae			p	a	p
amphipod	Amphipoda	Haustoriidae			a	a	p
amphipod	Amphipoda	Gammaridae	Gammarus	oceanicus	p	a	a
amphipod	Amphipoda	Gammaridae	Gammarus		p	a	a
amphipod	Amphipoda	Gammaridae			p	p	p
amphipod	Amphipoda	Gammaridae	Gammarus	obtusatus	a	a	p
amphipod	Amphipoda	Gammarellidae	Gammarellus	angulosus	p	p	p
amphipod	Amphipoda	Dexaminidae			p	p	a
amphipod	Amphipoda	Corophiidae			p	p	a
amphipod	Amphipoda	Caprellidae	Caprella	linearis	p	a	a
amphipod	Amphipoda	Caprellidae			p	p	a
amphipod	Amphipoda	Caprellidae	Caprella	septentrionalis	p	p	a
amphipod	Amphipoda	Aoridae	Leptocheirus	pinguis	p	p	a
amphipod	Amphipoda	Aoridae	Leptocheirus		a	p	a
anemone	Actiniaria				p	p	a
annelid	Hirudinea	Piscicolidae	Piscicola		a	p	a
annelid	Haplotaxidae	Naididae			p	a	a
annelid	Hirudinea				p	p	p
barnacle	Thecostraca				p	p	p
bivalve	Ostreoida	Pectinidae			a	p	p
bivalve	Veneroida	Cardiidae			a	p	a
bivalve	Ostreoida	Anomiidae	Anomia	simplex	p	p	p
chiton	Neoloricata	Ischnochitonidae	Tonicella	rubra	a	p	a
crab	Decapoda	Portunidae	Carcinus	maenas	p	a	p
crab	Decapoda	Paguridae	Pagurus	pollicaris	a	p	a
crab	Decapoda	Majidae	Hyas	araneus	p	p	p
crab	Decapoda	Inachoididae	Euprognatha	rastellifera	p	a	a
crab	Decapoda	Cancridae	Cancer	irroratus	p	p	p
crab	Decapoda	Cancridae	Cancer		p	a	p

crab	Decapoda	Cancridae	Cancer	borealis	p	a	p
Cumacea	Cumacea				p	p	p
echinoderm	Echinoida	Strongylocentrotidae	Strongylocentrotus	droebachiensis	a	p	a
echinoderm	Arbacioida	Arbaciidae	Arbacia	punctulata	a	p	a
echinoderm	Clypeasteroida				p	a	a
echinoderm	Echinoida				p	p	a
eggs	Decapoda	Brachyura			a	p	p
fish	Syngnathiformes	Syngnathidae			a	a	p
fish	Perciformes	Stromateidae	Poronotus	triacanthus	p	a	a
fish	Perciformes	Stromateidae	Peprilus	triacanthus	p	a	p
fish	Scorpaeniformes	Sebastidae	Sebastes	fasciatus	p	a	a
fish	Pleuronectiformes	Pleuronectidae			p	p	p
fish	Perciformes	Pholidae			p	a	a
fish	Perciformes	Labridae	Tautogolabrus	adspersus	p	a	p
fish	Scorpaeniformes	Cottidae	Myoxocephalus	octodecemspinosus	a	p	a
fish	Scorpaeniformes	Cottidae			p	p	p
fish	Clupeiformes	Clupeidae	Alosa	pseudoharengus	p	a	p
fish	Clupeiformes	Clupeidae			p	p	p
fish	Perciformes	Blennioidei			p	a	a
fish	Perciformes	Ammodytidae			p	p	p
gastropod	Nudibranchia	Tergipedidae			a	a	p
gastropod	Gastropoda				p	a	a
gastropod	Nudibranchia				p	p	p
hydroid	Hydroida				p	p	p
insect	Diptera				p	p	p
isopod	Isopoda	Janiridae	Jaera	marina	p	a	a
isopod	Isopoda	Idoteidae			p	p	p
isopod	Isopoda	Idoteidae	Idotea	phosphorea	a	p	p
isopod	Isopoda	Idoteidae	Idotea	balthica	p	a	p
isopod	Isopoda	Gnathiidae			p	p	p
lobster	Decapoda	Nephropidae	Homarus	americanus	p	p	p
polychaet	Terebellida	Terrebellidae			a	p	a
polychaet	Phyllodocida	Polynoidae	Lepidonotus	squamatus	a	p	a
polychaet	Phyllodocida	Polynoidae			p	p	p
polychaet	Terebellida	Pectinariidae	Pectinaria	granulate	a	p	a
polychaet	Phyllodocida	Nereididae			a	p	a
polychaet	Canalipalpata	Cirratulidae			a	p	a
polychaet	Aciculata				a	p	p
sea spider	Pantopoda	Pycnogonidae	Pycnogonum	littorale	a	p	a
seaweed	Fucales	Fucaceae	Pelvetiopsis		p	a	a
shrimp/krill/mysid	Decapoda	Penaeoidea	Caridea	penaeidae	a	a	p
shrimp/krill/mysid	Decapoda	Pandalidae	Pandalus	montagui	p	p	a
shrimp/krill/mysid	Decapoda	Pandalidae			p	p	p

shrimp/krill/mysid	Mysidacea	Mysidae	Mysis	mixta	a	p	a
shrimp/krill/mysid	Mysidacea	Mysidae			p	p	p
shrimp/krill/mysid	Mysidacea	Mysidae	Erthrops	erythrophthalma	a	a	p
shrimp/krill/mysid	Mysidacea	Mysidae	Neomysis	americana	a	p	p
shrimp/krill/mysid	Decapoda	Hippolytidae	Eualus		p	a	a
shrimp/krill/mysid	Decapoda	Hippolytidae	Lebbeus	microcerus	p	a	a
shrimp/krill/mysid	Decapoda	Hippolytidae	Eualus	pusiolus	p	p	p
shrimp/krill/mysid	Decapoda	Hippolytidae	Lebbeus	groenlandicus	p	p	p
shrimp/krill/mysid	Decapoda	Hippolytidae	Lebbeus	zebra	p	p	p
shrimp/krill/mysid	Decapoda	Hippolytidae	Lebbeus		p	a	p
shrimp/krill/mysid	Decapoda	Hippolytidae			p	a	p
shrimp/krill/mysid	Decapoda	Hippolytidae	Eualus	gaimardii	a	a	p
shrimp/krill/mysid	Decapoda	Hippolytidae	Eualus	fabricii	p	p	p
shrimp/krill/mysid	Euphausiacea	Euphausiidae	Meganyctiphanes	norvegica	a	p	a
shrimp/krill/mysid	Decapoda	Crangonidae	Crangon		p	p	p
shrimp/krill/mysid	Decapoda	Crangonidae	Crangon	septemspinosa	p	p	p
shrimp/krill/mysid	Euphausiacea				p	p	p
squid	Teuthida				p	a	a
zoeae	Decapoda	Megalops			a	a	p
zoeae	Decapoda	Brachyura			p	p	p
zoeae	Decapoda	Euphausiacea			p	p	p
zooplankton	Cladocera	Polyphemidae			p	p	p
zooplankton	Cladocera	Podonidae	Evadne		p	a	a
zooplankton	Cladocera	Podonidae	Podon		p	a	p
zooplankton	Monstrilloida	Monstrillidae			p	p	p
zooplankton	Copepoda	Clausocalanidae	Pseudocalanus		p	a	a
zooplankton	Cyclopoida	Caligidae			p	a	p
zooplankton	Calanoida				p	a	a
zooplankton	Cladocera				p	p	p

Appendix B. River Herring escapement and harvest numbers. *nc* = not counted.

System		*Spawning*	*Harvested*	*Total*
Dennys[A]	*2006*	*nc*	*none*	*nc*
	2007	*nc*	*none*	*nc*
	2008	69,739	*none*	69,739
St. George[B]	*2006*	*nc*	90,000	> 90,000
	2007	7332	300,000	> 307,332
	2008	47,109	513,840	> 560,949
Damariscotta[C]	*2006*	79,230	54,360	133,590
	2007	80,142	95,640	175,782
	2008	147,834	206,400	354,234

[A] *Dennys River Estuary was only sampled in 2006. In 2008, the MeDMR began counting river herring for the first time at their salmon counting weir in Dennysville. The Dennys River run is currently not harvested.*

[B] *In the St. George River, estimates of spawning river herring (likely all alewives) are for those fish that moved above the rock ramp at the outlet of Sennebec Pond only. There is considerable spawning habitat downstream of Sennebec Pond.*

[C] *Damariscotta River alewives were assessed by hand counts in 2006, hand counts and video in 2007, and hand counts in 2008.*