Analysis of herring diet in coastal waters of the Gulf of Maine: A step toward assessment of bottom-up ecosystem influences on Atlantic herring distribution and condition

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Abstract:

Herring diet has been regularly examined during the Northeast Fishery Science Center bottom trawl surveys since 1973, however none of the diet items have been identified beyond coarse taxonomic groupings (e.g., euphausids, copepods, chaetognaths). A more detailed taxonomic analysis of diet is impaired by fast digestion rates of herring stomachs, within which prey may be degraded after 1-2 hours if the process is not halted immediately at capture. Identification of prey items to the species level is critical for understanding of trophic interactions and bottom-up environmental forcing on the distribution of herring and their condition in the coastal Gulf of Maine. We used three methods, (whole fish frozen, stomach removed and frozen, and stomach removed and preserved in 95% ETOH) for preservation of herring stomachs from purse seine catches in the Gulf of Maine. Stomach contents from the ETOH preserved and stomach removed and frozen were more reliably identifiable to species level than the stomachs from the entire frozen fish. Individual stomachs removed and frozen were recommended as a preservation method due to the ease of processing the contents. In our examination of herring diet to date, we have found the most abundant prey items by quantity to be *Calanus finmarchicus*, *Neomysis americanus and Meganyctiphanes norvegica*. By weight, the three most consumed were *Meganyctiphanes norvegica*, *Ammodytes spp* and *Calanus finmarchicus.*

Introduction:

Sparse early (i.e., collected 30 or more years ago) data on the diet of adult Atlantic herring in the Gulf of Maine/Georges Bank region are for the most part reported in a handful of technical documents that are summarized in Tupper et al. (1998), Collette and Klein-McPhee (2002) and Stevenson and Scott (2005). Based on these studies, Stevenson and Scott (2005) report that Gulf of Maine herring have a diet dominated by euphausids, chaetognaths and copepods. Since 1973, the Northeast Fisheries Science Center has collected an extensive data set on food habits of major fish species, including Atlantic herring, acquired from analysis of stomach contents from the NEFSC bottom trawl surveys (Link and Almeida 2000; Smith and Link 2010). The data are analyzed down to major taxonomic groupings, but not to species level for the zooplankton. In these studies, approx. 1/4 to 1/3 of the Atlantic herring stomach contents were unidentifiable. Of the remainder, euphausiids and copepods constituted 15-25% of the diet by weight, and amphipods, mysids, larvaceans and decapods make up most of the rest.

While these data are useful for characterizing fish feeding habits in an ecosystem-level analysis of trophic interactions across the Gulf of Maine, more detailed information of herring feeding habits is required, specifically for understanding coastal food web interactions in inshore waters. Since species of dominant copepods, euphausiids and other taxa have different life histories, distributions and responses to environmental forcing, species identification of the dominant prey of Atlantic herring is needed in order to understand potential bottom up influences on herring distribution and condition in the inshore habitat.

We are particularly interested in determining the extent to which adult Atlantic herring feed on the planktonic copepod, *Calanus finmarchicus*, in summer in the western Gulf of Maine. In a thorough study of diet of herring in the southern Gulf of St. Lawrence in June, Darbyson et al. (2003) identified species of *Calanus* (mainly *Calanus finmarchicus* and the subarctic *Calanus glacialis*) as predominant in adult herring diet, accounting for 85% of the mass of the prey consumed. Similarly, *Calanus finmarchicus* is the predominant prey of herring in coastal areas off Norway, Iceland and in the northern North Sea (Dalpadado et al. 1998; Gislason and Astthorsson 2000; Maravelias et al. 2000). However, in the Baltic Sea, herring fed mainly on other, smaller copepod species, notably *Temora* spp. and *Centropages* spp.

In collaboration with New Hampshire and Massachusetts fishermen through a Northeast Consortium award to the Massachusetts Fisherman's Partnership, we monitored the zooplankton in the coastal, western Gulf of Maine between 2003-2008 (Runge and Jones in press). Relevant to the study here is the observation of a decline, by a factor of 5-10 decline, in the abundance of *Calanus finmarchicus* stages IV and V on Jeffreys Ledge in summer months between 2003-2005 (Figure 1). These are the large, lipid rich developmental stages that precede dormancy during the fall and winter months. They represent a unique source of food for herring in that the concentration of lipids found in the stage CV oil sacs is not available from other potential zooplankton prey in the region.

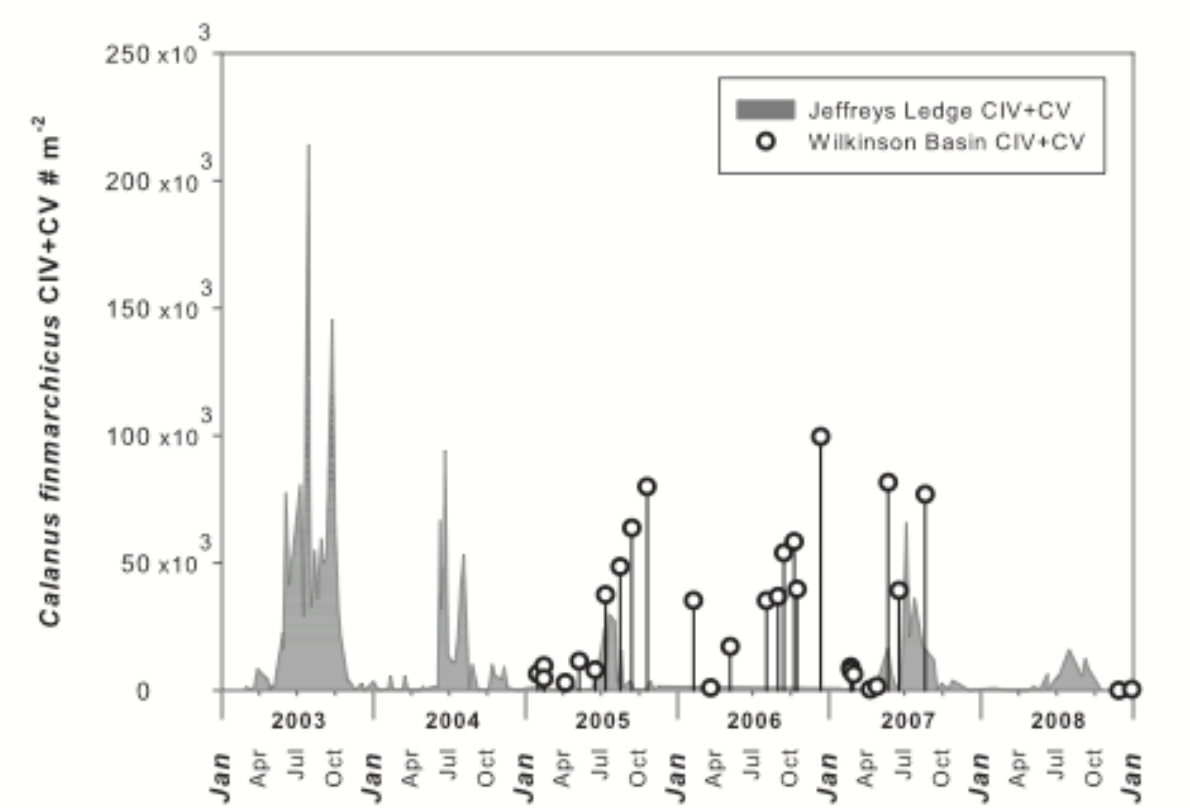

Figure 1. Abundance of *Calanus finmarchicus* Stage CIV and CV (number m^{-2} integrated over the water column) taken with a vertical, 200 μm mesh ring net tow at a station on New Scantum on Jeffreys Ledge (shading) and for comparison at the offshore UNH Coastal Observing Center station (started in mid-2005) in Wilkinson Basin (vertical lines with large dot), where more *Calanus* would be expected because the station is much deeper. Note no Jeffreys Ledge data were collected in 2006. We hypothesize that the shading is a proxy for the seasonal availability of zooplankton lipids on Jeffreys Ledge.

Calanus finmarchicus is a dominant member of the zooplankton assemblage captured in ring net samples on Jeffreys Ledge. Other prominent zooplankton species are the copepod species in the genera *Oithona*, *Centropages*, *Pseudocalanus* and *Temora*, as well as euphausid species and possibly *Neomysis americana*, the common mysid shrimp. Given the predominance of *Calanus finmarchicus* on Jeffreys Ledge and the finding that *Calanus finmarchicus* dominates the diet of Atlantic herring in other regions (e.g. southern Gulf of St. Lawrence, coastal Norway and northern North Sea), we hypothesize that *Calanus* is predominant in western Gulf of Maine herring diets during dominant *Calanus* years like 2003 and 2007 (Fig 1), but that other prey species predominate in years of low *Calanus* abundance, such as 2004-2005. Moreover, because *Calanus* is lipid rich relative to other available prey species, the fat content of adult herring will also vary, depending on the overall availability of *Calanus* during the period of summer feeding. As a step toward a mechanistic understanding of trophic connections affecting inshore herring population distribution and condition in coastal waters of the Gulf of Maine, we needed to establish the method for collection of herring that best preserves the morphological integrity of herring stomach contents. Digestion rates in herring stomachs are known to be very fast, on the order of hours. This NEC Project Development award allowed us to test three methods for collection and preservation of herring stomach contents. The study also provided new information on inshore herring diet during critical summer months of foraging.

Project objectives and scientific hypotheses:

The primary objective of this Project Development proposal was to determine which of three alternative methods for preservation of stomach contents of Atlantic herring (whole fish frozen, stomach removed and frozen, and stomach removed and preserved in 95% ETOH) yields the most accurate estimates of diet composition by species. A secondary objective was to contribute to a dataset on spatial and temporal variation in species composition of the diet of adult Atlantic herring in coastal waters of the Gulf of Maine. The outcome of the project will be a proven protocol for obtaining species-specific herring diet information, as well as preliminary information that is needed for design of a more comprehensive study about bottom up ecosystem and environmental influences on Atlantic herring distribution and condition in the inshore Gulf of Maine. Our guiding hypotheses for this larger study is as follows: Because *Calanus finmarchicus* is a lipid rich relative to other available prey species, the distribution and fat content of adult herring will vary, depending on the overall availability of *Calanus* during the period of summer feeding.

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Field Sampling:

We employed commercial fishing boats of purse-seine configuration. Samples were taken from the inshore Gulf of Maine herring stock during the months of June and July 2008, within the statistical area of 1A. Attempts were made in September and October to acquire samples whenever the fleet was allowed to fish during management closures but were unsuccessful.

Fishing tow was used as the statistical unit with a minimum of 30 fish per tow as the target number of samples. Standard fishing operations have the pursed catch immediately pumped onboard into an ambient/chilled seawater fish hold, The fish are stored there until arrival at the dock, which could be hours from the catch time. To halt the digestion process quickly, all sample fish were randomly retrieved while they were brought on board from each trawl and immediately processed. Processing involved the 3 treatments of 10 stomachs each: 1) removed and frozen separate (FS), 2) whole fish frozen (WF) and 3) stomach removed and placed in 95% ethanol (ETOH). Records of the general area of capture, time and date of capture, total weight of catch was recorded.

While planning the project we intended to have a 0.75 m^2, 200 μm mesh ring net sample taken at the time of the commercial fish catch to determine the zooplankton prey field the fish were inhabiting. However, we quickly found that on a purse seine boat there is no room or time for that type of sampling during fishing operations.

Laboratory Analysis:

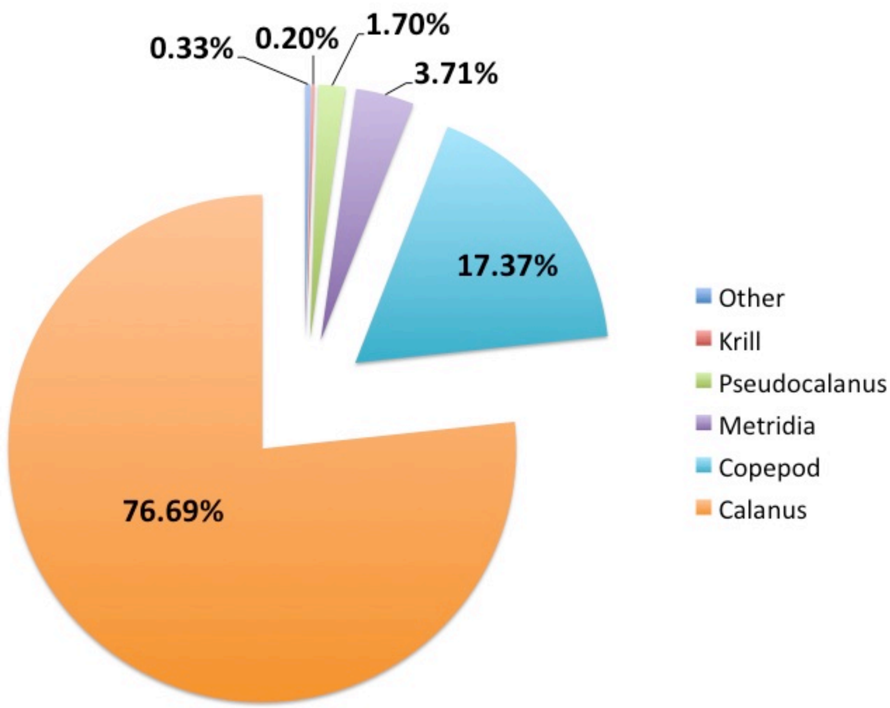
Frozen samples were thawed, fish total length was measured, and stomach removed from the whole fish if necessary. Contents of all the frozen stomachs were weighed to nearest .001 gram using a Mettler/Toledo benchtop scale. For ETOH preserved stomach contents the weight was estimated by using known species individual weight wet approximations. There were a total of 4 hauls yielding 94 fish stomach samples. The number of samples analyzed per treatment is: 16 for stomach removed and preserved in ethanol (ETOH), 44 for whole fish frozen (WF) and 34 for stomach removed and frozen (FS). Fish were obtained from Area 1A during June and July of 2008. More detailed information on time and location of capture is not available.

If the stomachs did not contain a large quantity of small prey items, the entire gut was enumerated. When contents were full with smaller prey items, larger items were removed, identified and weighed and all smaller zooplankton were diluted in seawater so that a Stemple pipette could be used to sub-sample for enumerating a minimum of 200 animals. All zooplankton was identified to species and stage where possible. The total prey count was then extrapolated by the dilution volume to obtain the total prey abundance for the entire stomach.

Data:

Of the 94 total stomachs examined, 6 were full of well-digested (non-identifiable) material and 18 were empty. All of the well-digested or empty stomachs were collected from a single haul that was taken at 13:00. All other hauls were taken between the hours of 21-23:00. Data from the midday haul were removed from further statistical analysis because the fish are presumed to have not been actively feeding during the time of capture (Darbyson 2003); hence their empty stomachs would skew the results. All prey items were ranked by percent contribution to the total abundance of gut contents. Each treatment was pooled and tested with ANOVA ($p<0.05$) for significant differences in percent identifiable stomach contents (% IDABLE). A pooled comparison of all stomach contents (even the well-digested copepods) revealed that *Calanus* was the most dominant prey item with *Metrida lucens* appearing as the second most identified dominant copepod (Figure 2).

Figure 2: Contribution to total number of prey taxa in the diet of herring from this NEC Project Development award. Fish were sampled from Area 1A June and July 2008.



Results and conclusions:

When all samples were pooled by treatment and analyzed by ANOVA, the ETOH and FS treatments yielded the highest mean percentage of identifiable stomach contents with mean values of 71% and 68%, respectively, and the WF treatment mean was 59%. While there was no significant difference between the means of the three treatments ($F= 0.4711$, $P <0.05$), the WF treatment showed more variable results in which contents of some WF treatments had very few identifiable properties (Figure 3). The variability of the whole fish treatment may be an effect of fish body size and the rate at which stomach contents would freeze thus halting digestion i.e. larger body size may have an "insulating" capacity hence prolonging the freezing of the stomach and allowing digestion to occur longer than in a smaller fish body.

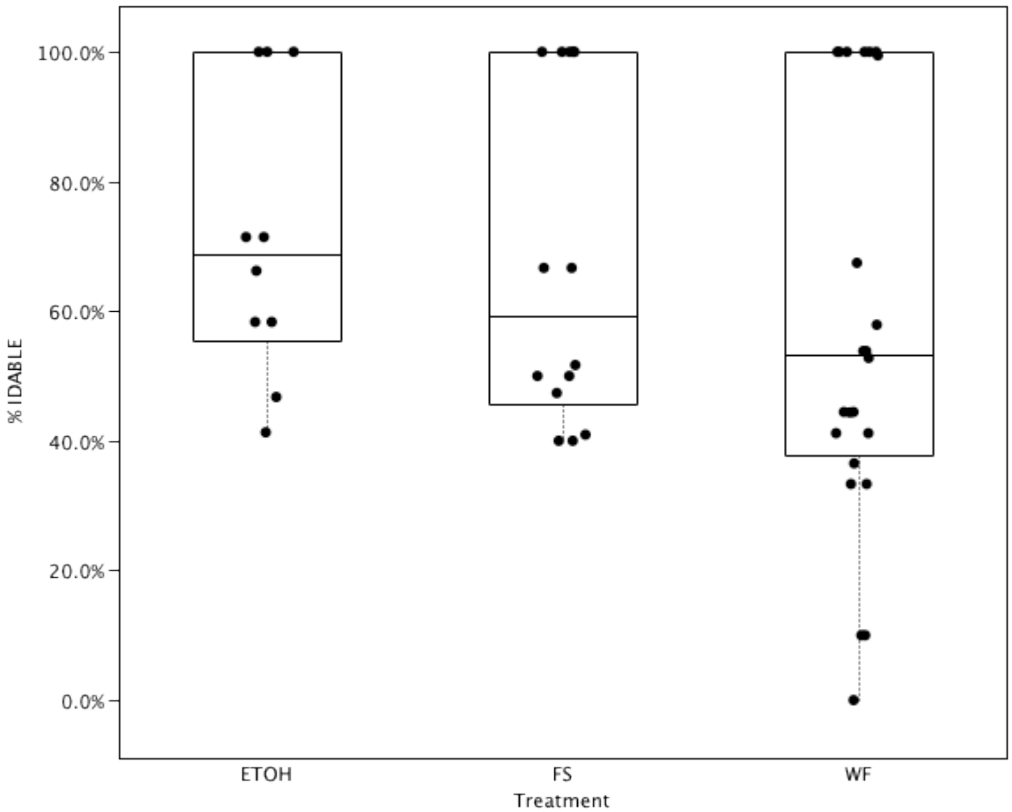


Figure 3: Percentage of gut contents identified (% IDABLE) from three different stomach preservation methods: stomach removed and preserved in 90% ethanol (ETOH), stomach removed and frozen (FS) and whole fish frozen (WF).

We conclude that the ETOH or FS treatments are preferable for preserving stomach contents, but that the WF treatment is also acceptable if the other two alternatives are not feasible for the particular circumstances of collection. While working with the ETOH and FS methods, it was found that frozen stomachs were more easily and efficiently weighed than stomachs diluted in ETOH. Therefore we recommend removal of stomachs (or in the very least a careful cutting of the abdominal cavity to expose the stomach allowing a quicker freezing) and immediately freezing as the most preferred method of preservation.

Time of capture has been found to be of great importance for the level of digestion that stomach contents will have undergone. Herring have been found to actively feed during the twilight hours of the day and hence any fish captured during midday will have well digested planktonic prey items (Figure 4).

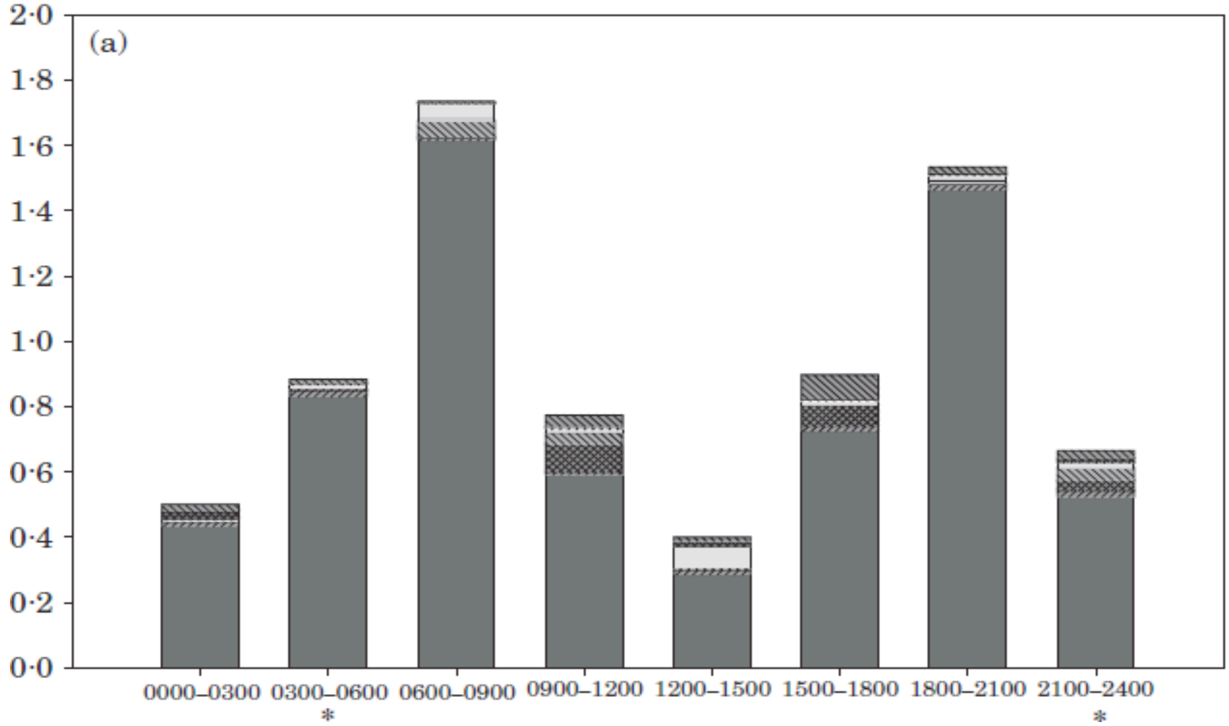


Figure 4: Bar graph reproduced from Darbyson et al. 2003 showing partial fullness index of fish stomach contents by hour of capture. *Calanus finmarchicus* prey items are indicated in solid grey.

As discussed above, some of our samples came from 13:00 and they were either empty or full of well digested material. Copepod prey items are the first to be digested presumably due to their smaller sizes. Larger items such as euphausiids will become well digested in whole but their eyes will resist the digestion process longer and remain countable in pairs. This is a tool that tuna biologists have used when enumerating euphausiids in stomach contents (pers comm Dr. Walt Golet). Fish, amphipods and euphausiids also remain in the stomach longer than copepods and are more easily counted. Figure 5 is an illustration of the varying degrees of digestion in different fish. Stomach contents that are defined as “well-digested” may still contain enough detail to be able to discern taxonomic groups, but valuable information on copepod species composition is lost. If the intent of a proposed sampling program is to enumerate feeding of herring in a spatial and temporal context then it is suggested that the hours of capture encompass the times when the fish are actively feeding, so that gut contents are more fresh and identifiable.

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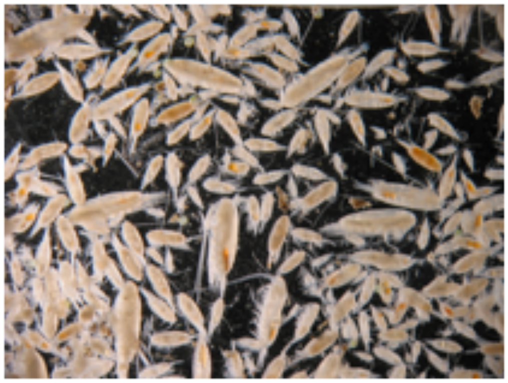
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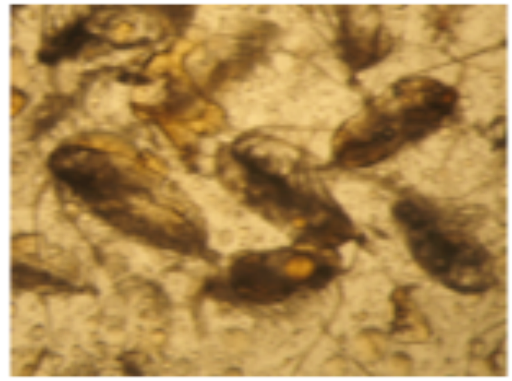
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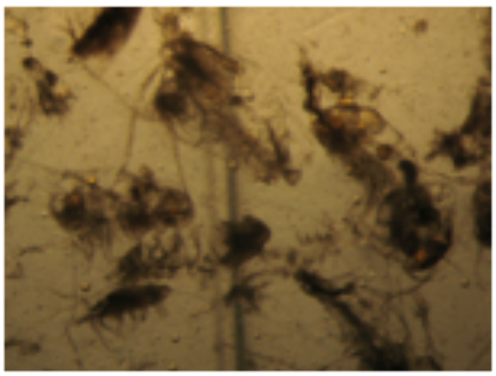


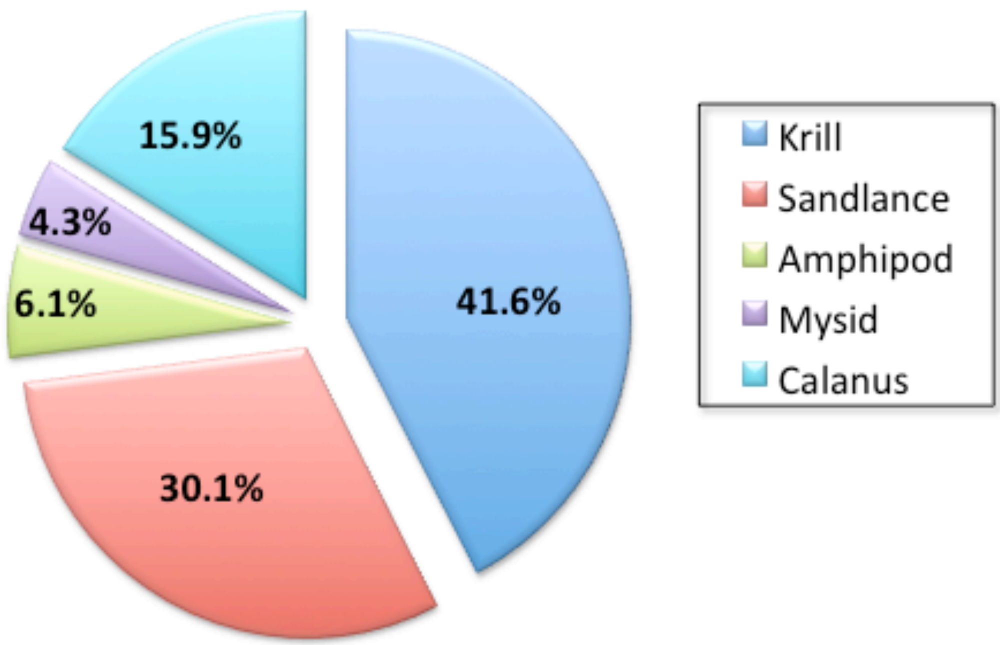
Figure 5 a-c: Pictures of the various states of condition of copepod prey items in herring stomachs with a) uneaten plankton sample from a preserved ring net cast sample b) "good" condition gut contents with most items identified as *C. finmarchicus* stage V and VI-F c) "well-digested" condition gut contents.

We used these techniques in a herring diet analysis collaborative study with Dr. J. Stockwell, Gulf of Maine Research Institute. For that project, samples were acquired from the Spring NMFS trawl survey on Georges Bank, during which they were flash frozen at the time of capture. These samples were also obtained during June and July 2008. Some samples were also obtained from fishing operations. Stomach contents from the latter were mostly well-digested stomach contents presumably from the long time between capture and freezing, in contrast to the good quality of the stomach contents in the immediately frozen NMFS trawl survey fish.

The diet analysis revealed *Calanus finmarchicus, Neomysis americanus* (mysid) and *Meganyctiphanes norvegica* (krill) to be the three most abundant of the 24 prey items identified in the herring stomachs (Figure 6). With respect to weight, the three most important prey were *Meganyctiphanes, Ammodytes* (sandlance) and *Calanus* (Figure 7). These results are very similar to results from Norwegian Sea studies which have found herring to specifically target the larger *Calanus* stages, all krill, amphipods and mysids (Dalpadado 2000; Prokopchuck et al. 2006; Gislason and Astthorsson 2000).

There appears to be a spatial difference in the diets between the fish from Area 1A and the Georges Bank. Area 1A supported diets consisting more of *Calanus*, other copepods and some krill. On Georges Bank, fish diets also contain larger items such as sandlance and krill in roughly equal proportion by weight to *Calanus*. These dietary differences may have significant ecological implications for understanding trophic interactions and physical forcing in the two areas.

Figure 7: Contribution of taxa to the diet of herring from the Spring NEFSC Trawl Survey as percent of weight of prey items.



Previous research indicates that the energy density of *Calanus* is ~ 29 kJ gm^{-1} (Comita et al 1966), *Ammodytes* ~ 6 kJ gm^{-1} (Anthony et al 2000), *Neomysis* ~ 2.0 kJ gm^{-1} (Lankford and Targett 1997) and *Meganyctiphanes* ~ 3.9 kJ gm^{-1} (Tyler 1973). It is clear that *Calanus* is a very high energy prey item. *Calanus* is known to be the primary food source for northern right whales and a main part of the diet for many other species. It is important to note that the aforementioned prey items have a seasonal fluctuation in their energy density that may be related to the stage or spawning condition of the species. For example, *M. norvegica* was found to have a seasonal maximum energy density during the late summer/early fall months that was more likely due to their increased size and gonad development but was also due to their increased lipid content (Tyler 1973).

Describe the scientific and/or technical results of the project and explain their significance in terms of the project objectives and the Northeast Consortium goals:

This research will provide additional information needed to assess trophic interactions and the influence of bottom-up environmental forcing on herring abundance and condition in inshore waters of the Gulf of Maine. Tupper et al. (1998) report that there is a positive correlation between herring feeding activity and fat content in coastal regions of the Gulf of Maine, and that the survival, growth and distribution of the coastal herring is influenced by the availability of copepod prey. Maravelias et al. (2000) found a significant correlation between zooplankton abundance and spatial distribution of herring aggregations in the northern North Sea. Based on these results, we hypothesize that the abundance and composition of zooplankton in the inshore coastal Gulf of Maine, in particular the abundance of the lipid-rich late stage *Calanus*, has a first order influence on the movement and distribution of herring schools and on fat content of herring individuals. The high inter-annual variability in zooplankton abundance and *Calanus* availability on Jeffreys Ledge (part of Area 1A) is likely the consequence of climate forced changes to upstream primary production cycles, influencing zooplankton production and /or changes to circulation and mixing patterns on Jeffreys Ledge, influencing the distribution and aggregation of *Calanus* in the inshore area. Understanding of these factors is needed in a balanced ecosystem approach to fisheries management, where not only fishing mortality but also environmental forcing needs to be taken into account.

The preliminary data obtained from the work outlined in this Project Development Final Report helped us evaluate these initial hypotheses and begin to design a full-fledged program to study environment, zooplankton and herring interactions in the coastal region on a more solid footing. First, the preliminary data provided insight into the species composition of herring prey relative to species composition measured in our plankton nets, and showed some evidence that *Calanus finmarchicus* is the primary prey of herring schools when it is predominant in the water column. Secondly, the award helped us develop and refine the methodology needed to accurately assess diet composition. The study by Darbyson et al. (2003) in the southern Gulf of St. Lawrence showed that gastric evacuation times are rapid, on the order of 1-2 h, so that special attention is needed to extract and preserve stomach contents immediately after capture. The Darbyson et al. (2003) study also showed that diet composition may vary on a day-night cycle correlated with herring feeding mode and depth in the water column. Our preliminary study allowed us to assess this source of variability in the coastal Gulf of Maine, and to plan for it in a broader research program.

Partnerships:

This project could not have occurred without the participation of fishermen. All the fish used in this study were obtained by the cooperation with the fishing fleet, who performed all the treatments at sea.

Impacts and applications:

The deliverable for this Project Development Award is a “fishermen friendly” method of preservation that has a minimum impact on normal fishing operations and that preserves contents of herring stomachs with a greater percentage of prey items identifiable to species. A methodology such as this is intended for use in research of diets of planktivorous fishes such as the herring, both Atlantic and river which have a very fast digestion process.

Related projects:

Composition and Seasonal Variation in Diet of Atlantic Herring in the Gulf of Maine, Dr. Jason Stockwell, Dr. Graham Sherwood and Dr. Andy Pershing funded by Large Pelagics Research Extramural Grant Program, UNH and Northeast Consortium

Presentations:

Northeast Consortium Project Participants Conference 2010

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