Workshop Report: Diadromous fish as marine prey workshop

November 19-20, 2020 (virtual)

Executive Summary

Over the past 20 years, efforts to restore diadromous fish in Maine's river systems have led to significant increases in run size for many species, namely river herring. As the abundance of river herring populations have increased, it has become more pertinent to understand role of river herring as prey for marine predators in the Gulf of Maine (GoM). To assess our current understanding of this ecological connection, we organized a workshop for scientists who are actively researching the role of diadromous fish as prey in the GoM. Over two days, scientists shared current research and preliminary results to foster discussion on the "state of the science". Preliminary results from Maine Department of Marine Resources trawl survey and traditional diet sampling indicate that river herring abundance is variable at spatial and temporal scales in the nearshore GoM, with indications of overall increased abundance in recent years. Despite the perceived increases in river herring abundance, river herring detection in diets has been relatively low among the small number of sampled marine predators. Of these sampled marine predators are Atlantic cod (*Gadus morhua*), a groundfish with low abundance and truncated size distribution. However, river herring have recently been detected for the first time in the diet of Atlantic Bluefin tuna (*Thunnus thynnus*) sampled in the GoM. Further, stable isotope analysis is proving to be a powerful tool for detecting the presence of freshwater prey contributions to the diets of marine predators at a broader temporal scale than traditional diet sampling. Participants discussed potential synergies within these investigations and committed to a future meeting to explore these topics further and formalize connections by coordinating sample collection, comparing methodologies, and sharing results. This suite of studies is slated to continue and therefore strengthen our understanding of the role of diadromous fish, especially river herring, as marine prey.

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Introduction

Maine has 12 native species of diadromous fish that historically supported significant fisheries and provided sustenance for people of the region. In the late 1800's, these populations collapsed due to dam construction and overfishing. Over the past 20 years, an expansive effort to improve freshwater connectivity by removing dams has provided opportunity for some species to rebound. River herring, the collective name of Alewife (*Alosa pseudoharengus*) and Blueback herring (*Alosa aestivalis*) have seen rapid reestablishment in some Maine river systems after dam removals with restored runs numbering from thousands to millions of individuals.

A primary goal of river herring restoration is managing rivers to support river herring populations, to maximize productivity and increase abundance. Hypothesized secondary benefits suggest that increased river herring populations may provide utility to the broader ecosystem that they inhabit. For example, Saunders *et al.* (2009) hypothesized on the ecological benefits of increased river herring populations providing a "prey buffer" for emigrating Atlantic salmon (*Salmo salar*) smolts. In the marine environment, Ames and Lichter (2013) hypothesized that Atlantic cod populations may have historically relied on juvenile river herring as forage during nearshore inhabitance prior to spawning. Hypotheses like these are not without basis:

> *"It would, therefore, appear that while the river-fisheries have been depreciated or destroyed by means of dams or by exhaustive fishing, the cod-fish have disappeared in equal ratio…* ***that the reduction in the cod and other fisheries, so as to become practically a failure, is due, to the decrease off our coast in the quantity, primarily, of alewives****; and, secondarily, of shad and salmon, more than to any other cause…"* US Fish and Fisheries Commissioner, Spencer Baird (1874)

Contemporary investigations of predator/prey and population dynamics between Atlantic cod and river herring began in the 2000's. Atlantic cod are classified as generalists, feeding on an abundance of prey items with evidence diet shifts coinciding with prey availably (Link and Garrison 2002, Link *et al.* 2009). Richardson *et al.* (2015) described the ability of the Atlantic cod stock to shift spatially in response to abundant prey (e.g. sand lance *Ammodytes* spp.) and the subsequent susceptibility to overfishing that spatial shifts can create. Further, Willis *et al.* (2013) concluded that shifting prey fields due to fisheries operations may have shifted diet preferences for Atlantic cod in the eastern Gulf of Maine (GoM).

While empirical evidence has driven the development of marine forage hypothesis, various modeling efforts have provided conceptual support by incorporating estimates of historical baselines and bioenergetics. Hall *et al.* (2012) derived estimates of biomass from the reported abundance of river herring that were present prior to dam construction in the 1700 and 1800's and concluded present-day River herring production was a fraction of pre-dammed capacity. Diaz *et al.* (2019) concluded that the hypothesis that cod productivity was limited by the lack of river herring forage was feasible based on their use of bioenergetics models coupled with observed GoM forage biomass trends.

River herring abundance within the GoM has increased in the past decades as a result of the various restoration efforts and this trend is expected to continue. This offers a unique opportunity to investigate the hypothesis put forth by Ames and Lichter (2013) where marine predators may capitalize on the increased abundance of river herring as prey. There are currently several studies investigating this topic at various scopes and scales using a range of techniques and technologies

A two-day workshop was organized to bring together researchers investigating the impact of river herring restoration on marine fish diets and productivity within the GoM. The workshop had 3 primary goals:

1) outline the projects informing this area of research;
2) describe the synergy and identify data gaps given current scope and methods; and
3) synthesize current state of the work and outline future steps if appropriate.

Day 1 of the workshop consisted of presentations describing each individual research effort assessing the contributions of diadromous fishes to marine predator diets. The presentations provided background on how the project originated, what has been accomplished to date, results to date and where the research is going. Day 2 consisted of an open but facilitated discussion by participants to discuss the current state of the science, our understanding of the topic, data and research gaps, and potential next steps.

Due to the COVID-19 pandemic, the two-day workshop was modified to a two half-day virtual workshop. The workshop was held November 19-20, 2020 and a total of 16 participants (Appendix I) participated. The workshop agenda can be found in Appendix II.

This meeting report summarizes the presentations and subsequent discussions which occurred in support of accomplishing the goals of the workshop. This product may serve as an outreach document within and among our respective institutions and could serve as the basis for future funding proposals or leadership briefings. An overarching goal of this entire effort was to strengthen and improve this focused research network for future collaborations.

For more information or inquires please contact Justin.Stevens@maine.edu (Maine Sea Grant).

Day 1 (Presentations)

Day 1 consisted of 6 presentations with a short question and answer period after each presentation. The presentation titles are listed below along with the presenter's name and affiliation and a few highlights:

1. **River herring catches within the ME NH Inshore Trawl Survey** (Appendix III)
    - Presenter: Rebecca Peters (Maine Department of Marine Resources)
        - Inshore ME Department of Maine Resource (ME DMR) groundfish survey conducted along NH and ME coasts during spring and fall since 2000
        - Catch and size data available for river herring and a variety of marine predators
        - Predator catches generally larger in fall than spring
        - River herring not a major proportion of catch, but complex spatial and temporal patterns of abundance are evident and need to be considered in diet work
2. **Groundfish consumption of river herring in Merrymeeting Bay and Penobscot Bay, Maine from 2012-2019** (Appendix IV)
    - Presenter: Mark Renkawitz (NOAA Fisheries Service)
        - Diet study of likely river herring predators in association with ME DMR Survey (2012 to present)
        - Over 2700 stomachs sampled to date with few positive river herring identification (n=33)
        - Small river herring consumed (~80% < 15cm)
        - Most consumed in Merrymeeting Bay and no evidence of seasonal trend
        - Slight signal of increased consumption over time (~half of confirmed identifications occurred in 2018/19)
3. **Diet composition of Atlantic cod in the inshore eastern Gulf of Maine** (Appendix V)
    - Presenter: Robyn Linner (University of Maine)
        - Cod diet study in association with the Maine Center for Coastal Fisheries' (MCCF) Eastern Gulf of Maine Sentinel Survey (2012 to present)
        - 86 samples analyzed to date and no river herring, primarily feeding on crabs, lobster and shrimp
        - Majority of cod caught are immature and small in size, relying more on crustaceans such as crabs, lobster and shrimp at this life stage.

        - Other fish species were identified as important prey items in this study, with many of the cod sampled being much smaller than the suggest size limit where a shift to piscivory would be expected.
        - Larger maturing specimens displayed a greater reliance on fish as prey
        - Continued sampling, especially of mature cod, may provide better insight to the importance of river herring to cod diet
4. **Assessing the contribution of YOY river herring to coastal food webs in the Gulf of Maine using compound-specific carbon stable isotope analysis** (Appendix VI)
    - Presenter: Simon Thorrold (Woods Hole Oceanographic Institution)
        - Estimating amino acid-specific carbon stable isotope values to identifying where the carbon has come from. Not useful for identifying individual prey items and therefore not evaluating alewife contributions to marine predator diets, but looking at freshwater carbon contributions to marine predation diets.
        - A variety of marine species (e.g. cod, haddock, mackerel, etc.) and alewife tissue samples analyzed a part of 2019 pilot project
        - Strong isotopic signature separating river herring samples from other marine species, which suggests that river herring are not significantly contributing the diets of the marine species sampled
        - A lot of consistency within species, which suggest the GoM coastal food web is tightly structured
5. **Marine derived nutrients in the Penobscot Bay Watershed: Pre and post river restoration** (Appendix VII)
    - Presenter: Karen Wilson (University of Southern Maine)
        - Overview of numerous studies assessing river herring contributions to marine diets via observation and stable isotope analysis
        - Sampling results suggest groundfish diets dominated by invertebrates
        - Identified pulse event of river herring in one year in one location, believed to be associated with localized juvenile emigration
        - Presented results describing freshwater and marine food web structure prior to significant Penobscot River river herring restoration efforts with post-restoration sampling ongoing (2020/21)

6. **The Foraging Ecology and Energetics of Atlantic Bluefin Tuna in the Gulf of Maine: An Unexpected Find** (Appendix VIII)
    - Presenter: Samantha Nadeau (University of Maine)
    - Report on recent diet study on Atlantic Bluefin tuna with comparison to previous studies conducted circa 1990 and 2006
    - Identified increased Atlantic menhaden (*Brevoortia tyrannus*) consumption given reduction in Atlantic herring (*Clupea harengus*) abundance
    - River herring consumption was documented for the first time in 2017 and continued through 2019 samples
    - Consumption was more frequent in July-October with mean fish size of 230 cm (range of 100 – 280)
    - Given declines in Atlantic herring abundance, Atlantic Bluefin tuna in the GoM appear to be switching to prey with similar energetic content

The presentations represent a comprehensive summary of the contemporary research efforts looking at the contributions of diadromous fishes to the diets of GoM marine fish predators. However, it was recognized that the presentations may not cover the full breadth of studies addressing this topic given the lack of marine mammal related investigations.

The information provided above and within the presentations in the Appendices should be considered preliminary and should not be cited without consent from the primary authors.

Day 2 (Discussion)

Day 2 consisted of discussions, which were focused on discussing the current scope of ongoing work as well as looking ahead to evaluate the need for increased collaboration and or communication. A series of questions were presented to the participants to help guide and structure the discussion, but additional topics were also explored.

Any questions from yesterday?

It was noted that preliminary results from the NOAA/ ME DMR diet study (**Appendix IV**) suggest relatively low contributions of diadromous fishes to the sampled marine predators. The question was raised if there was any information on the probability of encounter and if this information would help improve the interpretability of the results. The group agreed that the probability of encountering a marine predator that had recently consumed a diadromous fish was very important and should be addressed within any ensuing manuscripts and presentations. The abundance of diadromous fishes in Maine, specifically river herring, has been increasing in recent years due to a number of ongoing restoration efforts. This is particularly true within the Penobscot River watershed and bay, where the NOAA sampling is partially focused. However, even with an estimated river herring abundance of approximately 3 million adult returns in recent years, it was noted that this is still a “drop in the bucket” compared to the historical capacity of the Penobscot River specifically, or Maine more generally. It was also noted that the possibility of pulse feeding events that occur during very small windows of opportunity (i.e. adult river herring entering the bays and rivers or the outmigration of juvenile river herring) should also be considered when interpreting results.

Did ‘Day 1’ provide a comprehensive review of the research efforts investigating the role of diadromous fishes in nearshore marine predators?

Participants agreed that a comprehensive review was provided. A few other research efforts were noted and it was suggested that the Principle Investigators identified be contacted to learn more about the objectives of their studies/monitoring. Two specific projects identified were the Gulf of Maine Research Institute’s (GMRI) Casco Bay Aquatic Systems Survey and The Maine Center for Coastal Fisheries’ Alewife

Monitoring Project on the Bagaduce River. There was discussion regarding if there are similar diet focused research efforts occurring south of the GoM. Participants were not aware of any ongoing work. It was noted that there has been interest expressed by certain groups in the past, but this interest has not materialized in terms of resources and on the ground investigation. However, if the connection between river and diadromous fish restoration and the productivity of nearshore GoM marine predators could be developed further, interest outside of the GoM would likely increase.

The participants were interested in the large datasets available from the various groundfish survey programs conducted within the GoM. NOAA Fisheries has conducted annual surveys within the GoM since the 1960's and a wealth of catch data and statistics are available (see https://www.fisheries.noaa.gov/about/northeast-ecosystems-surveys). In addition, diet sampling in conjunction with these surveys have been ongoing since 1973. The entirety of this dataset can be accessed via the following https://fwdp.shinyapps.io/tm2020/. The entirety of the DMR MEHN database can also be accessed from the following https://mainedmr.shinyapps.io/MaineDMR_Trawl_Survey_Portal/, although a request for access is required.

When the studies are completed and the papers are published, will we have a better understanding of the dynamics of diadromous fish and nearshore GoM marine predator productivity?

The participants recognized that our desire to identify the connections between diadromous fishes and nearshore GoM marine predator productivity may not align with the timeline of how these dynamics may, or may not, develop given the slow rebuilding we are seeing with diadromous stocks. The group also recognized that the marine environment and suite of nearshore predators has changed considerably over that past 50 years and that these changes would also impact the development of any connections between the freshwater prey and marine predators. However, results from these studies are certainly informing the refinement of sampling techniques and focus of this research. As we learn more from these studies regarding methods, target species and the spatiotemporal focus can adjust as appropriate.

There was recognition that increasing the time series for some of these studies (e.g. NOAA/DMR survey sampling) will greatly increase our ability to detect potential relationships between diadromous fish and marine predation given changes in river herring abundances, abundance and catches of marine predators, etc. As an example, the re-initiation of diet sampling on Atlantic Bluefin tuna (ABFT) resulted in the identification of substantial quantities of river herring consumption. ABFT consumption of river herring has coincided with a shift in the spatial distribution of ABFT foraging in nearshore areas of the GoM. It was noted that continuation of this sampling program beyond the life of the current project is warranted to monitor the stability of, or potential changes to, ABFT feeding ecology.

The participants discussed the need to consider and compare notes across these various sampling efforts. Given the common nature of the various studies (i.e. feeding ecology of marine predators), comparing notes across efforts may provide further insights. As an example, the changes noted in the composition of ABFT diets appear to align with changes noted in catches during the MENH Inshore Trawl Survey. Combining these two datasets may provide further insights in to the ABFT feeding ecology.

If we are not any closer to having a better understanding of the dynamics of diadromous fish and nearshore GoM marine predator productivity, what is missing?

It was recognized that each of these studies have strengths and weaknesses in design and methodology. As an example, the NOAA/DMR sampling is providing robust data on the diet preference of nearshore groundfish species sampled during the survey. However, the timing of the survey is set and is not tied to any ecological cues and therefore may result in a spatiotemporal mismatch of nearshore marine predators feeding on diadromous fishes. The diet composition of Atlantic Cod studies is relying more on the sentinel survey and its ability to target untrawlable habitats where larger marine predators may exist. However, catches and sample size are still low for target species like Atlantic cod, likely a reflection of low abundance of Atlantic cod in the region. The stable isotope analysis studies will measure the consumption of freshwater origin carbon that exists in juvenile river herring, but once these river herring have existed in the marine environment for approximately six months or less, they may lose the freshwater signal. As such, the stable isotope work is an appropriate technique for detecting predations of juvenile river herring by marine predators, not adult river herring. Given this, it was noted that each study will provide an incomplete understanding of the larger issue. Combining the results of all the studies once completed, will provide the most comprehensive assessment possible.

There were some concerns raised that we may not be sampling at the right time or in the right spaces. The DMR ME-NH and Sentinel surveys both have set schedules and may not be properly timed with environmental cues that could be driving diadromous fish migrations within the marine environments. The DMR survey data can help inform the question of the potential for a spatiotemporal bias, based on the full time series of catch records, but it will take a fair amount of effort to decipher these data to inform the question. This is a necessary step however. Regardless, alternative sampling opportunities should be considered. The Maine Center for Coastal Fisheries upcoming ‘cod fishing derby’ could be a good option for obtaining larger Atlantic cod that have been underrepresented in previous sampling efforts. Other efforts that target sampling where we think fish are may also be appropriate for obtaining samples for these research efforts. Historical records noted the presence of large Atlantic cod entering estuarine environments as well as being caught in inshore fishing weirs. Possible investigations should be conducted even further inshore than we are currently sampling. A new project that will investigate the presence and dynamics of alewives in coastal environments within the GoM will begin in 2021. The project will run for 4 years and will be based out of the University of Maine’s Maine Center for Genetics in the Environment. The project is funded through a National Science Foundation EPSCoR program award. It is not known how effective this eDNA will be at monitoring the nearshore distribution of alewife, but it is another potential source of information that may help inform this topic.

Is the hypothesized connection between river herring abundance and migration and Atlantic cod abundance and productivity the correct hypothesis given the current state of river herring restoration and the abundance and distribution of GoM groundfish populations?

It has been hypothesized that the disappearance of nearshore GoM Atlantic cod population is tied to the demise of GoM river herring populations coupled with local fishing pressure. Investigating this connection is the impetus for many of the studies that have been presented and discussed during this workshop. It was noted that the root of this hypothesis is tied to the potential contribution of freshwater sourced carbon (i.e. diadromous fishes) to the diets and productivity of GoM nearshore marine predators. With the construction of numerous dams within the GoM watersheds the contribution of the freshwater carbon to the coastal food webs has been effectively shut off and it is unclear what effect on the carrying capacity of the marine environment. It’s unknown if small genetically isolated Atlantic cod populations that have been extirpated from near-shore regions will have the capacity to return even if river herring abundance continues to increase.

Results to date have not demonstrated a connection between significant river herring consumption and Atlantic cod. This is partially due to the low abundance of Atlantic cod as reflected by the low catches, low sample sizes and biased size distribution of the samples from the DMR ME NH and Sentinel surveys. It was noted that given this, maybe Atlantic cod is not the right species to examine. Preliminary results are showing predation of river herring by other GoM groundfish (e.g. spiny dogfish *Squalus acanthias*, whiting *Merluccius bilinearis*, red hake *Urophycis chuss*, white hake *Urophycis tenuis*, monkfish *Lophius americanus)*, although at low levels. However, lack of demonstration today doesn't mean we should discard the river herring- Atlantic cod hypothesis. Possibly, river herring need to be restored to some level before we can restore nearshore Atlantic cod stocks. It should be noted that connections between cod and river herring may be present, but only at levels of cod abundance that promote habitat use of near-shore areas, or that river herring populations (though increasing) are still well below the level required to sustain inshore cod. Investigating the contributions of diadromous fish to numerous other nearshore marine predators is a very pertinent research question given the continued focus on diadromous restoration efforts and the numerous managed groundfish and pelagic species present within the GoM.

Are there appropriate next steps for this group?

The participants all agreed that at a minimum, continued semi-formal communications would be a positive outcome from this meeting. Given the interconnected nature of these various studies, reconvening sometime in February 2021 before the various field samplings are initiated is warranted. Preliminary topics of discussion would be to provide updates on the projects, field plans and analyses and to coordinate sample collection and sharing as appropriate (e.g. juvenile river herring samples for stable isotope work, tissue samples for stable isotope work from predators with diadromous fish in their stomach as well as predators without diadromous fish in their stomach, etc.). Note: this meeting did occur on February 24, 2021 --- or something like this???

There was discussion about forming a larger, more formal, network of managers and researchers from both within and outside of the GoM who are interested in this topic. The idea would be to create a forum for continued communication and exchange of ideas and progress to date on various research and restoration projects. After some discussion the participants decided that wasn't warranted at that time. It was not clear what the benefit of such a group would be and participants recognized that it would be a failed effort unless a small group of individuals dedicated themselves to ensuring its continuation.

There was some discussion about developing proposals to compete for external funding to further the ongoing work and to initiate new projects in areas not currently being studied (i.e. Merrymeeting Bay, Passamaquoddy Bay, etc.) considering ongoing diadromous fish restoration efforts. Although no concrete next steps were identified or assigned, the group agreed to consider this possibility further, to look for potential funding sources, and to keep the communication on this topic ongoing as appropriate.

The group discussed the need for continued outreach on the various projects and the hypothesized role of diadromous fish on nearshore marine groundfish productivity. Although the hypothesis is still untested, if diadromous fish are shown to be a significant component of marine predator diets, this could greatly improve the resources available for diadromous fish restoration projects by various state and federal agencies and NGOs. The occurrence of this meeting and the dissemination of this report, could provide opportunities for work similar to that currently being done and future questions about the potential role of diadromous fish restoration in nearshore marine productivity.

Conclusions

Overall, the workshop was successful in achieving the stated objectives. Participants were provided an overview of the various ongoing projects investigating the role of diadromous fish as prey for marine fish predators. For many, it was the first time they had been made aware of these efforts and in other cases this was the first meeting of researchers working on similar projects. Researchers gained a better understanding of the interconnectedness of these projects and how marine surveys were providing samples for prey identification, but also provided opportunity for increased stable isotope sampling.

Through discussions participants were able to understand how these projects fit together and collectively provide a wider understanding for the role of diadromous fish as prey. Furthermore, numerous synergies between efforts with spatial-temporal overlap were identified that provided insight into the dynamics of diadromous fishes as marine prey. Data gaps within the current scope of the various efforts were identified and solutions were explored. As an example, diet sampling from the ME-NH Inshore survey could be extended into eastern GoM to provide a more comprehensive spatial assessment while also complimenting the Maine Center for Coastal Fisheries' Eastern Gulf of Maine Sentinel Survey. Synergies and gaps were also discussed between diet sampling and stable isotope analysis. These two methods are complementary techniques that describe foraging patterns at different scales, but collectively provide a more through temporal assessment. It was noted that expanded stable isotope sampling and analysis outside Penobscot Bay would provide valuable insight into the broader GOM dynamics of predators and prey.

Much of the work presented had a focus on the role of River herring as forage. It should be noted that other potential forage diadromous species such as Rainbow smelt (*Osmerus mordax*), American eel

(*Anguilla rostrata*), American shad (*Alosa sapidissima*) were not mentioned during the two-day workshop and their relative importance to the GoM food web is largely unknown.

The projects are all in early to middle stages of completion and final results are not expected till 2022 or 2023, with some longer-term sampling planned (e.g. NMFS diet work). This provides some opportunity to modify ongoing efforts to maximize efficacy. Existing surveys could benefit from expansion of sampling, increased collaboration among current researchers and communication with future potential collaborators (e.g. GMRI). Potential future research themes that would further the ongoing work were identified. As an example, the mining of existing survey datasets (e.g. NMFS and ME-NH trawls) was considered a top priority to better understand the spatial and temporal patterns of predator/ prey distributions and their estimated encounter rate. Based on the preliminary stable isotope results, a modest increase in predator and prey tissue sampling and stable isotope analysis would result in the development and visualization of the GoM food web complimenting the time series of diet information, which could serve as an important resource for future ecosystem modeling efforts.

The participants reviewed the workshop positively. They agreed that continued conversations, especially prior to the initiating of new field seasons, would be beneficial. Participants were eager to investigate new opportunities for further collaboration, whether it be related to sample collections or seeking outside funding to continue or expand ongoing efforts. Participants were also interested in staying abreast of the results and conclusions of the various studies given how connected they are with respect to the dynamics of diadromous fish as prey for marine predators.

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Appendix I: Participants (Day 1 and Day 2)

1. Justin Stevens, Maine Sea Grant (1,2)
2. Timothy Sheehan, NOAA Fisheries Service (1,2)
3. Carla Guenther, Maine Center for Coastal Fisheries (1,2)
4. Karen Wilson, University of Southern Maine (1,2)
5. Samantha Nadeau, University of Maine (1, 2)
6. Rebecca Peters, Maine Department of Marine Resources (1,2)
7. Simon Thorrold, Woods Hole Oceanographic Institution (1, 2)
8. Robyn Linner, University of Maine (1, 2)
9. Anne Hayden, Manomet (1, 2)
10. Stacy Rowe, NOAA Fisheries Service (1,2)
11. Matt Brewer, University of Southern Maine (1)
12. Gayle Zydlewski, Maine Sea Grant (1, 2)
13. Sean McDermott, NOAA Fisheries Service (1, 2)
14. Molly Payne Wynne, The Nature Conservancy (1)
15. Mark Renkawitz, NOAA Fisheries Service (1)
16. Walt Golet, University of Maine (1)

Appendix II: Agenda

Diadromous fish as marine prey workshop

November 19 -20, 2020

Thursday (presentations)

1:00-1:10 Greetings and Introductions

1:10-1:30 River Herring Catch in the MENH Inshore Trawl Survey – Rebecca Peters (Maine DMR)

1:30-1:50 Ground fish consumption of river herring in Merrymeeting Bay and Penobscot Bay, Maine from 2012-2019– Mark Renkawitz (NOAA Fisheries)

1:50-2:10 Diet Composition of Atlantic Cod in the Inshore Eastern Gulf of Maine – Robyn Linner (UMaine/MCCF)

2:10-2:20 BREAK

2:20-2:50 Stable Isotope analysis – Simon Thorrold (WHOI)

2:50-3:10 Marine derived nutrients in the Penobscot Bay Watershed: Pre and post river restoration - Karen Wilson (USM)

3:10-3:30 Evaluating the Foraging Ecology and Energetics of Atlantic Bluefin Tuna in the Gulf of Maine: An Unexpected Find – Samantha Nadeau (UMaine/GMRI)

3:30 – 3:45 – Q&A and Outline next steps for day 2

Friday (Discussions)

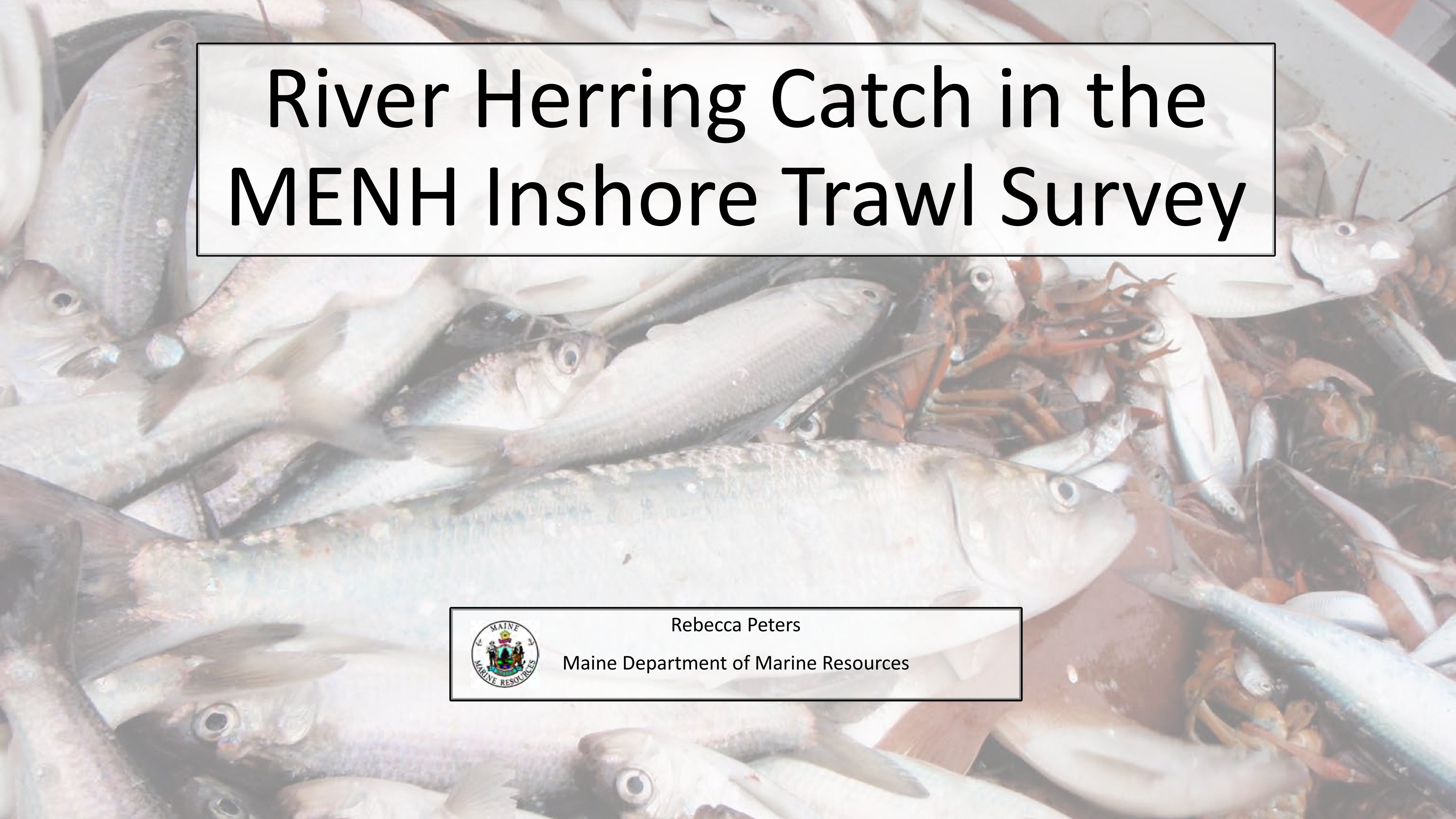
1:00-1:10 Greetings and Icebreaker activity

1:10 – 2:00 Discussion Session I – Theme = Deep dive into current scope of work

2:00 – 2:10 BREAK

2:10 – 3:00 Discussion Session II – Theme = Looking Ahead & Wrap-up

Appendix III: River herring catches within the ME NH Inshore Trawl Survey



River Herring Catch in the MENH Inshore Trawl Survey

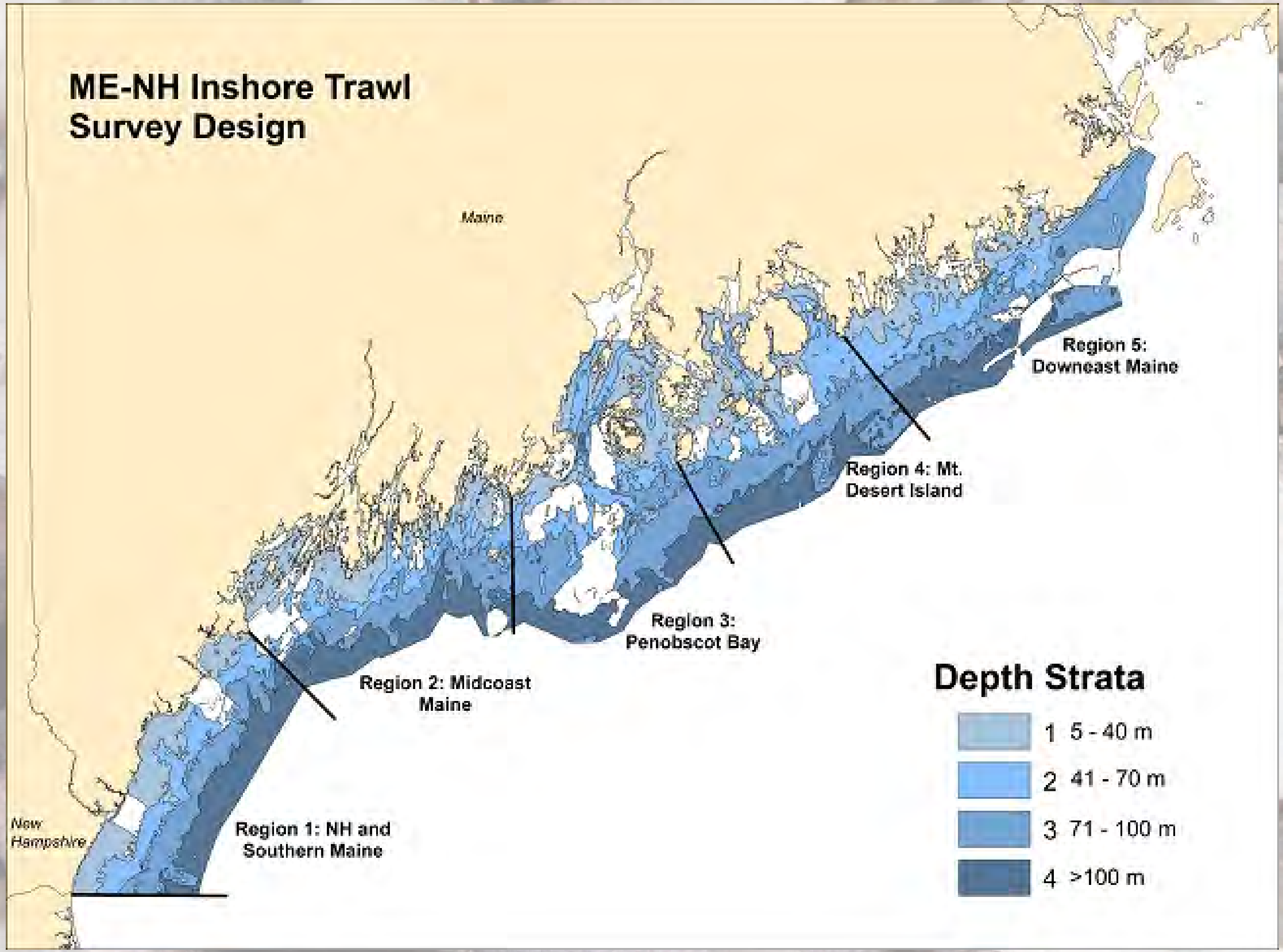
Rebecca Peters

Maine Department of Marine Resources

Survey overview

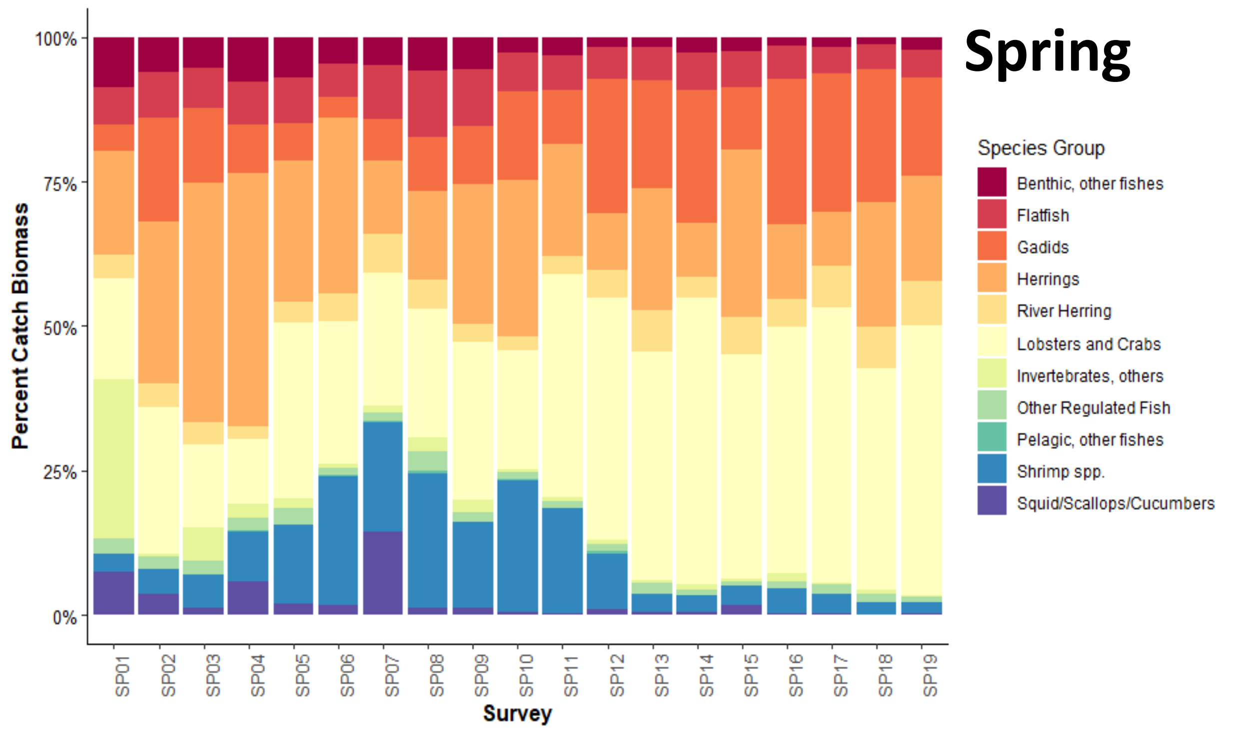
- Started in Fall 2000.
- Surveys occur biannually – spring and fall
  - Spring: May-June
  - Fall: September-October
- Survey design – stratified random
  - Five regions
  - Four depth stratums
- Collaborative survey
- Net – modified shrimp net
  - 2 inch polyethylene mesh
  - Cod end – 2 inch mesh with 1 inch liner

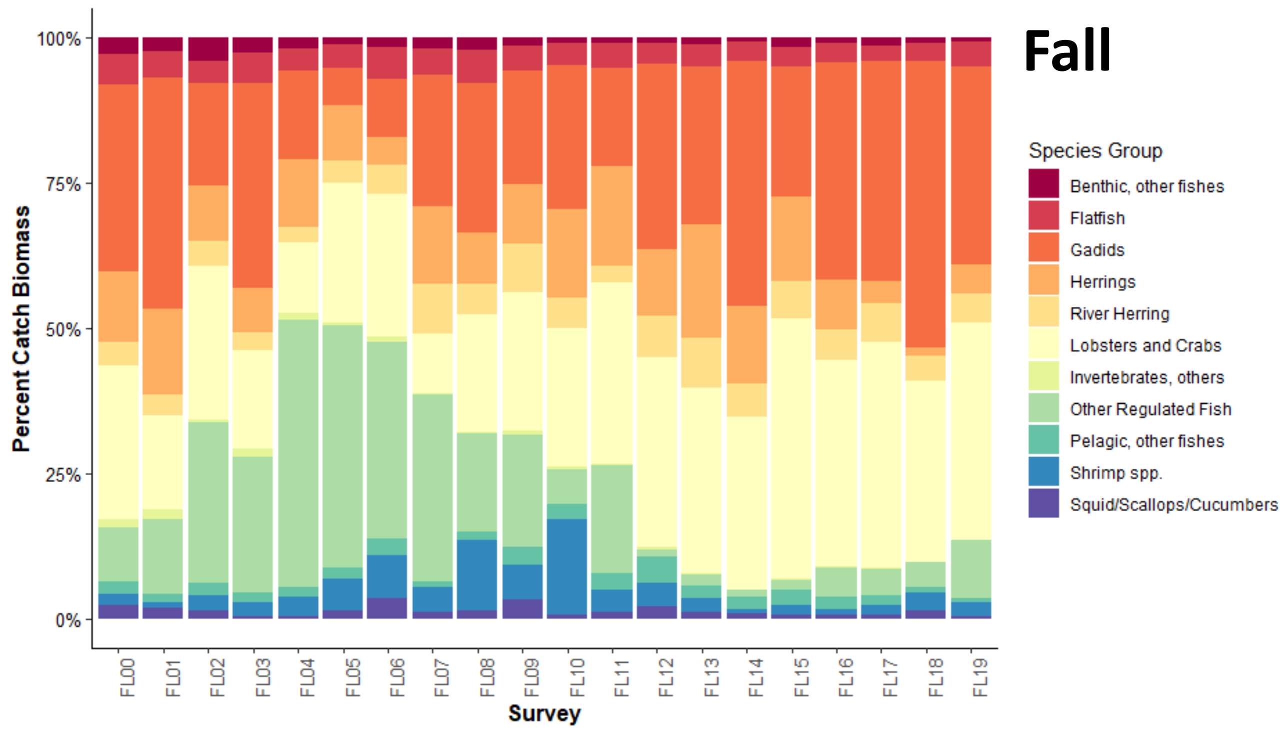
Survey design



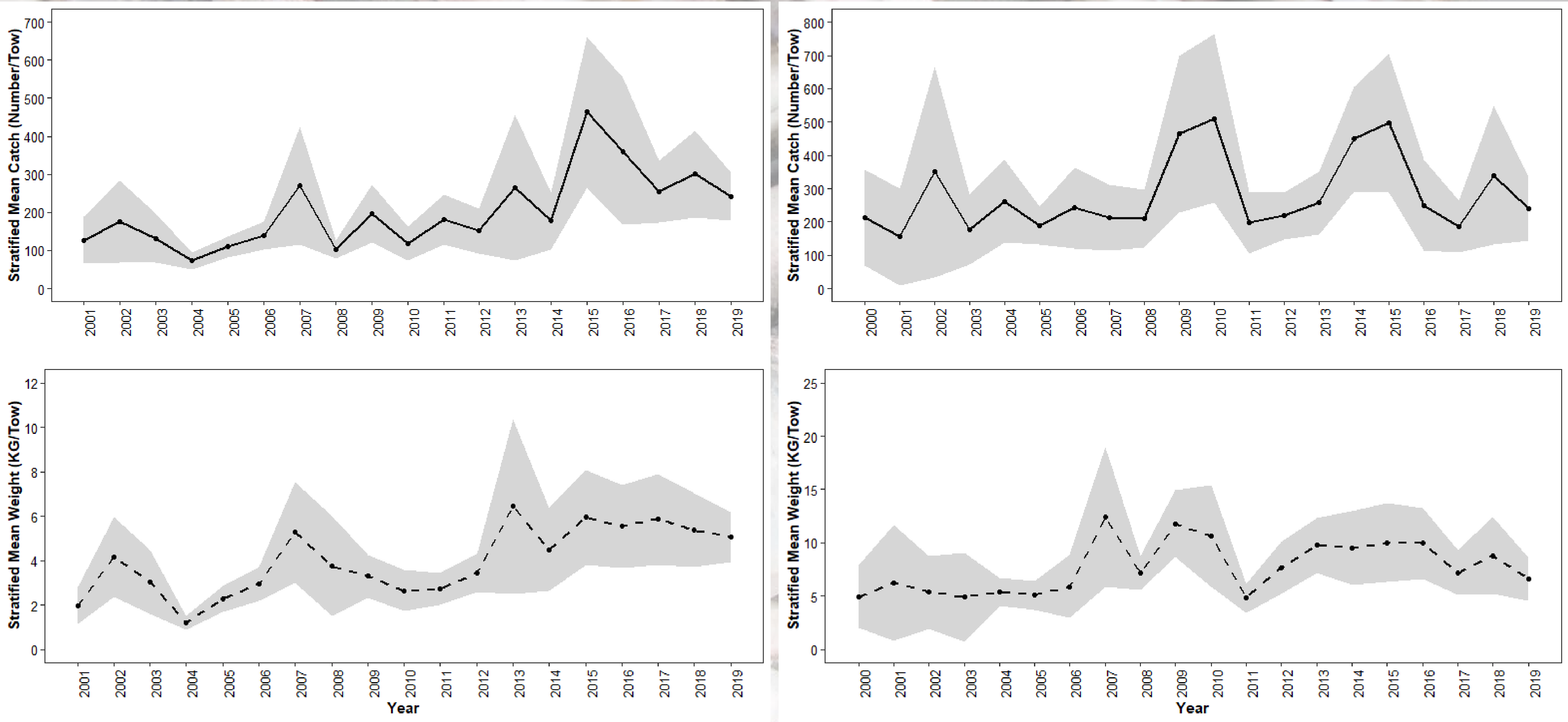
- Total survey area: 11774.98 km^2
- 120 stations each survey
  - Sampling area coverage: 1 station / 137 km^2
- 20 minute tows
  - Some can be shorter
- Tow speed of 2.5 knots
- Catch is sorted, weighed, and measured by species

River herring catch

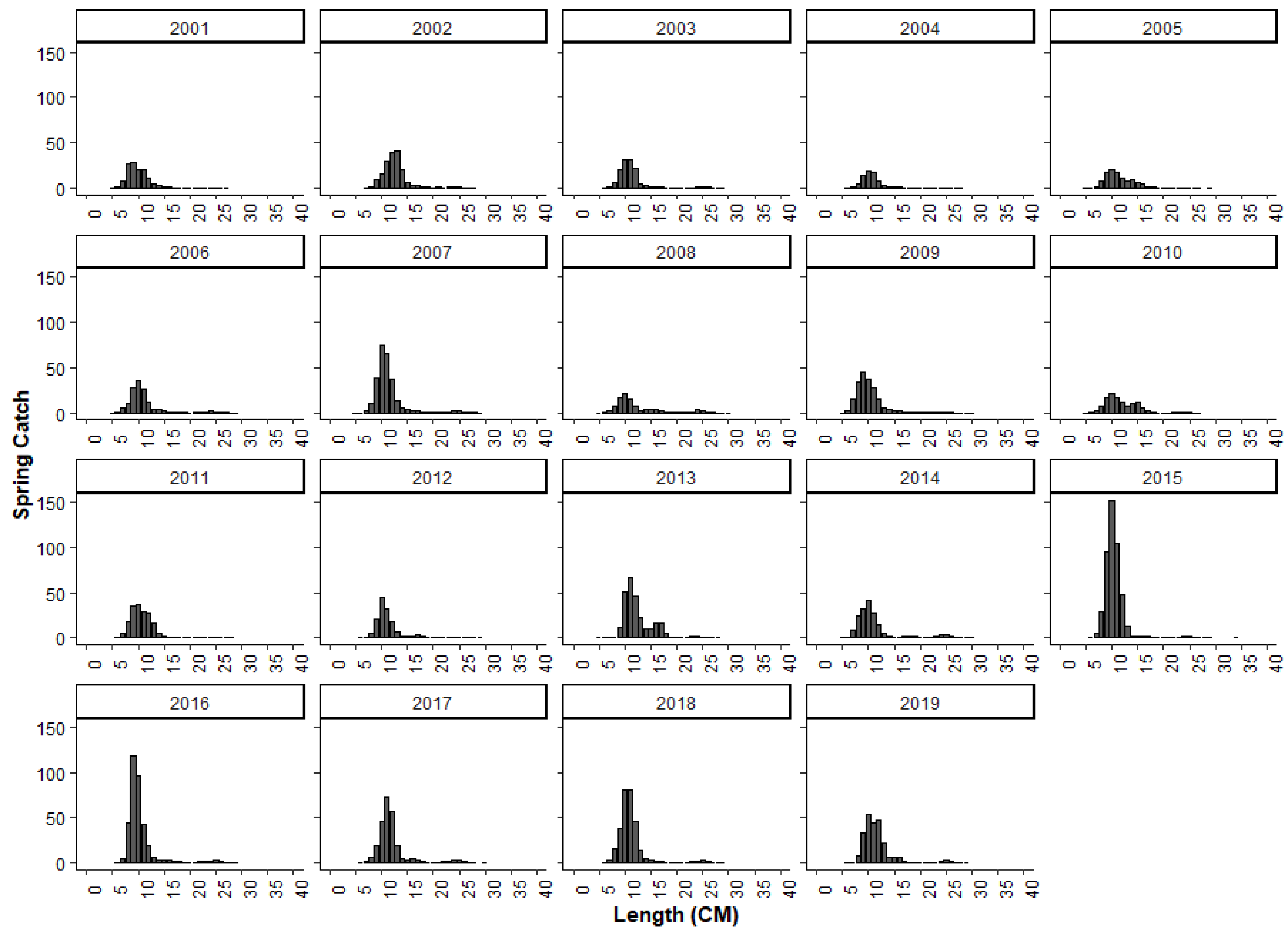




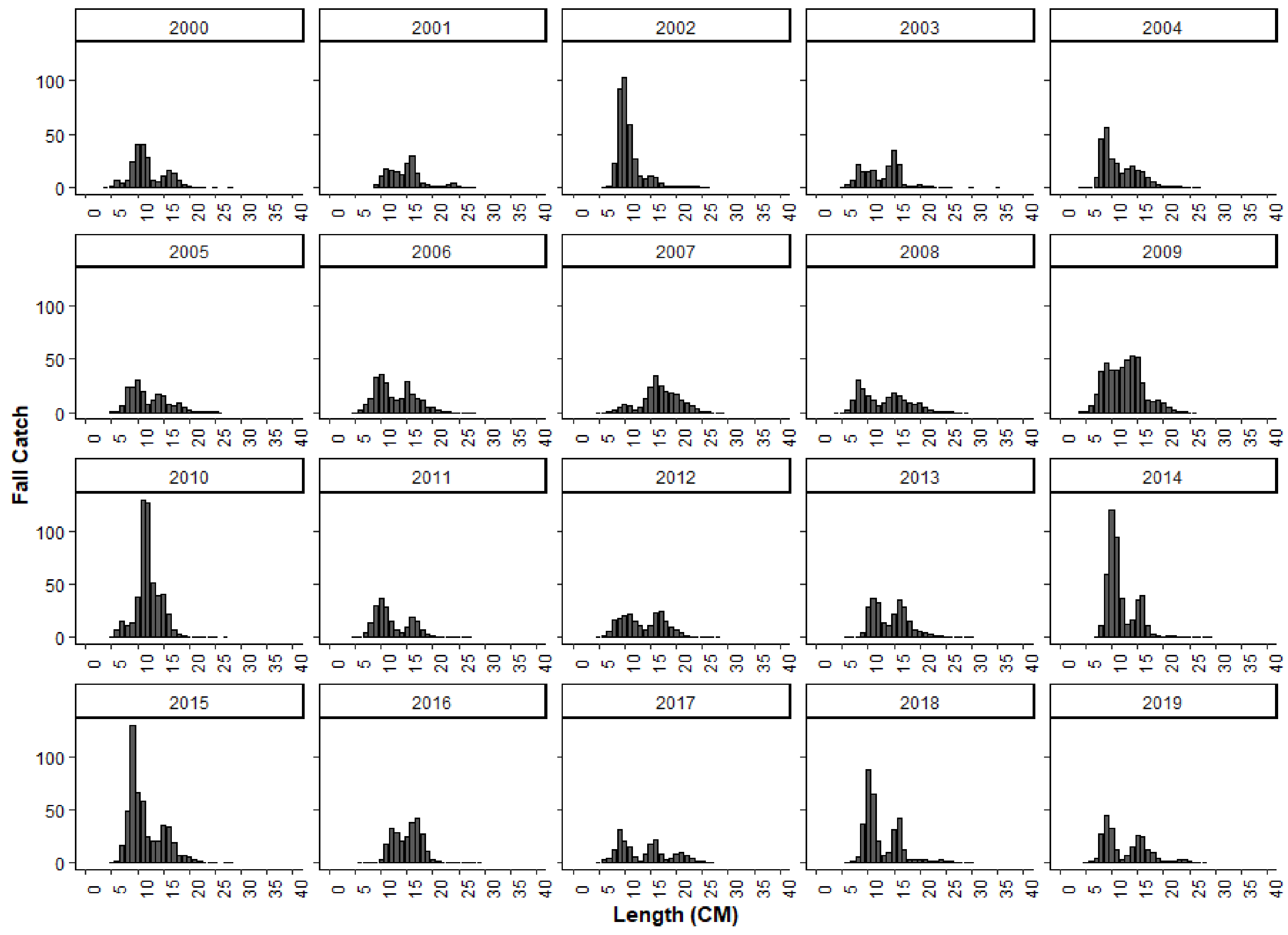
Alewife abundance and biomass indices



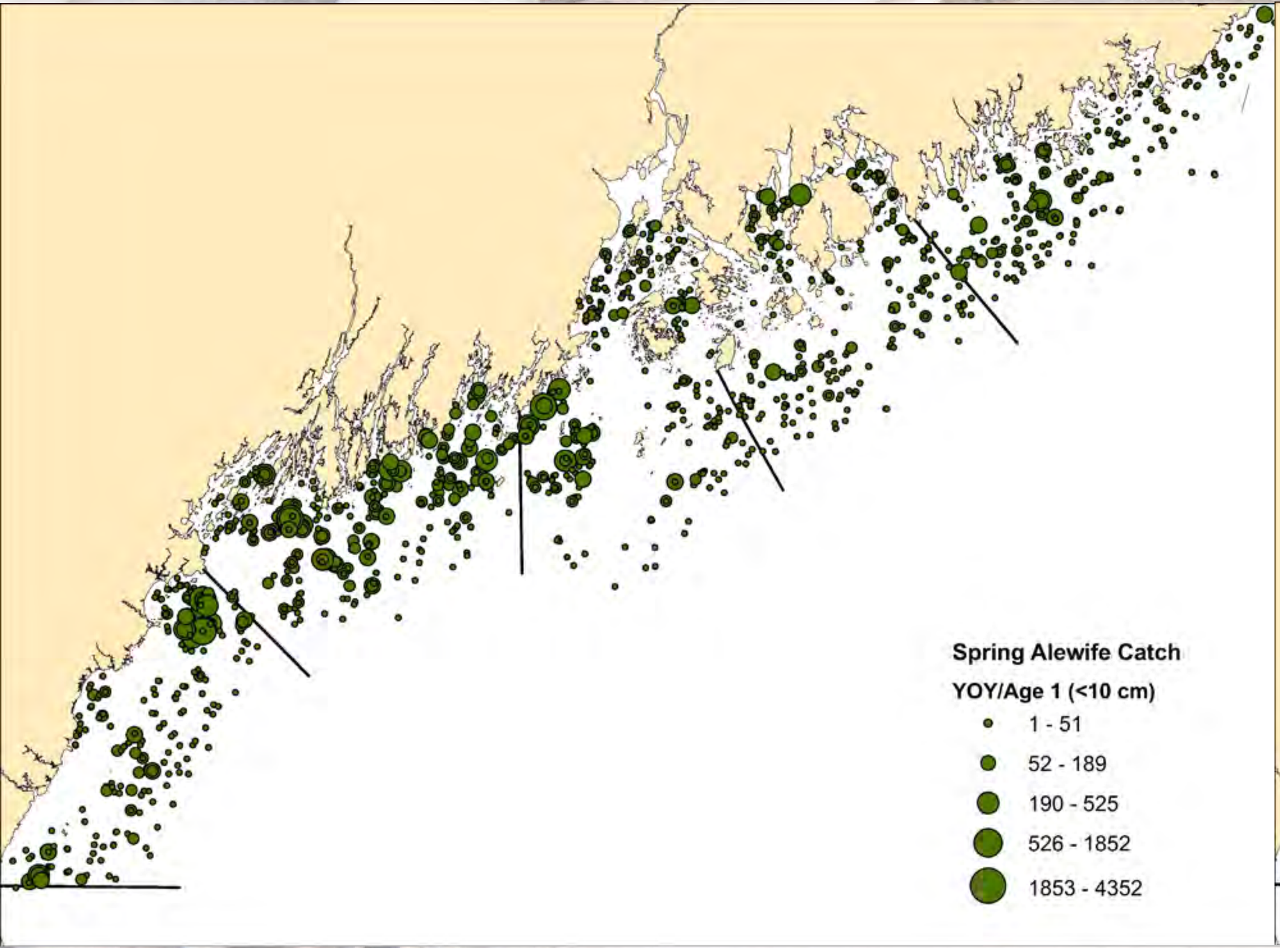
Alewife spring catch at length

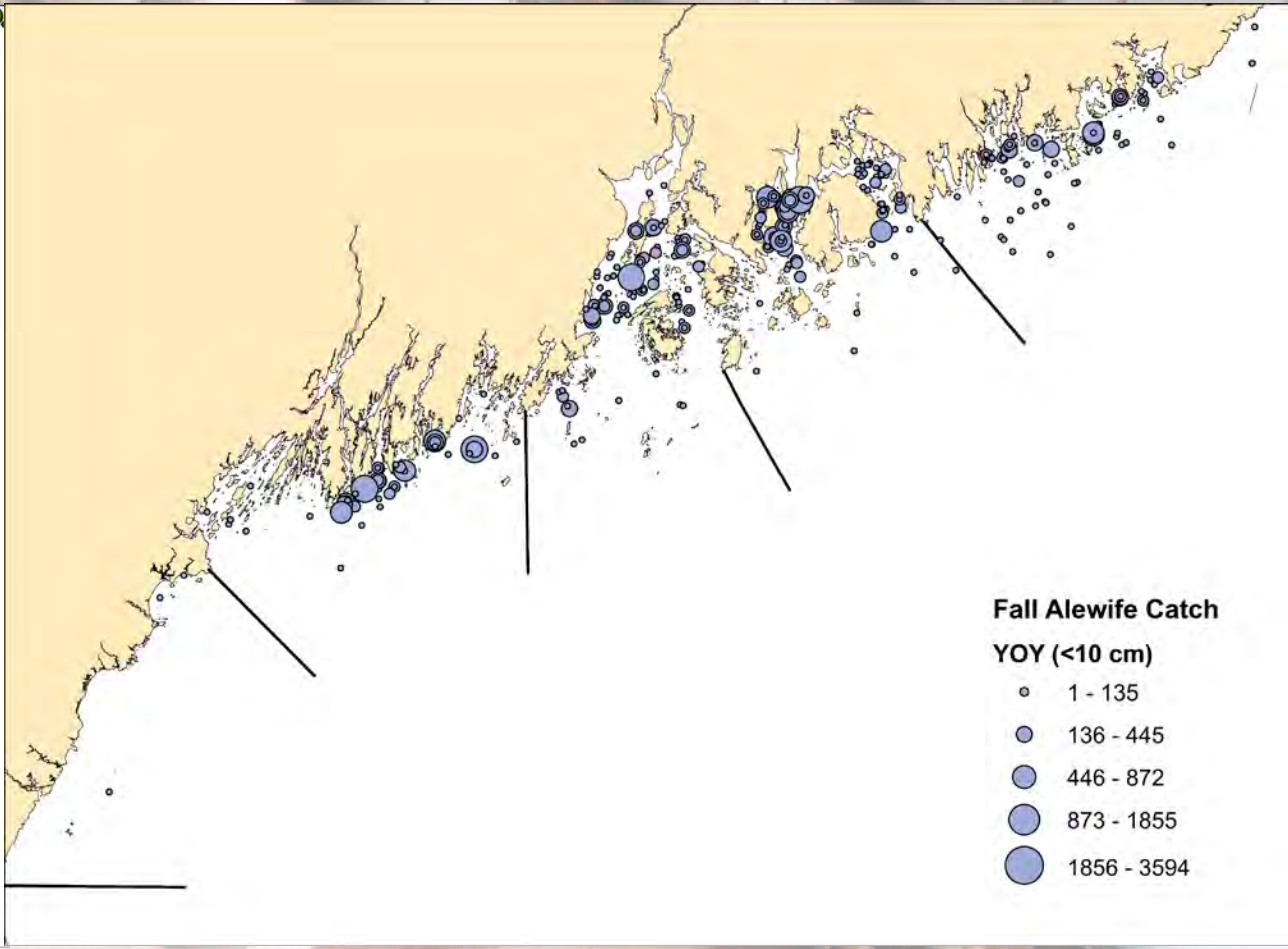


Alewife fall catch at length



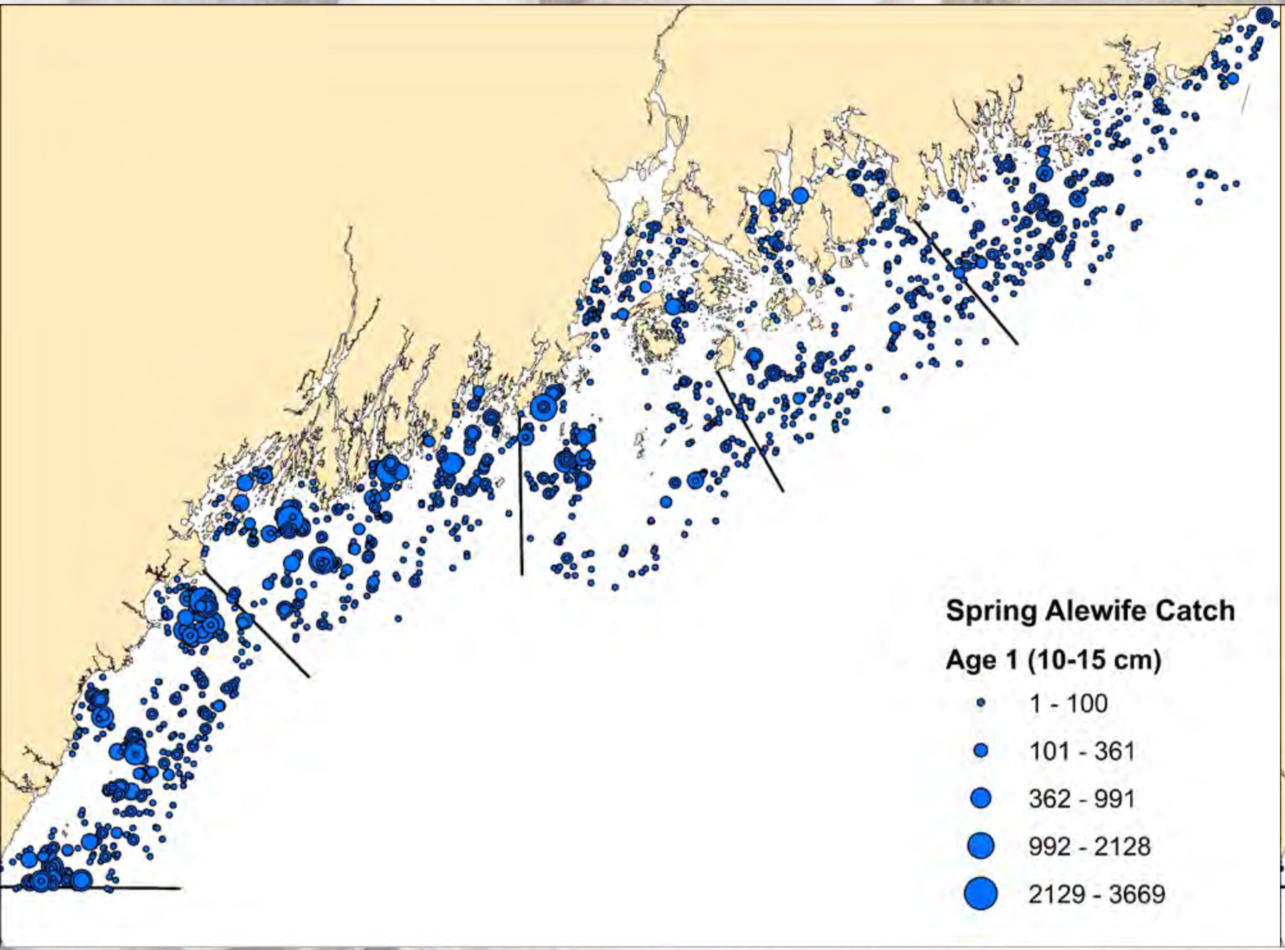
Alewife catch distribution: <10cm

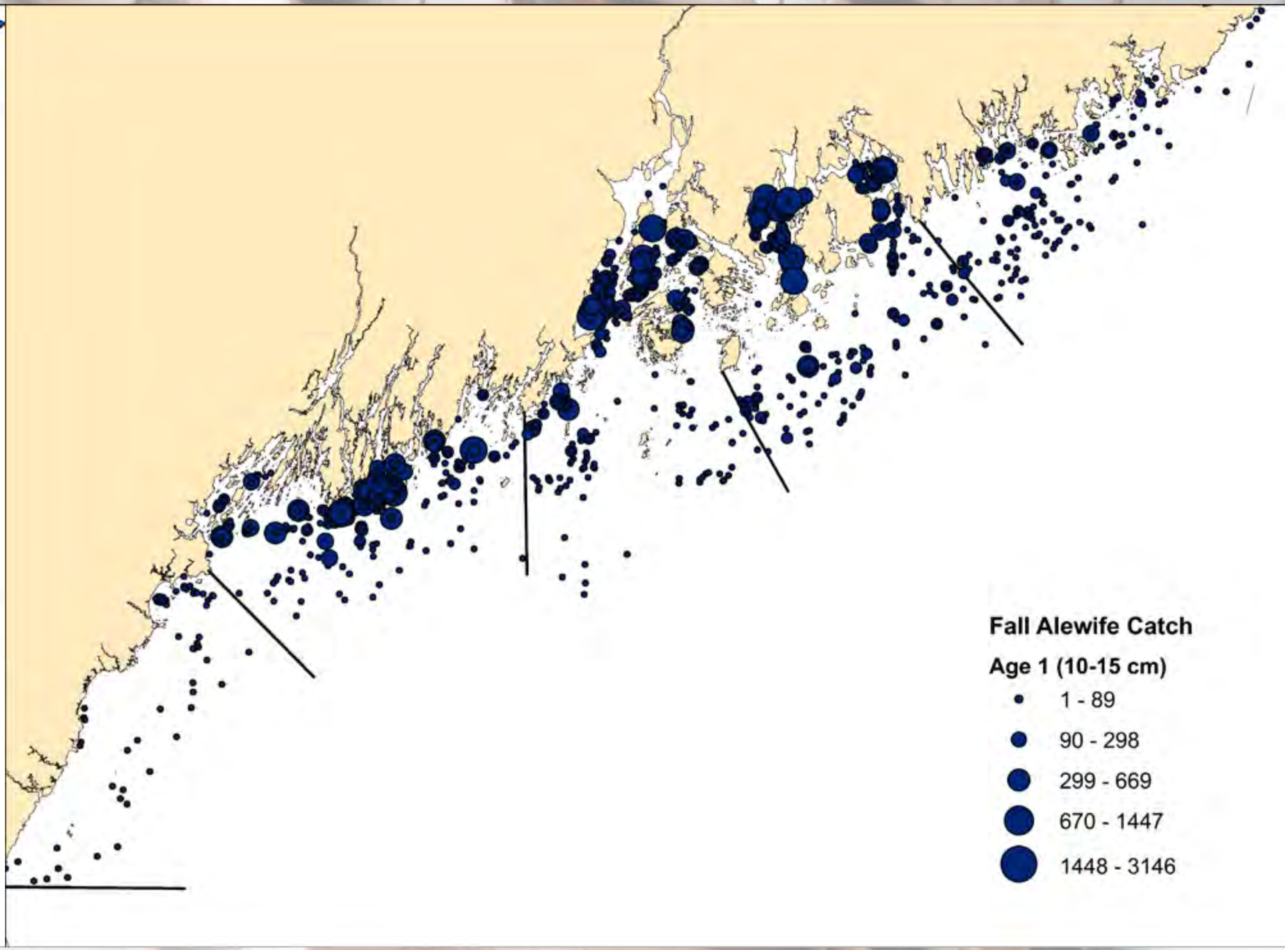




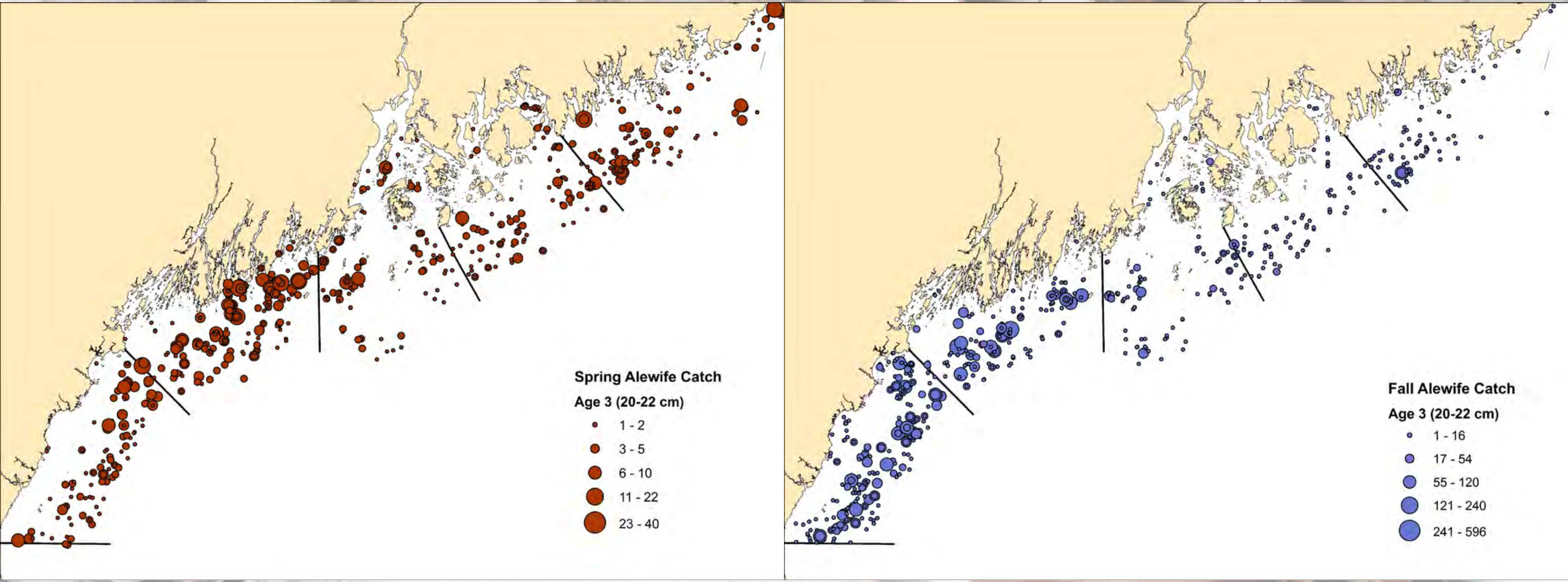
*Lengths were broken out using data provided from Karen Wilson

Alewife catch distribution: 10-15 cm

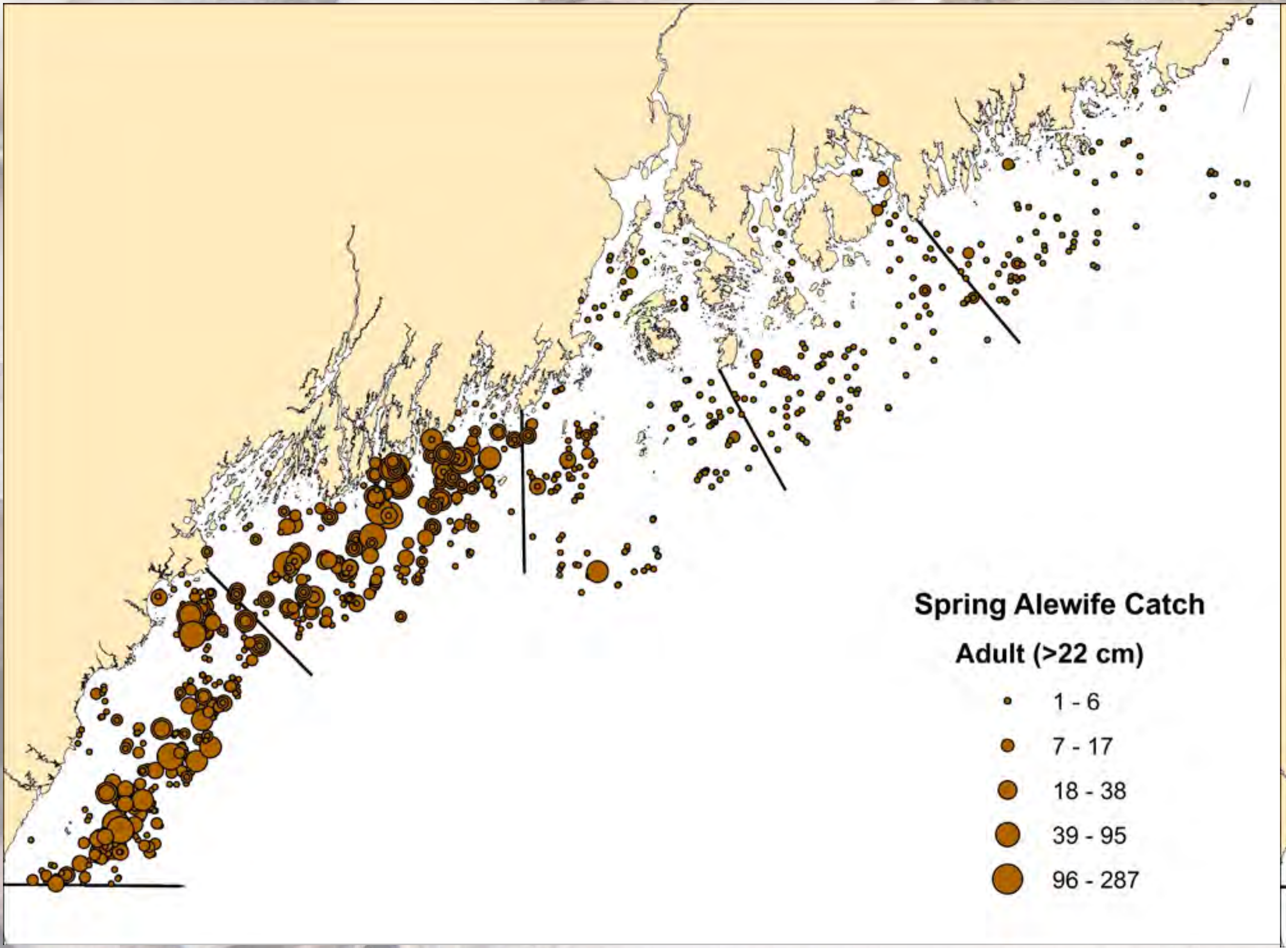


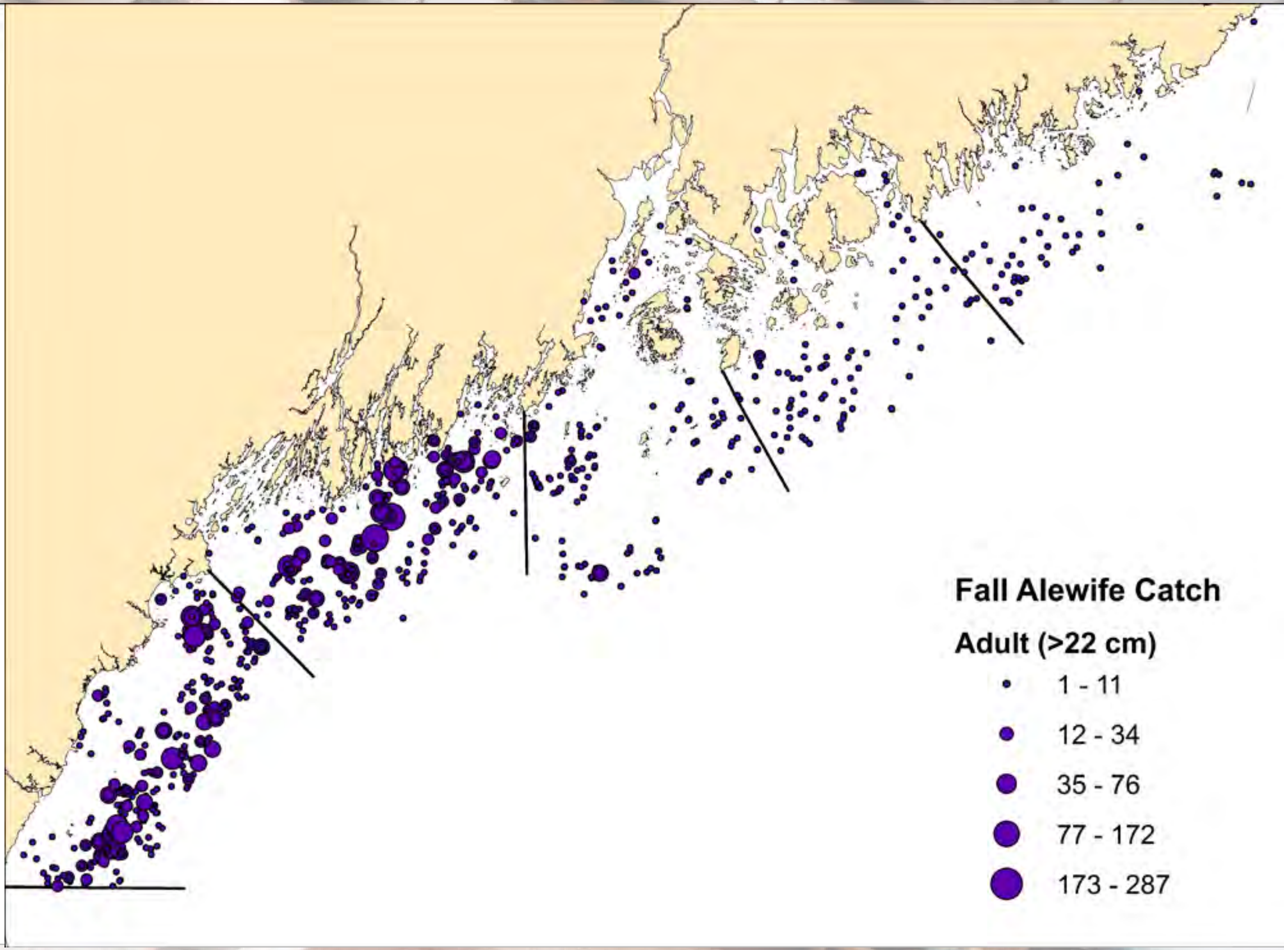


Alewife catch distribution: 20-22 cm

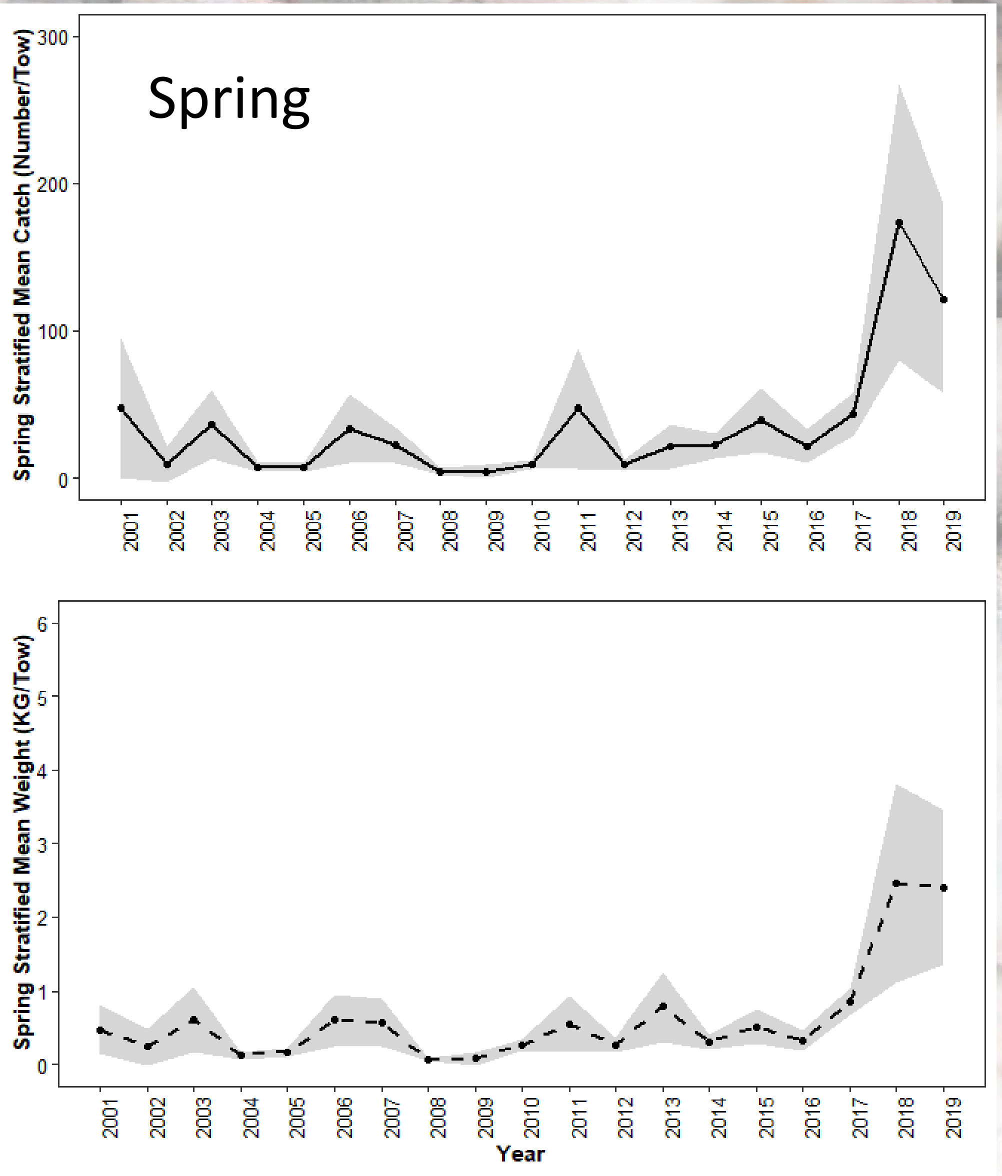


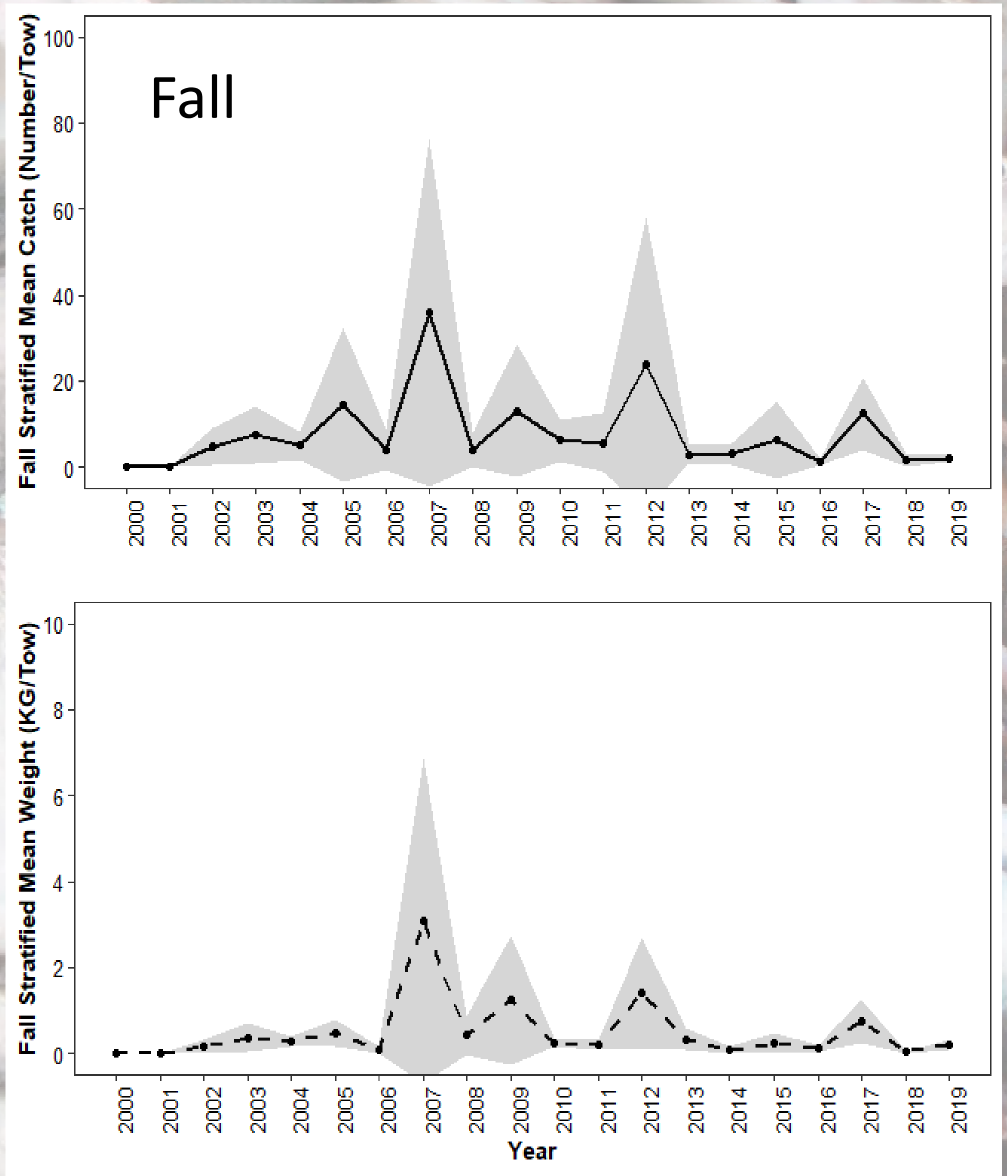
Alewife catch distribution: >22 cm





Blueback herring indices

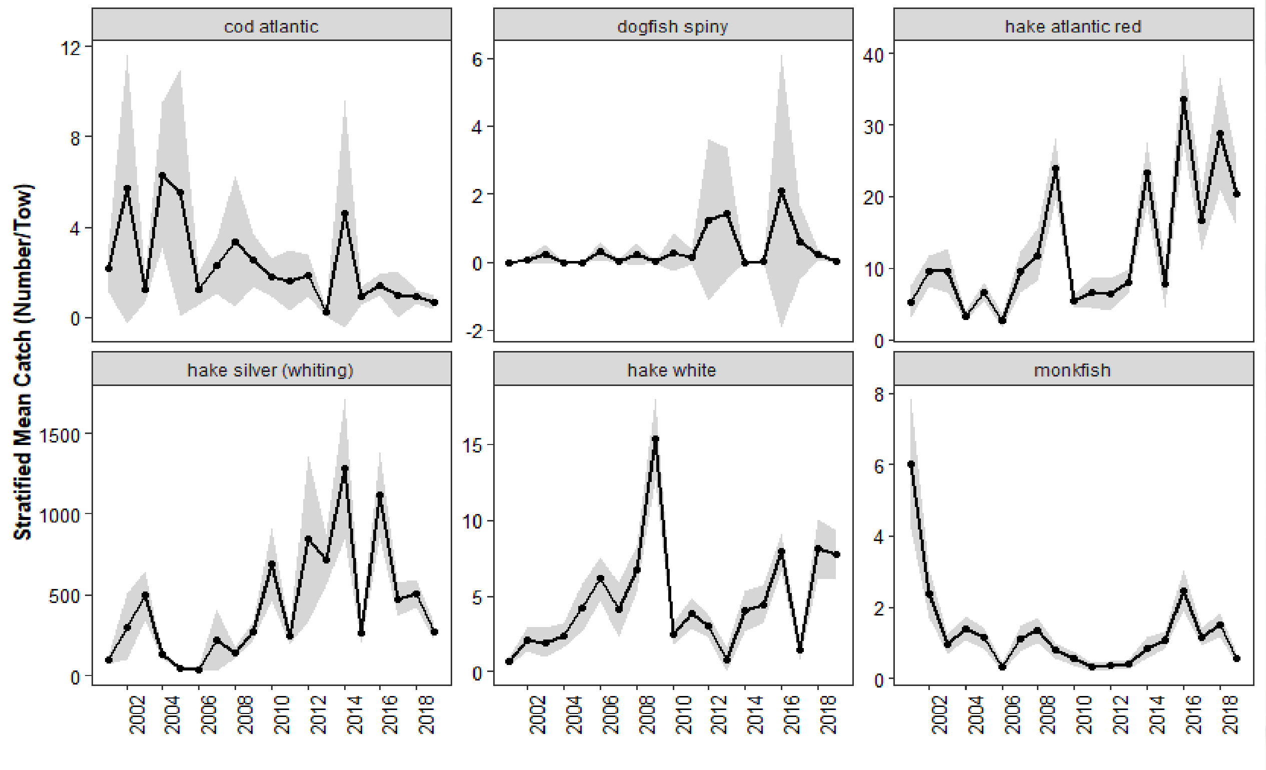




Predators in the survey

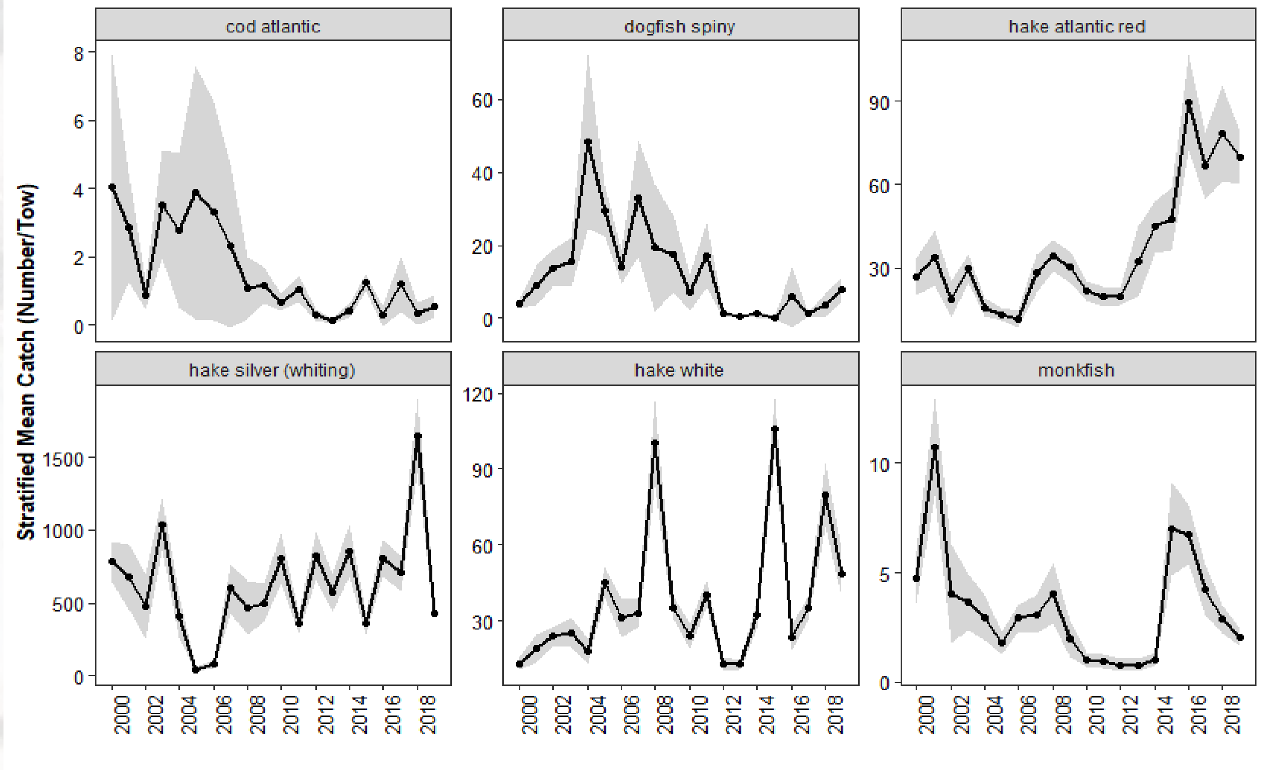
Spring

- Less predators are caught (except cod and silver hake)

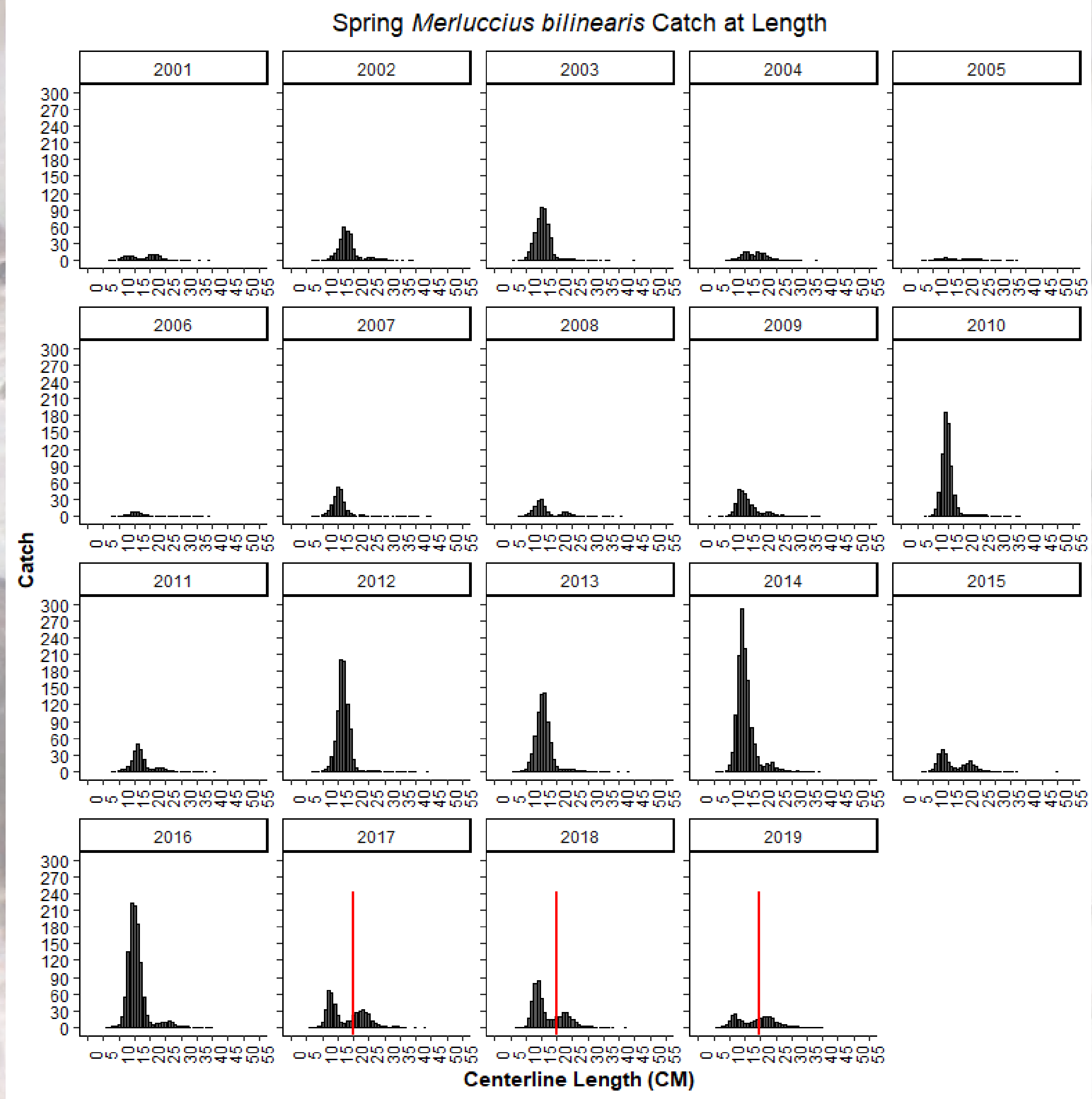


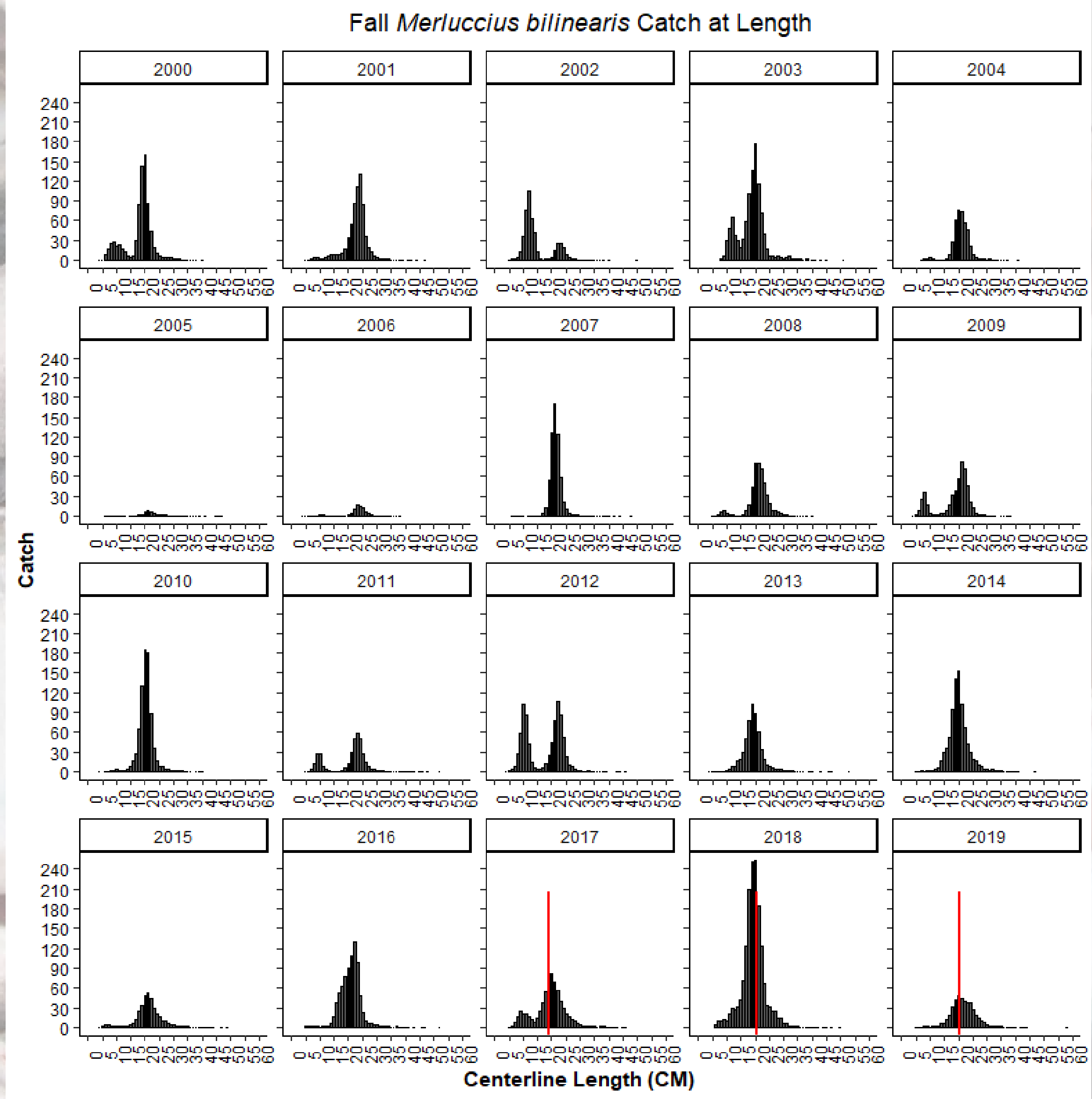
Fall

- More predators are caught

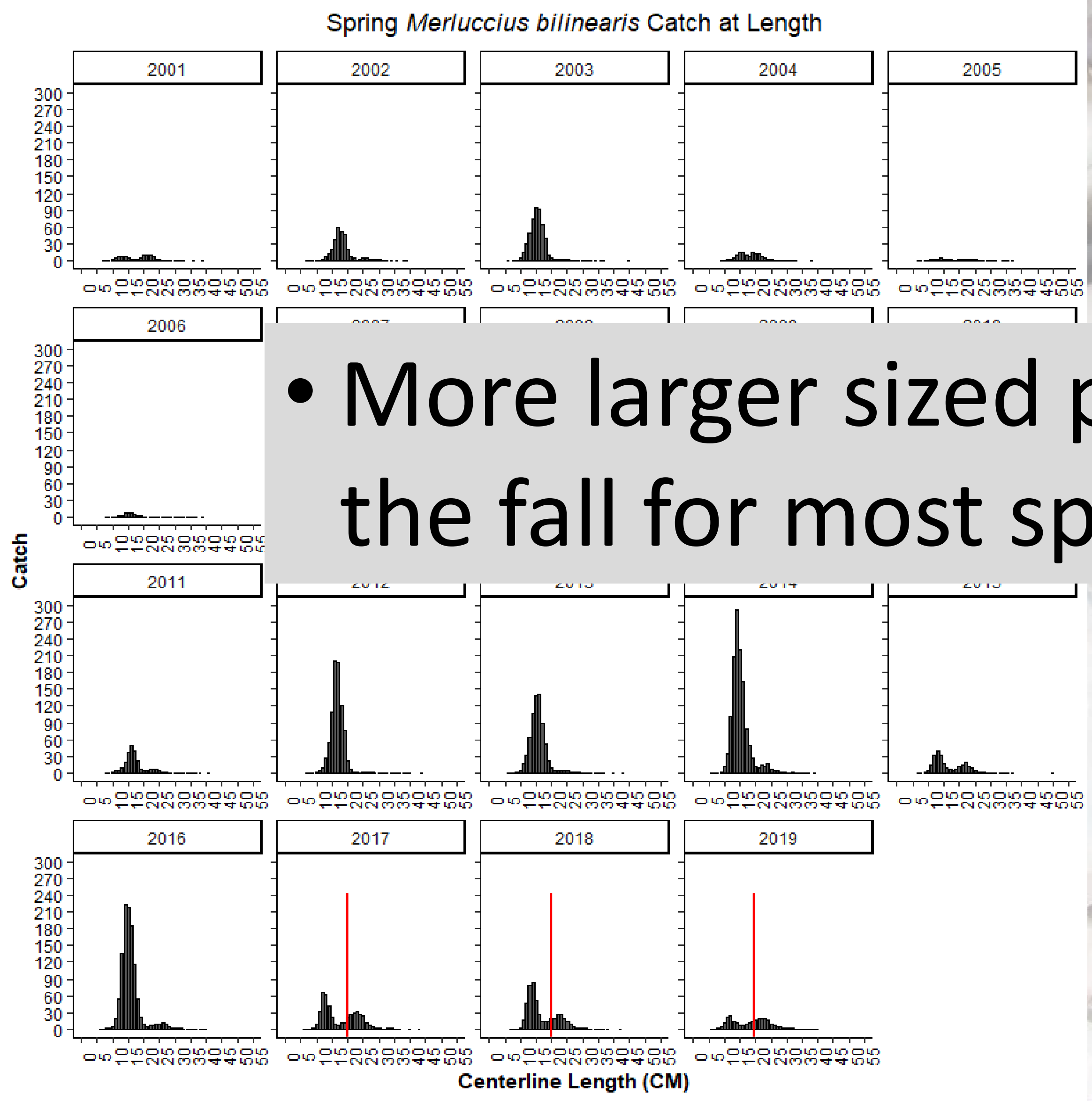


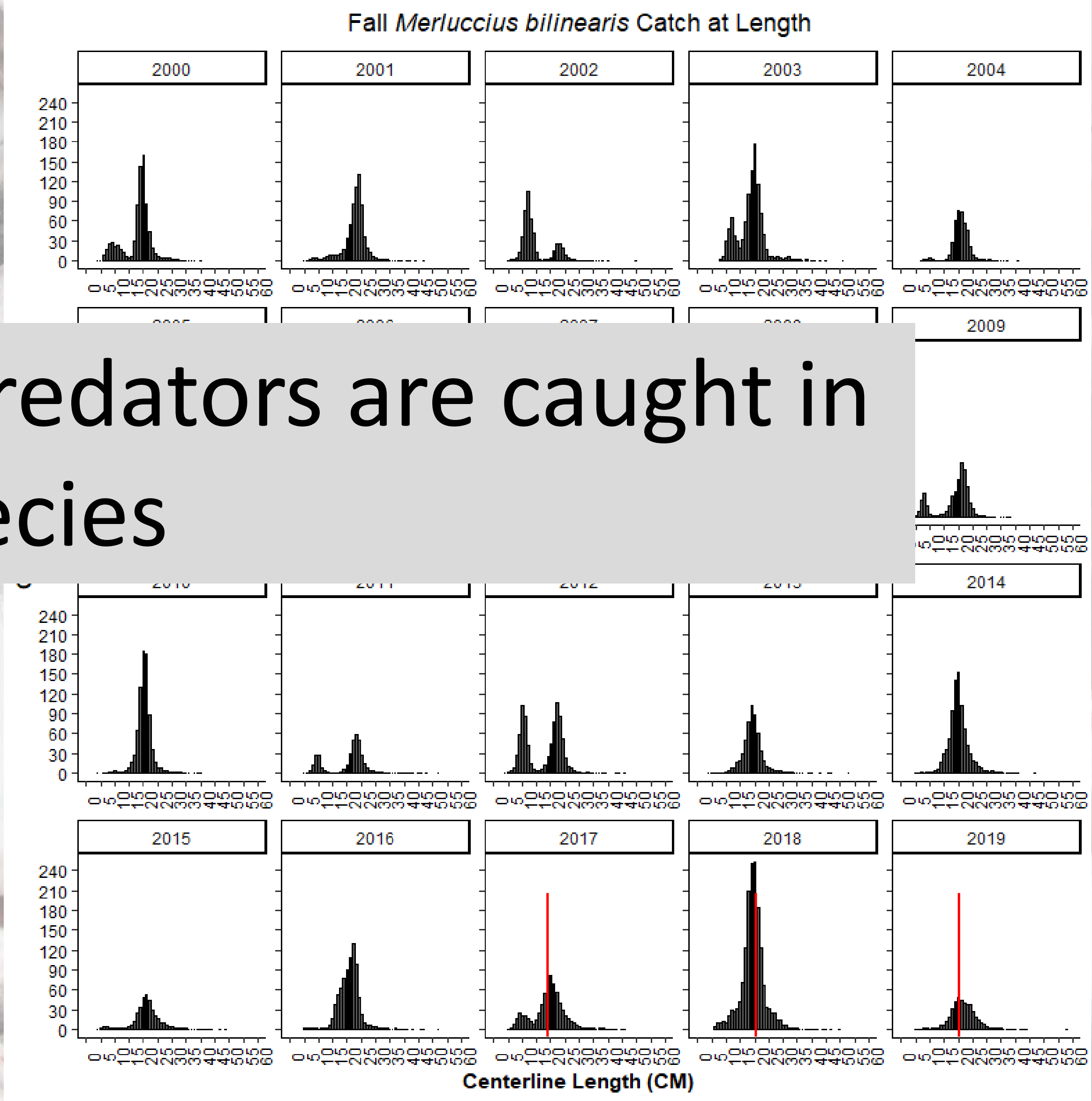
Predator lengths in the survey: silver hake





Predator lengths in the survey: silver hake





- More larger sized predators are caught in the fall for most species

Questions?

Appendix IV: Groundfish consumption of river herring in Merrymeeting Bay and Penobscot Bay, Maine from 2012-2019

Groundfish consumption of river herring in Merrymeeting Bay and Penobscot Bay, Maine from 2012-2019

Mark Renkawitz – NOAA Fisheries

River Herring as Prey Workshop

November 19-20, 2020

Who?

- Captain and Crew of the F/V Robert Michael
- Maine Department of Marine Resources
- NOAA Fisheries

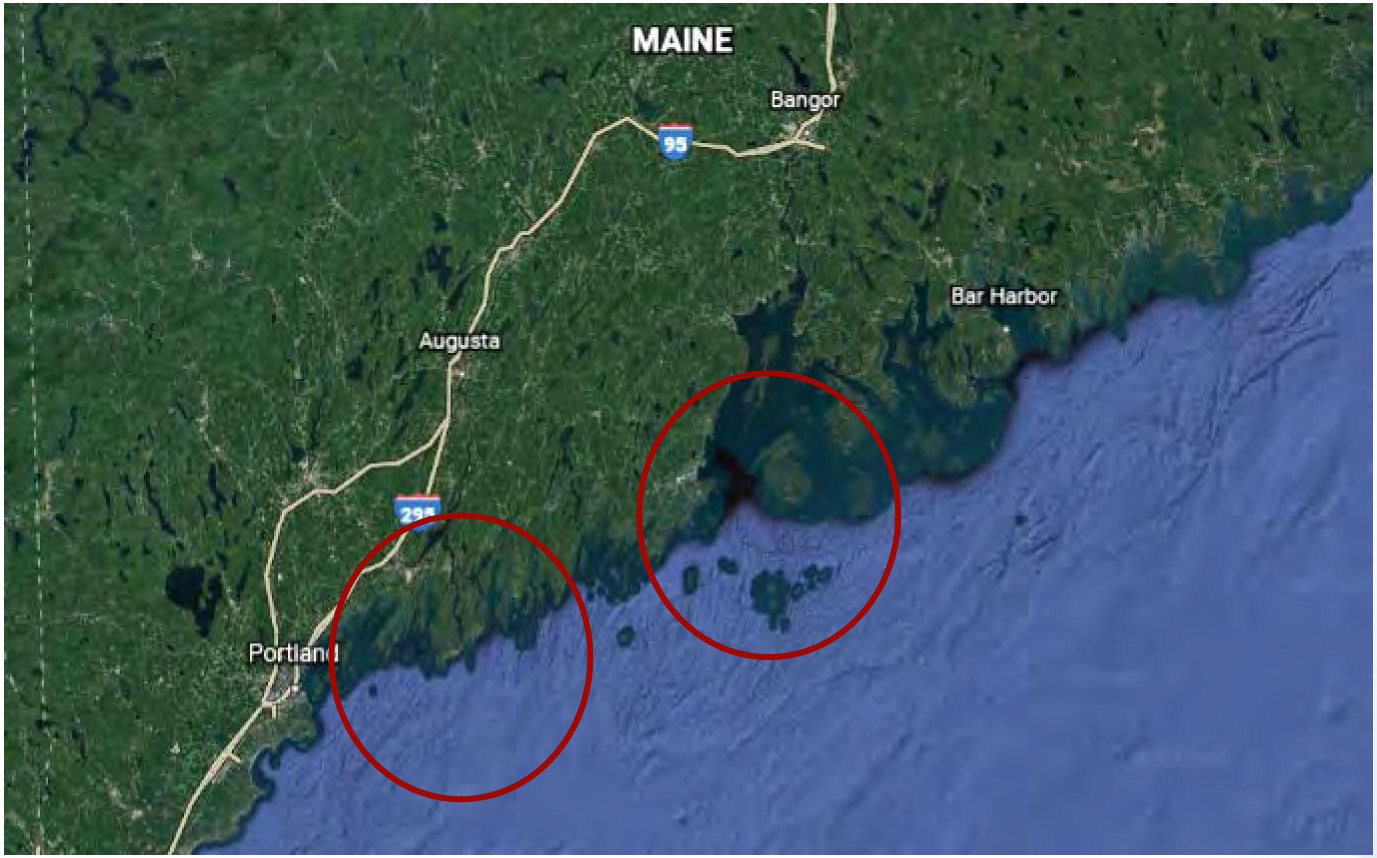
What are the questions?

- Do groundfish consume RH?
- What predators consume RH?
- Has RH consumption changed over time?
- Is RH predation similar in MMB and PNB?
- Is RH predation influenced by season?
- What RH ages/life stages are consumed?

NOAA FISHERIES

Where did we do the work?

- Merrymeeting Bay (Region 2) and Penobscot Bay (Region 3)



NOAA FISHERIES

What did we do?

- Sampling Platform: DMR Inshore Trawl Survey
- Years: 2012-2019
- Regions: Merrymeeting Bay and Penobscot Bay
- Collected and processed stomachs
- Primary: Atlantic cod, spiny dogfish, monkfish
- Secondary: whiting, white hake, red hake

NOAA FISHERIES

Expectations?

- All identified predators should consume RH
- Expected adult and juvenile RH consumption
- RH consumption should increase over time if they become more abundant
- RH predation should higher in MMB than PNB (restoration in progress)

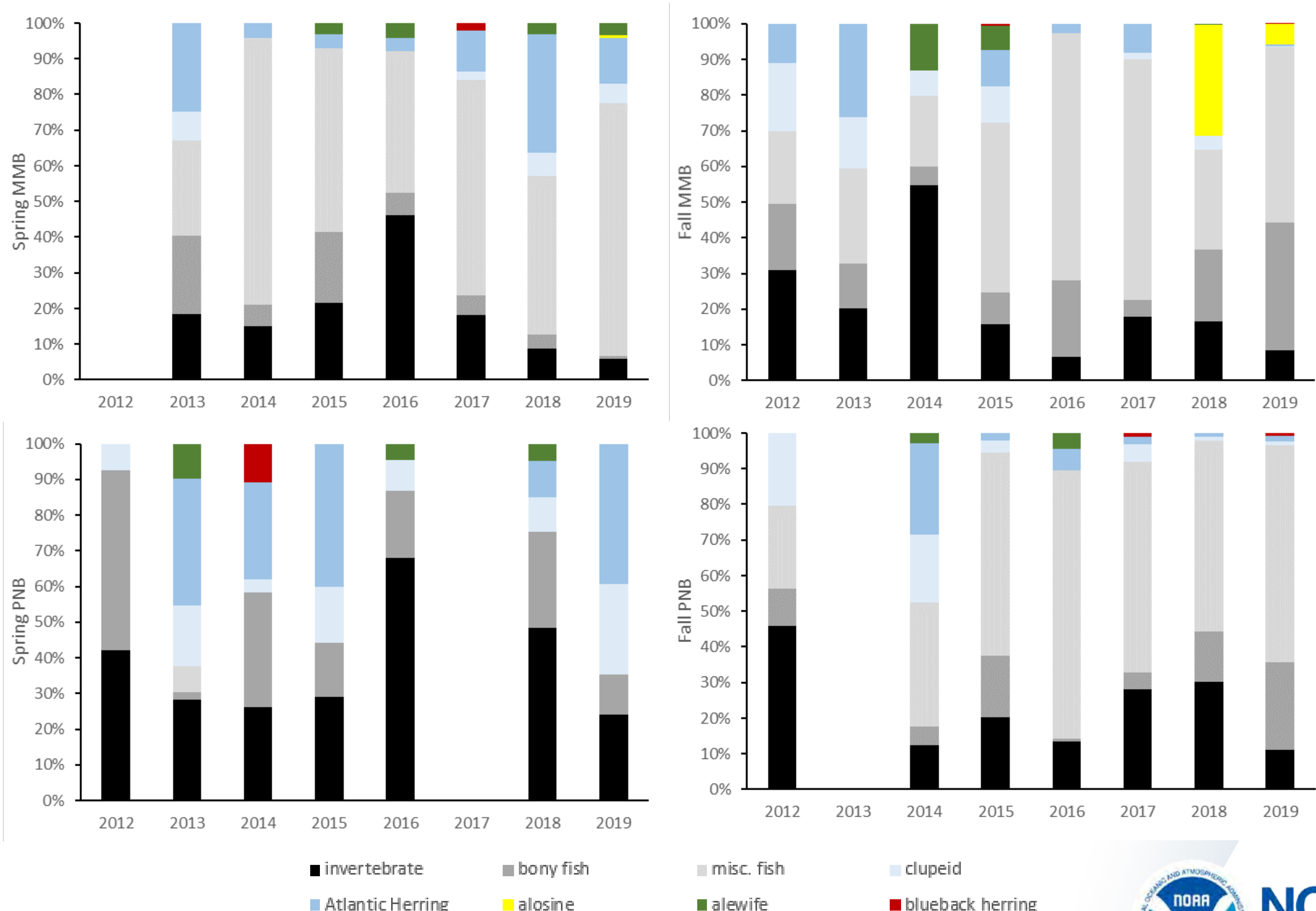
NOAA FISHERIES

Stomachs collected

	Spring			Fall		
Year	**MMB**	**PNB**	**Spring Total**	**MMB**	**PNB**	**Fall Total**
2012	*	41	41	72	41	113
2013	11	59	70	89	*	89
2014	105	98	203	99	105	204
2015	62	87	149	99	111	210
2016	106	99	205	70	100	170
2017	105	*	105	133	130	263
2018	99	143	242	116	131	247
2019	66	127	193	100	117	217
Total	**554**	**654**	**1208**	**778**	**735**	**1513**

NOAA FISHERIES

Groundfish diet (gravimetric)



NOAA FISHERIES

River Herring Predators

Year	spiny dogfish	whiting	red hake	white hake	monkfish	sea raven	Total
2012							**0**
2013					1		**1**
2014		1			2		**3**
2015		1			2	1	**4**
2016				1	4		**5**
2017		2					**2**
2018	3	3			3		**9**
2019	1	6	1	1			**9**
Total	**4**	**13**	**1**	**2**	**12**	**1**	**33**

- 73% of RH consumed in Merrymeeting Bay
- no evidence of a seasonal trend in RH consumption between regions
- 55% of RH consumed in 2018 and 2019

River Herring Lengths

Length (mm)	2012	2013	2014	2015	2016	2017	2018	2019	Total
71-80					1			1	2
81-90				1				1	2
91-100					2		1	4	7
101-110				1	1		2	1	5
111-120						1	2		3
121-130			1	1		1			3
131-140									0
141-150		1		1					2
151-160			1		1				2
161-170									0
171-180			1						1
180+							2		2

- 55% of RH consumed in 2018 and 2019
- Primarily juvenile RH consumed in MMB and PNB

Next Steps

- Continue sampling and processing predator stomachs on the DMR Inshore Trawl Survey
- Examine station-specific trawl data
- Examine RH CPUE data and examine trends
- Work on manuscript for peer review
- Evaluate genetic species assignments

NOAA FISHERIES

Questions and Discussion

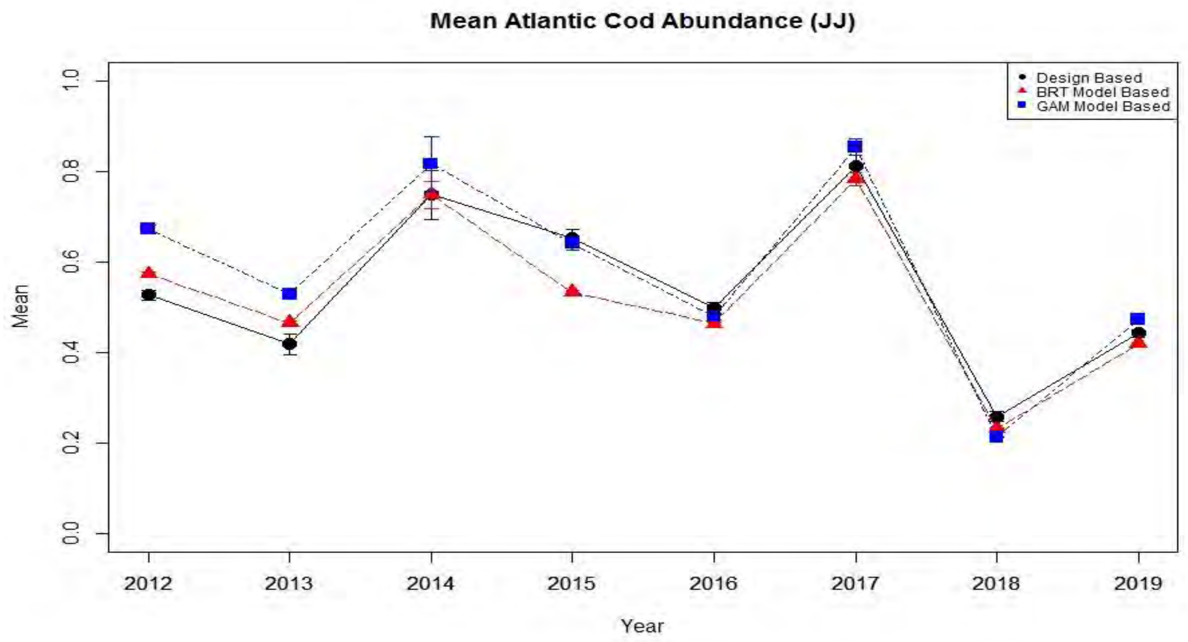
Appendix V: Diet composition of Atlantic cod in the inshore eastern Gulf of Maine

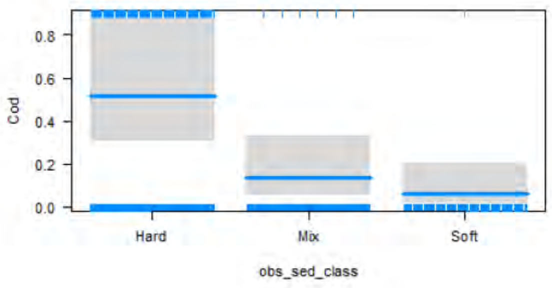
Diet Composition of Atlantic Cod in the Inshore Eastern Gulf of Maine

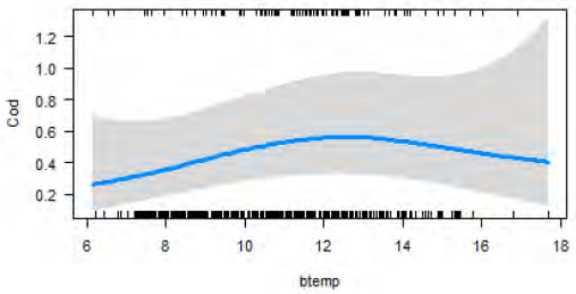
Robyn Linner

1865 THE UNIVERSITY OF MAINE
Maine Center for COASTAL FISHERIES

Sentinel Survey Objectives

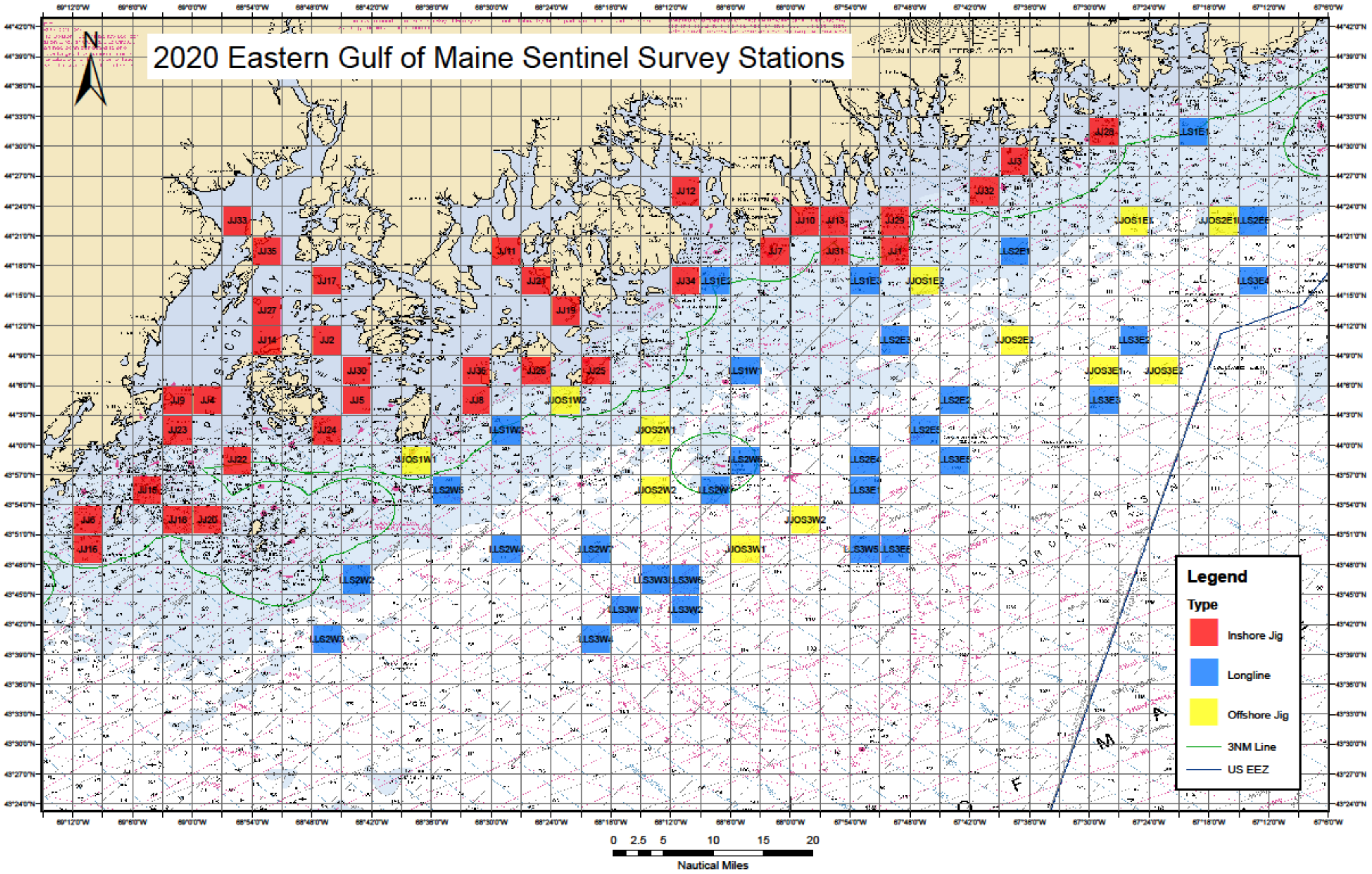






- Developed in 2010 as a partnership between MCCF & UMaine
- Fill in data gaps where state and federal trawl surveys cannot sample due to congestion of lobster gear
- Develop Abundance Indices and gain better understanding of habitat preferences for:
    - Atlantic Cod
    - White hake
    - Cusk
    - Atlantic Halibut

Sentinel Survey Design



- Stratified Random Design
  - Strata 0: 0-50m
  - Strata 1: 50-80m
  - Strata 2: 80-150m
  - Strata 3: 150m+
- Random Longline
  - 30 stations, Strata 1-3
- Random Offshore Jigging
  - 12 stations, Strata 1-3
- Random Inshore Jigging
  - 36 stations, Strata 0
- Fishermen’s Choice Stations
  - Targeting Atlantic Cod

Sentinel Survey Biological Sampling

Tissue samples taken

- Cusk
- Cod
- Halibut
- White hake
- Pollock
- Mackerel
- Haddock

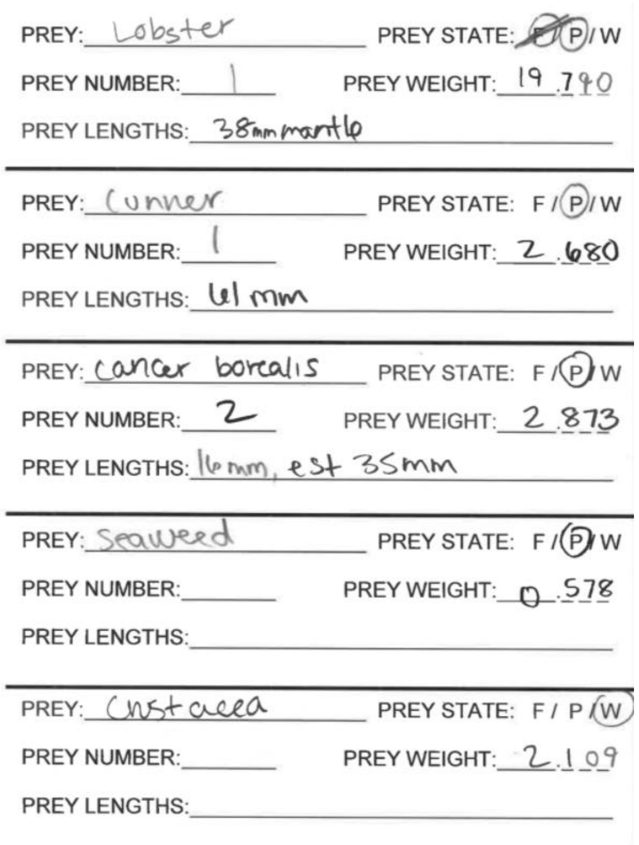
Additional Samples taken from cod

- Morphometric Photos
- Otoliths
- Stomach
- Fin Clips

Cod Stomach Sampling Research

Background

- ~ 200 cod stomachs from 2016-2020
  - 50/50 ethanol:H_2O 2016-2018
  - 95% ethanol 2019-2020
  - Vast majority immature fish
  - <55cm
- 93 analyzed
  - 83 analyzed in 2018
  - 10 analyzed 2/2020
- Collect prey species condition, number, weight, lengths (if applicable)



PREY: Lobster PREY STATE: F / P / W
PREY NUMBER: 1 PREY WEIGHT: 19.790
PREY LENGTHS: 38mm mantle

PREY: Cunner PREY STATE: F / P / W
PREY NUMBER: 1 PREY WEIGHT: 2.680
PREY LENGTHS: 61 mm

PREY: cancer borealis PREY STATE: F / P / W
PREY NUMBER: 2 PREY WEIGHT: 2.873
PREY LENGTHS: 16mm, est 35mm

PREY: Seaweed PREY STATE: F / P / W
PREY NUMBER:
PREY WEIGHT: 0.578
PREY LENGTHS:

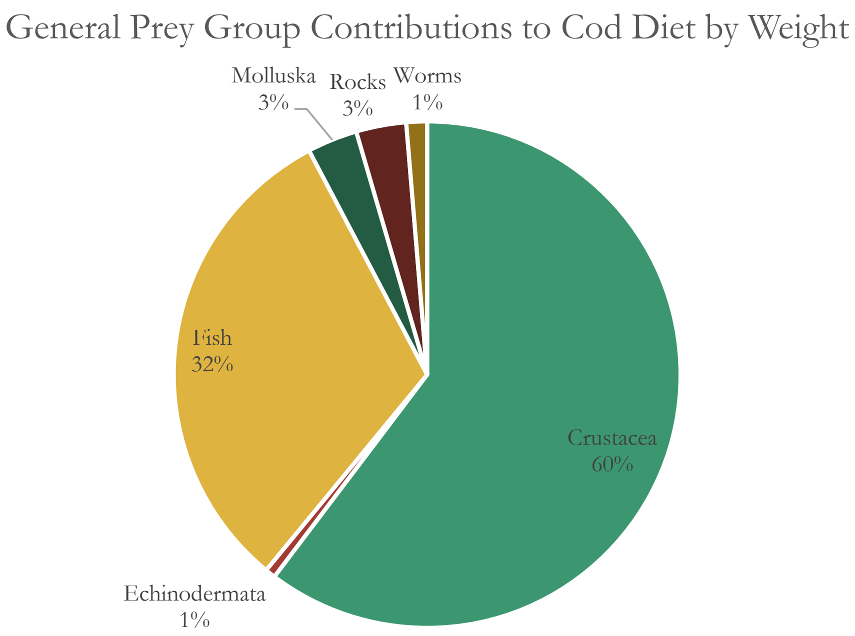
PREY: Crustacea PREY STATE: F / P / W
PREY NUMBER:
PREY WEIGHT: 2.109
PREY LENGTHS:

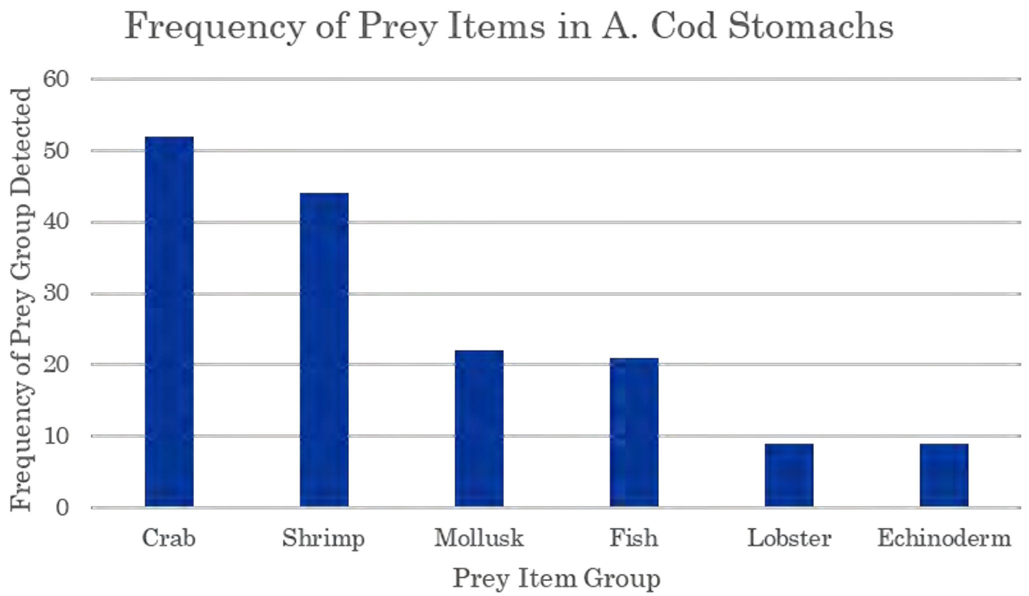
Research Questions

- Scope of my PhD: Importance of fine-scale surveys in their ability to identify trends in population dynamics that may be unique to a particular under sampled area, and unidentified by more broad-scale surveys
  - Diet Composition/Limitation.
    - Offshore vs. inshore, W vs E
    - Identify major prey species and incorporate into HSI
    - Relationship between cod and prey
      - Lobster
      - Shift to piscivory

Preliminary Findings- Major Prey Items

- 86 stomachs considered
  - 5 were empty
  - 2 had only items that could not be identified past Crustacea
- Not all prey items considered



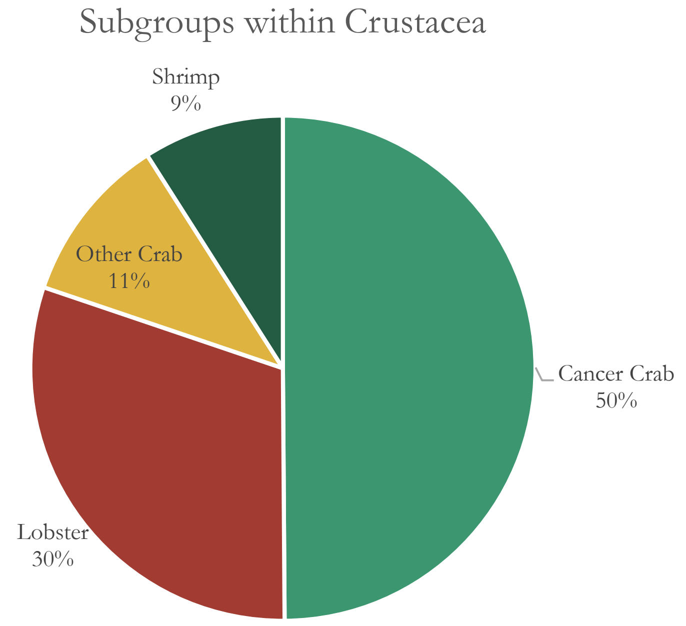


Preliminary Findings- Crustaceans

- Crabs
  - found to be a component of diet across a broad range of sizes, 21cm-52.5cm
  - Cancer crabs >80% of crabs identified
  - Shift to *Cancer borealis* after urchin overfishing?

- Lobster
  - Generally larger fish, mostly over 40cm, although a few at 30cm

- Shrimp
  - Found across all sizes of cod
  - Many specimens not identified to species, but Crangon, Pandalidae and Hippolytidae are most common



Preliminary Findings- Fish

- 23 fish present in 93 samples
  - No diadromous fish identified so far
  - Vast majority only identified to "bony fish"
  - Of those identified, Acadian redfish & Cunner most common
- Cod consuming fish
  - 28-60cm, most >35cm
  - Almost all identified as immature
  - largest & highest # of prey fish found in developing cod
- Shift to piscivory at maturity, or no?

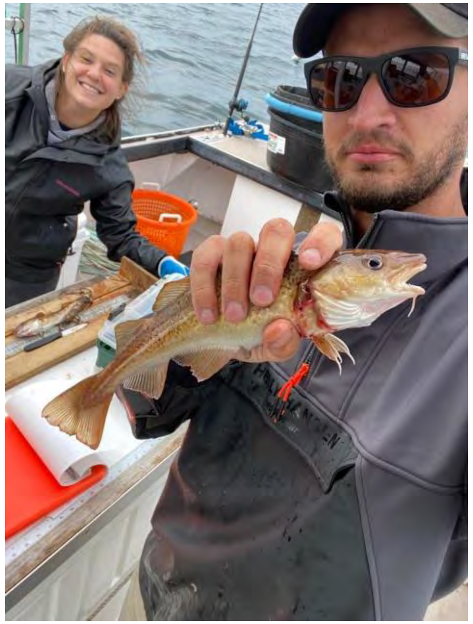
59cm, 5lb, F-Dev

60cm, 5lb, M-Dev

42cm, 1.5lb, M-Imm

Moving Forward

- The Sentinel Survey as a platform for diet studies beyond stomachs
  - Tissue samples- Simon Thorrold
  - Talks of cooperation/collaboration with DMR & NOAA
  - Opportunistic sampling for other external studies



- Expanding stomach collection
  - MCCF "Derby style" fishery targeting spawning cod
  - Spring MENH Inshore Trawl Survey
  - Stomachs from species other than cod

Appendix VI: Assessing the contribution of YOY river herring to coastal food webs in the Gulf of Maine using compound-specific carbon stable isotope analysis

Assessing the contribution of YOY river herring to coastal food webs in the Gulf of Maine using compound-specific carbon stable isotope analysis

Simon Thorrold, Leah Houghton

Woods Hole Oceanographic Institution

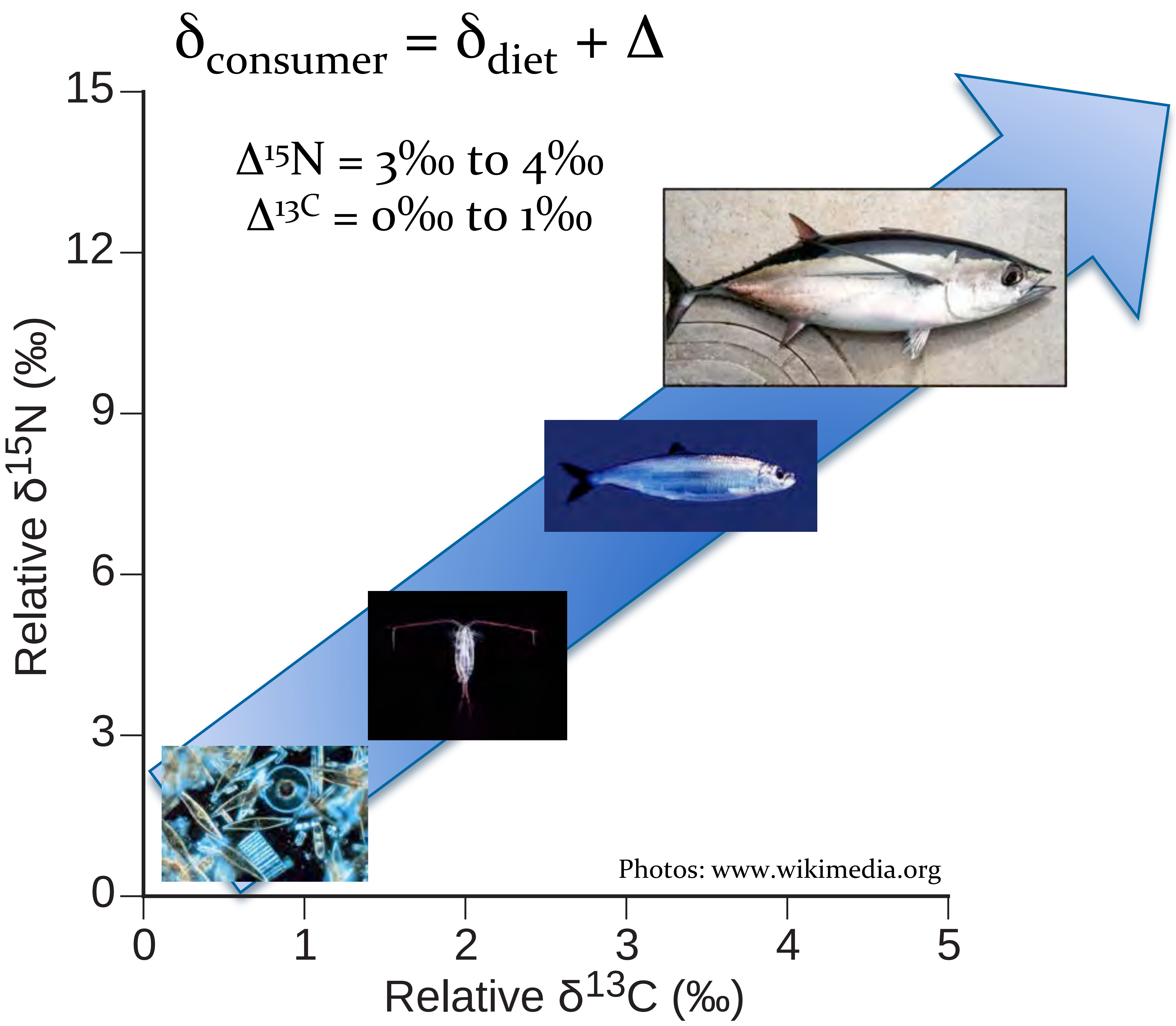
Carla Guenther

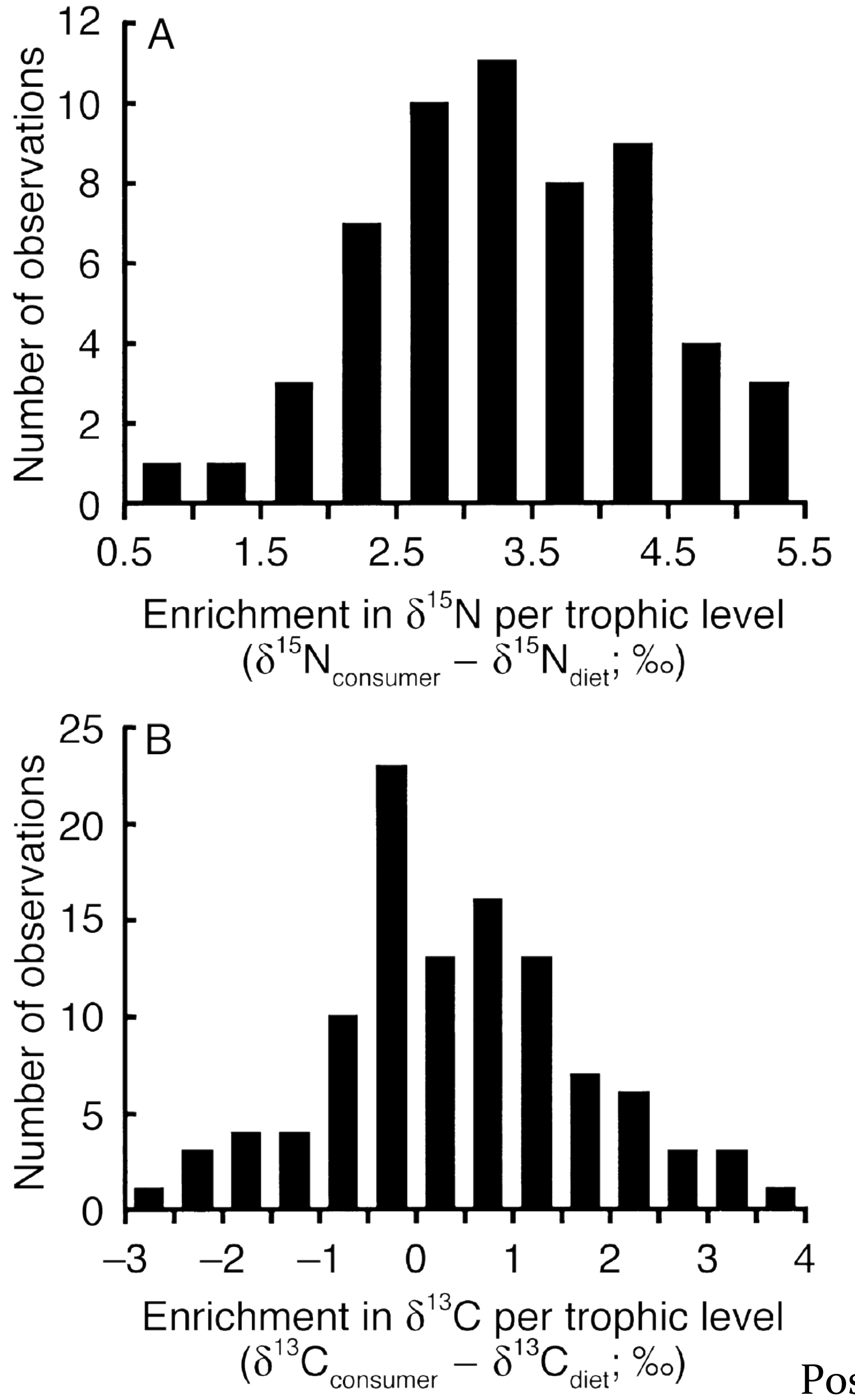
Maine Center for Coastal Fisheries

WOODS HOLE
OCEANOGRAPHIC
INSTITUTION

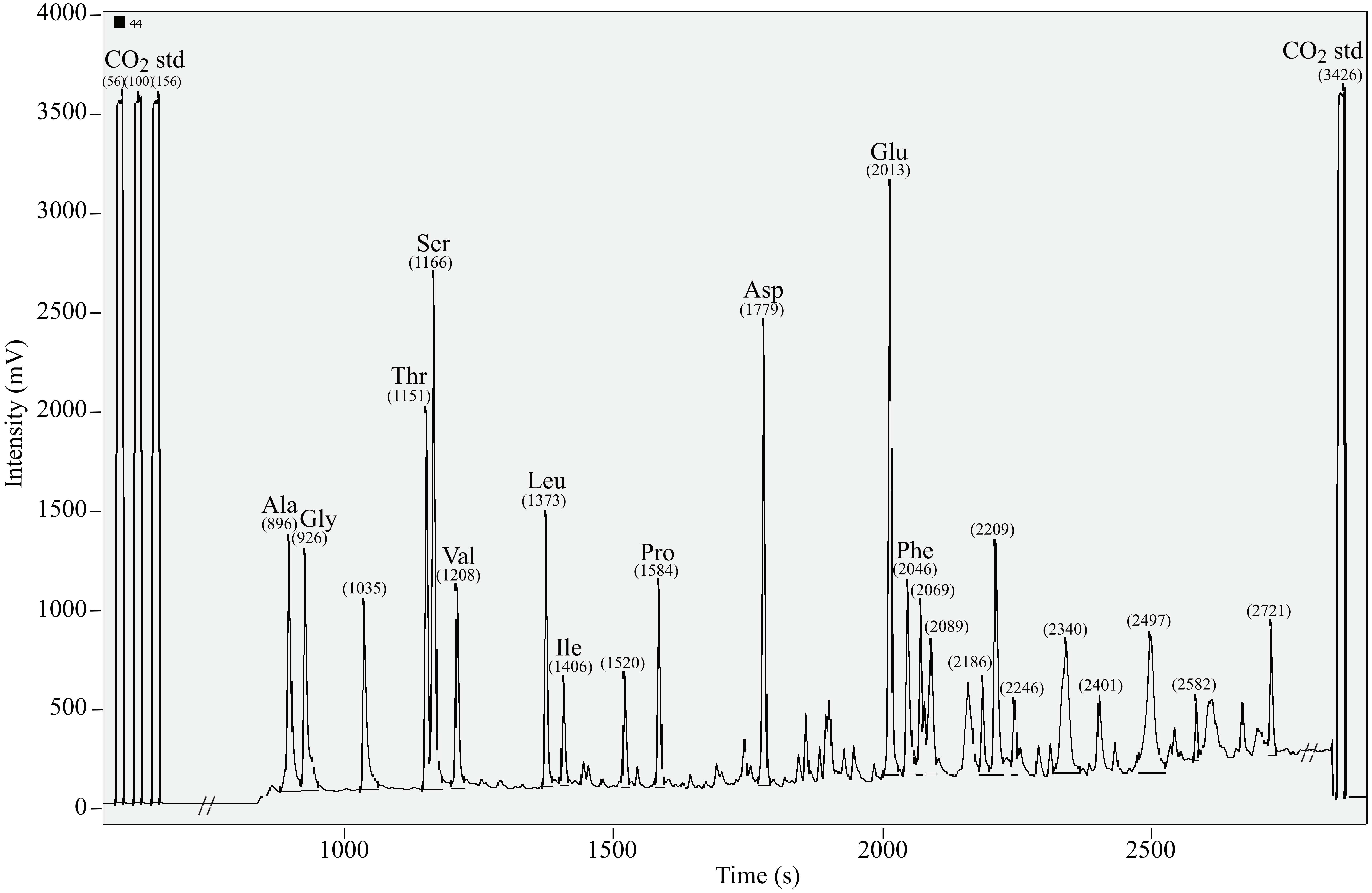
Maine Center for
COASTAL FISHERIES

Isotopes in ecology

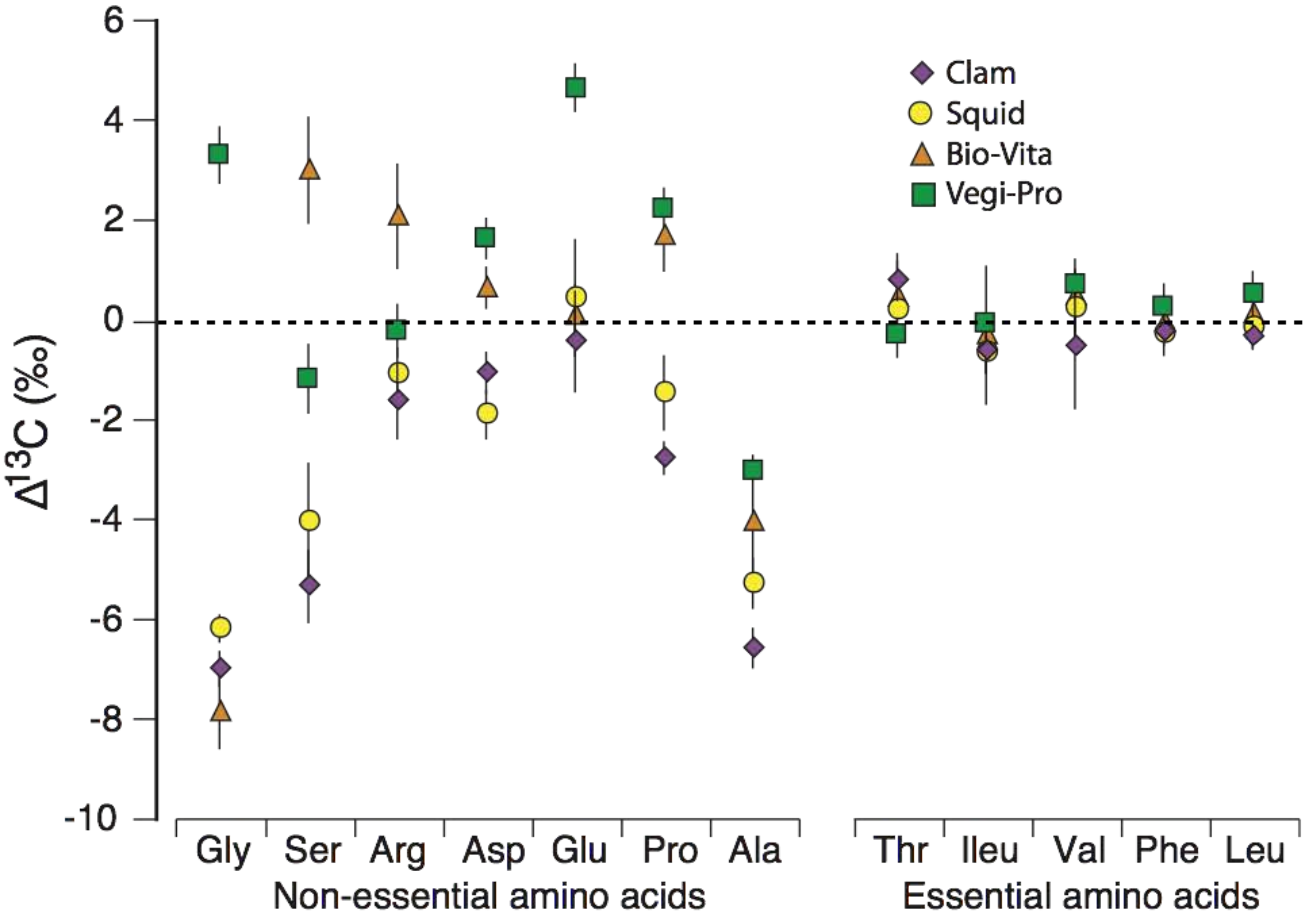




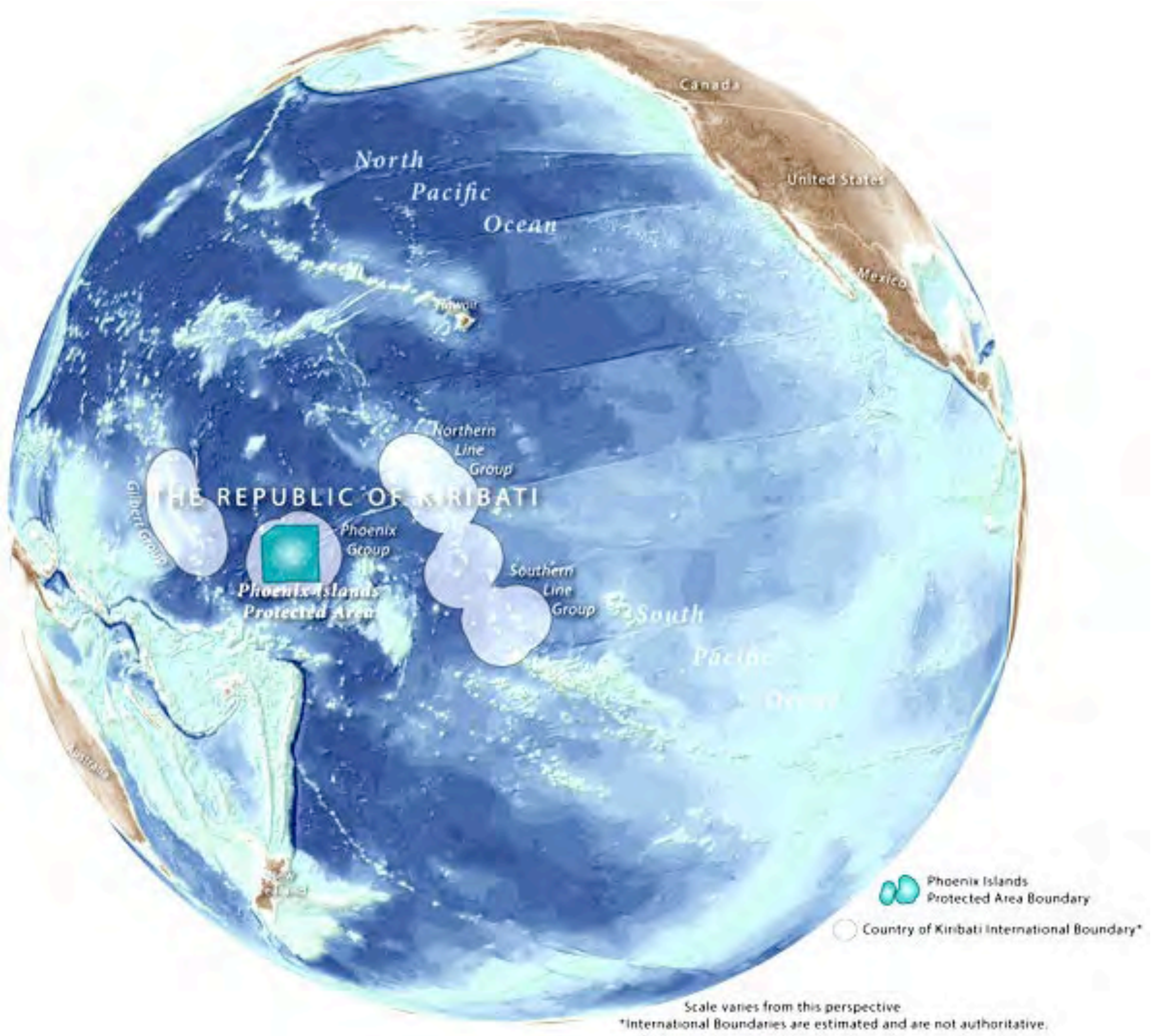
Post 2002



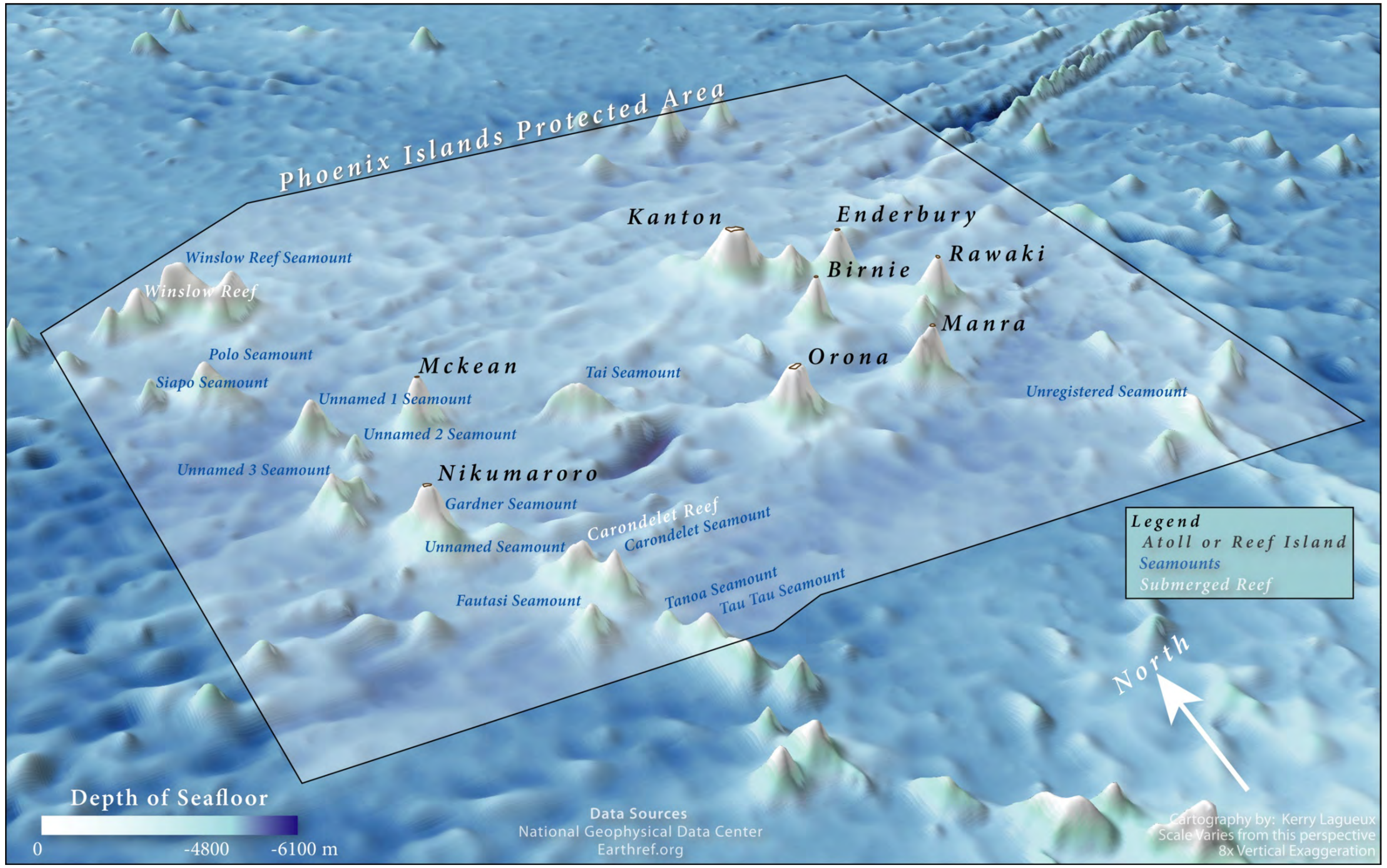
4000
3500
3000
2500
2000
1500
1000
500
0
Intensity (mV)
44
CO2 std
(56)(100)(156)
CO2 std
(3426)
Ala
(896)
Gly
(926)
(1035)
Thr
(1151)
Ser
(1166)
Val
(1208)
Leu
(1373)
Ile
(1406)
(1520)
Pro
(1584)
Asp
(1779)
Glu
(2013)
Phe
(2046)
(2069)
(2089)
(2186)
(2209)
(2246)
(2340)
(2401)
(2497)
(2582)
(2721)
1000
1500
2000
2500
Time (s)



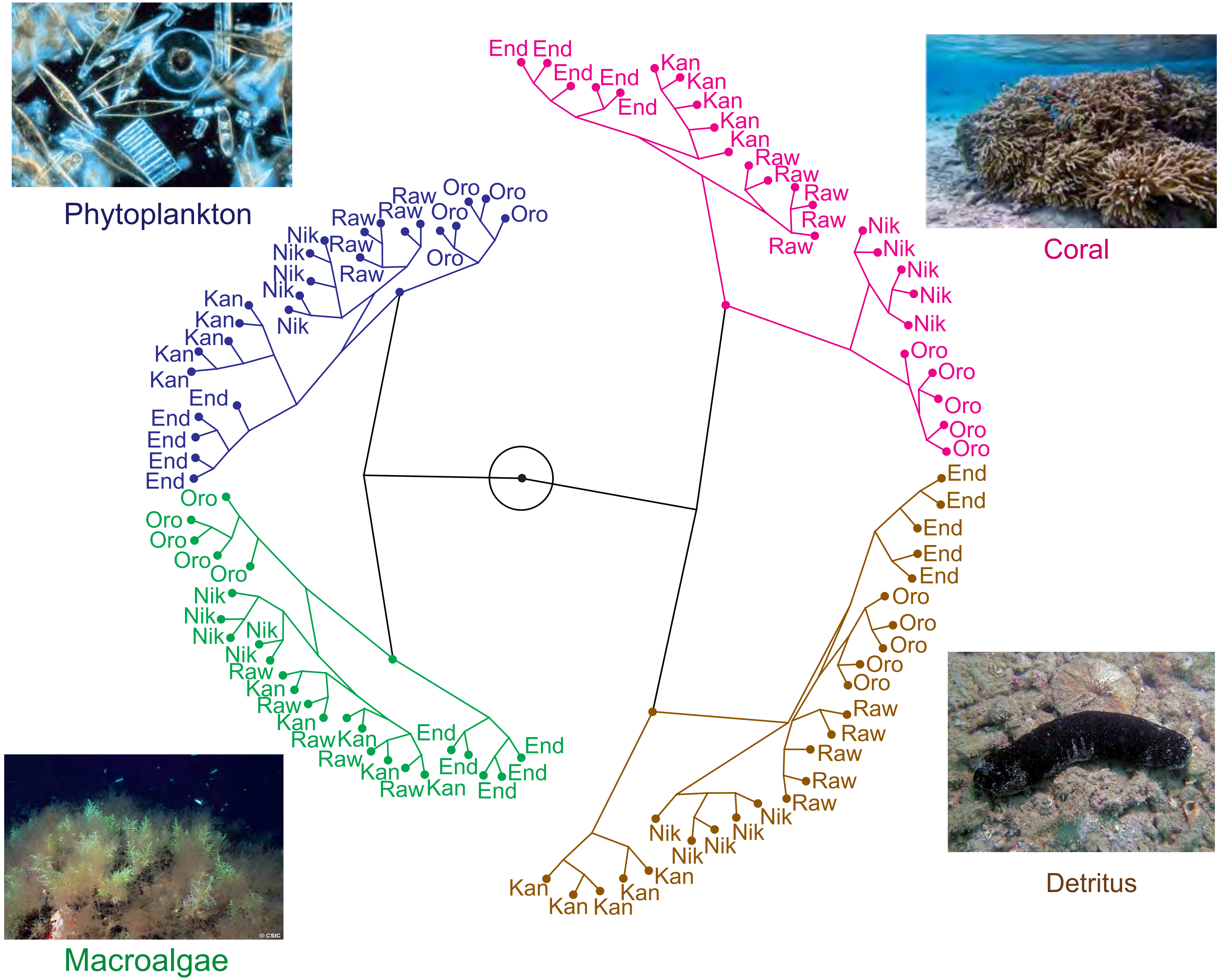
McMahon et al. (2010) J. Animal Ecol.



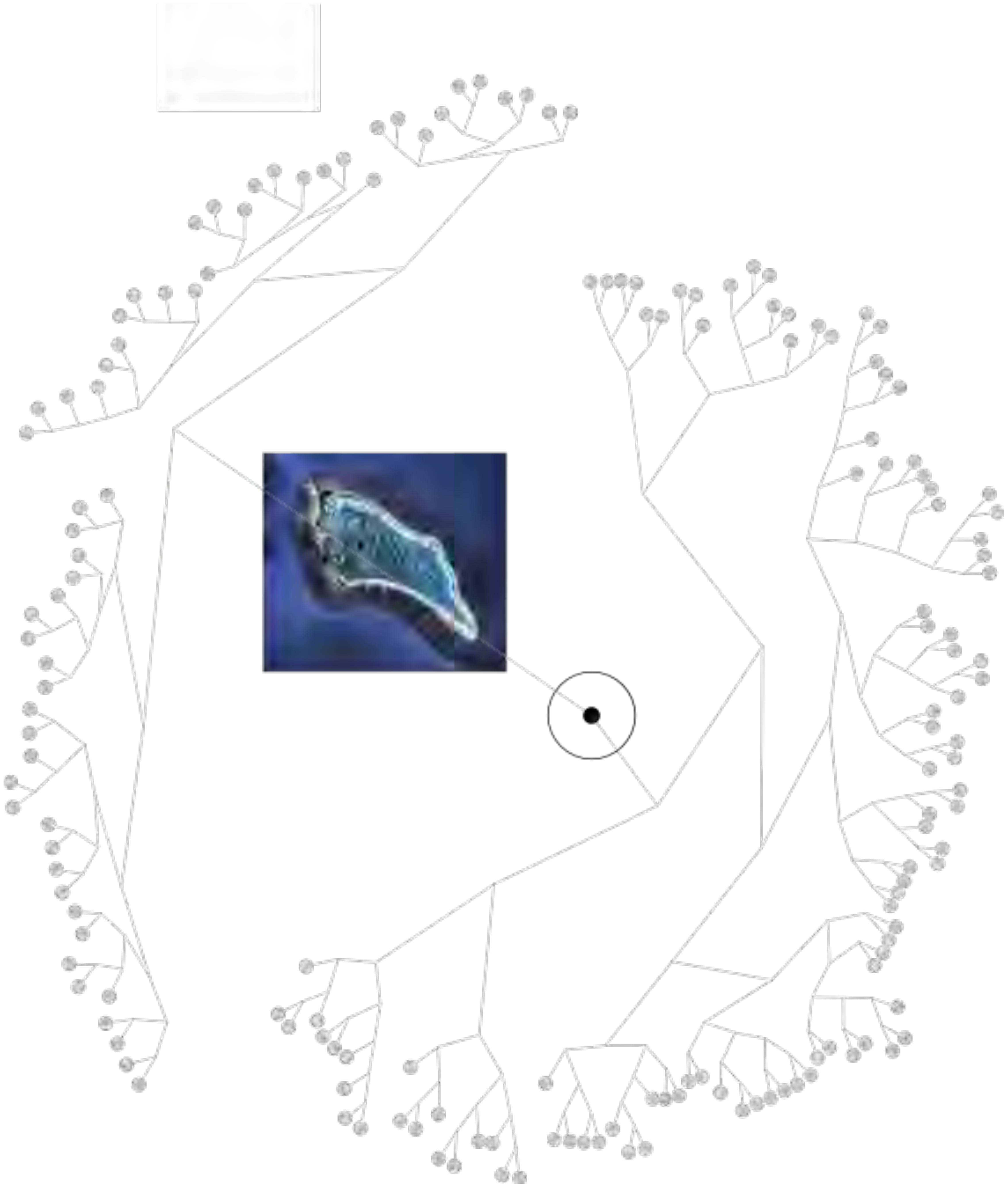
North Pacific Ocean
Canada
United States
Mexico
Hawaii
Northern Line Group
THE REPUBLIC OF KIRIBATI
Gilbert Group
Phoenix Group
Phoenix Islands Protected Area
Southern Line Group
South Pacific Ocean
Australia
Phoenix Islands Protected Area Boundary
Country of Kiribati International Boundary*
Scale varies from this perspective
*International Boundaries are estimated and are not authoritative.

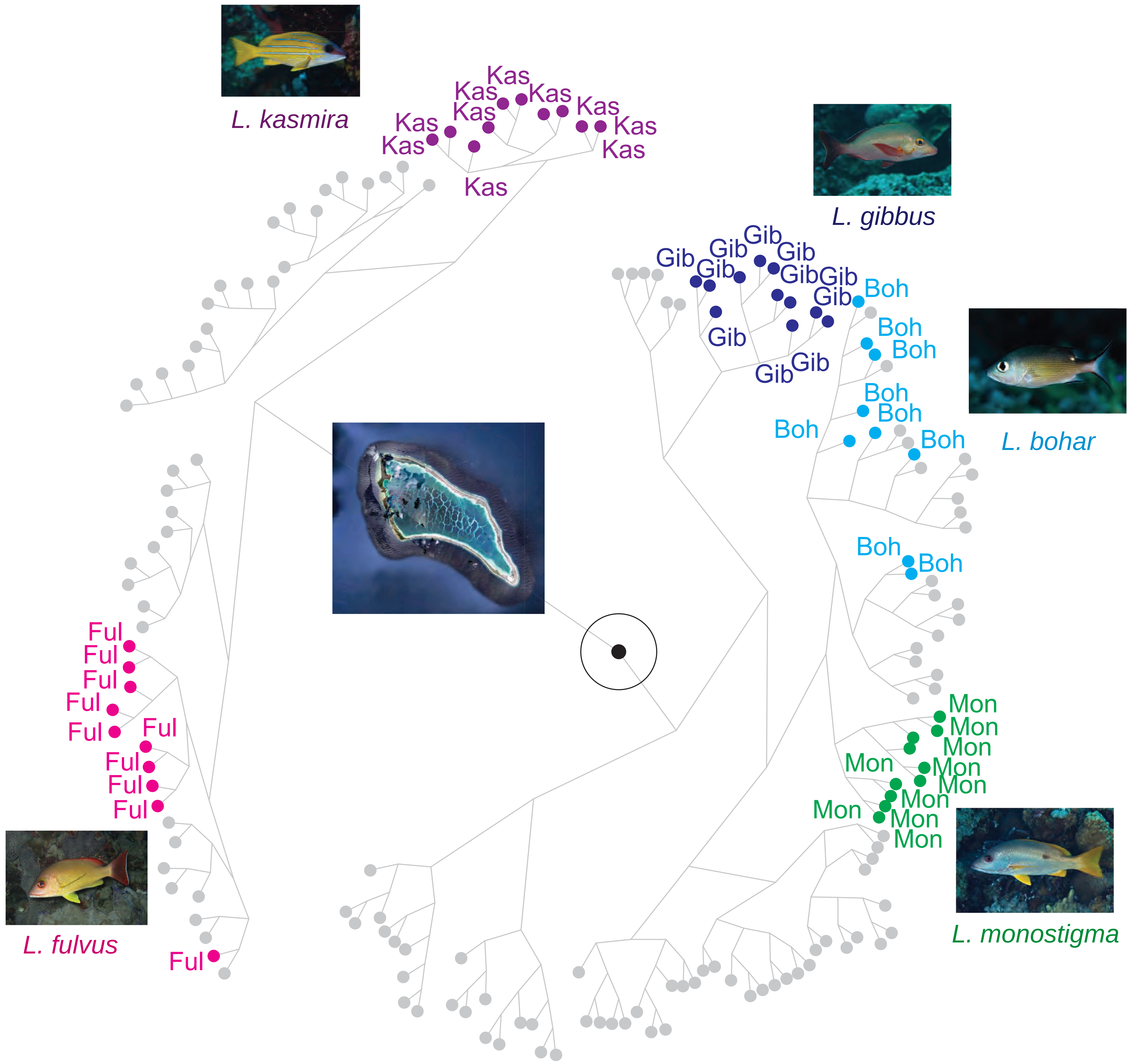


Phoenix Islands Protected Area
Kanton
Enderbury
Birnie
Rawaki
Manra
Orona
Mckean
Nikumaroro
Winslow Reef Seamount
Winslow Reef
Polo Seamount
Siapo Seamount
Tai Seamount
Unnamed 1 Seamount
Unnamed 2 Seamount
Unnamed 3 Seamount
Gardner Seamount
Unnamed Seamount
Carondelet Reef
Carondelet Seamount
Fautasi Seamount
Tanoa Seamount
Tau Tau Seamount
Unregistered Seamount
Legend
Atoll or Reef Island
Seamounts
Submerged Reef
North
Depth of Seafloor
0
-4800
-6100 m
Data Sources
National Geophysical Data Center
Earthref.org
Cartography by: Kerry Lagueux
Scale Varies from this perspective
8x Vertical Exaggeration

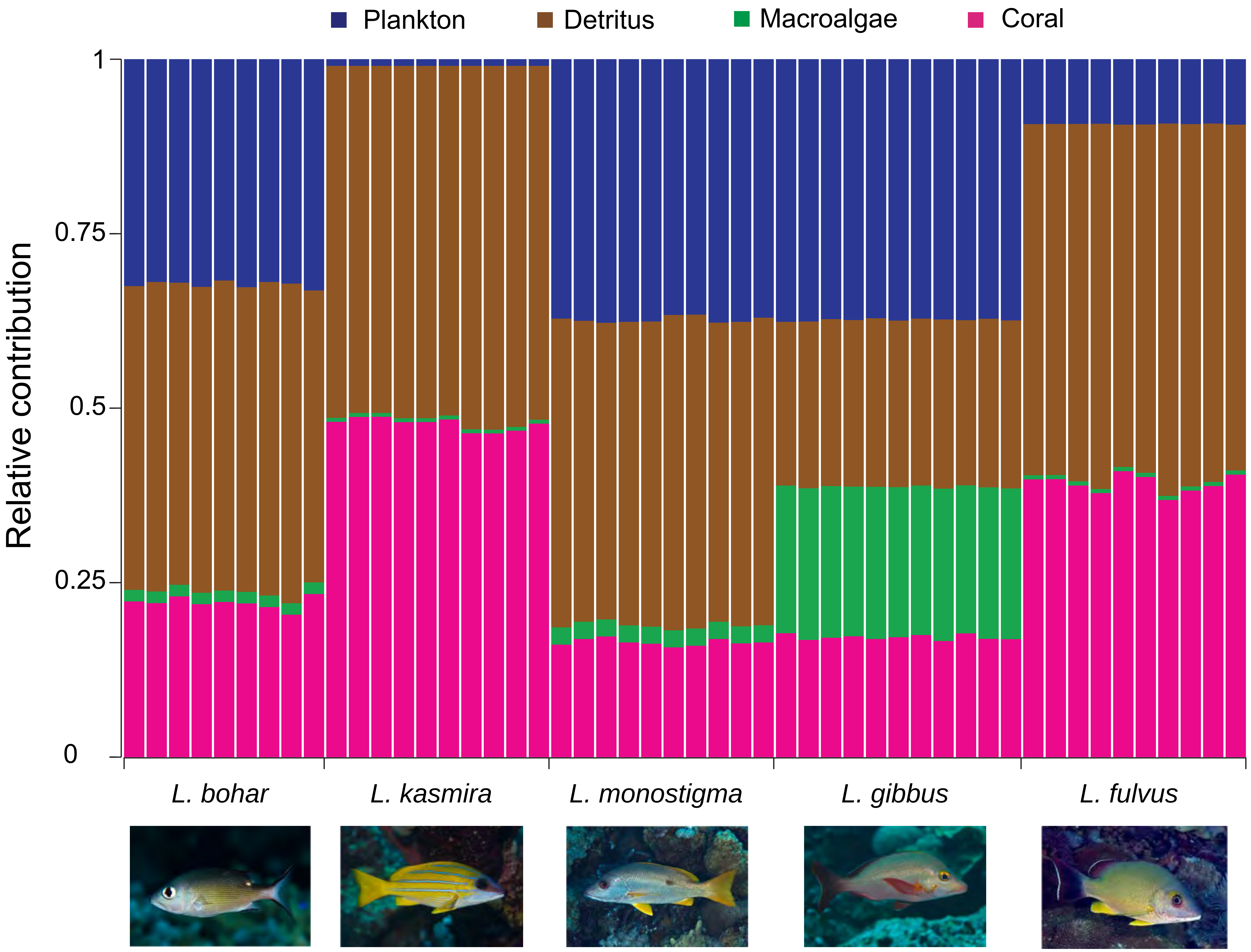


Phytoplankton
Coral
Macroalgae
Detritus
End
Kan
Raw
Nik
Oro

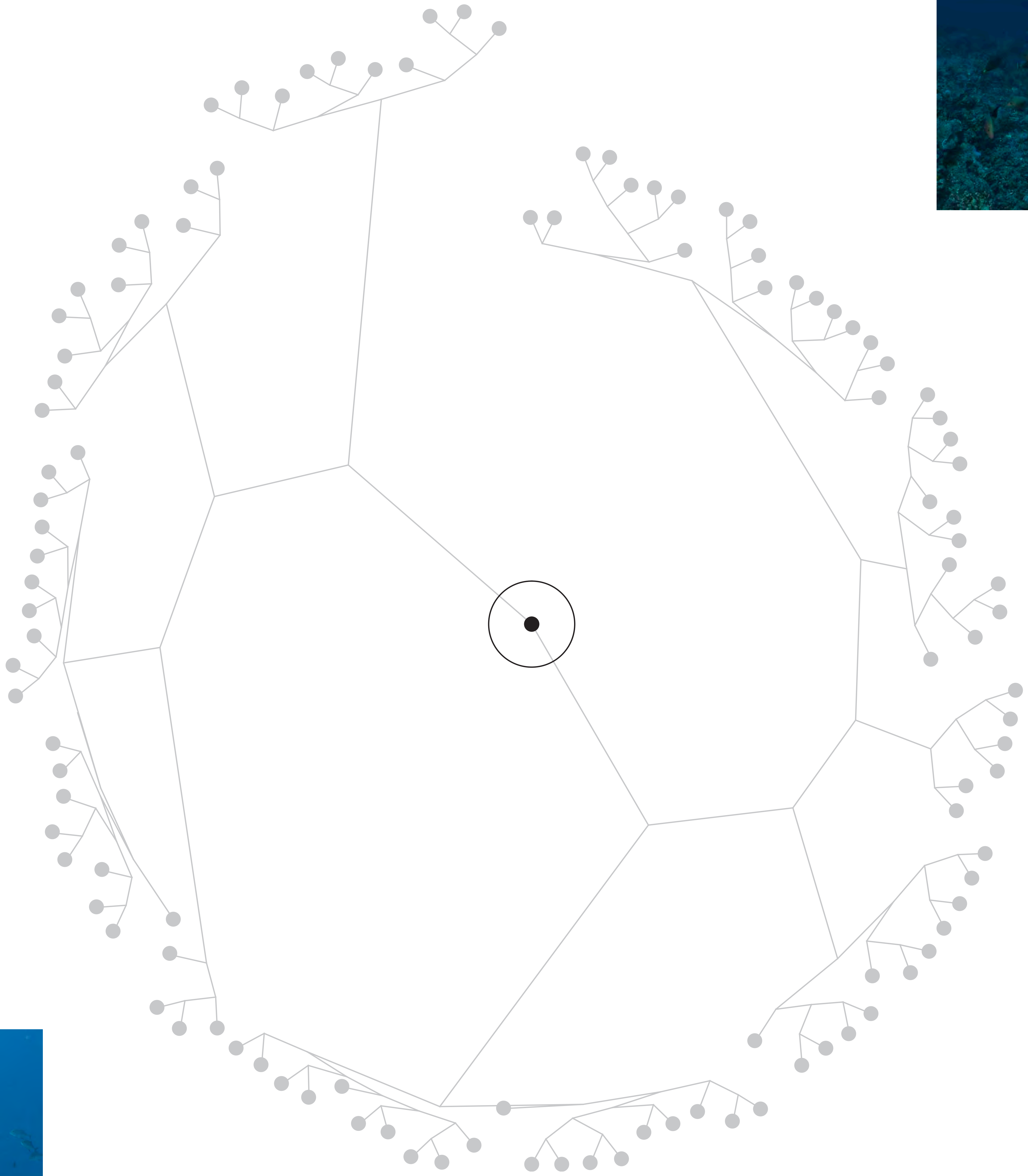




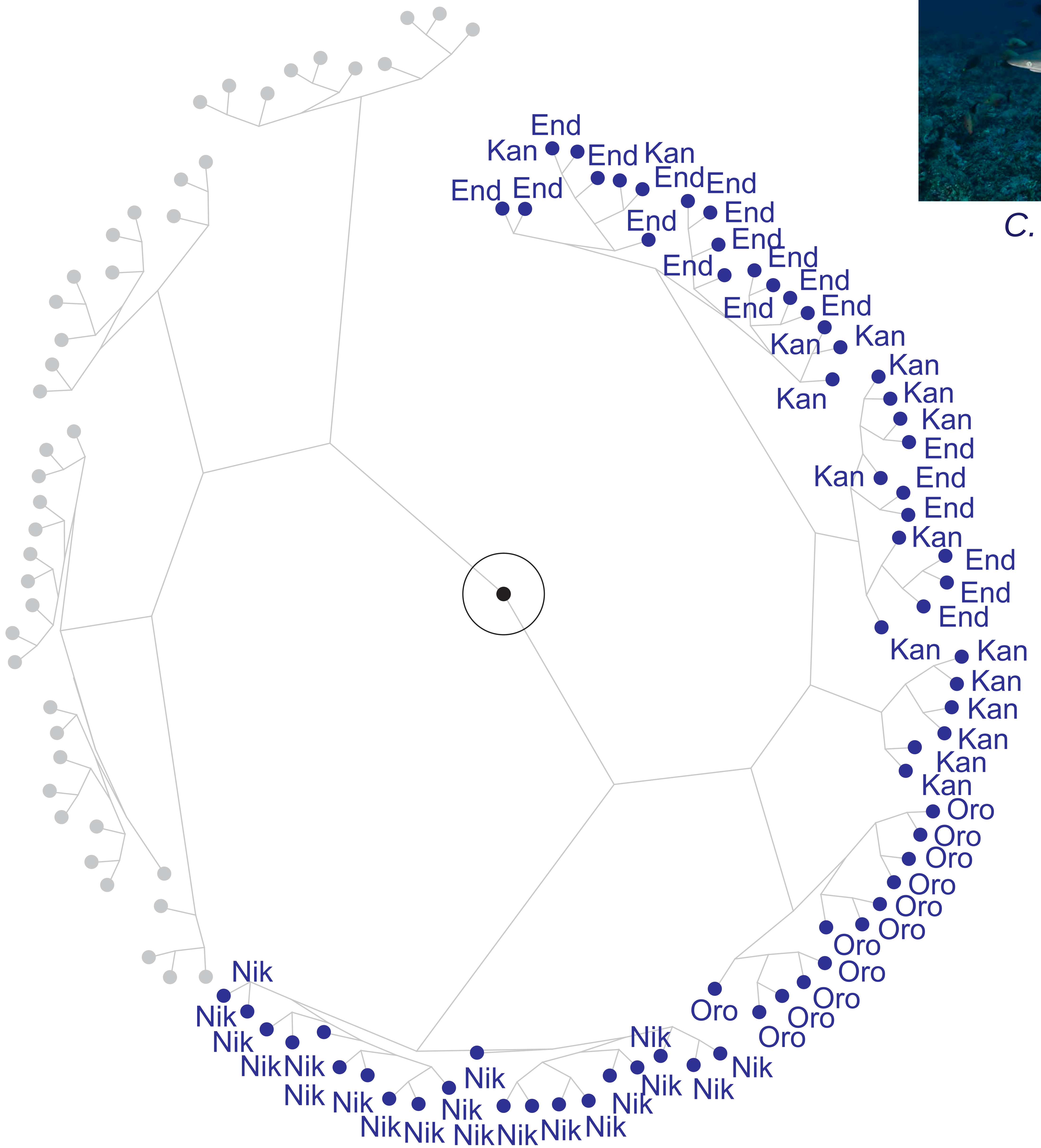
L. kasmira
L. gibbus
L. bohar
L. fulvus
L. monostigma
Kas
Gib
Boh
Ful
Mon


Plankton
Detritus
Macroalgae
Coral
Relative contribution
1
0.75
0.5
0.25
0
L. bohar
L. kasmira
L. monostigma
L. gibbus
L. fulvus

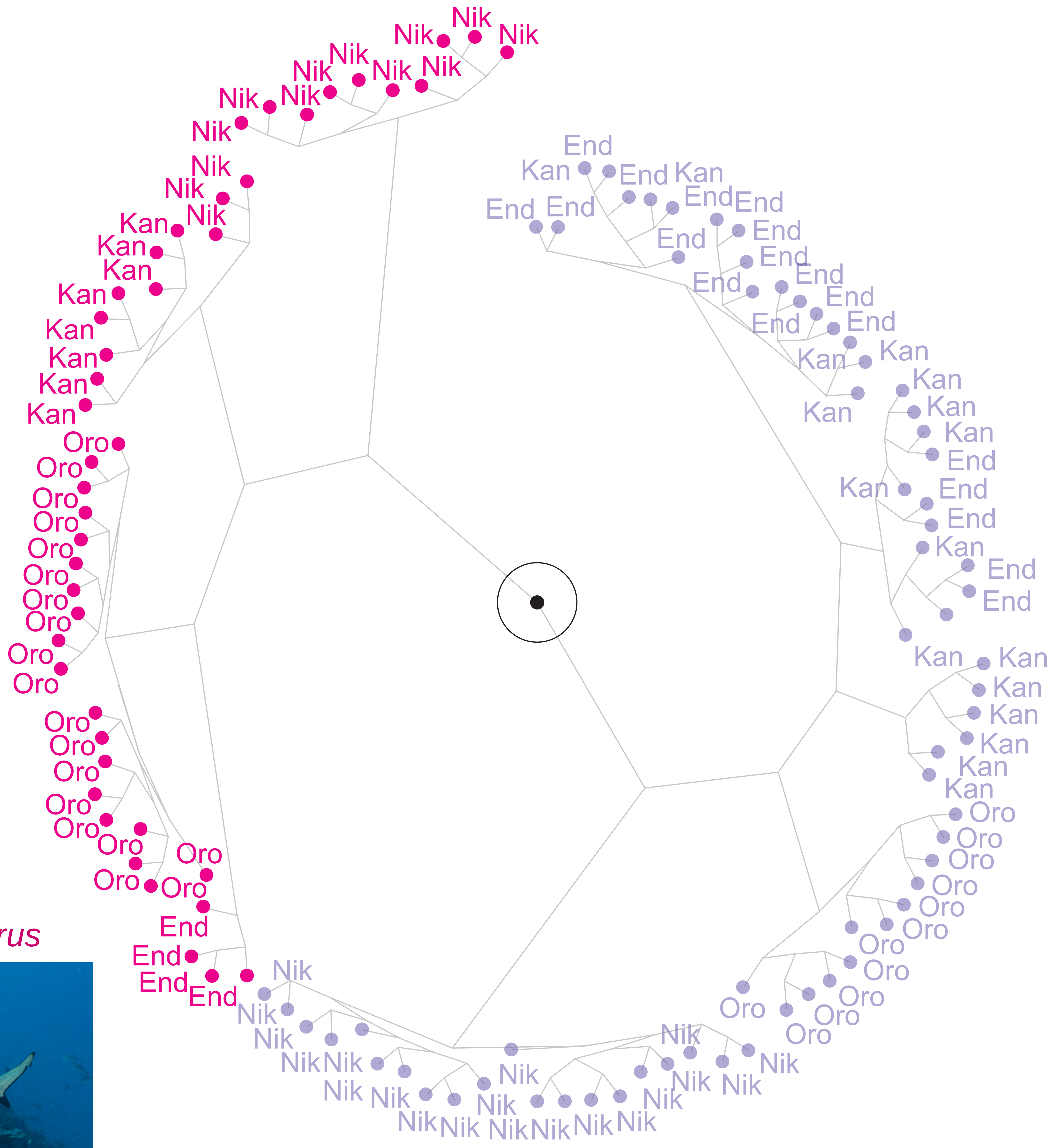
C. amblyrhyncos



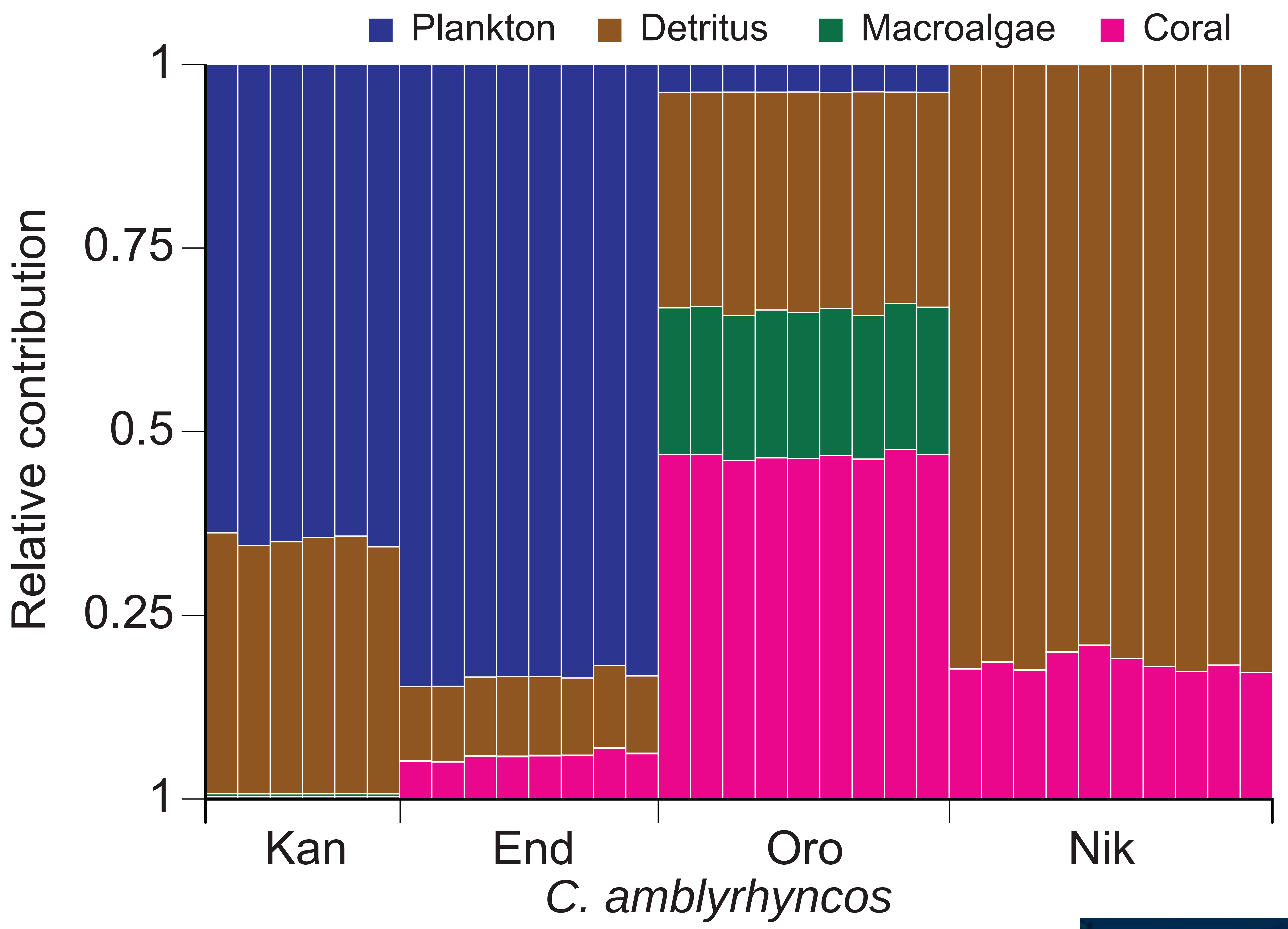
C. melanopterus

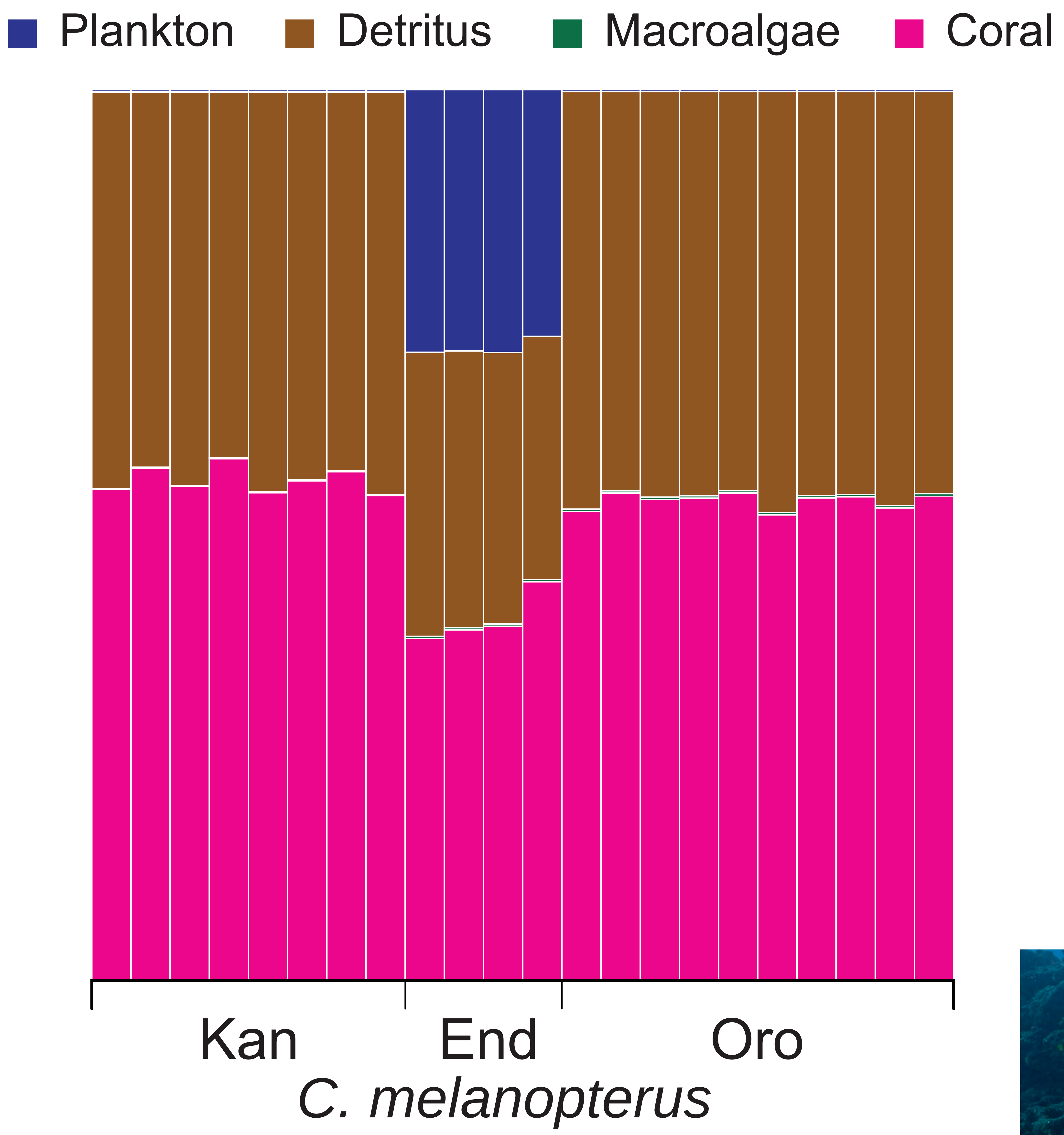


C. amblyrhyncos

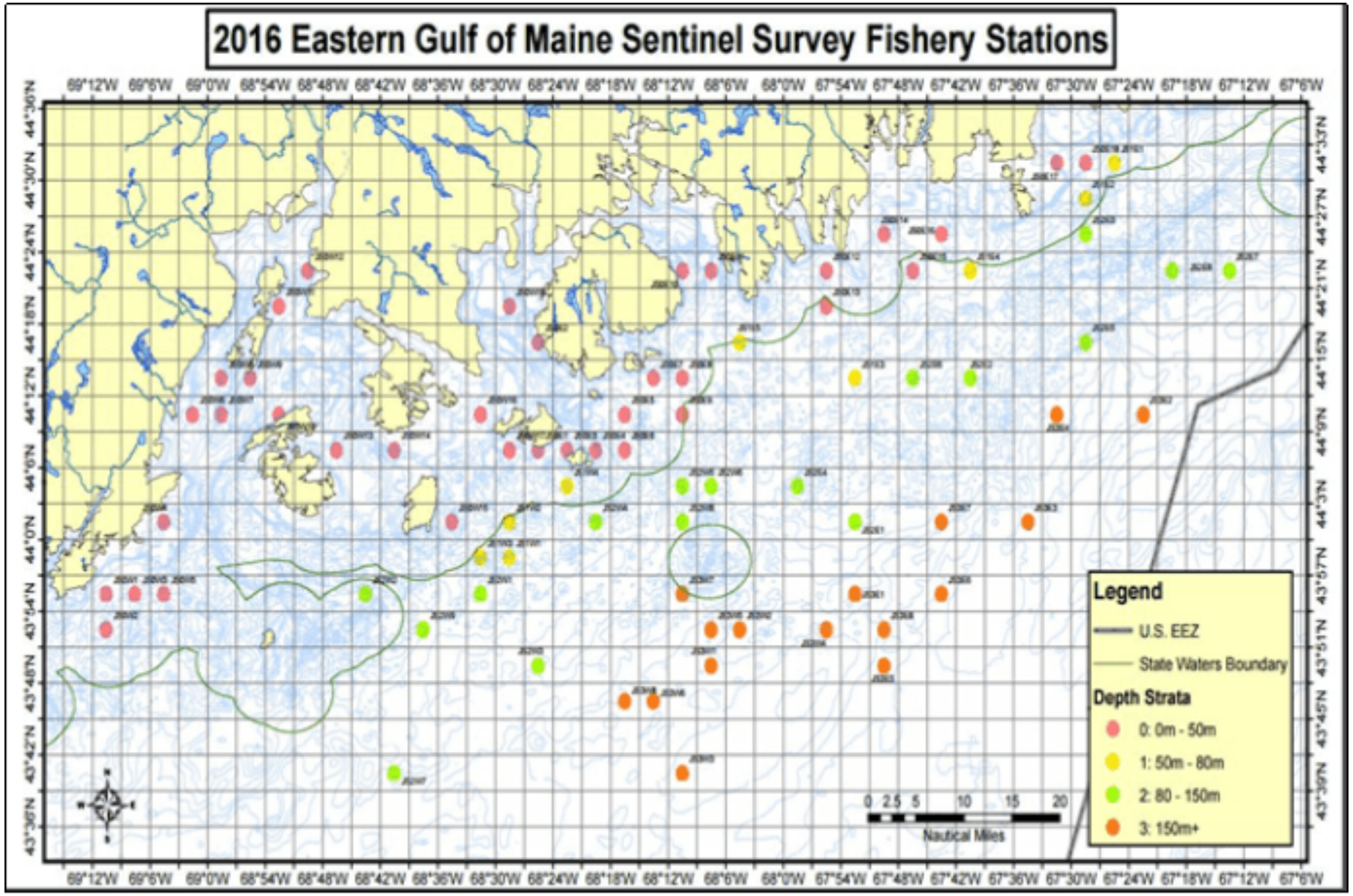


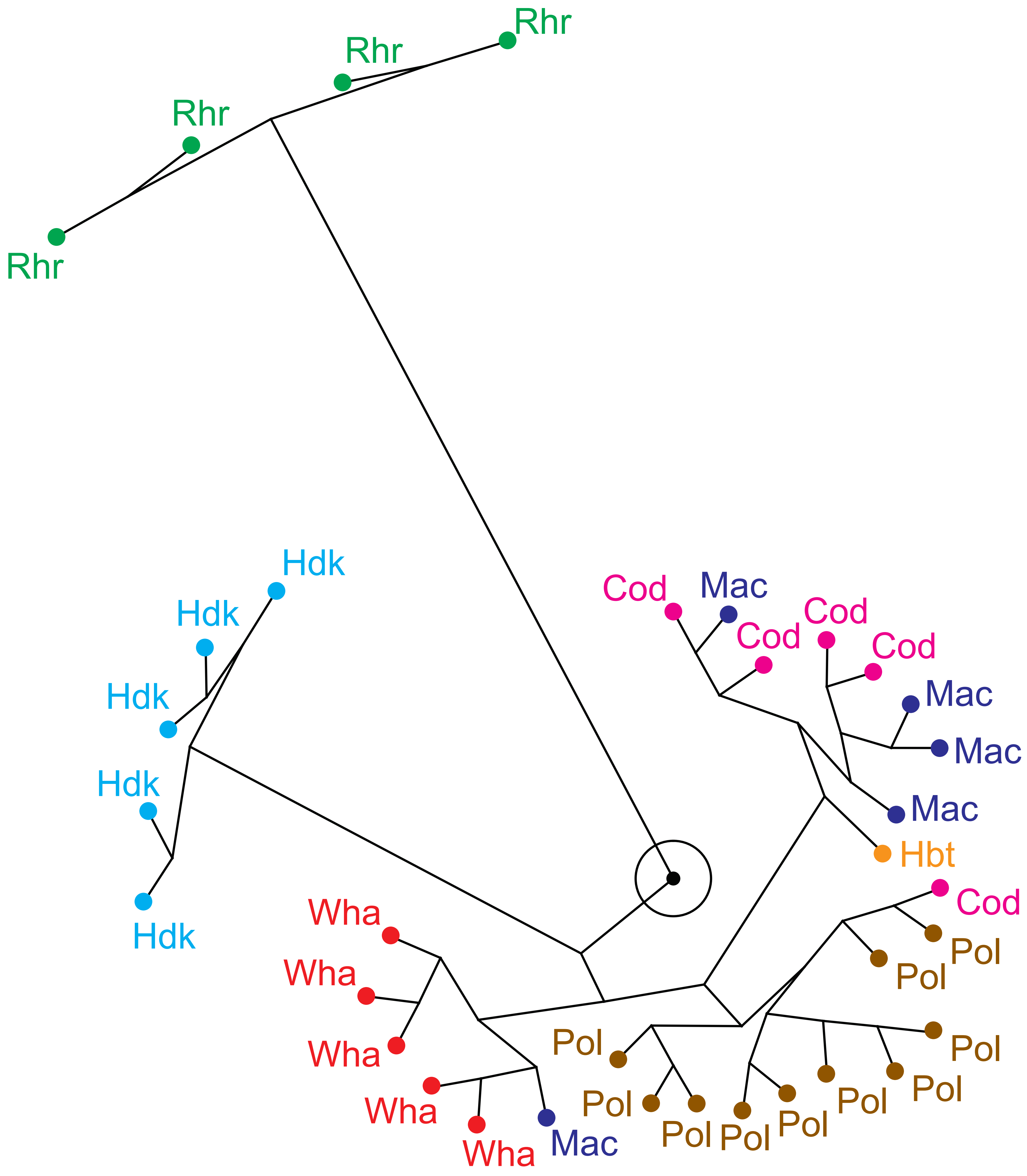
C. melanopterus


Plankton
Detritus
Macroalgae
Coral
Relative contribution
1
0.75
0.5
0.25
1
Kan
End
Oro
Nik
C. amblyrhyncos



Plankton
Detritus
Macroalgae
Coral
Kan
End
Oro
C. melanopterus


2016 Eastern Gulf of Maine Sentinel Survey Fishery Stations
Legend
U.S. EEZ
State Waters Boundary
Depth Strata
0: 0m - 50m
1: 50m - 80m
2: 80 - 150m
3: 150m+
0 2.5 5 10 15 20
Nautical Miles


Rhr
Rhr
Rhr
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Hdk
Hdk
Hdk
Hdk
Hdk
Cod
Mac
Cod
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Next steps

Analysis of 2020 samples - more river herring, coastal groundfish

Visualization of Gulf of Maine food webs using CS stable isotope analysis

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Maine Center for COASTAL FISHERIES

Appendix VII: Marine derived nutrients in the Penobscot Bay Watershed: Pre and post river restoration

Marine derived nutrients in the Penobscot Bay Watershed: Pre and post river restoration

With some thoughts from pre-pre restoration around the State of Maine

Dr. Karen Wilson, University of Southern Maine
Karen.Wilson@maine.edu

Diets and Stable Isotope Derived Food Web Structure of Fishes from the Inshore Gulf of Maine (Theo Willis, K. Wilson & Bev Johnson, 2016, Coasts and Estuaries)

Objective: quantify fish (esp. river herring) in diets of inshore (5 km) groundfish

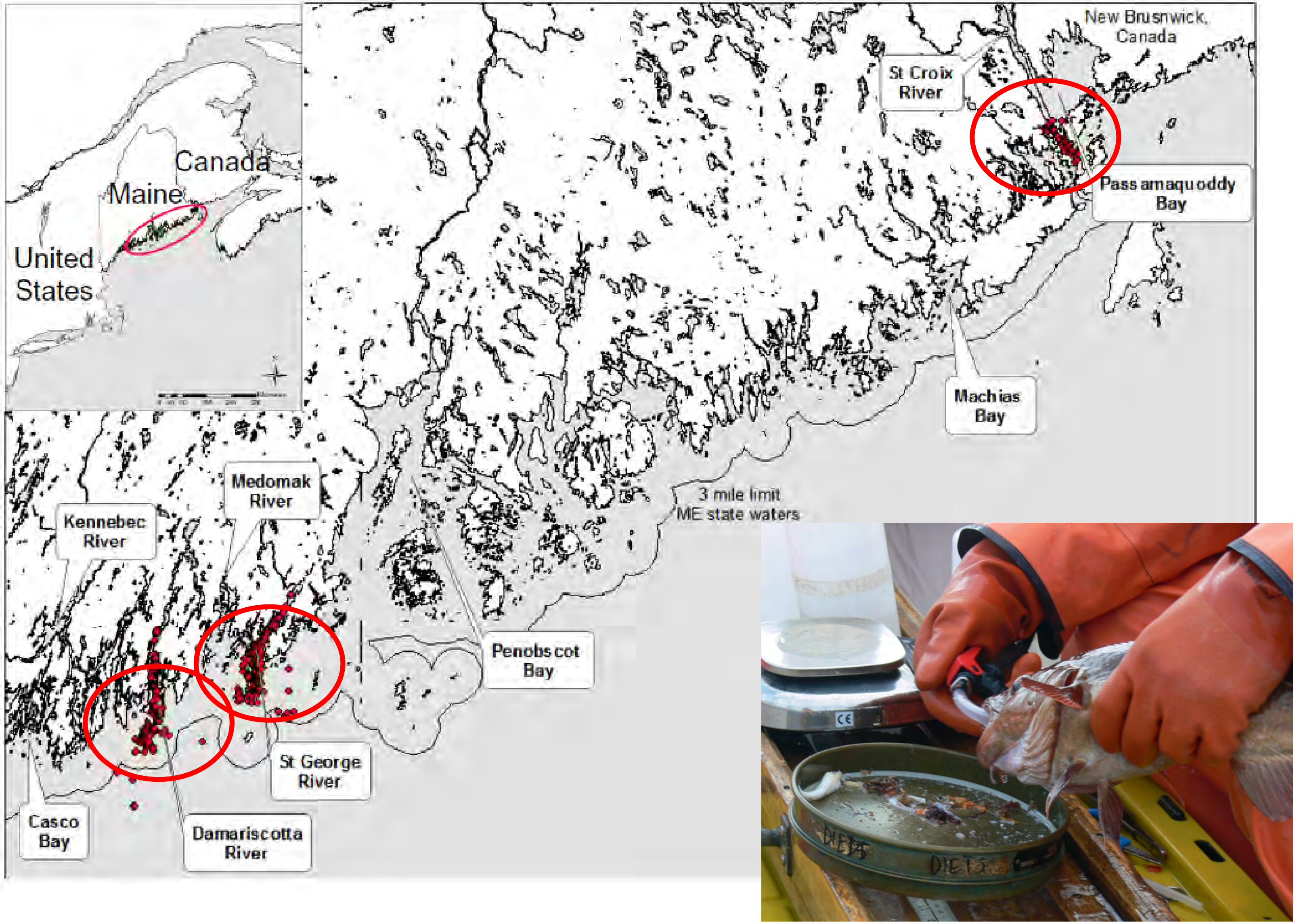
Dates: 2006-2008 (May, July, Oct)

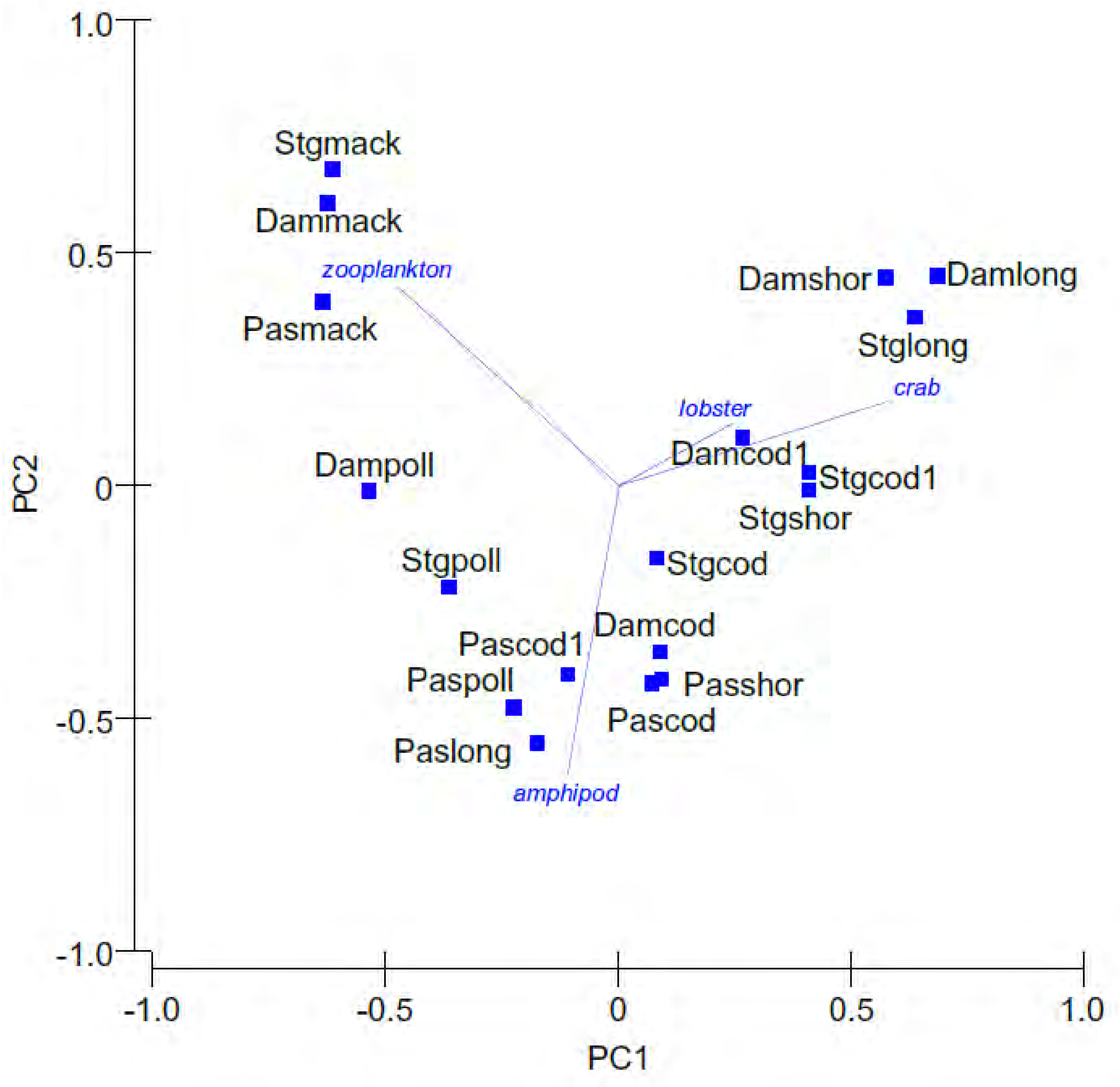
Study sites:

- Passamaquoddy (low)
- St. George
- Damariscotta (high)

Methods:

- Hook & line
- Gastric lavage
- Fin clips for isotopes





Results

- Groundfish most common in summer & fall
- Diets of all species dominated by invertebrates
- $\delta^{15}N$ isotopes were consistently depleted in Passamaquoddy fish (but not mussels)

Data: Theo Willis, K. Wilson & Bev Johnson, 2016, Coasts and Estuaries

River herring

- Identified in diets only in Damariscotta and St. George in fall 2007 after a dry late summer and heavy fall rains
- Pulse event (?)
- Data represent:

  mid-Kennebec restoration

  Pre-Penobscot restoration

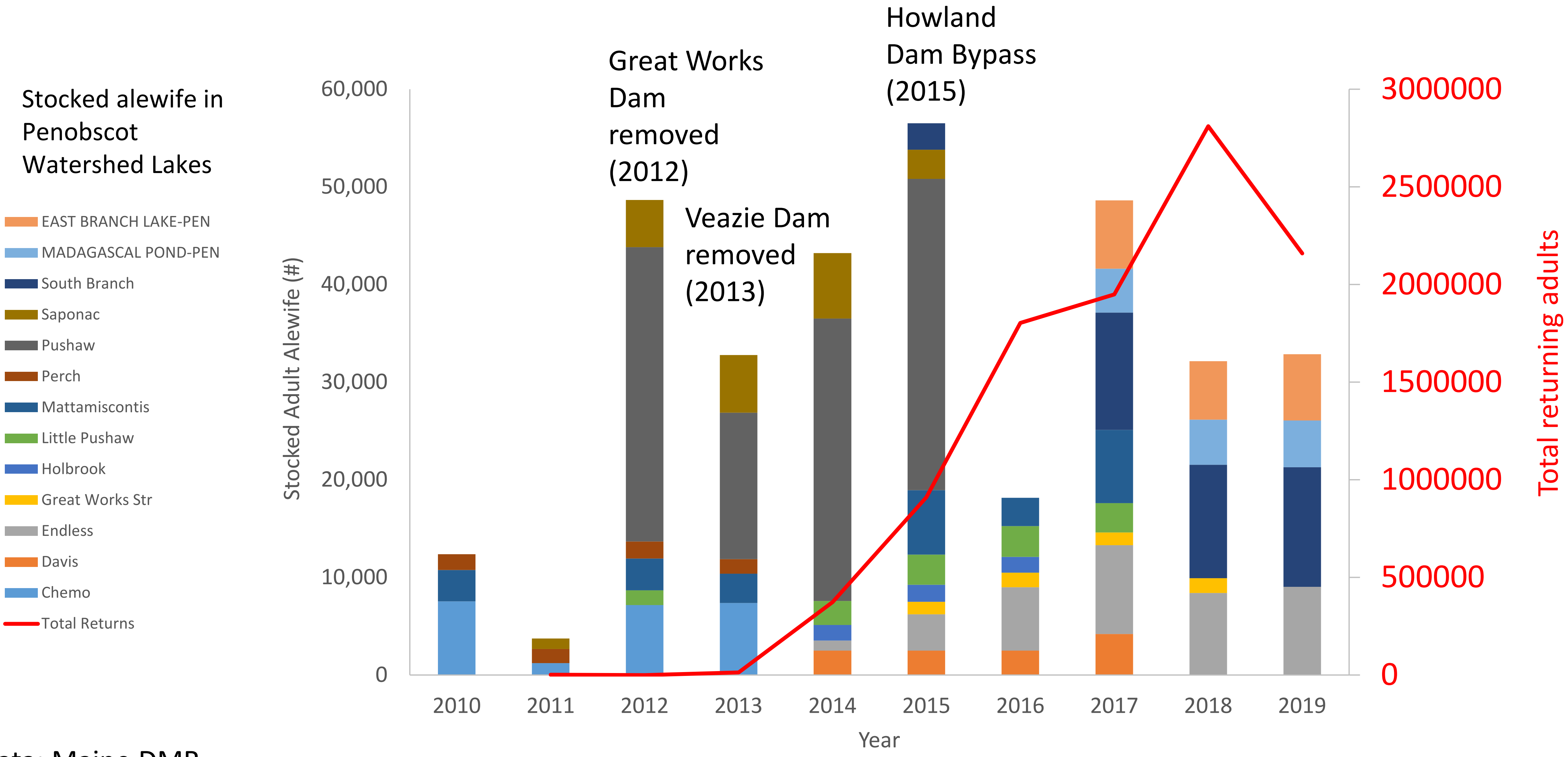
  Pre-St. Croix reopening

Photo: K. Wilson

Damariscotta October 2007

Photo: K. Wilson

Stocking and returns: Penobscot River Watershed



Data: Maine DMR

Trophic indicators of river restoration

Collaborators

- Graham Sherwood (GMRI)
- Matt Brewer (USM) – Biology Masters graduate student
- UMaine Penobscot Fish Survey Team
- MCCF Sentinel Survey
- MeDMR Inshore Trawl
- MBI (Chris Yoder)

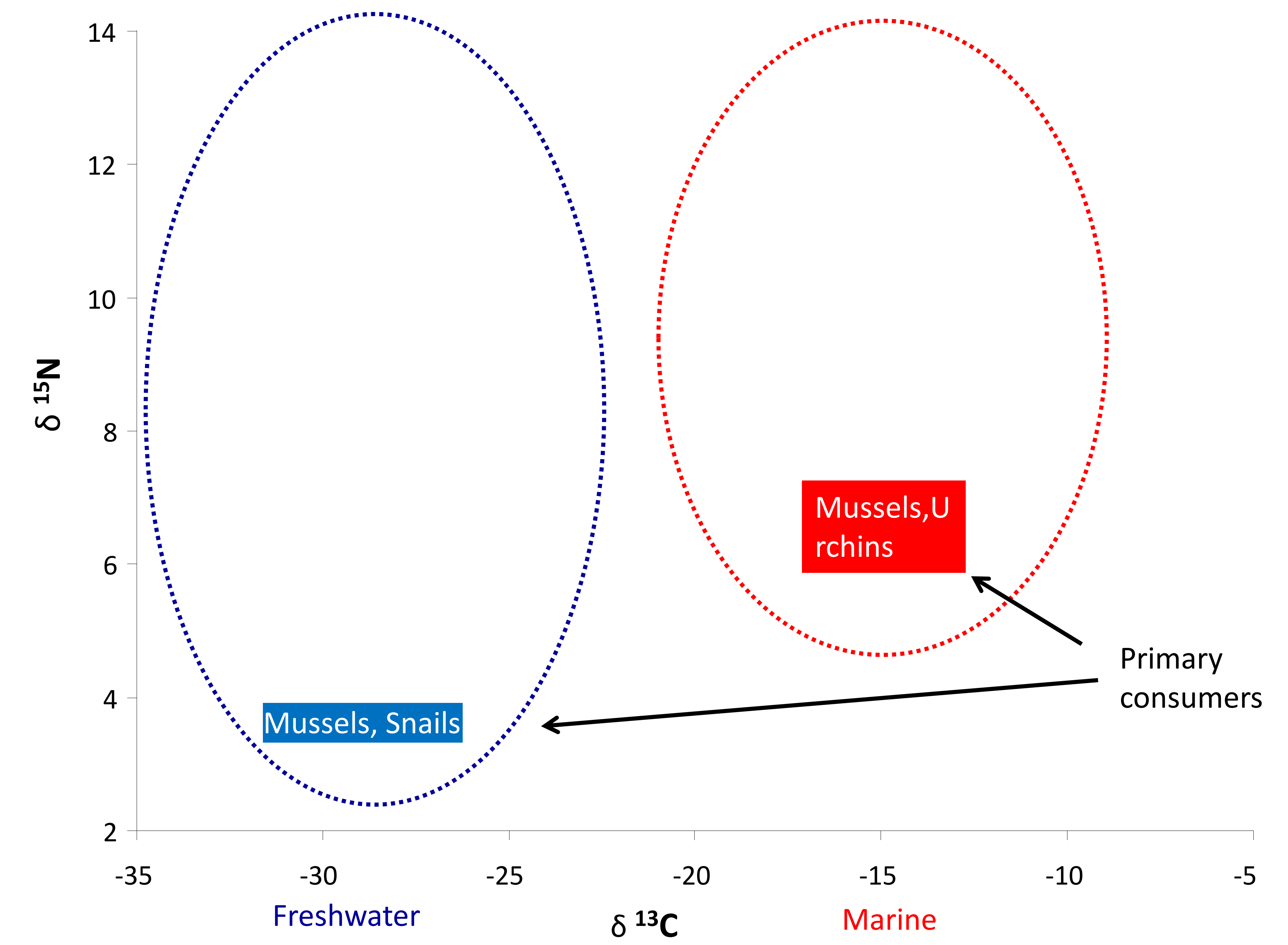
Funders

- TNC, NOAA/TNC, NSF Sustainability Solutions

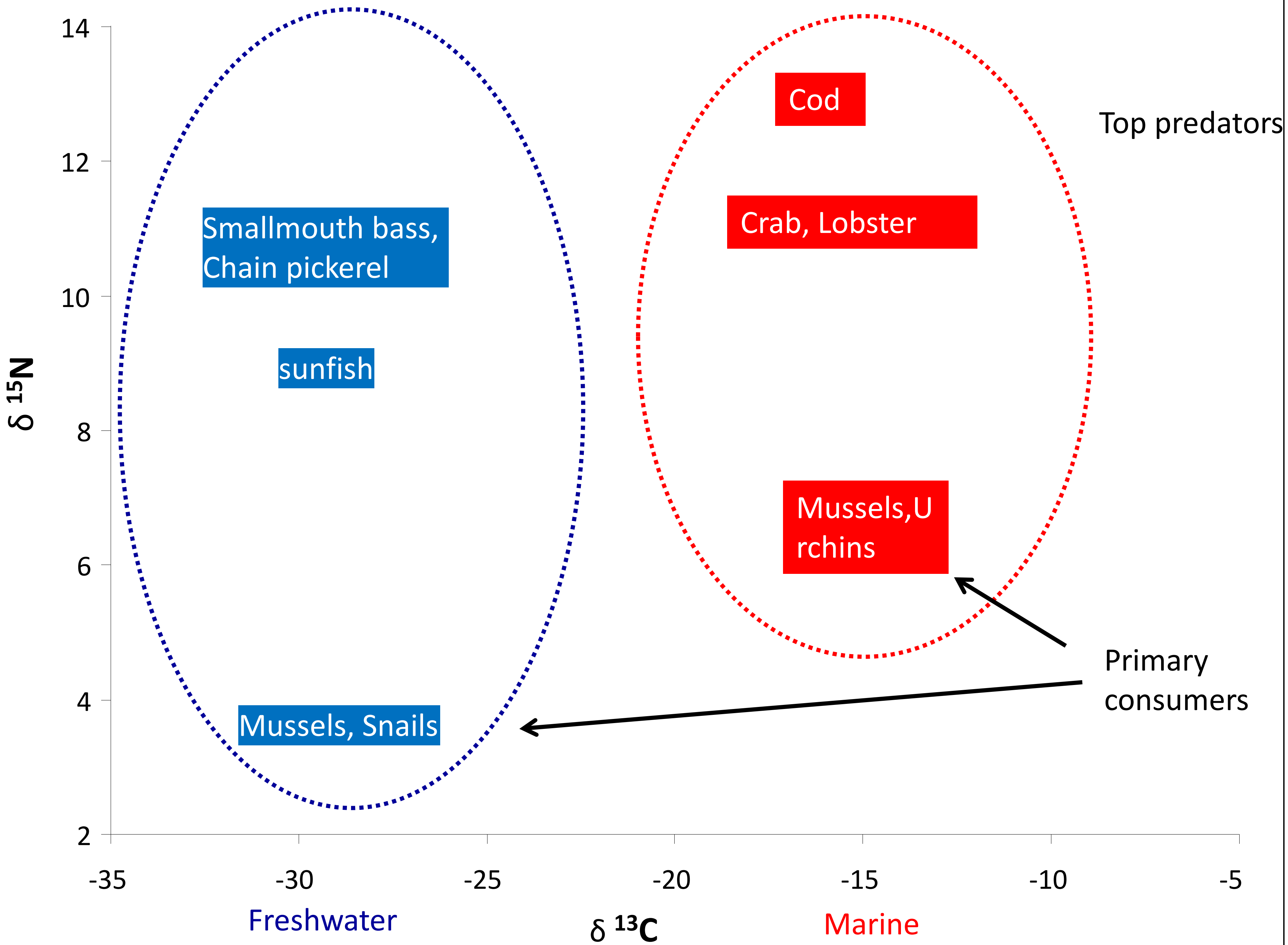
Food Web Restoration Indicators: Trophic levels

Trophic levels

- More trophic levels = more diverse predator-prey interactions
- greater prey availability
- greater ecosystem complexity (i.e., more pathways for food web interactions) (Post et al 2000, Post 2002)

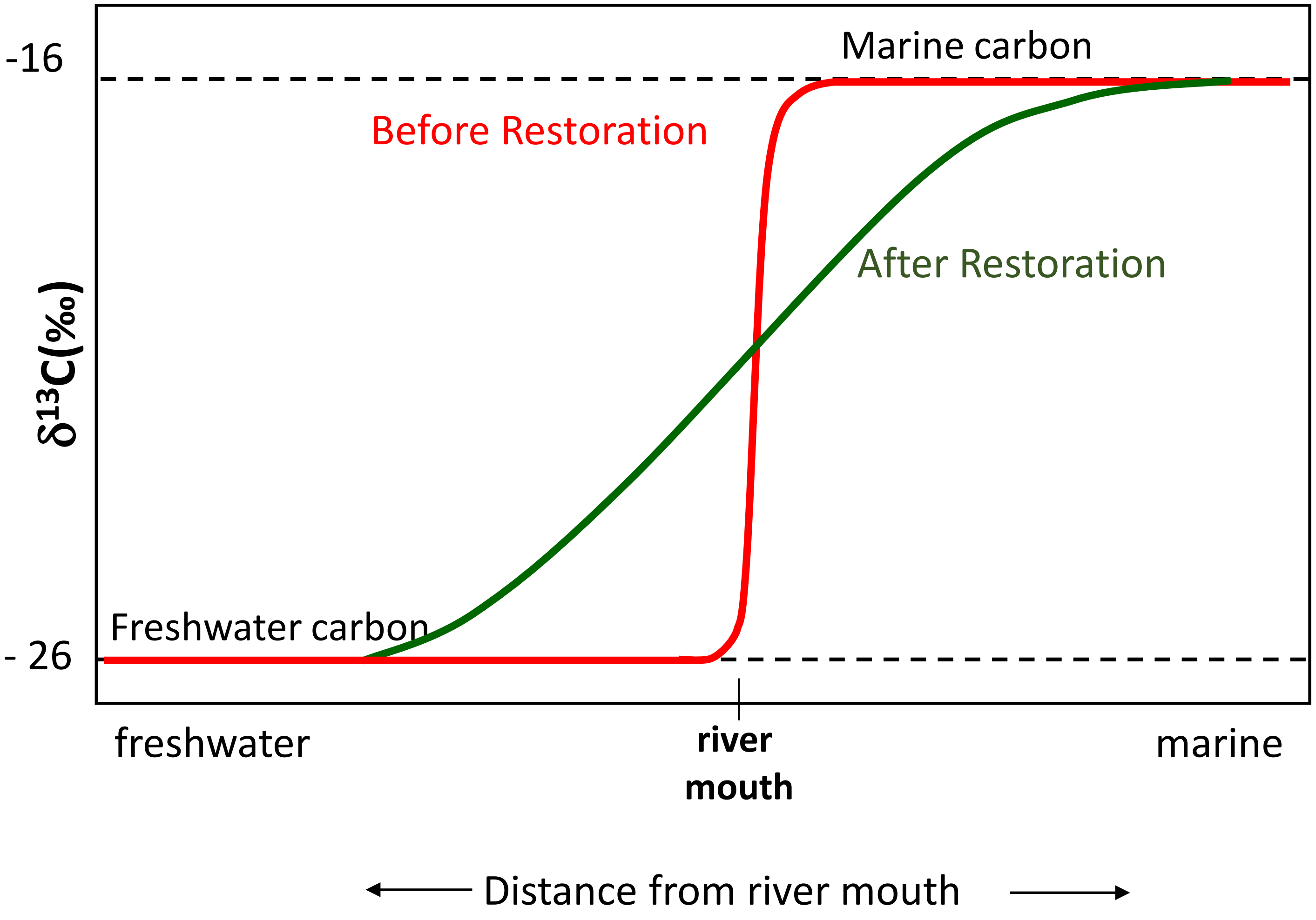


δ ¹⁵N
14
12
10
8
6
4
2
-35
-30
-25
-20
-15
-10
-5
δ ¹³C
Freshwater
Marine
Mussels,U rchins
Mussels, Snails
Primary consumers



Cod
Top predators
Crab, Lobster
Smallmouth bass, Chain pickerel
sunfish
Mussels,Urchins
Primary consumers
Mussels, Snails
δ 15N
δ 13C
Freshwater
Marine
14
12
10
8
6
4
2
-35
-30
-25
-20
-15
-10
-5

Food Web Restoration Indicators: Connectivity



- Greater reliance on prey from non-focal habitats (i.e., marine vs. freshwater) indicating increased marine-freshwater linkages **through anadromous fishes**
- **Measured as change in stable isotope values of target resident species reflecting increased reliance on marine or freshwater biomass**
  - Carbon, nitrogen, sulfur

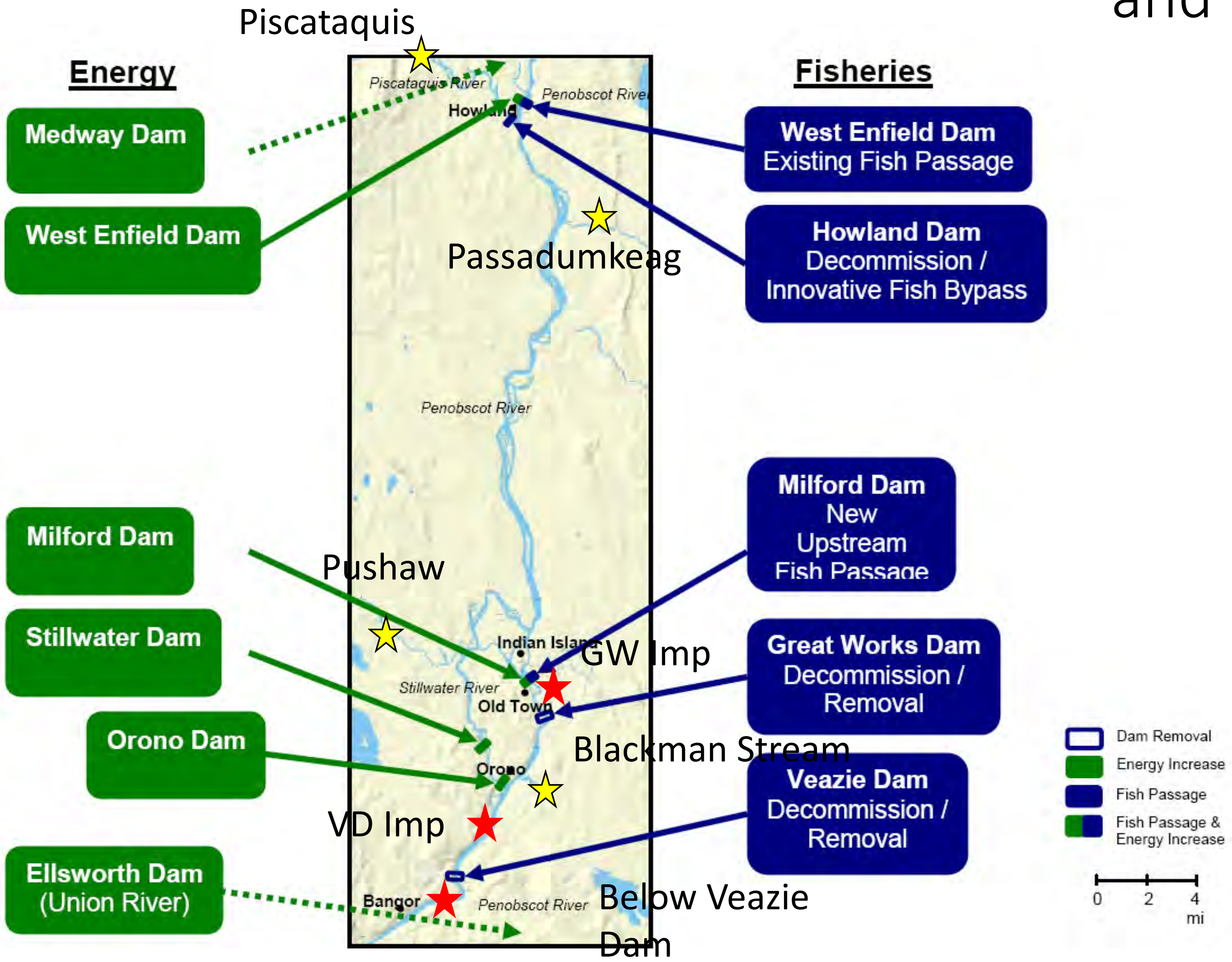
Research goals

- Establish baseline food web structure and marine/freshwater linkages in the Penobscot River watershed & inshore marine <u>before</u> river herring restoration (2009-2010) and after restoration (2020-2021)
- Compare Penobscot River food web to Kennebec River food web where high numbers of river herring should result in enriched (more marine) carbon isotope values and possibly elevated nitrogen isotope values (2010-2011 and 2020-2021)

Field collections

- Dorsal muscle tissue samples from common fish & top predators (bass, chain pickerel, cod, mackerel)
  - freshwater fish collected in collaboration with Penobscot PRRP Fish Surveys (UMaine) or by hook & line (USM)
  - marine fish collected in part in collaboration with MeDMR (Me/NH Nearshore Trawl Survey), GMRI, USM, MCCF Sentinel Survey
  - Larger fish: biopsy plugs & live release
- Tissue samples from food web base
  - primary consumers including snails (benthic algae) & mussels (phytoplankton)
  - secondary consumers (crayfish, crabs, insects)

Freshwater sites: Penobscot River and Tributaries



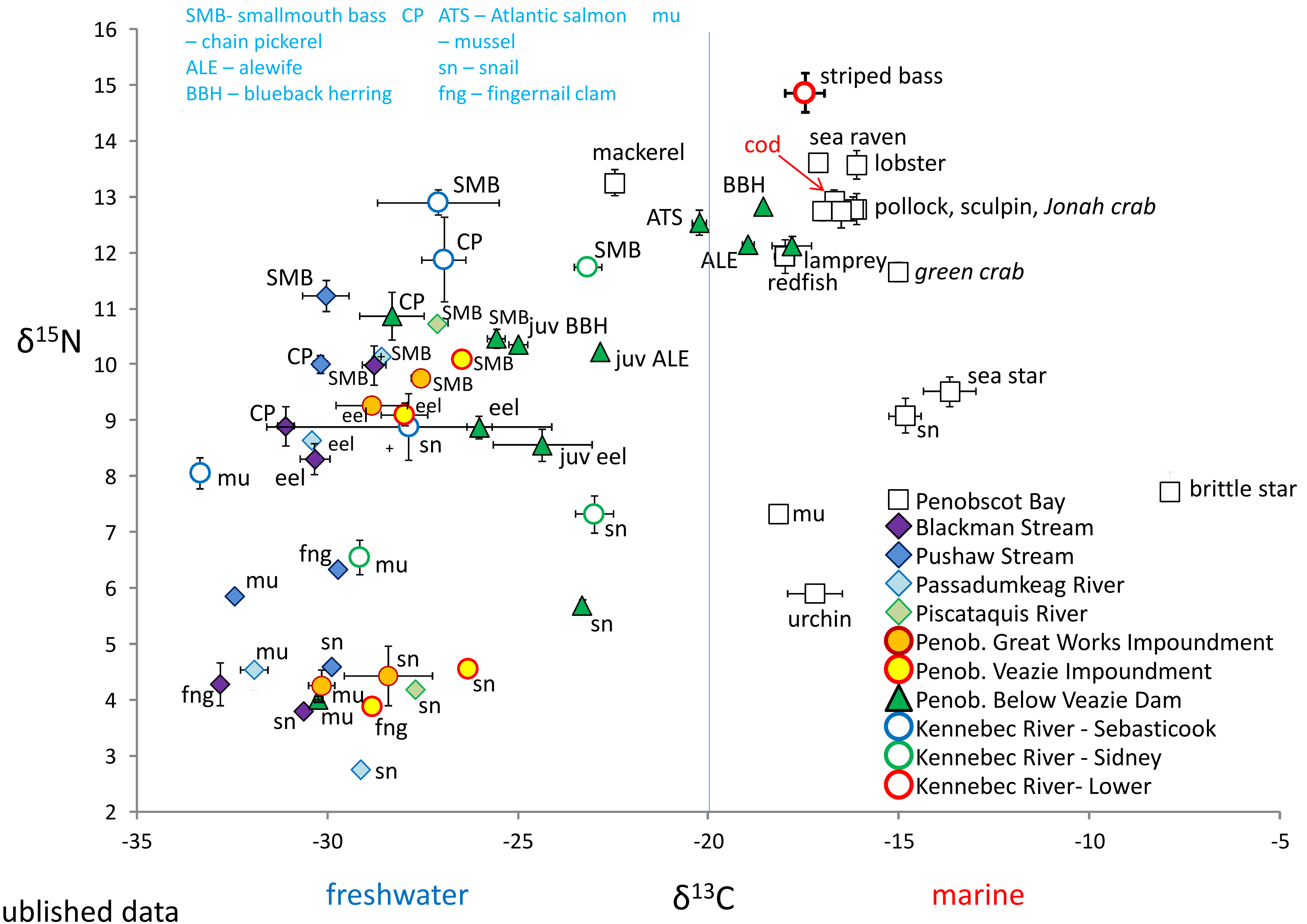
Freshwater sites: Kennebec River and Tributaries

- Sabasticook River (above & below dams)
- Main stem of Kennebec (below Lockwood Dam, Sidney & lower river)

Penobscot River 2009

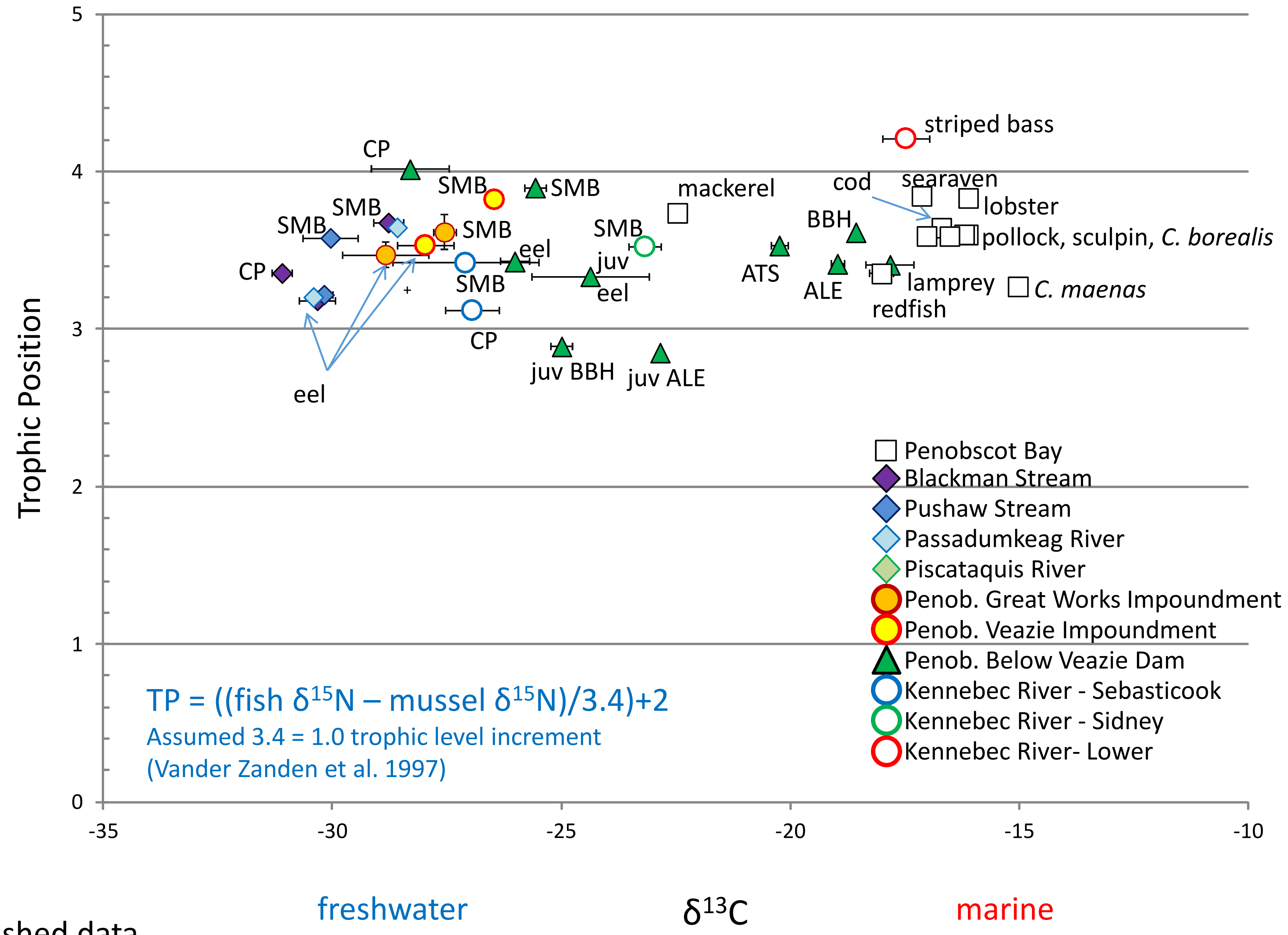
Marine sites: Penobscot Bay

Food Web Structure 2009-2011



Wilson & Sherwood, unpublished data

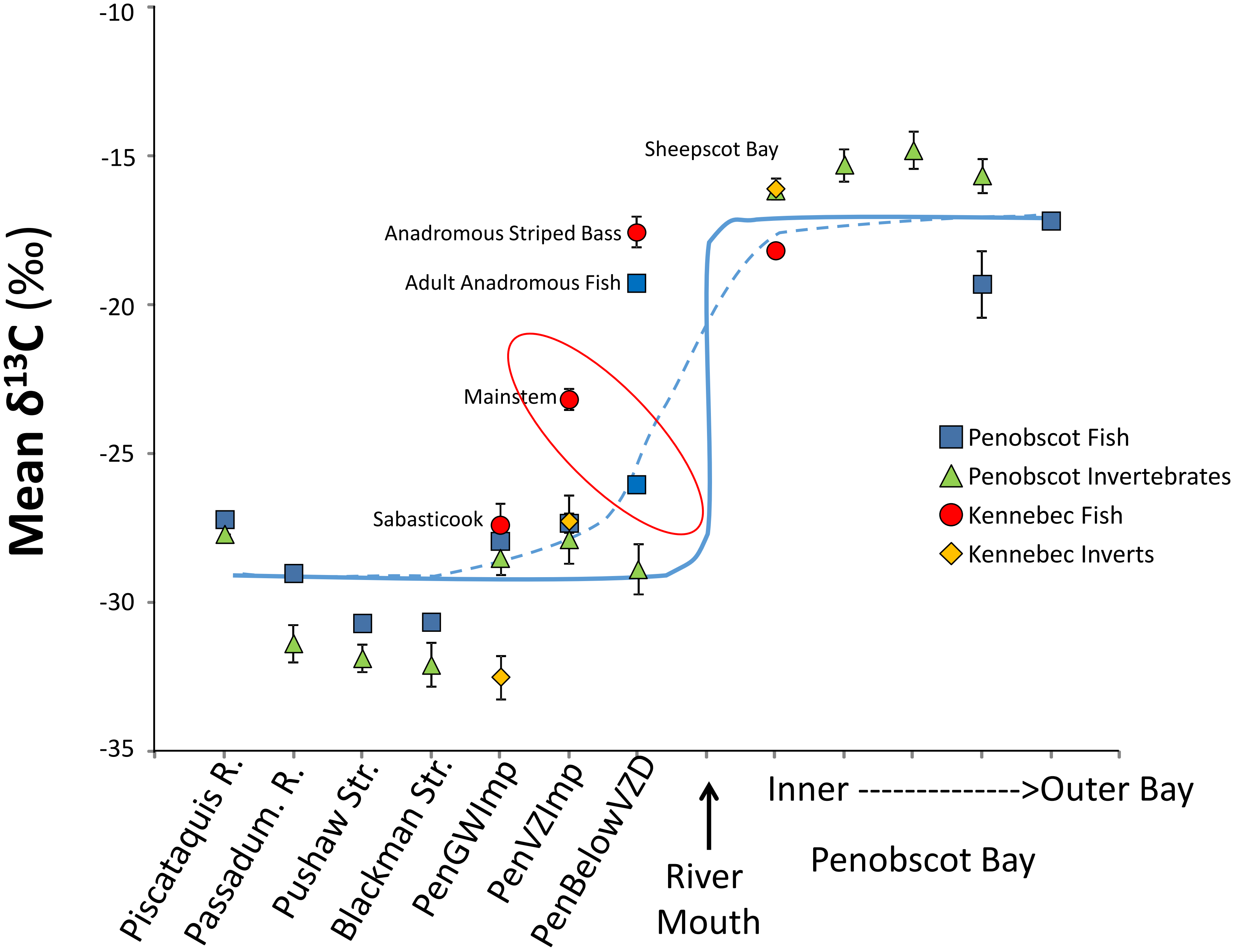
Trophic Position 2009-2011



Wilson & Sherwood, unpublished data

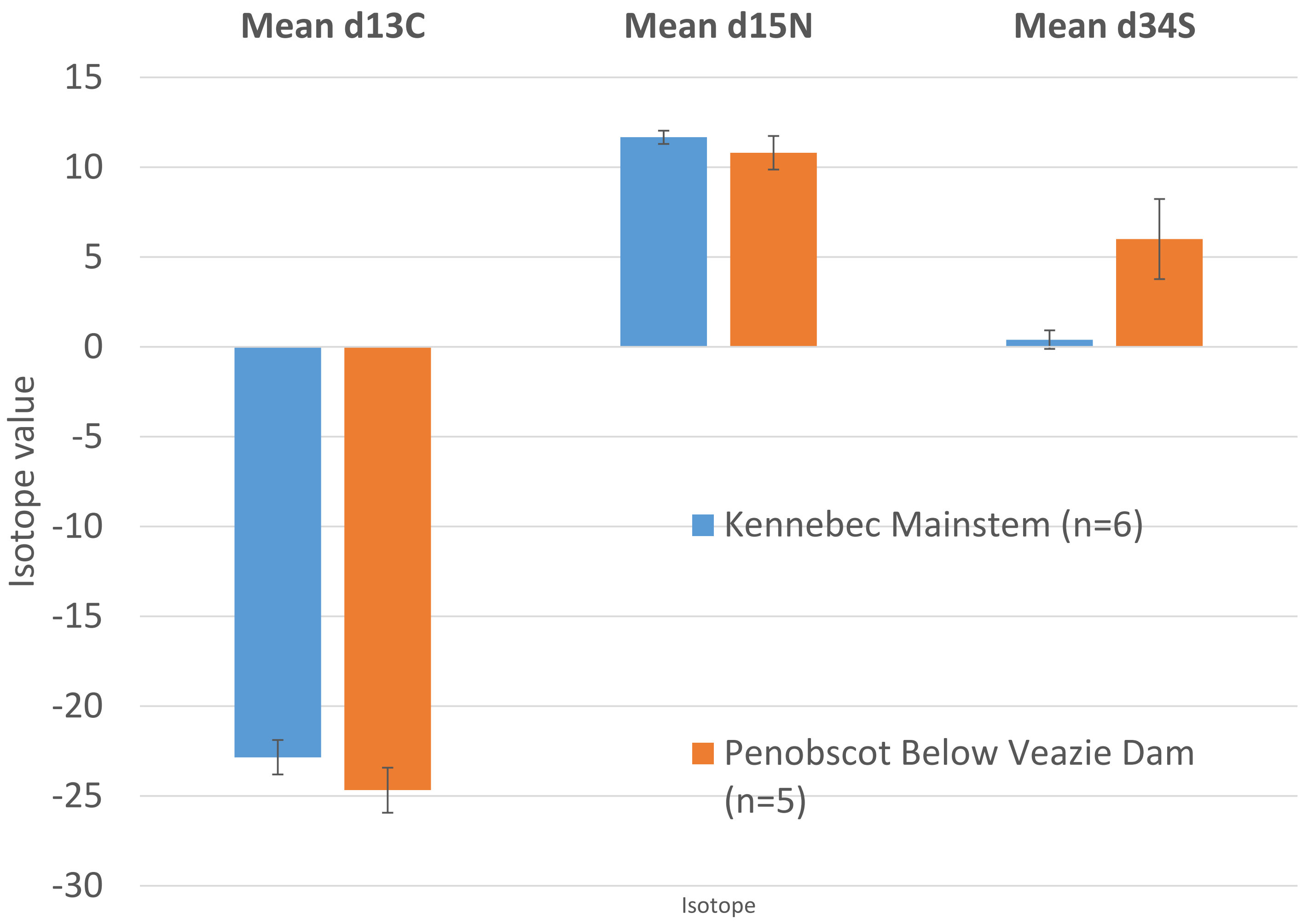
Connectivity (2009-2011)

Our expectation is that post- restoration in the Penobscot we should see more enriched carbon values further upstream, carried there by anadromous fishes returning to spawn.



Wilson & Sherwood, unpublished data

Connectivity – Sulfur (preliminary results)



High sulfur values indicate some marine influence below the (now former) Veazie Dam site on the Penobscot. Sulfur values in the Kennebec indicate little influence of marine-derived nutrients.

Smallmouth bass captured Spring 2010 (Pen) and 2011 (Ken); Data from Wilson unpublished.

Post-restoration sampling

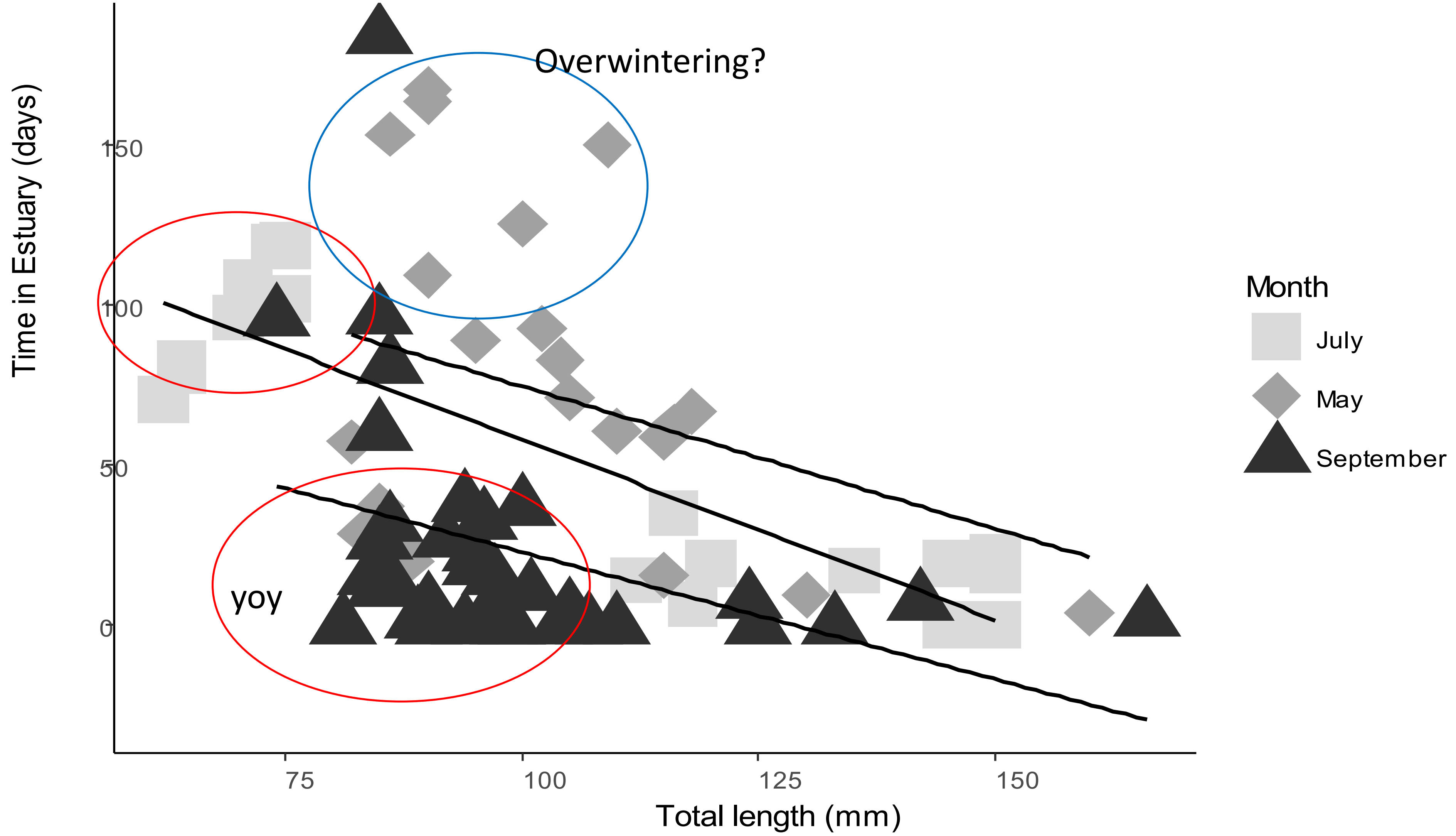
Freshwater

- Fall 2020: Penobscot & Kennebec
- Spring 2021: Penobscot & Kennebec

Marine

- Spring - Summer – Fall 2020/2021: Penobscot Bay (USM, MCCF, & ?) & Kennebec (USM & ?)

Estimated time in estuary (based on stable isotopes of muscle and liver)



Data from A. Webb; Derived using methods of Fuji et al. (2011)

Appendix VIII: The Foraging Ecology and Energetics of Atlantic Bluefin Tuna in the Gulf of Maine: An Unexpected Find

The Foraging Ecology and Energetics of Atlantic Bluefin Tuna in the Gulf of Maine: An Unexpected Find

Sammi Nadeau, Walt Golet,
John Logan, Gayle Zydlewski

Gulf of Maine
Research Institute
Science. Education. Community.

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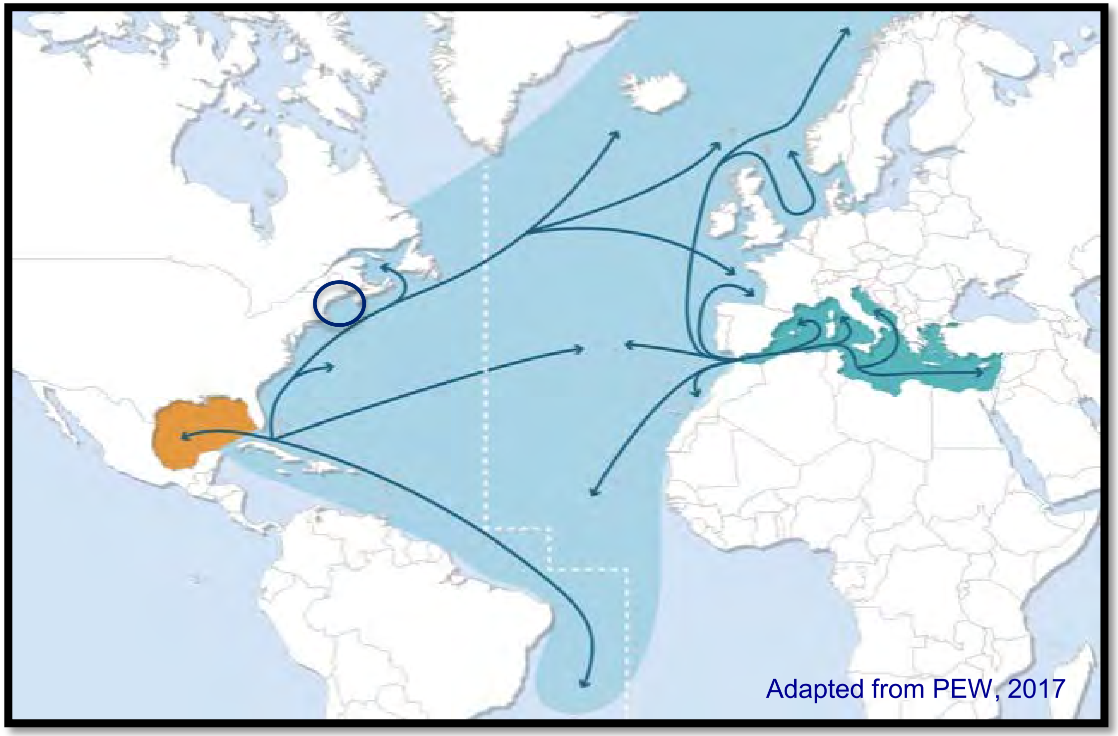
***Background*:**

- Atlantic Bluefin tuna (ABFT) are the largest species of tuna
  - Can grow up to 365 cm in length
  - Can weigh up to 680 kg

- Two individual spawning locations have been accepted
  - Eastern (Mediterranean)
  - Western (Gulf of Mexico)
  - Highly migratory



Introduction

Background:

- ABFT are an iconic GOM species that have been fished since the early 1900s
  - Historic and lucrative
- Presence of ABFT in GOM is due to foraging
  - ABFT are abundant in GOM from June to November
- Typically feed on species such as
  - Atlantic herring (*Clupea harengus;* primary prey item)
  - Atlantic mackerel (*Scomber scombrus*)
  - Sand lance (*Ammodytes spp.*)
  - Silver hake (*Merluccius bilinearis*)
  - Butterfish (*Peprilus triacanthus*)
  - Cephalopods

(Chase, 2002; Logan et al., 2015)

Atlantic herring, Atlantic States Marine Fisheries Commission

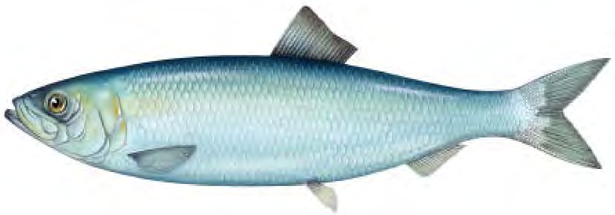
Current Concerns in the Gulf of Maine:

What we know

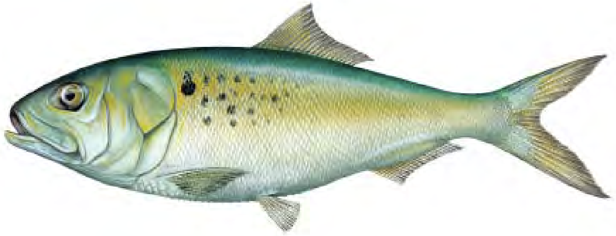
- Diet study hasn't been conducted in ~10 years
- ABFT rely heavily on Atlantic herring
- Atlantic herring population is compromised

What we do not know

- How the reduction of Atlantic herring will impact ABFT
  - Potential prey shifts



Atlantic herring, ASMFC

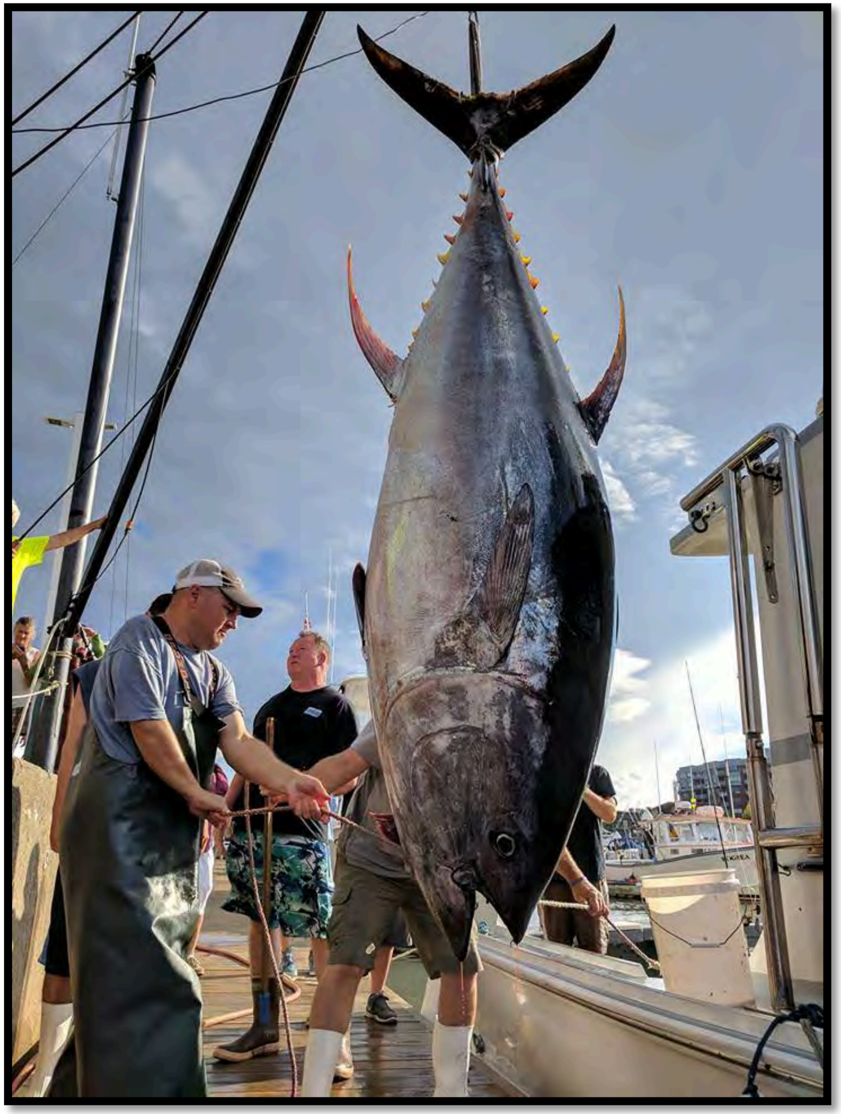


Atlantic menhaden, ASMFC

Objectives

Sampling:

- Collaboration among local GOM fishermen, dealers, and University of Maine/Gulf of Maine Research Institute
  - Weight, length, and sex
- Fishing Tournaments
  - Sturdivant Island Tuna Tournament (Portland, ME)
  - Bluefin Bonanza (Portland, ME)
- Obtaining samples can be difficult
  - Stomachs are a typically discarded at sea
  - Rapid digestion rate



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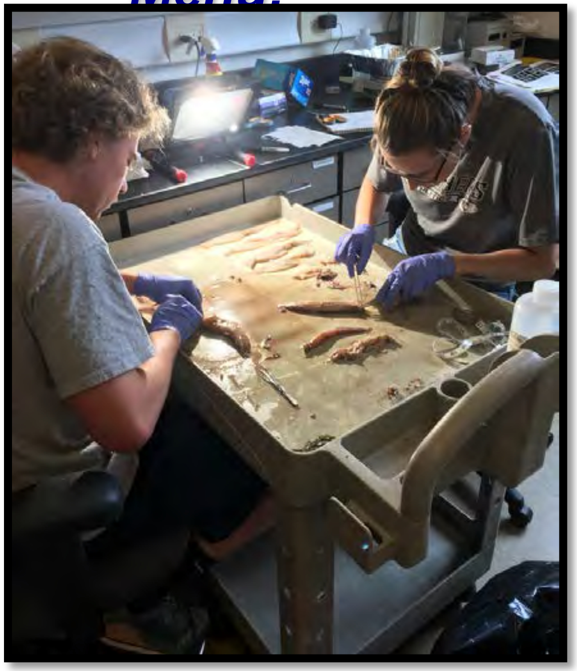
What's On The Menu:



Methods

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Evaluating Stomach Contents:

Identifying Prey Items

Step 1: Visually identify prey item to lowest taxonomic classification

Step 2: Remove otoliths and/or squid beaks

Step 3: Genetic barcoding

Merluccius bilinearis

Peprilus triacanthus

Brevoortia tyrannus

Melanogrammus aeglefinus

Clupea harengus

Scomber scombrus

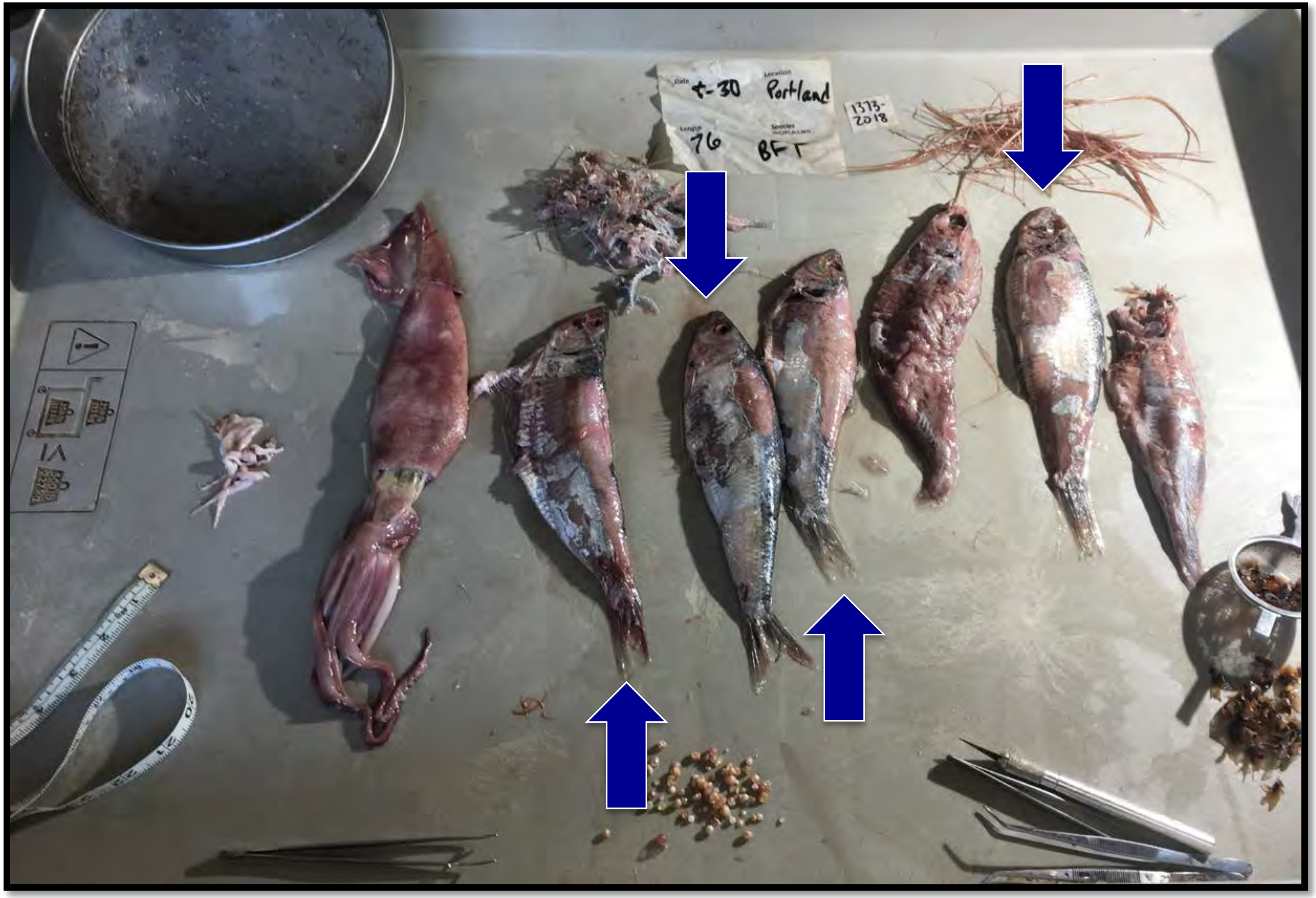
Illex illecebrosus beak

Methods

What Else Is On The Menu:

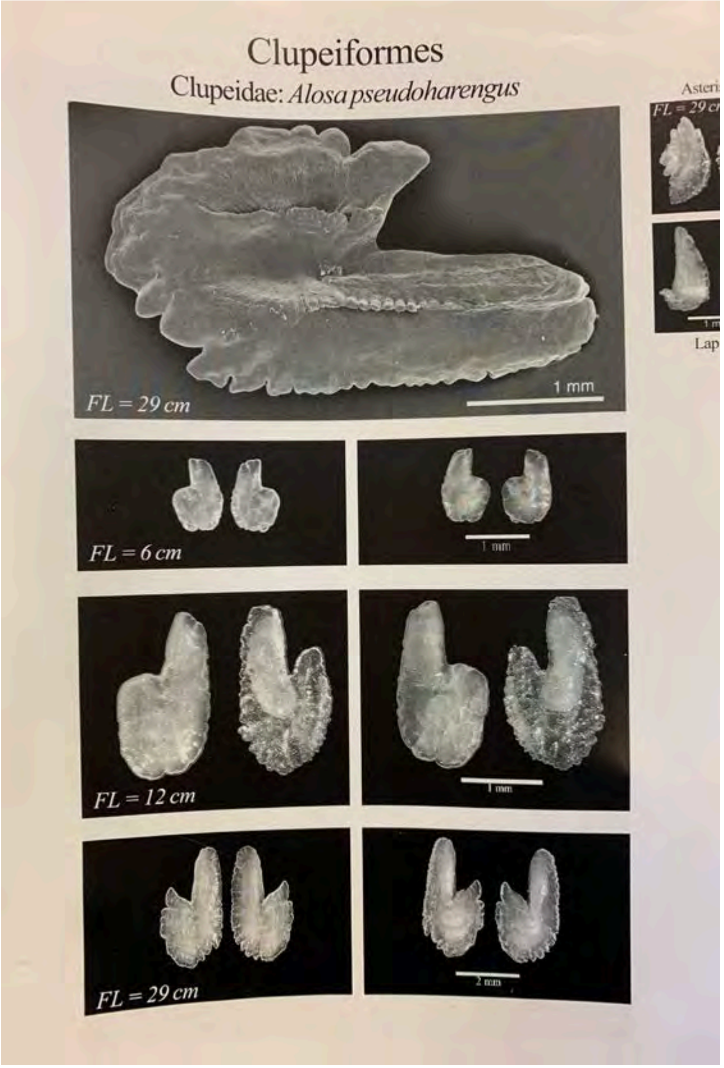
Methods

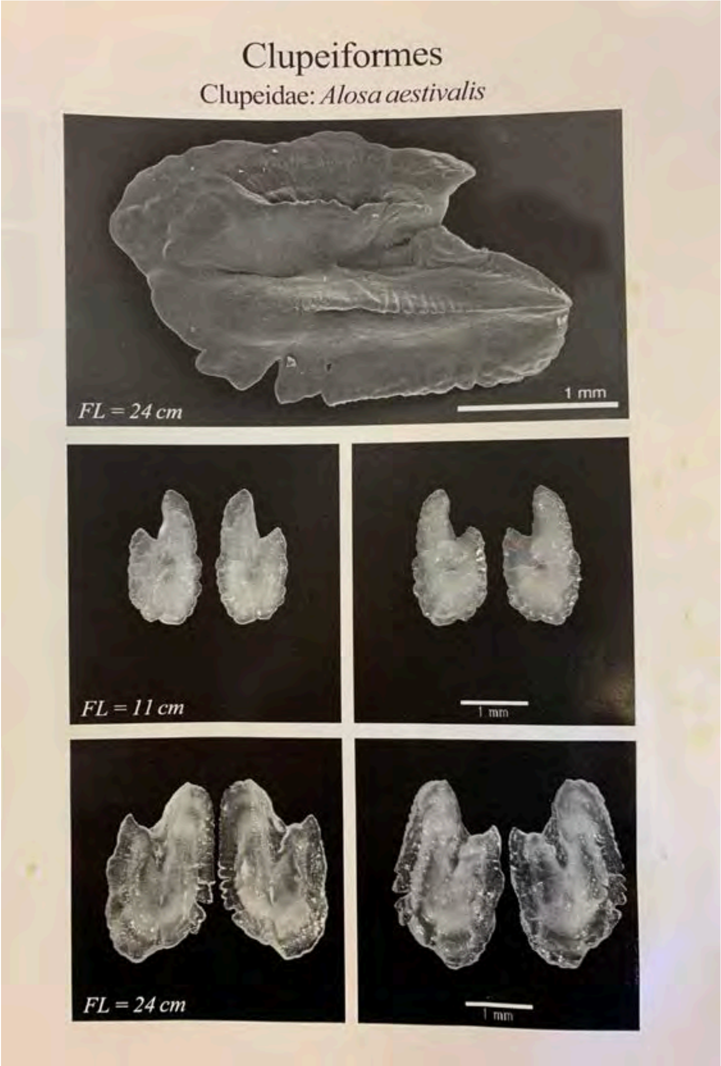
An Unexpected Find:



Methods

An Unexpected Find:





Methods

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An Unexpected Find:

Methods

Percent Presence:

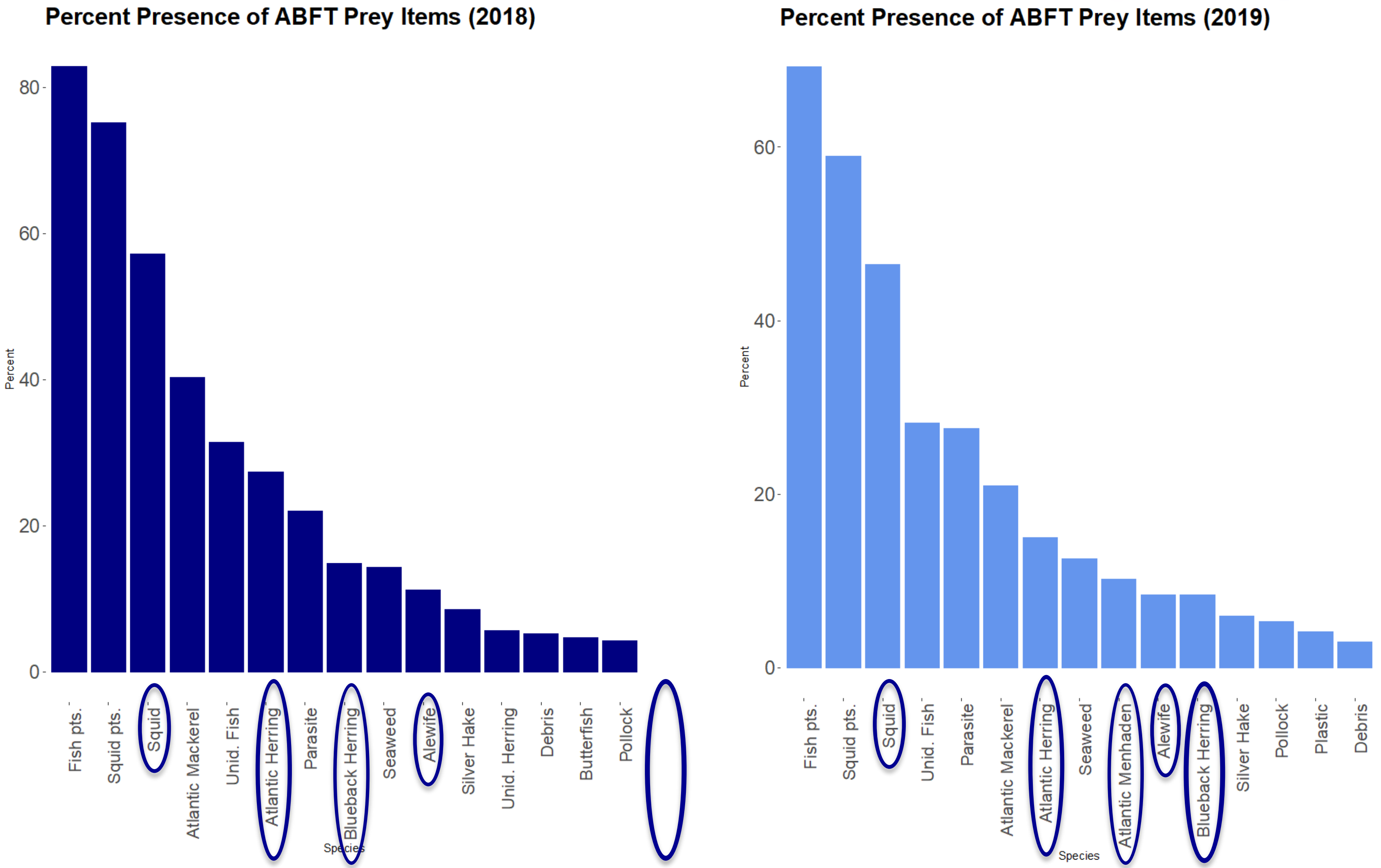

Figure 1: Percent presence of the top 15 species, plastic, debris (acorns, feathers, leaves, etc.) found in Atlantic bluefin tuna (*Thunnus thynnus)* stomachs in the 2018 (n=209) and 2019 (n=166) field season.

Results

Percent Mass:

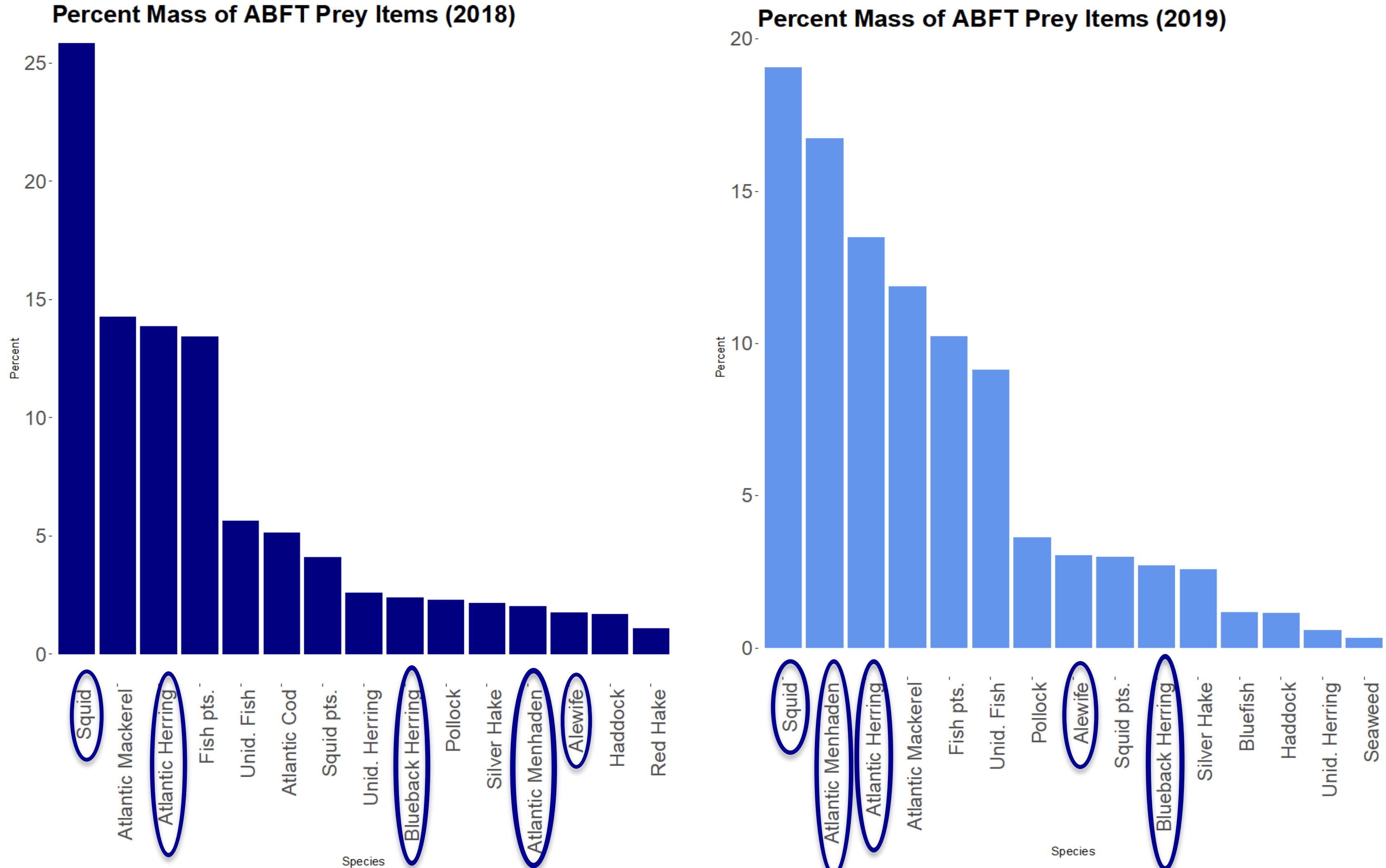

Figure 2: Average percent mass of the top 15 species, , plastic, debris (acorns, feathers, leaves, etc.) found in Atlantic bluefin tuna (*Thunnus thynnus*) stomachs from the 2018 (n=209) and 2019 (n=166) field season.

Results

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Across the Years:

Figure 3: Comparison of Atlantic bluefin tuna *(Thu us thynnus*) prey percent presence with previous GOM diet studies Chase, 2002 (1988-1992) and L an *et al*. 2015 (2004-2008).

Results

Across the Years:

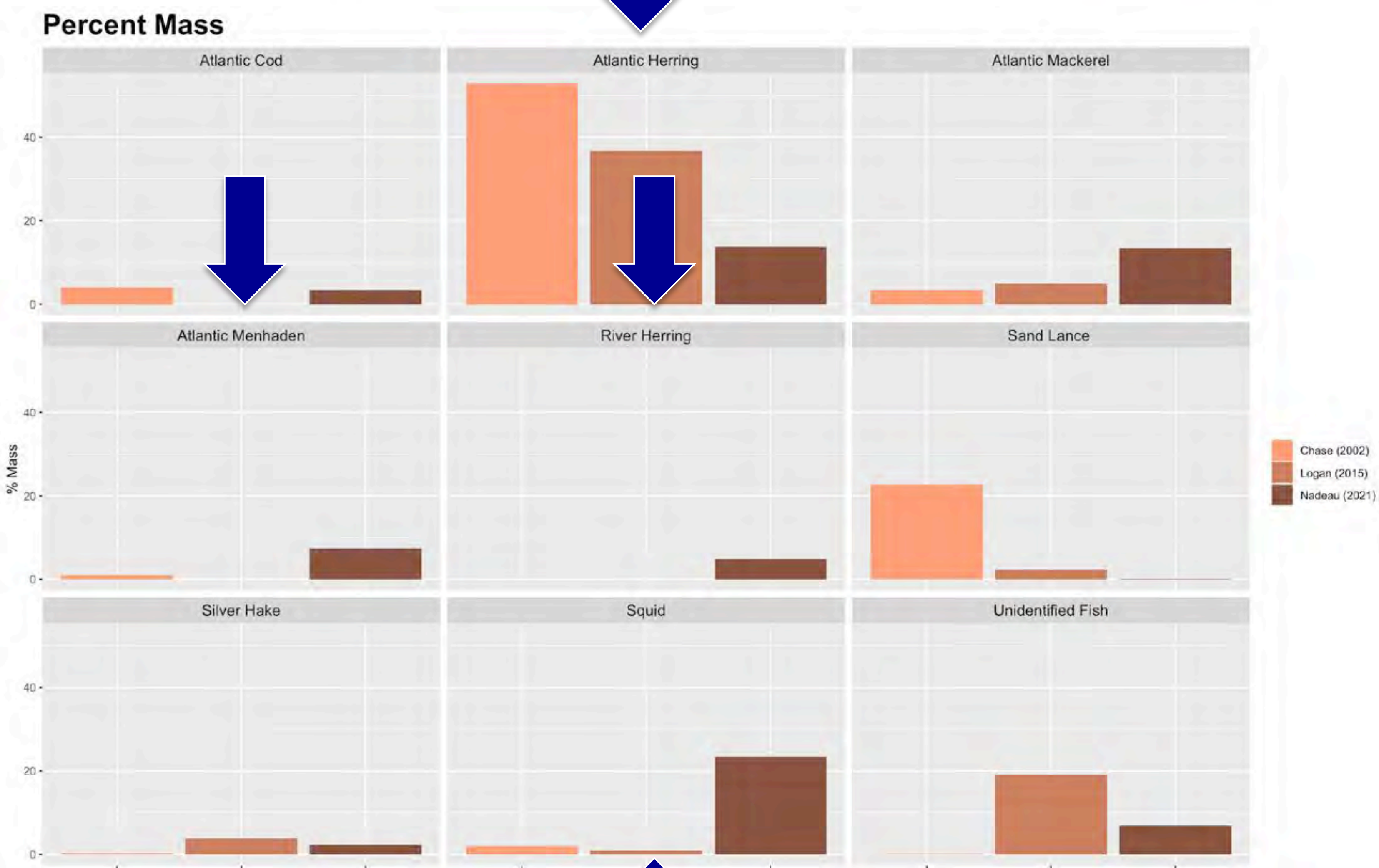

Figure 4: Comparison of Atlantic bluefin tuna *(Thunnus thynnus*) of prey item percent mass with previous GOM diet studies Chase, 2002 (1988-1992) and Logan *et al*. 2015 (2004-2008).

Results

River Herring Specifics:

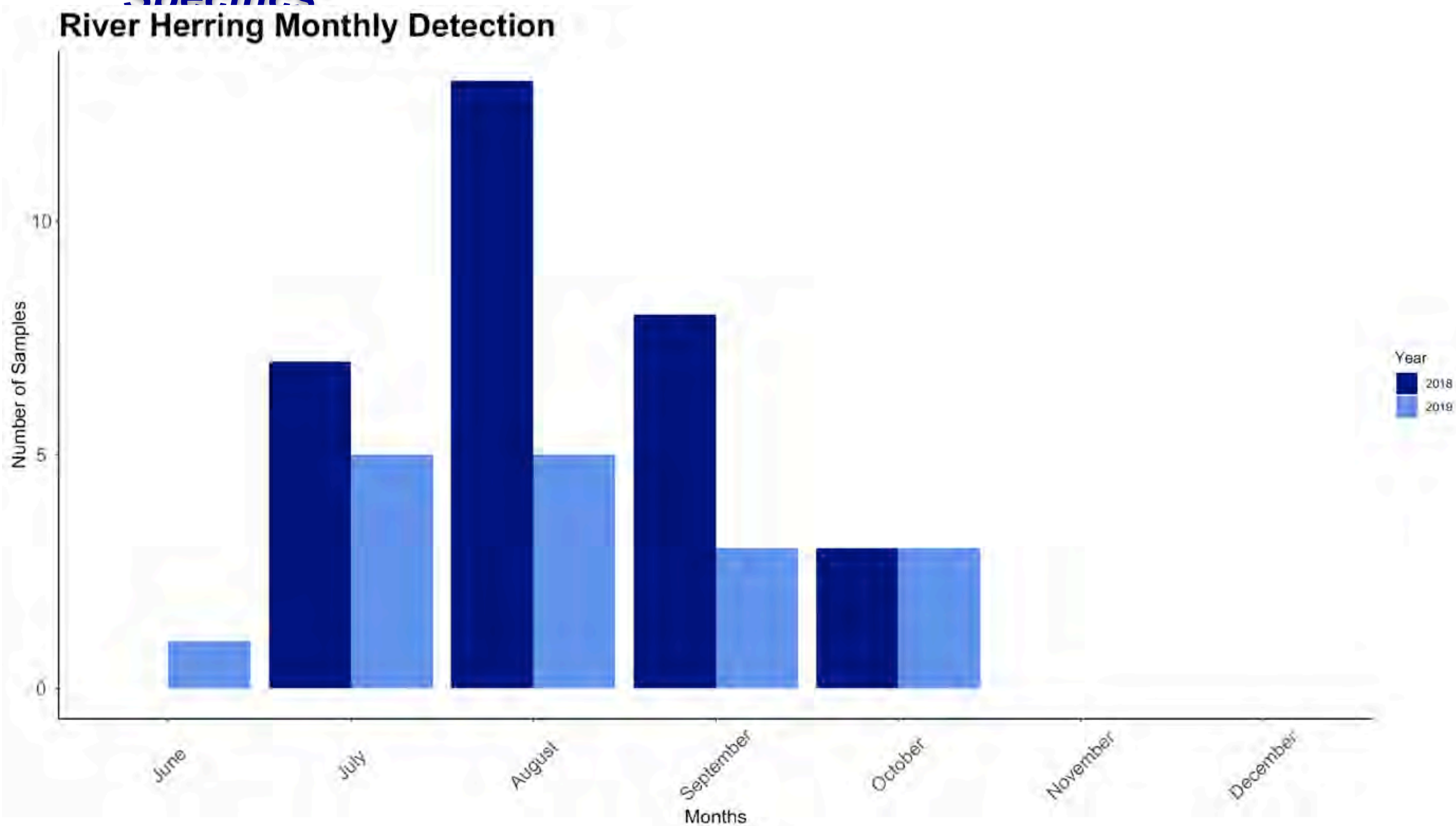

Figure 5: Seasonal Atlantic bluefin tuna *(Thunnus thynnus*) stomach samples containing river herring for both the 2018 (n = 37) and 2019 (n = 23) field seasons.

Results

River Herring Specifics:

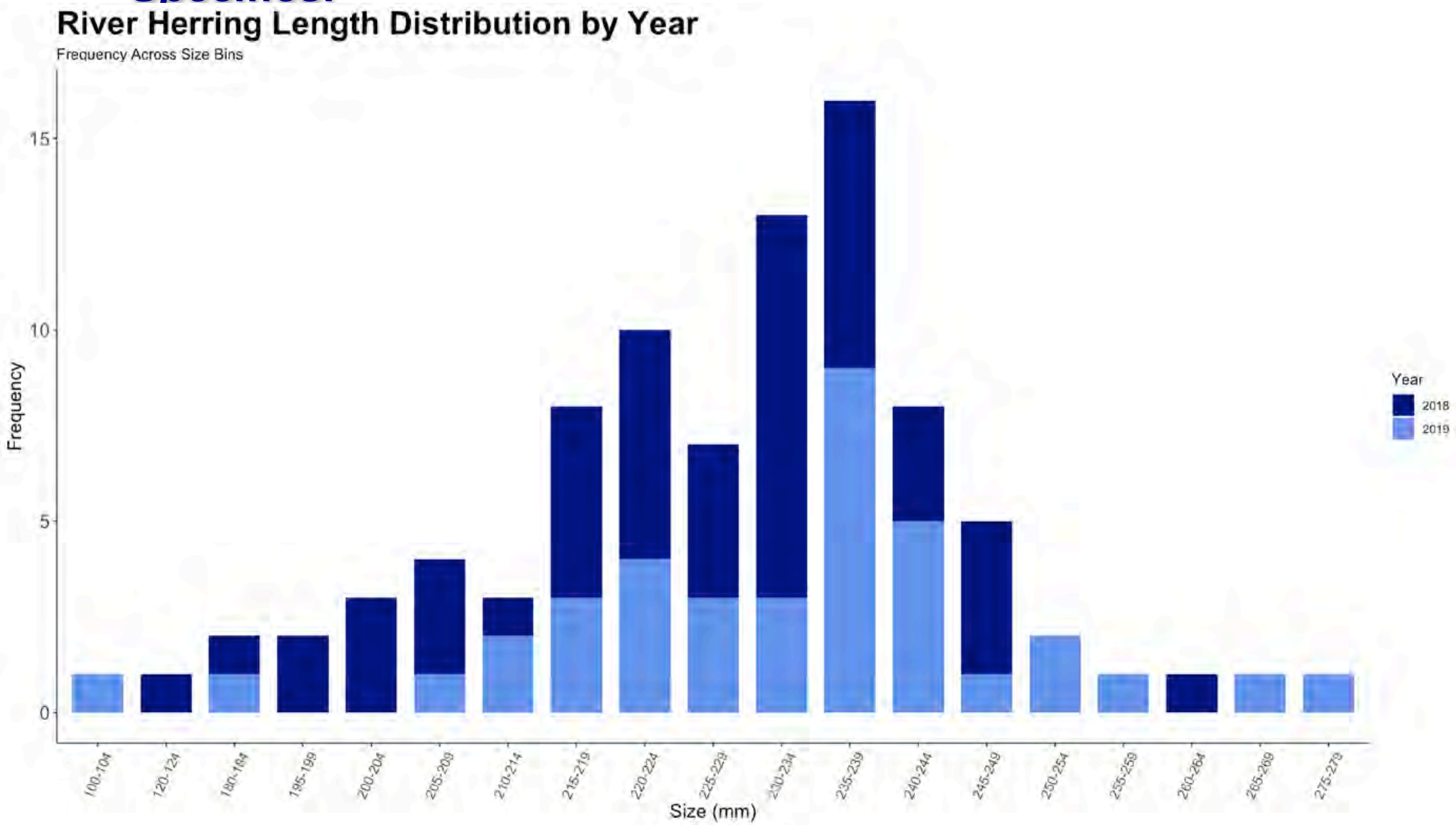

Figure 6: Length distribution of whole, consumed river herring found in Atlantic bluefin tuna *(Thunnus thynnus*) diet from the 2018 (n = 51) and 2019 (n = 38) field season.

Results

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Key Takeaways:

- We are seeing a foraging shift by ABFT in the GOM
    - Atlantic herring → squid/Atlantic mackerel and squid/Atlantic menhaden
- First time we have documented river herring in tuna diet in the GOM in the past 30 years
- Important to the GOM and its fishermen
    - Increased abundance of Atlantic menhaden and rebound of river herring
    - Increased inshore prey availability → tunas forage inshore → happy fishermen

What's Next?

- Complete the energetics and determine condition of tuna and prey items and of ABFT
  - Compare values with previous studies
    - Chase, 2002
    - Logan *et al.*, 2015

- Run stable isotope analysis (SIA)
  - Identify dominant prey items
  - Evaluate potential changes in trophic feeding

Results

Questions?

Contact:
samantha.b.nadeau@maine.edu
snadeau@gmri.org