Coastal Biodiversity Trawl of the Passamaquoddy Bay Area; 2009 to 2014

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ABSTRACT

A coastal biodiversity trawl was conducted within the Passamaquoddy Bay area of New Brunswick, Canada from July to October in 2009, 2011 to 2014. All species captured were identified and enumerated. The sampling effort required to observe 95% of the estimated species richness for the area was 19 to 20 trawl sets per year. Annual changes in the composition of the most abundant species were observed in part due to variable catchability of the trawl when encountering congregations of numerous small species in the water column (such as northern shrimp, jellyfish, Atlantic herring, silver hake). Despite this variability, several dominant species (such as American lobster, winter flounder, and longhorn sculpin) were consistently observed from year-to-year due to a more even distribution throughout the area. A diversity profile of three indices (Shannon-Weiner, Simpson’s, and Fisher’s Alpha) was advocated to capture changes in dominant taxa, sample variability, and species richness. Changes in indices were compared against historical environmental trends for temperature, salinity, and chlorophyll. A relationship between biodiversity and the environment was not observed due to the limited time series. Further sampling and a species-by-species examination were recommended as future considerations for this project. Size-frequency distribution and condition factor (fish only) were calculated for commonly caught species (such as alewife, Atlantic herring, longhorn sculpin, silver hake, winter flounder, American lobster). Catch size-frequency and condition where compared to known sizes at maturity and against a 15-year average condition for the Scotian Shelf and Bay of Fundy to assess the role of the Passamaquoddy Bay area in the life history of these organisms. This information established a baseline for biodiversity in this area to support monitoring of long term change.

RÉSUMÉ

Un relevé au chalut de la biodiversité côtière a été mené dans la zone de la baie Passamaquoddy au Nouveau-Brunswick (Canada) en 2009, et de 2011 à 2014, de juillet à octobre. Toutes les espèces capturées ont été identifiées et dénombrées. L’effort d’échantillonnage qui a été nécessaire pour observer 95 % de la richesse estimée des espèces de la zone était de 19 à 20 traits de chalut par année. Les changements annuels observés dans la composition des espèces les plus abondantes étaient en partie causés par la variabilité de la capturabilité du chalut lorsqu’il rencontrait des rassemblements de nombreuses petites espèces dans la colonne d’eau (comme la crevette nordique, les méduses, le hareng de l’Atlantique et le merlu argenté). Malgré cette variabilité, plusieurs espèces dominantes (comme le homard, la plie rouge et le chaboisseau à dix-huit épines) ont été observées de façon constante d’une année à l’autre en raison d’une répartition plus égale dans l’ensemble de la zone. Un profil composé de trois indices de diversité (Shannon-Weiner, Simpson et alpha de Fisher) a été préconisé pour déceler les changements liés aux taxons dominants, à la variabilité d’échantillonnage et à la richesse des espèces. Les variations des indices ont été comparées aux tendances environnementales historiques relatives à la température, à la salinité et à la chlorophylle. On n’a pas observé de relation entre la biodiversité et l’environnement, car la série chronologique était restreinte. D’autres échantillonnages et un examen espèce par espèce ont été recommandés pour des considérations futures dans le cadre de ce projet. La répartition par fréquence de taille et le coefficient de condition (poissons seulement) ont été calculés pour les espèces les plus souvent pêchées (comme le gaspareau, le hareng de l’Atlantique, le chaboisseau à dix-huit épines, le merlu argenté, la plie rouge et le homard). La fréquence et la condition des prises ont été comparées aux tailles connues à la maturité et à la moyenne de la condition sur 15 ans pour la plate-forme Néo-Écossaise et la baie de

Fundy afin d'évaluer le rôle de la zone de la baie Passamaquoddy dans le cycle biologique de ces organismes. Cette information a permis d'établir une base de référence pour la biodiversité dans cette zone qui contribuera au suivi des changements à long terme.

PREFACE

This document describes the data that has been collected for coastal biodiversity research in the Passamaquoddy Bay area and to monitor long-term change in local species presence, habitat utilisation, and health. The sampling activities were also intended to support other research programs including lobster and herring fisheries, research on the role of climate change in coastal areas, alternate species for integrated multitrophic aquaculture, and information for monitoring, assessment, and advice to present and future human activities in coastal areas.

1 INTRODUCTION

The Passamaquoddy Bay Area (Figure 1) is an inlet, located at the Southwestern end of the Bay of Fundy. It is bounded by the Canadian province of New Brunswick and the U.S. State of Maine. It has historically been an area of high productivity with fisheries dating back 10,000 years to the Passamaquoddy tribes, with many fisheries still holding cultural significance (Larsen 2004). Over the last fifty years, the coastal areas of the Bay have come under increasing pressure from both recreational and industrial use, mainly in the form of the fisheries and the aquaculture industry. In 2012 there were 1644 registered fishers in Southwest New Brunswick operating nearly 600 vessels (Cheney 2013). Concurrently there has also been increasing importance placed on Eco-tourism and its place in the economy of Southwest New Brunswick and the Bay of Fundy area in general. Historically, surveys had been conducted throughout the Bay, primarily to assess the health of individual commercial fish stocks (examples are Graham 1936, Dow and Baird 1960, Robichaud and Campbell 1991). While species specific information of this type continues to be valuable as a basis for periodic comparison, the importance of long-term surveys to establish baseline information for a broader range of species has long been understood (Moore 1977; Quinn 1980). Studies such as the MacKay seasonal survey from 1964-1978 (MacKay et al. 1978) and the MacDonald survey from 1976-1981 (MacDonald et al. 1984) offered methods and opportunity to monitor annual trends for a diversity of species and habitats. Despite these studies, the last 30 years have not seen systematic long-term monitoring of species presence and distribution in this area (with the notable exceptions of phytoplankton monitoring associated with shellfish toxicity and the presence of *Alexandrium fundyense*, (Martin et al 2014); and benthic monitoring associated with aquaculture, (Wildish et al. 1993)) leaving somewhat of a gap in our understanding of long-term species presence, migration, and habitat utilisation.

More recently, the Passamaquoddy Bay and surrounding areas were examined as candidates for designation as Ecologically and Biologically Significant Area (EBSA) in the Bay of Fundy (Buzeta and Singh 2008). This candidacy was based on criteria associated with the perceived uniqueness of the region; the aggregation of species, commercial or rare; and the contribution that the area plays with respect to species fitness (DFO 2004). The wealth of historical information, the number of important fisheries that take place within the area,and unique oceanographic conditions of tide, temperature and coastal relief make the Passamaquoddy Bay area a strong candidate for EBSA status. Several components of the area such as Head Harbour, West Iles, The Passages along with The Wolves and Macey's Bay, were recommended for designation as EBSAs, it was understood that the entire area acts as a larger ecological unit. "The Quoddy Region operates as a whole, and it is likely unique and irreplaceable for all of the Bay of Fundy" (Buzeta and Singh 2008). Based on this understanding, the authors believe that some level of long-term monitoring should be conducted to provide a measure of species and environmental changes in this unique ecosystem.

The establishment of a coastal biodiversity trawl survey seeks to remedy some of the current knowledge gaps by providing a degree of long-term baseline information on at least one component of the marine fauna in and around Passamaquoddy Bay. The objectives of this project are to better understand the sampling required to establish a baseline of species presence in the coastal zone such as Passamaquoddy Bay. In addition, a systematic measure of species presence over time can be used as a basis for further hypothesis testing of spatial and temporal variability (in relation to; sampling design, species migration patterns and life cycles, environmental conditions, and habitat). This data can be used to provide fundamental information to asses and report on the health of the Passamaquoddy Bay and the surrounding waterways.

2 METHODS AND MATERIALS

2.1 STATION LOCATION

For the purposes of this survey, the Bay was divided into four zones, the St. Croix Estuary (A), the Upper Bay (B) and Lower Bay (C) and the Outer Bay (D) (Figure 1). The categorization of these areas was based on historical sampling areas (MacDonald et. al. 1984), to allow long-term comparison, and on hydrographic zones of temperature and salinity as defined by Robinson et al. 1996. Respecting these areas, stations were randomly chosen throughout the summer season from early July through October in 2009, 2011 to 2014, with a goal to sample all areas over a two day period each month (Figure 1). To date, only this limited period was sampled to avoid interactions with annual fixed gear fisheries in the spring (March 31^{st} to June $29^{th)}$ and autumn (2^{nd} Tuesday in November to January 14^{th}).

Most trawls were conducted for 30 minutes at approximately 2.4 knots. Shorter trawls were required in some locations to avoid obstacles. As a result, abundance and biomass information was assessed on a per minute trawl basis. In 2009, aboard the CCGS Pandalus IV, a demersal trawl with a headline of approximately 13.7 m and a groundline of

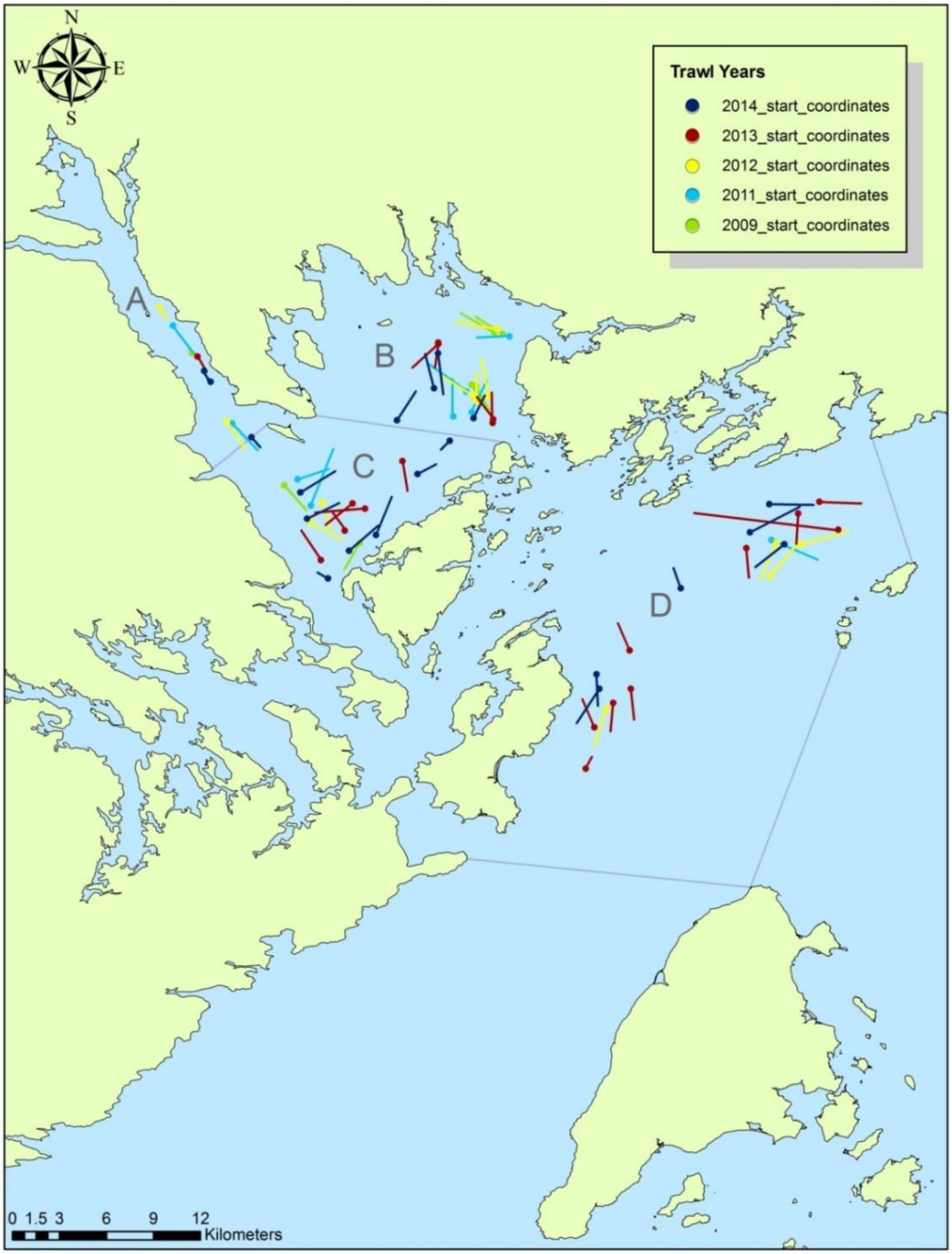

Figure 1. Passamaquoddy Bay area map illustrating sampling zones and trawl transects that were conducted from 2009-2014 (excluding 2010). Zone A - St. Croix Estuary, Zone B - Upper Bay, Zone C – Lower Bay, Zone D - Outer Bay.

18 m was used. The groundline was rigged with a rock hopper footrope using 12” and 7” discs. Mesh size was 1.6mm (#2444) x 50 mm at cod end (measured 42 mm knot to knot) and a 24 mm liner. Since 2011, all trawls have been conducted aboard the CCGS Viola M. Davidson, using a slightly smaller trawl gear, 12.5 m headline and 16.5 m rockhopper footrope but with same mesh sizes. A comparative survey was not conducted, and therefore changes in catch in 2009 compared to 2011 and onward cannot be fully quantified.

2.2 META DATA

Meta data collected during each trawl included: Set number, date, vessel, start time, end time, start location, end location, start depth, end depth, average depth of cod end, and average water temperature at cod end (see Appendix 2). Start and end positions and depths were based on vessel sounder and position. Depth and temperature at cod end were recorded every 30 seconds using a pressure temperature logger (Onset HOBO pressure temperature logger U20-001-03-TI).

2.3 CATCH DATA

The objective for each tow was to identify all species captured and to generate an accurate assessment of species abundance, size frequency, and biomass either directly or through an objectively quantifiable estimate. As an all species survey, catch measurements vary by taxa, the number of individuals typically encountered per tow, and in consideration of the most time efficient manner to the survey objectives. For all species, size and weight were recorded for up to 50 randomly selected individuals per tow while the remainder of the catch was counted and weighed. For high abundance species in which a total count would require too much time, the subsampled biomass of 50 individuals was used to estimate an average weight per individual and the total abundance estimated based on this average and the total species biomass for the tow. Weight was recorded using one of three calibrated electronic marine balances (Marel PL2260 Dual Range Marine scale accurate to 1 g up to 3 kg and 2g up to 6 kg, Marel 1100, or a Scanvaegt 8526 Marine Scale accurate to 5 g up to 15 kg). Length was recorded to the nearest millimeter (mm), using either a measuring board or analog measuring calipers. Specific size measurements by organism type were:

Fish

Size of fish based on total length (mm) and weight (g) of all individual fish per species was recorded for a sub sample of up to 50 individuals. The remaining catch was counted except in rare instances when the abundance exceeded our capacity to count all individuals in a timely fashion. For very high abundances a total catch weight was used to estimate species abundance based on the average weight per individual from the subsample.

Crab

Size of crab (excluding hermit crabs) was based on maximum carapace width (mm) including spines. All individuals per species were counted and weighed as above. Hermit crabs were identified, counted and weighed whole with the inclusion of the salvaged shell. This resulted in an overestimate of biomass for this taxa.

Lobster

For the American lobster (*Homarus americanus*), carapace length (mm), weight (g), and sex were recorded for up to 50 randomly selected individuals. Carapace length (CL) was measured from the eye cavity to the posterior edge of the carapace. For catches exceeded 50, all remaining lobsters were counted and total biomass was estimated based on the subsample for each tow. Indivdual lobster weight (wt) was not recorded in 2009, 2011, and 2012. Biomass reported for those years was based on estimates calculated from the regression ln(wt) = 2.647 x ln(CL) – 5.540, Adjusted R^2 = 0.841 (Table 1) based on data previously obtained in the Passamaquoddy Bay area (Waddy 2012). The protocol for future trawls was amended and individual weights for the sub-sample were taken at sea after 2012.

Table 1. Linear regression of weight (wt) in grams versus carapace length (CL) in mm for American lobster (*Homarus americanus)* in Passamaquoddy Bay (Waddy 2012). Dependent variable ln(wt). Independent variable ln(CL). Sample size (n) = 120.

	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
Model	B	Std. Error	Beta	t	P-value	Lower Bound	Upper Bound
Constant	-5.540	.473		-11.719	.000	-6.476	-4.604
ln(CL)	2.647	.106	.918	25.067	.000	2.438	2.856

Bivalves including scallop

Shell height (SH), hinge to outer rim, of live unbroken shells was measured to the nearest mm using calipers for up to a subsample of 50 individuals. The total weight (g) and count of each taxon included live broken shells. It should be noted that weights for bivalves were recorded periodically but not consistently. Estimates of deepsea scallop (*Placopectin magellanicus*) biomass were based on a regression ln(wt) = 3.272 x ln(SH) – 10.145, Adjusted R^2 = 0.847 (Table 2) from data collected in the Passamaquoddy Bay (Robinson 2012). Estimates of biomass for other bivalves from 2009 and 2011 were based on data obtained from tows of that year. Beginning in 2012 total biomass was recorded at sea for all bivalves.

Table 2. Linear regression of weight (wt) in grams versus shell height (SH) in mm for deepsea scallop (*Placopecten magellanicus)* in Passamaquoddy Bay (Robinson 2012). Dependent variable ln(wt). Independent variable ln(SH). Sample size (n) = 87.

	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
Model	B	Std. Error	Beta	t	P-value	Lower Bound	Upper Bound
Constant	-10.145	.700		-14.487	.000	-11.537	-8.753
ln(SH)	3.272	.150	.921	21.855	.000	2.975	3.570

<u>Other invertebrates</u>

The number of individuals and total weight by species was recorded for invertebrates such as shrimp, urchins, cucumbers, anemones, and sea stars. For instances in which a large number of individuals were captured (generally greater than 200) a sample of 50 individuals was weighed and used to estimate total abundance for that tow.

2.4 DATA ANALYSIS

<u>Species abundance and biomass</u>

Total number by species were used to assess changes in abundance of the most dominant species with respect to number of trawls and zones sampled. For tows that captured very high abundances of a species, the total number was estimated based on the average individual weight from a subsample of 50 multiplied by the total weight of that species in the tow. Total abundance and biomass per species were standardised per minute trawl to evaluate inter-annual trends and correlation with environmental and biodiversity indices. Biomass data was not collected in 2009.

Species richness and diversity

The accumulated number of taxa observed versus sampling effort was compared for each year. The Michaelis-Menten estimates of species richness were used to assess sampling completeness (Seaby and Henderson 2007) in terms of percent of species observed against the calculated estimate of species richness for each year and within zones. A plot of log abundance versus log species rank and a log series model fit test was applied to the data prior to calculating parametric diversity indices as many such indices assume a logarithmic decrease in abundance (Seaby and Henderson 2007). Three diversity indices were calculated to establish a diversity profile (Leinster and Cobbold 2012) for reporting changes in species presence and abundance without relying on any one index. Shannon-Wiener, although not independent of species richness (Smith and Wilson 1996) is calculated because of its general use in ecology and has some sensitivity to relative changes in dominant species (Seaby and Henderson 2007); Simpson's provides information on relative changes in sample variance (Camargo 1993, Smith and Wilson 1996, Seaby and Henderson 2007); and Fisher's Alpha is a standardised approximate for the number of species represented by a single individual and is independent of sample size (Seaby and Henderson 2007).

Environmental Indices

Annual fluctuations in temperature, salinity, and chlorophyll (since 2001) within the Passamaquoddy Bay area have been monitored monthly since 1990 using a Seacat SBE19 for temperature (accuracy of 0.01 ^{o}C, precision 0.005 ^{o}C), conductivity (accuracy of 0.001 S/m, precision 0.0005 S/m) and a Wetlabs WS3S flourometer for Chlorophyll-a (sensitivity 0.03 ug/l) (Robinson et. al. 1996). This data was normalised for the period of March to October to produce standardised environmental indices for the sampling period. The period chosen represents environmental conditions for months just preceding and during the survey. Indices (k_{Temp}, $k_{Salinity}$, $k_{Chlorophyll}$) are calculated as their parameter mean from March to October for the current year (u_C) minus each long term parameter mean from March to October for the previous time series (u_L) divided by the standard deviation of this long-term mean (σ_L) and are a standardised index commonly applied to monitoring environmental change (Wilks 2011). Information on instrument calibration and error was currently lacking and should be addressed to support in-depth analysis of environmental change and species diversity.

Size frequency distribution and condition indices

The size frequency distribution was determined for six of the most commonly observed species alewife (*Alosa pseudoharengus),* Atlantic herring *(Clupea harengus),* silver hake *(Merluccius bilinearis),* longhorn sculpin *(Myoxocephalus octodecemspinosus),* winter flounder (*Pseudopleuronectes americanus),* and American lobster *(Homarus americanus)***.** Based on the 50 randomly selected individuals from each tow, sizes were binned into 10 mm increments and the accumulated frequency at size is reported for the sample year. The condition factor for five commonly observed fish species: alewife (*A. pseudoharengus),* Atlantic herring *(C.harengus),* silver hake *(M. bilinearis),* longhorn sculpin *(M. octodecemspinosus),* and winter flounder (*P. americanus)* was calculated using the formula $\frac{10^N * W}{L^3}$ where N=5 (constant), W= weight in g, and L = total length in mm (Ricker 1975). Condition factor for each year was compared against a 15 year mean (1990-2005) of data collected during the DFO summer trawl survey (Emberley and Clark 2012). For comparison with condition based on fork length (FL) the formula FL = (0.8973 x total length) + 0.032

was used for conversion (DFO 2007).

3 RESULTS AND DISCUSSION

3.1 SAMPLING EFFORT AND DISTRIBUTION

A total of 66 trawls were successfully conducted and with the exception of 2009, all four zones (A to D) were sampled with an increase in the total number of sets each year (Table 3). The sampling protocol was designed to revisit historical trawl sites (MacDonald et. al. 1984) in order to assess the potential for investigating long term changes in species diversity. As a result, sampling distributions within zones A - C (Figure 1) are clustered in the location of historical trawls. Trawl locations are also bounded in part due to the presence of aquaculture sites or unfavourable bottom topography within the bay that would render the trawl ineffective. Sampling within zone D was less restricted in nature and most of the area between The Wolves and The Passages was considered trawlable. The number of species observed each year ranged from 37 to 75 (Table 4). Changes in the total number of species observed per trawl year and within each zone (Table 4) showed an increase in total species number associated with increased sampling effort and spatial coverage, following the inclusion of the Outer Bay (Zone D) after 2009 (Table 3). Therefore changes in effort must be accounted in the annual estimates of abundance, biomass, richness and diversity.

Table 3. Number of trawls conducted for each zone per year.

Zone	Year				
	2009	**2011**	**2012**	**2013**	**2014**
A	1	2	2	1	3
B	4	4	4	4	4
C	2	2	2	5	6
D	0	1	4	9	7
Total	7	9	12	19	20

Table 4. Number of species observed for each zone per year.

Zone	Year				
	2009	**2011**	**2012**	**2013**	**2014**
A	23	31	38	27	25
B	26	43	34	44	39
C	22	33	31	41	39
D	0	21	26	54	42
Total	37	60	60	75	59

3.2 SPECIES ABUNDANCE AND BIOMASS

With the exception of 2009, the total abundance of the most dominant species increased with sampling effort (Figure 2). To correct for the bias associated with increased effort, both species abundance and biomass were standardised by per minute trawl (Figures 3, 4). Even after this standardisation, a high abundance of the most dominant species relative to effort was still observed in 2009. The predominance of northern shrimp (*Pandalus borealis*) and moon jellyfish (*Aurelia aurita*) in 2009 catches make it difficult to compare this first year of sampling relative to catches for 2011 to 2014. In addition 2009 was the only year conducted from the CCGS Pandalus IV with a slightly larger gear configuration. The time series does not support further interpretation as to whether this is a gear effect or a natural cycle within Passamaquoddy Bay but the bias created by the presence of small yet highly abundant species in 2009 and potentially in the future would need to be evaluated when monitoring species changes in this area.

The composition and abundance of the most dominant species per minute trawl was variable from year to year (Figure 3). As previously stated, 2009 was dominated by northern shrimp (*P. borealis*) and moon jellyfish (*A.aurita*). In 2011 shrimp were still observed in high abundance but winter flounder (*P. americanus*), deepsea scallop (*Placopecten magellanicus*), and Atlantic herring (*C. harengus*) were also observed. In 2012, silver hake (*M. bilinearis*) dominated the catch and continued to be widely abundant into 2013 and 2014. Other species, Montague shrimp (*Pandalus montagui*), winter flounder (*P. americanus*) and mudstars (*Ctenodiscus crispatus*) were also captured in high abundance during this period. On July 10th, 2014 a single trawl in zone D observed over 800,000 brittlestars (*Ophiopholis aculeate*) . This was considered an unusual catch and the data was excluded from the present analysis though it may be included in future studies with increased sampling of the area.

The composition of dominant species as biomass per minute trawl was less variable (Figure 4). Large bodied species such as American lobster (*H. americanus*), orange-footed cucumber (*Cucumaria frondosa*), and winter flounder (*P. americanus*) consistently account for a high proportion of the biomass observed from 2011 to 2014 (Note that biomass was not measured in 2009). Silver hake (*M. bilinearis*) had also made up a large proportion of the biomass since 2012. Other species such as Atlantic herring (*Clupea harengus*) and longfin squid (*Doryteuthis pealeii*) were observed with moderate biomass in at least one year (Figure 4). The periodic occurrence of species such as northern shrimp (*Pandalus borealis*), moon jellyfish (*Aurelia aurita*), herring (*Clupea harengus*), and longfin squid (*Doryteuthis pealeii*) may in part be due peaks in abundance but also a result of variable catchability in the trawl for species that school in large numbers versus species that are more evenly distributed on the bottom such as American lobster (*H. americanus*), orange-footed cucumbers (*C. frondosa)*, and winter flounder (*P. americanus*). The effect of trawl and vessel type between 2009 and subsequent years were not evaluated and may also be a contributing factor in these changes. A high degree of caution was adopted for the interpretation of the 2009 sample.

Changes in environmental indices for salinity, temperature, and chlorophyll were compared against annual species abundance (Figure 3) and biomass (Figure 4). The average 5 m temperature from March to October has been slightly above the long term average since 2010. Both the average salinity and chlorophyll from March to October have fluctuated above and below the long term average. None of these changes were considered statistically significant; however temperature was slightly above the long term average for the last three years and the small deviations in salinity appeared to follow both changes in abundance and biomass (Figures 3 and 4). The effects of salinity on recruitment and catchability of fishes in estuaries has been well documented (Elliot and Hemingway 2002) and additional time series may be detect such a relationship.

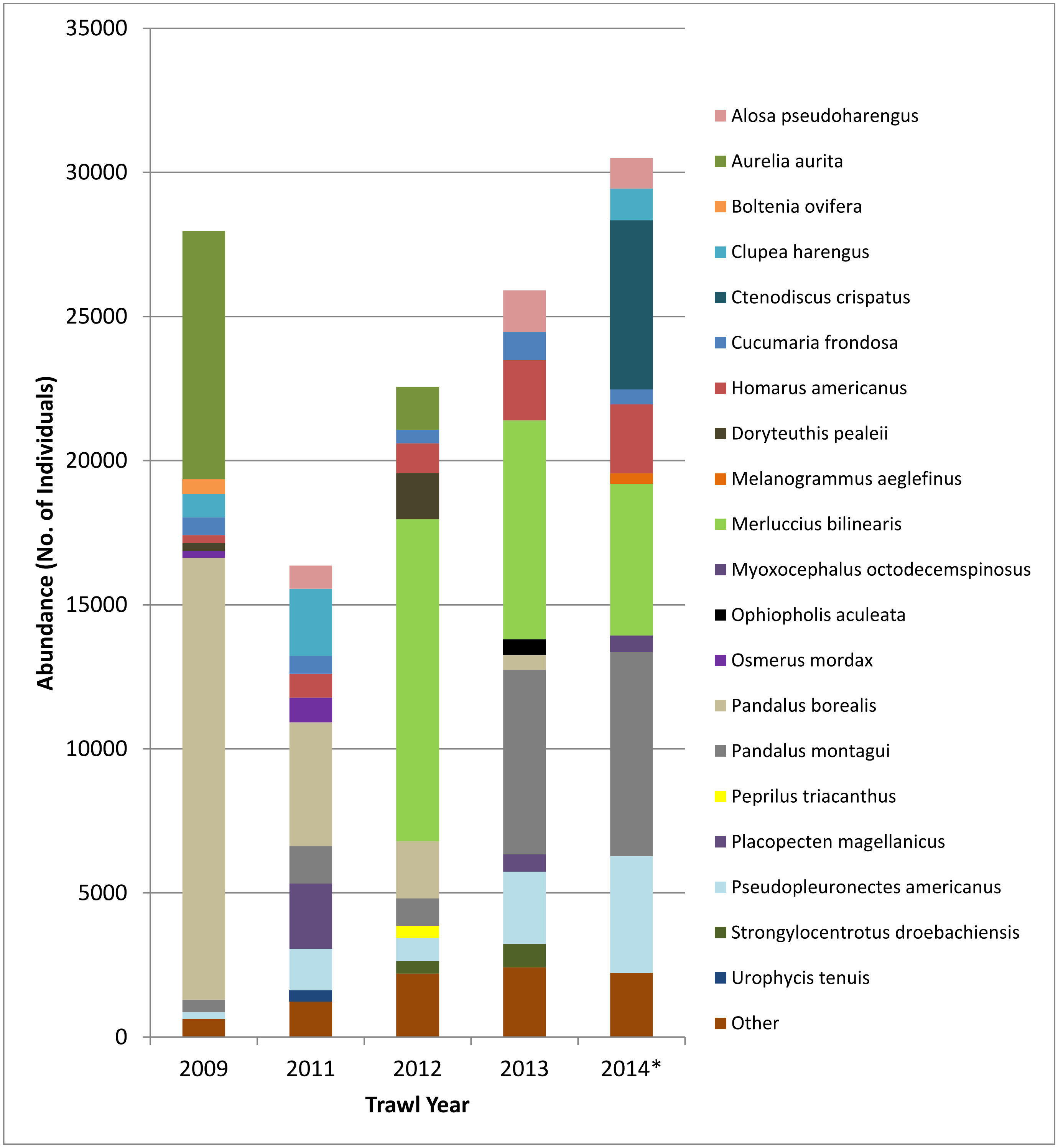

Figure 2. Total abundance for the ten most dominant species within each year 2009 – 2014 (excluding 2010). *Note, for the 2014 trawl year, *Ophiopholis aculeate* was omitted from the abundance calculations due to very high abundance (>800, 000) in a single trawl (10/07/2014).

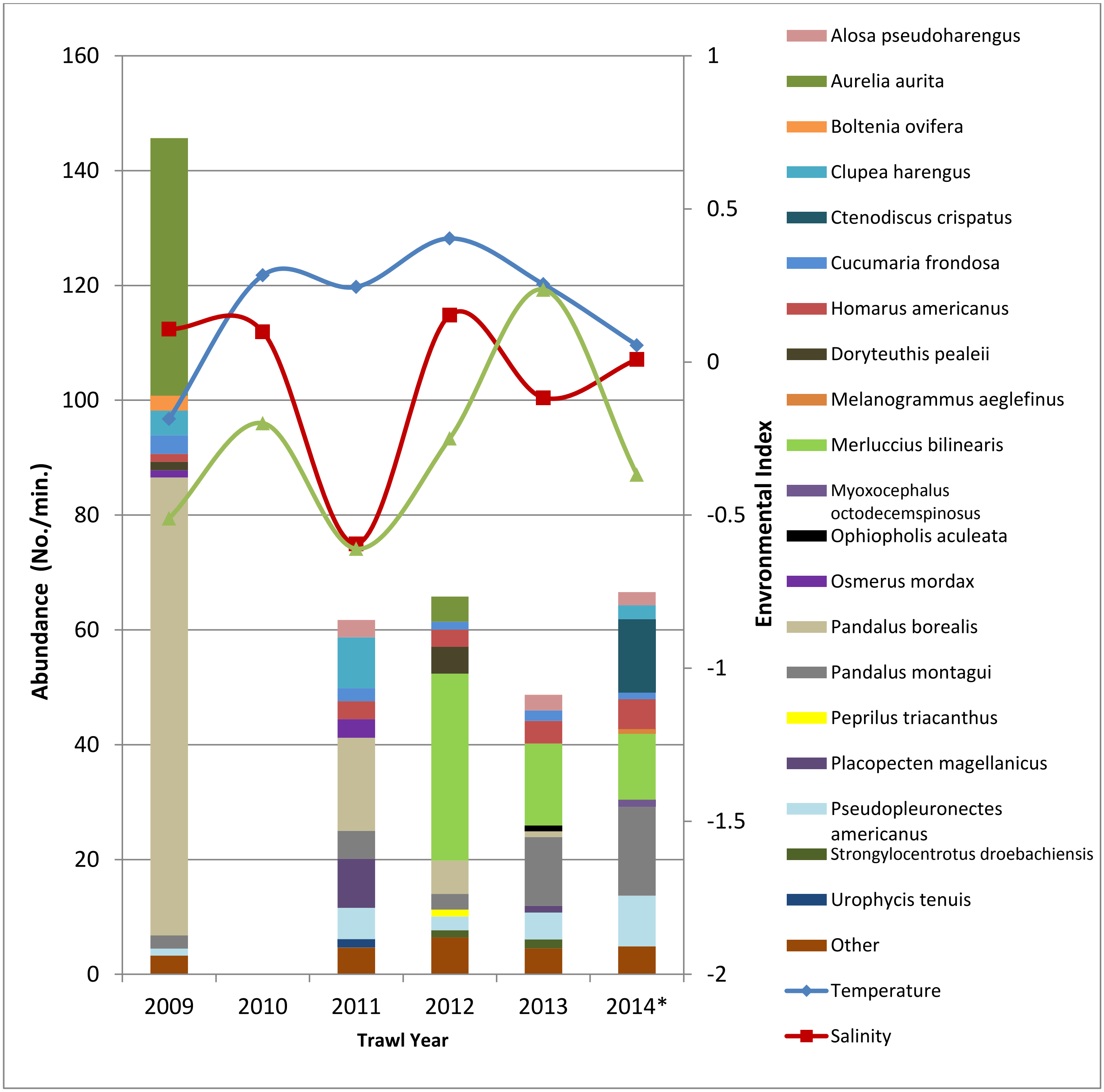

Figure 3. Total abundance per minute trawl for the ten most dominant species within each year 2009 – 2014 (excluding 2010) compared with the standardized environmental anomaly for temperature, salinity, and chlorophyll. * Note, for the 2014 trawl year, *Ophiopholis aculeate* was omitted from the abundance calculations due to very high abundance (>800, 000) in a single trawl (10/07/2014).

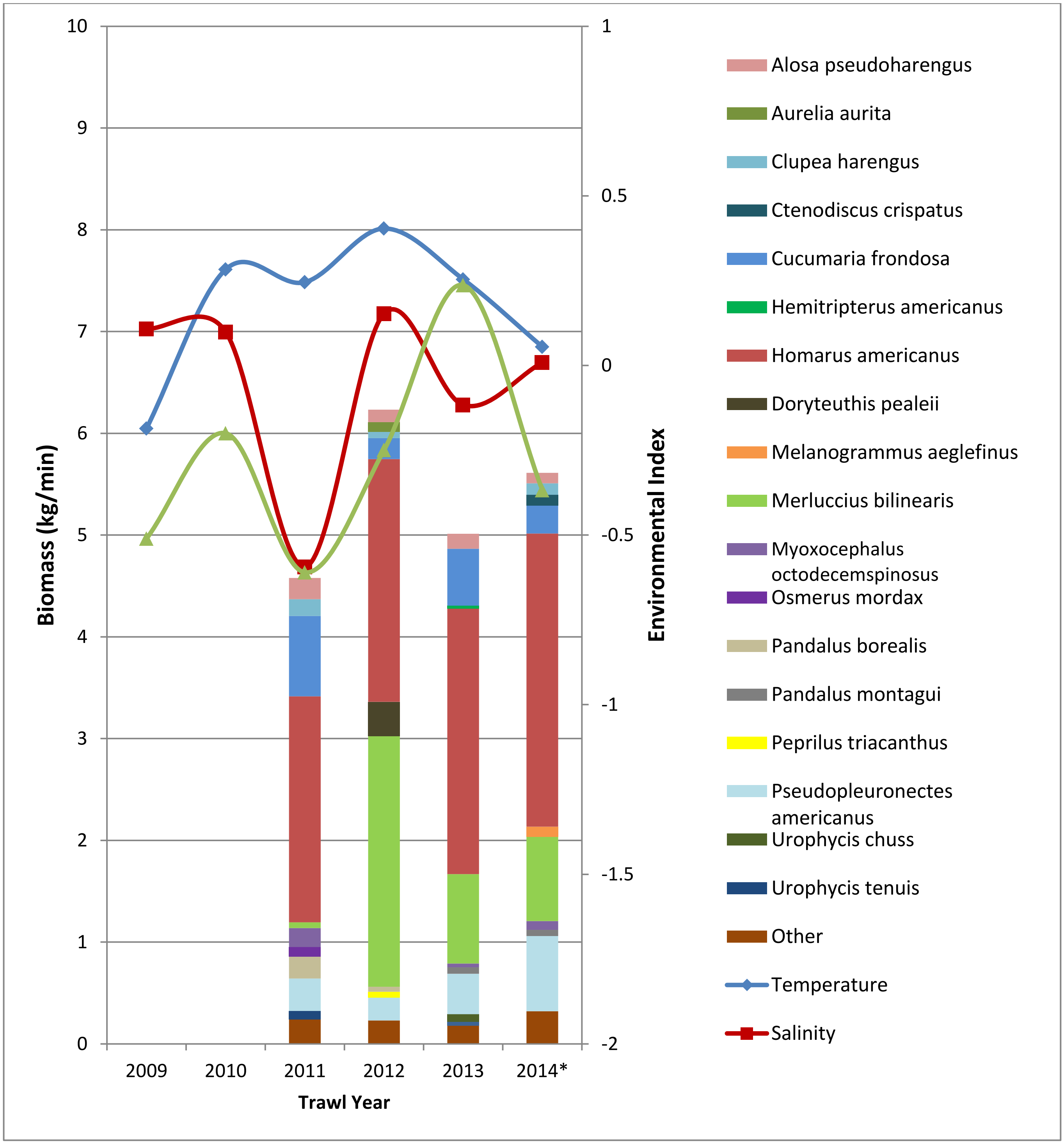

Figure 4. Total biomass per minute trawled (kg/min) for the ten most dominant species within each year 2011-2014 compared with the standardized environmental anomaly for temperature, salinity, and chlorophyll. *Note for the 2014 trawl year, *Ophiopholis aculeate* was omitted from the biomass calculations due to very high abundance (>800, 000) in a single trawl (10/07/2014).

3.3 SPECIES RICHNESS AND DIVERSITY

The Michaelis-Menten estimates of species richness were calculated for each year and indicated that at least 19 trawls per season would capture over 90% of the estimated species using the methods described (Table 5). In general, as the number of species observed approaches the estimate, a greater confidence can be applied to the annual sample to monitor changes in species diversity and richness. We observed that diversity indices could be impacted by changes in rare (less abundant) species. Such an effect was observed in 2013 in which several species not typically observed in other years (Appendix 1) were captured and despite being represented by only a few individuals raised both the observed number and the Michaelis-Menten estimate. In 2014 several of those less abundant species were not observed despite a sampling effort that was comparable to 2013 (Table 5). The absence of these less common taxa resulted in a lower estimate of species richness. Whether this is an effect of sampling effort or real changes in species richness should be investigated with further time series and improved measures of sampling effort such as area swept.

The amount of effort required to observe 75 to 95% percent of the estimated species in each zone was much lower than the effort required for the entire area (Tables 6 and 7). This suggests that species captured and perhaps associated habitats within each zone were more homogenous when compared to sampling the entire Passamaquoddy Bay area. Rank abundance plots (log abundance versus log rank) for each year indicated that catch results were dominated by a relatively small number of abundant species. When many species are represented with near equal abundance a rank abundance plot presents a

Table 5. Number of trawl sets compared with observed species and the Michaelis-Menten estimate of species richness used to infer completeness of sampling effort in each year.

Year	No. of Trawls	Observed Species	Estimated Species	% Observed/Estimated
2009	7	37	97	38
2011	9	60	70	86
2012	12	60	79	76
2013	19	75	80	94
2014	20	59	59	100

Table 6. Sampling effort by zone for the 2013 trawl season comparing observed species against the Michaelis-Menten estimate of species richness.

Zone	No. of Trawls	Observed Species	Estimated Species	%Observed/Estimated
B	4	44	52	85
C	5	41	43	95
D	9	54	65	83

Table 7. Sampling effort by zone for the 2014 trawl season comparing observed species against the Michaelis-Menten estimate of species richness.

Zone	No. of Trawls	Observed Species	Estimated Species	%Observed/Estimated
A	3	26	33	79
B	4	39	50	78
C	6	39	52	75
D	7	42	51	82

trend line with a slope that is closer to zero. As the slope becomes more negative (Figure 5), the more heavily weighted the total abundance is towards a smaller number of highly abundant species. The survey data did fit a similar log series model for all years except

2014 (Figure 5). The 2014 trawl year contained a single trawl that recorded an estimated 800,000 brittle stars (*O. aculeate).* This unique observation skewed the log-abundance trend for the most dominant species (see 2014* in Figure 5). For the purposes of calculating parametric biodiversity indices, this data was removed so that the 2014 survey would fit the log series model and would be comparable to other sample years. This brittle star data was also excluded from the abundance and biomass calculations in that year. In general, smaller sized yet numerous species such as northern shrimp dominate the annual abundance results. A reduction in the number of northern shrimp after 2011 (Figure 3) was replaced by an abundance of silver hake (*M. bilinearis*), montague shrimp (*P. montagui*) and mudstar (*Ctenodiscus crispatus*). In 2012, silver hake (*M. bilinearis*) were a dominant species for the entire Passamaquoddy Bay area with the highest catches recorded in outer zone D and a lower within the estuary, zone A.

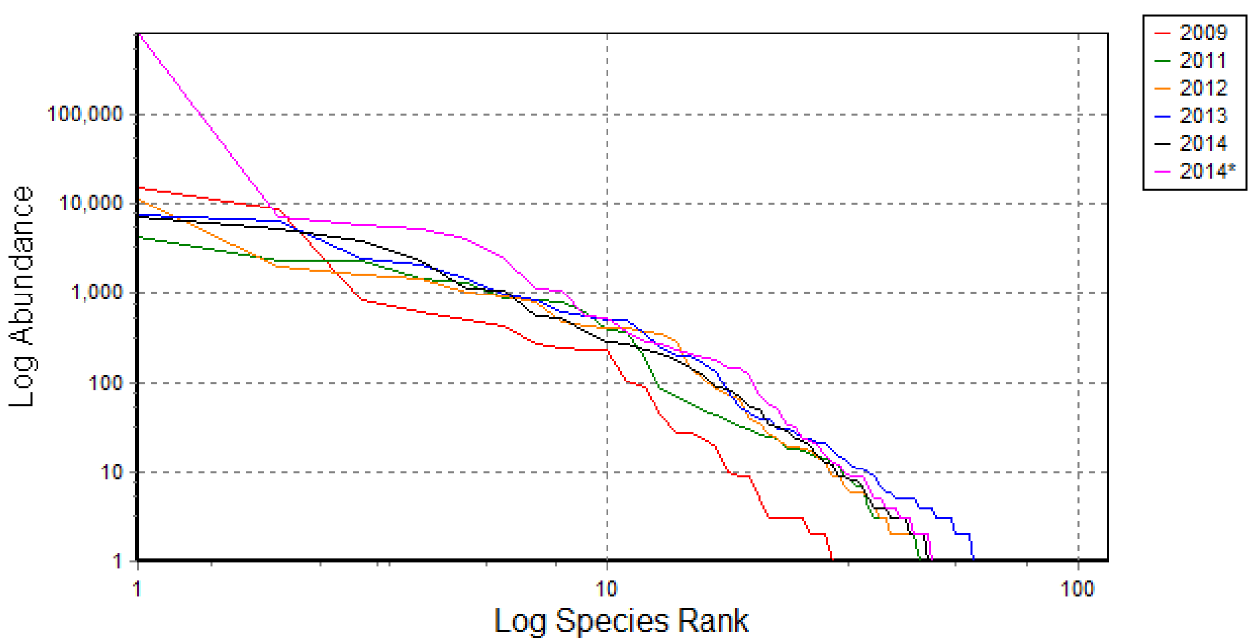

Figure 5. Rank abundance plots for survey years 2009, 2011-2014 illustrating a logarithmic decrease in species abundance with rank. Note 2014* includes a single set that recorded over 800,000 brittle stars. This set was subsequently removed for the purposes of calculating parametric diversity indices.

3.4 BIODIVERSITY TRENDS

Three biodiversity indices, Shannon-Wiener , Simpson's , and Fisher's Alpha, were reported to establish a baseline profile of species diversity upon which to assess changes over time (Table 8). Although the data from all years fit a logarithmic decrease in abundance (Figure 5), the sampling in 2009, 2011, and 2012 were not as complete as in 2013 and 2014 (Table 5) and a more conservative interpretation of indices should be taken for these years.

Table 8. Diversity indices for the trawl years 2009, 2011 to 2014.

Year	Shannon-Wiener	Simpson's	Fisher`s Alpha
2009	1.3	2.5	4.2
2011	2.4	7.5	8.3
2012	2.0	3.7	7.8
2013	2.3	5.9	9.8
2014	2.2	6.7	7.1

The Shannon-Wiener index ranged from 1.3 to 2.4 (Table 8). This index, which reflects changes in the ratio between number of species and abundance (Southwood and Henderson 2000), is lower in 2009 than what would normally be expected for ecological data (1.5 to 3.5, May 1975). The lower diversity was also reflected in both the Simpson's and Fishers Alpha for 2009 (Table 8). Insufficient sampling in 2009 relative to the estimated species richness (Table 5), the high abundance of northern shrimp and jellyfish as previously indicated (Figure 3) and not having sampled all ecological zones (Table 4) are likely to have contributed to the lower diversity observed in 2009. Simpson's index was positively correlated with Shannon-Weiner (Pearson Correlation Coefficient 0.974, P=0.025) and both appear to respond similarly to changes in the estimated species richness (Table 5). While this type of correlation is known (Smith and Wilson 1996), Simpson's offers a perspective on evenness and relative changes in the diversity for the most abundant species (Hurlbert 1971, Seaby and Henderson 2007) and over time may provide an aspect of a biodiversity profile that is representative of sample variance (Margurran 2004) in order to provide information on habitat variability. Fisher's Alpha was less correlated with both Shannon-Weiner and Simpson's (Pearson Correlation Coefficient with H 0.405, P=0.594; with D 0.192, P=0.797) yet closely associated to species richness. Fisher's Alpha can be used as a relative index to track the number of species represented by a single individual and is independent of sample size when the number of individuals exceeds 1000 (Seaby and Henderson 2007). This would be a more robust index to examine when sample years are periodically dominated by high numbers of individuals as observed in a year dominated by species such as shrimp, jellyfish, and hake (Figure 3). Fisher's Alpha was highest in 2013 in contrast with Shannon-Weiner and Simpson's highest values in 2011. Fisher's Alpha coincided with the highest number of observed species (Table 5) but lowest total standardized abundance for the time series (Figure 3).

The annual changes in biodiversity did not correlate with the standardized environmental indices for temperature, salinity, and chlorophyll (Figure 6). As previously indicated only the last two sample years (2013 and 2014) were considered a sufficient sample to estimate species richness and associated biodiversity indices. The relationship between diversity and environment will continue to be monitored as the time series is extended. We also note that annual changes in environmental indices are less than one standard deviation of the March to October mean (Figure 6) and did not represent a statistically significant deviation from natural variability. Annual deviations did not appear to be correlated with changes in diversity indices for this time series, however long term environmental trends may influence changes in the most dominant species that comprise the catch and should be examined further.

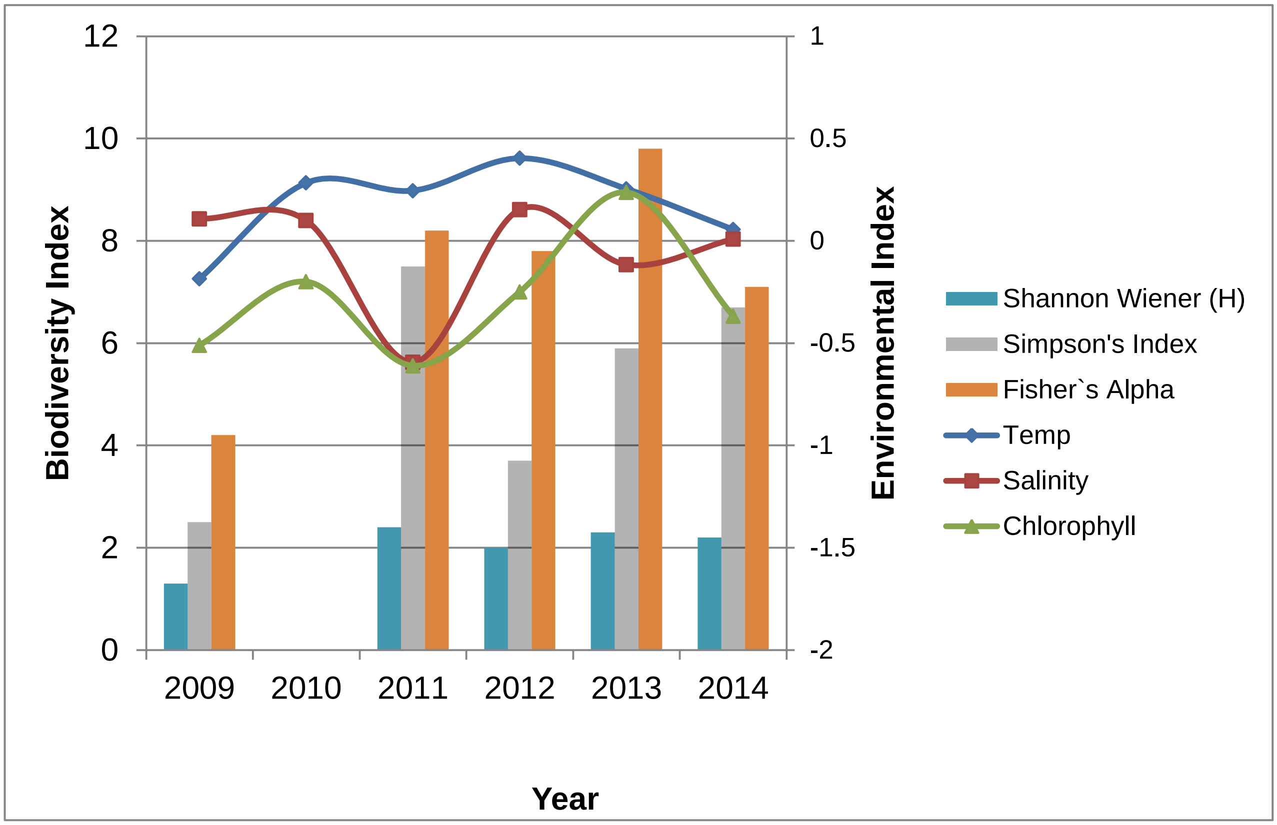

Figure 6. Biodiversity indices compared against the standardized March-October environmental anomaly for temperature, salinity and chlorophyll.

3.5 SIZE FREQUENCY DISTRIBUTION AND CONDITION FACTOR

The annual size frequency distribution for five fish species plus lobster were calculated to better understand the catchability of the trawl and population structure within the study area.

The size frequency distribution of alewife (*A. pseudoharengus*) was variable annually with a mean total length ranging from 182 to 268 mm. The largest mean was observed in 2009, a year which also had the fewest specimens collected with anywhere from one to three size classes (Figure 7). It is likely that multiple year classes were represented with the largest cohorts being the three to five years based on previous length at age estimates (Jessop et al. 1982, Scott and Scott 1988). This suggested that either the population structure within the Passamaquoddy Bay area is variable from year-to-year or that catchability from the trawl was not consistent. The later condition may be a result of schooling behavior of this species. In most years, much of the catch was below what is considered the average size range at maturity (254-305 mm fork length, Scott and Scott 1988). The catch in 2013 reported a greater proportion of larger individuals that could be considered a spawning component.

The size frequency distribution of herring (*C. harengus*) had an annual mean total length from 130 to 218 mm (Figure 8) and from one to three sizes classes. Size at maturity for herring in the Passamaquoddy Bay area is reported to occur between 250 to 260 mm total length (Boyar 1968, Sinclair et. al. 1982), an age at maturity between three and four years with some variability in the percentage of age three herring that spawn from year-to-year (Munroe 2002). Approximately 3% (24 of 920) of the catch between 2009 and 2014 was at or above the total length at maturity. A subsample of herring captured in 2013 and 2014 were aged and showed to be predominately one and two years in 2013 and one to six years in 2014. This indicated that the majority of the samples captured in the Passamaquoddy Bay area were of a pre-adult size and age.

The size frequency distribution of silver hake (*M. bilinearis*) had an annual mean total length from 189 to 215 mm (Figure 9). One large size class appeared to dominate the sample in every year. Median total length at maturity is reported to be 231 mm for females and 223 mm for males (O'Brien et al. 1993). Using total length ≥ 223 mm as length at maturity 4%, 42% and 43% of silver hake for 2009, 2011 and 2012 respectively, fell into this category and so the upper portion of the size class distributions are likely to represent an inshore spawning component for this region.

The size frequency distribution of longhorn sculpin (*Myoxocephalus octodecemspinosus*) had an annual mean total length from 198 to 242 mm (Figure 10). The annual size distribution of the catch was variable. Years 2009 and 2011 were dominated by a large size class over 170 mm TL while most recent years (2013, 2014)observed a more even distribution (Figure 10). In southern New England maturity is reported to occur in the third year of growth at an estimated size of 210 mm (Morrow 1951). Catches for 2009, 2011, and 2012 showed wide representation from all age classes with the majority of specimens falling into the two to five age class (189 of 296 individuals). If growth is presumed to be slower in the colder waters of the Passamaquoddy Bay area, this would suggest that many of the individuals sampled are at or near size at maturity.

The size frequency distribution of winter flounder (*P. americanus*) had an annual mean total length from 171 to 195 mm (Figure 11). In most years the distribution did not reveal distinct size classes. The sample was typically dominated by one large size class within the 170 to 200 mm range with only a relatively few larger individuals recorded (Figure 11). Maturity for this species is a function of size by gender over age with variable growth reported throughout the east coast (Witherell and Burnett 1993, Klein-MacPhee 2002). An estimate of size at maturity for this region would be about 260 mm TL for males and closer to 300 mm TL for females based on data obtained for specimens captured North of Cape Cod Massachusetts (Witherell and Burnett 1993). Length data for winter flounder showed a majority of fish in the 110 mm – 200 mm TL category (778 of 1127 individuals) which is estimated to be 1 to 2 year old fish (Penttila et al. 1989, Witherell and Burnett 1993). This indicated that nearly all of the individuals sampled were juveniles.

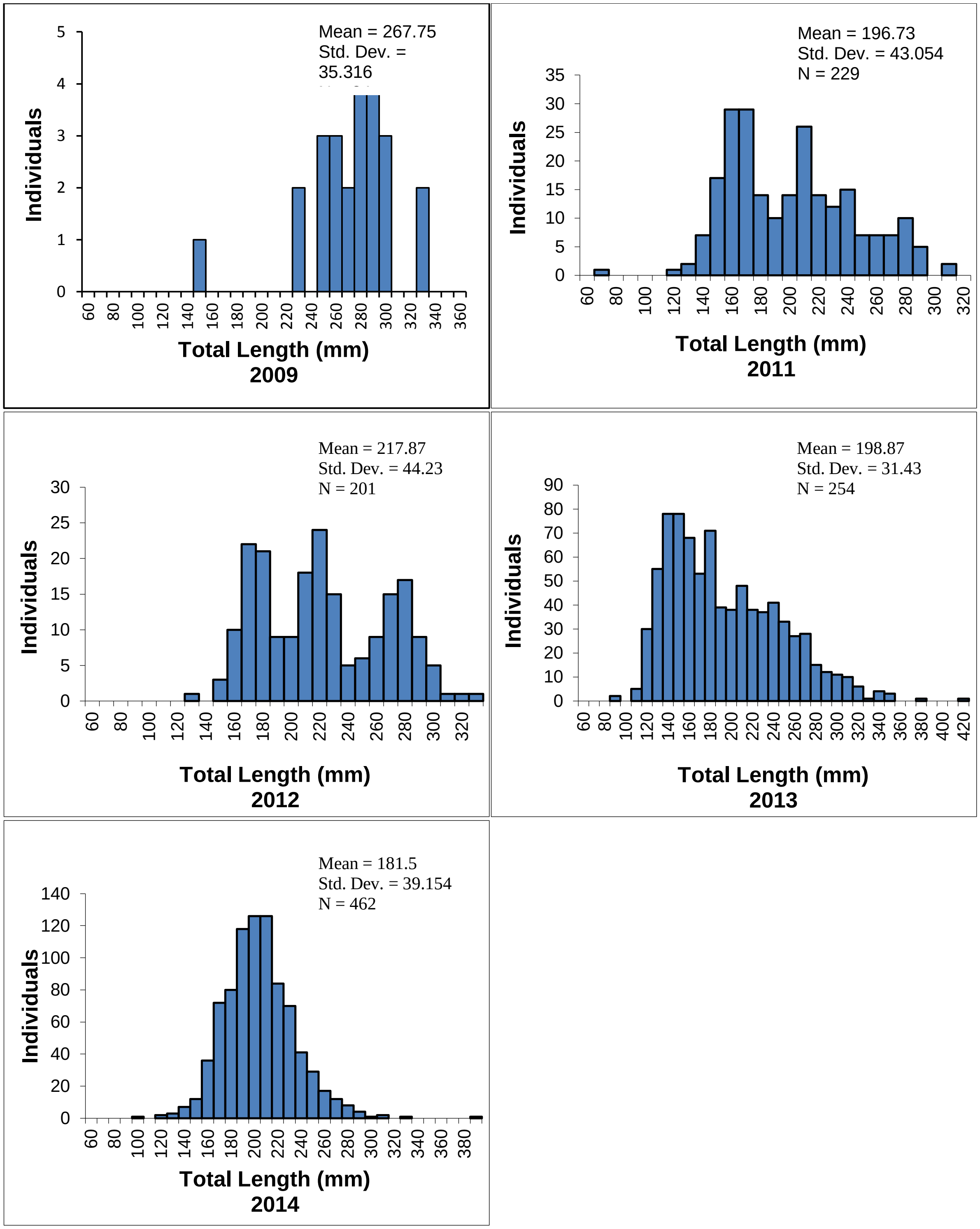

Figure 7. Size frequency distribution of alewife (*Alosa pseudoharengus)* for the trawl years 2009-2014.

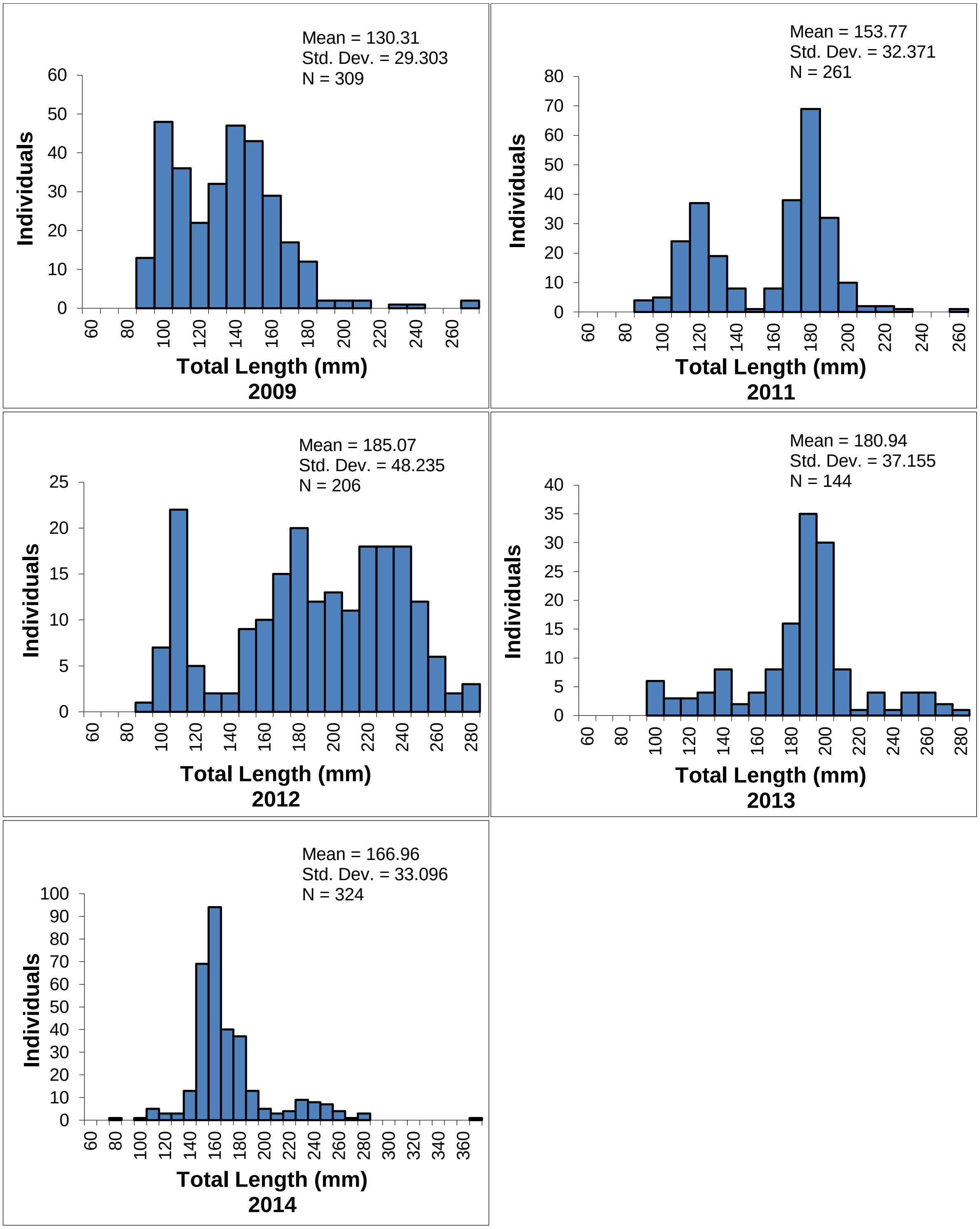

Figure 8. Size frequency distribution of herring (*Clupea harengus)* for the trawl years 2009-2014.

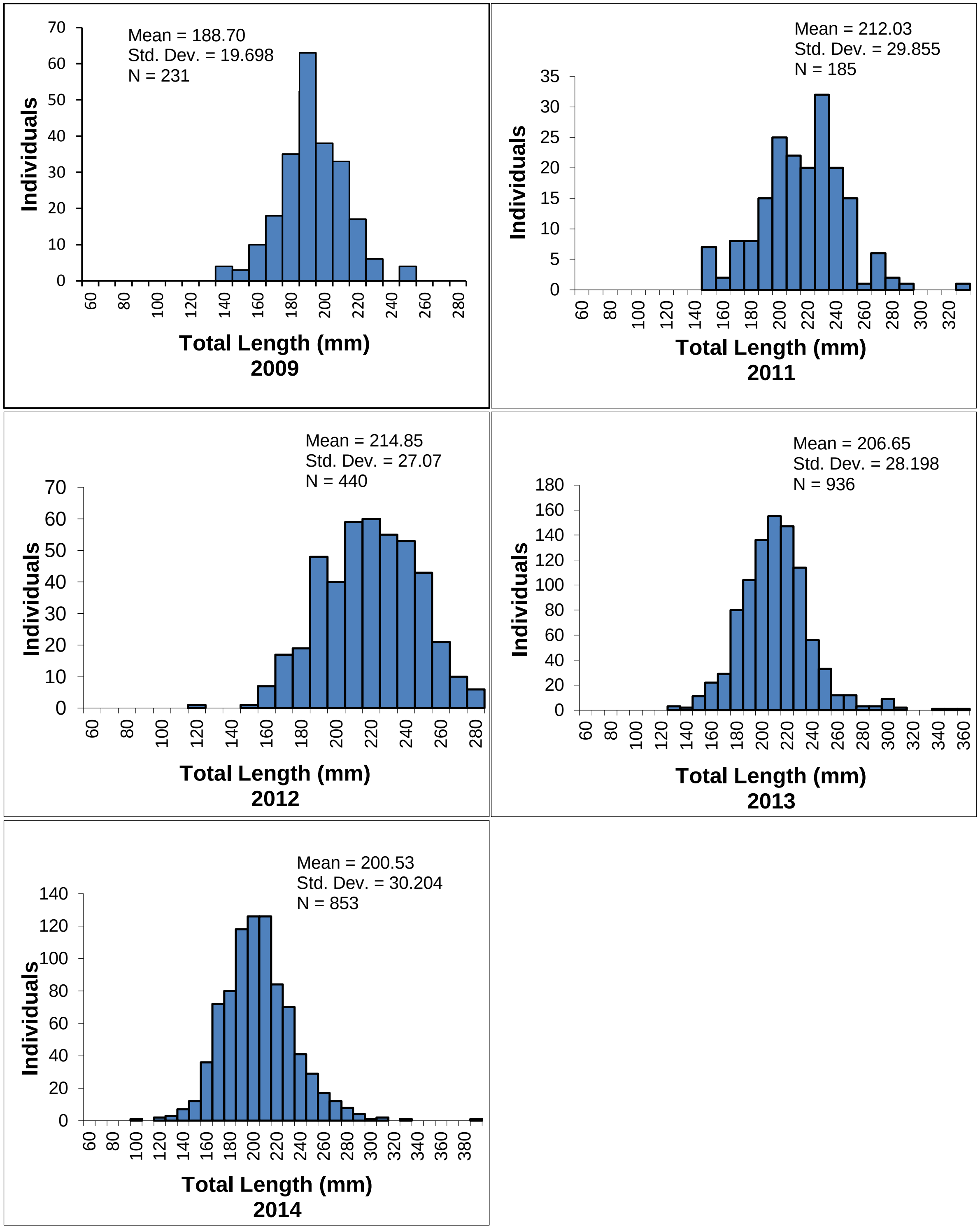

Figure 9. Size frequency distribution of silver hake (*Merluccius bilinearis)* for the trawl years 2009-2014.

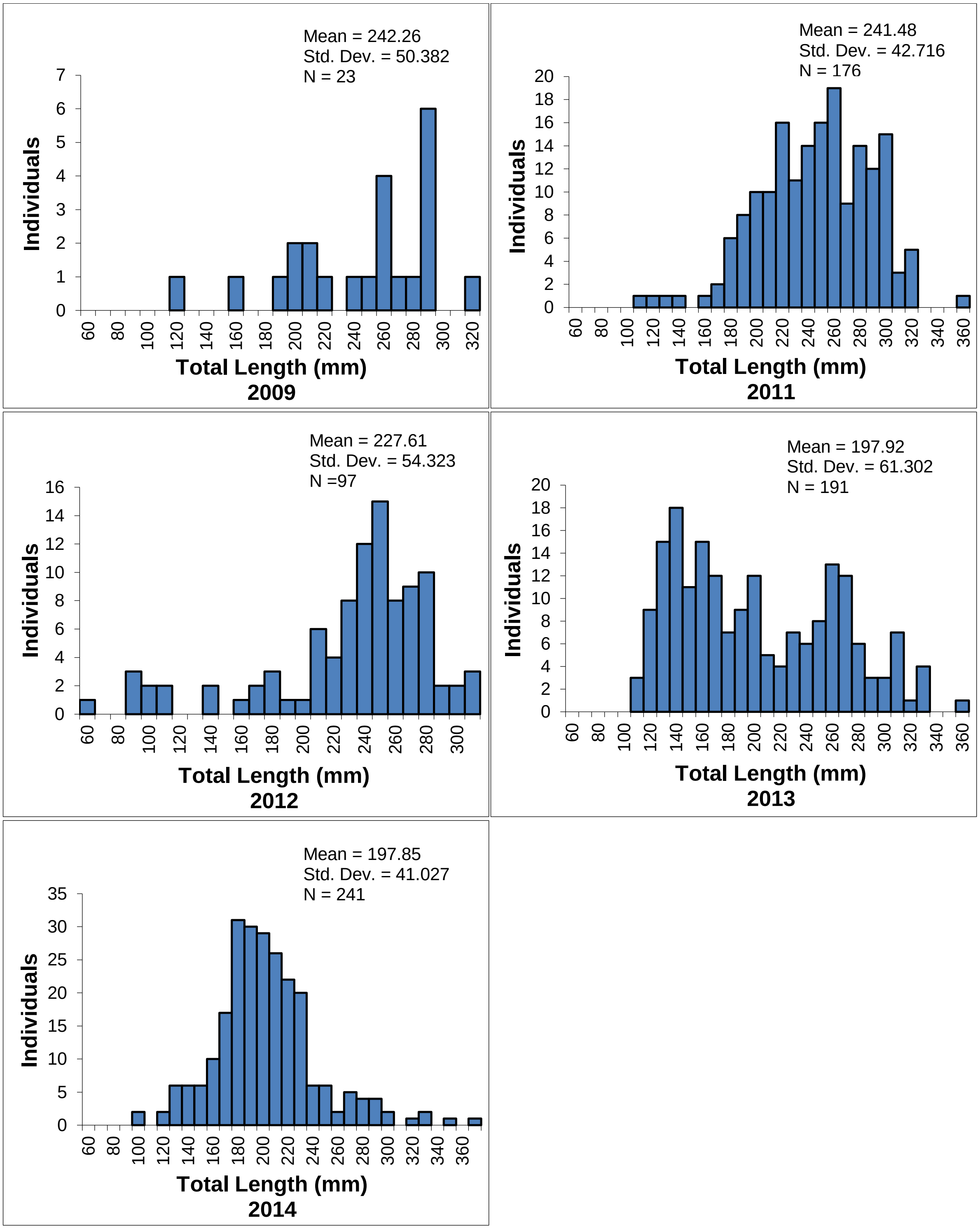

Figure 10. Size frequency distribution of longhorn sculpin (*Myoxocephalus octodecemspinosus)* for the trawl years 2009-2014.

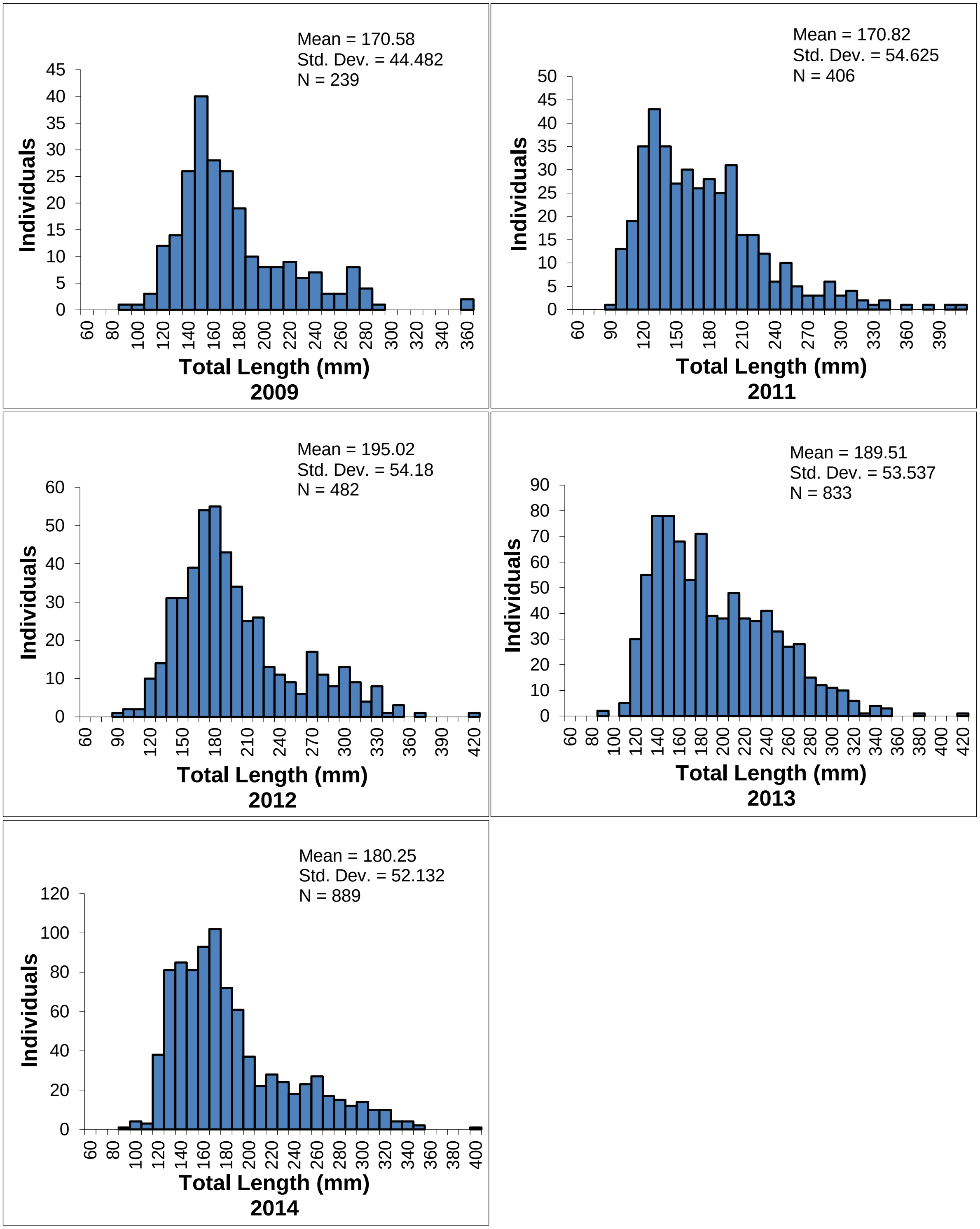

Figure 11. Size frequency distribution of winter flounder (*Pseudopleuronectes americanus)* for the trawl years2009-2014.

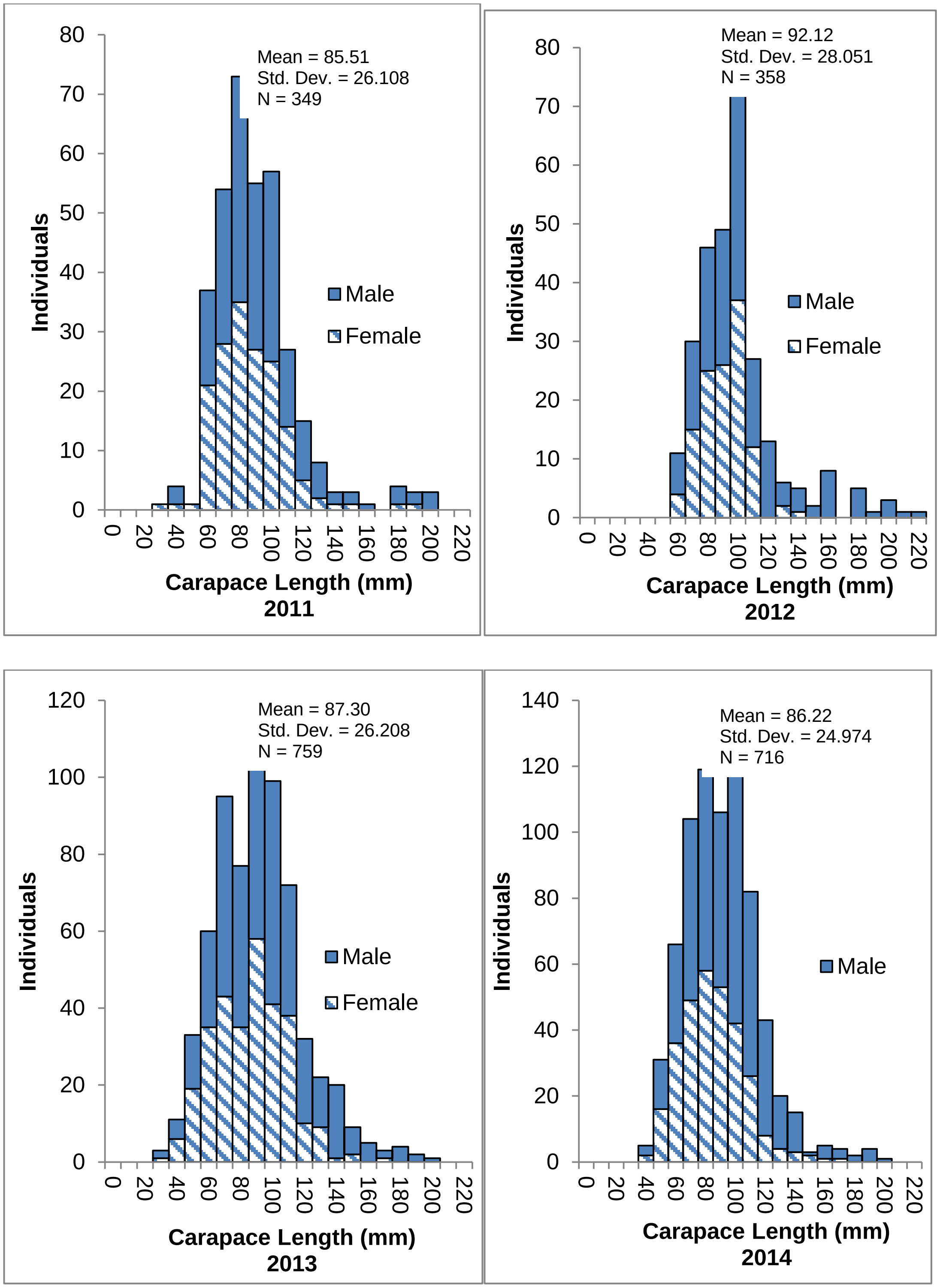

Figure 12. Size frequency distribution of American lobster (*Homarus americanus)* for the trawl years 2011-2014 categorised by sex.

The size frequency distribution for American lobster (*H. americanus*) (Figure 12) had an annual mean total length from 86 to 92 mm carapace length (CL). Although much of the trawl sample represents a size that has recruited to the fishery, the trawl did sample pre-recruits down to 40 mm CL. Larger lobsters greater than 140 mm CL were occasionally captured, less than 10 per year. There was an even proportion of males and female observed in most sizes with the exception that few large females above a carapace length of 140 mm were observed (Figure 12).

Monitoring changes in condition for Passamaquoddy Bay fishes as a method to evaluate fish health (Jobling 2002) should be interpreted with consideration to both life history and reproductive state. Condition factor for alewife was below the 15 year mean for the Scotian Shelf and Bay of Fundy since 2011 with 2013 significantly lower than other years (Figure 13).

Alewife (*A. pseudoharengus*) in the Bay of Fundy generally spawn in upstream tributaries beginning late April or early May (Munroe 2002). This may continue for up to 2 months as it is temperature dependent between 12 to 15 ^{o}C (Munroe 2002). If the survey observed this species during the early portion of July then these samples may be closer to post spawning and generally lighter than the 15 year mean for alewife observed in the offshore trawls. The condition factor for Atlantic herring was at or just slightly above the 15 year mean with no significant difference among years (Figure 14).

Atlantic herring (*C. harengus*) in this region are thought to spawn every month from April to November depending on the population (Munroe 2002). However, spring spawners are considered uncommon for this area and all of the herring that have been observed in this survey (Figure 14) were below the median size at maturity (Munroe 2002). This would suggest that the spawning condition for herring caught in this survey would not be a contributing factor when monitoring changes in condition factor.

The condition factor for silver hake (*M. bilinearis*) was above the 15 year mean since 2011 with 2013 being significantly greater than other years (Figure 15). This increase in condition follows three years of slightly elevated water temperature and increased catch in 2012 (Figure 3). It is also noted that a proportion of the catch was at a mature size and this elevated condition could represent a pre-spawning state for this species, known to spawn in the inshore waters of the Gulf of Maine during the summer (Berrien and Sibunka 1999).

The condition factor for longhorn sculpin (*M. octodecemspinosus*) was just below the 15 year mean for all years except 2012 in which it was just above (Figure 16). Although these differences were not significantly different, the size frequency distribution in 2012 indicated a larger proportion of the catch in the largest size classes (Figure 10) and possibly in adult pre-spawing condition.

The condition factor for winter flounder (*P. americanus*) was at or near the 15 year mean with no significant differences among years (Figure 17).

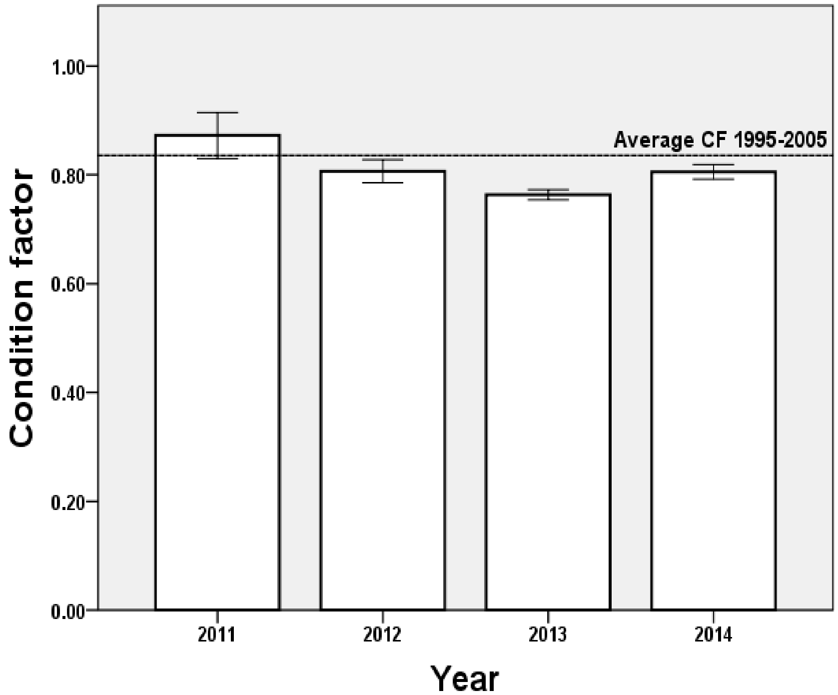

Figure 13. Condition factor for alewife (*Alosa pseudoharengus)* compared to 15 year (1990 – 2005) mean for Scotian Shelf and Bay of Fundy. Error bars represent 95% confidence interval on the mean.

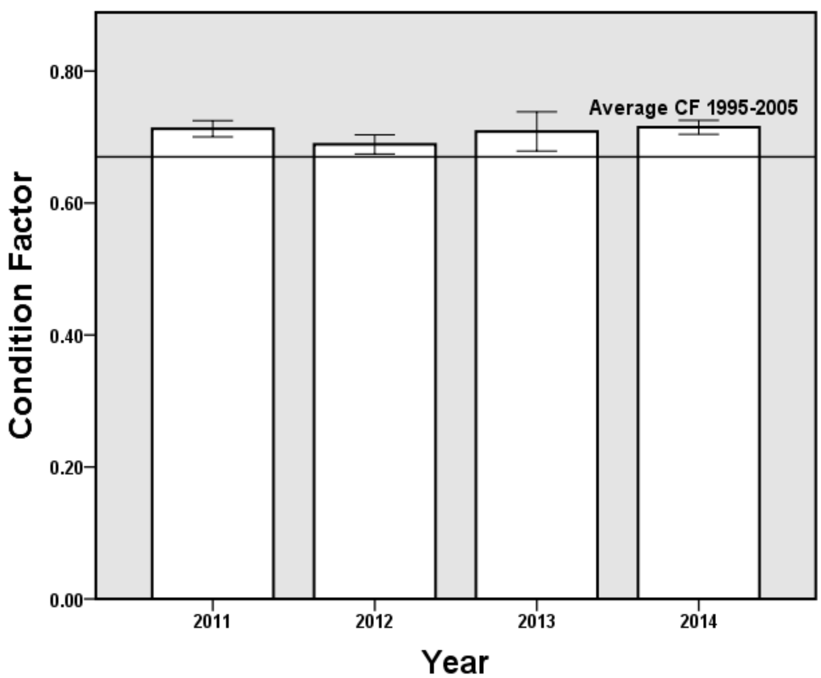

Figure 14. Condition factor for Atlantic herring (*Clupea harengus)* compared to 15 year (1990 – 2005) mean for Scotian Shelf and Bay of Fundy. Error bars represent 95% confidence interval on the mean.

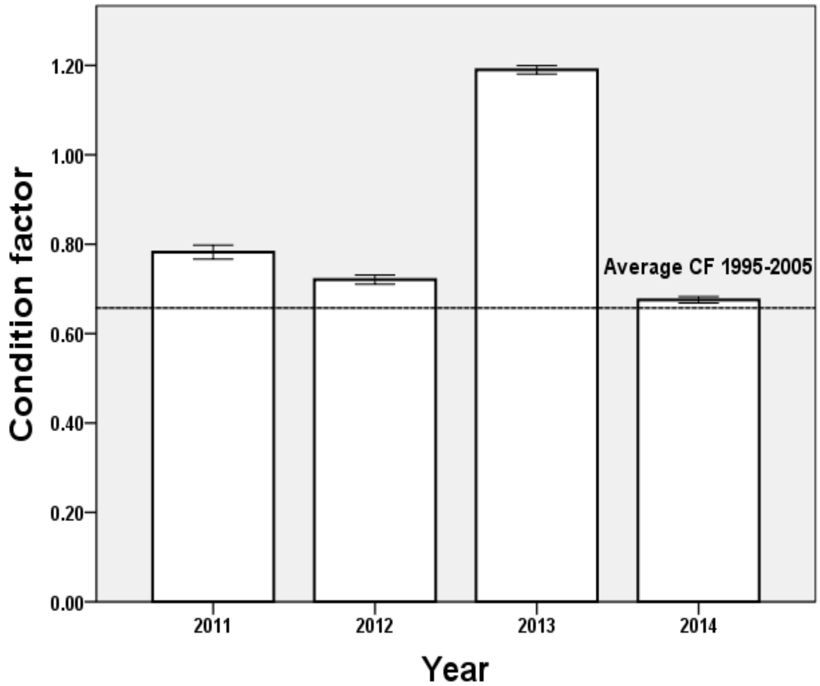

Figure 15. Condition factor for silver hake (*Merluccius bilinearis)* compared to 15 year (1990 – 2005) mean for Scotian Shelf and Bay of Fundy. Error bars represent 95% confidence interval on the mean.

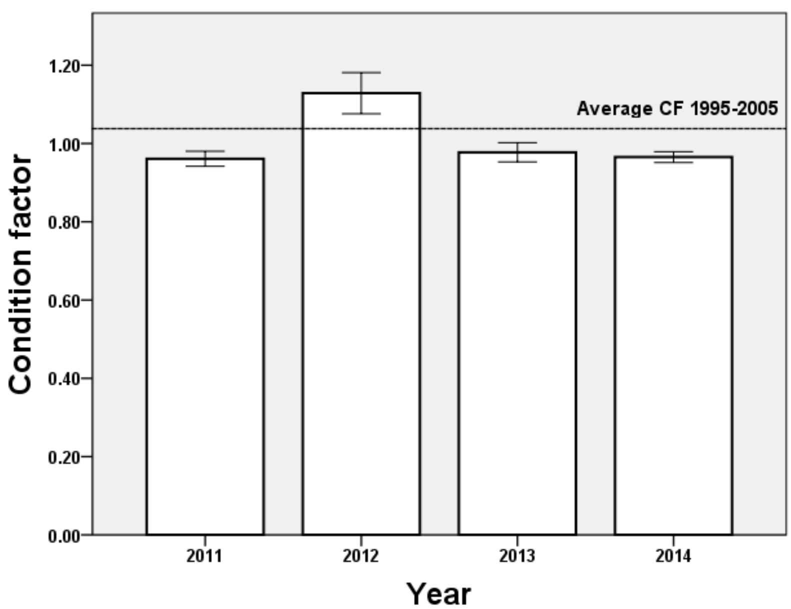

Figure 16. Condition factor for longhorn sculpin (Myoxocephalus octodecemspinosus) compared to 15 year (1990 – 2005) mean for Scotian shelf Bay of Fundy. Error bars represent 95% confidence interval on the mean.

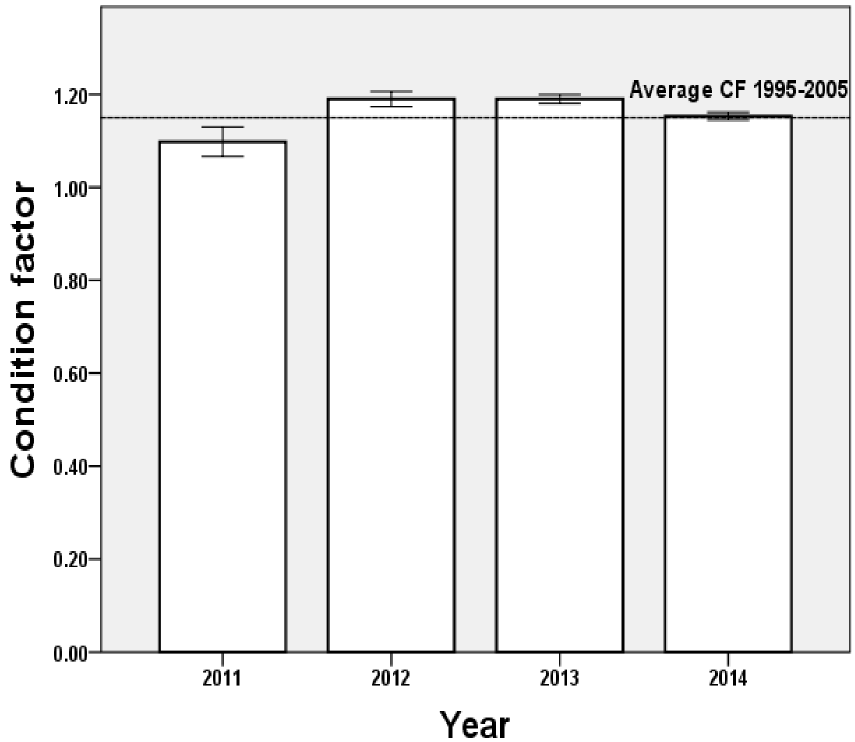

Figure 17. Condition factor for winter flounder (*Pseudopleuronectes americanus)* compared to 15 year (1990 – 2005) mean for Scotian Shelf and Bay of Fundy. Error bars represent 95% confidence interval on the mean.

4 CONCLUSIONS

4.1 SAMPLING

Trawl sampling in the coastal zone presents its own set of challenges. Coastal relief, underwater obstacles, and human activities such as aquaculture sites and fixed gear fisheries restrict the amount of trawlable bottom. This requires compromises in both the area covered and time of year that sampling is conducted. Despite these challenges, the survey has been able to repeatedly trawl in several locations throughout the Passamaquoddy Bay area to establish a sample that is annually comparative. The gear was restricted in its ability to capture all species in all habitat types. It was assumed that some species that were known to occur in this area were not sampled by the survey due to both gear type and time of year. Therefore, absence in the data set did not necessarily imply an absence of the species. More importantly, it was assumed that gear and timing of the survey perform consistently from year-to-year so that even though not all species were observed, changes in what was captured can be used to monitor biodiversity provided that sampling was sufficient to catch most of what was catchable. This assumption was generally supported in the sampling after 2012 where effort (at least 19 trawl set per year) was sufficient to observe a high percentage of the estimated species richness.

4.2 SPECIES ABUNDANCE AND BIOMASS

Abundance and biomass increased with effort from 2011 to 2014. This was standardised to a catch per unit effort (per minute trawl). Despite standardisation, there were changes in the composition of the most abundant species annually. The catch data showed transient periods of high abundance and biomass for several species such as moon jellyfish (*A. aurita*), shrimp (*P. borealis* and *P. montagui*), sea cucumber (*C. frondosa*), brittlestar (*O.aculeate)* and fishes such as herring (*C. harengus*) and silver hake (*M. bilinearis*). One trawl alone netted nearly 406 kg of brittlestar (an estimate of nearly 812,000 individuals). The clumped distribution of such species on the bottom and in the water column emphasise characteristics of the trawl in the coastal environment and an ability to periodically intercept large numbers during a tow. Biodiversity indices used to monitor long-term changes should be robust to this data. The catch data indicated biomass was generally dominated by the presence of American lobster (*H. americanus*) throughout the Passamaquoddy Bay area. This is usually the largest species captured which would account for the high relative biomass in all years. In 2012, the largest abundance and biomass was observed in silver hake (*M. bilinearis*). The presence of silver hake (*M. bilinearis)* in higher abundance and biomass coincided with above average water temperature in the Passamaquoddy Bay area in 2012. Strong trends with environmental conditions were not clearly evident through such a short time series. A comprehensive evaluation of environmental conditions such as temperature, salinity, and chlorophyll on species and abundance and biomass in the Passamaquoddy Bay area would require additional time series and species-by-species analysis.

4.3 SPECIES RICHNESS AND DIVERSITY

Obtaining a minimum number of trawls required to sample most if not all species was a critical objective for this project. Reliable estimates of species richness and diversity required an adequate sample that observed most if not all of the catchable species (i.e. species observed close to or equal to a Michaelis-Menten estimate). Annual sampling in the Passamaquoddy Bay area required as many as 19 to 20 trawls during the summer and early autumn period (July to October) to observe over 95% of the estimated species richness for all four zones (A – D). Fewer sets resulted in a greater error on the estimate of species richness and indices calculated from data prior to 2013 would have a greater margin of error. Additional time series from 2013 onward were needed to establish a baseline for species richness and biodiversity as well as to assess annual trends in conjunction with environmental indices. Within zones, fewer trawl sets were required to observe a high percentage of the estimated species richness. This indicated that species composition (and perhaps habitat) within each zone was more homogenous when compared to the entire sampling area. Limitations of the trawl, both in area sampled and seasonality, meant that annual changes in species richness and diversity should only be compared relative to each other as long as the sampling methods with respect to gear type and time of year remain the same.

Annual variability in species abundance and the tendency for punctuated changes in the most dominant species suggested that different indices should be regularly applied to establish a profile of biodiversity. These indices would capture relative changes in species richness as well track the importance of dominant species in the sample, sample variability, and diversity independent of sample size.

4.4 ENVIRONMENT AND BIODIVERSITY INDICES

Tracking changes in the environment relative to the catch is an important measurement to understand the underlying mechanisms that play a role in species distribution and diversity. The importance of environmental conditions such as temperature, salinity, and chlorophyll would be better understood with a longer biological series and continued environmental monitoring in the coastal zone.

4.5 SIZE FREQUENCY DISTRIBUTION AND CONDITION FACTOR

Size composition and health for some of the most dominant and regularly occurring species could be a good indicator for monitoring long term changes within the Passamaquoddy Bay ecosystem. Simple metrics of size frequency and condition factor inform investigators on the role these species play within this coastal area or conversely the role of the Passamaquoddy Bay area to species life history. This information can help determine whether the species is utilising this coastal area as a juvenile nursery, feeding ground, or spawning location. Differences between the long term average and the yearly average were observed in most years but with limited correlation observed. Alewife (*A. pseudoharengus*) indicated a decreasing condition factor from 2011 to 2013 while silver hake (*M. bilinearis*) showed an increased condition in 2013. However, trends were based on a limited time series only. The ability of this survey to monitor changes in this area relative to the local environment and the Scotian Shelf and Bay of Fundy will require further investigation.

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APPENDIX 1.

Table A1. List of all species in alphabetical order captured during the Passamaquoddy Bay trawl surveys from 2009 to 2014. Nomenclature based on World Register of Marine Species (WoRMS) http://www.marinespecies.org/.

Species / Common name	2009	2011	2012	2013	2014
Agarum cribrosum		x			
Alosa pseudoharengus	x	x	x	x	x
Alosa sapidissima		x	x	x	x
Amaroucium sp.	x				
Amblyraja radiata				x	x
Aphrodita aculeata				x	x
Aspidophoroides monopterygius				x	x
Astarte castanea		x		x	x
Asterias forbesi		x			
Asterias vulgaris	x	x	x	x	x
Aurelia aurita	x	x	x	x	x
Balunus balunus				x	
Bathypolypus arcticus		x		x	
Bolinopsis infundibulum				x	x
Boltenia ovifera	x	x	x	x	
Buccinum undatum			x		
Campanularia sp.			x		
Cancer borealis					x
Cancer irroratus		x	x	x	x
Carcinus maenas				x	
Chlamys islandica				x	
Ciona intestinalis	x	x	x	x	
Clinocardium ciliatum		x	x	x	x
Clupea harengus	x	x	x	x	x
Crangon septemspinosa			x	x	x
Crossaster papposus			x		
Cryptacanthodes maculatus		x			x
Ctenodiscus crispatus		x	x	x	x
Cuaudina arenata		x	x	x	
Cucumaria frondosa	x	x	x	x	x
Cyclopterus lumpus	x			x	x
Didemnum sp.	x		x		
Doryteuthis pealeii	x	x	x	x	x
Enchelyopus cimbrius		x	x	x	x
Gadus morhua	x	x		x	x
Glyptocephalus cynoglossus		x	x	x	x
Chlorophyta	x				
Halichondria sp.	x		x	x	x

Halocynthia pyriformis		x	x		
Harmothoe imbricata	x				
Hemitripterus americanus	x	x	x	x	x
Henricia sanguinolenta	x	x	x	x	x
Hippoglossoides platessoides		x	x	x	x
Hippoglossus hippoglossus		x	x		x
Homarus americanus	x	x	x	x	x
Hyas araneus				x	x
Hyas coarctatus			x		
Isodycta palmata	x	x	x	x	
Lebbeus groenlandicus	x	x	x	x	
Lepiodonotus squamatus		x	x	x	
Leucoraja erinacea	x	x	x	x	x
Leucoraja ocellata	x	x		x	x
Limanda ferruginea				x	
Lithodes maja				x	
Lophius americanus			x	x	x
Lycodes lavalaei				x	x
Melanogrammus aeglefinus		x	x	x	x
Mercenaria mercenaria		x		x	x
Merluccius bilinearis	x	x	x	x	x
Metridium senile		x	x	x	
Microgadus tomcod		x	x	x	
Molgula sp.			x		
Myoxocephalus aenaeus					x
Myoxocephalus octodecemspinosus	x	x	x	x	x
Myoxocephalus scorpius				x	
Mytilus edulis			x		
Ophiopholis aculeata		x	x	x	x
Osmerus mordax	x	x	x		x
Ostreidae sp.		x			
Pagurus acadianus			x	x	
Pandalus borealis	x	x	x	x	x
Pandalus montagui	x	x	x	x	x
Peprilus triacanthus	x	x	x	x	x
Phaeophyta		x			
Placopecten magellanicus	x	x	x	x	x
Pollachius virens		x			x
Prionotus corolinus					x
Pseudopleuronectes americanus	x	x	x	x	x
Rajella bathyphilus		x		x	
Rhodophyta	x				
Reinhardtius hippoglossoides		x			
Scomber scombrus		x	x	x	x
Scophthalmus aquosus	x	x	x	x	x

Sebastes fasciatus		x		x	x
Semirossia tenera				x	x
Sclerocrangon boreas				x	x
Solamen glandula				x	
Solaster endeca	x				
Spisula solidissima			x	x	x
Squalus acanthias			x	x	
Stenotomus chrysops				x	
Strongylocentrotus droebachiensis	x	x	x	x	x
Styela clava		x			
Styela montereyensis					x
Suberites ficus				x	
Taelia felina	x				
Tautogolabrus adspersus			x		
Triglops murrayi		x		x	x
Triglops sp.	x				
Tubularia sp.			x		
Ulvaria subbifurcata				x	
Filograna sp.				x	
Urophycis chuss			x	x	x
Urophycis tenuis	x	x	x	x	x
Urticina felina		x	x	x	
Zoarces americanus		x	x	x	x

APPENDIX 2.

Metadata table describing database structure, tables, and variables in Oracle database.

DFO Server = PTRAN

Account Name = BOF_TRAWL_SURVEYS

Tables = BOF_TRAWL_SURVEYS_SETS

BOF_TRAWL_SURVEYS_CATCHES

BOF_TRAWL_SURVEYS_SAMPLES

BOF_TRAWL_SURVEYS_SETS

MISSION	Unique mission identification code for each trawl year
SETNO	Unique identification code for each set within a trawl year
STATION	One of four trawl areas A-River Area, B-Upper Passamaquoddy Bay Area, C-Lower Passamaquoddy Bay Area, D- Outer Passamaquoddy Bay Area
DATETIME_START	Time trawl began (hh:mm)
DATETIME_FINISH	Time trawl ended (hh:mm)
LATITUDE_START	Latitudinal coordinates in decimal degrees where trawl began
LONGITUDE_START	Longitudinal coordinates in decimal degrees where trawl began
LATITUDE_FINISH	Latitudinal coordinates in decimal degrees where trawl ended
LONGITUDE_FINISH	Longitudinal coordinates in decimal degrees where trawl ended
DEPTH_START	Beginning trawl depth (metres)
DEPTH_FINISH	End trawl depth (metres)
SPEED	Vessel trawl speed (knots)
AVG_TEMP	Average temperature at cod end (^{o}C)
AVG_DEPTH	Average depth at cod end (^{o}C)
PRINCIPLE_INVESTIGATOR	Name of principle investigator
DATA_PROCESSOR	Name of data processor
PROJECT_NAME	Name of project
VESSEL	Name of vessel
GEAR_TYPE	Type of trawl method

BOF_TRAWL_SURVEYS_CATCHES

MISSION	Unique mission identification code for each trawl year
SPECIES_CODE	Numerical species identification code
STATION	One of four trawl areas A-River Area, B-Upper Passamaquoddy Bay Area, C-Lower Passamaquoddy Bay Area, D- Outer Passamaquoddy Bay Area
SETNO	Unique identification code for each set within a trawl year
SCIENTIFIC_NAME	Identification to lowest taxon level
COMMON_NAME	Common name for each species
NUMBER_CAUGHT	Total number of individuals caught
BIOMASS	Total biomass of individual species captured in grams
COMMENTS	Comment section

BOF_TRAWL_SURVEYS_SAMPLES

MISSION	Unique mission identification code for each trawl year
SPECIES_CODE	Numerical species identification code
SETNO	Unique identification code for each set within a trawl year
SCIENTIFIC_NAME	Identification to lowest taxon level
COMMON_NAME	Common name for each species
FISH_LENGTH	Measurement in millimetres of total length for all fish species, shell width for bivalves except scallop species where shell height was measured, and carapace length from posterior portion of cephalothorax to eye socket
WEIGHT	Individual mass measured in grams
SEX	M(male) F(female) and FB(berried female)
COMMENTS	Comment section

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