# PENOBSCOT RIVER MERCURY STUDY

## Chapter 16

## Analysis of aquatic and wetland food webs in the Penobscot estuary

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1. Penobscot River Mercury Study

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# 1 SUMMARY

Mercury (Hg) within aquatic and wetland food webs was examined using stable isotopes and diet analyses. In 2009, the Hg concentrations and isotopic signatures for carbon, nitrogen and sulfur were determined for target species including fish, lobster, and birds and for potential invertebrate prey. The study had three goals, to determine the food web source of Hg for each target species, to establish the length of each food web and so the trophic level of the target species at each study site, and to examine the level of site fidelity for target species, to learn whether species forage within one local area or travel among different sites.

In the aquatic food web, the combined results of the stable isotope and stomach content diet analyses found that most fish fed in the benthic food web in the main stem of the river with a partial or complete shift to a pelagic diet in Penobscot Bay. Eels fed in the benthic food web along the entire lower Penobscot. Tomcod also fed on benthic prey in the lower river, with a gradual shift to a partial pelagic diet in Penobscot Bay. Mummichog fed on benthic invertebrates with some contribution from wetland insects, possibly flushed into tidal sloughs. In rainbow smelt we found a mixed benthic and pelagic diet in the lower river with a full shift to a pelagic diet in Penobscot Bay. Lobster mixed their natural diet from the benthic food web with pelagic fish bait eaten from traps. In the wetland food web the diet of marsh birds was tied to invertebrates and insects including amphipods, orb-weaving spiders, katydids, leafhoppers and horseflies. Further, a consistent relationship was found in both the Penobscot and reference marshes in which Hg concentrations in birds were 10 times greater than the methyl Hg concentrations found in invertebrate prey in a given marsh.

The length of the aquatic and wetland food webs leading to our target species were similar, with the upper trophic levels for fish and lobster ranging from 3.7 to 3.95 trophic units and the upper trophic levels for birds ranging from 3.5 to 4.2 trophic units. The range of trophic levels for bird species extended lower than for fish and shellfish. No relationship was found between trophic level and Hg accumulations in the target species, eliminating differences in food web length as an explanation for differences in Hg concentrations among sites.

Site fidelity varied among fish species, from mummichog with no apparent movement among sample sites, tomcod which moved within reaches, but not between the river and bay, to eel, in the lower river, smelt, and lobster which showed extensive movement, either by them or their prey. Wetland birds had limited site fidelity with movement among the marshes along the lower Penobscot, but had minimal exchange with birds at upstream or coastal reference sites.

## 2 STUDY GOALS

Two studies of food webs were conducted in 2009 in the Penobscot estuary; the first was in the aquatic environments of the lower river and bay and the second was in the wetlands adjacent to the Penobscot River. The aquatic food web study in the river and bay combined stomach content diet analysis for four target fish species with stable isotope analysis of all levels of the aquatic food web. The wetland food web study examined the trophic structure of the summer marsh community using stable isotope signatures in five bird species and a range of wetland invertebrates. The study had three primary goals:

1. MERCURY SOURCE - First, to determine the source of Hg entering each food web. The source of carbon to a given food web, whether benthic or pelagic, freshwater or marine, aquatic or terrestrial, defines the habitat from which mercury (Hg) enters that food web. Understanding where Hg enters the food web is essential for modeling the movement and attenuation of Hg in the system, for predicting Hg exposure to upper trophic level biota, and for designing effective remediation efforts.

APPROACH - Carbon source was traced using the results of the stomach content diet analyses in fish and the $\delta^{13}C$ stable isotope signatures in the invertebrates, fish and birds studied at each site.

2. TROPHIC LEVEL - Second, to establish the length of the food web at each study site to confirm that geographic variation in Hg concentrations in the biota, especially in the target fish and bird species, was due to variable exposure from that habitat and not to spatial variation in the trophic position of the monitored species. Species feeding at a higher trophic level in the food web could be exposed to greater methyl Hg concentrations, potentially creating a bias in geographic comparisons.

APPROACH - Trophic position and food web length were determined by combining the results from stomach content diet analyses of target fish species with $\delta^{15}N$ isotope signatures from both invertebrates and target fish and bird species at each study site.

3. SITE FIDELITY - Third, to examine the level of site fidelity of the target species among the different study sites. If site fidelity is low, and organisms regularly feed at study sites with differing levels of Hg contamination, methyl Hg exposure due to geographic variation would be difficult to detect. Conversely, strong site fidelity would indicate limited fish and bird movements, and stronger linkage of methyl Hg exposure to localized contamination and conditions.

APPROACH - Site fidelity was examined using the combined results of the $\delta^{13}C$ and $\delta^{34}S$ isotope signatures in target species and in local invertebrates.

# 3 INTRODUCTION

Hg, in the form of methyl Hg, biomagnifies in food webs. Methyl Hg enters the food web through absorption by primary producers, those plants that convert light energy into carbon-based molecules and form the base of the food web (Chen and Folt 2005). In aquatic systems primary producers may be free-floating phytoplankton, which form the base of the pelagic food web, or algal mats covering the sediment which form the base of the benthic food web. Methyl Hg is easily assimilated by consumers and difficult to excrete; therefore, it biomagnifies in the food web, reaching ever increasing concentrations in higher trophic level organisms.

Determining where Hg enters the food web is key to reducing Hg exposure in upper trophic level organisms. Once Hg is absorbed by primary producers (Chen et al. 2008), it moves inevitably from prey to predator up the food web, and cannot be stopped without denying food to consumers. Two methods are commonly used to track the source of Hg. Since methyl Hg comes primarily from ingested food (Hall et al. 1997), determining an organism's diet through stomach content analysis reveals the immediate dietary source of Hg to an organism. Yet stomach content analysis defines the diet only during a given sampling period, and it may not define the overall trophic level of an organism in the long term, nor does it directly reveal where prey species picked up their own Hg load given the variable dietary habits of some fish. Stable isotope analysis provides information useful for addressing these additional questions.

Elements are defined by the number of protons in their nucleus, whereas isotopes of the elements are defined by their number of neutrons. In their more common form, carbon, nitrogen and sulfur have an equal number of protons and neutrons in the nucleus of the atom. Some isotopes are unstable, i.e. subject to radioactive decay, whereas others are stable, i.e. do not decay. In the stable isotopes of carbon, nitrogen and sulfur, the weight of the additional neutrons make these isotopes heavier than the more common form of the element. The isotopic signature of an organism is the difference between the ratio of the heavier isotope ($^{13}C$, $^{15}N$, or $^{34}S$) to the more common, lighter isotope ($^{12}C$, $^{14}N$, or $^{32}S$), relative to the ratio for an international standard. The isotopic signature for a tissue is defined when the tissue is formed; the signature does not change unless the tissue itself changes through turnover.

Stable isotope signatures are expressed in δ notation defining the following relationship:

$$\delta X = [(R_{sample} - R_{standard}) - 1] \times 1000$$

where X, in the current study, is $^{13}C$, $^{15}N$, or $^{34}S$, and R is the ratio of the heavy to light isotope $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{34}S/^{32}S$ for either the sample or an internationally recognized standard ($^{13}C$, PeeDee Belemnite; $^{15}N$, atmospheric $N_2$; $^{34}S$, Canyon Diablo)

The isotopic signature of some elements, especially carbon, nitrogen, and sulfur, describe different aspects of an organism's foraging strategy, whether they feed on terrestrial or aquatic, benthic or pelagic, freshwater or marine food sources – or a mixture of food webs (Peterson and Fry 1987; Hesslein et al. 1993; Hobson 1999), or their relative trophic level within the food web.

## 3.1 Background on Stable Isotopes

### 3.1.1 $\delta^{15}N$

The isotopic signature of $\delta^{15}N$ is used primarily to define the trophic level of an organism. With each increase of one trophic level, the $\delta^{15}N$ values increase by approximately 3.4‰ (per mil; part per thousand) in aquatic food webs leading to fish, and by approximately 2.4‰, in wetland or terrestrial food webs leading to birds (Cabana and Rasmussen 1994; Post 2002; McCutcheon et al. 2003). This trophic level increase in stable isotope signatures is termed trophic enrichment or trophic fractionation. For $\delta^{15}N$, enrichment occurs because relatively more of the lighter isotope, $^{14}N$, is excreted with nitrogenous waste (DeNiro and Epstein 1981). Estimates of trophic level for an organism can be calculated using the $\delta^{15}N$ signature, once they are standardized to the $\delta^{15}N_{base}$, i.e. the isotopic ratio in the primary producers at the base of the organism's food web, for each sample area. The $\delta^{15}N_{base}$ can vary widely among habitats and study sites because of both natural processes and human activities, and it is therefore used to correct for variability among sites. These ratios are enriched in marine systems relative to freshwater systems, and in benthic or inshore environments relative to pelagic food webs (Michener and Schnell 1994; Newsome et al. 2007). Once the $\delta^{15}N_{base}$ of a given food web is established – typically using longer-lived primary consumers - the trophic level of an organism in that food web can be directly estimated using established models (Post 2002).

### 3.1.2 $\delta^{13}C$

The isotopic signature for $\delta^{13}C$ also varies among habitats, but unlike $\delta^{15}N$ signatures, the $\delta^{13}C$ ratio increases only slightly, 0.5-1.0‰ per trophic level, from primary producers at the base of the food web to higher trophic level consumers (Post 2002). Relatively more of the lighter $^{12}C$ isotope is used in metabolic reactions and lost through respiration and excretion (DeNiro and Epstein 1978), slightly shifting the ratio to the heavier isotope in upper trophic level organisms. This relative stability of $\delta^{13}C$ isotopes in the food web makes $\delta^{13}C$ signatures valuable for tracking carbon flow in and among food webs, and can be used to define the base of an organism's food web (Hobson 1999).

$\delta^{13}C$ ratios show general patterns of change across multiple gradients. In general, higher $\delta^{13}C$ ratios (less negative values) in aquatic systems are associated with marine environments, and inshore and benthic habitats. Lower $\delta^{13}C$ ratios (more negative values) are associated with freshwater and terrestrial systems, and offshore and pelagic food webs (Post 2002, Newsome et al. 2007). In some environments the gradients may appear to be in conflict, shifting the ratios in opposite directions, yet within a site where other variables are held constant, they correctly distinguish between benthic or pelagic and aquatic or terrestrial food webs. The $\delta^{13}C$ values of whole tissues are affected by the lipid content of the tissue because lipids are lighter in $\delta^{13}C$ than proteins. To account for this, given that we report on a food web study of multiple organisms with a wide range of lipid values, the $\delta^{13}C$ values in the aquatic food web were statistically normalized to the lipid content of each sample, using the C:N ratio (Post et al. 2007).

The greatest differences between the raw and normalized ratios were found in the lower aquatic invertebrates, where lipid normalization altered the pattern of the $\delta^{13}C$ isotopes among the various species within a site and among sites for a given species. This C:N ratio method of lipid normalization is not effective in terrestrial invertebrates and was not used in analysis of the wetland food web.

### 3.1.3 $\delta^{34}S$

The ratios of $\delta^{34}S$ are used primarily to distinguish between freshwater and marine food webs because organisms relying on marine sulfur are higher in $\delta^{34}S$ than those relying on freshwater sulfur (Hobson et al. 1997; Newsome et al. 2007; Ramos et al. 2009). The sulfur ratios had been considered to be stable among trophic levels, although recent findings suggest that fractionation may increase the ratio by up to 0.8‰ per trophic level (Florin et al. 2011). In addition, the pattern of $\delta^{34}S$ ratios associates smaller ratios with benthic primary producers and marsh plants, especially those growing in relatively anoxic habitats. Larger $\delta^{34}S$ ratios indicate a more pelagic food web based on phytoplankton (Michener and Schnell 1984, Newsome et al. 2007).

# 4 METHODS

## 4.1 Stomach Content Diet Analysis

The diets of the four target fish species (American eel, *Anguilla rostrata*; tomcod, *Microgadus tomcod*; rainbow smelt, *Osmerus mordax*; and mummichog, *Fundulus heteroclitus*) were determined using stomach content analyses of fish caught in the lower Penobscot River and upper Penobscot Bay (Figure 16-1). The Orrington-Bucksport (OB) reach was studied in the greatest detail, with samples collected from all four fish species. Eels were the only fish sampled in the more upstream reaches, Old Town – Veazie (OV), upstream of the Veazie Dam and so outside of the direct aquatic influence of the HoltraChem facility, and Brewer-Orrington (BO), immediately upstream of the HoltraChem site. The ES reach in upper Penobscot Bay was represented by two species, tomcod and rainbow smelt. Lobster were not included in the stomach content analyses as the most recent meal of the sampled lobsters would likely be the Atlantic herring bait used to lure them into the traps.

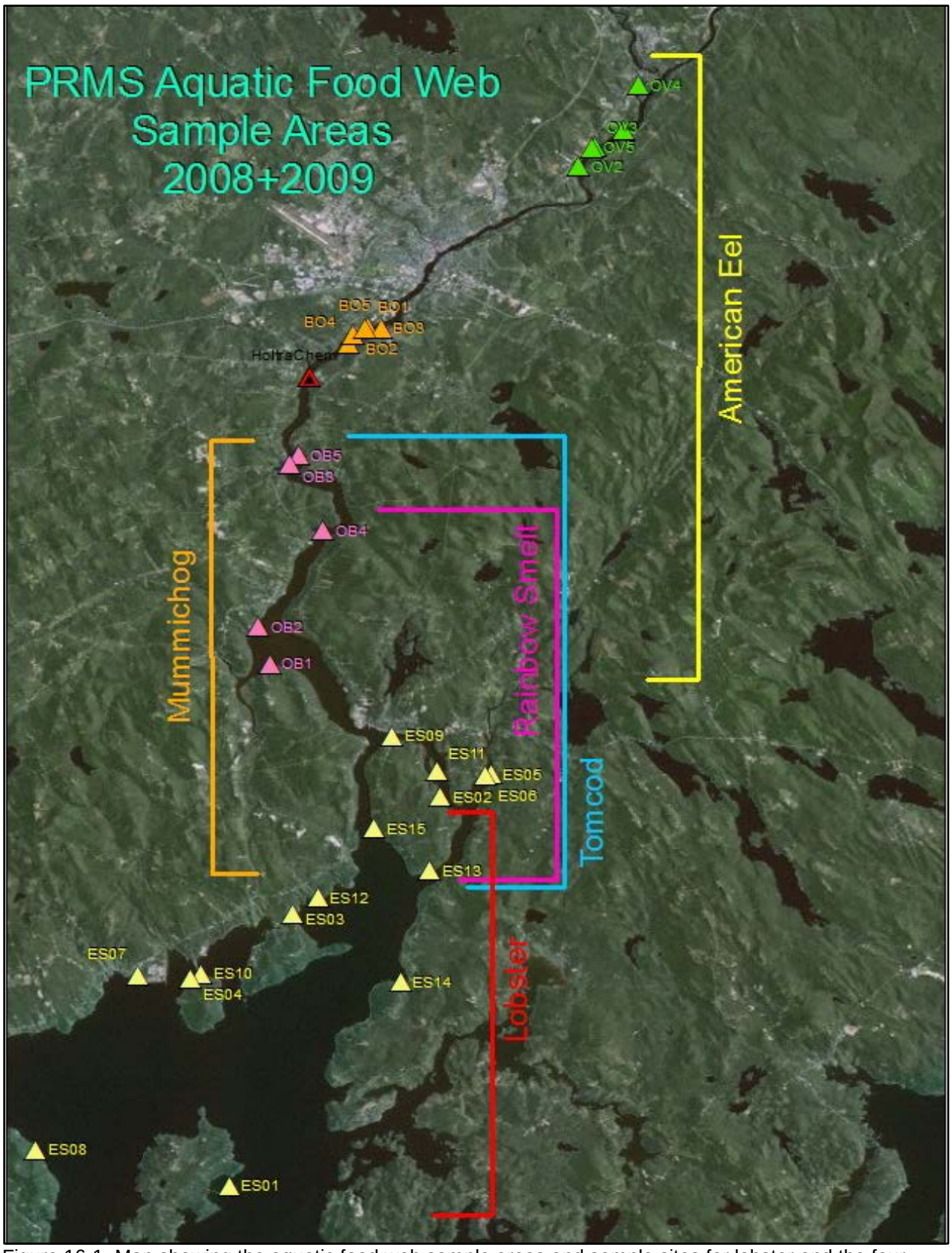


Figure 16-1. Map showing the aquatic food web sample areas and sample sites for lobster and the four fish species analyzed.

Samples were collected by trawl, traps, and electrofishing at established monitoring sites in September of 2009. Fish were chilled on ice immediately after capture and necropsied at the lab within hours of capture. For selected individuals, stomach contents were removed during necropsy and put into ICHEM glass vials filled with 6% formalin. When appropriate, formalin was injected into the stomach to arrest further deterioration of the contents. Following preservation with formalin, samples were transferred to ethanol for storage pending identification.

Species were identified to the lowest possible taxon, to species where possible, and to genus, family, or order when species identification was not possible due to the condition (digested stage) of the organism. Samples were weighed to the nearest 0.01 g to determine the weight contribution of each prey item and taxa. Analysis of stomach content data used the percent weight contribution of each taxa identified.

### 4.2 Stable Isotope Analysis

Stable isotopes and total and methyl Hg were determined in fish, lobster and possible invertebrate prey collected in September 2009, and in archived fish and lobster samples collected in 2008. Muscle samples were analyzed in fish and lobster, the soft tissue was analyzed in bivalves and snails, and other invertebrates were analyzed whole. Composite samples were created when individual sample weights were insufficient for the analytical procedures to be performed.

In the wetland study, non-lethal blood samples were collected from birds and analyzed for stable isotope and Hg concentrations. Blood samples best represent local exposure in birds after they have been resident a minimum of two to four weeks (McKinnon et al. 2012). Birds were sampled from early June to late July in 2009. Hg and stable isotopes were also analyzed in a subset of archived samples of bird blood collected in the summer of 2008.

Wetland invertebrates were sampled in early to mid-August 2009 and were analyzed for stable isotopes, total Hg and methyl Hg. At certain marshes sample dates differed for birds and invertebrates, with bird samples collected up to six weeks prior to collections of invertebrate samples. Given that prey availability is expected to change over the summer, invertebrates sampled in August may not reflect prey available to foraging birds in June, prior to the birds' sampling dates.

Invertebrates were collected along 50 m parallel transects, identified at each marsh site as T01, transect 1, and T02, transect 2 (Figure 16-3). At all marshes, transect 1 was located on the edge of the marsh platform near the river, and transect 2 was located in the interior of the marsh platform. The foraging ranges of marsh birds were assumed to encompass the invertebrate sample sites.

There was no dedicated study to identify ingested prey in marsh birds. Several incidental observations were made of prey carried by adult birds, presumably to chicks in the nest. Stable isotope data were used to identify prey consumed by the target bird species along with reports from the literature on the breeding season diet of marsh birds.

All stable isotope analyses were done at the Colorado Plateau Stable Isotope Laboratory at Northern Arizona University. Analyses for $\delta^{15}N$, $\delta^{13}C$, $\delta^{34}S$, %N and %C were run using a Thermo-Finnigan Delta$^{plus}$ Advantage gas isotope-ratio mass spectrometer interfaced with a Costech Analytical ECS4010 elemental analyzer. The isotopic signatures for $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ were expressed relative to the standard ratios for Vienna Pee Dee Belemnite for carbon, air for nitrogen, and Canyon Diablo Troilite for sulfur. A standard compliment of quality control procedures were performed including duplicate analyses on 10% of the samples, isotope (IAEA CH6, IAEA CH7, IAEA N1, IAEA N2, and IAEA S1-6) and elemental calibration standards, and drift and linearity standards (NIST peach leaves).

Summaries of raw data for this study are provided in Appendices 16-1 to 16-8.


Figure 16-2. Map showing the wetland food web sample areas for the lower Penobscot River.

### 4.2.1 $\delta^{15}N_{base}$

As mentioned in the introduction, in order to compare the $\delta^{15}N$ among different habitats, and to estimate the trophic position of organisms sampled, raw $\delta^{15}N$ values must be standardized using the $\delta^{15}N_{base}$ for each habitat. Sampling the primary producers that comprise the $\delta^{15}N_{base}$ is not always possible, nor is it necessarily desirable given the reported temporal variation in the $\delta^{15}N$ isotopic signatures of aquatic primary producers and detritus (Post 2002). To address this issue, the $\delta^{15}N$ signature of long-lived primary consumers (e.g. snails, clams) is often used to determine the $\delta^{15}N_{base}$, which assumes that primary consumers integrate the fluctuations in isotopic signatures of the primary producers over time, giving a more accurate isotopic value.

### 4.2.2 Aquatic $\delta^{15}N_{base}$

In 2009 in the ES reach, samples were collected from the base of both the benthic and pelagic food webs to establish the $\delta^{15}N_{base}$ for each sample site (methods described below in the Trophic Level section). The grazing snail *Littorina*, a primary consumer, was collected at all four ES sites (Tables 16-3 and 16-4), and was used to establish the $\delta^{15}N_{base}$ of the benthic food web in ES. Blue mussels (*Mytilus edulis*), which consume phytoplankton, were used to establish the $\delta^{15}N_{base}$ in the pelagic food web in ES.

Amphipods were used to establish the $\delta^{15}N_{base}$ for the benthic food web in the lower river reaches of BO and OB. No primary consumer was available for the OV reach. We therefore sampled and analyzed oligochaete worms, most of which are predatory secondary consumers, to estimate the $\delta^{15}N_{base}$ of the benthic food web in OV.

For the pelagic food web in the OV reach, a primary consumer, the filter-feeding freshwater mussel *Elliptio*, was used to calculate the $\delta^{15}N_{base}$. No pelagic primary consumer was collected in BO. The pelagic $\delta^{15}N_{base}$ in OB was calculated using the primary consumer *Neomysis* shrimp and the secondary consumer *Crangon* shrimp. However, the isotopic signature of *Crangon* shrimp do not exclusively represent the $\delta^{15}N_{base}$ of the pelagic food web as *Crangon* are omnivores feeding in both benthic and pelagic food webs.

### 4.2.3 Wetland $\delta^{15}N_{base}$

The $\delta^{15}N$ signatures in the target bird species were standardized to the base of the wetland food web using the $\delta^{15}N$ value for marsh amphipods (methods described below in the Trophic Level section). The Talitride family of amphipods includes both primary consumers and omnivores foraging on detrital material. For these estimates, we assumed that all birds were secondary consumers on amphipods, and that 100% of the bird diet came from the wetland food web. Invertebrates were not collected at all of the sites where birds were sampled. At those sites, the $\delta^{15}N_{base}$ from the closest adjacent site was used to calculate trophic position of the birds (Table 16-3).

## 4.3 Trophic Level

Trophic levels of target species of fish, lobster and birds were estimated using established models using $\delta^{15}N$ reported in Post (2002) and given in Table 16-1. For fish and lobster, the percent contribution to the diet from either the benthic or pelagic food webs (i.e. benthic or pelagic carbon sources) was estimated from the diet composition determined from either stomach content analyses (fish) or from published reports in the literature (lobster; Hudon and Lamarche 1989; Grabowski et al. 2010).

Stomach content analyses defined fish diet during limited sample periods in September 2009 and may not reflect the long-term diet over the preceding weeks or months prior to collection. The broader, long-term diet would have contributed to both the stable isotope signature and the accumulation of Hg in fish muscle.

Assigning the organism used for the $\delta^{15}N_{base}$ to either benthic or pelagic carbon sources was based on the foraging strategy of the organism. For example, bivalves that filter phytoplankton from the water column were determined to have a pelagic carbon source. Benthic grazing snails were determined to have a benthic carbon source.

**Table 16-1. Models used to estimate trophic position of target fish, lobster and bird species using primary or secondary consumers as the $\delta^{15}N_{base}$.**

| **Models used to estimate trophic position of biota (Post 2002)** |
|---|
| For primary consumers |
| $$\boldsymbol{Trophic\ Position} = \frac{\boldsymbol{\delta^{15}N}}{\mathbf{3.4}}$$ |
| For secondary consumers feeding in one food web with one carbon source |
| $$\boldsymbol{Trophic\ Position} = \boldsymbol{\lambda} + \frac{\boldsymbol{\delta^{15}N}_{\boldsymbol{secondary\ consumer}} - \boldsymbol{\delta^{15}N}_{\boldsymbol{base}}}{\boldsymbol{\Delta^{15}N}}$$ |
| For secondary consumers feeding in two food webs with two carbon sources |
| $$\boldsymbol{Trophic\ Position} = \boldsymbol{\lambda} + \frac{(\boldsymbol{\delta^{15}N}_{\boldsymbol{secondary\ consumer}} - [\boldsymbol{\delta^{15}N}_{\boldsymbol{base1}} * \boldsymbol{\alpha} + \boldsymbol{\delta^{15}N}_{\boldsymbol{base2}} * (\mathbf{1} - \boldsymbol{\alpha})])}{\boldsymbol{\Delta^{15}N}}$$ |
| NOTE: |
| $\lambda$ = trophic position of $\delta^{15}N_{base}$ ( δ15N of primary consumer/3.4(aquatic) or /2.4 (terrestrial) |
| $\Delta^{15}N$ = enrichment of $\delta^{15}N$ per trophic level |
| $\alpha$ = percent contribution of the benthic or pelagic carbon source to the diet of the secondary consumer |

**Table 16-2. Values used to estimate trophic position in fish and lobster using the models given in Table 1. Carbon sources are designated as benthic or pelagic, or a mixed contribution from both carbon sources (food webs). The taxa representing the $\delta^{15}N_{base}$ are given for each target species and sample site, along with the percent contribution of that carbon source (food web) to the diet (α). The value for the trophic position of the $\delta^{15}N_{base}$ (λ), from base 1, if only one carbon source is consumed, or from bases 1 and 2 if two carbon sources are consumed, is also given.**

| FISH + SHELLFISH TARGET SPECIES | | PREY BASE | | | $\delta^{15}N_{base1}$ | | | | $\delta^{15}N_{base2}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FOOD WEB SITE | TARGET SPECIES | 1° Consumers | 2° Consumers with 1 Carbon Source | 2° Consumers with 2 Carbon Sources | TAXA | ESTIMATED TROPHIC LEVEL | $\delta^{15}N$ ‰ | α | TAXA | ESTIMATED TROPHIC LEVEL | $\delta^{15}N$ ‰ | 1- α | λ |
| | | Carbon source | Carbon source | Carbon source | | | | | | | | | |
| BO3 | American eel | | benthic | | Oligochaete | 1.64 | 5.58 | 100 | | | | 0 | 1.64 |
| BO4 | American eel | | benthic | | Oligochaete | 1.81 | 6.14 | 100 | | | | 0 | 1.81 |
| OB1 | American eel | | | benthic+pelagic | Amphipod | 2.45 | 8.34 | 80 | Neomysis | 1.59 | 5.41 | 20 | 2.30 |
| OB3 | American eel | | | benthic+pelagic | (use OB5) | | | | | | | | |
| OB5 | American eel | | | benthic+pelagic | Amphipod | 2.00 | 6.80 | 80 | Neomysis | 1.59 | 5.41 | 20 | 1.90 |
| OV4 | American eel | | benthic | | Oligochaete | 1.04 | 3.50 | 100 | | | | 0 | 1.04 |
| ES13 | Mummichog | | benthic | | Littorina | 2.63 | 8.93 | 100 | | | | 0 | 2.63 |
| OB1 | Mummichog | | benthic | | Amphipod | 2.45 | 8.34 | 100 | | | | 0 | 2.45 |
| OB5 | Mummichog | | benthic | | Amphipod | 2.00 | 6.80 | 100 | | | | 0 | 2.00 |
| ES04 | Lobster | | | benthic+pelagic | Littorina | 2.26 | 7.67 | 53 | Mytilus | 1.89 | 6.42 | 47 | 2.09 |
| ES13 | Lobster | | | benthic+pelagic | Littorina | 2.63 | 8.93 | 53 | Mytilus | 2.24 | 7.62 | 47 | 2.45 |
| ES15 | Lobster | | | benthic+pelagic | Littorina | 2.70 | 9.19 | 53 | Mytilus | 2.31 | 7.87 | 47 | 2.52 |
| ESFP | Lobster | | | benthic+pelagic | Littorina | 2.51 | 8.55 | 53 | Mytilus | 2.23 | 7.59 | 47 | 2.38 |
| H | Lobster | | | benthic+pelagic | (use ES04) | | | | | | | | |
| KC | Lobster | | | benthic+pelagic | (use ES04) | | | | | | | | |
| PC | Lobster | | | benthic+pelagic | (use ES04) | | | | | | | | |
| ES02 | Rainbow smelt | | pelagic | | Mytilus | (ES13) | | 100 | | | | 0 | |
| ES03 | Rainbow smelt | | pelagic | | Mytilus | (ESFP) | | 100 | | | | 0 | |
| ES04 | Rainbow smelt | | pelagic | | Mytilus | 1.89 | 6.42 | 100 | | | | 0 | 1.89 |
| ES05 | Rainbow smelt | | pelagic | | Mytilus | (ES13) | | 100 | | | | 0 | |
| ES09 | Rainbow smelt | | pelagic | | Mytilus | (ES15) | | 100 | | | | 0 | |
| ES13 | Rainbow smelt | | pelagic | | Mytilus | 2.24 | 7.62 | 100 | | | | 0 | 2.24 |
| ES15 | Rainbow smelt | | pelagic | | Mytilus | 2.31 | 7.87 | 100 | | | | 0 | 2.31 |
| ESFP | Rainbow smelt | | pelagic | | Mytilus | 2.23 | 7.59 | 100 | | | | 0 | 2.23 |
| OB1 | Rainbow smelt | | pelagic | | Neomysis | 1.59 | 5.41 | 100 | | | | 0 | 1.59 |
| OB4 | Rainbow smelt | | pelagic | | Neomysis | 1.59 | 5.41 | 100 | | | | 0 | 1.59 |

**Table 16-3. (continued)**

| FISH + SHELLFISH TARGET SPECIES | | PREY BASE | | | $\delta^{15}N_{base1}$ | | | | $\delta^{15}N_{base2}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FOOD WEB SITE | TARGET SPECIES | 1° Consumers | 2° Consumers with 1 Carbon Source | 2° Consumers with 2 Carbon Sources | TAXA | ESTIMATED TROPHIC LEVEL | $\delta^{15}N$ ‰ | α | TAXA | ESTIMATED TROPHIC LEVEL | $\delta^{15}N$ ‰ | 1- α | λ |
| | | Carbon source | Carbon source | Carbon source | | | | | | | | | |
| ES02 | Tomcod | | | benthic+pelagic | (use ES13) | | | | | | | | |
| ES05 | Tomcod | | | benthic+pelagic | (use ES13) | | | | | | | | |
| ES09 | Tomcod | | | benthic+pelagic | (use ES15) | | | | | | | | |
| ES13 | Tomcod | | | benthic+pelagic | Littorina | 2.63 | 8.97 | 35 | Mytilus | 2.24 | 7.62 | 65 | 2.38 |
| ES15 | Tomcod | | | benthic+pelagic | Littorina | 2.70 | 9.19 | 35 | Mytilus | 2.31 | 7.87 | 65 | 2.45 |
| OB1 | Tomcod | | | benthic+pelagic | Amphipod | 2.45 | 8.34 | 50 | Neomysis | 1.59 | 5.41 | 50 | 2.02 |
| OB4 | Tomcod | | | benthic+pelagic | (use OB1) | | | | | | | | |
| OB5 | Tomcod | | | benthic+pelagic | Amphipod | 2.00 | 6.80 | 80 | Neomysis | 1.59 | 5.41 | 20 | 1.92 |
| **INVERTEBRATE + PREY TAXA** | | | | | | | | | | | | | |
| ALL | Amphipod | benthic | | | | | | | | | | | |
| OB4 | Worm (Annelid) | benthic | | | | | | | | | | | |
| ES | Atlantic Herring (lobster bait) | | pelagic | | Mytilus | 2.23 | 7.38 | 100 | | | | 0 | 2.23 |
| ALL | Blue mussels (Mytilus) | pelagic | | | | | | | | | | | |
| OB1 | Sand shrimp (Crangon) | | | benthic+pelagic | Amphipod | 2.45 | 8.34 | 75 | Neomysis | 1.59 | 5.41 | 25 | 2.20 |
| OB3 | Sand shrimp (Crangon) | | | benthic+pelagic | (use OB5) | | | | | | | | |
| OB4 | Sand shrimp (Crangon) | | | benthic+pelagic | Amphipod | 2.24 | 7.60 | 75 | Neomysis | 1.59 | 5.41 | 25 | 2.10 |
| OB5 | Sand shrimp (Crangon) | | | benthic+pelagic | Amphipod | 2.00 | 6.80 | 75 | Neomysis | 1.59 | 5.41 | 25 | 1.90 |
| OV4 | Freshwater mussel (Elliptio) | pelagic | | | | | | | | | | | |
| ES04 | Blood worm (Glycera) | | benthic | | Littorina | 2.26 | 7.67 | 100 | | | | 0 | 2.26 |
| ES13 | Blood worm (Glycera) | | benthic | | Littorina | 2.63 | 8.93 | 100 | | | | 0 | 2.63 |
| ES15 | Blood worm (Glycera) | | benthic | | Littorina | 2.70 | 9.19 | 100 | | | | 0 | 2.70 |
| ALL | Periwinkle snail (Littorina) | benthic | | | | | | | | | | | |
| ALL | Soft-shell clam (Mya) | pelagic | | | | | | | | | | | |
| ES04 | Sand worm (Neanthes) | | benthic | | Littorina | 2.26 | 7.67 | 100 | | | | 0 | 2.26 |
| ES13 | Sand worm (Neanthes) | | benthic | | Littorina | 2.63 | 8.93 | 100 | | | | 0 | 2.63 |
| ESFP | Sand worm (Neanthes) | | benthic | | Littorina | 2.51 | 8.55 | 100 | | | | 0 | 2.51 |
| ALL | Insect larvae | benthic | | | | | | | | | | | |
| ALL | Opossum shrimp (Neomysis) | pelagic | | | | | | | | | | | |
| ALL | Worm (Oligochaete) | benthic | | | | | | | | | | | |
| ALL | Worm (Polychaete) | benthic | | | | | | | | | | | |
| ALL | Zooplankton | pelagic | | | | | | | | | | | |

**Table 16-4. Values used to estimate trophic position in wetland birds using the models given in Table 16-1.**

| WETLAND BIRD - $\delta^{15}N_{base}$ values for TROPHIC LEVEL ESTIMATION | | | | |
|---|---|---|---|---|
| | 2° consumer in wetland food web | | | |
| FOOD WEB SITE | $N_{base}$ TAXA | YEAR SAMPLED | $\delta^{15}N_{base}$ | λ |
| Bald Hill Cove N | (use W17N) | | 2.34 | 1.04 |
| W17N | Amphipod | 2009 | 2.34 | 1.04 |
| W17S | (use W17N) | | 2.34 | 1.04 |
| MM-Treat Pt | (use MM-SW) | | 3.7 | 1.64 |
| MM-Car | (use MM-SW) | | 3.7 | 1.64 |
| MM-NE | (use MM-SE) | | 1.68 | 0.75 |
| MM-SE | Amphipod | 2009 | 1.68 | 0.75 |
| MM-Jetti | (use MM-SW) | | 3.7 | 1.64 |
| MM-SW | Amphipod | 2009 | 3.7 | 1.64 |
| MM-S174 | Amphipod | 2010 | 2.71 | 1.2 |
| Leaches Pt (all sites) | (mean values) | | 3.04 | 1.4 |
| MDI (Tremont, Bass Ha | (mean values) | | 3.04 | 1.4 |
| Scarborough | Amphipod | 2009 | 4.79 | 2.13 |
| RCNWR | (use Scarborough) | | 4.79 | 2.13 |

# 5 MIXING MODELS

An isotopic mixing model was used to estimate the percent contribution made by potential prey taxa to the diet of each target species of fish or bird. This Bayesian model, SIAR (Stable Isotope Analysis in R; Parnell et al. 2010), used all three isotopes, $\delta^{15}N$, $\delta^{13}C$, and $\delta^{34}S$ to estimate the range of percent contributions from each prey taxa.

The trophic enrichment factors used in the SIAR model varied slightly between the aquatic and wetland food webs. In the aquatic food web with target fish species as the top consumers, we used enrichment factors (mean ± SD) of 3.42 ± 0.99 for $\delta^{15}N$, 0.39 ±1.3 for $\delta^{13}C$, and 0.5 ± 0.68 for $\delta^{34}S$ (Post 2002; McCutcheon et al. 2003). In the wetland food web with marsh birds as the top consumers, we used enrichment factors of 2.25 ± 0.3 for $\delta^{15}N$, 0.5 ± 0.14 for $\delta^{13}C$, and 0.5 ± 0.65 for $\delta^{34}S$ (Hobson 1999; Mc Cutcheon et al. 2003). The findings from the wetland analysis were limited by the timing of the sample collection, discussed in detail in the results section, and gaps in the dataset.

## 5.1 Note On Figures

In all of the figures that follow, the sites listed in the legend are listed in geographic order - from north to south along the Penobscot River and down to Verona Island and from northeast to southwest in Penobscot Bay. The legend can often be used as a tool for interpreting geographic trends in the graphs presented. Comparing the site names to the maps for the aquatic (Figure 16-1) and the wetland (Figure 16-2) sampling locations further clarifies geographic trends.

## 5.2 Aquatic Food Web - Source Of Mercury In The Lower Penobscot

## 5.3 Benthic V Pelagic

Note that data summaries for aquatic food chains can be found in Appendices 16-1 to 16-3.

## 5.4 OV Reach

The OV reach in the lower Penobscot River extends upstream of the Veazie Dam to the town of Old Town, and is used as a local aquatic reference site as it lies upstream of the aquatic influence of the HoltraChem facility. The American eel is the only species currently chosen for long-term monitoring in OV, and the only fish species in OV included in the aquatic food web study.

### 5.4.1 OV - American eel

The findings of the stomach content analyses indicate that eels in this reach feed primarily in the benthic food web (Table 16-4). The sample size of American eels in OV was small but useable; stomachs from seven eels had identifiable prey remains, with a combined stomach content weight of over 17 grams. In that combined sample, the eel diet by weight was primarily Oligochaete worms (62%), followed by crayfish (17%), and mollusks (9%) (Table 16-4). Based on these findings, almost 80% of the eel's diet (worms and crayfish) was part of the benthic food web with approximately 10 % of the diet comprised of Mollusca remains, either in the benthic food web (if the remains are from surface-grazing snails) or the pelagic food web (if the remains are from filter-feeding bivalves). The results of the stable isotope analyses help clarify this finding.

**Table 16-5. Results of stomach content analyses (% mass of individual taxa) from four species of fish collected in September 2009 from the lower Penobscot River and upper Penobscot Bay.**

| Fish Prey Analysis, September 2009 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Reach | OV | BO | OB | | | | ES | |
| Fish species | Eel | Eel | Eel | Tomcod | Rainbow smelt | Mummichog | Tomcod | Rainbow smelt |
| number of useable stomachs | 7 | 7 | 26 | 55 | 8 | 12 | 19 | 34 |
| total number of stomachs | 7 | 12 | 44 | 59 | | | 19 | |
| total stomach contents weight (g) | 17.62 | 1.80 | 49.08 | 13.22 | 5.52 | 0.31 | 5.19 | 3.23 |
| | | | | | | | | |
| Fish prey items | % by weight | % by weight | % by weight | % by weight | % by weight | % by weight | % by weight | % by weight |
| | | | | | | | | |
| **SEMI-PELAGIC INVERTEBRATES** | | | **0.12** | **4.16** | **14.95** | **0.00** | **47.40** | **90.07** |
| **Zooplankton** | | | | | | | | |
| Calanoida | | | | | | | | 56.38 |
| Chaetognatha (worms, could be in plankton or benthos) | | | | | | | | 0.15 |
| Mysidacea | | | | 0.30 | | | | 7.42 |
| Mysis mixta | | | 0.08 | 0.53 | 6.16 | | 2.89 | |
| Neomysis americana | | | 0.04 | 3.33 | 8.79 | | 44.51 | 26.12 |
| | | | | | | | | |
| **EPI-BENTHIC INVERTEBRATES** | **17.48** | **10.00** | **96.94** | **73.95** | **9.33** | **9.84** | **40.75** | **9.20** |
| **Amphipods*** | | | | | | | | |
| Ampithoidae (amphipod) | | | | 0.08 | | | | |
| Ampelisca verilli (amphipod) | | | | 0.19 | | | | |
| Corophium sp. (Gammarid amphipod) | | | | 0.23 | | | 0.10 | |
| Gammaridae | | | | 1.02 | | 6.56 | | |
| Gammaridae remains | | | | 0.08 | | | | |
| Gammarus lawrencianus | | | | 1.13 | | | | |
| Gammarus sp. | | | | 1.17 | 0.09 | | | |
| **Isopods** | | | | | | | | |
| Anthuridea (isopod) | | | 0.53 | | | | | |
| Cirolana polita (isopod, scavenger on dead) | | | | 0.08 | | | | |
| Cyathura polita (isopod) | | | 0.94 | 0.15 | | | | |
| Edotea phosphorea (isopod) | | | | 0.04 | | | 0.19 | |
| Edotea sp. (isopod) | | | | | | | 0.19 | |
| Jaera marina (isopod) | | | | 0.04 | | | | |

**Table 16-6. (continued)**

| Fish Prey Analysis, September 2009 (continued) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Reach | OV | BO | OB | | | | ES | |
| Fish species | Eel | Eel | Eel | Tomcod | Rainbow smelt | Mummichog | Tomcod | Rainbow smelt |
| number of useable stomachs | 7 | 7 | 26 | 55 | 8 | 12 | 19 | 34 |
| total number of stomachs | 7 | 12 | 44 | 59 | | | 19 | |
| total stomach contents weight (g) | 17.62 | 1.80 | 49.08 | 13.22 | 5.52 | 0.31 | 5.19 | 3.23 |
| | | | | | | | | |
| Fish prey items | % by weight | % by weight | % by weight | % by weight | % by weight | % by weight | % by weight | % by weight |
| | | | | | | | | |
| **Snails** | | | | | | | | |
| Gastropoda operculum | 0.06 | | | | | | | |
| **Decapods** | | | | | | | | |
| Crangon septemspinosa | | | 93.54 | 63.88 | 9.24 | | 5.49 | 9.20 |
| Crangon sp. | | | | 0.61 | | | 0.10 | |
| Crustacea remains | 0.17 | | 0.01 | 4.92 | | | 3.08 | |
| Decapoda remains | | | 1.92 | | | | | |
| Orconectes sp. (crayfish) | 17.25 | | | | | | | |
| Shrimp Decapoda | | 10.00 | | 0.35 | | 3.28 | 31.60 | |
| | | | | | | | | |
| **ENDO-BENTHIC INVERTEBRATES** | **61.58** | **46.11** | | **0.04** | | | **3.09** | |
| Nematoda | | 46.11 | | | | | | |
| Oligochaeta | 61.01 | | | | | | | |
| Pectinaria sp. Tube (annelid worm) | | | | | | | 0.10 | |
| Polychaeta remains | 0.57 | | | 0.04 | | | 2.99 | |
| | | | | | | | | |
| **FISH** | | | **1.53** | **19.40** | **74.82** | | | |
| Atlantic herring | | | | | 74.82 | | | |
| Mummichog | | | 1.45 | | | | | |
| Pisces remains | | | 0.08 | 19.40 | | | | |
| | | | | | | | | |
| **SHELLFISH** | **8.51** | | | | | | | |
| Mollusca | 8.51 | | | | | | | |

**Table 16-7. (continued)**

| Fish Prey Analysis, September 2009 (continued) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Reach | OV | BO | OB | | | | ES | |
| Fish species | Eel | Eel | Eel | Tomcod | Rainbow smelt | Mummichog | Tomcod | Rainbow smelt |
| number of useable stomachs | 7 | 7 | 26 | 55 | 8 | 12 | 19 | 34 |
| total number of stomachs | 7 | 12 | 44 | 59 | | | 19 | |
| total stomach contents weight (g) | 17.62 | 1.80 | 49.08 | 13.22 | 5.52 | 0.31 | 5.19 | 3.23 |
| | | | | | | | | |
| Fish prey items | % by weight | % by weight | % by weight | % by weight | % by weight | % by weight | % by weight | % by weight |
| | | | | | | | | |
| | | | | | | | | |
| **INSECTS** | **2.61** | **43.34** | | | | **90.16** | | |
| Digested Arthropoda | | 0.28 | | | | | | |
| Digested Insecta remains | | 20.28 | | | | | | |
| Insecta (ants?) | | | | | | 65.57 | | |
| Insecta pupa | 0.62 | | | | | | | |
| Perlidae (stonefly) | | 22.78 | | | | | | |
| Suborder Oniscidea (terrestrial sow bug) | 1.76 | | | | | | | |
| Terrestrial Insecta legs | 0.23 | | | | | | | |
| Winged Insecta | | | | | | 24.59 | | |
| | | | | | | | | |
| **ANIMAL** | **9.19** | | **0.11** | **1.36** | | | **0.10** | |
| Animal remains | 9.19 | | 0.11 | 1.36 | | | 0.10 | |
| | | | | | | | | |
| **PLANT** | **0.57** | | | **0.98** | **0.18** | | **8.57** | **0.15** |
| Detritus | | | | 0.30 | | | | |
| Plant material | | | | 0.15 | | | | |
| Terrestrial detritus | | | | | | | 8.48 | |
| Wood fragments | 0.57 | | | 0.53 | 0.18 | | 0.10 | 0.15 |
| | | | | | | | | |
| Unidentified digested remains | | | 0.49 | | 0.91 | | 0.10 | 0.31 |
| | | | | | | | | |
| *Amphipods possibly semi-pelagic | | | | | | | | |

The 2008 and 2009 $\delta^{13}C$ signatures of eels and their potential prey items in the OV reach support the finding that eels in OV are supported by the benthic food web (Figure 16-3). The $\delta^{13}C$ signature of the eels, -25.8‰, is slightly heavier (less negative) than that of the benthic Oligochaete worm at -28.1‰. If a significant portion of the eel diet were coming from the pelagic food web the eels' $\delta^{13}C$ signature would be expected to be midway between the signature of the benthic Oligochaete worm and that of the freshwater mussel *Elliptio* (-33.6‰), which filters plankton from the water column. This was not the case, as seen in Figure 16-3. The eels' $\delta^{13}C$ signature is slightly heavier (less negative) than the signature from the Oligochaete worm, likely due to trophic fractionation of $^{13}C$, and indicates reliance of the eels on a benthic carbon source.

### 5.5 BO Reach

The BO reach is directly upstream of the HoltraChem facility and potentially subject to discharges from the plant that could be carried upstream on an incoming flood tide. As in OV, American eels were the only fish species sampled in the BO reach in 2009, and the only fish sampled as part of the aquatic food web study.

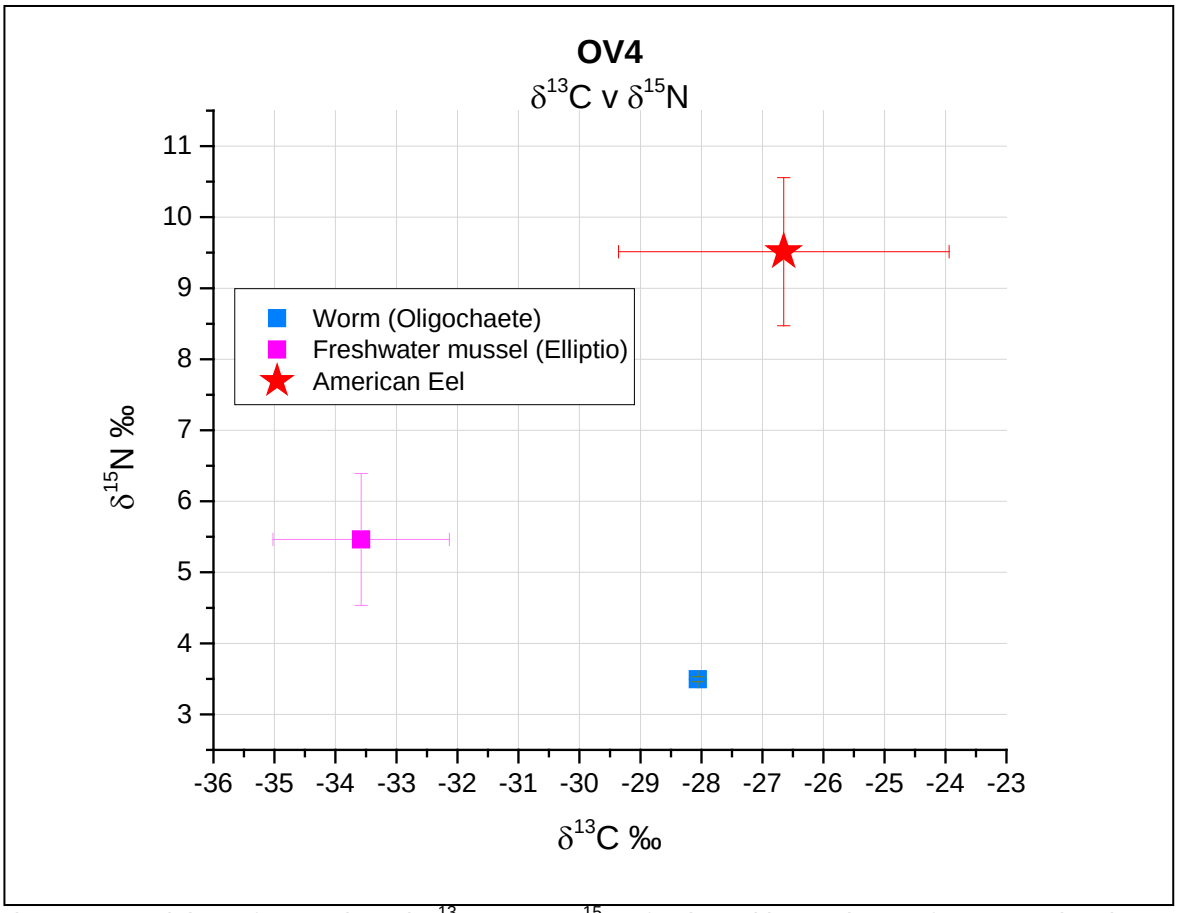


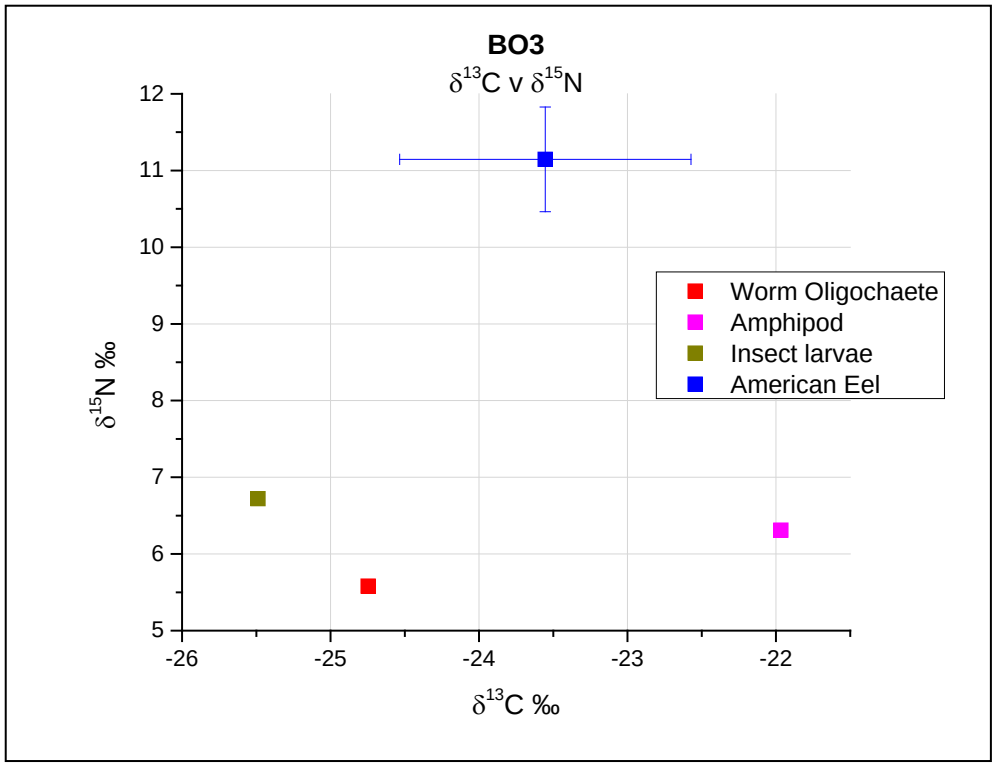

Figure 16-3. Biplots of mean (± SD) $\delta^{13}C$ versus $\delta^{15}N$ of eels and invertebrates from OV. The close similarity of the $\delta^{13}C$ signatures for eels and the presumed base of the benthic food web (Oligochaete worm) support the stomach content findings that eels in the OV reach feed in the benthic food web.

### 5.5.1 BO - American Eel

Seven of the 12 eel stomachs collected from BO3 and BO4 contained useable remains. The combined weight of the prey items from those stomachs was small (1.8 grams) (Table 16-4). In that combined dataset, benthic worms (Nematoda) comprised 46% of the eel diet by weight while aquatic insects (Perlidae and digested insect remains) comprised 43% of the dietary mass. Decapod shrimp added another 10% to the weight of the diet. These findings suggest that eels in BO, like those in OV, feed primarily in the benthic food web, but given the limited data, these findings should be interpreted with caution.

Although no invertebrates using a pelagic carbon source were sampled at the BO sites, the isotope findings supported the results of the stomach content analysis for eels in the BO reach that eels were feeding primarily on benthic food. The $\delta^{13}C$ signatures for eels from two intertidal sites in BO3 and BO4 were compared to those of potential prey items sampled at the same sites (Figure 16-4). In BO3, the mean $\delta^{13}C$ signature for the eels (-23.6‰) was slightly heavier than that of the Oligochaete worms (-24.8‰) and the insect larvae (-25.5‰). This difference could be explained by either trophic enrichment of the C isotopes as they move through the food web to the eel, or by a contribution to the eel diet from amphipods, which had a slightly heavier $\delta^{13}C$ signature at -22.0‰. While no amphipods were specifically found in the stomach contents from eels captured in the BO reach, a small fraction of the contents in BO3 were digested remains from the Phylum Arthropoda, which could include Amphipods. If eels were feeding from the pelagic food web at this site their $\delta^{13}C$ signature would likely have been lighter, i.e., more negative.

A somewhat similar result was found downstream at BO4. The $\delta^{13}C$ signatures for eel and Oligochaete worms -24.2‰ and -23.9‰, respectively), with both less enriched in $^{13}C$ than for amphipods sampled at that site (-21.0‰).



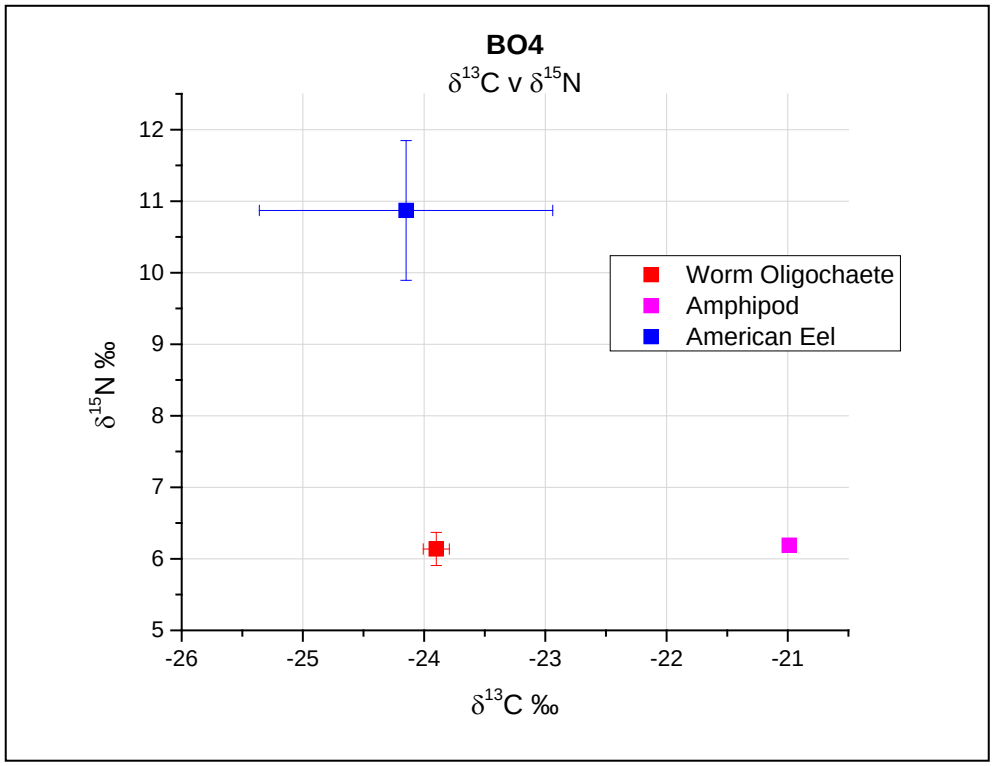




Figure 16-4. Biplots of mean (± SD) $\delta^{13}C$ versus $\delta^{15}N$ of eels and invertebrates from BO3 and BO4. The $\delta^{13}C$ signature of the eels at BO3 are equidistant between the $\delta^{13}C$ values for two benthic invertebrates, supporting earlier findings that eels feed in the benthic food web at this site. The eel $\delta^{13}C$ signature at BO4 is similar to the benthic worm at this site.

## 5.6 OB Reach

The OB reach begins 3 miles downstream of the HoltraChem facility at OB5 and extends south to Bowden Point at OB1, near the mouth of the Marsh River. Diet analysis using both stomach contents and stable isotopes was examined in four fish species in this reach, American eel, tomcod, rainbow smelt and mummichog.

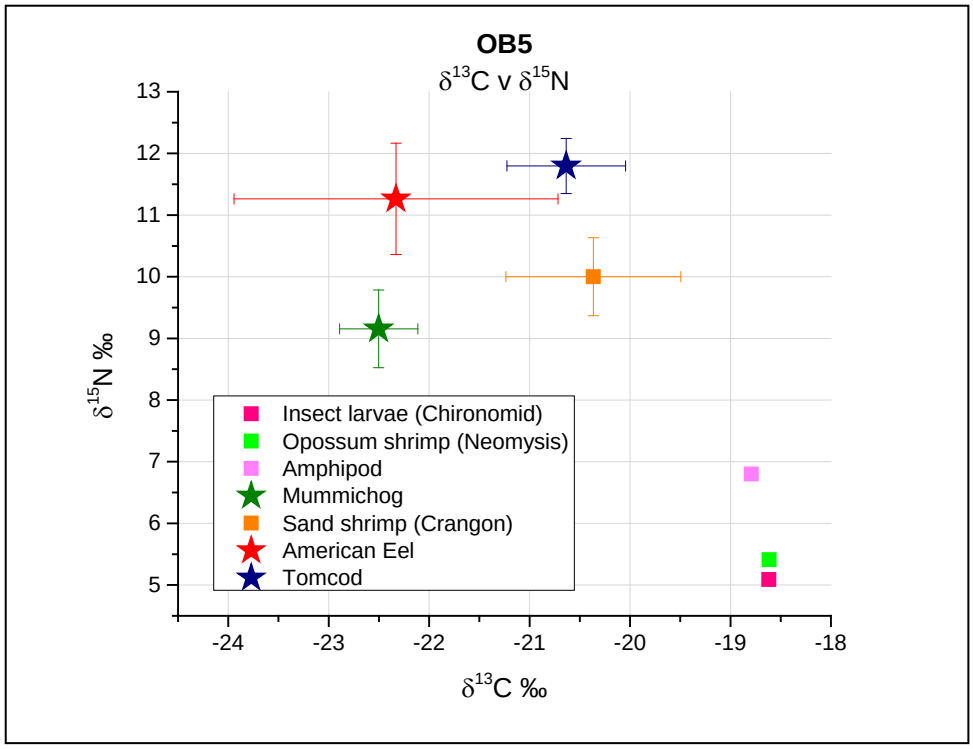
### 5.6.1 OB - American Eel

There was an overall shift in the diet of eels in OB to *Crangon* shrimp from the benthic worms, crayfish and aquatic insects eaten in OV and BO. This finding was based on examination of eel stomachs collected in the OB reach (n=15; stomach content weight, 37 g; Table 16-4). *Crangon* comprised over 95% of the diet by weight at both ends of the OB reach, OB5 at the north end and OB1 at the south. The diet was more varied in the middle of the reach at OB4, just north of Winterport, where close to 20% of the eel diet consisted of fish, primarily mummichog, and isopods.

*Crangon* shrimp are omnivores, feeding primarily on detritus and to a lesser extent on benthic invertebrates, including polychaetes, larvae and eggs, isopods, amphipods and demersal species found in the lower water column, including mysid shrimp (Price 1962; Oh et al. 2001). If the diet of *Crangon* shrimp in the lower Penobscot matches that described in the literature, these shrimp feed primarily in the benthic food web with a partial contribution from the pelagic food web via mysid shrimp.

However, the results from the stable isotope analyses only partially support the results of the stomach content analyses. The $\delta^{13}C$ signatures for eels sampled at OB5 indicate that eels in the northern portion of OB had a broader diet during the summer months than was evident from the stomach content analysis (Figure 16-5). If *Crangon* actually comprised 95% of the eels' summer diet, we would expect that the $\delta^{13}C$ signatures for the eels would be equal to or heavier than the carbon signature in the shrimp. This is because there is a slight increase expected in $\delta^{13}C$ values with each increase in trophic level. Instead, at OB5 the $\delta^{13}C$ signature for sand shrimp *Crangon* (-20.4‰) was heavier than for eels (-22.3‰). Also, the $\delta^{15}N$ signatures were closer than expected between the prey shrimp and the predator eels, indicating that the shrimp are not likely to be the sole carbon source.

The stable isotope analyses at OB5 suggest an alternative prey for the eels. The $\delta^{13}C$ of mummichog, 22.3‰, matched well with that of the eel, 22.5‰. Also, the eels' $\delta^{15}N$ signature was 2.1‰ greater than found for the mummichog, a more appropriate increase in the nitrogen isotopic signature for one trophic step between prey and predator. The discrepancy between the results of the stomach content analyses and the stable isotope findings may reflect the different time scales of the two methods. Stomach content analysis indicates prey consumed hours before capture whereas stable isotope analysis of fish muscle integrates the diet over several months.



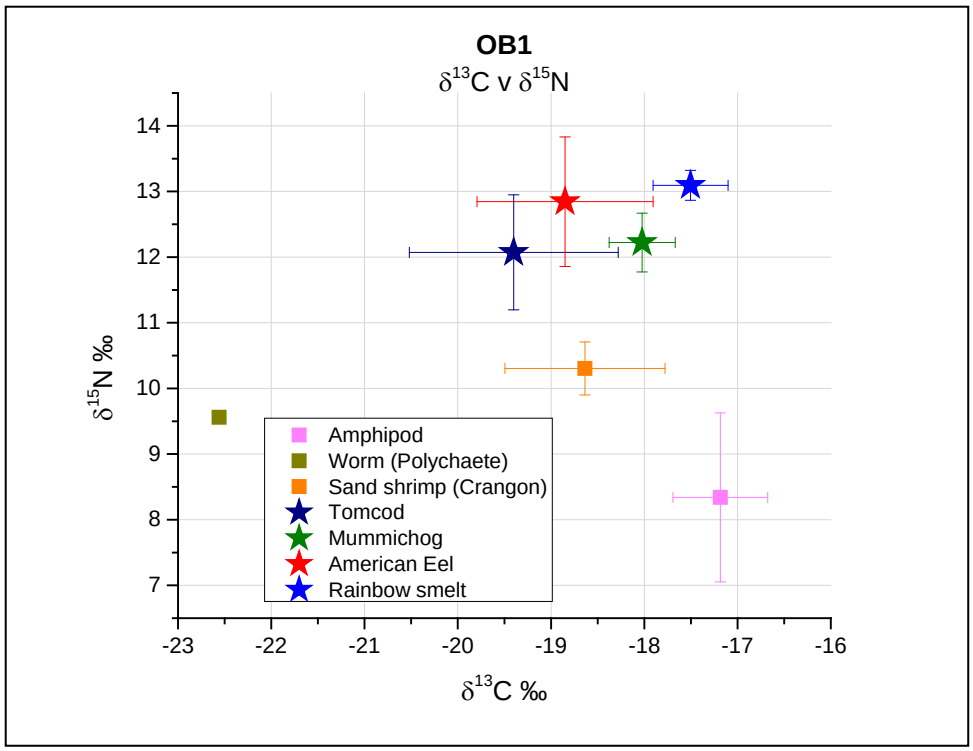




Figure 16-5. Biplots of mean (± SD) δ13C versus δ15N of the four fish species and invertebrates sampled at OB5 and OB1. In OB5 the δ13C signatures in eel and mummichog indicate a seasonal prey contribution from prey taxa other than the benthic taxa included in this sample. In OB1 the δ13C signature for *Crangon* shrimp is slightly heavier than for tomcod and American eels, suggesting a long-term seasonal consumption of other prey with a lighter δ13C signature, possibly Polychaete worms.

At OB1 (Figure 16-5), the $\delta^{13}$C signatures for Crangon shrimp and eels were very similar, at -18.6‰ and -18.9‰, respectively, which, in addition to the roughly 1 trophic level increase in $\delta^{15}$N, supports the findings of the stomach content analysis that *Crangon* shrimp comprised a large portion of the eel diet. While the carbon isotope data from the eels suggests they feed primarily on Crangon shrimp, additional foraging is again likely on prey with a lighter carbon signature, as the $\delta^{13}$C signature for eels was slightly lighter than that of the shrimp. At this site, polychaete worms had a lighter $\delta^{13}$C signature and may contribute to the eel diet. In the OV and BO reaches upstream, benthic worms were present in eel stomachs.

In the SIAR mixing model, for OB1 and OB4, *Crangon* were estimated to comprise between 73 and 82% of the eel diet at the 95% probability level. OB5, which was north of these two sites, could not be included in the mixing model because invertebrate sample sizes were too small for the analyses.

In summary, while the findings from the stomach content analyses suggest that *Crangon* shrimp, a benthic prey species with some contribution from the pelagic food web, constitute over 95% of the eel diet in OB, the stable isotope results indicate that *Crangon* contribute a lower percentage of the eel diet in the northern end of the reach near OB5. At OB5, based on the stable isotope analysis, mummichogs are likely prey of the eels. At OB1, benthic worms or prey with lighter $\delta^{13}$C signatures may be consumed in addition to the shrimp. The eel diet appears to shift moving downriver from benthic worms to epi-benthic shrimp and mummichog. Throughout the lower Penobscot, eels forage primarily in the benthic food web.

### 5.6.2 OB - Tomcod

The sand shrimp, *Crangon septemspinosa*, comprised almost 70% of the tomcod diet by weight (Table 16-4). Sixty tomcod stomachs were examined from the OB reach, almost all contained identifiable prey remains, which had a combined prey weight exceeding 13 grams. In the reach as a whole, the diet also included unidentified fish remains (20%), amphipods and isopods (4%), and semi-pelagic invertebrates (4%), primarily the opossum shrimp, *Neomysis americana*.

However, there were notable differences in the tomcod diet between the north end of the reach, where *Crangon* and other decapod remains made up ~ 85-90% of the ingested prey, and the south end of the reach at OB1, where *Crangon* and other decapod remains comprised less than 40% of the diet, and fish comprised close to 50% of the tomcod prey.

The stable isotope findings for tomcod caught in the OB reach partially reflect this diet shift. At OB5 (Figure 16-5), at the north end of the reach where *Crangon* dominated the tomcod diet, the $\delta^{13}$C signatures for *Crangon* and tomcod were very similar, and the 2‰ greater $\delta^{15}$N value found for tomcod, indicates a higher trophic position as expected for a consumer. At OB1 (Figure 16-5), where fish remains comprised most of the diet, the $\delta^{13}$C signature for tomcod was somewhat lighter (~1‰ less) than for *Crangon* shrimp, suggesting the existence of another prey item that is more pelagic in origin with a lighter isotope signature. At OB4 (Figure 16-6), midway between OB5 at the north end of the

OB reach and OB1 at the south end, the $\delta^{13}C$ signature for tomcod was again somewhat lighter than for the *Crangon* shrimp.

The results from the SIAR mixing model partially reflect this diet shift. At OB4, the mixing model predicted that Crangon contributed 91-95% of the tomcod diet, at the 95% probability level. In contrast, at OB1 further to the south, *Crangon* represented 46-52% of the tomcod diet at the 95% probability level, suggesting the presence of another significant prey item in the summer diet of the tomcod.

To summarize, *Crangon*, primarily part of the benthic food web, dominate the tomcod diet in the OB reach, especially in the northern section, but in the southern end of the reach organisms from more of a pelagic food web also contribute to the tomcod diet.

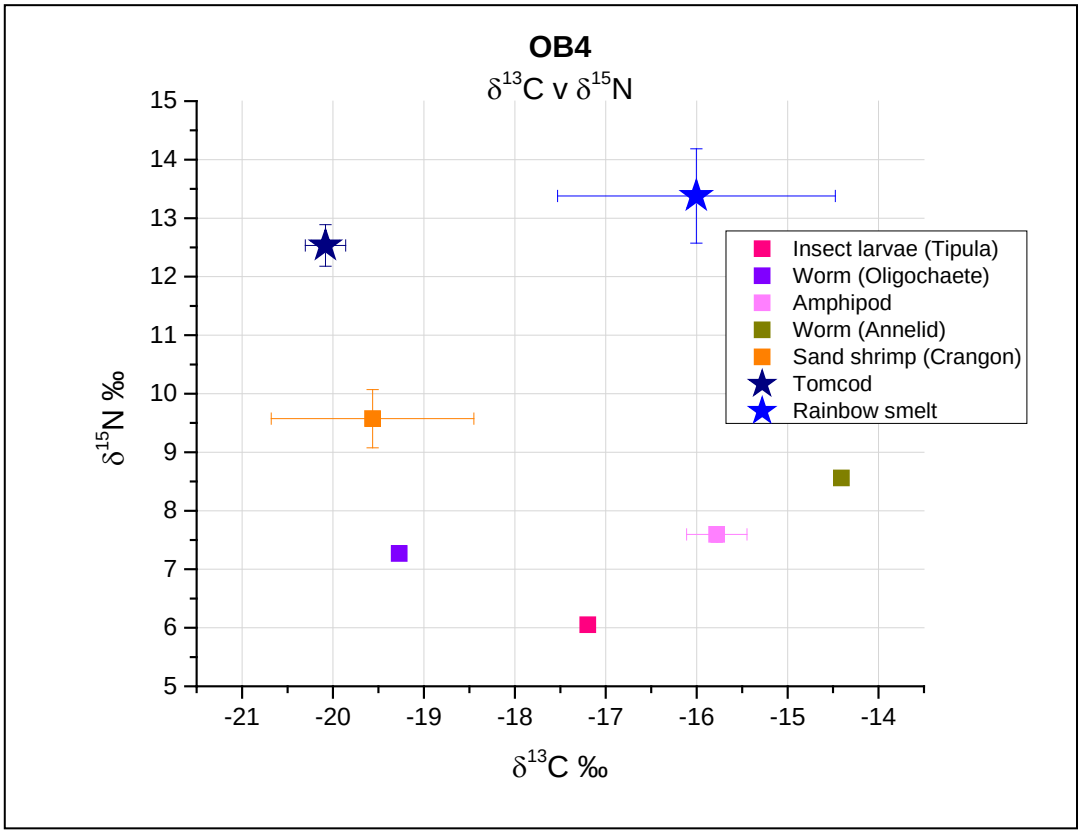



Figure 16-6. Biplot of mean (± SD) $\delta^{13}C$ versus $\delta^{15}N$ of fish and invertebrates sampled from OB4. The relatively heavy $\delta^{13}C$ signature found in rainbow smelt at OB4 suggests a larger benthic contribution to their diet than evidenced by the findings from the stomach content analyses.

### 5.6.3 OB - Rainbow smelt

Based on stomach content analyses, rainbow smelt fed primarily in the pelagic food web (Table 16-4). Smelt stomach samples were collected only at the southern end of the OB reach at OB1. Identifiable prey remains were found in all eight stomachs analyzed, yielding a combined total prey weight of 5.5 grams. In the combined sample, 70% of the diet by weight was Atlantic herring, followed by Mysid shrimp (15%) and *Crangon* shrimp (9%). Atlantic herring feed on plankton, primarily the copepod *Calanus*, which is a primary consumer of phytoplankton (Collette and Klein-MacPhee 2002). Given that herring feed primarily in the pelagic food web, combining the herring and Mysid shrimp portions of the diet, over 85% of the diet of rainbow smelt at the southern end of OB originated in the pelagic food web during our fall 2009 sample period.

Stable isotopes were analyzed from rainbow smelt collected at two sites in this reach, OB4 (Figure 16-6) and OB1 (Figure 16-5). Those findings add limited insight to the diet of rainbow smelt in the lower OB reach. Neither Atlantic herring nor Mysid shrimp, the dominant prey items identified in stomach content analyses of OB rainbow smelt, were sampled in the area. The $\delta^{13}$C signature of the rainbow smelt was notably heavier at OB4 than found in the *Crangon* shrimp, in agreement with the small contribution of *Crangon* to the smelt's stomach contents, but the signatures were in good agreement at OB1, with the smelt 1‰ heavier than the shrimp.

In summary, stomach content analyses of rainbow smelt suggest a strong contribution from the pelagic food web, through Atlantic herring and Mysid shrimp, at the southern end of the OB reach. The findings from stable isotope analyses, compromised by the absence of prey identified in the stomach content analyses, do not support this. The heavier $\delta^{13}$C signature in the smelt suggests a longer-term contribution from other prey linked to the benthic food web. It is not possible to resolve this discrepancy with the available data.

### 5.6.4 OB - Mummichog

The mummichog diet, as represented by the stomach content analyses, was 90% adult insects (Table 16-4). Mummichog were sampled in the OB reach, with 40% of the stomachs sampled (n=12) containing identifiable remains. The combined weight of the prey remains was low, 0.3 grams, but possibly representative given the size of these small fish. Winged insects were found in stomachs of fish at the northern end of the reach at OB5 and insect body parts, possibly ants, were found in stomachs of fish at OB1 to the south. Amphipods made up another 7% of the diet. These prey taxa, identified from stomach contents, came from both the terrestrial and the benthic food webs. This is in agreement with published reports of mummichog moving onto the marsh platform during spring tides and grazing along the flooded marsh surface, making mummichog a key link to subtidal food webs (Weisberg and Lotrich 1982; Abraham 1985).

In our sample of stomachs collected over a few days in early September, insects that possibly came from the marsh surface comprised 90% of the ingested prey. This may not represent the overall and longer term diet, as Weisberg and Lotrich (1982)

estimated that up to 75% of the mummichog diet came from subtidal areas. If their diet estimate is correct for the lower Penobscot River, high spring tides or storm runoff may have enhanced mummichog consumption of marsh insects during our sample period. However, the collections occurred primarily in a neap tide cycle, when moderate tides would not have flooded the marsh platform until the very end of the sample period, reducing mummichog foraging on the flooded marsh. Rainstorms may have increased surface water runoff, sweeping insects from the marsh platform into adjacent slough channels.

The stable isotope analyses add limited clarity to the mummichog diet in OB. At OB5 (Figure 16-5), the mummichog $\delta^{13}C$ signature was almost 4‰ lighter than that of amphipods, the only known prey item sampled, indicating other prey in the mummichog diet with an even lighter signature, probably of terrestrial origin. At OB1, the mummichog $\delta^{13}C$ signature was slightly lighter than that of their known amphipod prey, but heavier than the Crangon shrimp and polychaete worms sampled at that site, both of which, based on these isotope results, may contribute to the mummichog diet.

To summarize our findings on the mummichog diet, stomach contents analysis indicated a large contribution from insects from the marsh platform. The stable isotope analyses cannot confirm this diet given the absence in our dataset of relevant terrestrial insect prey items that were analyzed for stable isotopes, although the suggested contribution from prey with lighter $\delta^{13}C$ signatures could be met from prey from terrestrial-based food webs.

## 5.7 ES Reach

The ES reach extends from Bucksport south to Islesboro in Penobscot Bay. Stomach content analyses were done on fish from five sites in the reach, and stable isotopes were analyzed for fish from three of those sites. The four stable isotope sites included ES15 on the West Channel of Verona Island, ES13 on the southern tip of Verona Island, ESFP at the tip of Fort Point, and ES04, a site near Searsport along the northern shore of Penobscot Bay.

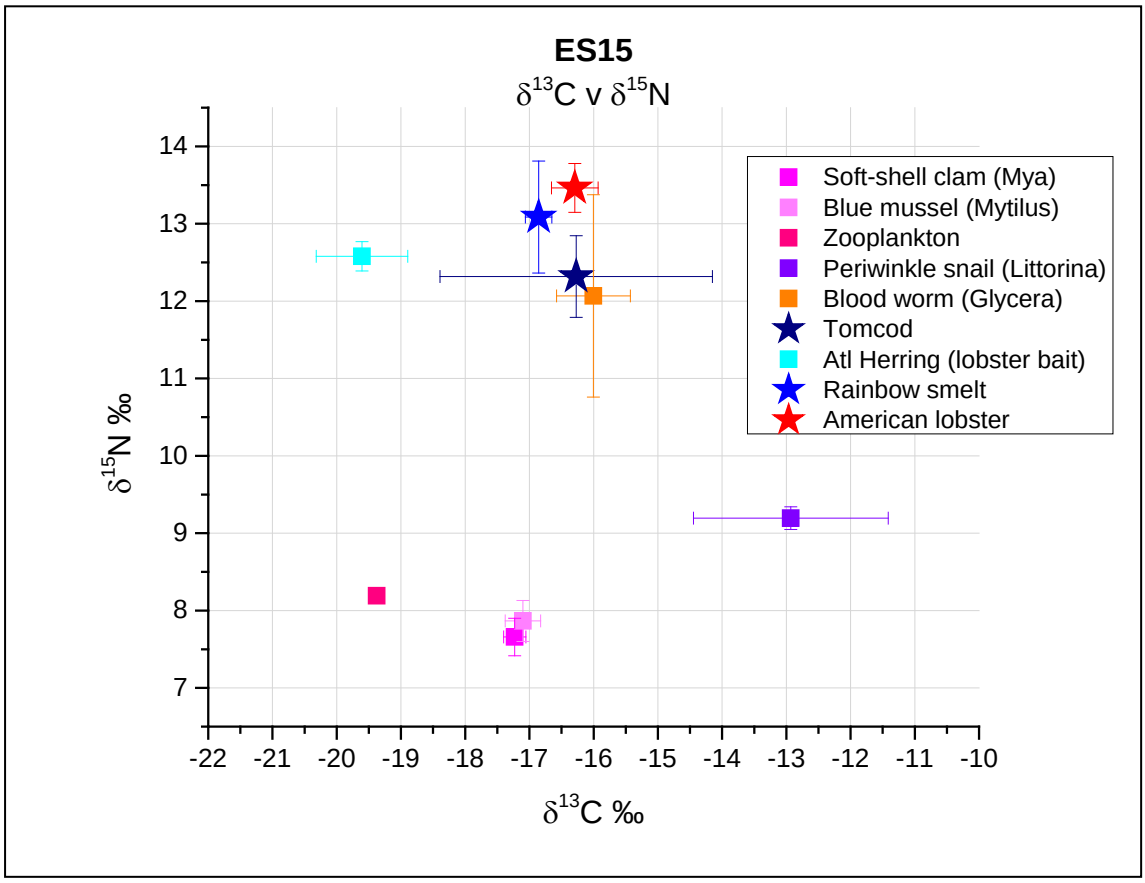



Figure 16-7. Stable isotope bi-plots from ES15, along the west side of Verona Island, compare $\delta^{13}C$ and $\delta^{15}N$ signatures for invertebrates, tomcod, smelt and lobster. Based on these findings, both fish and lobster appear to have a mixed diet from both the benthic and pelagic food webs.

### 5.7.1 ES - Tomcod

Tomcod in the northern ES reach, based on stomach content analyses, fed in both the pelagic and benthic food webs (Table 16-4). Tomcod were sampled at two sites in the ES reach, ES15 on the west side of Verona Island, and ES13 on the southern tip of Verona Island. The stomachs from all 15 tomcod contained identifiable prey remains, with a combined prey weight of 3.8 grams. Overall, the opossum shrimp, *Neomysis americana*, formed the largest part of the tomcod diet (47%) in the combined data from both sites, followed by epi-benthic invertebrates (41%), primarily decapod shrimp, specifically the sand shrimp, *Crangon sp.*, and the opossum shrimp.

At individual sites, the tomcod diets were slightly different despite the close proximity of the two sites sampled. At ES15, decapod shrimp were the primary prey eaten, while at ES13, a few miles south, the opossum shrimp, *Neomysis* was the dominant prey taxa. Polychaete worms were only found in tomcod from ES13.

These slight differences in tomcod diet, based on stomach content analysis, did not produce any major difference in the stable isotope signatures between the two sites. The tomcod $\delta^{13}C$ signature was slightly lighter (~0.5 ‰) at ES15 (Figure 16-7), relative to ES13 (Figure 16-8) where lighter signatures would be expected as more pelagic prey was found in tomcod stomachs at ES13. At both sites, the $\delta^{13}C$ signature for tomcod was heavier than that of the blue mussels, near the base of the pelagic food web, and lighter than the periwinkle snail, near the base of the benthic food web. As such, the $\delta^{13}C$ values suggest that the carbon base supporting tomcod comes from a combination of the benthic and pelagic food webs.

Yet, at both sites the SIAR mixing model indicated a somewhat greater contribute from the pelagic food web rather than the benthic food web. While the mixing model did not identify one dominant prey taxa, the model predicted that the greatest proportion of the tomcod diet came from filter-feeding bivalves and zooplankton. At ES13, benthic worms and snails were estimated to be a smaller proportion of the diet than reported for ES15, reflecting the findings from the stomach content analyses that found a greater contribution from the pelagic food web at ES13.

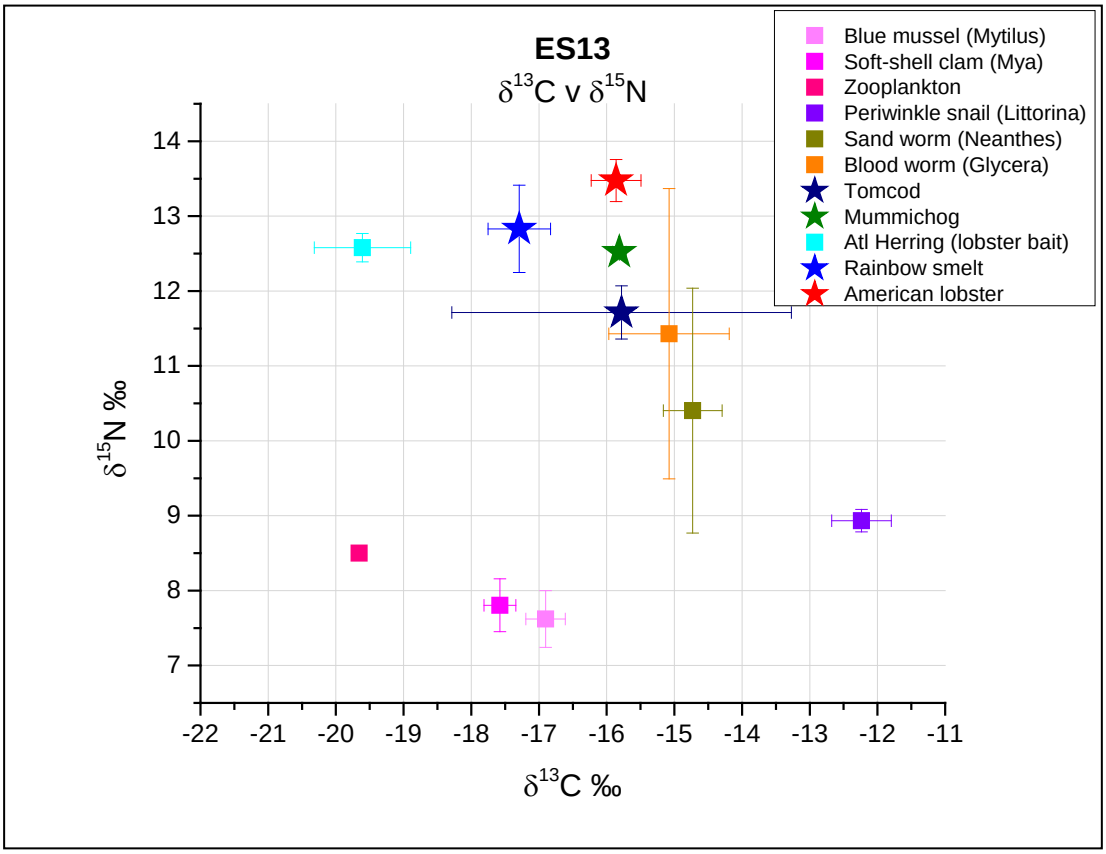



Figure 16-8. Stable isotope bi-plot from ES13, at the southern tip of Verona Island, compares $\delta^{13}C$ and $\delta^{15}N$ signatures for invertebrates, tomcod, mummichog, rainbow smelt and lobster. The isotopic signatures for suggest tomcod and lobster forage in both the benthic and pelagic food webs, while rainbow smelt forage more in the pelagic food web.

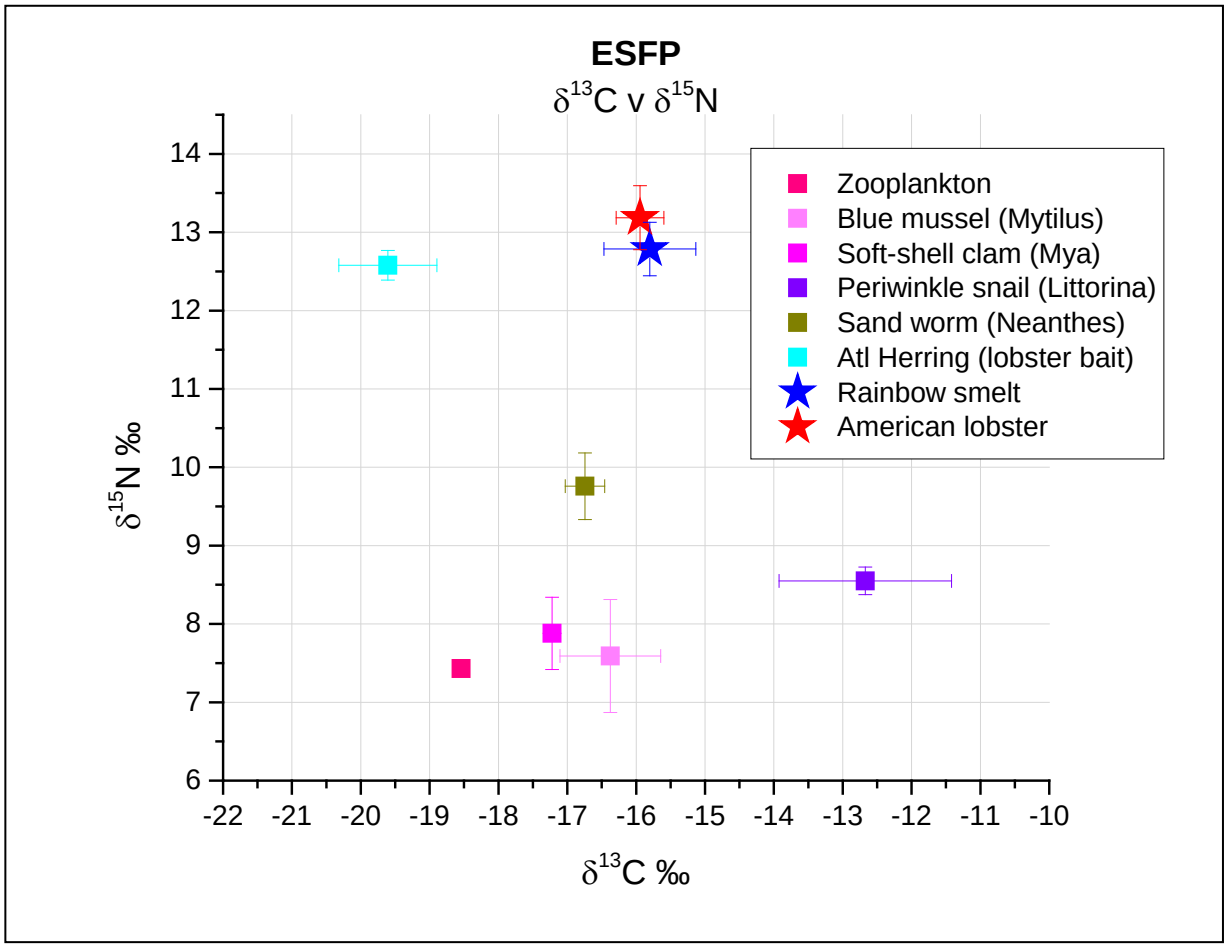



Figure 16-9. Stable isotope bi-plots from ESFP, at the Fort Point peninsula, compares $\delta^{13}C$ and $\delta^{15}N$ signatures for invertebrates, rainbow smelt and lobster. For rainbow smelt, the somewhat heavier $\delta^{13}C$ signature at this site matches the more benthic diet indicated by the stomach content analyses. The lobster diet mixes the benthic and pelagic food webs.

In summary, stomach content analyses of tomcod indicated a mixed diet from both the pelagic food web, represented by *Neomysis* shrimp, especially at ES13, and the benthic food web, represented by Crangon shrimp and polychaete worms, especially at ES15. The pattern of stable isotope signatures agreed with the finding of a mixed benthic and pelagic diet.

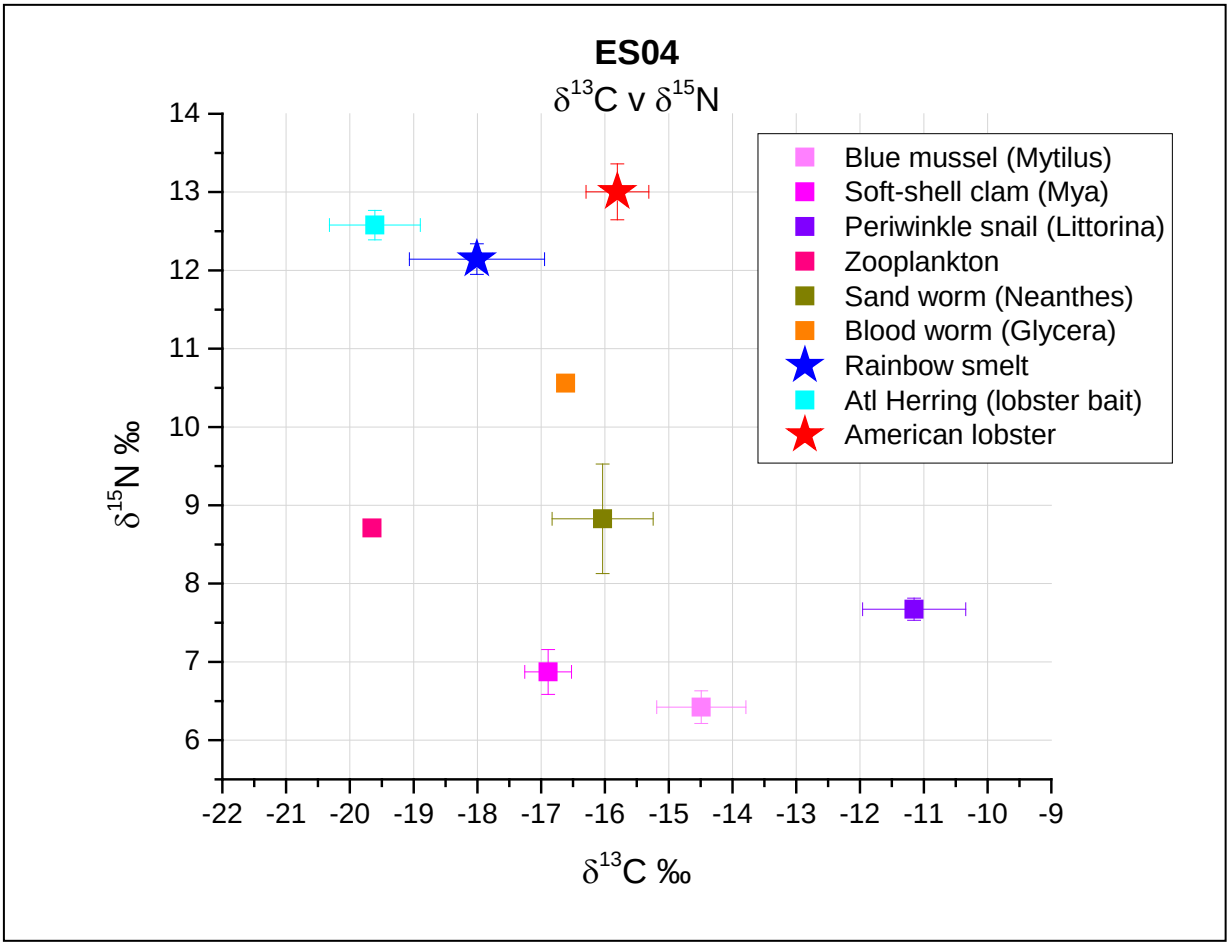



Figure 16-10. Stable isotope bi-plot from ES04, the reference site toward the west side of upper Penobscot Bay near Searsport, compares $\delta^{13}C$ and $\delta^{15}N$ signatures for invertebrates, rainbow smelt and lobster. These results indicate that lobster fed from both the benthic and pelagic food webs and smelt fed primarily in the pelagic food web.

### 5.7.2 ES - Rainbow smelt

Rainbow smelt, based on stomach content analyses (Table 16-4), fed primarily in the pelagic food web at the northern and western ends of the reach and in the benthic food web in the middle of the reach. A large number of rainbow smelt were collected for stomach content analyses from three sites in the ES reach. Thirty four of the 46 stomachs contained useable prey remains with a combined total weight of 3.2 grams. At the northern and western edges of the area sampled the rainbow smelt were feeding in the pelagic food web. At ES13, 98% of the ingested prey was the opossum shrimp *Neomysis americanus*, a pelagic species, while at ES04 near Searsport the planktonic copepod *Calenoida* comprised over 90% of the identified prey, by weight. At ESFP, at Fort Point, midway between the other two sites, the epi-benthic sand shrimp, *Crangon septemspinosa*, comprised over 95% of ingested prey.

The stable isotope findings support the stomach content analysis that rainbow smelt sampled in the ES reach feed primarily from the pelagic food web. At the two northern most sites, ES13 (Figure 16-8) and ES15 (Figure 16-7; stomach contents were not analyzed at this latter site), the $\delta^{13}$C signatures for rainbow smelt were equivalent to that of the blue mussel, *Mytilus edulis*, a primary consumer used to define the base of the pelagic food web in ES. At both sites, the $\delta^{13}$C signature for plankton itself was lighter, relative to rainbow smelt, by about -2.5‰. As described earlier, plankton signatures can vary widely over the short-term, while filter-feeding mussels integrate the signal from phytoplankton over a longer time period (Post, 2002). This variability in zooplankton signatures was more evident at ES04 (Figure 16-10) where the rainbow smelt $\delta^{13}$C signature was equidistant between that of the zooplankton and the mussels from that site. Conversely, at ESFP (Figure 16-9), where stomach content analyses identified the more benthic *Crangon* shrimp as the dominant prey of the rainbow smelt, the $\delta^{13}$C signature for the smelt was slightly heavier than found for the blue mussels from that site, and equidistant between the lighter zooplankton and the heavier periwinkle (*Littorina*) snails, representing the base of the benthic food web. This supports the finding that some prey from the benthic food web are consumed by smelt at ESFP.

The SIAR mixing model did not identify dominant prey taxa at the ES sites. There was a slight increase in the contribution of zooplankton at ES13, estimated at 20-25% of the smelt diet at the 95% confidence level.

In summary, for rainbow smelt in the ES reach, the findings from both the stomach content analyses and the stable isotope analyses indicate the smelt diet is primarily from the pelagic food web in the northern and western portions of the reach. In the central portion of the reach at Fort Point (ESFP) prey from the benthic food web, *Crangon* shrimp, contributed significantly to the diet, as indicated by the results of the stomach content analyses.

### 5.7.3 ES - Lobster

Stable isotope analysis was used to define the lobster's diet from four sampling areas in upper Penobscot Bay. Stomach content analyses were not attempted on lobster, as the most recent meal of the trapped lobster would likely be the Atlantic herring bait used to lure them into the traps.

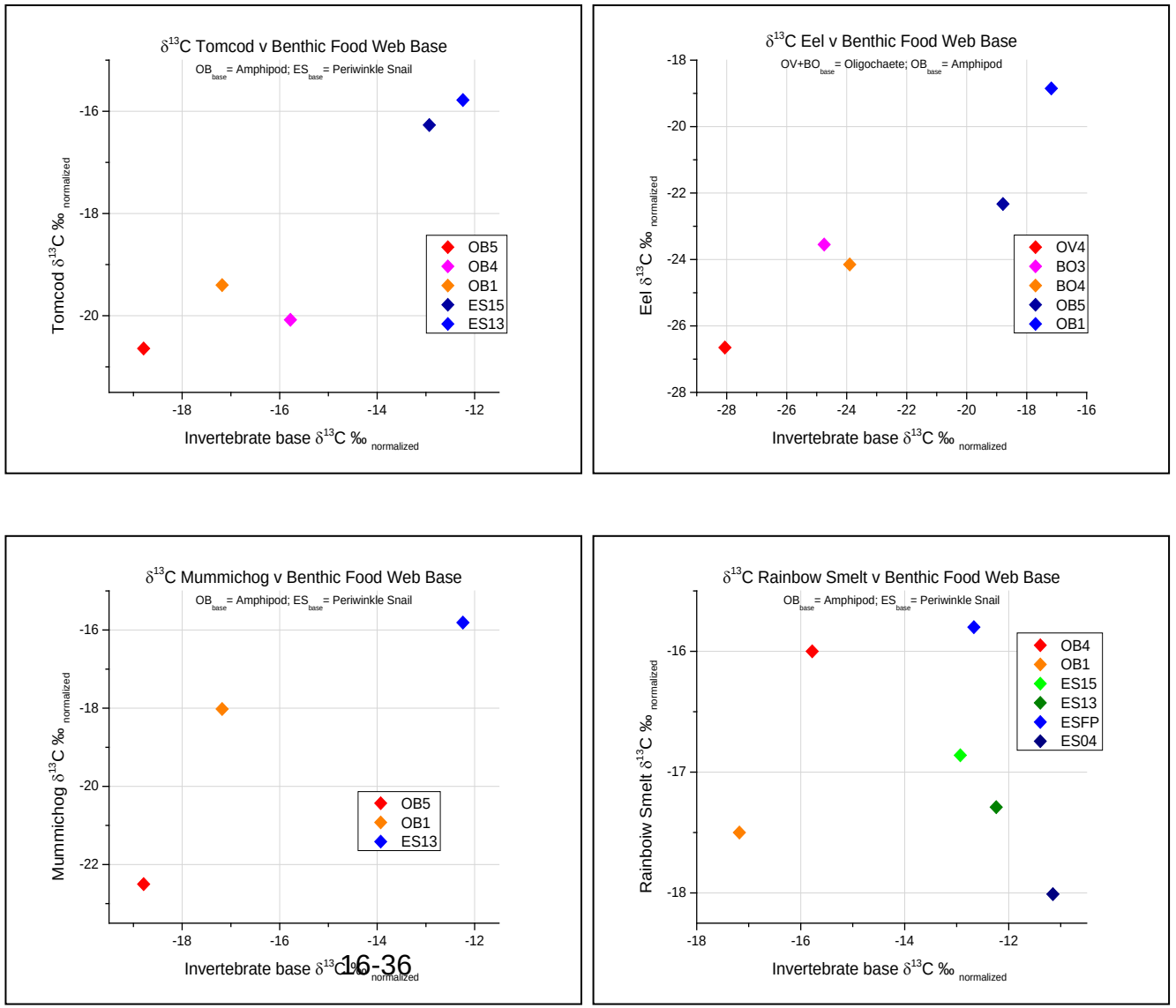
The $\delta^{13}C$ signatures for lobster were virtually unchanged throughout the sample region, ranging from ES04 (SW Sears Island, -15.8‰; Figure 16-10) to ES15 (Odum Ledge, -16.3‰; Figure 16-7), with only small changes that matched those at the base of the benthic food web. Of greater interest is the possible contribution to lobster diet between the Atlantic herring bait used in the lobster traps and the natural benthic prey of lobster. Lobsters are reported to routinely enter traps, feed on the bait, and leave the traps, making herring bait a significant portion of their diet. Grabowski et al. (2010) estimated that 33-45% of the growth in lobsters is due to ingestion of herring bait. Natural prey may reflect regional differences in $\delta^{13}C$ in the biota, whereas lobster bait is usually caught far offshore and used randomly throughout Penobscot Bay. The mean $\delta^{13}C$ signature for lobster bait (-19.6‰; n = 6) was assumed to be representative of all Atlantic herring bait used in Penobscot Bay, and may have contributed to the similarity of the lobster $\delta^{13}C$ signature in that area. The lobster $\delta^{13}C$ signatures were equidistant between the lighter Atlantic herring bait caught offshore (-19.6‰) and the heavier signal from the periwinkle snails (-12.9‰ to -11.2‰), at the base of the benthic food web, and equivalent to the signature for the blue mussels caught at each site. The natural lobster diet is dominated by crabs (detrital/benthic food web), mussels (pelagic food web), snails (benthic food web), and urchins (benthic food web) (Elner and Campbell 1987; Hudon and Lamarche 1989; Grabowski et al. 2010).

In summary, based on the findings from stable isotope analyses, lobsters in the ES reach consume prey from both the benthic and pelagic food webs. The contribution from the pelagic food web is likely from lobster bait eaten from lobster traps and does not reflect local exposure to either stable isotopes or Hg.

## 5.8 δ13c Signatures in Fish and Benthic Invertebrates

A direct comparison of the $\delta^{13}C$ signatures for benthic invertebrates and fish provides further support that certain fish species forage primarily in the benthic food web. The graphs in Figure 16-11 illustrate the relationship between the $\delta^{13}C$ signature in benthic invertebrates and that of tomcod, American eel, mummichog and rainbow smelt across sites.

Figure 16-11. The $\delta^{13}C$ values between benthic invertebrates and fish collected at the same sample sites, plotted in the graphs below, were strongly correlated in tomcod and eel, suggestive in mummichog, but not correlated in rainbow smelt, which feeds primarily in the pelagic food web.



A strong significant correlation was found for tomcod and eel ($P< 0.05$), the $r^2$ greater than 0.8, with slopes of 0.6 (tomcod) and 0.8 (eel). This strong correlation in $\delta^{13}C$ signatures of benthic invertebrates and these two fish species suggests that tomcod and eel feed primarily in the benthic food web. Mummichog appeared to have a similar relationship, but with a small n of 3 the correlation was not significant. Conversely, the $\delta^{13}C$ values for benthic invertebrates did not correlate with those of rainbow smelt ($P=0.70$). Earlier findings indicate that rainbow smelt feed primarily in the pelagic food web.

# 6 TROPHIC LEVEL of TARGET SPECIES

The trophic position of the target fish species and lobster were estimated using established models (Post 2002) defined in Table 16-1 and described in the Methods.

## 6.1 Eel

Stable isotopes were analyzed from eels sampled at six sites along the lower Penobscot River, from OV4, upstream of the Veazie Dam, to OB1 near the mouth of the Marsh River on the lower Penobscot. Four of the six sites were sampled for stable isotopes in both 2008 and 2009 and two sites were sampled only in 2008. Mean trophic level did not vary within sites at the locations sampled in both years (two-sample t-test, $P > 0.05$), allowing data from those sites to be pooled across years.

Eel trophic levels ranged from 2.8 to 3.7, over almost a full trophic level, and were significantly different among sites, (ANCOVA, $P < 0.05$, adjusted for eel age). Two sites were significantly different from the remaining four (Tukey's HSD, $\alpha = 0.05$). Eels sampled at the reference site OV4 had significantly lower trophic levels than all other sites while eels from OB1 had significantly greater trophic levels than two of the more central sites. Note, the estimate of eel trophic level at OV4 should be viewed with caution as the $\delta^{15}N_{base}$ (oligochaete) used in the calculation had an n of 1.

Mean Hg concentrations in eels were unrelated to their mean trophic level, supporting the premise that geographic differences in Hg concentrations relate to differences in local exposure levels and not to differences in food web structure. The greatest Hg concentrations were found in eels from BO4, with a mean concentration of total Hg in muscle of 660 ng/g wet. wt. (antilog of least square mean (LSM), adjusted for age). Eels from BO4 also had the second lowest mean trophic level of 3.2. While eels from OV4 had the lowest mean trophic level (2.8) and the lowest mean total Hg concentrations, eels from OB1 had the greatest trophic level (3.7) and the second lowest Hg concentration (Figure 16-12).

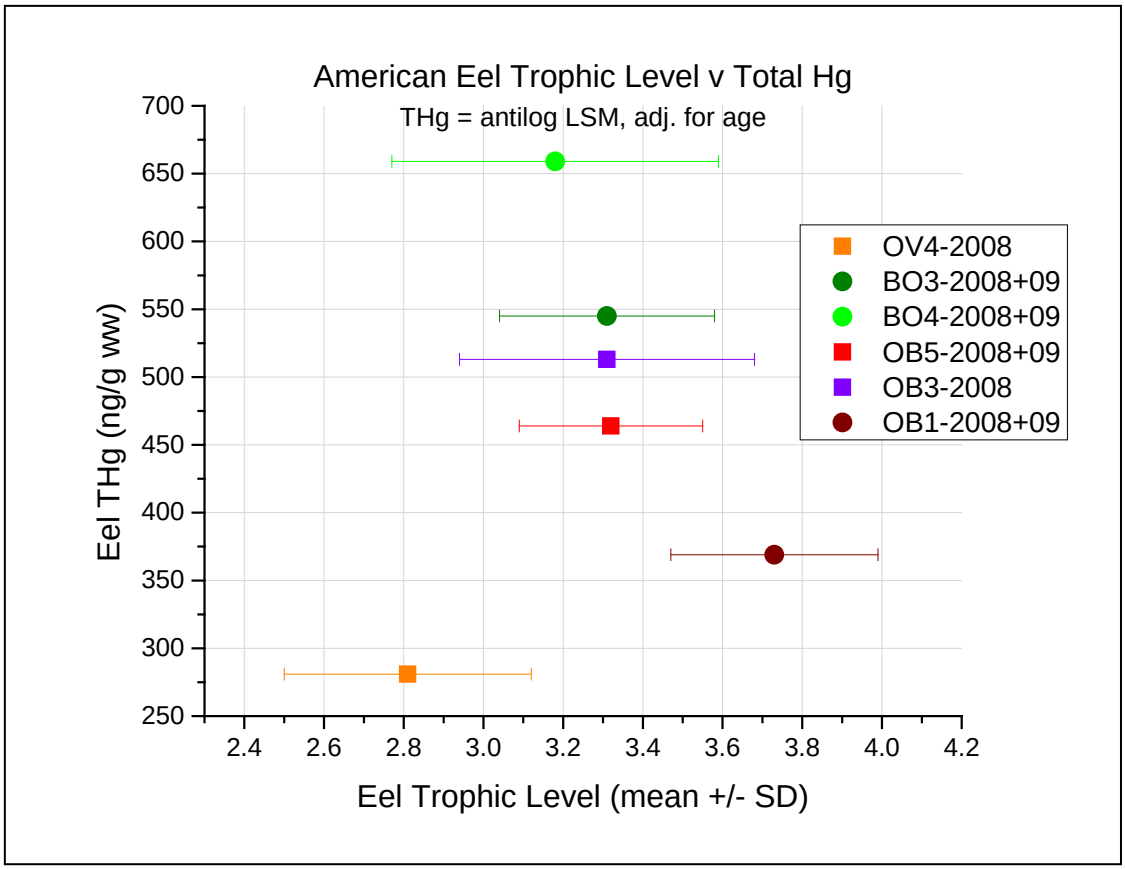



Figure 16-12. American eel trophic level versus mean total Hg, antilog of least squares means, adjusted for eel age. Hg concentrations in eel muscle were not related to trophic level in the eels sampled.

## 6.2 Tomcod

Tomcod were sampled for stable isotopes and Hg at eight sites in the OB and ES reaches in 2008 and 2009. One site, OB1, was sampled in both years, and data were pooled when no significant difference was found in trophic levels between years (two-sample t-test, $P > 0.05$). The range in trophic levels in tomcod was small (3.44-3.76 trophic units; Figure 16-13). Trophic level varied significantly (ANCOVA, adjusted for fish length, $P < 0.05$) across sites, though only two pair-wise comparisons were significantly different (Tukey HSD, $\alpha = 0.05$). The trophic level of tomcod at ES05, near the mouth of the Orland River, was significantly greater than those of either OB5 or ES13. All other sites were statistically equivalent.

Similar to the pattern for eels, there was no relationship between trophic level and Hg concentrations in tomcod across sites, again supporting the premise that geographic differences in Hg concentrations relate to differences in local exposure levels and not to differences in food web structure. The site with the greatest Hg concentrations in tomcod (OB5; 206 ng/g wet. wt.; antilog LSM, adjusted for length) had the second lowest estimated trophic level in this species, 3.5 trophic units. Conversely, tomcod

sampled at ES05 had the greatest trophic level (3.8) and Hg concentrations at the bottom of the range. This is the opposite of what would be expected if increased trophic level was the primary factor causing elevated Hg concentrations.

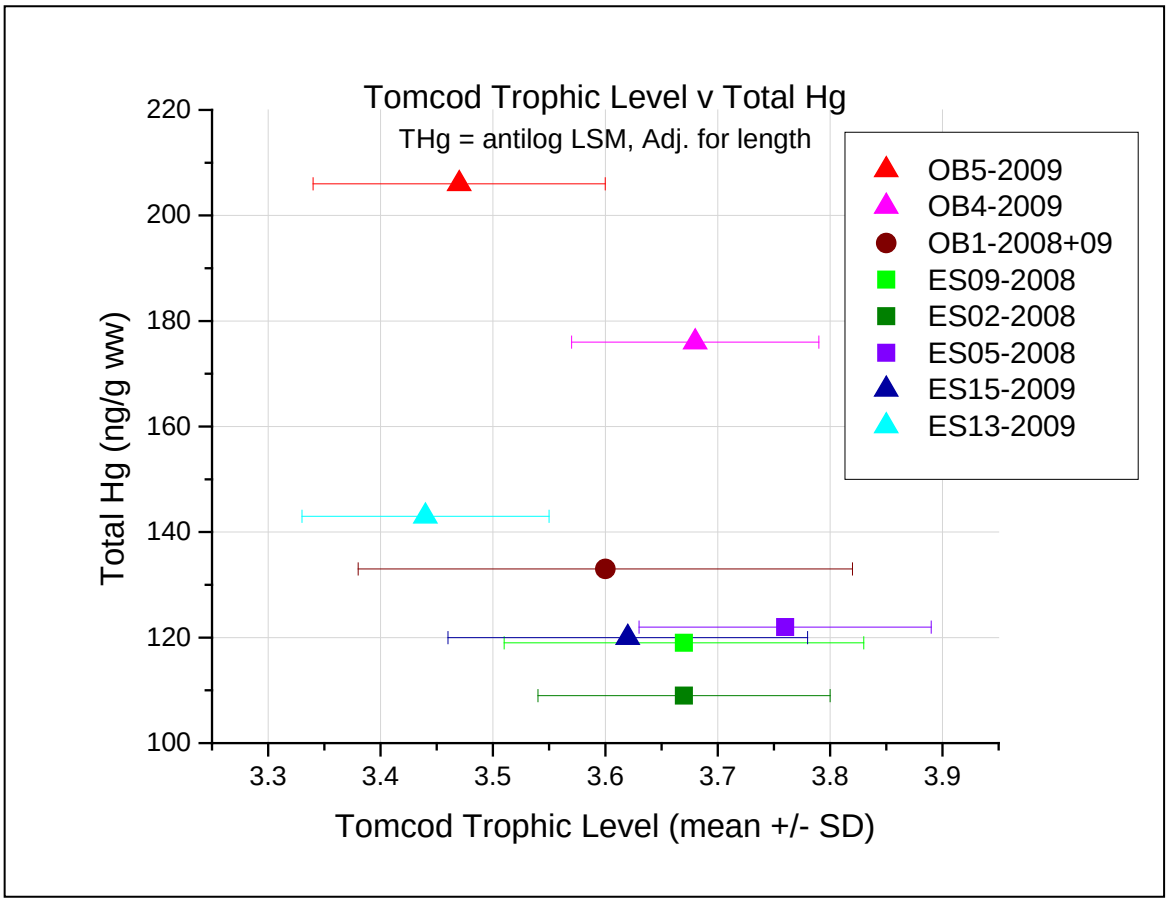



Figure 16-13. Rainbow smelt trophic levels versus mean total Hg, antilog of least squares means, adjusted for fish length. At all sites, except ES04, there was no correlation between trophic level and Hg concentrations in rainbow smelt. At ES04, the reference site near Searsport, both trophic level and Hg concentrations were low.

## 6.3 Rainbow Smelt

Rainbow smelt were sampled for stable isotopes at ten sites in the OB and ES reaches in 2008 and 2009. Data from each of three sites, which were sampled in both years, were pooled across years after no significant differences in trophic level were found between years (two-sample t-test, $P > 0.05$). While trophic levels varied little among sites, ranging from 3.6 to 3.9 trophic units, the trophic level at ES15, on the west side of Verona Island was significantly greater than at ES04, the reference site near Searsport (ANCOVA, adjusted for fish length, $P < 0.05$; Tukey's HSD, $\alpha = 0.05$; Figure 16-14).

As for eels and tomcod, Hg concentrations in rainbow smelt did not vary in relation to trophic level, although the reference site ES04 had one of the lowest mean Hg concentrations and fish from that site fed at the lowest trophic level found for smelt. At the remaining sites trophic level varied by less than 0.2 trophic units while Hg almost doubled across sites in a manner independent of fish trophic level.

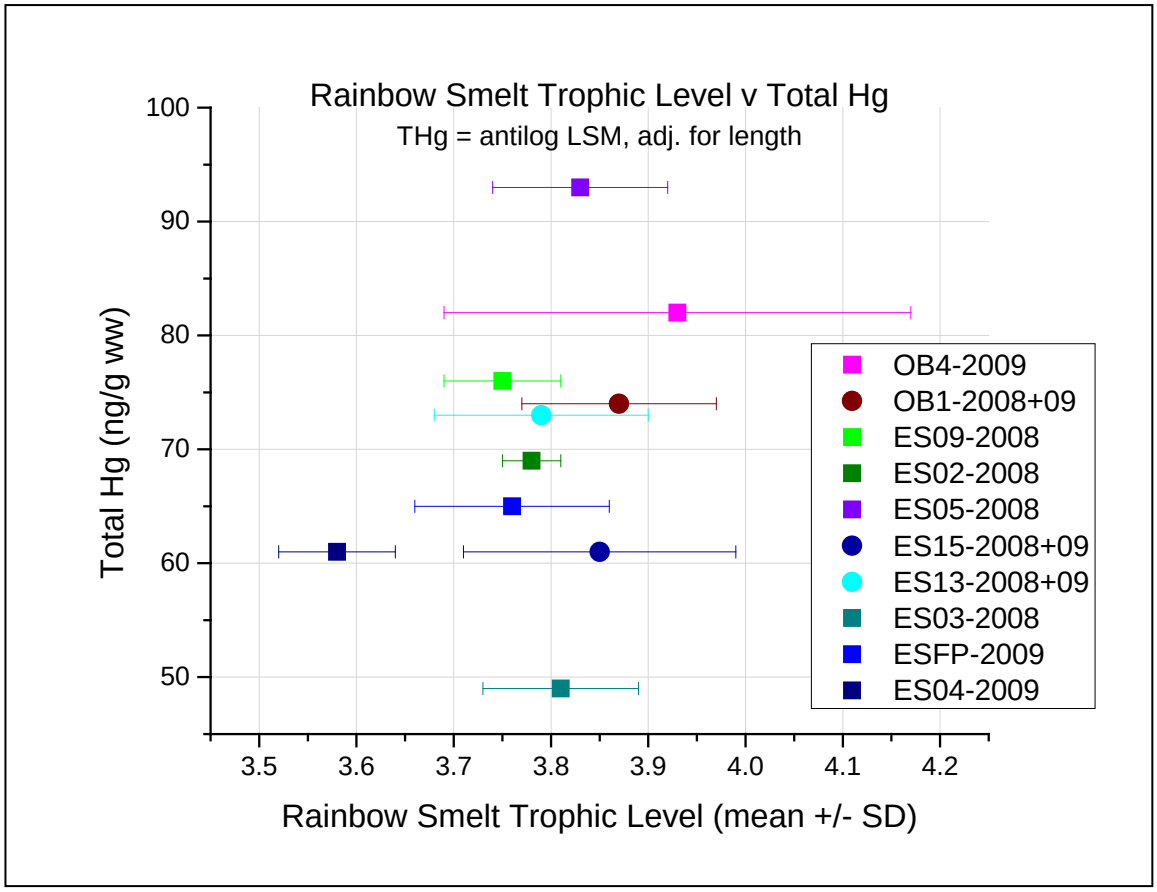



Figure 16-14. Tomcod trophic levels versus mean total Hg, antilog of least squares means, adjusted for fish length. No relationship was evident between muscle Hg concentrations in tomcod and tomcod trophic level in the lower Penobscot region.

## 6.4 Lobster

Stable isotope signatures were determined in lobster from seven sites in upper Penobscot bay in 2008 and 2009. Four sites were sampled in both years; data were pooled for those sites as no significant difference in estimated trophic level was found between years in those sites (two-sample, t-test, $P > 0.05$).

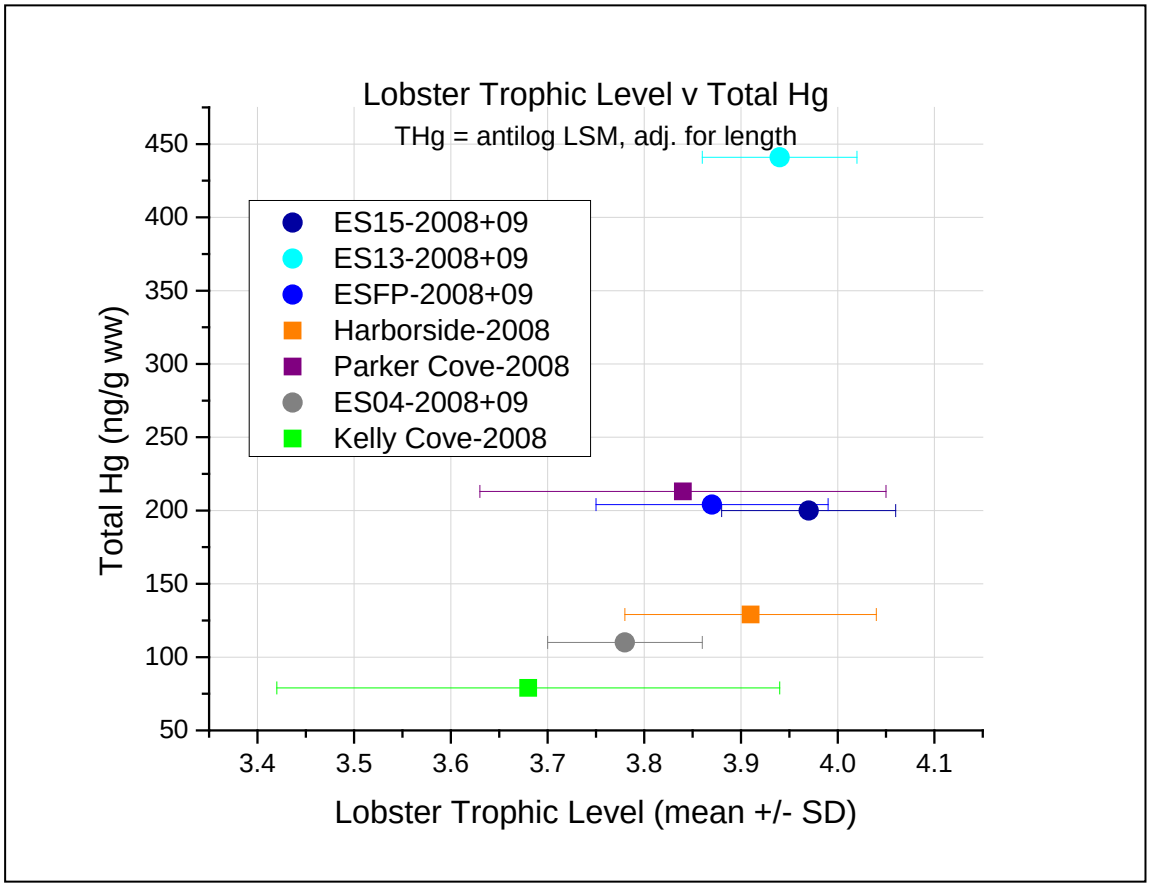



Figure 16-15. Lobster trophic levels versus mean total Hg, antilog of least squares means, adjusted for carapace length. Overall there was no correlation between trophic level and Hg concentrations in lobster. Lobster from the two sites with the lowest Hg concentrations also had the lowest estimated trophic levels.

The range in trophic levels in lobster among sites was small, ranging from 3.7 to 4.0 trophic units (Figure 16-15). However, there were significant differences among sites. The trophic level in lobsters sampled at Kelly Cove, on the far west side of Penobscot Bay, was significantly lower than at five of the six other sites (ANCOVA, adjusted for carapace length, $P < 0.05$, Tukey HSD, $P < 0.05$), and the lobster trophic level at ES04, near Sears Island, was significantly lower than the northernmost site, ES15.

In the full data set there was no relationship between trophic level and Hg concentrations in lobster tail. Lobster sampled at Kelly Cove in 2008 had both the

lowest THg concentration and the lowest estimated trophic level of any site sampled. And at Kelly Cove and ES04 (SW Sears Island), Hg appeared to increase with trophic level, but this trend did not continue at the other five lobster sample sites. Between ES15 (Odum Ledge) to the north, past ES13 (South Verona) and ESFP (Fort Point), to Parker Cove and Harborside to the south, trophic level varied by ~0.1 trophic units while tail muscle total Hg varied from 130 to 440 ng/g wet. wt..

In summary, there was no relationship between trophic level and Hg concentrations in American eel, tomcod, rainbow smelt or lobster.

# 7 SITE FIDELITY OF TARGET SPECIES

In the following discussion, $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ signatures in fish and invertebrates are analyzed for evidence of site fidelity. Comparing the overlap in isotopic signatures gives a qualitative indication of movement among sites. All three isotopes examined in this study are expected to show steady increases toward heavier δ signatures in more saline waters (Newsome et al. 2007). Distinct differences in salinity among sample sites should translate into distinct isotopic differences in resident species. If site fidelity is strong within a given species, with limited or no movement among the sites sampled, we expect to find distinct differences in the isotopic signatures of the biota among those sites.

## 7.1 Benthic Invertebrates in the lower Penobscot River

Three benthic or epibenthic invertebrates were sampled at multiple sites in the lower reaches of the Penobscot River. With a few exceptions, all three taxa, Oligochaete worms, amphipods and sand shrimp (*Crangon*), had progressively heavier δ signatures for carbon and sulfur in samples collected from sites further downstream. The $\delta^{13}C$ and $\delta^{34}S$ values for Oligochaetes (Figure 16-16) and amphipods (Figure 16-17) appeared to be widely separated, with up to 5‰ differences between successive downstream sites. Small sample sizes in those taxa likely limited variance within sites.

*Crangon* shrimp (Figure 16-18) also had heavier $\delta^{13}C$ and $\delta^{34}S$ values at the more saline sites at the south end of the OB reach (OB4 and OB1). Little difference in δ values was found between the adjacent sites of OB5 and OB3 at the north end of the reach. Overall, $\delta^{15}N$ signatures increased at the downstream sites for all three taxa sampled in the lower river. Oligochaete worms had a steady increase in δ values collected at increasingly saline sites. The increase was not as sequential in amphipods or *Crangon* shrimp, possibly due in part to the difference in sample range among those three taxa. Oligochaete worms were collected farthest upstream in freshwater.

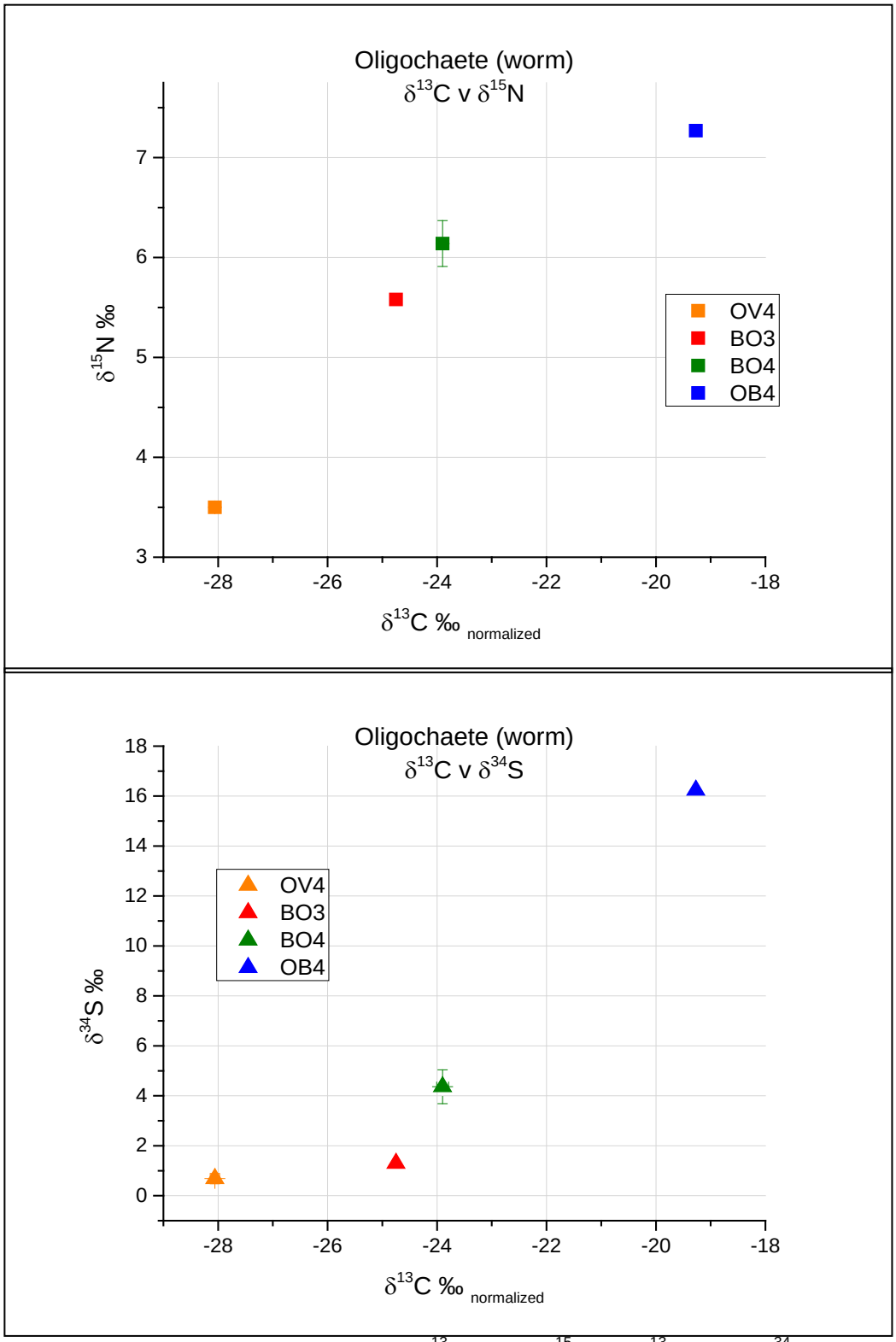



Figure 16-16. Oligochaete worm – Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. δ signatures of all three isotopes increased in samples of Oligochaete worms collected from progressively downstream sites in the lower Penobscot River.

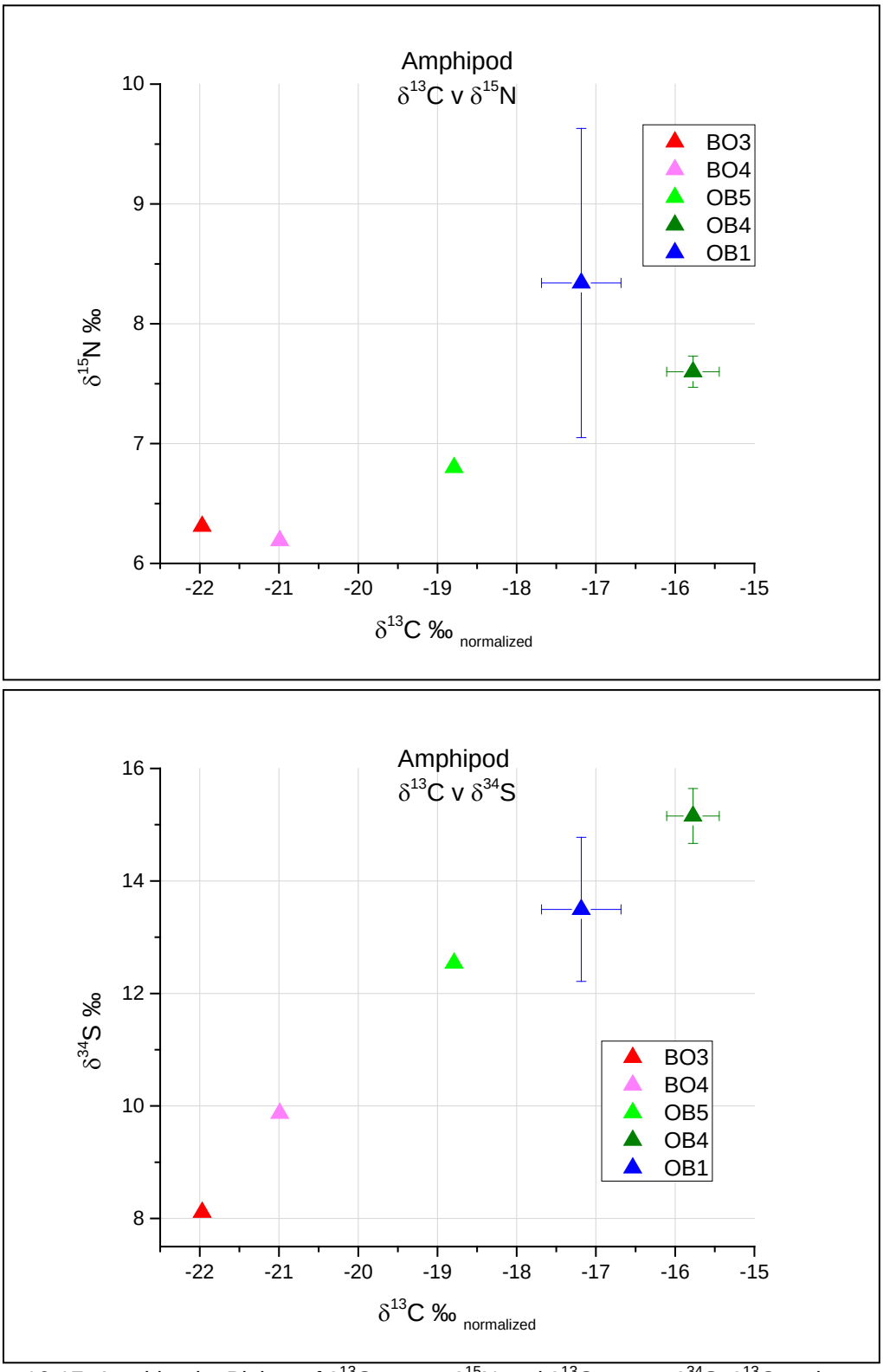



Figure 16-17. Amphipod – Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. $\delta^{13}C$ and $\delta^{34}S$ signatures in amphipods increased steadily with salinity at sites further downstream in the lower Penobscot River. $\delta^{15}N$ values showed some increase at downstream sites.

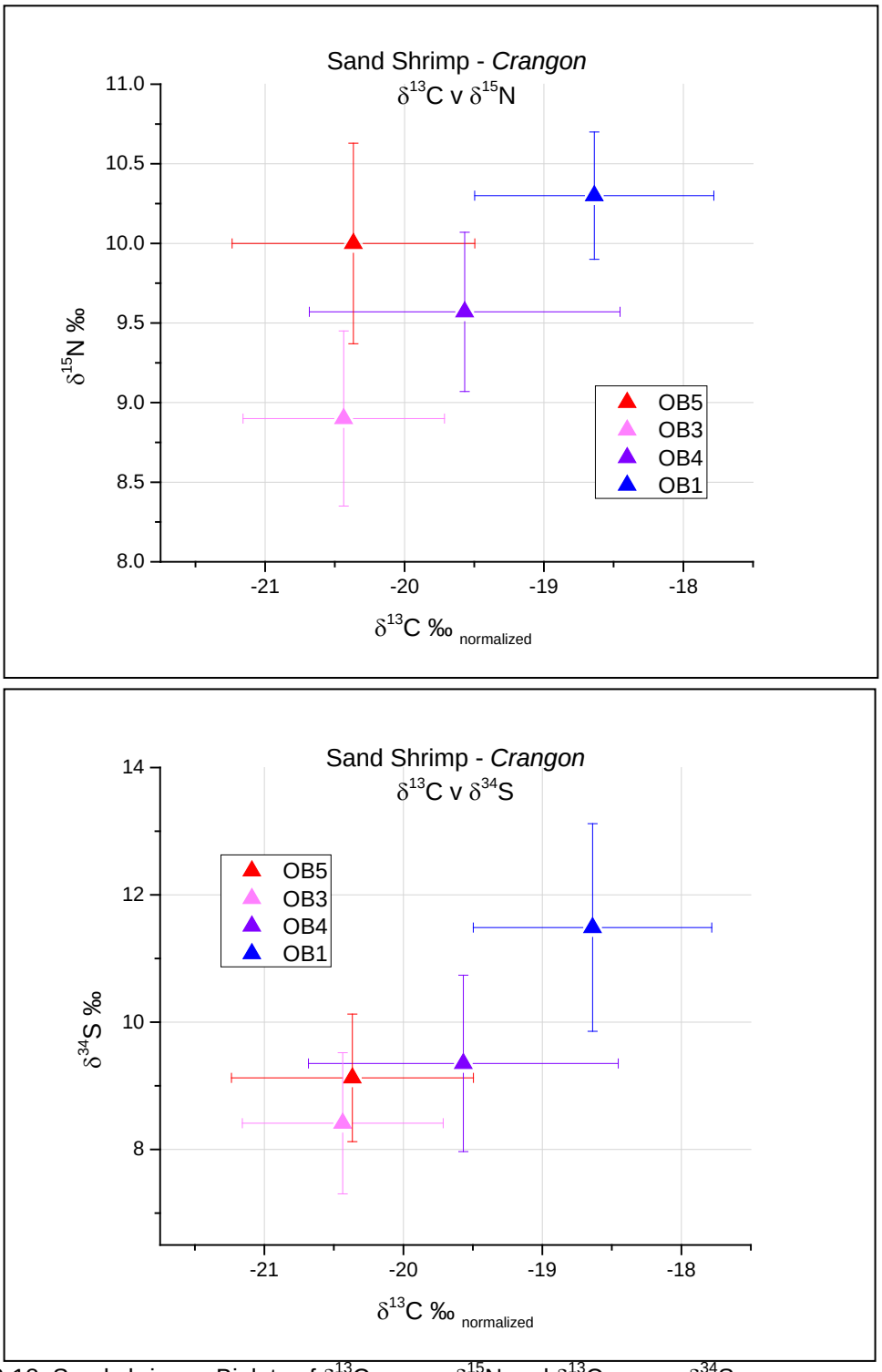


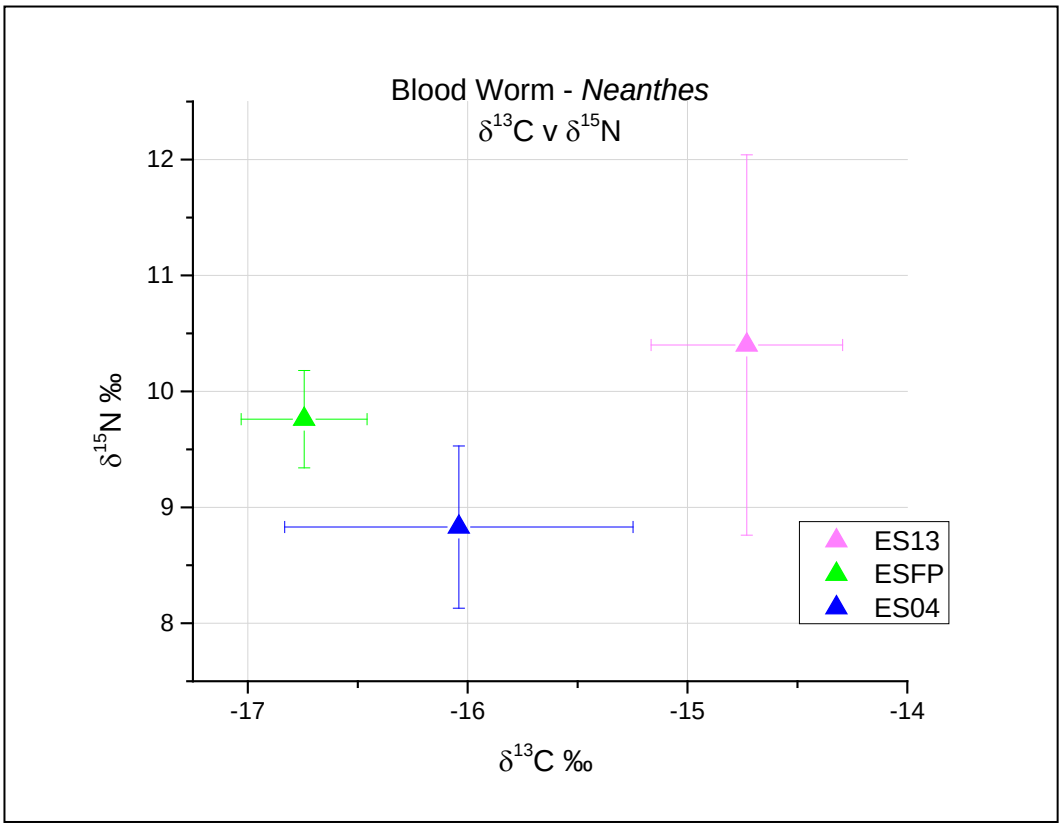

Figure 16-18. Sand shrimp – Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. Sand shrimp, collected only in the OB reach, had increased $\delta^{13}C$ and $\delta^{34}S$ signatures at the downstream sites, consistent with expected increases in salinity. Little difference was found at the adjacent sites of OB5 and OB3.

## 7.2 Invertebrates in upper Penobscot Bay

Three invertebrate taxa were sampled at multiple sites in the ES reach of upper Penobscot Bay. Two invertebrates at the base of the benthic food web, the blood worm *Neanthes* (Figure 16-19) and the periwinkle snail *Littorina* (Figure 16-20), had no consistent geographic variation in δ values except for a slight increase in $\delta^{13}$C signatures toward the south and west.

Blue mussels, at the base of the pelagic food web, had no overall geographic trend based on isotope signatures (Figure 16-21). The $\delta^{13}$C values hovered around -17‰. $\delta^{34}$S values were lighter in mussels collected in 2009, a very wet year with unusually high runoff during the summer, than in 2008. $\delta^{15}$N declined slightly, but with extensive overlap, from the northeast sites to the southwest of the bay. One site, ES04 in 2009, was notably different than the other mussels sites sampled; $\delta^{13}$C was enriched while both $\delta^{34}$S and $\delta^{15}$N was lower relative to the other sites.

In summary, distinct differences in δ isotope values were found in benthic invertebrates sampled at sites in the OV, BO and OB reaches. These differences at the base of the food web may be found in upper trophic levels if the fish have distinct home ranges in the lower reaches of the river. In contrast, in the ES reach in upper Penobscot Bay, no pattern was found in δ isotope values in two benthic invertebrates near the base of the food web. Further, no consistent pattern was found in δ isotope values in blue mussels, at the base of the pelagic food web. It is therefore less likely that upper trophic level organisms in the ES reach will have distinct differences in their isotopic signatures among sites.



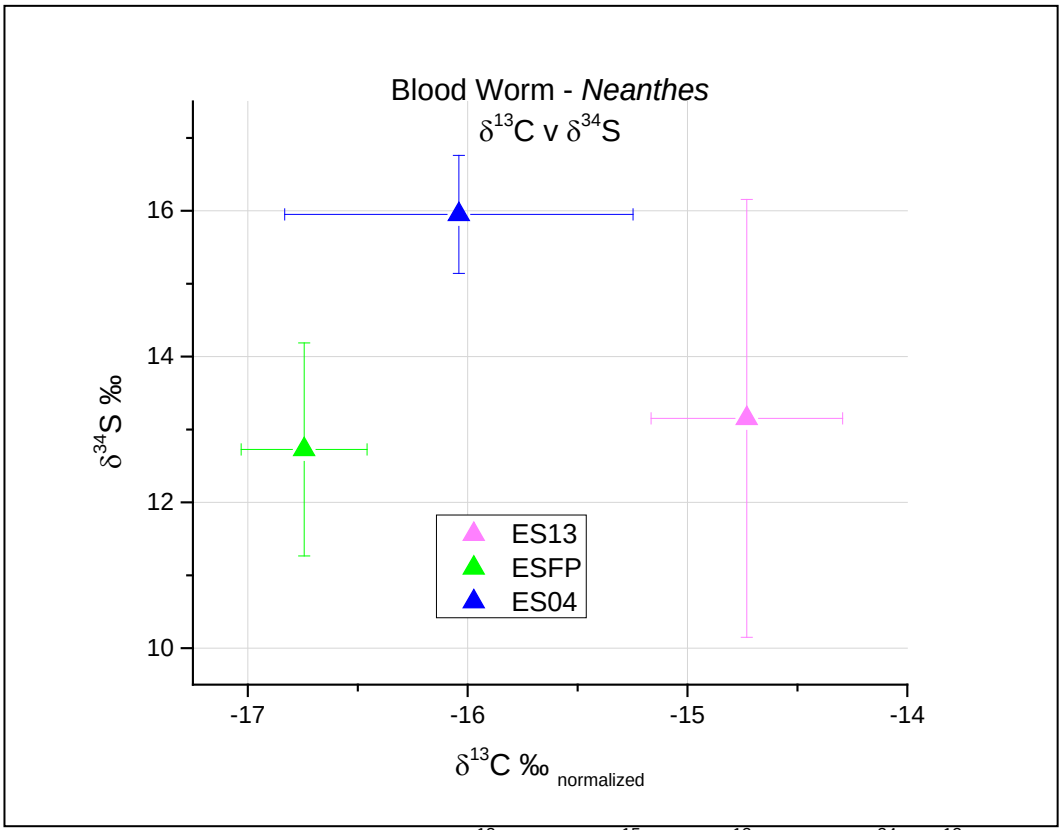




Figure 16-19. Blood worm – Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. $\delta^{13}C$ signatures in *Neanthes* worms increased further south and west in Penobscot Bay, but there was no pattern evident in δ values for nitrogen or sulfur.

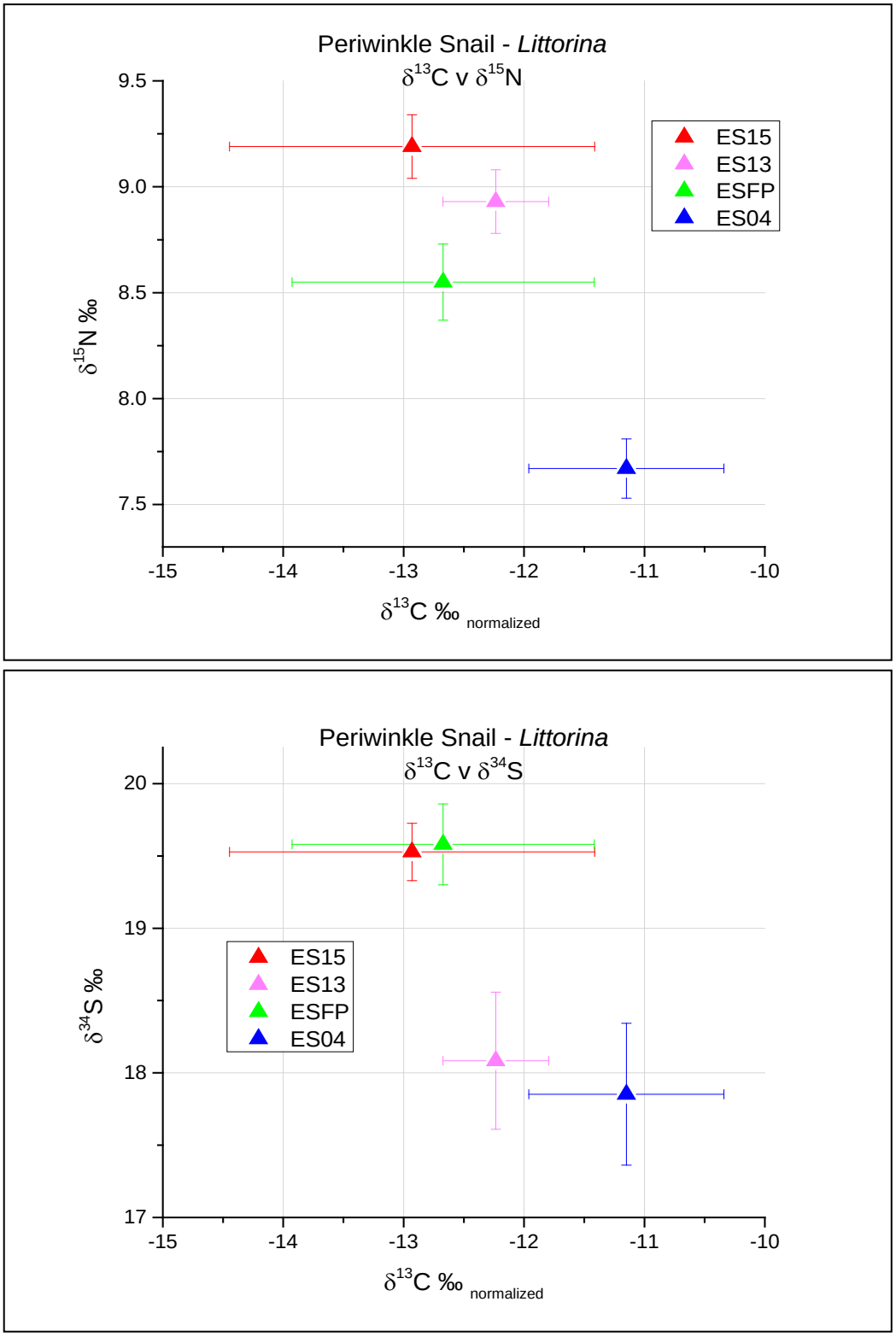



Figure 16-20. Periwinkle snail – Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. $\delta^{13}C$ values varied little in *Littorina* snails among the four ES sites sampled. There was no geographic variation in $\delta^{34}S$ signatures in Penobscot Bay, $\delta^{15}N$ declined by 1.5‰ at sites further south and west in the bay.

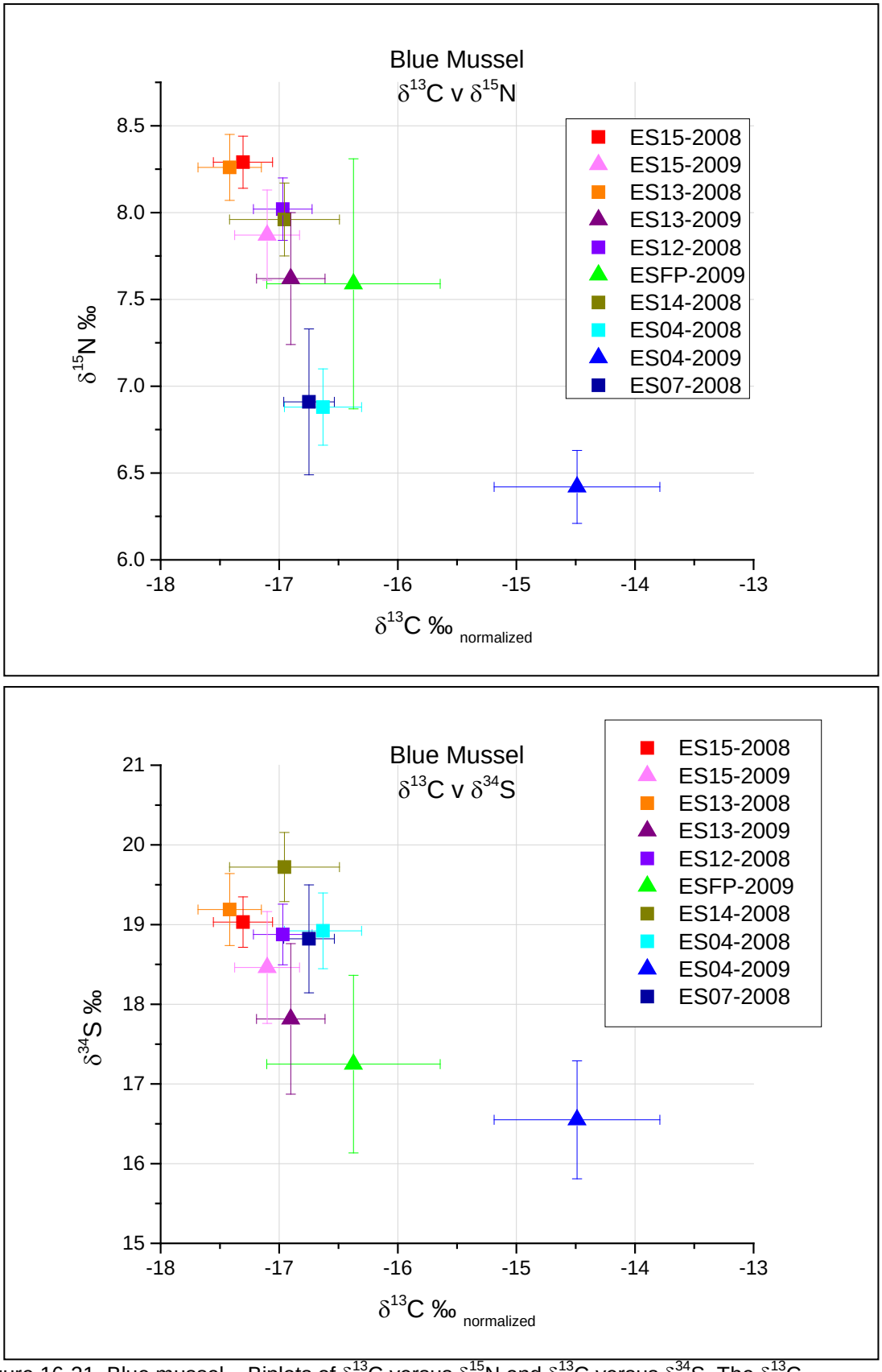


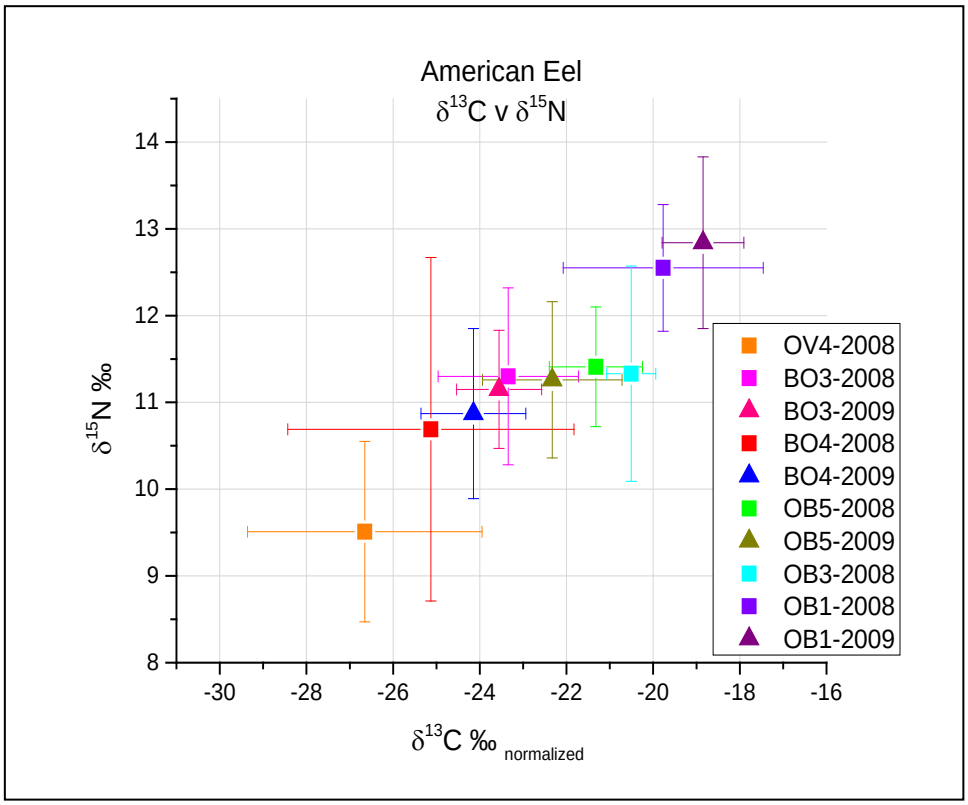

Figure 16-21. Blue mussel – Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. The $\delta^{13}C$ values for blue mussel did not vary among the ES sites sampled,. $\delta^{34}S$ values were lower in 2009 relative to 2008, but showed no geographic variation. $\delta^{15}N$ signatures declined overall, moving south and west with extensive overlap. The exception for all three isotopes was notably lower values at ES04 in 2009.

### 7.2.1 American Eel

Overall increases in the δ isotope values were found in American eels at sites advancing south along the lower Penobscot River. The $\delta^{13}C$ and $\delta^{15}N$ signatures were lightest in the freshwater reach of OV. South of the Veazie Dam, from BO3 to OB1, there was a steady increase in both $\delta^{13}C$ and $\delta^{15}N$ signatures, from -26‰ to -19‰, and from 11.3 to 12.8‰, respectively, indicative of an increase in the marine influence on these isotopes (Figure 16-22). The $\delta^{34}S$ signature was also lightest at the freshwater site of OV4. Just south of the Veazie Dam the δ isotope values for sulfur jumped 6‰ to 9‰ at BO3, and remained unchanged through OB5, 8 miles downstream. There followed a slight increase in $\delta^{34}S$ values from OB3 down to the southernmost eel site of OB1. There was visible overlap of the eel $\delta^{13}C$ signatures for $\delta^{13}C$ and $\delta^{15}N$, and for $\delta^{34}S$ south of the Veazie Dam. This finding indicates eel movement among adjacent sample sites or resource movement in this dynamic tidal system.

Further, the steady increase in isotopic signatures with increasing salinity is additional evidence for the earlier finding that the eel diet remains in the benthic food web. A shift to the pelagic food web, which has lighter isotopic signatures than the benthic food web, would have negated the salinity-driven increase in isotope values.

In summary, overlap of means for all three isotopes suggests movement by the eels among adjacent sample sites south of Veazie Dam, but little movement between the OV reach above the dam and the sites downriver. No pattern in δ isotope values was found between 2008 and 2009, the two years in which eels were sampled for stable isotopes. Also, these δ values provide additional support to the previous finding that eels feed consistently in the benthic food web throughout the lower Penobscot sample area.



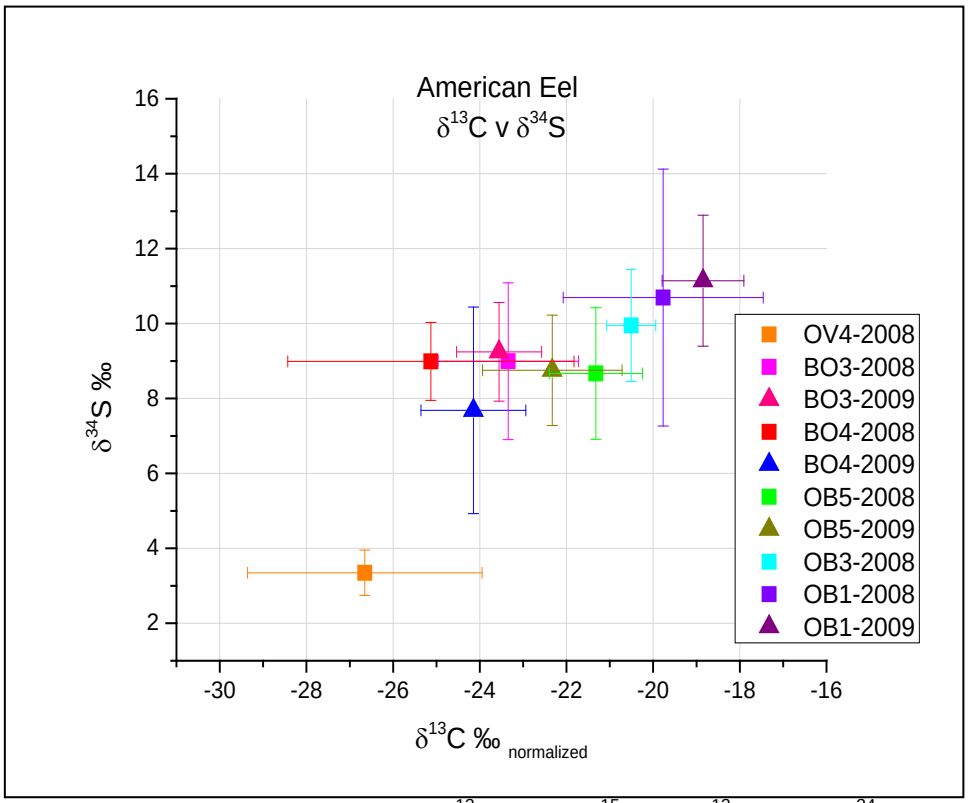




Figure 16-23. American eel - Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. The δ values for all three isotopes increase in eels toward the lower river, but there is extensive overlap of all isotopic signatures, especially below Veazie Dam, indicating an overlap of eel foraging areas, movement among areas, or resource mixing with tides.

### 7.2.2 Tomcod

There was an overall trend toward increasing $\delta^{13}C$ and $\delta^{34}S$ signatures in tomcod in the lower Penobscot River and far upper portions of Penobscot Bay (Figure 16-23). As in eel, these increases indicated a greater marine influence near the mouth of the Penobscot River. There was some evidence that tomcod partially shift to a pelagic food web in the southern parts of the sample area. In the ES reach, $\delta^{34}S$ values are slightly lighter at the more downstream sites, possibly due to the lighter signatures expected in pelagic prey. $\delta^{15}N$ values changed little among all sites, less than 1‰, and no geographic trend in nitrogen isotope signatures was found.

Obvious overlap of $\delta^{13}C$ and $\delta^{34}S$ values within each reach sampled suggested regular mixing of tomcod among sites within the OB and upper ES reaches. The absence of any overlap of $\delta^{13}C$ values between the OB and ES reaches, and the large jump in $\delta^{13}C$ values of 3‰ between the two reaches, suggested limited movement between the southern end of OB and the ES sites south of Bucksport.

In summary, the stable isotope signatures for tomcod suggested limited mixing within the OB and ES reach, and no exchange of foraging tomcod between the two reaches. The clear increase in both $\delta^{34}S$ and $\delta^{13}C$ with increasing salinity suggested foraging primarily in the benthic food web in both reaches sampled.

### 7.2.3 Mummichog

The isotope signatures of mummichog were geographically distinct and showed little overlap among sites, especially for $\delta^{15}N$ and $\delta^{13}C$ (Figure 16-24). These findings support the hypothesis of limited mixing of mummichog among the sites sampled and a consistent focus on the benthic food web. However, the small number of sites sampled suggests caution should be used when applying these results to the broader system.

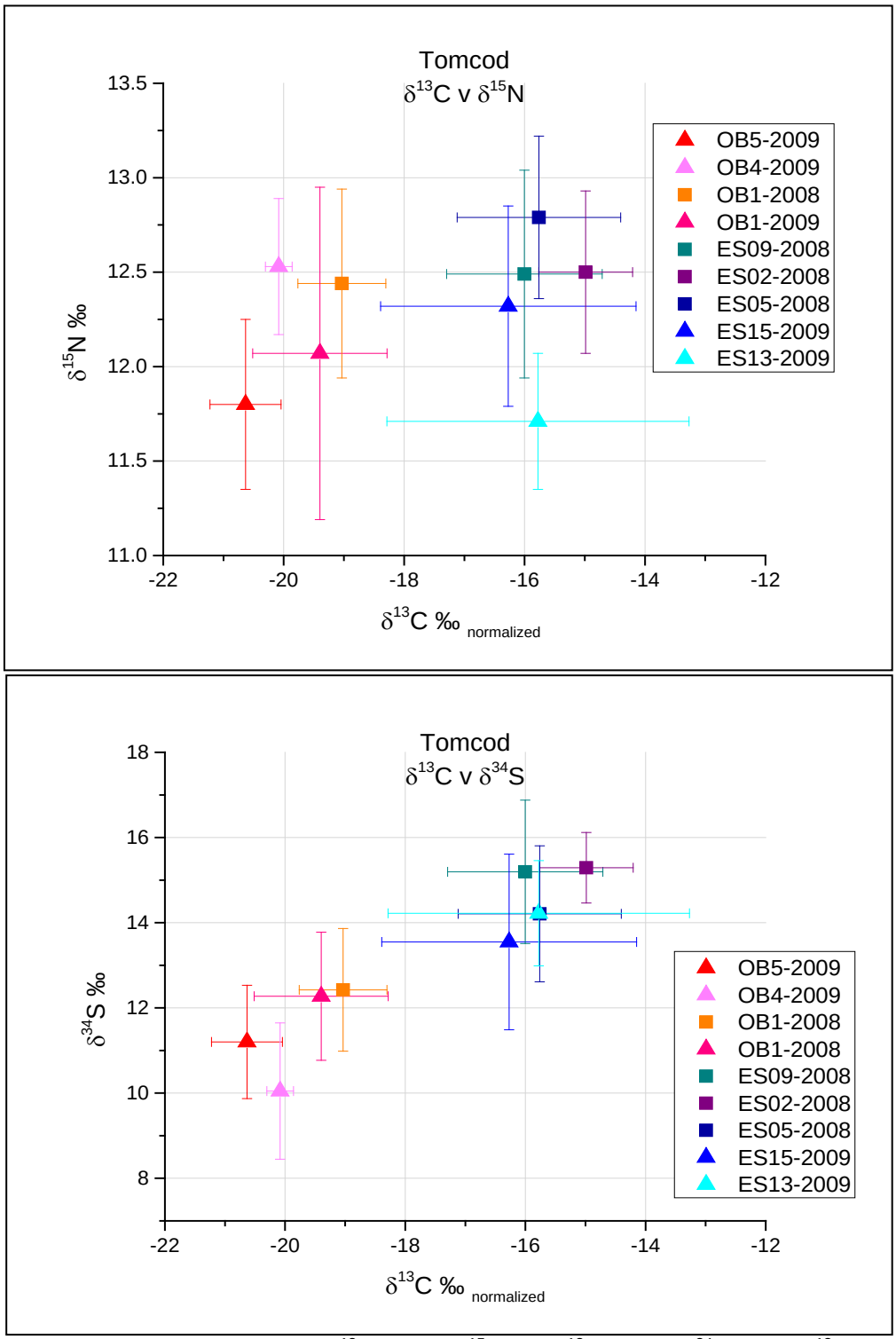
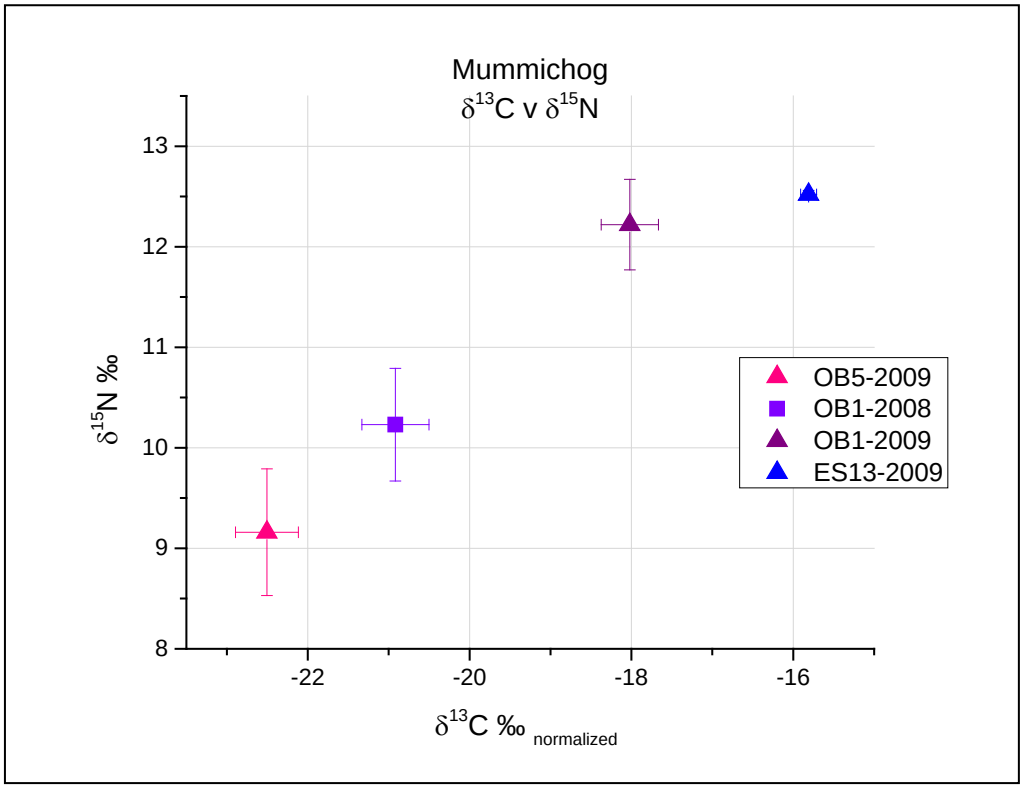



Figure 16-24. Tomcod - Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. Both $\delta^{13}C$ and $\delta^{34}S$ increased at downriver sites in the lower Penobscot River and to a limited extent in upper Penobscot Bay,, with some geographic mixing around Verona Island sites. A partial shift to pelagic prey may be evident in the lower $\delta^{34}S$ signatures at the southern end of ES. No geographic pattern was found for $\delta^{15}N$ in tomcod, which changed little among the sites sampled.



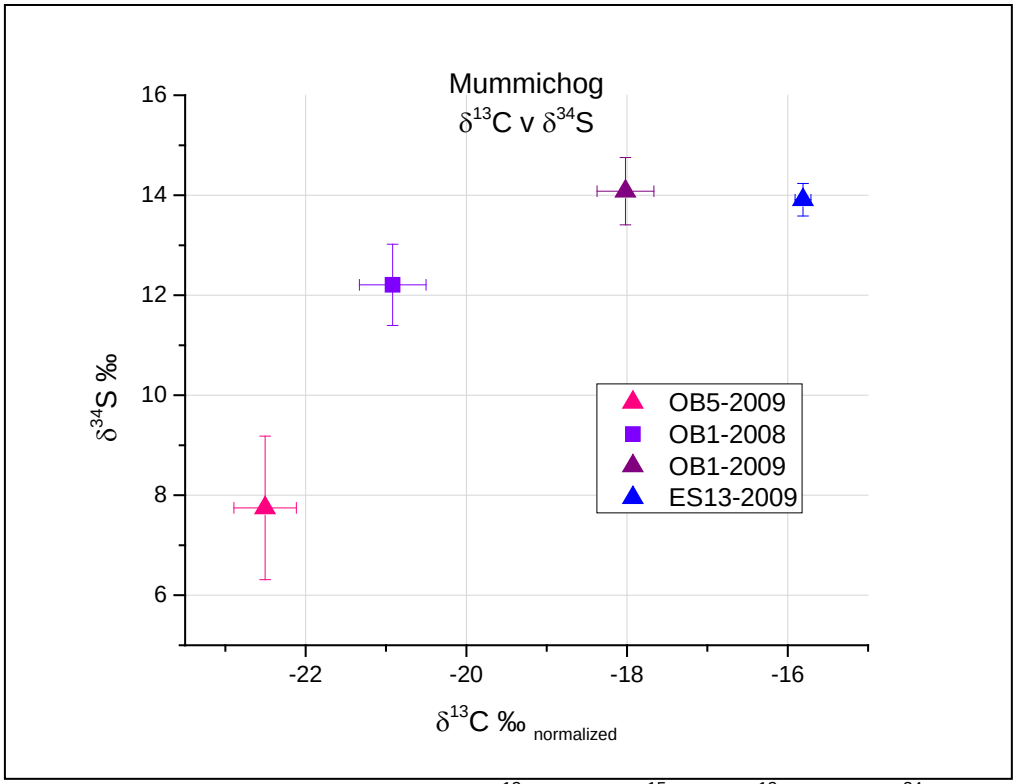




Figure 16-25. Mummichog - Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. Distinct δ values in mummichog increased with downstream salinity, indicating limited movement of mummichog among the sites sampled and a consistent focus on the benthic food web.

### 7.2.4 Rainbow Smelt

Rainbow smelt were collected from the lower OB reach and at multiple sites in the ES reach. The mean $\delta^{13}$C and $\delta^{34}$S signatures in smelt varied among sites but with no geographic pattern evident (Figure 16-25). The absence of a pattern, despite increasing salinity at sites further downstream in the river and upper bay, may indicate conflicting trends in δ isotope values. Increased salinity would be associated with heavier $\delta^{13}$C values, while a shift from a benthic to a pelagic carbon source (food web) would lead to lighter $\delta^{13}$C values. Since downstream sites have increased salinity, the absence of a trend toward heavier carbon isotopes further supports a downstream shift in the smelt diet. Evidence for this shift was found earlier in the stomach content analysis, which indicated foraging in the pelagic food web in parts of the ES reach. Alternately, the absence of a geographic trend toward increasingly heavier isotopes could also reflect less site fidelity in this species.

A distinct pattern was found in the $\delta^{34}$S signatures in rainbow smelt between 2008 and 2009. There was no overlap in the mean $\delta^{34}$S signatures between 2008 (15-17‰) and 2009 (12.5 – 14‰) (Figure 16-25). This may have resulted from an abnormally large volume of freshwater runoff during the unusually rainy summer of 2009. A similar pattern was seen in 2009 in the $\delta^{34}$S signatures in blue mussels, another species in the pelagic food web.

### 7.2.5 Lobster

The δ isotope values in lobster varied little and had no geographic trends within the study area (Figure 16-26). This may reflect the large contribution to the lobster diet from lobster bait which is caught offshore and distributed randomly in lobster traps, and so would not reflect any nearshore trend in isotope values. Movement of lobsters among the defined sample areas would also produce these random isotope values.

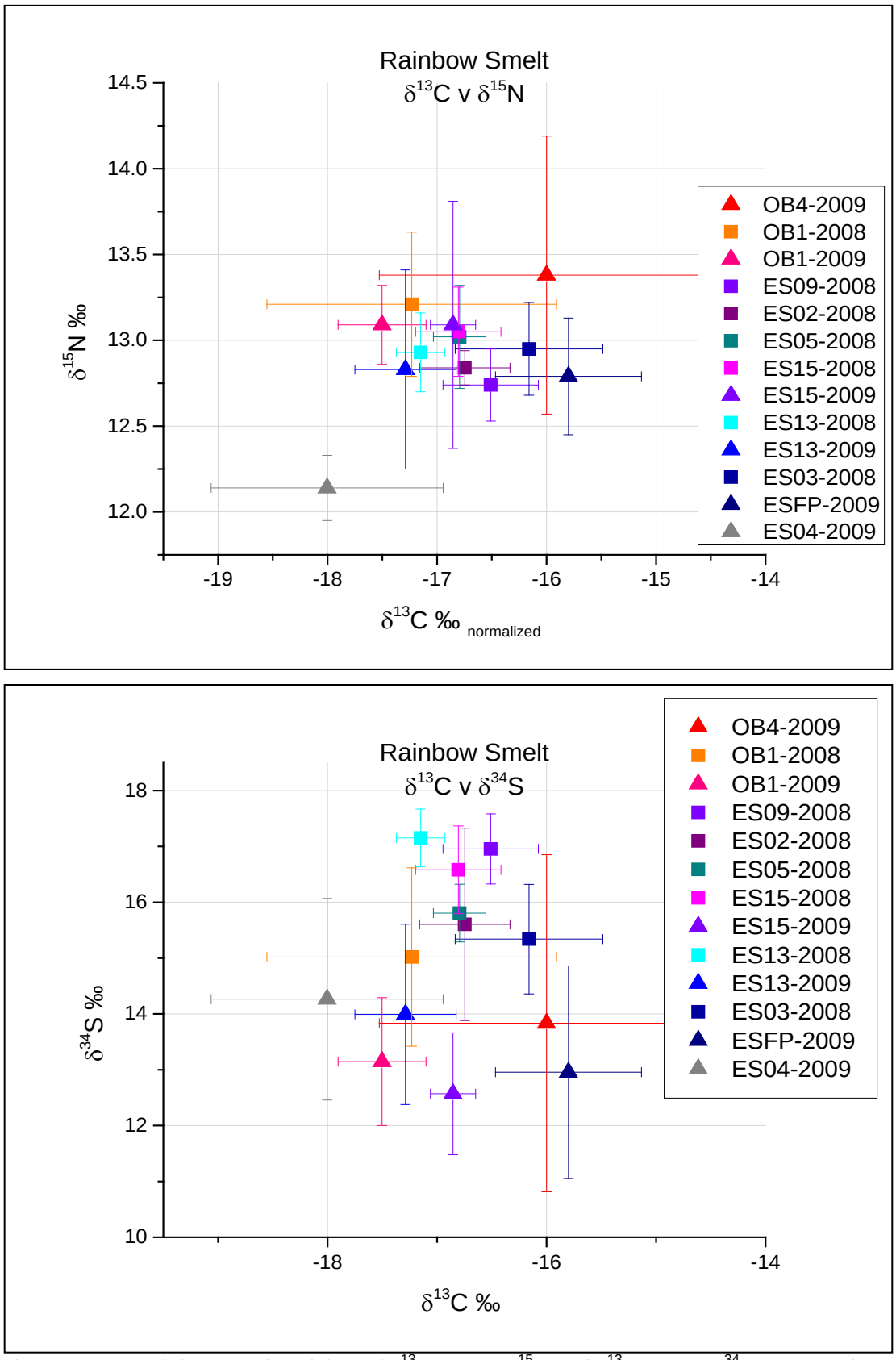
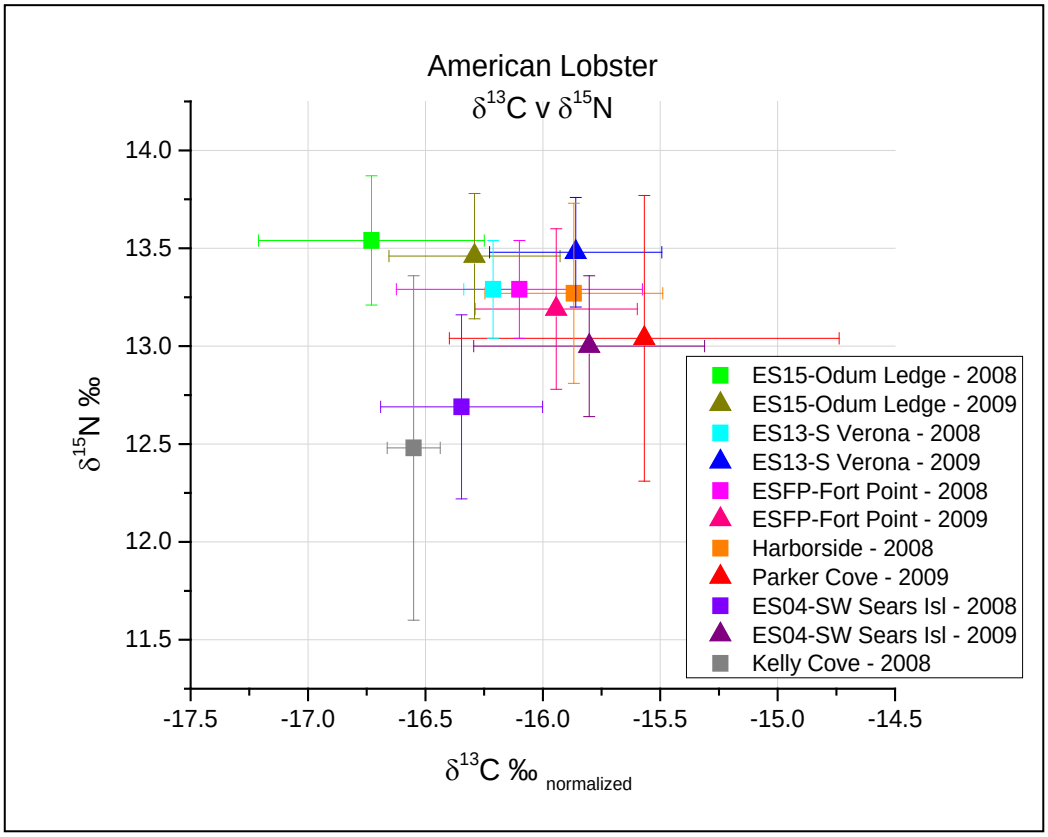



Figure 16-26. Rainbow smelt - Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. No consistent geographic variation in δ isotope values was evident for rainbow smelt, indicating either foraging by smelt in the pelagic food web or lack of site fidelity. Distinct differences were found in $\delta^{34}S$ values between 2008 and 2009, possibly related to high freshwater outflow in 2009.



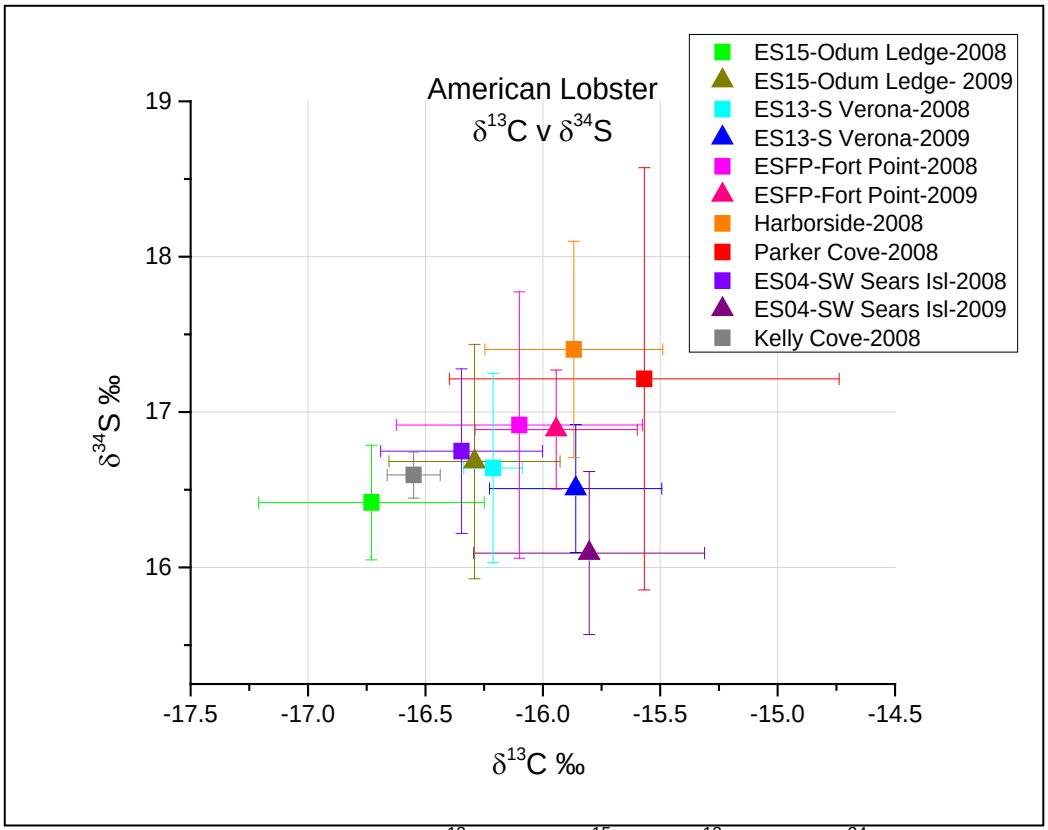




Figure 16-26. American lobster - Biplots of $\delta^{13}C$ versus $\delta^{15}N$ and $\delta^{13}C$ versus $\delta^{34}S$. No geographic separation or trend was found in δ isotope values in lobster.

# 8 WETLAND FOOD WEBS IN TIDAL MARSHES LOWER PENOBSCOT RIVER and SCARBOROUGH MARSH

## 8.1 Introduction

Stable isotopes were used to examine food web structure and understand Hg sources and variability in tidal marshes bordering the lower Penobscot River and at Scarborough Marsh, a reference site in southern Maine. Sufficient data for analysis were collected from three Penobscot area marshes, W17-North, Mendall Marsh-East and Mendall Marsh-West (Figure 16-33).

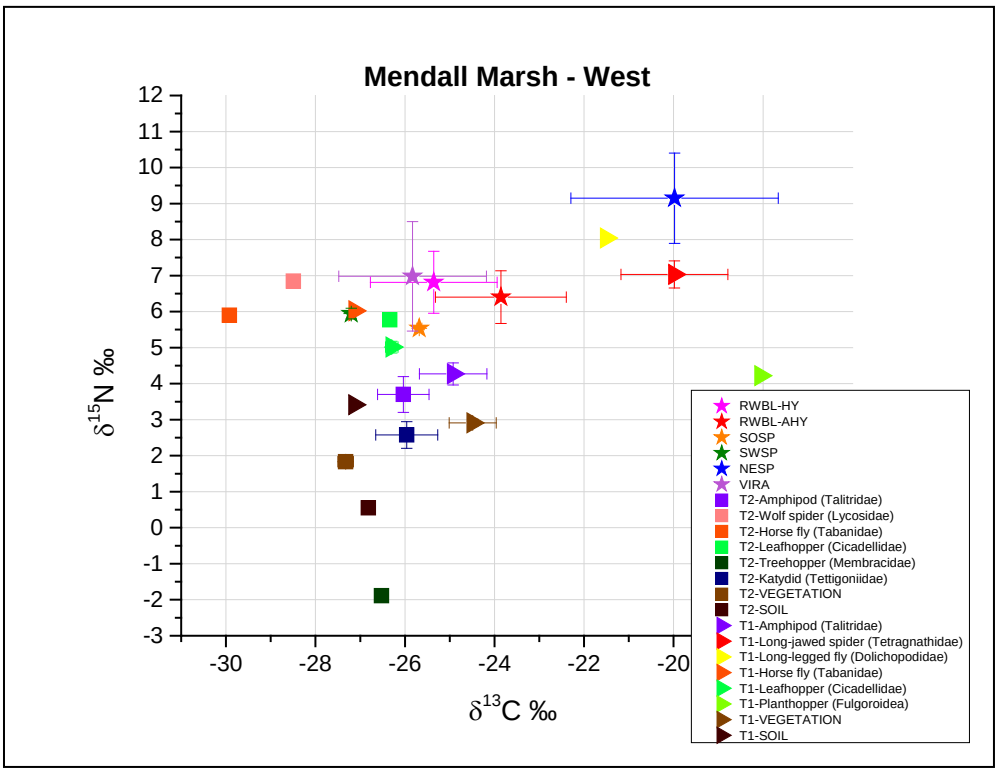
The following discussion focuses on five bird species, Nelson's sparrow (NESP; *Ammodramus nelsoni*), song sparrows (SOSP; *Melospiza melodia*), swamp sparrows (SWSP; *Melospiza georgiana*), red-winged blackbirds (RWBL; *Agelaius phoeniceus*), and Virginia rails (VIRA; *Rallus limicola*), sampled in sufficient numbers for comparison among sites. At some sites both adult birds, after hatch year (AHY), and recently fledged birds, hatch year (HY), were sampled.

Note that raw data summaries for wetland food chains can be found in Appendices 16-4 to 16-8.

## 8.2 Mendall Marsh-West

In 2009, five species of birds and six invertebrate taxa were sampled as part of the food web study in Mendall Marsh-West. Bi-plots in Figure 16-27 depict the relationships between the target bird species and potential prey species sampled. All sparrows were sampled at Mendall Marsh-West from June 11 to16, Virginia rails were sampled in late June, and red-winged blackbirds were sampled primarily in mid to late July. Invertebrates were sampled in late July to early August.

There is strong evidence that the long-jawed spider, an orb-weaving spider in the Family Tetragnathidae, comprised almost half of the diet of the Nelson's sparrow at Mendall West. The mean $\delta^{13}C$ signature for the Nelson's sparrow was the heaviest of all of the birds sampled at this site, -20‰, and was similar to that of long-jawed spiders collected from Transect 1. The $\delta^{15}N$ signature for the sparrow was 2.2‰ greater than for the spider, an appropriate difference between predator and prey. The $\delta^{34}S$ values for these two taxa were also in good agreement, both near 6‰. Further, results from the SIAR mixing model for this site estimated that the spider was 46 to 58% of the sparrow's diet at the 95% probability level. Shriver et al. (2011) reported additional prey for the Nelson's sparrow, many of which were sampled at Mendall West. However, none of those other possible prey taxa, including amphipods, nocturnal wolf spiders, and leafhoppers, were indicated as prey for Nelson's sparrows at this site, based on their much lighter isotopic signatures.



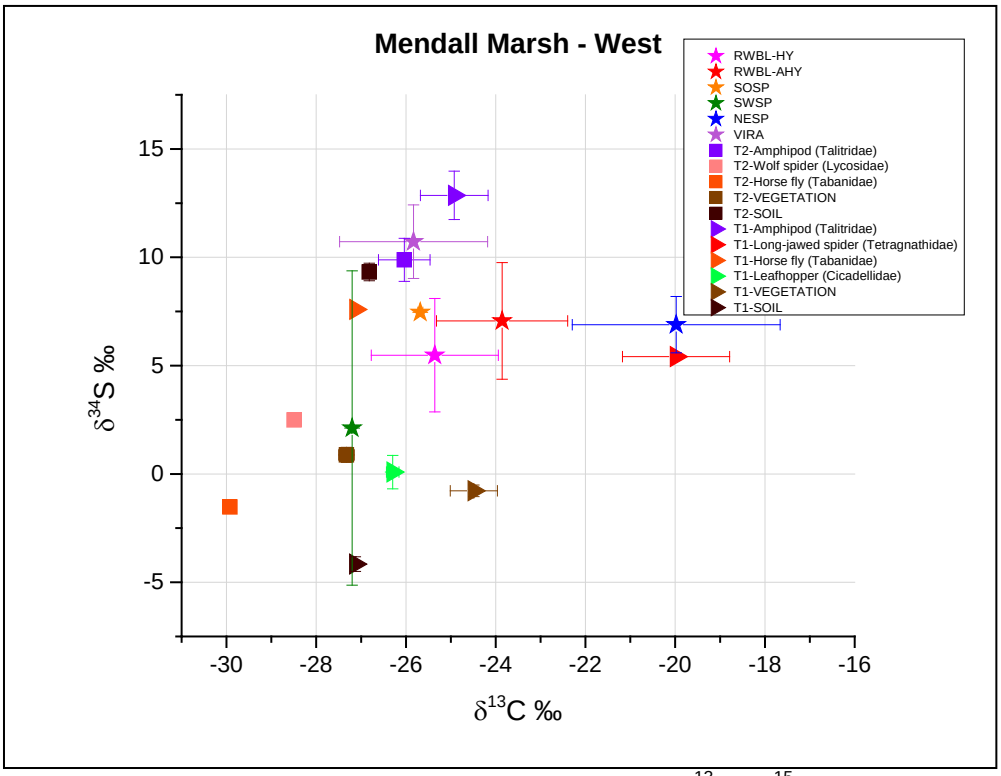




Figure 16-27. Mendall Marsh West - Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top) and $\delta^{13}C$ v $\delta^{34}S$ (bottom). All birds sampled were adults, except for young-of-the-year red-winged blackbirds (RWBL-HY). Invertebrates were sampled at two sites, transect 1 (T1), at the water's edge, and transect 2 (T2) in the marsh interior.

Katydids (Tettigoniidae) and amphipods (Talitridae) may have contributed to the diet of song sparrows at Mendall West. Song sparrows had a lighter $\delta^{13}$C signature, -26‰, than the Nelson's sparrow. This lighter carbon signature roughly matched the carbon signature for amphipods, katydids and leafhoppers (Cicadellidae). And, amphipods and katydids had a suitably lighter $\delta^{15}$N signature for prey contributing to the song sparrow diet. The $\delta^{15}$N for the leafhoppers was equivalent to that of the song sparrow, eliminating leafhoppers as potential prey for the song sparrow. Further, the $\delta^{34}$S signatures for song sparrows and amphipods from transect 2 were somewhat comparable; data for sulfur isotopes were not available for katydids. Given the available isotope data for this site, katydids and amphipods were the only possible prey taxa eaten by song sparrows. Song sparrows are not obligate marsh feeders. They have a varied diet in the summer that may include up to 60% plant material, though if they are foraging on the marsh, snails and worms contribute significantly to their diet (Arcese et al. 2002).

Swamp sparrows had the lightest $\delta^{13}$C signature of all birds sampled, and their isotopic signatures did not match well with any invertebrate sampled. Leafhopper (Cicadellidae), spider (Lycosidae and Tetragnathidae) and fly (Tabanid) taxa did have $\delta^{13}$C signatures similar to that of the swamp sparrows. However, those taxa had $\delta^{15}$N values equivalent to or greater than the sparrows, eliminating them as possible prey given the expected trophic enrichment of $\delta^{15}$N from prey to predator.

Both hatch year and adult (AHY) red-winged blackbirds were sampled at Mendall Marsh-West in mid to late July of 2009, just before invertebrates were sampled at this site. Both age classes had similar isotopic signatures, suggesting a similar diet. Of the invertebrates sampled, amphipods and katydids (Tettigoniidae) were the most likely prey consumed, based on comparable $\delta^{13}$C signatures and appropriately lower $\delta^{15}$N signatures. However, amphipods had $\delta^{34}$S values roughly 5‰ greater than the red-wings, suggesting that amphipods were not a large part of the red-wing diet.

The mean $\delta^{13}$C signature for Virginia rails was in the same range as amphipods (Talitridae), leafhoppers (Cicadellidae) and katydids (Tettigoniidae). Also, the $\delta^{15}$N signatures of all three prey taxa were appropriately lighter if they were part of the rail diet. Amphipods, present throughout the summer, would have been available to foraging rails and the similar $\delta^{34}$S signatures between amphipods and rails (10 to 12‰) support their inclusion in the rail diet. The sulfur isotope signature for leafhoppers was much lower than found for rails, at 0‰, reducing the likelihood that they were part of the rail diet. Katydids were not analyzed for sulfur isotopes due to insufficient sample mass.

In summary, at Mendall Marsh-West stable isotope signatures suggest that long-jawed spiders (Tetragnathidae) contribute significantly to the diet of Nelson's sparrows. Katydids (Tettigoniidae) and amphipods (Talitridae) may have contributed to a greater or lesser degree to the diet of song sparrows, red-winged blackbirds and Virginia rails. No dominant prey taxa were identified for swamp sparrows from our available data set.

### 8.2.1 Mercury in the Food Web of Mendall Marsh – West

Hg concentrations in marsh birds were roughly 10 times those in possible invertebrate prey at Mendall West. The graph below (Figure 16-28) compares whole-body methyl Hg concentrations in invertebrate prey taxa and total Hg concentrations in blood sampled from marsh birds to their $\delta^{15}$N signatures. Methyl Hg concentrations in the invertebrate taxa identified as prey ranged from 0.04 µg/g wet. wt. in katydids to 0.17 µg/g wet. wt. in amphipods from transect 2. The long-jawed spider had a methyl Hg concentration less than amphipods at 0.11 µg/g wet. wt.. The greatest methyl Hg concentrations were in the Tabanid horse flies, which reached 0.85 µg/g wet. wt. in the sample from transect 1 on the edge of the marsh.

The total Hg concentrations in bird blood in most adult marsh birds ranged from 2.9 µg/g wet. wt. in Virginia rails to 4.4 µg/g wet. wt. in red-winged black birds. In this 2009 sample, swamp sparrows and Nelson's sparrows had equivalent concentrations at 3.3 and 3.2 µg/g wet. wt., respectively. Total Hg concentrations were less than 1 µg/g wet. wt. in the song sparrow, which is not an obligate marsh forager, and in young, recently fledged red-wing blackbirds. Rapid growth in the hatch year birds, combined with lateral transfer of Hg from the blood to growing feathers, likely contributed to low Hg concentrations in blood of the hatch year red-wings.

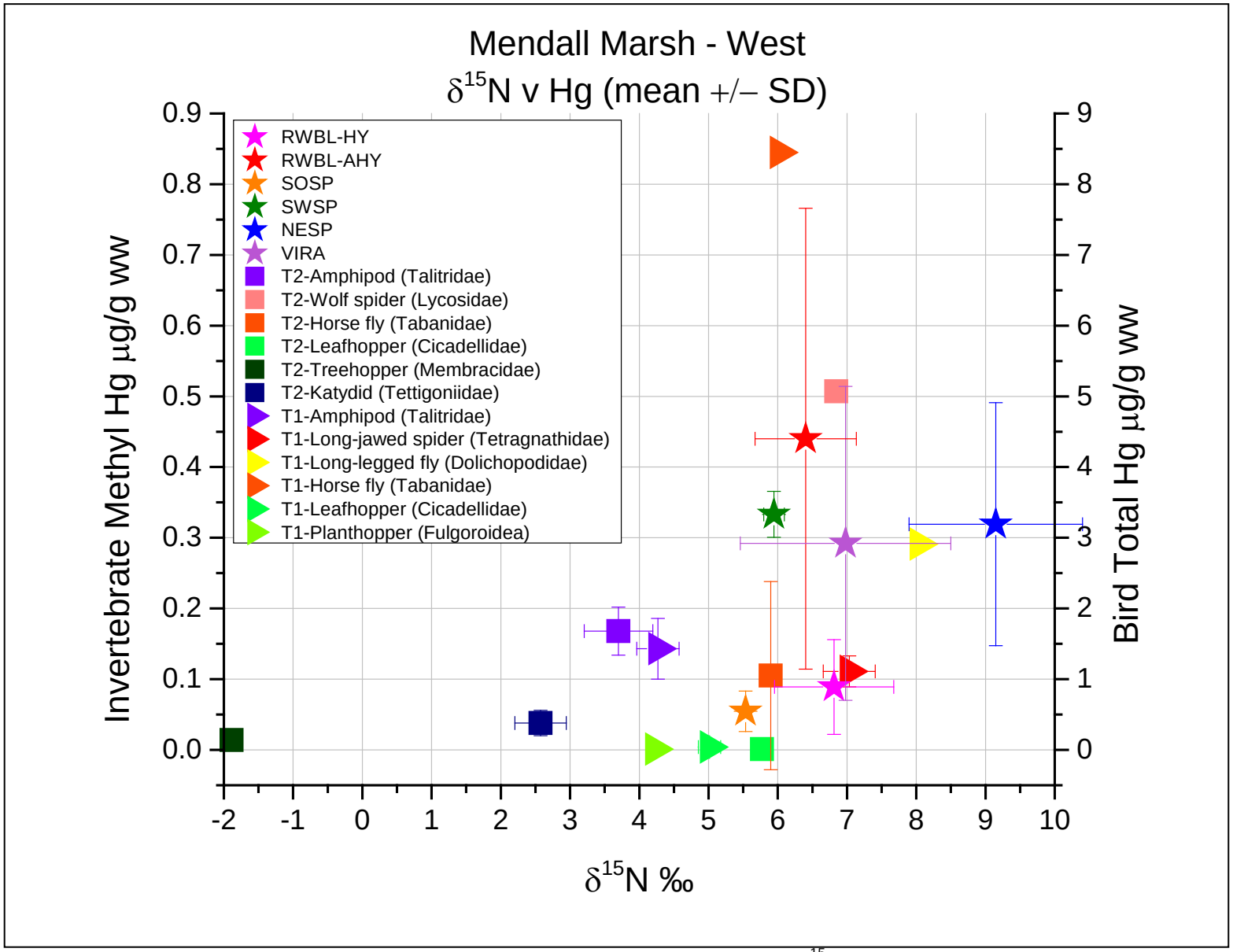



Figure 16-28. Hg concentrations in birds and possible invertebrate prey compared to their $\delta^{15}N$ signatures at Mendall Marsh – West. Concentrations in the marsh birds were roughly ten times greater than in the possible invertebrate prey.

## 8.3 Mendall Marsh East (MM-E)

At Mendall East four species of birds were sampled at each of two bird collection sites at the north and south ends of the marsh (Figure 16-2). Most birds were sampled in early July (7/1-7/11) with the exception of red-winged blackbirds and two hatch-year Virginia rails sampled up to July 29th, 2009. Invertebrates were sampled two to four weeks later in mid- August (8/13) at two transects near the western edge of the marsh, T1 on the marsh edge by the river, and T2 in the marsh interior. Both transects were midway between the two bird sampling sites.

At Mendall East, the $\delta^{13}C$ values for the invertebrate samples were different between the two transects. At transect 1 on the edge of the marsh, $\delta^{13}C$ values ranged from -27.7 to -26.8‰, while at transect 2, in the marsh interior, values were higher and ranged from -24.4 to -17.3‰ and included Tetragnathidae spiders and two fly taxa with isotopic signatures too heavy to be possible prey of the birds (Figure 16-29). This increase in $\delta^{13}C$ signatures from transect 1 to 2 is the opposite of what would be expected in moving from a semi-aquatic to a more terrestrial food web, perhaps reflecting the ubiquitous presence of shallow water pools and salt pannes throughout the interior of the Mendall East marsh platform.

The long-jawed spider (Tetragnathidae) did not appear to be part of the Nelson's diet at Mendall East, because of the spider's heavier signatures for $\delta^{13}C$ and $\delta^{15}N$ at the T1 transect, and lighter $\delta^{13}C$ signature at the T2 transect (Figure 16-29). The mean $\delta^{13}C$ signature for the Nelson's sparrow was 3‰ lighter and less variable at Mendall East than at the adjacent Mendall West site, indicating a difference in diet between the two areas. The absence of the long-jawed spider in the Nelson's diet at Mendall East is in contrast to its large contribution to the Nelson's diet at Mendall West. Based on the Nelson's $\delta^{13}C$ and $\delta^{15}N$ signatures, possible invertebrate prey include three invertebrates from transect 1, katydids (Tettigonbiidae), leafhoppers (Cicadellidae), and amphipods (Talitridae). However, the $\delta^{34}S$ signatures for two of those taxa were notably heavier or lighter than the sulfur signature for the Nelson's sparrow. Of the invertebrates sampled, the long-jawed spider was the only one with the same $\delta^{34}S$ signal as the Nelson's.

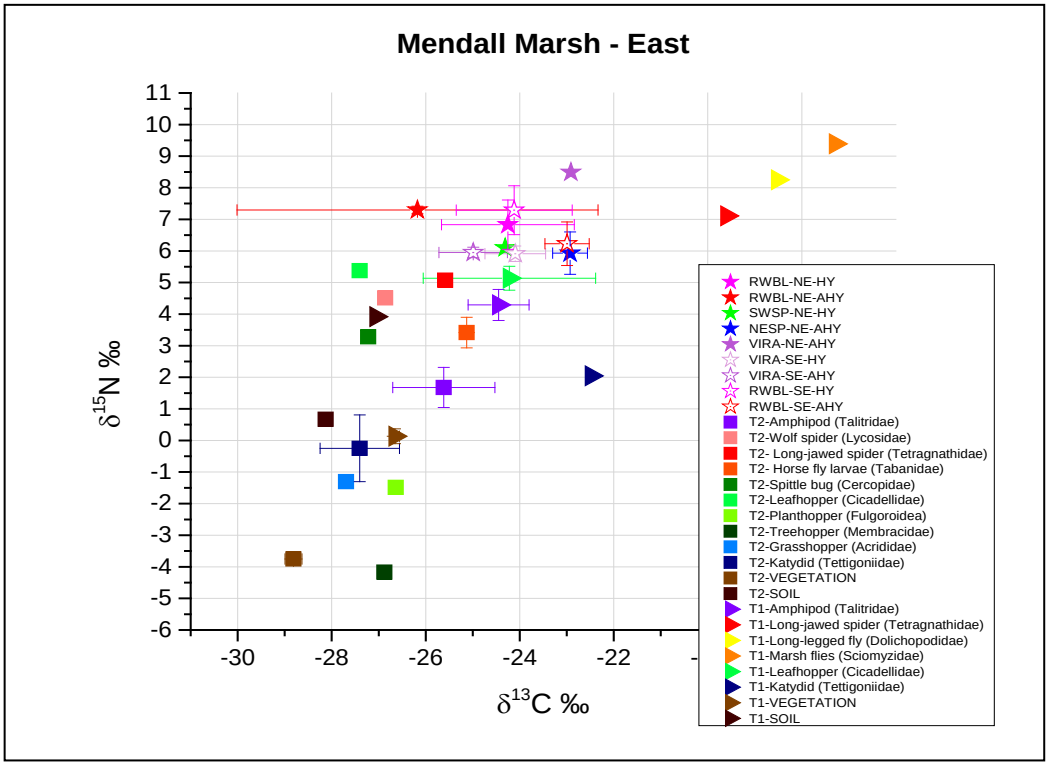
Amphipods (Talitridae), leafhoppers (Cicadellidae) from T1 and horsefly larvae (Tabanidae) from T2 are the most likely prey items for the swamp sparrow in our pool of invertebrates, based on their $\delta^{13}C$ and $\delta^{15}N$ signatures. The one swamp sparrow sampled at Mendall East had a $\delta^{13}C$ signature 3‰ heavier than the swamp sparrows sampled at Mendall West. This difference partially reflects a slight shift in $\delta^{13}C$ values at the base of the Mendall East food web; amphipod $\delta^{13}C$ values were over 1 ‰ greater at Mendall East relative to Mendall West while the T1 leafhopper increased by over 2 ‰. Sulfur isotope values were not available for swamp sparrows.

Red-winged blackbirds in both age classes were sampled at both the northeast and southeast sample areas. Overall the $\delta^{15}N$ (6.2 to 7.3‰) and $\delta^{13}C$ (-24 to -23‰) signatures were similar between sites and age classes, indicating similar diets (the mean $\delta^{13}C$ for the two adults sampled in the northeast (-26‰) was driven by one

individual with an extremely light signal). Based on $\delta^{13}C$ and $\delta^{15}N$ signatures, the possible prey taxa for adult (AHY) and hatch year (HY) red-winged blackbirds were similar to the two sparrow species sampled at this site, that is amphipods (Talitridae), leafhoppers (Cicadellidae), and katydids (Tettigoniidae) from transect T1 and horse fly larvae (Tabanidae) and the long-jawed spider (Tetragnathidae) at transect T2. The $\delta^{34}S$ for the long-jawed spider matched well with the sulfur signatures for the red-wings, but the available sulfur signatures for other possible prey did not match as well. The SIAR mixing model identified the long-jawed spider as contributing 17 – 22% of the diet of the hatch year red-wings from the northeast sample. Low to no contribution was predicted by the mixing model for the other possible prey taxa.

Using the Virginia rail and invertebrate $\delta^{13}C$ and $\delta^{15}N$ signatures as a guide, possible rail prey include amphipods (Talitridae), katydids (Tettigonidae) from transect T1, and horsefly larvae (Diptera) and the long-jawed spider (Tetragnathidae) from transect T2. The $\delta^{34}S$ ratio for amphipods and katydids matched well with that of the rails and the $\delta^{34}S$ signatures of rails and long-jawed spiders were in the same general range. All of these prey taxa are reported to contribute to the diet of rails in the summer (Conway 1995). However, the mixing model did not predict that any of these taxa individually contributed more than 10% to the rail diet. Virginia rails were sampled primarily in the southeast region of Mendall East. The one adult sampled in the northeast had heavier $\delta^{13}C$ and $\delta^{15}N$ signatures relative to the rails from the southeast.

In summary, at Mendall Marsh-East the stable isotope signatures suggested all four bird species shared a similar diet that may have included amphipods (Talitridae), katydids (Tettigoniidae), leafhoppers (Cicadellidae), and horsefly larvae (Tabanid). In addition, long-jawed spiders (Tetragnathidae) likely contributed to the diet of red-winged blackbirds and Virginia rails.



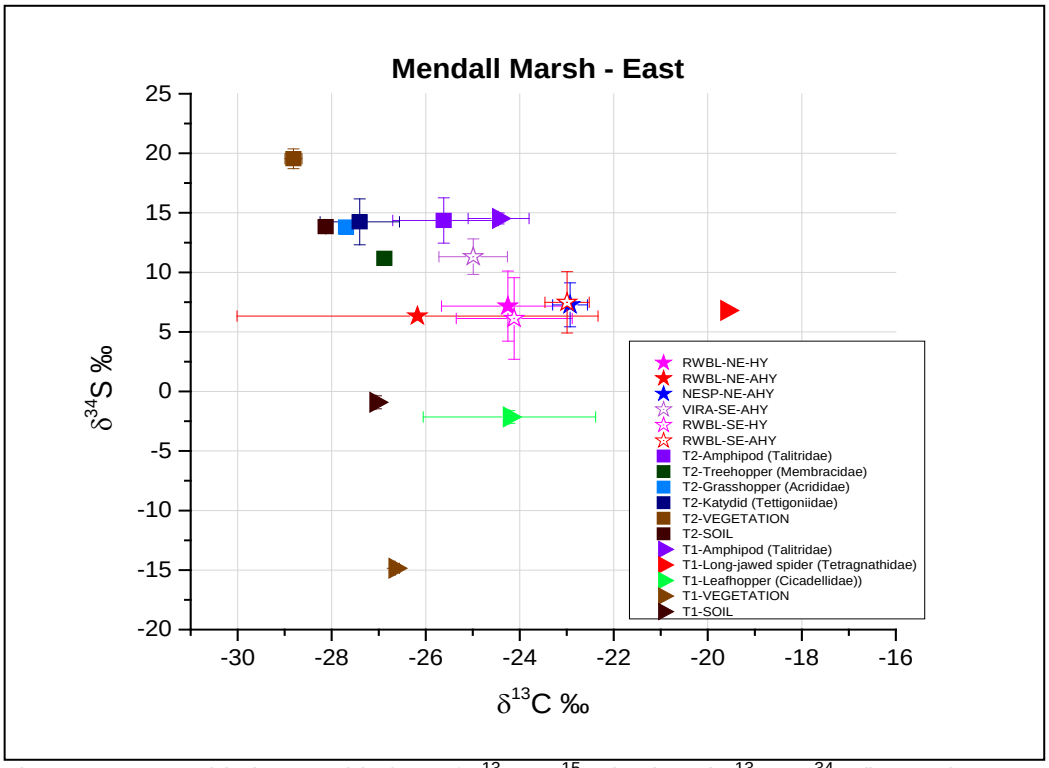




Figure 16-29. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top) and $\delta^{13}C$ v $\delta^{34}S$ (bottom) for samples collected at Mendall Marsh-East. Both adult (AHY) and hatch year (HY) birds were sampled at two sample areas, northeast (NE) and southeast (SE). Invertebrates were sampled at two sites, transect 1 (T1), at the water's edge, and transect 2 (T2) in the marsh interior.

### 8.3.1 Mercury in the Food Web of Mendall Marsh – East

Total Hg concentrations in bird blood were again roughly 10 times higher than methyl Hg concentrations in marsh invertebrates (Figure 16-30). The methyl Hg concentrations in invertebrates identified as prey of marsh birds ranged from 0.02 µg/g wet. wt. in katydids to 0.34 µg/g wet. wt. in long-jawed spiders sampled at transect 2. Horsefly larvae had notably lower concentrations at Mendall East, 0.2 µg/g wet. wt., than found in the adult horse flies at Mendall West (0.5 to 0.85 µg/g wet. wt.). The lowest Hg concentrations in bird blood at Mendall East, from 0.8 to 1.5 µg/g wet. wt., were found primarily in the hatch year birds; red-winged blackbirds, Virgina rail and swamp sparrow. In these recently fledged birds, the combined effects of rapid somatic growth and feather growth would act to lower blood Hg concentrations, assuming a constant dietary exposure. One adult bird, a Virginia rail from the northeast sample area also had a relatively low blood Hg concentration. The other adult birds had greater mean blood Hg concentrations, from 3 to 5.9 µg/g wet. wt..

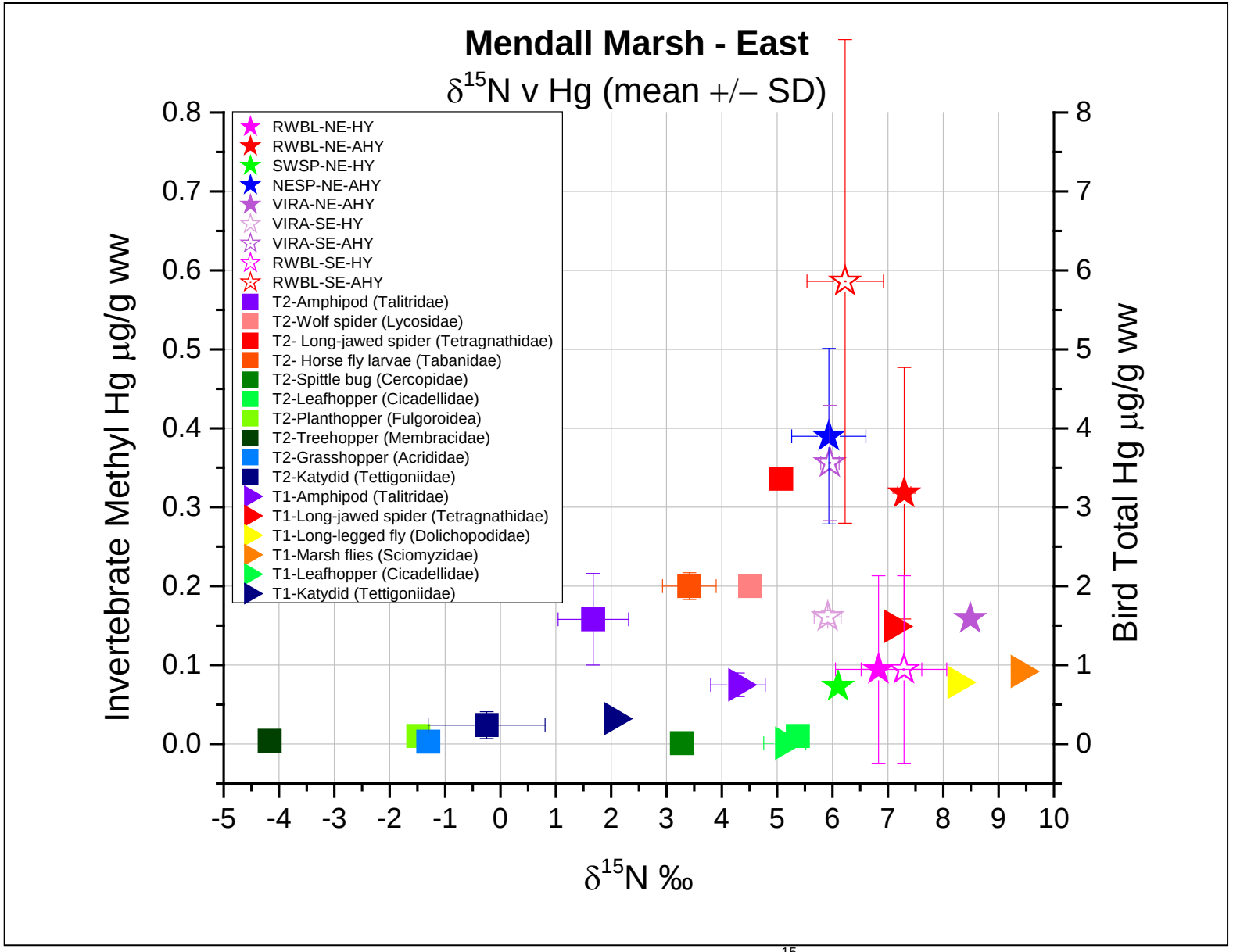



Figure 16-30. Hg concentrations in birds and possible invertebrate prey compared to their $\delta^{15}N$ signatures at Mendall Marsh – East. Concentrations in the marsh birds were roughly ten times greater than in the possible invertebrate prey.

## 8.4 W17

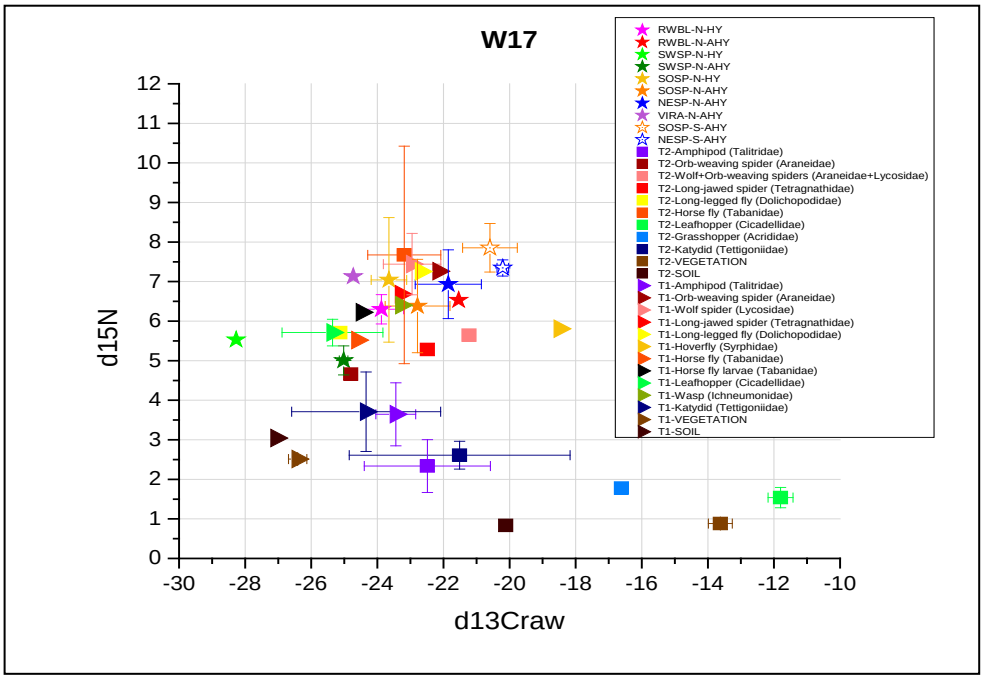
W17 North and South, are two sections of a small pocket marsh on the west shore of the Penobscot River just south of the town of Winterport. (Figure 16-2) Four species of birds were sampled there in mid-July of 2009 and Virginia rails were sampled a few weeks earlier on June 22nd. Invertebrates were sampled three to six weeks later on August 4th, at two transects in the northern area of W17.

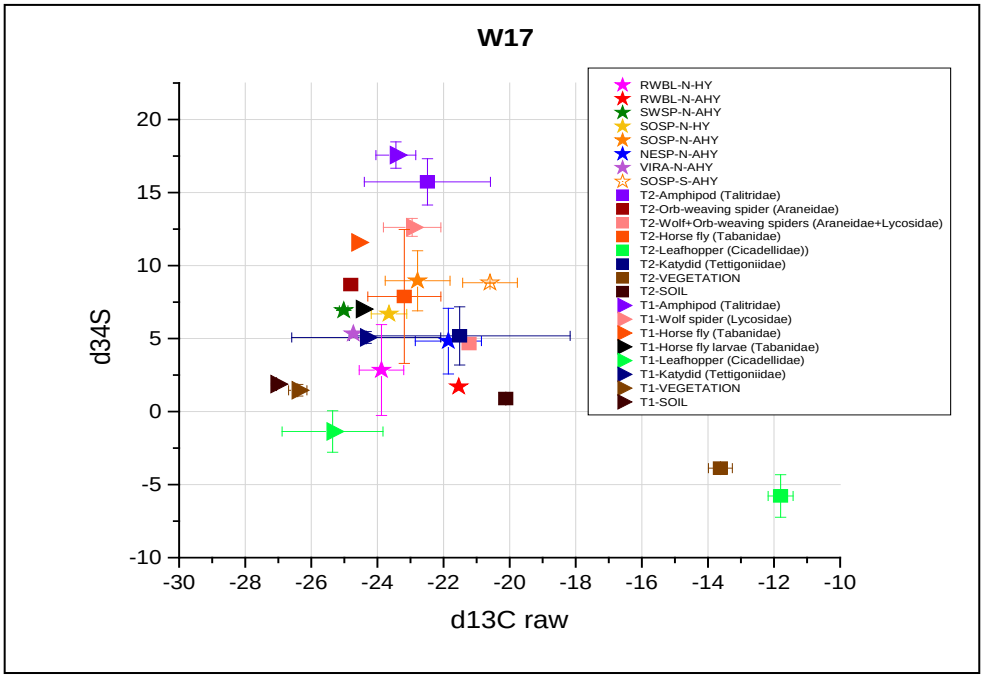
The $\delta^{13}$C signatures from the birds were in the same range as the $\delta^{13}$C values from most of the invertebrates from both transects. However, two taxa, grasshoppers (Acrididae; -17‰) and leafhoppers (Cicadellidae; -12‰ ) sampled in transect 2, were unlikely prey as their $\delta^{13}$C values were much heavier than found in any of the birds sampled. And, except for amphipods (Talitridae) and katydids (Tettigoniidae), many of the invertebrates sampled at transect 1 on the outer edge of the marsh, had $\delta^{15}$N signatures equal to or greater than found in the birds, making it unlikely that many of those invertebrates from transect 1 were eaten by the birds (Figure 16-31).

Several spider taxa including long-jawed spiders (Tetragnathidae) and a mixed composite sample of orb-weaving (Araneidae) and wolf spiders (Lycosidae) form transect T2, had appropriate $\delta^{13}$C and $\delta^{15}$N values to be part of the diet of the Nelson's sparrow. And, the $\delta^{34}$S ratio for the wolf and orb-weaving spiders was the same as found in the Nelson's (5‰), further evidence that the Nelson's ate those spiders. Amphipods (Talitridae) and katydids (Tettigoniidae) from transect T2 were also possible prey, based on $\delta^{13}$C and $\delta^{15}$N ratios, but only the katydids had a good match with the Nelson's for the $\delta^{34}$S ratio. The mixing model did not predict that any of the spiders or amphipods contributed to the Nelson's diet. Most Nelson's sparrows were sampled at W17-North and found to have slightly lighter $\delta^{13}$C values (-22‰) than in Nelson's sampled at W17-South (-20‰).

The adult swamp sparrow diet at W17 likely included katydids (Tettigonidae). The $\delta^{13}$C signatures suggest that the orb-weaving spider (Araneidae) sampled in the marsh interior at transect 2 and katydids from transect 1 are both possible prey. The $\delta^{34}$S ratios for the orb-weaving spider and the katydids matched well with that of the swamp sparrows. However, the $\delta^{15}$N ratio for the spider was too similar to that of the swamp sparrow for the spider to be a significant part of the sparrow's diet, while the $\delta^{15}$N signature for the katydid was appropriately lighter to be a prey item for the sparrow. Adult swamp sparrows sampled at W17 had the lightest $\delta^{15}$N signature found for any bird species sampled at this site, 5‰. Their mean $\delta^{13}$C ratio, -25‰ was also relatively light. Lighter still was the $\delta^{13}$C ratio for the one hatch year swamp sparrow sampled there.

Figure 16-31. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top) and $\delta^{13}C$ v $\delta^{34}S$ (bottom) for samples collected at W17-North and W17-South. Both adult (AHY) and hatch year (HY) birds were sampled at the northern sample area. Invertebrates were sampled at two sites, transect 1 (T1), at the water's edge, and transect 2 (T2) in the marsh interior.



Carbon and nitrogen isotopic signatures for adult and hatch year song sparrows from W17-N identify several possible prey taxa including amphipods, katydids (Tettigonidae), and long-jawed spiders (Tetragnathidae). The katydids and long-jawed spiders also had appropriate $\delta^{34}S$ signatures, but the sulfur ratio for amphipods was much greater than for the song sparrows, making them unlikely prey. The song sparrows sampled at W17-South had heavier $\delta^{13}C$ and $\delta^{15}N$ ratios than those sampled at the adjacent northern site, but equivalent $\delta^{34}S$ ratios, and far fewer prey options. This suggests limited foraging exchange between the two sites for this species.

Based on $\delta^{13}C$ signatures, flies (Dolichopodidae and Tabanidae), leafhoppers (Cicadellidae) from T1, orb-weaving spiders (Araneidae), katydids (Tettigoniidae), and amphipods (Tettigonidae) are all possible prey taxa to the hatch year red-wing blackbirds. The small trophic enrichment for $\delta^{15}N$ of 1‰ between the birds and the flies and leafhoppers probably eliminates those taxa from the diet. The orb-weaving spiders, katydids and amphipods have appropriate $\delta^{15}N$ signatures, but the $\delta^{34}S$ ratio for amphipods was much too high to be considered red-wing prey. The one adult red-winged blackbird sampled at W17 had a heavier $\delta^{13}C$ ratio than the hatch-year birds, possibly indicating dissimilar diets. The mixing model did not identify any dominate prey taxa.

One Virginia rail was sampled at W17. The bird had a relatively heavy $\delta^{15}N$ value, 7‰, and based on the bird's $\delta^{13}C$ ratio, possible prey included the long-legged fly (Dolichopodidae) and the orb-weaving spider (Araneidae)from transect 2, and the leafhoppers (Cicadellidae) and horseflies (Tabanidae) from transect 1

In summary, the isotopic evidence suggests that the birds at W17 share numerous prey taxa. Several spider taxa and katydids (Tettigonidae) appeared to be part of the diet of Nelson's sparrows, song sparrows, and red-winged blackbirds. In addition, red-winged blackbirds and Virginia rails included leafhoppers (Cicadellidae) and horseflies (Tabanidae) in their diet. The diet of swamp sparrows may have included katydids.

### 8.4.1 Mercury in the Food Web of W17

As found at the other marshes along the lower Penobscot River, the concentration of total Hg in bird blood at W17 was approximately 10 times greater than the concentration of methyl Hg in invertebrates sampled from the same marsh (Figure 16-39). Adult horse flies had the greatest methyl Hg concentrations of any invertebrate, from 0.7 to 1.2 µg/g wet. wt., with lower methyl Hg in a horse fly larvae, 0.3 µg/g wet. wt.. Katydids, at 0.04 µg/g wet. wt., were again at the low end of the range of methyl Hg concentrations in invertebrates possibly eaten by the birds. Horse flies from transect 2, at 1.2 µg/g wet. wt., had the greatest methyl Hg concentration.

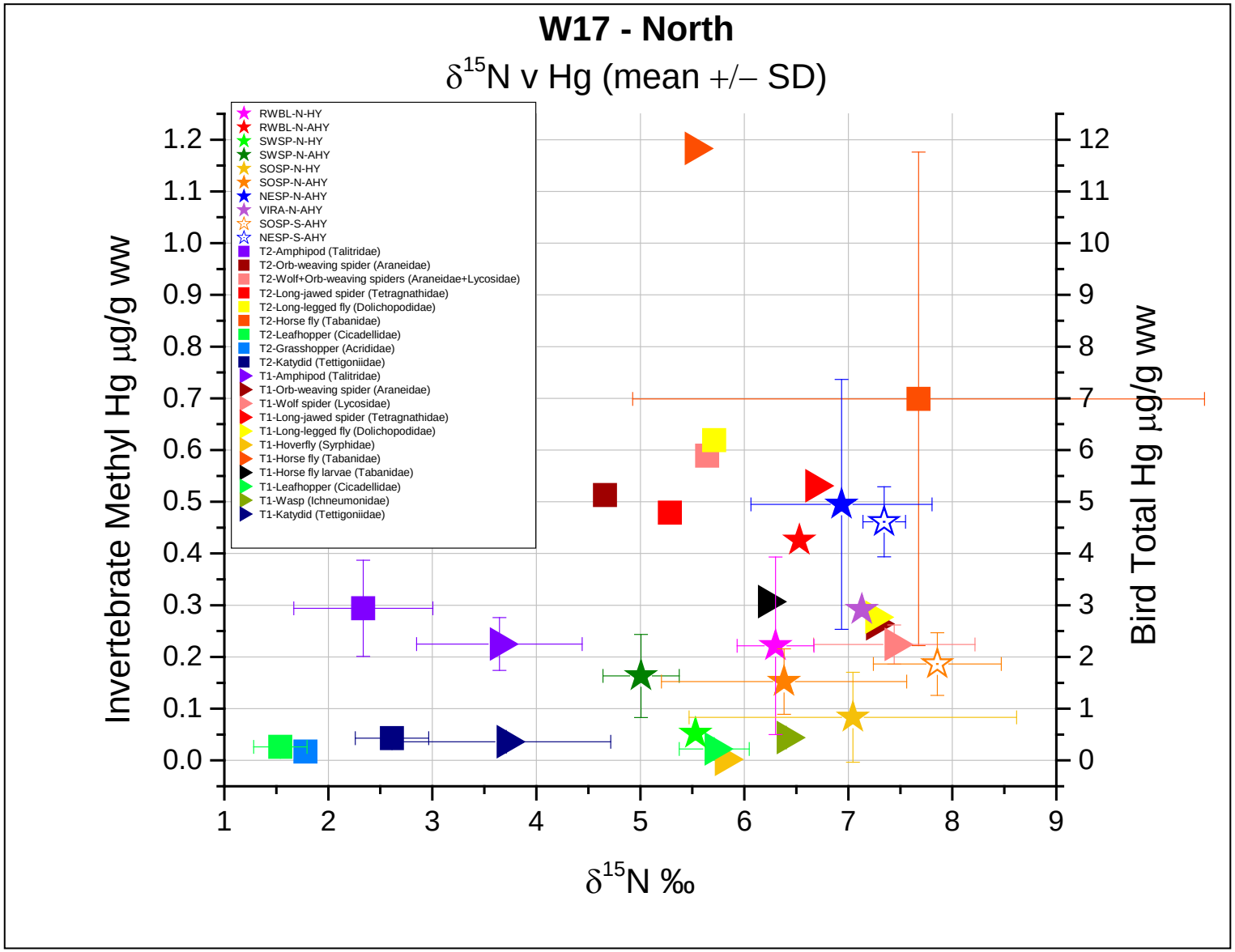



Figure 16-32. Mercury concentrations in birds and possible invertebrate prey compared to their $\delta^{15}N$ signatures at W17-North. Concentrations in the marsh birds were roughly ten times greater than in the possible invertebrate prey.

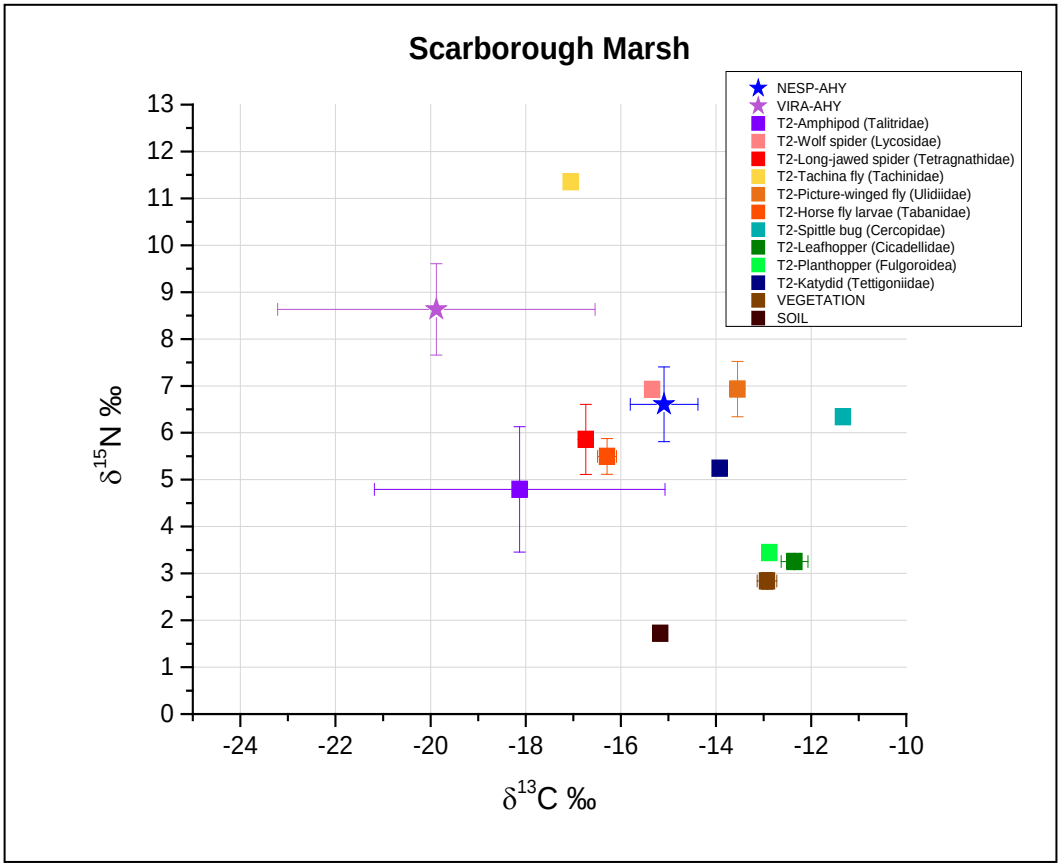
Total Hg in the blood of hatch year song and swamp sparrows, less than 1 µg/g wet. wt., were only slightly lower than for the adults of those species. The hatch year red-wings had a greater mean total Hg at 2.2 µg/g wet. wt., similar to the adult Virginia rail at 3 µg/g wet. wt.. Nelson's sparrow had the greatest mean blood Hg concentration at almost 5 µg/g wet. wt., slightly greater than found for the adult red-wings.

## 8.5 Scarborough Marsh

In 2009, two bird species, Nelson's sparrow and Virginia rail, were sampled at the reference site of Scarborough Marsh for comparison with possible prey invertebrates from one transect,T2, in the interior of the marsh. Virginia rails were sampled in mid-July (7/7-23/2009), Nelson's sparrows were sampled during the first week of August (8/4-6/2009), and invertebrates were collected on August 18th.

The $\delta^{13}C$ signature for Nelson's sparrows sampled at Scarborough Marsh were notably heavier, with a mean of -15‰ (Figure 16-33), relative to the $\delta^{13}C$ ratios found at sites along the lower Penobscot (-23‰ to -20‰). This reflects a shift in the entire food web, as the $\delta^{13}C$ signature for amphipods, near the base of the food web, increased by 4 to 8‰, to -18‰ at Scarborough Marsh. Several possible prey taxa were sampled though none had ideal ratios to be prey of the sparrows. The long-jawed spider (Tetragnathidae), horse-fly larvae (Tabanidae), and katydid (Tettigonidae) were possible contributors to the Nelson's diet, based on $\delta^{13}C$ and $\delta^{15}N$ signatures. Comparing the $\delta^{34}S$ ratios, the long-jawed spider was a good match to the Nelson's. Virginia rails had little agreement in stable isotope signatures between this species and possible prey taxa. Using the $\delta^{13}C$ and $\delta^{15}N$ ratios, amphipods (Talitridae) were the only likely taxa contributing to the rail diet, yet the amphipod and rail sulfur signatures were not in agreement. Still, the mixing model predicted that amphipods contributed 27 to 36 % to the rail diet.

In summary, based on the stable isotope signatures, and the available invertebrate data set collected at Scarborough Marsh, possible prey for the Nelson's sparrow included the long-jawed spider (Tetragnathidae), and the katydid (Tettigoniidae). Amphipods were possible prey to Virginia rails foraging at Scarborough Marsh.



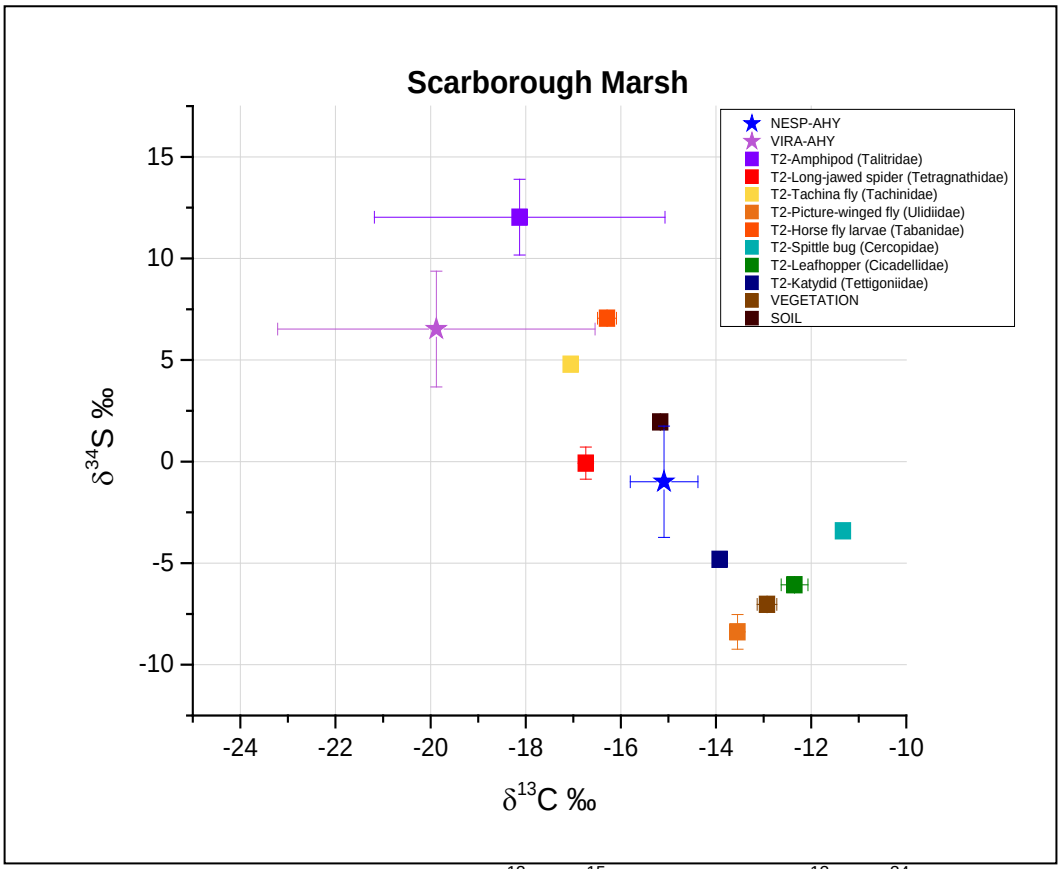




Figure 16-33. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for bird and invertebrate samples collected at the reference site of Scarborough Marsh. Invertebrates were sampled at one site, transect 2 (T2) in the marsh interior.

### 8.5.1 Mercury in the Food Web of Scarborough Marsh

Hg concentrations in the food web at the Scarborough Marsh reference site had the same relationship between Hg in marsh invertebrates and Hg in bird blood as found at the marshes along the lower Penobscot River. Whole body methyl Hg concentrations in invertebrate prey were ten times lower at Scarborough Marsh than at marshes along the lower Penobscot, ranging from planthoppers at 0.005 µg/g wet. wt. to long-jawed spiders at 0.035 µg/g wet. wt. (Figure 16-34). Total Hg concentrations in bird blood were similarly lower, between 0.16 µg/g wet. wt. for Virginia rails to 0.78 µg/g wet. wt. for Nelson's sparrows.

This consistent relationship in food web Hg concentrations at all four marshes studied gives direct evidence of the link between methyl Hg accumulation in marsh birds and the methyl Hg levels in their invertebrate prey.

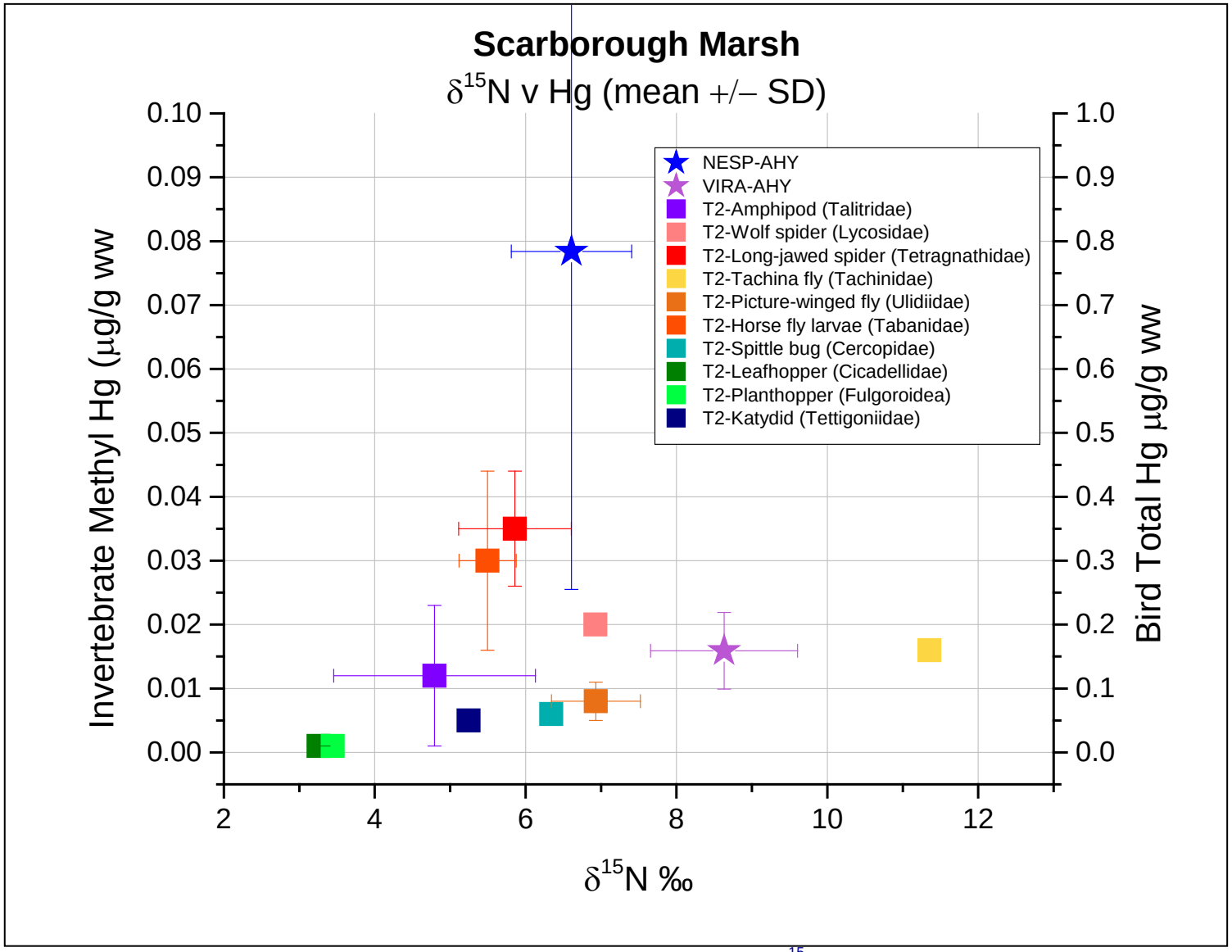



Figure 16-34. Hg concentrations in birds and possible invertebrate prey compared to their $\delta^{15}N$ signatures at Scarborough Marsh. Concentrations in the marsh birds were roughly ten times greater than in the possible invertebrate prey.

# 9 TROPHIC LEVEL of WETLAND BIRDS

In this section we compare the estimated trophic position of each target bird species to the total Hg concentration in their blood. Hg, in the form of methyl Hg, biomagnifies with trophic position and therefore is highest in birds that are top predators. Geographic differences in Hg accumulation in bird blood could be due to differences in the trophic position of birds and not to differences in exposure concentrations at distant sites. The relationship between trophic position and Hg accumulation answers whether geographic patterns of Hg accumulation in birds are due to variable Hg exposure or variable trophic positions at those sites.

The concentrations of both Hg and stable isotopes in bird blood primarily reflect local exposure through diet if the birds have been resident for four to seven weeks (Ackerman et al. 2008; Eagles-Smith et al. 2009; McKinnon et al. 2012). With shorter residence times, the blood concentrations are expected to reflect exposure at areas previously occupied, with some influence from local exposure. This factor is important in migratory birds, including all marsh birds examined in this food web study, that arrive at their Penobscot breeding sites from areas with different Hg concentrations and stable isotope signatures.

## 9.1 Nelson's Sparrow

There was no correlation between trophic position and Hg accumulation in blood for the Nelson's sparrow (Figure 16-35). A mean trophic position for Nelson's of 3 trophic units was found in birds from W17-North, which had the highest mean blood Hg concentration of 5 µg/g (2009), and also in the birds sampled at the reference site of Scarborough Marsh, where mean blood Hg concentrations were among the lowest found, 0.8 µg/g wet. wt. (Figure 16-35). The greatest trophic levels were found in birds sampled at the Southwest and Jetti sites of Mendall Marsh in 2009, 4.1 and 4.4 trophic units, respectively. Total Hg concentrations at those sites were relatively moderate in 2009, at 3.2 µg/g wet. wt.. In contrast, birds sampled at Mendall Marsh–Southeast in 2008 had the lowest estimated trophic position, 1.8 trophic units, but also moderate Hg concentrations, 3.2 µg/g wet. wt..

At two sites, Nelson's sparrows were analyzed for stable isotopes and Hg in both 2008 and 2009. At both sites, W17-North and Mendall Marsh-Northeast, there was little difference in Hg concentrations or trophic position between the years sampled.

Both adult and hatch year chicks, recently fledged, were sampled at the Mendall Marsh-Northeast site. While adults had a slightly lower trophic position, 3.1 compared to 3.6 trophic units for the hatch year chick, Hg in the adults, 4.4 µg/g wet. wt., was much greater than in the blood of the hatch year bird, 0.6 µg/g wet. wt.. The lower concentration in the recently fledged bird reflects growth dilution and/or lateral transfer of Hg to the growing feathers of the chicks (Becker et al. 1994; Eagles-Smith et al. 2009; Ackerman et al. 2011).

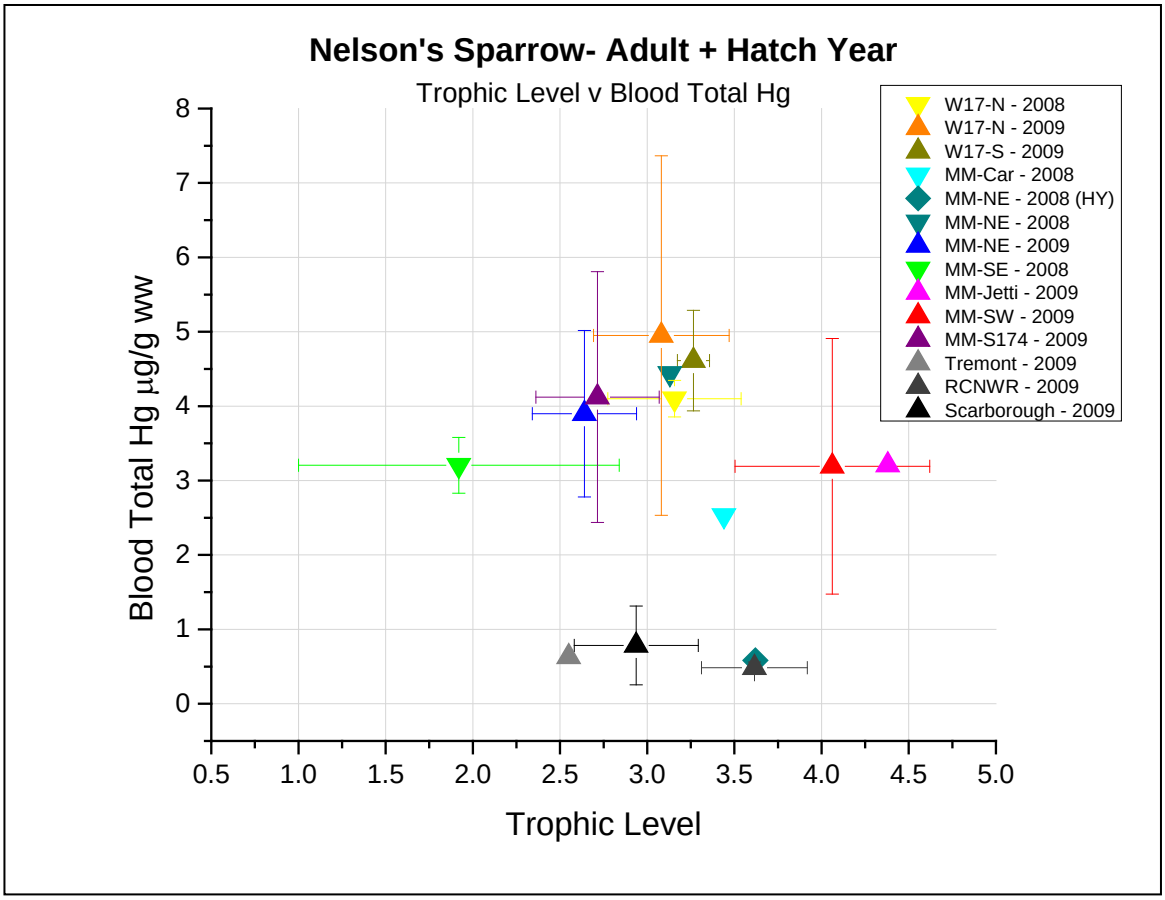



Figure 16-35. Nelson's sparrow trophic level versus mean total Hg in blood. Trophic level and Hg concentrations in blood were not correlated in Nelson's sparrows sampled in 2008 and 2009.

## 9.2 Swamp Sparrow

Swamp sparrows sampled in 2008 and 2009 had no correlation between trophic level and Hg concentrations in blood (Figure 16-36). Hg concentrations were greatest in blood from swamp sparrows from Mendall Marsh-Southwest (3.3 µg/g wet. wt.), yet the trophic position of those birds was below average for this species, at 2.6 trophic units. Adult swamp sparrows at W17-North had the lowest trophic position for this species, 2.2 trophic units, with relatively moderate Hg concentrations, 1.6 µg/g wet. wt.. Conversely, the one swamp sparrow at the reference site of Bass Harbor, on Mt. Desert Island, had a trophic level of 3.5 trophic units, the highest for this species, and a Hg concentration of 1.2 µg/g wet. wt.. Both adult and hatch year birds were sampled at two sites (W17 and Mendall Marsh-South174) but no consistent pattern was found between age class, trophic level or Hg concentration in the blood.

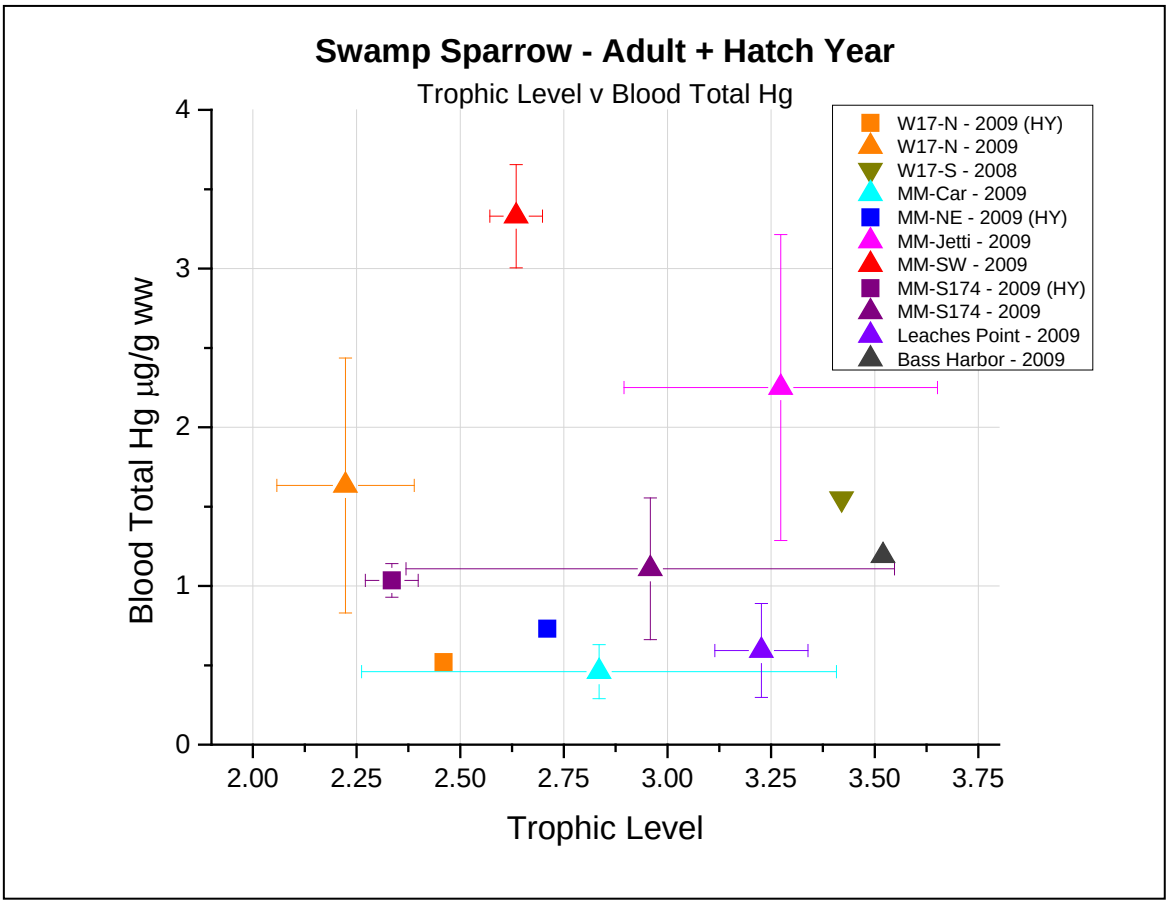



Figure 16-36. Swamp sparrow trophic level versus mean total Hg in blood. Trophic level and Hg concentrations in blood were not correlated in swamp sparrows sampled in 2008 and 2009.

## 9.3 Song Sparrow

As for other songbird species, song sparrows had no correlation between trophic position and Hg concentrations in their blood. (Figure 16-37) Hg levels varied randomly along the entire range of trophic positions found, from 2.3 to 3.8 trophic units. Hatch year birds, recently fledged, were sampled along with adult birds at two sites in 2009. At Bald Hill Cove, hatch year birds fed at 1 trophic unit greater than the adult birds, with little difference in Hg concentrations. At W17-N the hatch year birds had a lower Hg concentration while feeding at a greater trophic level than adults, suggesting both growth dilution in the hatch years and lateral transfer of Hg to their growing feathers.

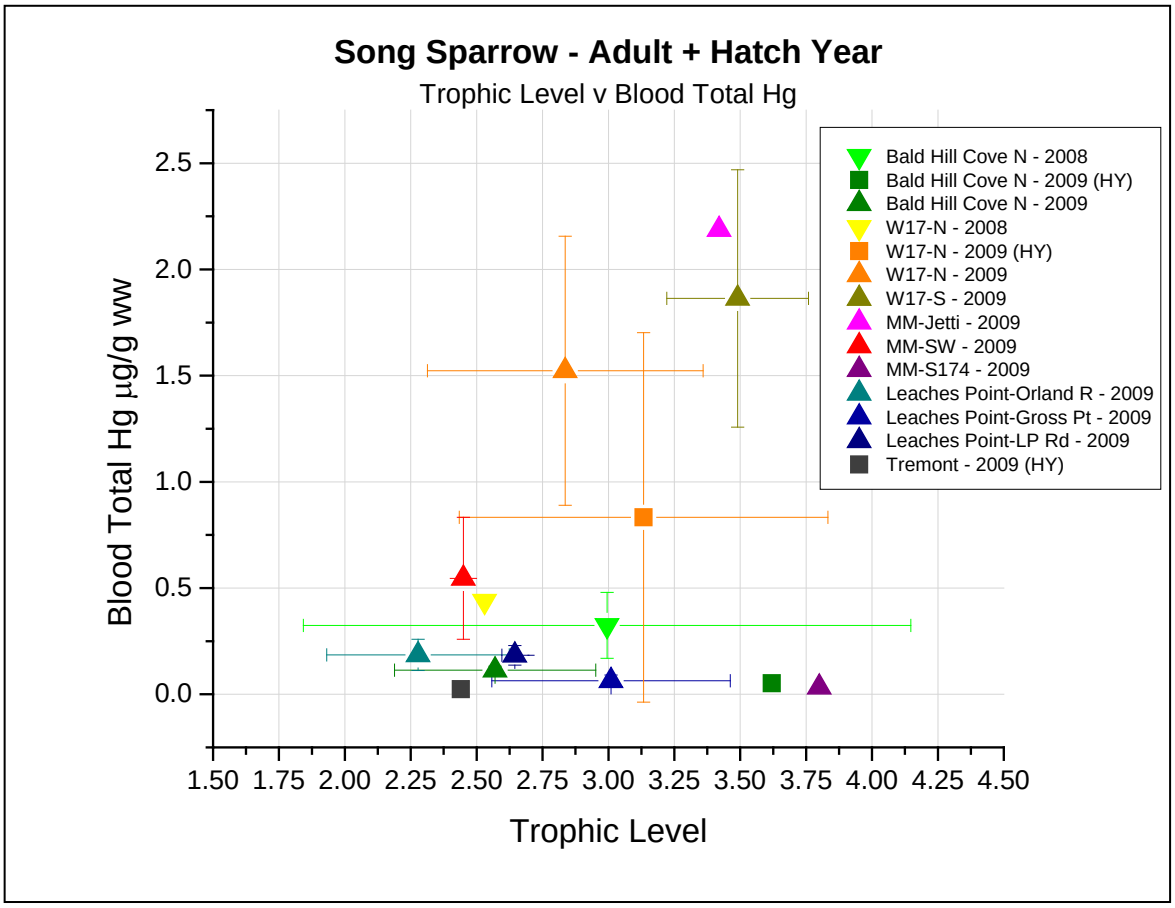



Figure 16-37. Song sparrow trophic level versus mean total Hg in blood. Trophic level and Hg concentrations in blood were not correlated in song sparrows sampled in 2008 and 2009.

## 9.4 Virginia Rails

Virginia rails had no correlation between trophic position and Hg concentrations in blood. Rails foraging at the highest trophic level (3.8 trophic units) were sampled at the Scarborough Marsh reference site (2009), where blood Hg concentrations were lowest for this species, 0.2 µg/g. In contrast, Hg concentrations were at the low end of the range (1.4 µg/g wet. wt.) for rails at the two sites having the lowest trophic position, 2.4 trophic units, Mendall Marsh-Southwest and Southeast in 2008 (Figure 16-38).

Lower Hg concentrations in rails in 2008 may have resulted from late summer sampling dates. At all three sites where rails were sampled in both 2008 and 2009, Hg concentrations were lower in 2008 relative to 2009. Birds were sampled in late June to early July in 2009 and four to five weeks later in early August in 2008. The rails' arrival date to the Penobscot marshes should not have been a factor in their reported Hg concentrations. Given their expected arrival dates (Conway 1995), the 2009 birds had six or more weeks for their blood Hg concentrations to equilibrate to local exposure levels before sampling. However, the later sampling dates in 2008 may have coincided with the late summer molt of primary feathers, the associated lateral transfer of Hg from the circulating blood to the growing feathers, and subsequent reductions in blood Hg concentrations (Braune 1987; Ackerman et al. 2011).

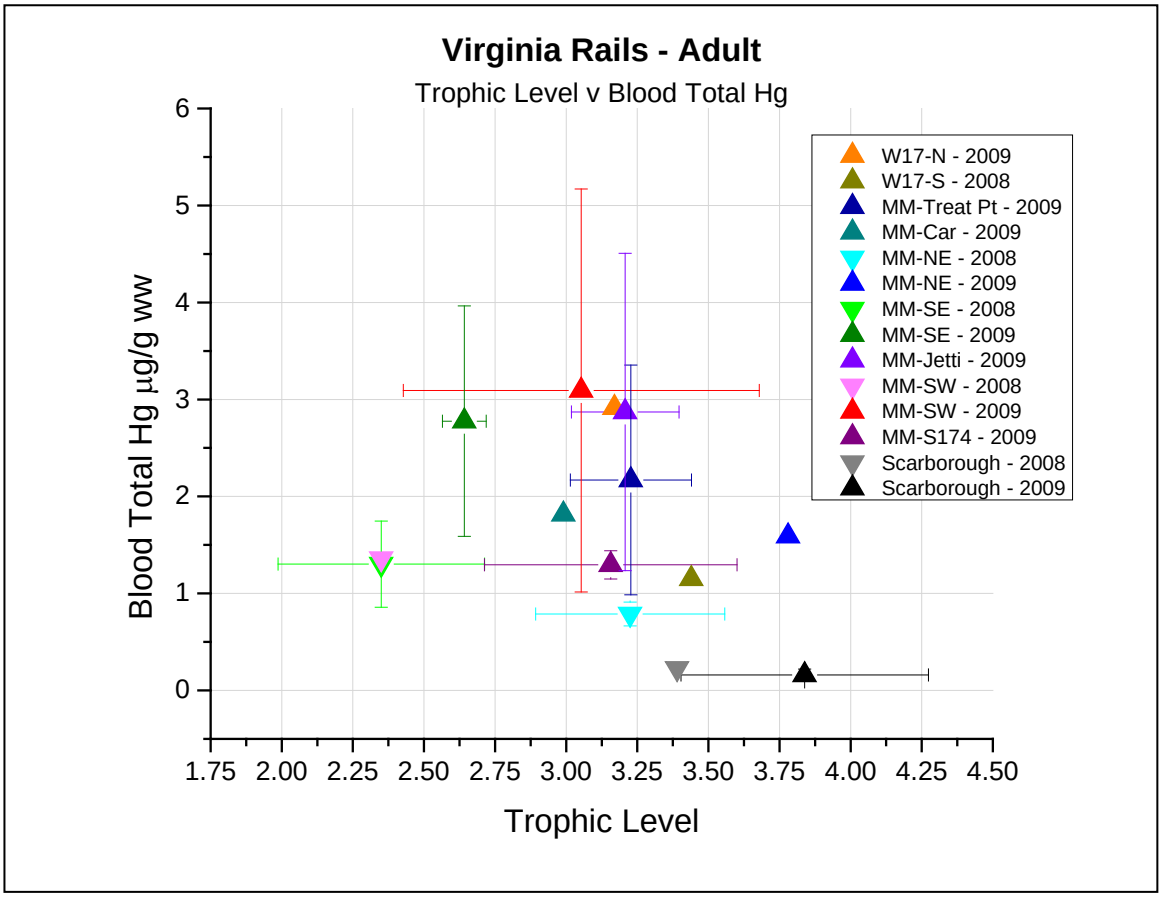



Figure 16-38. Virginia rail trophic level versus mean total Hg in blood. No correlation was found between trophic position and Hg concentrations in blood in Virginia rails. In the Mendall Marsh sites sampled in both 2008 and 2009, the birds sampled in 2009 had greater trophic positions and Hg concentrations relative to those sampled in 2008.

## 9.5 Red-Winged Blackbirds

Hg concentrations in adult red-winged blackbirds varied independently of trophic position. The highest trophic position for this species (3.8 trophic units) was from the reference site of Scarborough Marsh, which also had the lowest Hg concentration (0.1 µg/g wet. wt.; Figure 16-39). The greatest Hg concentrations (mean of 4.3 to 5.9 µg/g wet. wt.) were found in birds from Mendall Marsh and W17, with trophic levels clustered between 2.8 and 3.0 trophic units.

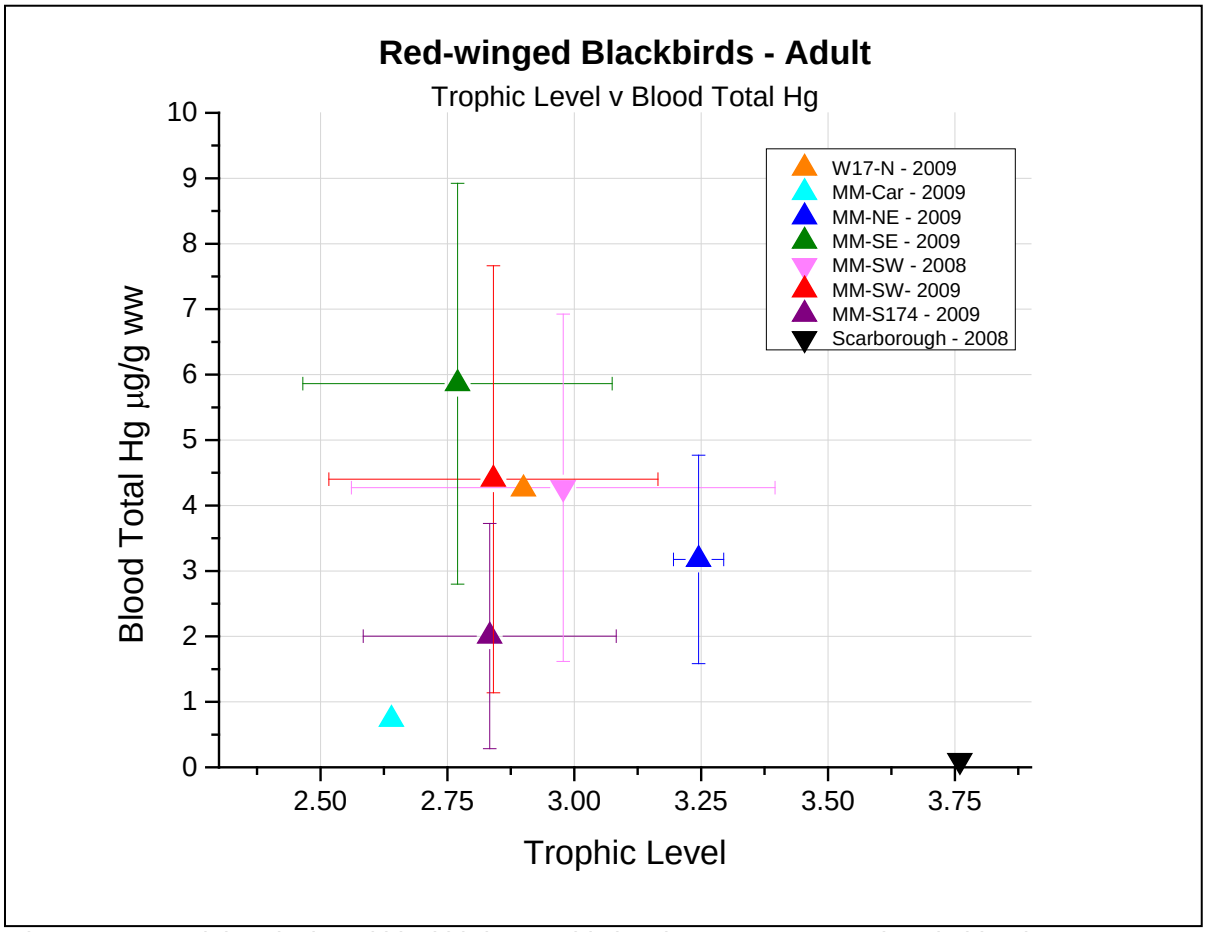



Figure 16-39. Adult red-winged blackbirds - trophic level versus mean total Hg in blood. Hg concentrations in adult red-winged blackbirds did not vary with trophic position.

Results from a large sample of red-winged blackbird hatch years are plotted in Figure 16-40. Most had mean blood Hg concentrations at or below 1.0 µg/g wet. wt. (exception was W17 at ~2 µg/g wet. wt.), and were clustered around a trophic position of 3.0 trophic units (means of 2.75 to 3.25). Hg concentrations in hatch years were consistently lower than found in adult red-wings. Again, this reflects the somatic growth dilution of the Hg body burden and the lateral transfer of Hg into growing feathers. (Eagles-Smith et al. 2009; Ackerman et al. 2011) The trophic levels of adults and hatch year birds were similar within sites and years.

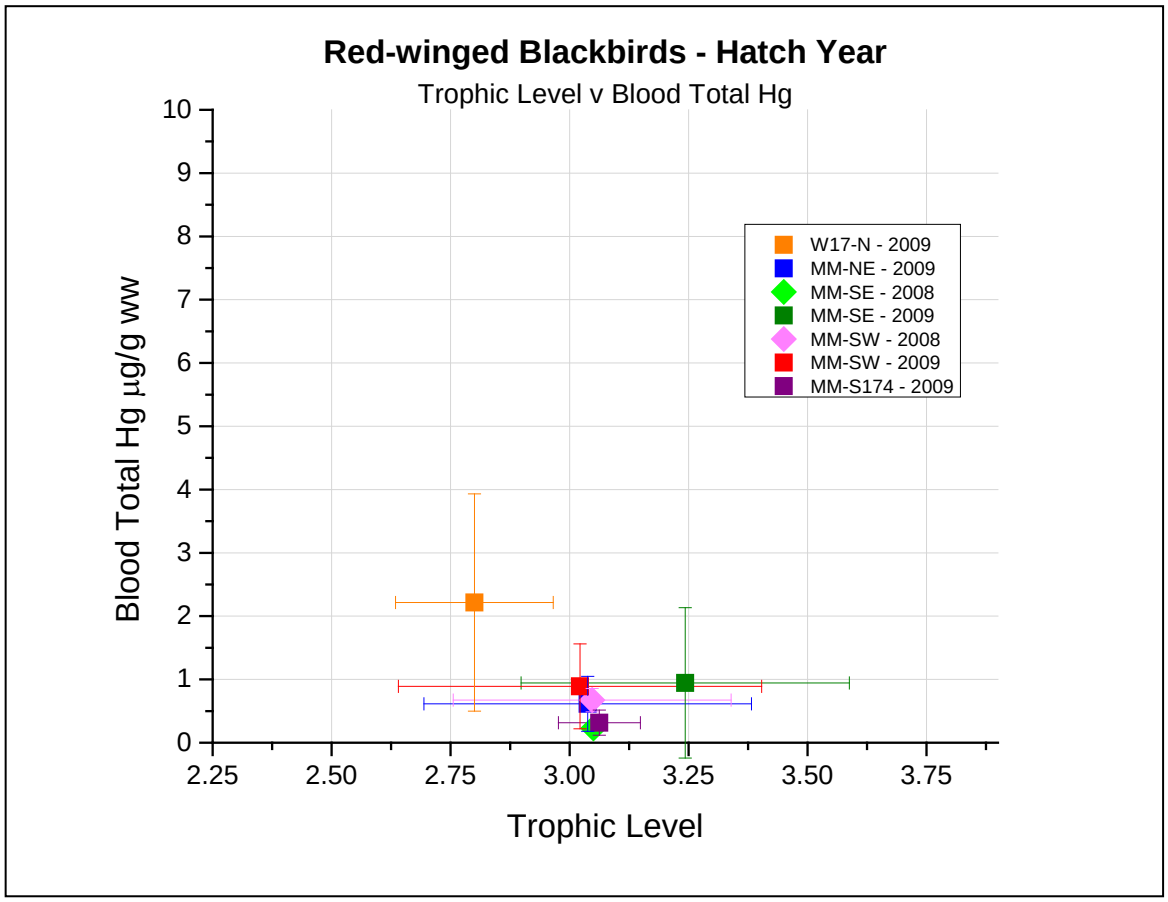



Figure 16-40. Hatch year red-winged blackbirds - trophic level versus mean total Hg in blood. Hg concentrations in the hatch year red-wing blackbirds were consistently lower than found in the adult red-wings from the same site. No correlation was found between trophic level and Hg concentrations in the blood.

# 10 SITE FIDELITY OF TARGET SPECIES WETLAND FOOD WEB

Using stable isotopes to examine site fidelity in the wetland bird species is limited by the close proximity of the sites along the lower Penobscot River (Figure 16-2). If site fidelity is strong within a given species, with limited or no movement among the sites sampled, and the base isotopic signatures vary among sites, we expect to find distinct differences in the isotopic signatures of the biota among those sites.

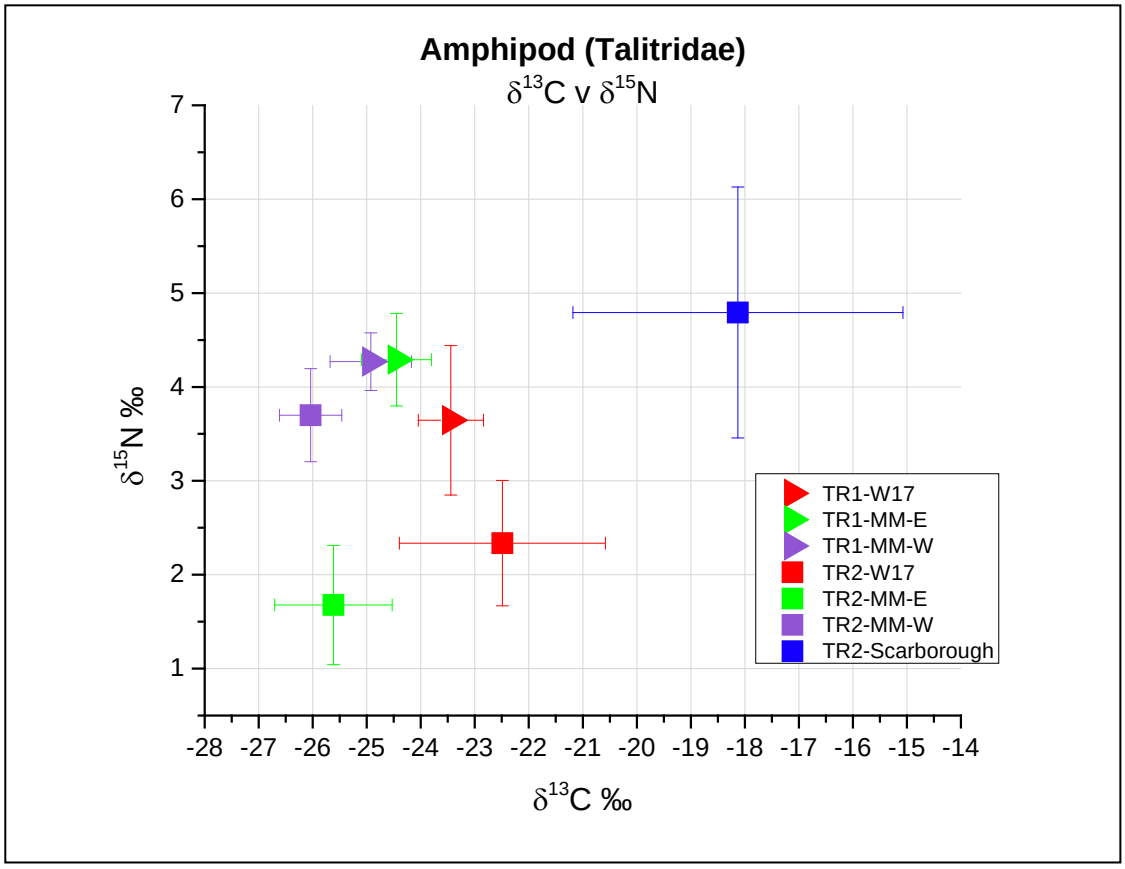
While all three isotopes used in this study become progressively heavier from terrestrial to aquatic environments, and with increases in salinity (Newsome et al. 2007), there was little difference in these factors among the three Penobscot sites. All three marshes are bordered by wooded hills, but drainage from those hills is partially funneled away from the marsh platform by deep tidal sloughs ringing large portions of each marsh. The Mendall Marsh sites, East and West, may have a greater freshwater influence from the Marsh River draining between them, relative to W17 which lies along the Penobscot River. Yet salinity differences are expected to be small as all three sites are within 2 miles of where the Marsh River enters the Penobscot River, and are subject to tidal flooding twice a day. The mouth of the Marsh River is 10 miles upstream of where the Penobscot River enters the bay.

The reference site, Scarborough Marsh, lies 150 miles to the south of the Penobscot, along Maine's outer coast. The sampling site was in the center of the marsh, four miles upstream from the mouth of the Scarborough River.

## 10.1 Marsh Invertebrates along the lower Penobscot River and in Scarborough Marsh

There was some overlap in the isotopic signatures of $\delta^{13}C$ and $\delta^{15}N$ in amphipods (Talitridae) at the three Penobscot sites (Figure 16-41). Samples from transect T1, along the outer shore of the marsh, had relatively greater $\delta^{15}N$ values than found in samples collected at transect T2, in the marsh interior. The $\delta^{13}C$ ratio was notably heavier in amphipods sampled at transect 2 in Scarborough Marsh (-18‰), relative to those sampled along the Penobscot (-26 to -22‰). The $\delta^{34}S$ signatures appeared to be greater at W17 relative to the Mendall Marsh sites, perhaps due to greater marine influence along the mainstem of the Penobscot. These trends are not strong, given the overlap among sites, but heavier isotopic ratios of sulfur, at W17, and nitrogen in samples from transect T1 may indicate a greater marine influence at those sample locations.

The carbon signatures of long-jawed spiders (Tetragnathidae; Figure 16-42) varied widely among sites, except between MME and MMW. Along the Penobscot River $\delta^{13}C$ values ranged between -26 and -20‰, and were again greatest at Scarborough Marsh (-17‰; Figure 16-50). Nitrogen signatures were 1-2‰ greater in spiders sampled at transect T1 relative to transect T2. Sulfur isotopic ratios were 5 to 7 ‰ greater at the Mendall Marsh transect T1 sites relative to spiders collected in the interior of Scarborough Marsh ($\delta^{34}S$ = 0‰).The sharp drop in $\delta^{34}S$ values between the amphipods (12‰) and these spiders (0‰) is notable.



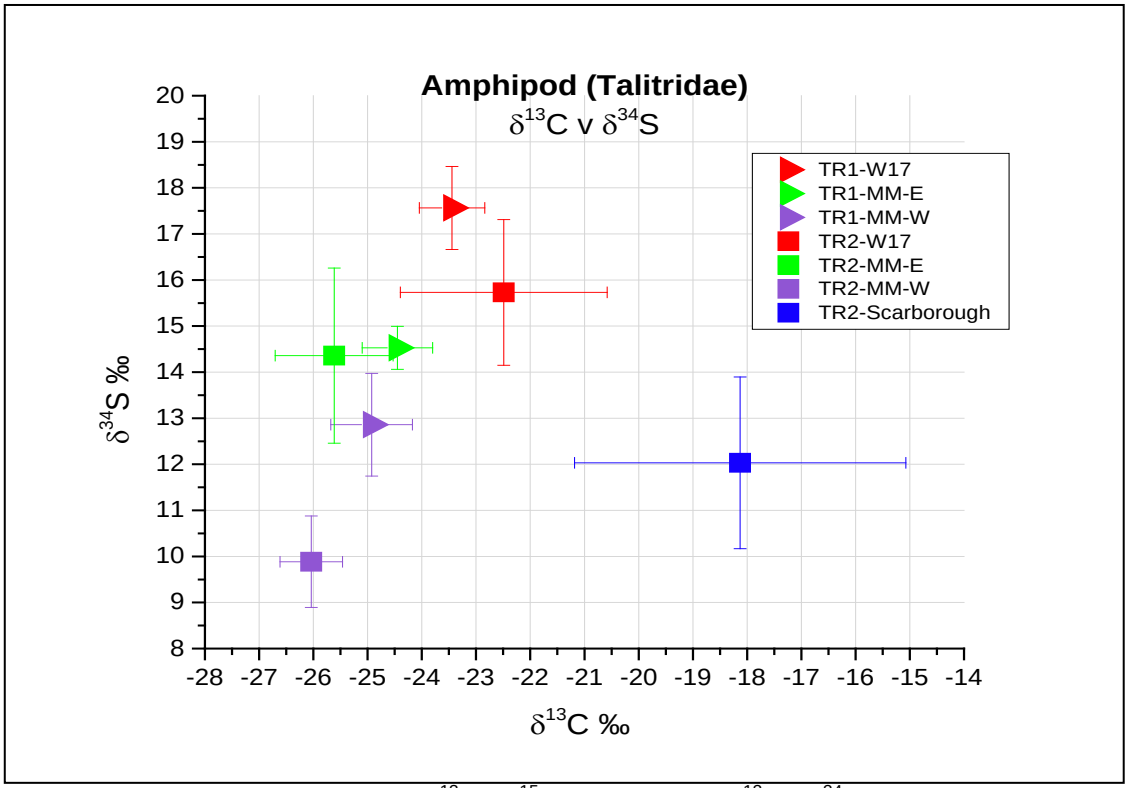
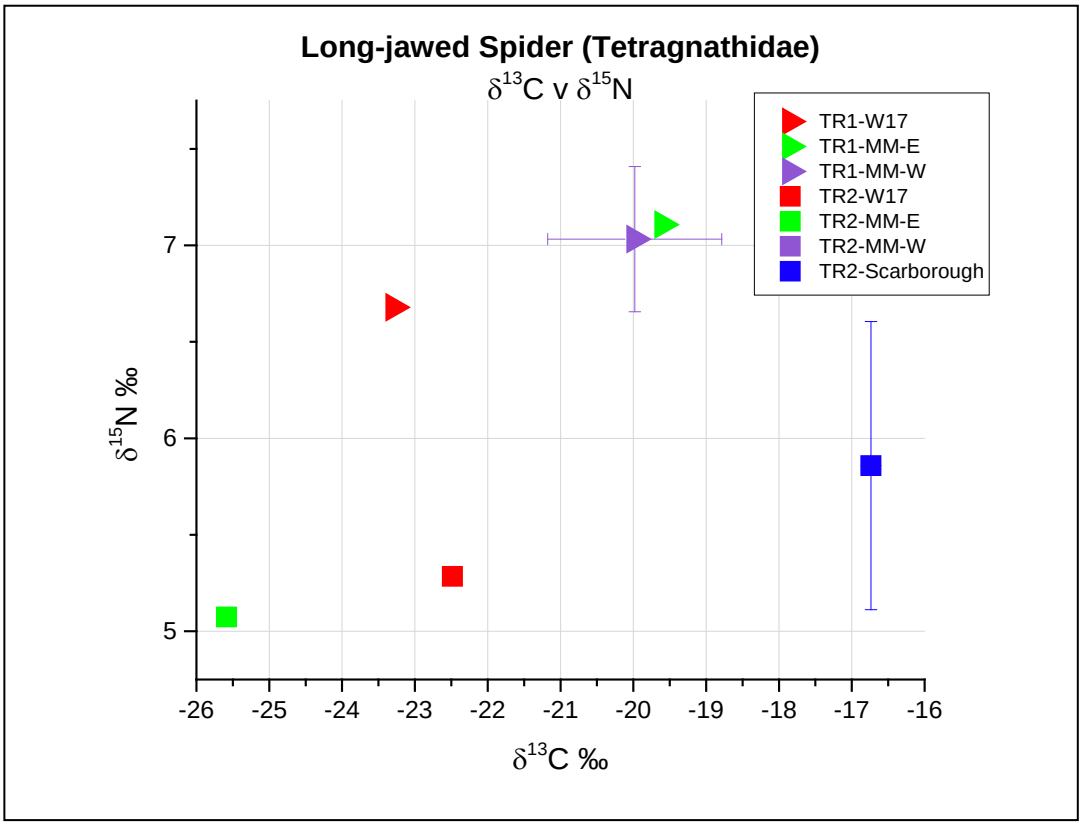




Figure 16-41. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for Amphipods (Talitridae). Invertebrates were sampled at two sites, transect 1 (TR1), at the water's edge, and transect 2 (TR2) in the marsh interior.



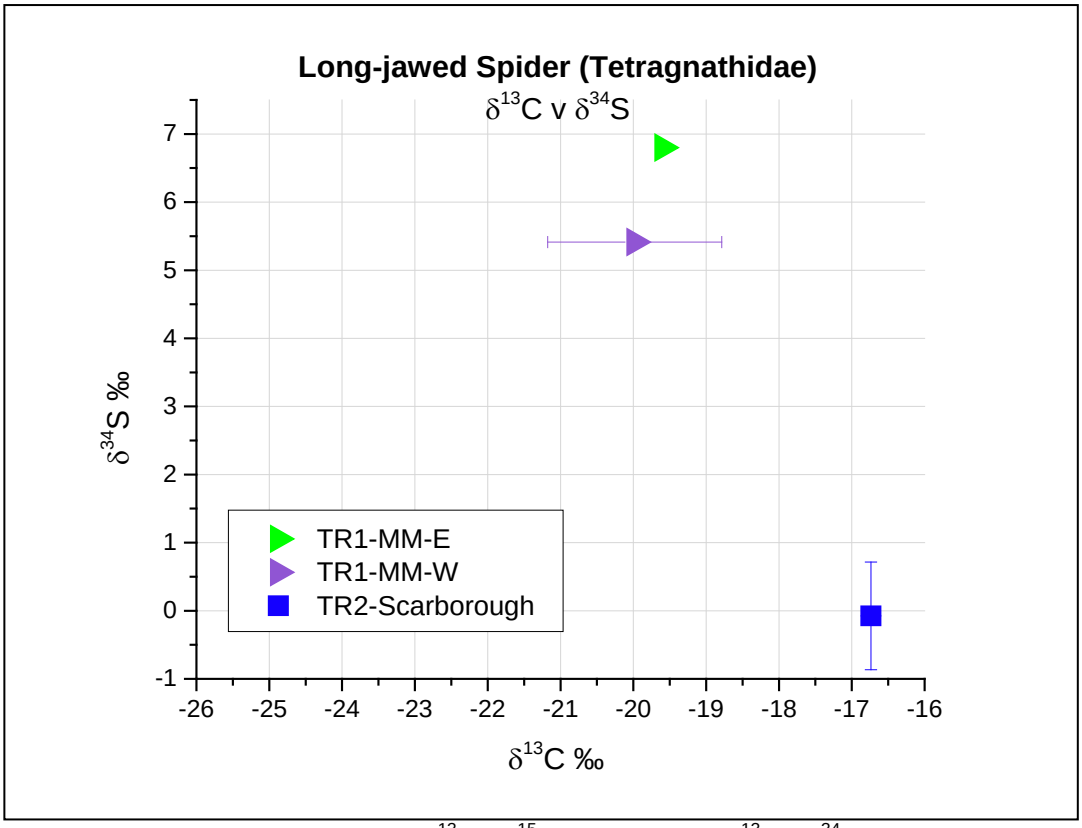




Figure 16-42. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for long-jawed spiders (Tetragnathidae). Invertebrates were sampled at two sites, transect 1 (TR1), at the water's edge, and transect 2 (TR2) in the marsh interior.

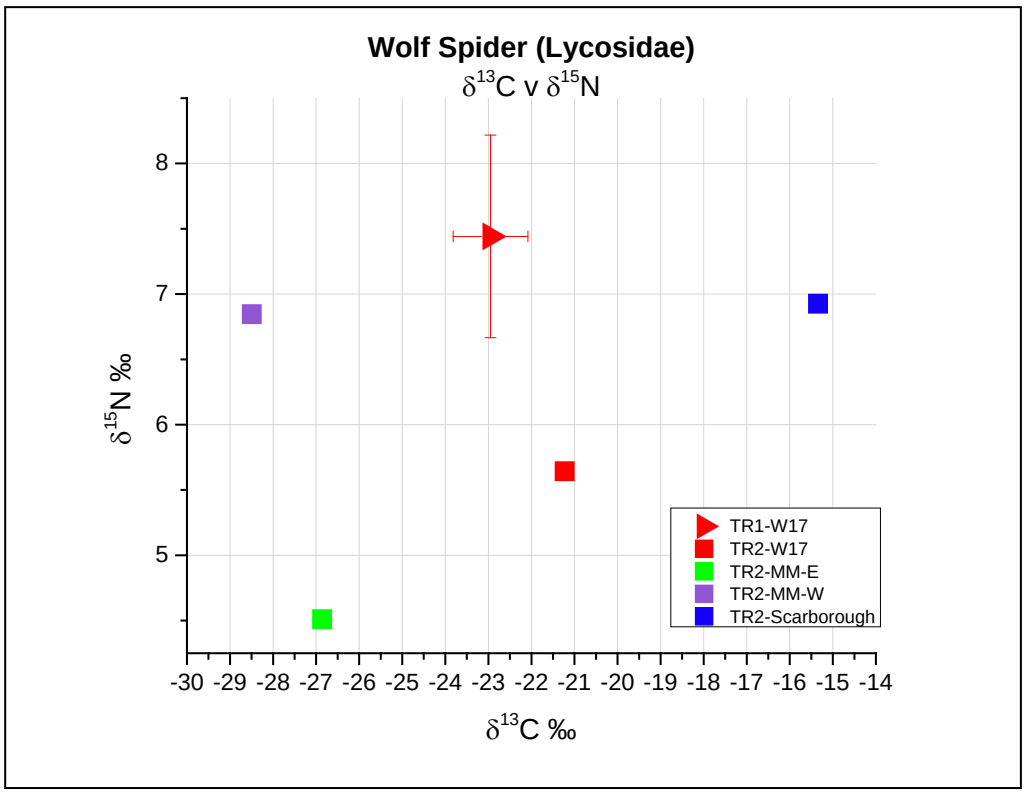
Wolf spiders (Lycosidae) showed a possible trend in carbon signatures among the Penobscot sites, lighter in Mendall Marsh (-29 to -27‰), heavier at W17 (~22‰), possibly due to greater salinity, with the heaviest ratio at Scarborough,15‰ (Figure 16-43). There was no overlap in carbon signatures among the sites, but often only one composite sample was collected at each site. $\delta^{15}$N values ranged from 4.5 to 7.5, with no apparent geographic trend. Sulfur isotopes were run on only three samples, limiting the comparison, but again the heaviest $\delta^{34}$S ratio was at transect 1 (W17, 12.5‰), on the outer edge of the marsh.

The $\delta^{15}$N values for horseflies (Tabanid), adults unless otherwise shown on legend, hovered around 6‰ across most sites (Figure 16-44). Carbon isotopes at the Penobscot sites ranged from -30‰ to -23‰, greatest at the W17 sites, while Scarborough again had the highest $\delta^{13}$C signature at -16‰. Horseflies were sampled at both the outer and interior invertebrate transect at two of the Penobscot sites, and again had greater $\delta^{34}$S values at the outer transect along the water's edge, T1.

Leafhoppers (Cicadellidae) were very similar in carbon (-24 to -28‰) and nitrogen (5 to 6‰) signatures at both Mendall Marsh sites and at the transect 1 site at W17 (Figure 16-45). However, the values for samples collected at transect 2 at both W17 and Scarborough Marsh were unexpectedly alike, both having $\delta^{13}$C values near 12‰, and $\delta^{15}$N values between 1.5 and 3‰. Sulfur signatures were similarly grouped, and uniformly low at all sites (0 to -6‰). There is no obvious explanation for this grouping of all three isotopes.

The isotopic signatures of katydids (Tettigoniidae) varied little by transect, except at MME, as was found in the amphipods and spiders, but samples from Scarborough Marsh again had the greatest ratios for $\delta^{13}$C (-14‰) and $\delta^{15}$N (5‰), and the lowest signature for sulfur (-5‰; Figure 16-46). Within the Penobscot samples there was no consistent trend in isotopic signatures between transects T1 and T2, or between Mendall Marsh and W17.

Samples of vegetation had a similar grouping of stable isotope signatures (Figure 16-47) as did the leafhoppers, which suck plant sap from leaves or stems. Scarborough Marsh and transect T2, in the interior of the marsh, at W17, had the heaviest carbon signature (-13‰) of all sites sampled. Carbon isotopes at the other Penobscot sites ranged from -29 to -24‰. Nitrogen and sulfur isotopes ranged widely, but with no apparent pattern.



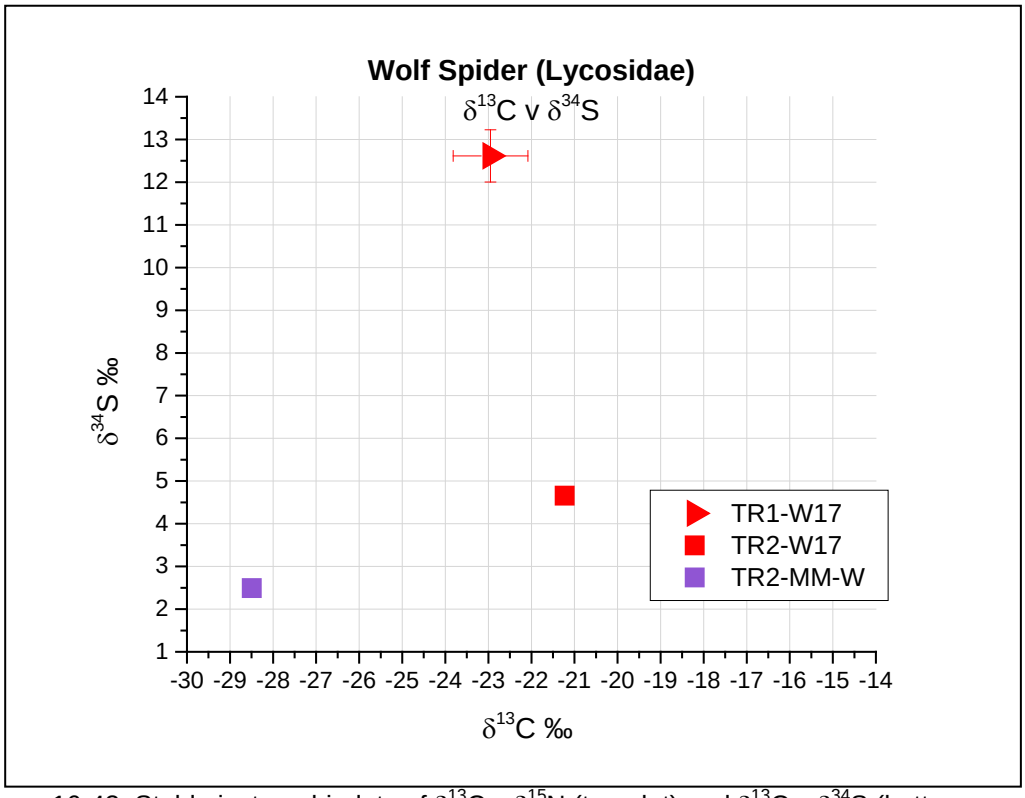




Figure 16-43. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for wolf spiders (Lycosidae). Invertebrates were sampled at two sites, transect 1 (TR1), at the water's edge, and transect 2 (TR2) in the marsh interior.

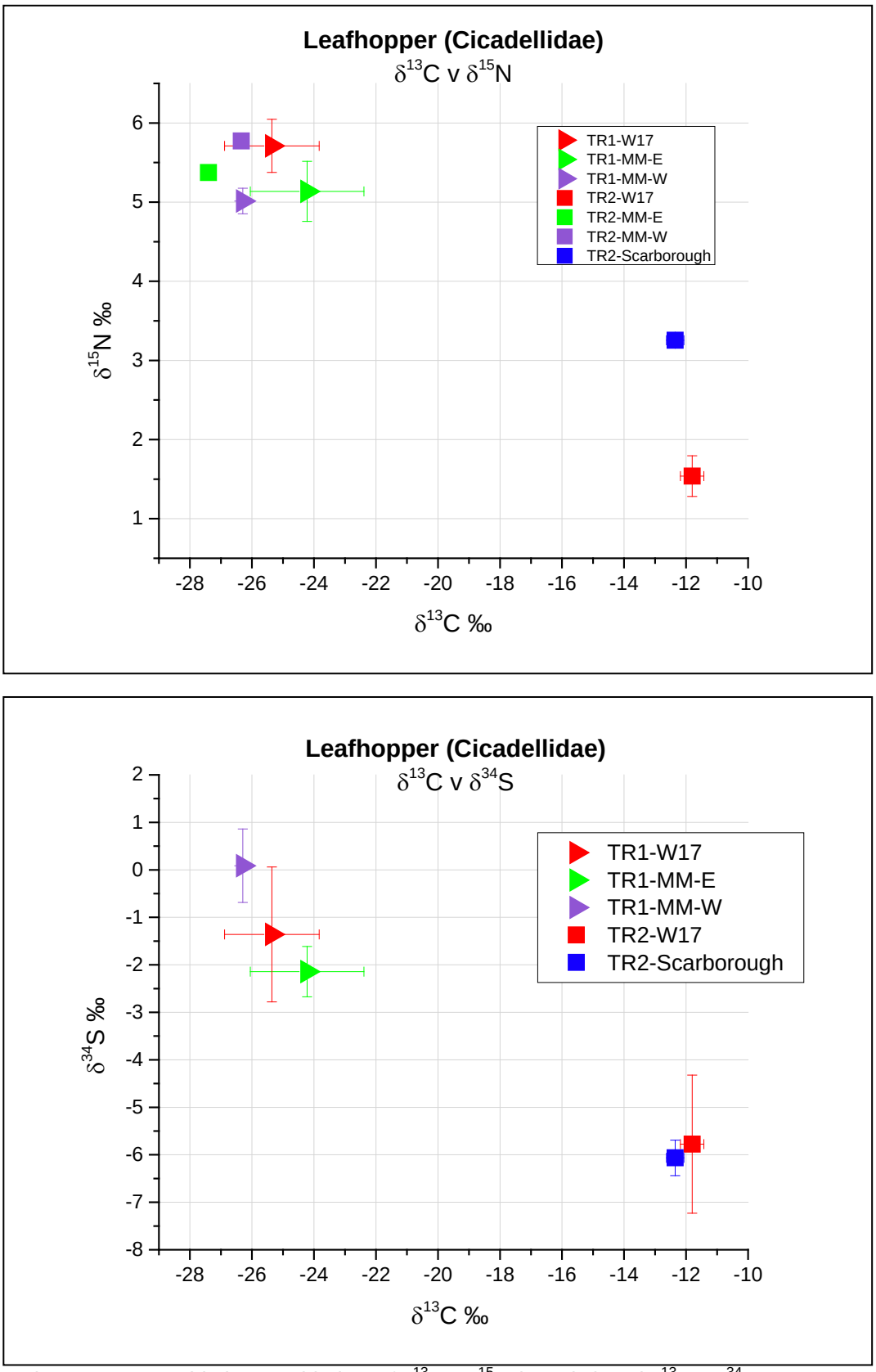



Figure 16-44. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for horseflies (Tabanid). Invertebrates were sampled at two sites, transect 1 (TR1), at the water's edge, and transect 2 (TR2) in the marsh interior.

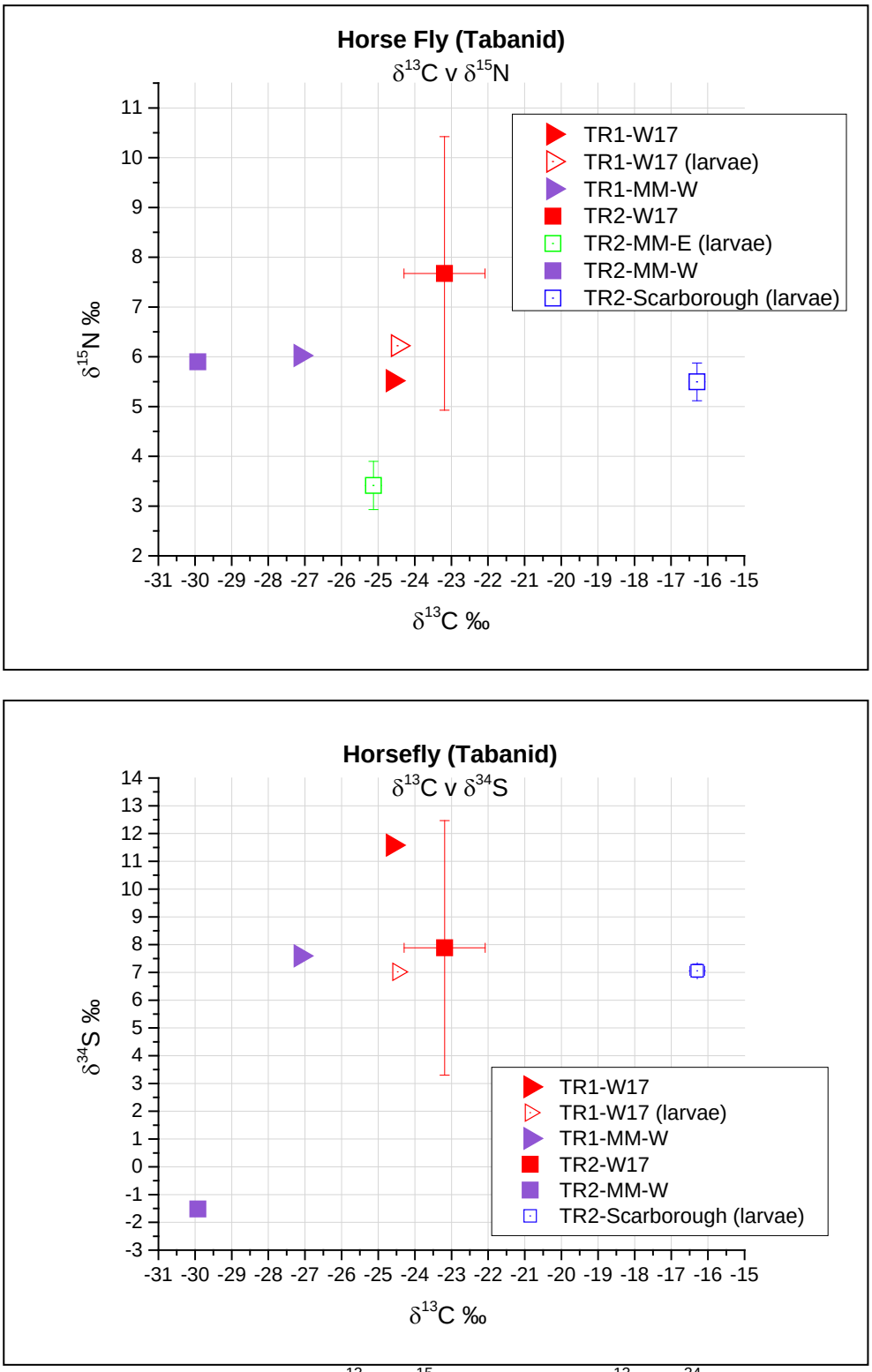
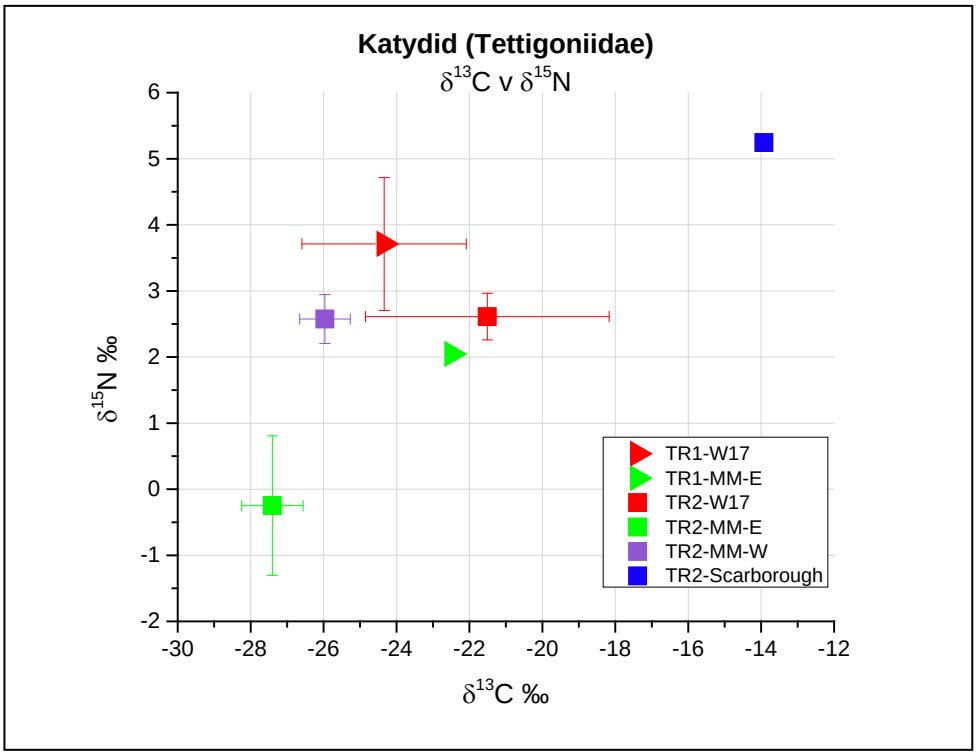



Figure 16-45. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for leafhoppers (Cicadellidae). Invertebrates were sampled at two sites, transect 1 (TR1), at the water's edge, and transect 2 (TR2) in the marsh interior.



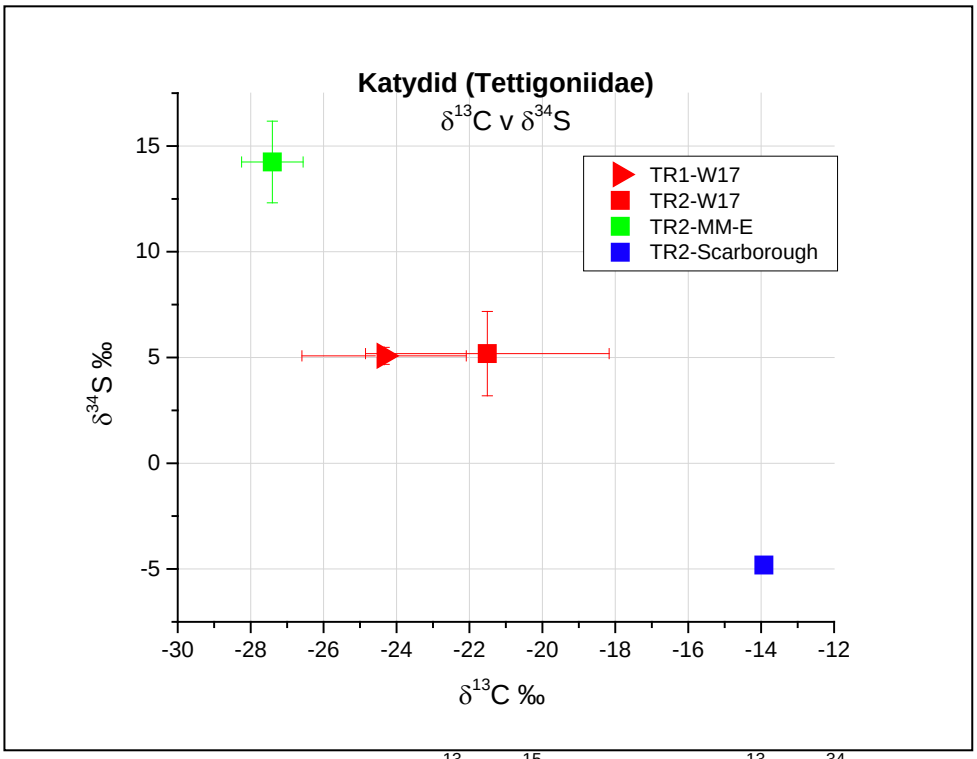
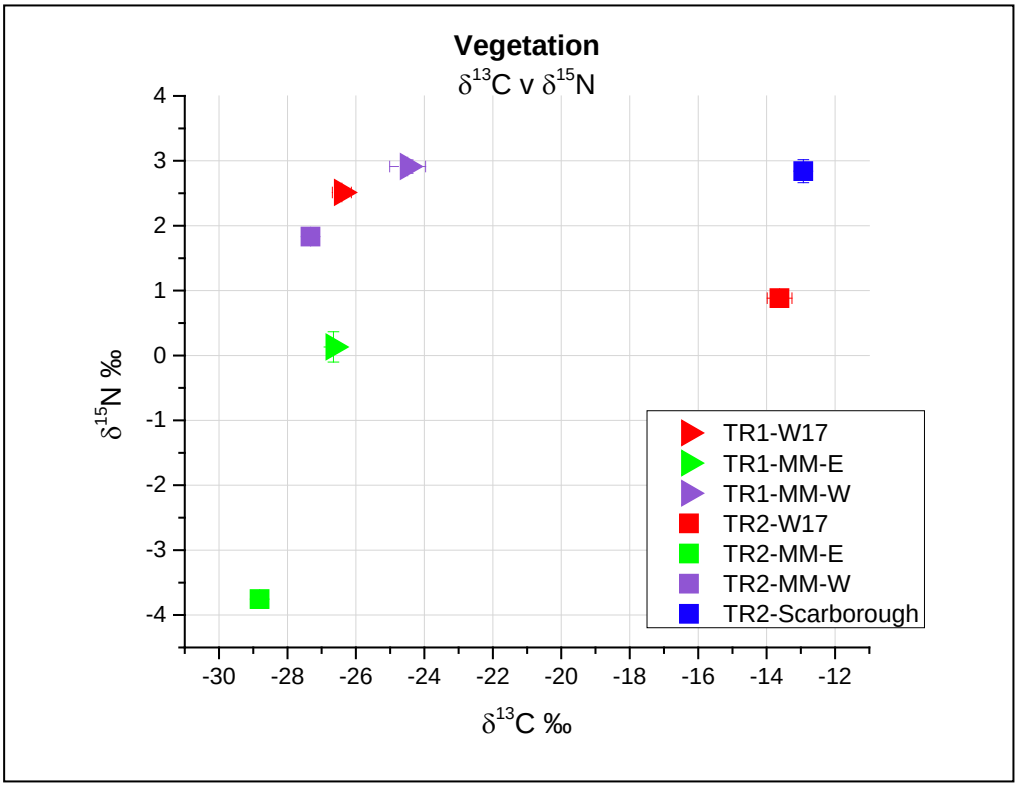




Figure 16-46. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for katydids (Tettigonidae). Invertebrates were sampled at two sites, transect 1 (TR1), at the water's edge, and transect 2 (TR2) in the marsh interior.



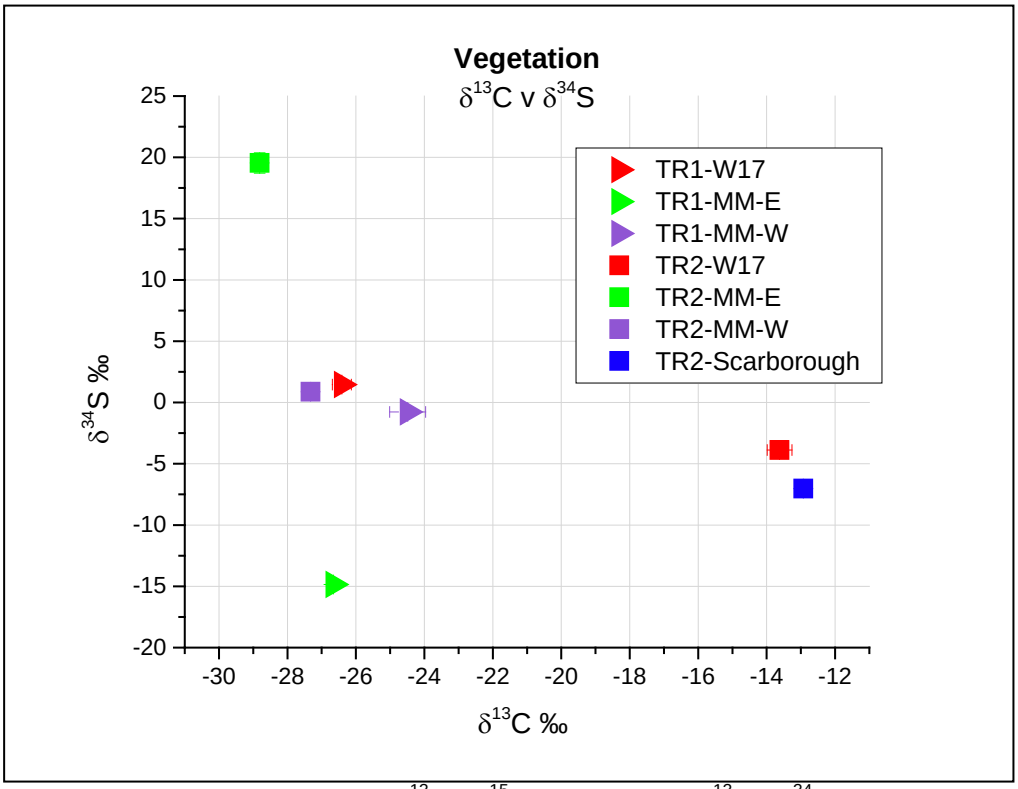
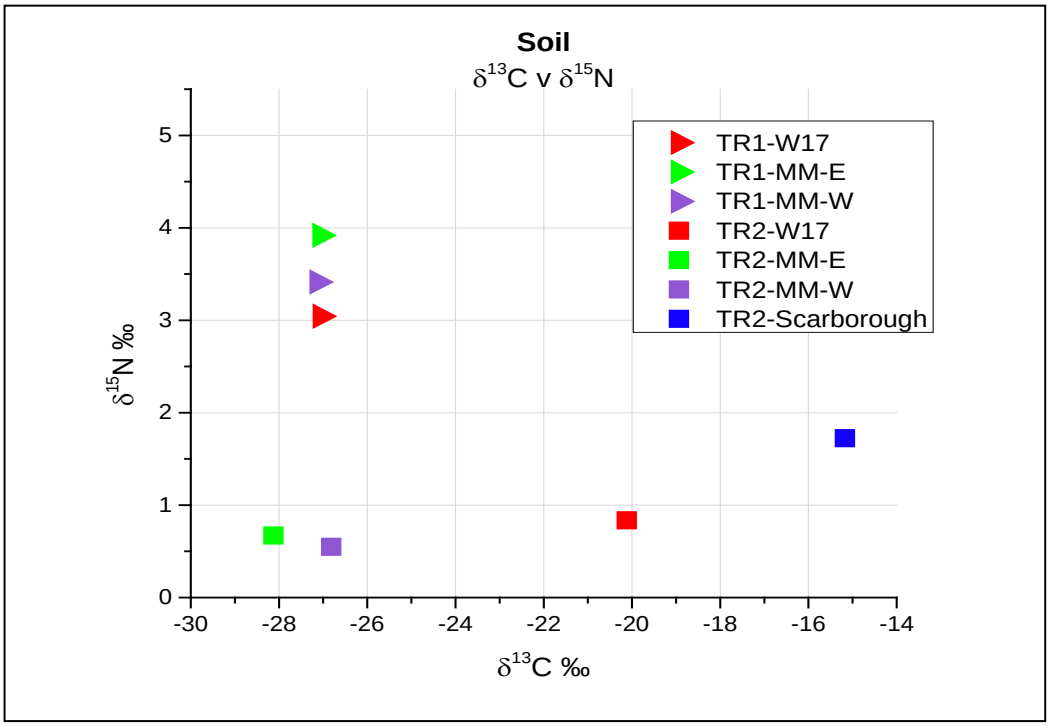




Figure 16-47. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for vegetation. Vegetation was sampled at two sites, transect 1 (TR1), at the water's edge, and transect 2 (TR2) in the marsh interior.



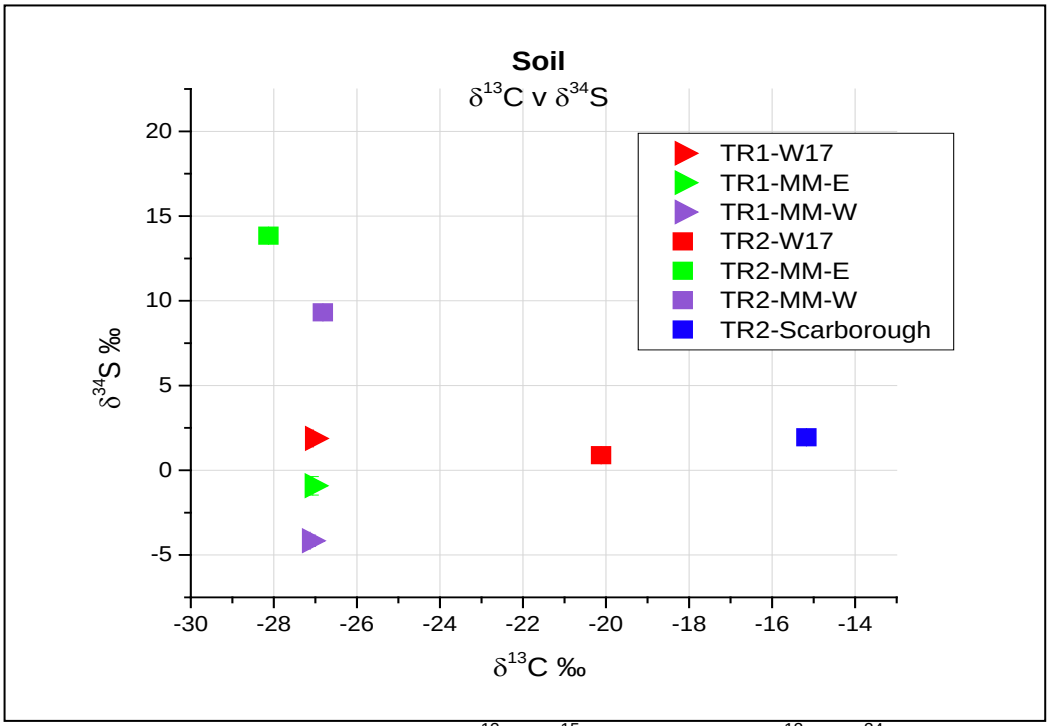




Figure 16-48. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for soil. Soil was sampled at two sites, transect 1 (TR1), at the water's edge, and transect 2 (TR2) in the marsh interior.

Isotope signatures in the soil at the invertebrate collection sites followed a pattern similar to the vegetation and leafhoppers (Figure 16-48). Scarborough (-15‰) and the interior transect (T2) at W17 (-20‰) had the heaviest carbon isotope signature of any of the sites sampled, while the remaining Penobscot sites hovered around -27‰. The transect T1 sites in the Penobscot region had similar $\delta^{15}$N values, around 3.5‰, the heaviest of any sites sampled, and $\delta^{34}$S values at and below 0‰, similar to the values for the leafhoppers, and much lower than all of the other invertebrate species sampled.

# 11 SUMMARY OF FINDINGS

Carbon isotope signatures were consistently heavier by 3 to 12‰ in invertebrates sampled at Scarborough Marsh than at any of the marshes examined along the lower Penobscot River. The large distance between this reference site, and the study sites along the lower Penobscot, reduces the usefulness of this finding for examining site fidelity. However, within the Penobscot system the two spider taxa, long-jawed spiders and wolf spiders, had distinctly different $\delta^{13}$C signatures that may be useful in examining site fidelity in birds, among the Penobscot sites.

Nitrogen isotopes did not vary geographically among the sites examined, except that signatures for amphipods and katydids were elevated at Scarborough Marsh.

The $\delta^{34}$S signatures for most invertebrates were elevated at transect T1, along the water's edge, relative to the marsh interior. In addition, sulfur isotopes were elevated in amphipods at both sites in W17.

## 11.1 Marsh Birds along the lower Penobscot River and in Scarborough Marsh

There was extensive overlap in $\delta^{13}$C signatures in Nelson's sparrows at sites along the lower Penobscot River (Figure 16-49). The carbon signatures in Nelson's sampled along the southern Maine coast at Scarborough Marsh and the Rachel Carson National Wildlife Refuge (RCNWR) were notably heavier, matching the heavier carbon isotopes found in invertebrate taxa. The $\delta^{15}$N signatures overlapped at many of the Penobscot sites. The greatest nitrogen signatures were in Nelson's sampled at the adjacent sites of MM-Jetti and MM-Southwest. Sulfur isotope signatures had similar ratios at the Penobscot sites, though somewhat higher at MM-S174. Based on these findings, movement may have occurred among the marshes sampled along the lower Penobscot River, but exchange between the Penobscot and the southern Maine site is unlikely.

Carbon signatures in song sparrows are somewhat heavier at the upstream sites of W17 and Bald Hill Cove, relative to sites in lower Mendall Marsh, the LP (Leaches Point) sites along the east side of Verona Island, and at the reference site on MDI (Mount Desert Island; Figure 16-50). Yet the $\delta^{13}$C signatures have a small range and overlap, suggesting movement among sites. The $\delta^{15}$N signatures range widely without any geographic trend. Most $\delta^{34}$S signatures hover at 7.5‰, with those at Bald Hill Cove MM-Jetti and along the Orland River closer to 0‰.

Among the sites sampled no pattern was found for any of the stable isotopes examined for swamp sparrows (Figure 16-51). At the adjacent sites of MM-Jetti and MM-SW there was an unusually wide range in $\delta^{13}C$ values and $\delta^{34}S$ values, respectively.

There was extensive overlap in the $\delta^{13}C$ signatures for red-winged blackbirds sampled along the lower Penobscot (Figure 16-52). No samples of red-wings were collected at any reference site in 2009. $\delta^{15}N$ signatures were slightly greater in most hatch year birds, except for adults at MM-NE, again with extensive overlap of ratios. Similarly, $\delta^{34}S$ signatures were clustered in a tight range with extensive overlap.

Virginia rails sampled in the central portion of Mendall Marsh had a very small range of $\delta^{13}C$ signatures, between -26 and -24‰, suggesting regular movement among those sites (Figure 16-53). The Mendall Marsh site at the far southern end of the marsh (MM-S174) had a slightly lighter ratio, but again with likely overlap. The carbon ratio was distinctly heavier in rails sampled at Scarborough Marsh. Rails from Scarborough Marsh also had $\delta^{15}N$ ratios at the high end of the range and $\delta^{34}S$ values at the low end of the sulfur range. Except for Scarborough Marsh, there was no difference among the three stable isotopes for Virginia rails.

In summary, the only clear distinction between sampling regions was found for the Nelson's sparrows and Virginia rails sampled at Scarborough Marsh and along the lower Penobscot River. Based on the extensive overlap of stable isotope signatures, there was regular movement within the lower Penobscot sampling area in four of the five bird species examined. Song sparrows, which were sampled over a wider geographic range, extending from Bald Hill Cove north of Winterport to the Orland River south of Bucksport and on to a reference site on Mt. Desert Island, had a slight geographic trend towards heavier $\delta^{13}C$ and $\delta^{15}N$ signatures at the more northern sites along the Penobscot River.

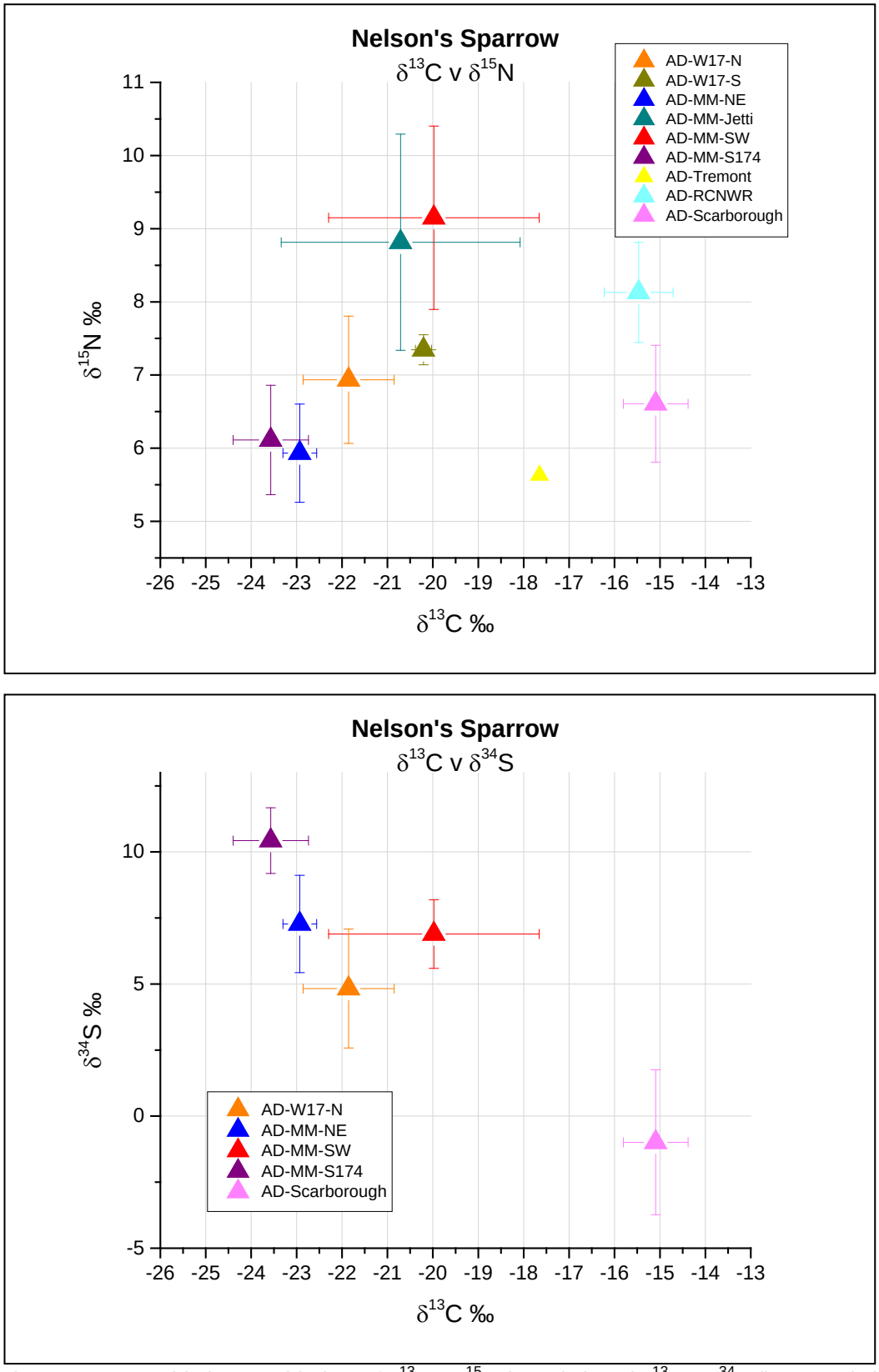



Figure 16-49. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for adult Nelson's sparrows.

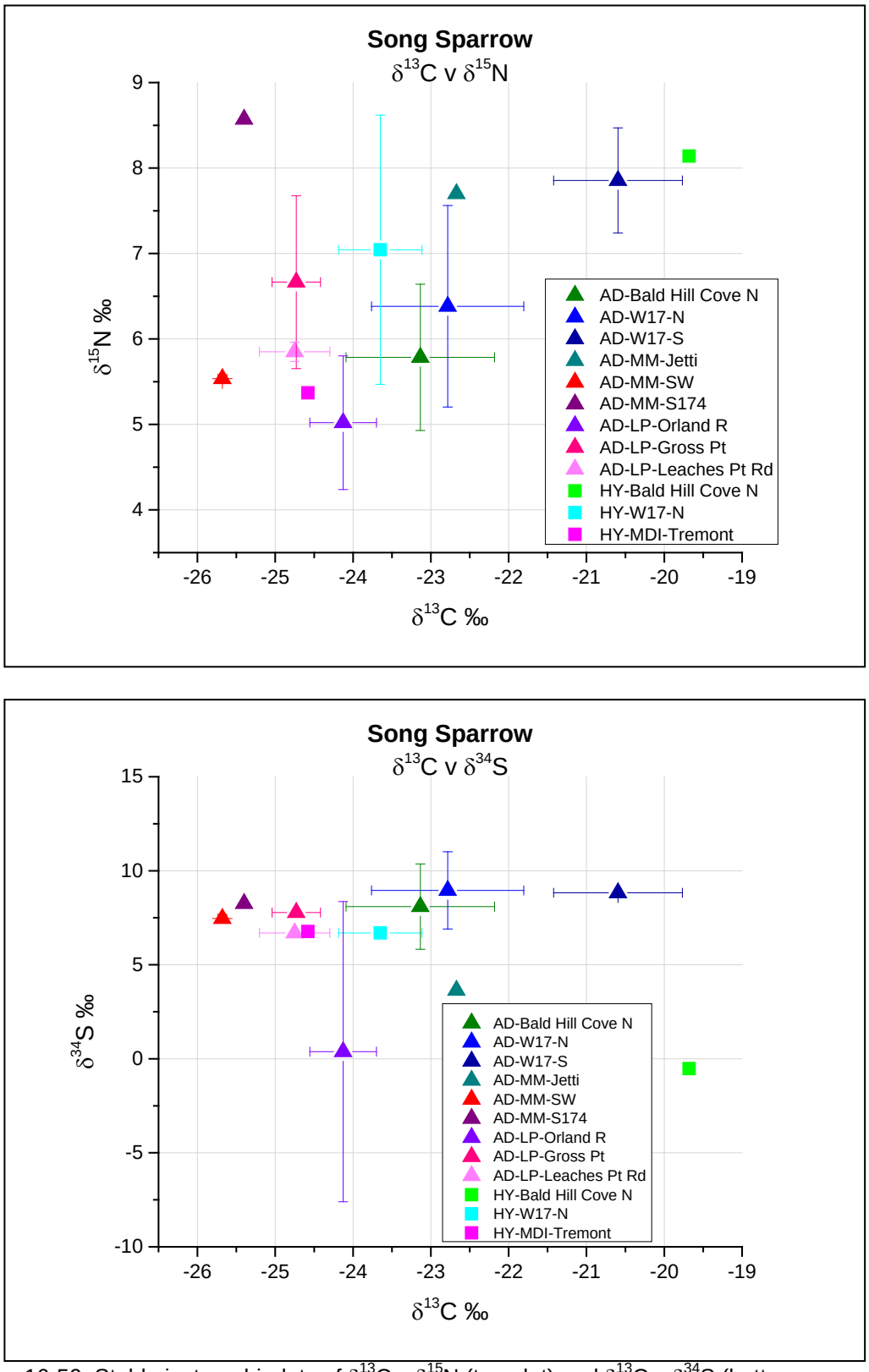
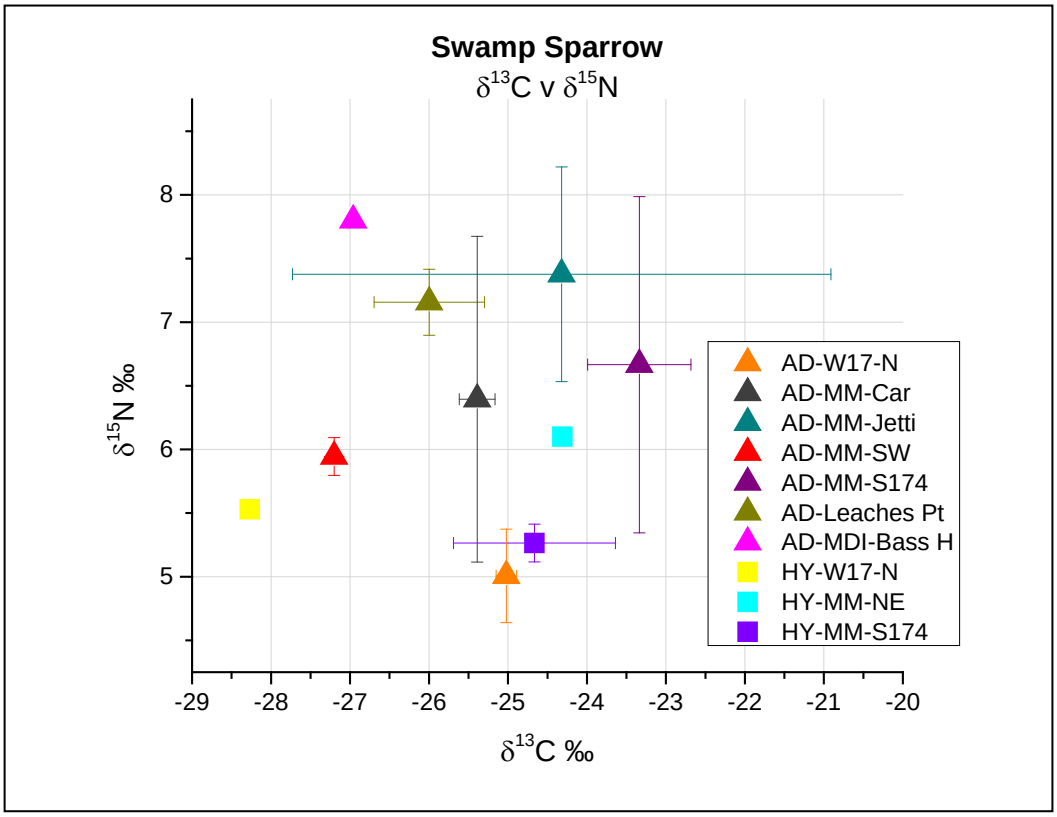



Figure 16-50. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for song sparrows, both adult (AD) and hatch year (HY).



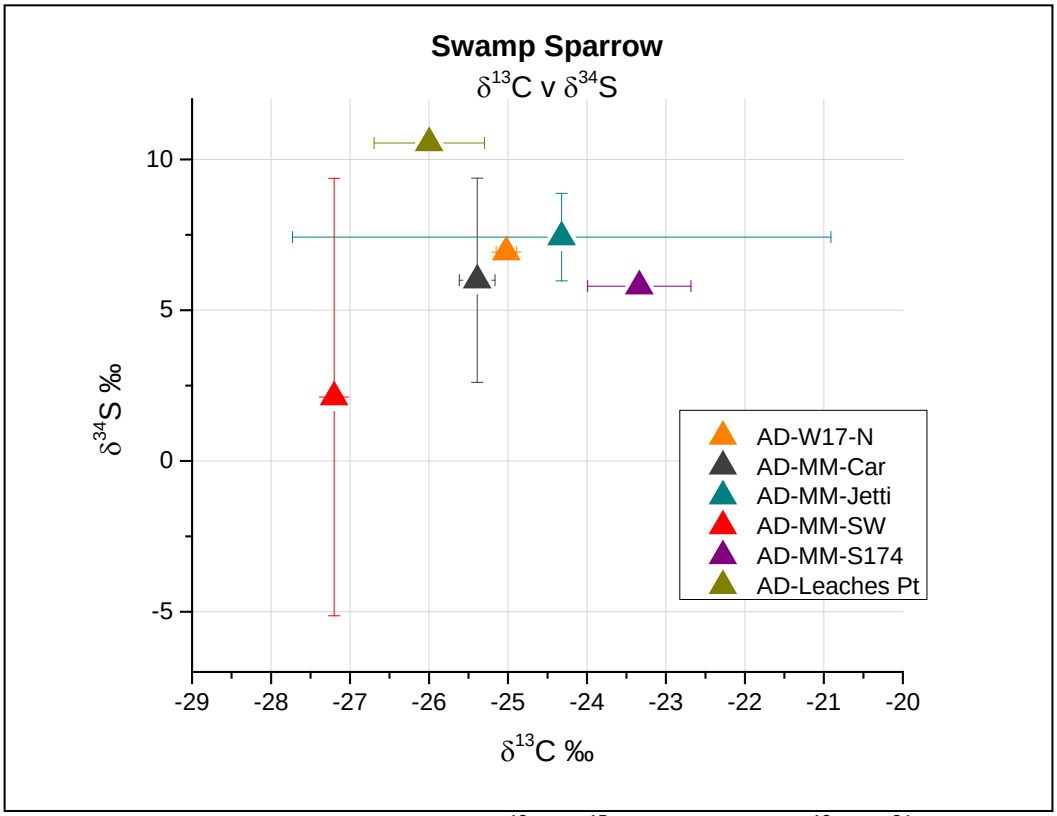
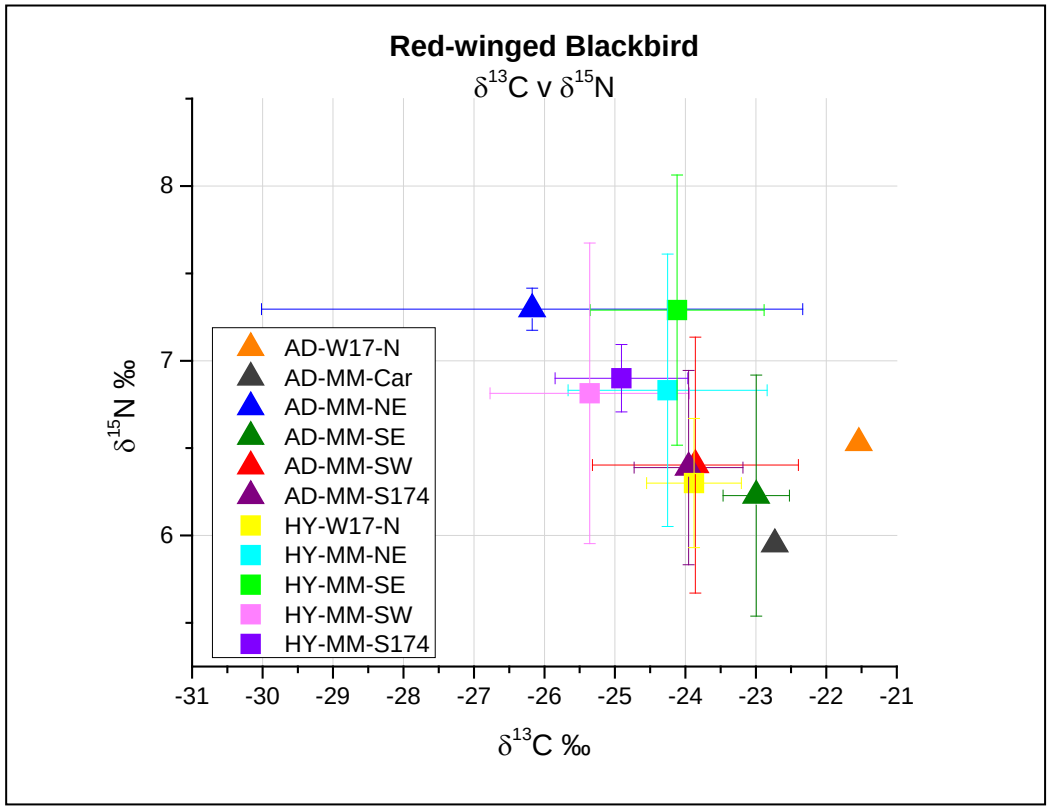




Figure 16-51. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for swamp sparrows



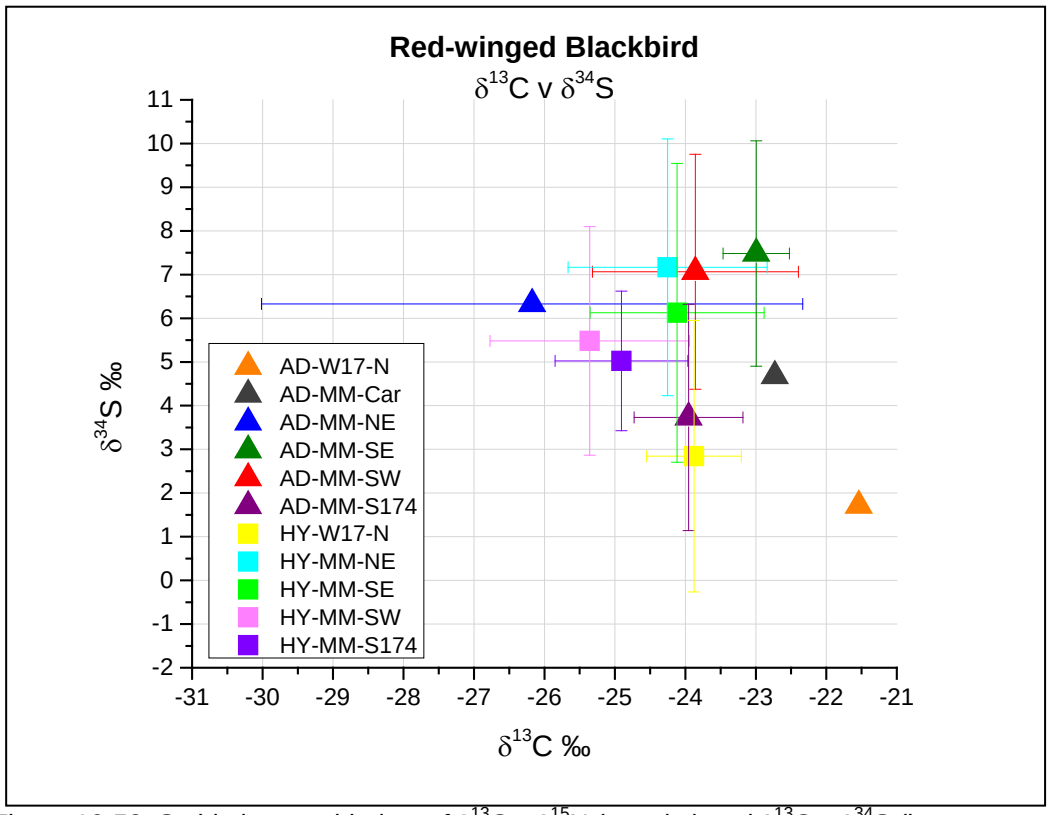
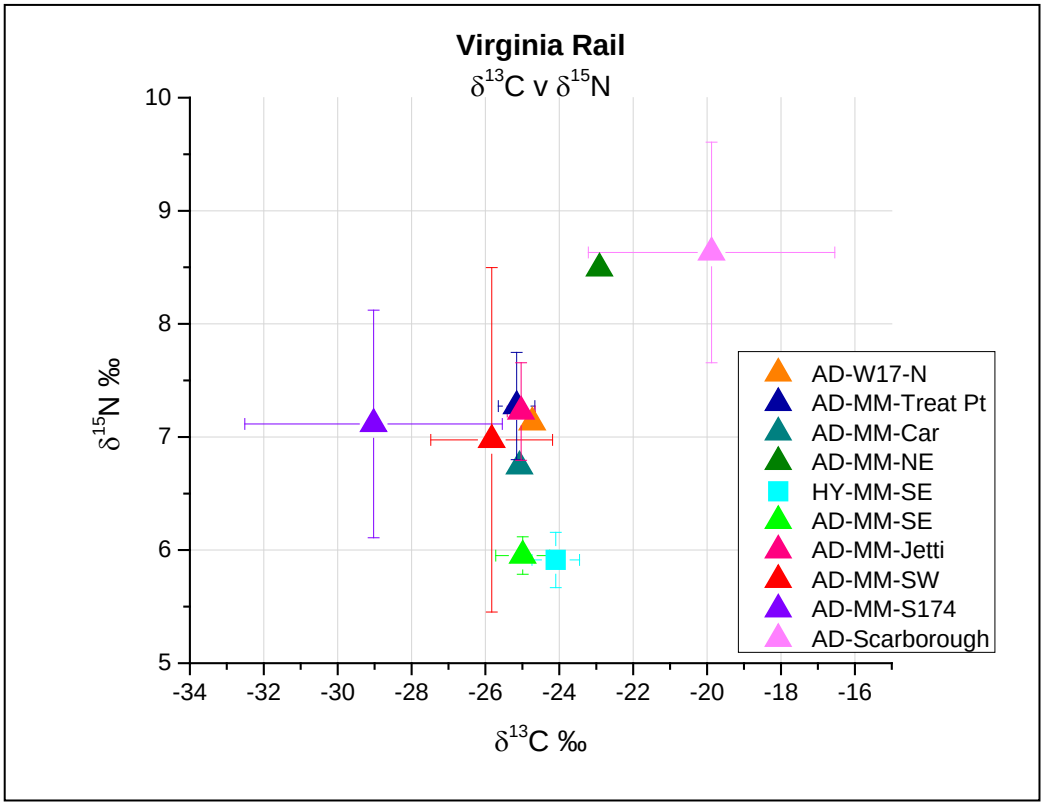




Figure 16-52. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for red-winged blackbirds



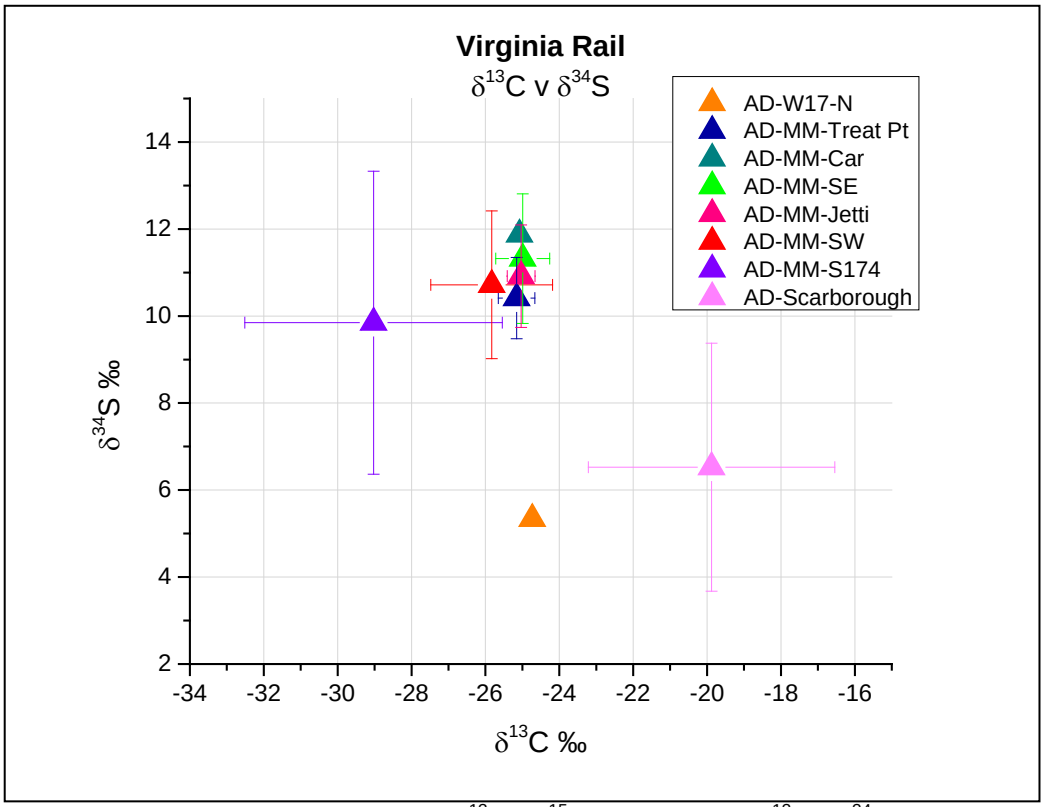




Figure 16-53. Stable isotope bi-plots of $\delta^{13}C$ v $\delta^{15}N$ (top plot) and $\delta^{13}C$ v $\delta^{34}S$ (bottom plot) for Virginia rails.

# 12 REFERENCES


Abraham, B.J. 1985. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (mid-Atlantic)--Mummichog and striped killifish. U.S. Fish and Wildlife Service Biological Report 82 (11.40). U.S. Army Corps of Engineers, TR EL-82-4. 23 pp.

Ackerman, J.T., C.A. Eagles-Smith, J.Y. Takekawa, J.D. Bluso, T.L. Adelsbach. 2008 Mercury concentrations in blood and feathers of prebreeding Forester's terns in relation to space use of San Francisco Bay, California, USA, habitats. Environmental Toxicology and Chemistry. 27(4):897-908.

Ackerman, J.T., C.A. Eagles-Smith, M.P. Herzog. 2011 Bird mercury concentrations change rapidly as chicks age: toxicological risk is highest at hatching and fledging. Environmental Science and Technology. 45(12):5418-5425.

Arcese, P., M.K. Sogge, A.B. Marr, M.A. Patton. 2002. Song sparrow (Melospiza melodia). In The Birds of North America. Edited by A. Poole and F. Gill, Philadelphia, PA.

Becker, P.H., D. Henning, R.W. Furness. 1994. Differences in mercury contamination and elimination during feather development in gull and tern broods. Archives of Environmental Contamination and Toxicology. 27:162-167.

Braune, B.M. 1987 Comparison of total mercury levels in relation to diet and molt for nine species of marine birds. Archives of Environmental Contamination and Toxicology. 16:217-224.

Cabana, G. and J.B. Rasmussen. 1994. Modelling food chain structure and contaminant bioaccumulation using stable nitrogen isotopes. Nature. 372:255-257.

Chen, C. A., Amirbahman, N. Fisher, G. Harding, C. Lamborg, D. Nacci, D. Taylor. 2008. Methylmercury in marine ecosystems: spatial patterns and processes of production, bioaccumulation, and biomagnification. Ecohealth. 5(4):399-408.

Chen, C.Y. and C.L. Folt. 2005. High plankton densities reduce mercury biomagnification. Environmental Science and Technology. 39(1):115-121.

Collette, B.B. and G. Klein-McPhee. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine. Smithsonian Institution Press, Washington.

Conway, C.J. 1995. Virginia rail (Ralius limicola). In The Birds of North America. Edited by E. A. Poole and F. Gill, Philadelphia, PA.

DeNiro, M.J. and S. Epstein. 1978. Influence of diet on the distribution of carbon isotopes in animals. Geochimica et Cosmochimica Acta. 42:495-506.

DeNiro, M.J. and S. Epstein. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. Geochimica et Cosmochimica Acta. 45(3):341-351.

Eagles-Smith, C.A., J.T. Ackerman, S.E.W. De La Cruz, J.T. Takekawa. 2009 Mercury bioaccumulation and risk to three waterbird foraging guilds is influenced by foraging ecology and breeding stage. Environmental Pollution. 157:1993-2002.

Elner, R.W. and A. Campbell. 1987. Natural diets of lobster Homarus americanus from barren ground and macroalgal habitats off southwestern Nova Scotia, Canada. Marine Ecology Progress Series. 37:131-140.

Florin, S.T., L.A. Felicetti, C.T. Robbins. 2011. The biological basis for understanding and predicting dietary-induced variation in nitrogen and sulphur isotope ratio discrimination. Functional Ecology. 25:519-526.

Grabowski, J.H., E.J. Clesceri, A.J. Baukus, J. Gaudette, M. Weber, P. O. Yund. 2010. Use of herring bait to farm lobsters in the Gulf of Maine. PLoS ONE 5(4): e10188.doi:10:1371/journal.pone.0010188.

Hall, B.D., R.A. Bodaly, R.J.P. Fudge, J.W.M. Rudd, D.M. Rosenberg. 1997 Food as the dominant pathway of methylmercury uptake by fish. Water, Air, and Soil Pollution. 100(1-2):13-24.

Hesslein, R.H., K.A. Hallard, P. Ramlal. 1993. Replacement of sulfur, carbon and nitrogen in tissue of growing boad whitefish (Coregonus nasus) in response to a change in diet traced by $\delta$34S, $\delta$13C, and $\delta$15N. Canadian Journal of Fisheries and Aquatic Science. 50:2071-2076,

Hobson, K.A., and R.G. Clark. 1992. Assessing avian diets using stable isotopes I: turnover of 13C in tissues. The Condor. 94:181-188.

Hobson, K.A. 1999. Tracing origins and migration of wildlife using stable isotopes: a review. Oecologia. 120:314-326/

Hobson, K.A., K.D. Hughes, P.J. Ewins. 1997. Using stable-isotope analysis to identify endogenous and exogenous sources of nutrients in eggs of migratory birds: applications to Great Lakes contaminants research. The Auk. 114(3):467-478.

Hudon, C. and G. Lamarche. 1989. Niche segregation between American lobster Homarus americanus and rock crab Cancer irroratus. Marine Ecology Progress Series. 52:155-168.

Logan, J.M., T.D. Jardine, T.J. Miller, S.E. Bunn, R.A. Cunjak, M.E. Lutcavage. 2008. Lipid corrections in carbon and nitrogen stable isotope analyses: comparison of chemical extraction and modeling methods. Journal of Animal Ecology. 77:838-846.

Post, D.M. 2002. Using stable isotopes to estimate trophic position: models, methods, and assumptions. Ecology. 83(3):703-718.

Post, D.M., C.A. Layman, D.A. Arrington, G. Takimoto, J. Quattrochi, C.G. Montana. 2007. Getting to the fat of the matter: models, methods and assumptions for dealing with lipids in stable isotope analyses. Oecologia. 152(1):179-189.

McCutchan J.H., W.M. Lewis, C. Kendall, C.C. McGrath. 2003. Variation of trophic shift for stable isotope ratios of carbon, nitrogen and sulfur. OIKOS. 102:378-390.

McKinnon, E.A., K.C.Fraser, A.W. Diamond, C.C. Rimmer, J.M. Townsend. 2012. Stable-hydrogen isotope turnover in red blood cells of two migratory thrushes: application to studies of connectivity and carry-over effects. Journal of Field Ornithology. 83(3):306-314.

Michener, R.H. and D.M. Schell. 1994 Stable isotope ratios as tracers in marine and aquatic food webs. In:K. Lajtha K. and R.H. Michener (eds) Stable isotopes in ecology and environmental science. Blackwell, Oxford, pp 138-157.

Newsome, S.D., C.M. delRio, S. Bearhop, D.L. Phillips 2007. A niche for isotopic ecology. Frontiers in Ecology and Environment. 5(8):429-436.

Oh, C., R.G.Hartnell, R.D.M. Nash. 2001. Feeding ecology of the common shrimp Crangon crangon in Port Erin Bay, Isle of Man, Irish Sea. Marine Ecology Progress Series. 214:211-223.

Peterson, B.J. and B. Fry. 1987. Stable isotopes in ecosystem studies. Animal review of Ecology and Systematics. 18:293-320.

Price, K.S. 1962. Biology of the sand shrimp, Crangon septemspinosa, in the shore zone of the Delaware Bay region. Chesapeake Science. 3:244-255.

Ramos, R., F. Ramirez, C. Sanpera, L. Jover, X. Ruiz 2009. Feeding ecology of yellow-legged gulls (Larus michahellis) in the Western Mediterranean: a comparative assessment using conventional and isotopic methods. Marine Ecology Progress Series. 377:289-296.

Shriver, W.G., T.P. Hodgman, A.R. Hanson. 2011. Nelson's sparrow (Ammodramus nelson), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu.prxy4.ursus.maine.edu/bna/species/719.

Weisberg, S.B. and V.A. Lotrich. 1982. The importance of an infrequently flooded intertidal marsh surface as an energy source for the mummichog Fundulus heteroclitus: an experimental approach. Marine Biology. 66:307-310.

# APPENDIX

**Appendix 16 - 1a. Summary statistics for the aquatic food web in the lower Penobscot. Carbon, nitrogen and sulfur stable isotope signatures for fish and shellfish collected in 2008 in the Penobscot River and Bay. The $\delta^{13}C$ signatures were lipid normalized using the C:N ratio. OV = Old Town – Veazie reach; BO = Brewer – Orrington reach; OB = Orrington – Bucksport reach; ES = estuarine reach (Penobscot Bay).**

| Year | Site | Taxa | mean length mm | SD length | mean age years | SD age | n for SI | mean $\delta^{15}N$ ‰ | SD $\delta^{15}N$ ‰ | mean normalized $\delta^{13}C$ ‰ | SD normalized $\delta^{13}C$ ‰ | mean $\delta^{34}S$ ‰ | SD $\delta^{34}S$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2008 | BO3 | eel | 0.0 | 0.0 | 7.3 | 2.1 | 16 | 11.30 | 1.02 | -23.34 | 1.62 | 8.99 | 2.09 |
| 2008 | BO4 | eel | 0.0 | 0.0 | 8.0 | 6.1 | 4 | 10.69 | 1.98 | -25.13 | 3.30 | 8.99 | 1.04 |
| 2008 | ES02 | smelt | 130.0 | 22.9 | 0.0 | 0.0 | 3 | 12.84 | 0.10 | -16.75 | 0.41 | 15.60 | 1.72 |
| 2008 | ES02 | tomcod | 135.6 | 29.0 | 0.0 | 0.0 | 9 | 12.50 | 0.43 | -14.99 | 0.78 | 15.29 | 0.83 |
| 2008 | ES03 | smelt | 146.6 | 33.8 | 0.0 | 0.0 | 9 | 12.95 | 0.27 | -16.16 | 0.67 | 15.34 | 0.98 |
| 2008 | ES04 | lobster | 78.7 | 14.5 | 0.0 | 0.0 | 15 | 12.69 | 0.47 | -16.35 | 0.35 | 16.75 | 0.53 |
| 2008 | ES04 | mussels | 49.3 | 6.0 | 0.0 | 0.0 | 8 | 6.88 | 0.22 | -16.63 | 0.33 | 18.92 | 0.47 |
| 2008 | ES05 | smelt | 136.2 | 16.8 | 0.0 | 0.0 | 5 | 13.02 | 0.30 | -16.80 | 0.24 | 15.81 | 0.52 |
| 2008 | ES05 | tomcod | 155.5 | 37.2 | 0.0 | 0.0 | 10 | 12.79 | 0.43 | -15.76 | 1.36 | 14.21 | 1.60 |
| 2008 | ES07 | mussels | 57.5 | 6.2 | 0.0 | 0.0 | 8 | 6.91 | 0.42 | -16.75 | 0.21 | 18.82 | 0.68 |
| 2008 | ES09 | smelt | 111.4 | 15.0 | 0.0 | 0.0 | 8 | 12.74 | 0.21 | -16.51 | 0.44 | 16.96 | 0.63 |
| 2008 | ES09 | tomcod | 149.7 | 44.0 | 0.0 | 0.0 | 10 | 12.49 | 0.55 | -16.00 | 1.29 | 15.20 | 1.68 |
| 2008 | ES12 | mussels | 53.9 | 9.5 | 0.0 | 0.0 | 8 | 8.02 | 0.18 | -16.97 | 0.25 | 18.88 | 0.38 |
| 2008 | ES13 | lobster | 90.2 | 10.2 | 0.0 | 0.0 | 5 | 13.29 | 0.25 | -16.22 | 0.12 | 16.64 | 0.61 |
| 2008 | ES13 | mussels | 61.3 | 10.6 | 0.0 | 0.0 | 8 | 8.26 | 0.19 | -17.42 | 0.27 | 19.19 | 0.45 |
| 2008 | ES13 | smelt | 108.3 | 12.5 | 0.0 | 0.0 | 9 | 12.93 | 0.23 | -17.15 | 0.22 | 17.15 | 0.52 |
| 2008 | ES14 | mussels | 70.8 | 12.4 | 0.0 | 0.0 | 9 | 7.96 | 0.21 | -16.96 | 0.46 | 19.72 | 0.43 |
| 2008 | ES15 | lobster | 93.8 | 8.1 | 0.0 | 0.0 | 5 | 13.54 | 0.33 | -16.73 | 0.48 | 16.42 | 0.37 |
| 2008 | ES15 | mussels | 55.3 | 6.1 | 0.0 | 0.0 | 9 | 8.29 | 0.15 | -17.30 | 0.25 | 19.03 | 0.32 |
| 2008 | ES15 | smelt | 120.6 | 33.6 | 0.0 | 0.0 | 8 | 13.05 | 0.26 | -16.81 | 0.39 | 16.58 | 0.79 |
| 2008 | ESFP | lobster | 81.3 | 14.6 | 0.0 | 0.0 | 10 | 13.12 | 0.41 | -16.31 | 0.22 | 16.92 | 0.86 |
| 2008 | H | lobster | 89.1 | 12.5 | 0.0 | 0.0 | 10 | 13.27 | 0.46 | -15.87 | 0.38 | 17.40 | 0.70 |
| 2008 | KC | lobster | 89.0 | 8.5 | 0.0 | 0.0 | 2 | 12.48 | 0.88 | -16.55 | 0.11 | 16.60 | 0.15 |
| 2008 | OB1 | eel | 0.0 | 0.0 | 7.5 | 2.4 | 6 | 12.55 | 0.73 | -19.77 | 2.31 | 10.70 | 3.43 |
| 2008 | OB1 | fundulus | 75.1 | 10.9 | 0.0 | 0.0 | 11 | 10.23 | 0.56 | -20.94 | 0.43 | 12.21 | 0.81 |
| 2008 | OB1 | smelt | 156.9 | 47.2 | 0.0 | 0.0 | 9 | 13.21 | 0.42 | -17.23 | 1.32 | 15.02 | 1.60 |
| 2008 | OB1 | tomcod | 173.8 | 35.7 | 0.0 | 0.0 | 10 | 12.44 | 0.50 | -19.04 | 0.73 | 12.42 | 1.44 |
| 2008 | OB3 | eel | 0.0 | 0.0 | 6.3 | 0.6 | 3 | 11.33 | 1.24 | -20.51 | 0.57 | 9.95 | 1.50 |
| 2008 | OB5 | eel | 0.0 | 0.0 | 6.8 | 1.3 | 7 | 11.41 | 0.69 | -21.32 | 1.08 | 8.67 | 1.76 |
| 2008 | OV4 | eel | 0.0 | 0.0 | 8.4 | 3.3 | 10 | 9.51 | 1.04 | -25.79 | 2.10 | 3.35 | 0.61 |
| 2008 | PC | lobster | 77.8 | 20.7 | 0.0 | 0.0 | 5 | 13.04 | 0.73 | -15.57 | 0.83 | 17.21 | 1.36 |

**Appendix 16 - 2b. Summary statistics for the aquatic food web in the lower Penobscot. Total Hg and methyl Hg for fish and shellfish collected in 2008 in the Penobscot River and Bay. OV = Old Town – Veazie reach; BO = Brewer – Orrington reach; OB = Orrington – Bucksport reach; ES = estuarine reach (Penobscot Bay).**

| Year | Site | Taxa | mean length mm | SD length | mean age years | SD age | n for THg ww | mean THg ng/g ww | SD THg ww | n for MeHg ww | mean MeHg ng/g ww | SD MeHg ww | n for THg dw | mean THg ng/g dw | SD THg dw | n for MeHg dw | mean MeHg ng/g dw | SD MeHg dw |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2008 | BO3 | eel | 0.0 | 0.0 | 7.3 | 2.1 | 16 | 626.9 | 362.5 | 3 | 799.0 | 188.9 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | BO4 | eel | 0.0 | 0.0 | 8.0 | 6.1 | 4 | 763.8 | 412.1 | 1 | 879.0 | . | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES02 | smelt | 130.0 | 22.9 | 0.0 | 0.0 | 3 | 74.0 | 33.8 | 2 | 62.0 | 41.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES02 | tomcod | 135.6 | 29.0 | 0.0 | 0.0 | 9 | 105.0 | 34.9 | 2 | 95.5 | 0.7 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES03 | smelt | 146.6 | 33.8 | 0.0 | 0.0 | 9 | 61.8 | 31.1 | 2 | 48.5 | 21.9 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES04 | lobster | 78.7 | 14.5 | 0.0 | 0.0 | 15 | 97.9 | 41.1 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES04 | mussels | 49.3 | 6.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 8 | 136.8 | 33.0 | 0 | 0.0 | 0.0 |
| 2008 | ES05 | smelt | 136.2 | 16.8 | 0.0 | 0.0 | 5 | 96.2 | 42.4 | 2 | 73.5 | 27.6 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES05 | tomcod | 155.5 | 37.2 | 0.0 | 0.0 | 10 | 132.1 | 35.9 | 2 | 102.5 | 33.2 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES07 | mussels | 57.5 | 6.2 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 8 | 139.3 | 44.7 | 0 | 0.0 | 0.0 |
| 2008 | ES09 | smelt | 111.4 | 15.0 | 0.0 | 0.0 | 8 | 65.4 | 24.0 | 2 | 79.0 | 46.7 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES09 | tomcod | 149.7 | 44.0 | 0.0 | 0.0 | 10 | 126.2 | 46.2 | 2 | 75.5 | 4.9 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES12 | mussels | 53.9 | 9.5 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 7 | 433.3 | 111.4 | 7 | 176.7 | 45.6 |
| 2008 | ES13 | lobster | 90.2 | 10.2 | 0.0 | 0.0 | 5 | 595.0 | 335.6 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES13 | mussels | 61.3 | 10.6 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 7 | 766.7 | 112.4 | 7 | 247.6 | 24.8 |
| 2008 | ES13 | smelt | 108.3 | 12.5 | 0.0 | 0.0 | 8 | 51.1 | 11.9 | 2 | 50.0 | 12.7 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES14 | mussels | 70.8 | 12.4 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 7 | 596.3 | 180.7 | 7 | 183.9 | 52.3 |
| 2008 | ES15 | lobster | 93.8 | 8.1 | 0.0 | 0.0 | 5 | 305.4 | 130.9 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ES15 | mussels | 55.3 | 6.1 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 6 | 569.7 | 242.4 | 6 | 157.7 | 21.1 |
| 2008 | ES15 | smelt | 120.6 | 33.6 | 0.0 | 0.0 | 7 | 52.3 | 20.5 | 2 | 72.5 | 29.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | ESFP | lobster | 81.3 | 14.6 | 0.0 | 0.0 | 10 | 193.7 | 104.2 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | H | lobster | 89.1 | 12.5 | 0.0 | 0.0 | 10 | 159.0 | 91.4 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | KC | lobster | 89.0 | 8.5 | 0.0 | 0.0 | 2 | 88.0 | 5.7 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | OB1 | eel | 0.0 | 0.0 | 7.5 | 2.4 | 6 | 382.7 | 128.7 | 2 | 217.0 | 33.9 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | OB1 | fundulus | 75.1 | 10.9 | 0.0 | 0.0 | 11 | 263.2 | 37.5 | 3 | 63.3 | 49.1 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | OB1 | smelt | 156.9 | 47.2 | 0.0 | 0.0 | 9 | 120.2 | 80.4 | 2 | 168.5 | 157.7 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | OB1 | tomcod | 173.8 | 35.7 | 0.0 | 0.0 | 10 | 164.3 | 89.3 | 2 | 164.5 | 136.5 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | OB3 | eel | 0.0 | 0.0 | 6.3 | 0.6 | 3 | 488.7 | 145.1 | 2 | 346.0 | 18.4 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | OB5 | eel | 0.0 | 0.0 | 6.8 | 1.3 | 7 | 394.3 | 81.1 | 1 | 317.0 | . | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | OV4 | eel | 0.0 | 0.0 | 8.4 | 3.3 | 9 | 348.3 | 189.9 | 2 | 394.5 | 217.1 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2008 | PC | lobster | 77.8 | 20.7 | 0.0 | 0.0 | 5 | 219.4 | 135.9 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |

**Appendix 16 - 3a. Summary statistics for the aquatic food web in the lower Penobscot (2009 - OV, BO, OB, and ES04). Carbon, nitrogen and sulfur stable isotope signatures for fish, shellfish, and invertebrates collected in 2009 in the Penobscot River and Bay. The $\delta^{13}C$ signatures were lipid normalized using the C:N ratio. OV = Old Town – Veazie reach; BO = Brewer – Orrington reach; OB = Orrington – Bucksport reach; ES = estuarine reach (Penobscot Bay).**

| Year | Site | Taxa | mean length mm | SD length | mean age years | SD age | n for SI | mean $\delta^{15}N$ ‰ | SD $\delta^{15}N$ ‰ | mean normalized $\delta^{13}C$ ‰ | SD normalized $\delta^{13}C$ ‰ | mean $\delta^{34}S$ ‰ | SD $\delta^{34}S$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | OV4 | Oligochaete | 0.0 | 0.0 | 0.0 | 0.0 | 2 | 3.50 | 0.04 | -28.06 | 0.09 | 0.69 | 0.21 |
| 2009 | OV4 | Elliptio | 85.0 | 24.2 | 0.0 | 0.0 | 5 | 5.46 | 0.93 | -33.58 | 1.45 | 3.38 | 0.48 |
| 2008 | OV4 | eel | 0.0 | 0.0 | 8.4 | 3.3 | 10 | 9.51 | 1.04 | -25.79 | 2.10 | 3.35 | 0.61 |
| 2009 | BO3 | Amphipod | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 6.31 | | -21.97 | | 8.11 | |
| 2009 | BO3 | insect larvae | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 6.72 | | -25.49 | | 2.43 | |
| 2009 | BO3 | Oligochaete | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 5.58 | | -24.75 | | 1.30 | |
| 2009 | BO3 | eel | 0.0 | 0.0 | 6.3 | 1.0 | 7 | 11.15 | 0.68 | -23.55 | 0.98 | 9.24 | 1.32 |
| 2009 | BO4 | Amphipod | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 6.19 | | -20.99 | | 9.87 | |
| 2009 | BO4 | Oligochaete | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 6.14 | 0.23 | -23.90 | 0.11 | 4.36 | 0.68 |
| 2009 | BO4 | eel | 0.0 | 0.0 | 6.8 | 1.9 | 5 | 10.87 | 0.98 | -24.15 | 1.21 | 7.68 | 2.76 |
| 2009 | OB1 | Amphipod | 0.0 | 0.0 | 0.0 | 0.0 | 2 | 8.34 | 1.29 | -17.18 | 0.51 | 13.50 | 1.28 |
| 2009 | OB1 | Polychaete | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 9.56 | | -22.56 | | | |
| 2009 | OB1 | Crangon | 0.0 | 0.0 | 0.0 | 0.0 | 11 | 10.30 | 0.40 | -18.64 | 0.86 | 11.49 | 1.63 |
| 2009 | OB1 | fundulus | 76.8 | 3.8 | 0.0 | 0.0 | 6 | 12.22 | 0.45 | -18.02 | 0.35 | 14.08 | 0.67 |
| 2009 | OB1 | smelt | 170.3 | 10.0 | 0.0 | 0.0 | 7 | 13.09 | 0.23 | -17.50 | 0.40 | 13.15 | 1.14 |
| 2009 | OB1 | eel | 0.0 | 0.0 | 8.2 | 1.9 | 7 | 12.84 | 0.99 | -18.85 | 0.94 | 11.14 | 1.75 |
| 2009 | OB1 | tomcod | 141.3 | 35.7 | 0.0 | 0.0 | 13 | 12.07 | 0.88 | -19.84 | 0.59 | 12.27 | 1.50 |
| 2009 | OB3 | Crangon | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 8.90 | 0.55 | -20.43 | 0.72 | 8.41 | 1.11 |
| 2009 | OB4 | Amphipod | 0.0 | 0.0 | 0.0 | 0.0 | 2 | 7.60 | 0.13 | -15.78 | 0.33 | 15.16 | 0.49 |
| 2009 | OB4 | insect larvae | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 6.05 | | -17.20 | | 12.37 | |
| 2009 | OB4 | Oligochaete | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 7.27 | | -19.27 | | 16.24 | |
| 2009 | OB4 | Annelid | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 8.56 | | -14.41 | | 13.50 | |
| 2009 | OB4 | Crangon | 0.0 | 0.0 | 0.0 | 0.0 | 13 | 9.57 | 0.50 | -19.56 | 1.11 | 9.35 | 1.39 |
| 2009 | OB4 | smelt | 170.3 | 83.4 | 0.0 | 0.0 | 3 | 13.38 | 0.81 | -16.00 | 1.53 | 13.83 | 3.02 |
| 2009 | OB4 | tomcod | 186.5 | 52.5 | 0.0 | 0.0 | 6 | 12.53 | 0.36 | -20.08 | 0.22 | 10.05 | 1.60 |
| 2009 | OB5 | Amphipod | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 6.80 | | -18.79 | | 12.54 | |
| 2009 | OB5 | insect larvae | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 5.09 | | -18.62 | | 3.57 | |
| 2009 | OB5 | Neomysis | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 5.41 | | -18.61 | | 5.71 | |
| 2009 | OB5 | Crangon | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 10.00 | 0.63 | -20.36 | 0.87 | 9.13 | 1.00 |
| 2009 | OB5 | fundulus | 66.8 | 20.5 | 0.0 | 0.0 | 12 | 9.16 | 0.63 | -22.63 | 0.30 | 7.75 | 1.43 |
| 2009 | OB5 | eel | 0.0 | 0.0 | 6.9 | 0.9 | 7 | 11.26 | 0.90 | -22.33 | 1.61 | 8.75 | 1.47 |
| 2009 | OB5 | tomcod | 129.4 | 40.5 | 0.0 | 0.0 | 8 | 11.80 | 0.45 | -20.64 | 0.59 | 11.20 | 1.33 |
| 2009 | ES | Atl Herring | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 12.58 | 0.19 | -19.61 | 0.71 | 16.86 | 0.55 |
| 2009 | ES04 | zooplankton | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 8.71 | | -19.65 | | 19.26 | |
| 2009 | ES04 | mussels | 50.6 | 4.7 | 0.0 | 0.0 | 10 | 6.42 | 0.21 | -14.49 | 0.70 | 16.55 | 0.74 |
| 2009 | ES04 | Mya | 59.6 | 9.2 | 0.0 | 0.0 | 5 | 6.87 | 0.29 | -16.89 | 0.37 | 15.79 | 0.79 |
| 2009 | ES04 | smelt | 76.2 | 22.0 | 0.0 | 0.0 | 5 | 12.14 | 0.19 | -18.01 | 1.06 | 14.26 | 1.80 |
| 2009 | ES04 | Glycera | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 10.56 | | -16.62 | | 14.33 | |
| 2009 | ES04 | Neanthes | 0.0 | 0.0 | 0.0 | 0.0 | 4 | 8.83 | 0.70 | -16.04 | 0.79 | 15.95 | 0.81 |
| 2009 | ES04 | Littorina | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 7.67 | 0.14 | -11.15 | 0.81 | 17.85 | 0.49 |
| 2009 | ES | Atl Herring | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 12.58 | 0.19 | -19.61 | 0.71 | 16.86 | 0.55 |
| 2009 | ES04 | lobster | 80.7 | 12.7 | 0.0 | 0.0 | 11 | 13.00 | 0.36 | -15.80 | 0.49 | 16.09 | 0.52 |

**Appendix 16 - 4b. Summary statistics for the aquatic food web in the lower Penobscot (2009 - OV, BO, OB, and ES04). Total Hg and methyl Hg for fish, shellfish, and invertebrates collected in 2009 in the Penobscot River and Bay. OV = Old Town – Veazie reach; BO = Brewer – Orrington reach; OB = Orrington – Bucksport reach; ES = estuarine reach (Penobscot Bay).**

| Year | Site | Taxa | mean length mm | SD length | mean age years | SD age | n for THg ww | mean THg ng/g ww | SD THg ww | n for MeHg ww | mean MeHg ng/g ww | SD MeHg ww | n for THg dw | mean THg ng/g dw | SD THg dw | n for MeHg dw | mean MeHg ng/g dw | SD MeHg dw |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | OV4 | Oligochaete | 0.0 | 0.0 | 0.0 | 0.0 | 2 | 55.5 | 10.6 | 2 | 2.5 | 0.7 | 2 | 316.5 | 21.9 | 2 | 16.0 | 5.7 |
| 2009 | OV4 | Elliptio | 85.0 | 24.2 | 0.0 | 0.0 | 5 | 94.6 | 18.9 | 5 | 66.2 | 11.9 | 5 | 916.4 | 56.3 | 5 | 645.2 | 81.4 |
| 2008 | OV4 | eel | 0.0 | 0.0 | 8.4 | 3.3 | 9 | 348.3 | 189.9 | 2 | 394.5 | 217.1 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | BO3 | Amphipod | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | BO3 | insect larvae | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | BO3 | Oligochaete | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | BO3 | eel | 0.0 | 0.0 | 6.3 | 1.0 | 7 | 458.9 | 127.7 | 7 | 424.4 | 109.3 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | BO4 | Amphipod | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | BO4 | Oligochaete | 0.0 | 0.0 | 0.0 | 0.0 | 2 | 139.0 | 35.4 | 4 | 30.3 | 8.0 | 2 | 632.5 | 132.2 | 4 | 138.8 | 31.8 |
| 2009 | BO4 | eel | 0.0 | 0.0 | 6.8 | 1.9 | 5 | 704.6 | 201.5 | 5 | 610.2 | 190.4 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB1 | Amphipod | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 9.0 | | 1 | 7.0 | | 1 | 127.0 | | 1 | 105.0 | |
| 2009 | OB1 | Polychaete | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB1 | Crangon | 0.0 | 0.0 | 0.0 | 0.0 | 11 | 58.4 | 17.0 | 11 | 50.0 | 16.3 | 11 | 291.7 | 65.1 | 11 | 250.1 | 66.1 |
| 2009 | OB1 | fundulus | 76.8 | 3.8 | 0.0 | 0.0 | 6 | 210.8 | 45.1 | 2 | 204.5 | 29.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB1 | smelt | 170.3 | 10.0 | 0.0 | 0.0 | 7 | 107.0 | 24.9 | 2 | 79.0 | 4.2 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB1 | eel | 0.0 | 0.0 | 8.2 | 1.9 | 7 | 446.0 | 279.4 | 7 | 414.1 | 268.7 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB1 | tomcod | 141.3 | 35.7 | 0.0 | 0.0 | 13 | 153.5 | 88.5 | 6 | 117.8 | 88.6 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB3 | Crangon | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 82.2 | 10.3 | 5 | 44.0 | 13.1 | 5 | 342.8 | 32.2 | 5 | 182.4 | 48.4 |
| 2009 | OB4 | Amphipod | 0.0 | 0.0 | 0.0 | 0.0 | 2 | 24.5 | 2.1 | 2 | 13.0 | 1.4 | 2 | 171.0 | 0.0 | 2 | 92.5 | 3.5 |
| 2009 | OB4 | insect larvae | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 43.0 | . | 1 | 8.0 | | 1 | 332.0 | | 1 | 62.0 | |
| 2009 | OB4 | Oligochaete | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB4 | Annelid | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 20.0 | . | 1 | 5.0 | | 1 | 211.0 | | 1 | 57.0 | |
| 2009 | OB4 | Crangon | 0.0 | 0.0 | 0.0 | 0.0 | 13 | 77.4 | 11.4 | 13 | 48.5 | 13.4 | 13 | 371.9 | 48.0 | 13 | 231.5 | 54.4 |
| 2009 | OB4 | smelt | 170.3 | 83.4 | 0.0 | 0.0 | 3 | 180.3 | 194.8 | 1 | 301.0 | | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB4 | tomcod | 186.5 | 52.5 | 0.0 | 0.0 | 6 | 281.0 | 216.0 | 5 | 257.6 | 225.5 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB5 | Amphipod | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB5 | insect larvae | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 60.0 | | 1 | 10.0 | | 1 | 563.0 | | 1 | 97.0 | |
| 2009 | OB5 | Neomysis | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB5 | Crangon | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 75.3 | 12.9 | 6 | 56.8 | 12.4 | 6 | 375.0 | 64.0 | 6 | 284.5 | 66.8 |
| 2009 | OB5 | fundulus | 66.8 | 20.5 | 0.0 | 0.0 | 12 | 142.1 | 64.1 | 7 | 147.0 | 75.1 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB5 | eel | 0.0 | 0.0 | 6.9 | 0.9 | 7 | 568.9 | 329.1 | 7 | 492.7 | 264.5 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | OB5 | tomcod | 129.4 | 40.5 | 0.0 | 0.0 | 8 | 183.3 | 42.2 | 5 | 138.6 | 45.1 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES | Atl Herring | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 50.0 | 17.2 | 6 | 53.8 | 10.5 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES04 | zooplankton | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 5.0 | | 1 | 2.0 | | 1 | 43.0 | | 1 | 13.0 | . |
| 2009 | ES04 | mussels | 50.6 | 4.7 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 10 | 91.3 | 19.1 | 10 | 55.6 | 8.0 |
| 2009 | ES04 | Mya | 59.6 | 9.2 | 0.0 | 0.0 | 5 | 19.6 | 2.3 | 5 | 17.2 | 2.9 | 5 | 105.2 | 7.5 | 5 | 93.2 | 15.2 |
| 2009 | ES04 | smelt | 76.2 | 22.0 | 0.0 | 0.0 | 5 | 36.4 | 10.4 | 4 | 29.0 | 7.6 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES04 | Glycera | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 8.0 | | 1 | 3.0 | | 1 | 45.0 | | 1 | 15.0 | . |
| 2009 | ES04 | Neanthes | 0.0 | 0.0 | 0.0 | 0.0 | 4 | 13.5 | 0.6 | 4 | 5.0 | 1.2 | 4 | 75.3 | 5.0 | 4 | 28.5 | 4.8 |
| 2009 | ES04 | Littorina | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 27.4 | 4.4 | 5 | 10.8 | 2.2 | 5 | 117.6 | 18.7 | 5 | 47.6 | 8.2 |
| 2009 | ES | Atl Herring | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 50.0 | 17.2 | 6 | 53.8 | 10.5 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES04 | lobster | 80.7 | 12.7 | 0.0 | 0.0 | 11 | 129.3 | 67.7 | 11 | 120.1 | 67.6 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |

**Appendix 16 - 5a. Summary statistics for carbon, nitrogen and sulfur stable isotope signatures for fish, shellfish, and invertebrates collected in 2009 in Penobscot Bay (2009 – ES13 through ESFP). The $\delta^{13}C$ signatures were lipid normalized using the C:N ratio. OV = Old Town – Veazie reach; BO = Brewer – Orrington reach; OB = Orrington – Bucksport reach; ES = estuarine reach (Penobscot Bay).**

| Year | Site | Taxa | mean length mm | SD length | mean age years | SD age | n for SI | mean $\delta^{15}N$ ‰ | SD $\delta^{15}N$ ‰ | mean normalized $\delta^{13}C$ ‰ | SD normalized $\delta^{13}C$ ‰ | mean $\delta^{34}S$ ‰ | SD $\delta^{34}S$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | ES13 | zooplankton | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 8.50 | | -19.66 | | 14.89 | |
| 2009 | ES13 | mussels | 56.2 | 12.1 | 0.0 | 0.0 | 10 | 7.62 | 0.38 | -16.90 | 0.29 | 17.82 | 0.94 |
| 2009 | ES13 | Mya | 36.0 | 12.8 | 0.0 | 0.0 | 5 | 7.80 | 0.35 | -17.58 | 0.23 | 15.42 | 0.41 |
| 2009 | ES13 | smelt | 133.6 | 19.7 | 0.0 | 0.0 | 5 | 12.83 | 0.58 | -17.29 | 0.46 | 13.99 | 1.61 |
| 2009 | ES13 | tomcod | 106.4 | 26.3 | 0.0 | 0.0 | 5 | 11.71 | 0.36 | -15.78 | 2.51 | 14.22 | 1.24 |
| 2009 | ES13 | Glycera | 0.0 | 0.0 | 0.0 | 0.0 | 2 | 11.43 | 1.94 | -15.08 | 0.89 | 11.29 | 0.30 |
| 2009 | ES13 | Neanthes | 0.0 | 0.0 | 0.0 | 0.0 | 3 | 10.40 | 1.64 | -14.73 | 0.43 | 13.15 | 3.00 |
| 2009 | ES13 | Littorina | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 8.93 | 0.15 | -12.24 | 0.44 | 18.08 | 0.47 |
| 2009 | ES13 | fundulus | 62.0 | 1.4 | 0.0 | 0.0 | 2 | 12.52 | 0.04 | -15.81 | 0.10 | 13.91 | 0.33 |
| 2009 | ES | Atl Herring | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 12.58 | 0.19 | -19.61 | 0.71 | 16.86 | 0.55 |
| 2009 | ES13 | lobster | 87.6 | 4.7 | 0.0 | 0.0 | 5 | 13.48 | 0.28 | -15.86 | 0.37 | 16.51 | 0.41 |
| 2009 | ES15 | zooplankton | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 8.19 | | -19.38 | | 14.65 | . |
| 2009 | ES15 | mussels | 58.2 | 9.6 | 0.0 | 0.0 | 10 | 7.87 | 0.26 | -17.10 | 0.28 | 18.46 | 0.70 |
| 2009 | ES15 | Mya | 51.6 | 13.0 | 0.0 | 0.0 | 5 | 7.66 | 0.24 | -17.23 | 0.17 | 14.63 | 0.88 |
| 2009 | ES15 | smelt | 124.0 | 44.8 | 0.0 | 0.0 | 5 | 13.09 | 0.72 | -16.86 | 0.21 | 12.57 | 1.09 |
| 2009 | ES15 | tomcod | 159.8 | 43.3 | 0.0 | 0.0 | 4 | 12.32 | 0.53 | -16.27 | 2.12 | 13.55 | 2.06 |
| 2009 | ES15 | Glycera | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 12.07 | 1.31 | -16.00 | 0.57 | 15.46 | 1.16 |
| 2009 | ES15 | Littorina | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 9.19 | 0.15 | -12.93 | 1.52 | 19.53 | 0.20 |
| 2009 | ES | Atl Herring | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 12.58 | 0.19 | -19.61 | 0.71 | 16.86 | 0.55 |
| 2009 | ES15 | lobster | 87.2 | 11.0 | 0.0 | 0.0 | 12 | 13.46 | 0.32 | -16.29 | 0.36 | 16.68 | 0.75 |
| 2009 | ESFP | zooplankton | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 7.43 | | -18.54 | | 18.27 | |
| 2009 | ESFP | mussels | 45.7 | 6.5 | 0.0 | 0.0 | 10 | 7.59 | 0.72 | -16.38 | 0.73 | 17.25 | 1.11 |
| 2009 | ESFP | Mya | 65.6 | 16.5 | 0.0 | 0.0 | 5 | 7.88 | 0.46 | -17.22 | 0.11 | 17.11 | 0.35 |
| 2009 | ESFP | smelt | 125.8 | 20.8 | 0.0 | 0.0 | 5 | 12.79 | 0.34 | -15.80 | 0.67 | 12.96 | 1.90 |
| 2009 | ESFP | Neanthes | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 9.76 | 0.42 | -16.74 | 0.29 | 12.73 | 1.46 |
| 2009 | ESFP | Littorina | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 8.55 | 0.18 | -12.67 | 1.25 | 19.58 | 0.28 |
| 2009 | ES | Atl Herring | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 12.58 | 0.19 | -19.61 | 0.71 | 16.86 | 0.55 |
| 2009 | ESFP | lobster | 87.5 | 5.0 | 0.0 | 0.0 | 12 | 13.19 | 0.41 | -15.94 | 0.35 | 16.89 | 0.38 |

**Appendix 16 - 6b. Summary statistics for total Hg and methyl Hg for fish, shellfish, and invertebrates collected in 2009 in Penobscot Bay (2009 – ES13 through ESFP). OV = Old Town – Veazie reach; BO = Brewer – Orrington reach; OB = Orrington – Bucksport reach; ES = estuarine reach (Penobscot Bay).**

| Year | Site | Taxa | mean length mm | SD length | mean age years | SD age | n for THg ww | mean THg ng/g ww | SD THg ww | n for MeHg ww | mean MeHg ng/g ww | SD MeHg ww | n for THg dw | mean THg ng/g dw | SD THg dw | n for MeHg dw | mean MeHg ng/g dw | SD MeHg dw |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | ES13 | zooplankton | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 22.0 | | 1 | 1.0 | . | 1 | 384.0 | . | 1 | 25.0 | . |
| 2009 | ES13 | mussels | 56.2 | 12.1 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 10 | 523.7 | 107.4 | 10 | 253.4 | 79.0 |
| 2009 | ES13 | Mya | 36.0 | 12.8 | 0.0 | 0.0 | 5 | 113.0 | 21.7 | 5 | 87.0 | 18.1 | 5 | 795.0 | 173.3 | 5 | 611.0 | 142.3 |
| 2009 | ES13 | smelt | 133.6 | 19.7 | 0.0 | 0.0 | 5 | 100.2 | 30.4 | 4 | 58.5 | 23.8 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES13 | tomcod | 106.4 | 26.3 | 0.0 | 0.0 | 5 | 110.8 | 33.9 | 4 | 107.5 | 21.5 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES13 | Glycera | 0.0 | 0.0 | 0.0 | 0.0 | 2 | 39.5 | 3.5 | 2 | 8.0 | 0.0 | 2 | 244.0 | 67.9 | 2 | 50.5 | 7.8 |
| 2009 | ES13 | Neanthes | 0.0 | 0.0 | 0.0 | 0.0 | 3 | 33.0 | 8.7 | 3 | 16.7 | 10.8 | 3 | 220.7 | 65.7 | 3 | 113.0 | 77.1 |
| 2009 | ES13 | Littorina | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 99.6 | 6.4 | 5 | 30.6 | 7.0 | 5 | 472.4 | 37.7 | 5 | 143.0 | 21.3 |
| 2009 | ES13 | fundulus | 62.0 | 1.4 | 0.0 | 0.0 | 2 | 257.0 | 77.8 | 1 | 264.0 | | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES | Atl Herring | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 50.0 | 17.2 | 6 | 53.8 | 10.5 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES13 | lobster | 87.6 | 4.7 | 0.0 | 0.0 | 5 | 466.0 | 108.1 | 5 | 445.8 | 113.2 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES15 | zooplankton | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 24.0 | | 1 | 1.0 | | 1 | 474.0 | | 1 | 23.0 | . |
| 2009 | ES15 | mussels | 58.2 | 9.6 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 10 | 472.2 | 121.9 | 10 | 232.9 | 61.3 |
| 2009 | ES15 | Mya | 51.6 | 13.0 | 0.0 | 0.0 | 5 | 39.0 | 4.2 | 5 | 24.0 | 9.2 | 5 | 257.0 | 39.8 | 5 | 158.8 | 68.0 |
| 2009 | ES15 | smelt | 124.0 | 44.8 | 0.0 | 0.0 | 5 | 69.8 | 28.2 | 1 | 22.0 | | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES15 | tomcod | 159.8 | 43.3 | 0.0 | 0.0 | 4 | 137.3 | 54.2 | 1 | 66.0 | | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES15 | Glycera | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 21.2 | 3.4 | 5 | 8.0 | 1.2 | 5 | 131.8 | 25.1 | 5 | 51.0 | 11.9 |
| 2009 | ES15 | Littorina | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 110.8 | 16.7 | 5 | 28.0 | 3.3 | 5 | 469.4 | 80.9 | 5 | 120.8 | 23.3 |
| 2009 | ES | Atl Herring | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 50.0 | 17.2 | 6 | 53.8 | 10.5 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ES15 | lobster | 87.2 | 11.0 | 0.0 | 0.0 | 12 | 245.9 | 136.0 | 12 | 235.1 | 130.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ESFP | zooplankton | 0.0 | 0.0 | 0.0 | 0.0 | 1 | 5.0 | | 1 | 2.0 | | 1 | 47.0 | | 1 | 17.0 | . |
| 2009 | ESFP | mussels | 45.7 | 6.5 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 10 | 309.5 | 70.2 | 10 | 189.0 | 40.5 |
| 2009 | ESFP | Mya | 65.6 | 16.5 | 0.0 | 0.0 | 5 | 27.6 | 3.3 | 5 | 21.6 | 4.0 | 5 | 148.4 | 28.8 | 5 | 114.8 | 26.8 |
| 2009 | ESFP | smelt | 125.8 | 20.8 | 0.0 | 0.0 | 5 | 63.6 | 22.6 | 4 | 39.5 | 3.8 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ESFP | Neanthes | 0.0 | 0.0 | 0.0 | 0.0 | 4 | 32.8 | 8.0 | 5 | 7.6 | 3.4 | 4 | 107.3 | 25.3 | 5 | 25.4 | 13.4 |
| 2009 | ESFP | Littorina | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 62.4 | 5.6 | 5 | 27.6 | 3.4 | 5 | 180.0 | 18.2 | 5 | 79.6 | 10.7 |
| 2009 | ES | Atl Herring | 0.0 | 0.0 | 0.0 | 0.0 | 6 | 50.0 | 17.2 | 6 | 53.8 | 10.5 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |
| 2009 | ESFP | lobster | 87.5 | 5.0 | 0.0 | 0.0 | 12 | 273.3 | 177.1 | 12 | 255.0 | 164.4 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 |

**Appendix 16 - 7a. Summary statistics for the wetland food web at Mendall Marsh East. Carbon, nitrogen and sulfur stable isotope signatures for marsh birds and invertebrates collected in 2009.**

| AREA | GROUP | SITE ID | ORDER | SPECIES /FAMILY | AGE CLASS | N | mean $\delta^{15}N$ ‰ | SD $\delta^{15}N$ ‰ | mean $\delta^{13}C_{raw}$ ‰ | SD $\delta^{13}C_{raw}$ ‰ | mean $\delta^{34}S$ ‰ | SD $\delta^{34}S$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MM-E | BIRD | MM-Northeast | . | NESP | AHY | 31 | 5.93 | 0.67 | -22.93 | 0.37 | 7.27 | 1.84 |
| MM-E | BIRD | MM-Northeast | . | RWBL | AHY | 2 | 7.30 | 0.12 | -26.18 | 3.84 | 6.33 | . |
| MM-E | BIRD | MM-Northeast | . | RWBL | HY | 10 | 6.83 | 0.78 | -24.25 | 1.41 | 7.17 | 2.94 |
| MM-E | BIRD | MM-Northeast | . | SWSP | HY | 1 | 6.10 | . | -24.31 | . | . | . |
| MM-E | BIRD | MM-Northeast | . | VIRA | AHY | 1 | 8.49 | . | -22.91 | . | . | . |
| MM-E | BIRD | MM-Southeast | . | RWBL | HY | 14 | 7.29 | 0.77 | -24.12 | 1.23 | 6.13 | 3.42 |
| MM-E | BIRD | MM-Southeast | . | RWBL | AHY | 5 | 6.23 | 0.69 | -22.99 | 0.47 | 7.48 | 2.58 |
| MM-E | BIRD | MM-Southeast | . | VIRA | AHY | 3 | 5.95 | 0.17 | -24.99 | 0.73 | 11.32 | 1.49 |
| MM-E | BIRD | MM-Southeast | . | VIRA | HY | 2 | 5.91 | 0.24 | -24.10 | 0.64 | . | . |
| MM-E | INVERT | ME_1 | Homoptera | Cicadellidae | | 4 | 5.14 | 0.38 | -24.22 | 1.83 | -2.14 | 0.53 |
| MM-E | INVERT | ME_1 | Diptera | Dolichopodidae | | 1 | 8.25 | . | -18.52 | . | . | . |
| MM-E | INVERT | ME_1 | Diptera | Sciomyzidae | | 1 | 9.39 | . | -17.29 | . | . | . |
| MM-E | INVERT | ME_1 | Amphipoda | Talitridae | | 6 | 4.29 | 0.49 | -24.45 | 0.65 | 14.53 | 0.47 |
| MM-E | INVERT | ME_1 | ARANAEA | Tetragnathidae | | 1 | 7.11 | . | -19.60 | . | 6.80 | . |
| MM-E | INVERT | ME_1+2 | ORTHOPTERA | Tettigoniidae | | 1 | 2.04 | . | -22.48 | . | . | . |
| MM-E | INVERT | ME_2 | ORTHOPTERA | Acrididae | | 2 | -1.30 | . | -27.70 | . | 13.80 | . |
| MM-E | INVERT | ME_2 | Homoptera | Cercopidae | | 1 | 3.28 | . | -27.22 | . | . | . |
| MM-E | INVERT | ME_2 | Homoptera | Cicadellidae | | 1 | 5.37 | . | -27.40 | . | . | . |
| MM-E | INVERT | ME_2 | Homoptera | Fulgoroidea | | 1 | -1.48 | . | -26.64 | . | . | . |
| MM-E | INVERT | ME_2 | ARANAEA | Lycosidae | | 1 | 4.51 | . | -26.86 | . | . | . |
| MM-E | INVERT | ME_2 | Homoptera | Membracidae | | 1 | -4.17 | . | -26.88 | . | 11.17 | . |
| MM-E | INVERT | ME_2 | Diptera (Larvae) | Tabanidae | | 2 | 3.41 | 0.48 | -25.13 | 0.07 | . | . |
| MM-E | INVERT | ME_2 | Amphipoda | Talitridae | | 7 | 1.68 | 0.64 | -25.62 | 1.09 | 14.36 | 1.90 |
| MM-E | INVERT | ME_2 | ARANAEA | Tetragnathidae | | 1 | 5.07 | . | -25.59 | . | . | . |
| MM-E | INVERT | ME_2 | ORTHOPTERA | Tettigoniidae | | 12 | -0.25 | 1.06 | -27.40 | 0.84 | 14.24 | 1.93 |
| MM-E | SOIL | ME_1 | | SOIL | | 1 | 3.92 | . | -27.06 | . | -0.92 | 0.55 |
| MM-E | SOIL | ME_2 | | SOIL | | 1 | 0.67 | . | -28.13 | . | 13.84 | 0.23 |
| MM-E | VEG | ME_1 | | VEGETATION | | 3 | 0.13 | 0.23 | -26.66 | 0.10 | -14.85 | 0.30 |
| MM-E | VEG | ME_2 | | VEGETATION | | 3 | -3.75 | 0.12 | -28.81 | 0.18 | 19.54 | 0.83 |

**Appendix 16 - 8b. Summary statistics for the wetland food web at Mendall Marsh East. Total Hg and methyl Hg for marsh birds and invertebrates collected in 2009.**

| AREA | GROUP | SITE ID | ORDER | SPECIES /FAMILY | AGE CLASS | N | MEAN THg ug/g ww | SD THg ug/g ww | MEAN THg ug/g dw | SD THg ug/g dw | MEAN MeHg ug/g dw | MeHg SD ug/g dw | mean WEIGHT g | SD weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MM-E | BIRD | MM-Northeast | . | NESP | AHY | 31 | 3.899 | 1.120 | . | . | . | . | . | . |
| MM-E | BIRD | MM-Northeast | . | RWBL | AHY | 2 | 3.177 | 1.592 | . | . | . | . | . | . |
| MM-E | BIRD | MM-Northeast | . | RWBL | HY | 10 | 0.614 | 0.434 | . | . | . | . | . | . |
| MM-E | BIRD | MM-Northeast | . | SWSP | HY | 1 | 0.730 | . | . | . | . | . | . | . |
| MM-E | BIRD | MM-Northeast | . | VIRA | AHY | 1 | 1.590 | . | . | . | . | . | . | . |
| MM-E | BIRD | MM-Southeast | . | RWBL | HY | 14 | 0.945 | 1.188 | . | . | . | . | . | . |
| MM-E | BIRD | MM-Southeast | . | RWBL | AHY | 5 | 5.861 | 3.063 | . | . | . | . | . | . |
| MM-E | BIRD | MM-Southeast | . | VIRA | AHY | 3 | 3.557 | 0.730 | . | . | . | . | . | . |
| MM-E | BIRD | MM-Southeast | . | VIRA | HY | 2 | 1.605 | 0.078 | . | . | . | . | . | . |
| MM-E | INVERT | ME_1 | Homoptera | Cicadellidae | | 4 | . | . | 0.022 | 0.005 | 0.001 | . | 0.0116 | 0.0014 |
| MM-E | INVERT | ME_1 | Diptera | Dolichopodidae | | 1 | . | . | 0.352 | . | 0.297 | . | 0.0029 | . |
| MM-E | INVERT | ME_1 | Diptera | Sciomyzidae | | 1 | . | . | 0.693 | . | 0.386 | . | 0.0128 | . |
| MM-E | INVERT | ME_1 | Amphipoda | Talitridae | | 6 | . | . | 0.318 | 0.062 | 0.253 | 0.048 | 0.0772 | 0.0190 |
| MM-E | INVERT | ME_1 | ARANAEA | Tetragnathidae | | 1 | . | . | 0.520 | . | 0.474 | . | 0.0031 | . |
| MM-E | INVERT | ME_1+2 | ORTHOPTERA | Tettigoniidae | | 1 | . | . | 0.123 | . | 0.137 | . | 0.0111 | . |
| MM-E | INVERT | ME_2 | ORTHOPTERA | Acrididae | | 2 | . | . | 0.034 | 0.002 | 0.015 | 0.019 | 0.0297 | 0.0311 |
| MM-E | INVERT | ME_2 | Homoptera | Cercopidae | | 1 | . | . | 0.014 | . | 0.001 | . | 0.0106 | . |
| MM-E | INVERT | ME_2 | Homoptera | Cicadellidae | | 1 | . | . | 0.026 | . | 0.020 | . | 0.0057 | . |
| MM-E | INVERT | ME_2 | Homoptera | Fulgoroidea | | 1 | . | . | 0.043 | . | 0.019 | . | 0.0014 | . |
| MM-E | INVERT | ME_2 | ARANAEA | Lycosidae | | 1 | . | . | 1.111 | . | 0.689 | . | 0.0241 | . |
| MM-E | INVERT | ME_2 | Homoptera | Membracidae | | 1 | . | . | 0.032 | . | 0.009 | . | 0.0054 | . |
| MM-E | INVERT | ME_2 | Diptera (Larvae) | Tabanidae | | 2 | . | . | 1.590 | 0.176 | 1.197 | 0.096 | 0.0528 | 0.0511 |
| MM-E | INVERT | ME_2 | Amphipoda | Talitridae | | 7 | . | . | 0.763 | 0.226 | 0.599 | 0.265 | 0.0754 | 0.0298 |
| MM-E | INVERT | ME_2 | ARANAEA | Tetragnathidae | | 1 | . | . | 1.521 | . | 1.283 | . | 0.0139 | . |
| MM-E | INVERT | ME_2 | ORTHOPTERA | Tettigoniidae | | 12 | . | . | 0.097 | 0.063 | 0.084 | 0.065 | 0.1250 | 0.1142 |
| MM-E | SOIL | ME_1 | | SOIL | | 1 | . | . | 0.606 | . | 0.048 | . | . | . |
| MM-E | SOIL | ME_2 | | SOIL | | 1 | . | . | 0.458 | . | 0.007 | . | . | . |
| MM-E | VEG | ME_1 | | VEGETATION | | 3 | . | . | . | . | . | . | . | . |
| MM-E | VEG | ME_2 | | VEGETATION | | 3 | . | . | . | . | . | . | . | . |

**Appendix 16 - 9a. Summary statistics for the wetland food web at Mendall Marsh West. Carbon, nitrogen and sulfur stable isotope signatures for marsh birds and invertebrates collected in 2009.**

| AREA | GROUP | SITE ID | ORDER | SPECIES /FAMILY | AGE CLASS | N | mean $\delta^{15}N$ ‰ | SD $\delta^{15}N$ ‰ | mean $\delta^{13}C$raw ‰ | SD $\delta^{13}C$raw ‰ | mean $\delta^{34}S$ ‰ | SD $\delta^{34}S$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MM-W | BIRD | MM-Southwest | . | NESP | AHY | 11 | 9.15 | 1.25 | -19.98 | 2.32 | 6.89 | 1.30 |
| MM-W | BIRD | MM-Southwest | . | RWBL | HY | 11 | 6.81 | 0.86 | -25.36 | 1.41 | 5.48 | 2.62 |
| MM-W | BIRD | MM-Southwest | . | RWBL | AHY | 14 | 6.40 | 0.73 | -23.86 | 1.46 | 7.06 | 2.69 |
| MM-W | BIRD | MM-Southwest | . | SOSP | AHY | 2 | 5.54 | 0.04 | -25.68 | 0.06 | 7.46 | . |
| MM-W | BIRD | MM-Southwest | . | SWSP | AHY | 2 | 5.95 | 0.15 | -27.20 | 0.01 | 2.12 | 7.25 |
| MM-W | BIRD | MM-Southwest | . | VIRA | AHY | 6 | 6.98 | 1.52 | -25.83 | 1.65 | 10.72 | 1.70 |
| MM-W | INVERT | MW_1 | Homoptera | Cicadellidae | . | 2 | 5.01 | 0.16 | -26.30 | 0.14 | 0.09 | 0.77 |
| MM-W | INVERT | MW_1 | Diptera | Dolichopodidae | . | 1 | 8.04 | . | -21.51 | . | . | . |
| MM-W | INVERT | MW_1 | Homoptera | Fulgoroidea | . | 1 | 4.22 | . | -18.06 | . | 0.00 | 0.00 |
| MM-W | INVERT | MW_1 | Diptera | Tabanidae | . | 1 | 6.02 | . | -27.12 | . | 7.59 | . |
| MM-W | INVERT | MW_1 | Amphipoda | Talitridae | . | 11 | 4.27 | 0.31 | -24.92 | 0.75 | 12.86 | 1.11 |
| MM-W | INVERT | MW_1 | ARANAEA | Tetragnathidae | . | 3 | 7.03 | 0.38 | -19.98 | 1.20 | 5.41 | . |
| MM-W | INVERT | MW_2 | Homoptera | Cicadellidae | . | 1 | 5.77 | . | -26.34 | . | 0.00 | 0.00 |
| MM-W | INVERT | MW_2 | ARANAEA | Lycosidae | . | 1 | 6.85 | . | -28.49 | . | 2.49 | . |
| MM-W | INVERT | MW_2 | Homoptera | Membracidae | . | 1 | -1.89 | . | -26.53 | . | 0.00 | 0.00 |
| MM-W | INVERT | MW_2 | Diptera (Larvae) | Tabanidae | . | 1 | 5.90 | . | -29.92 | . | -1.52 | . |
| MM-W | INVERT | MW_2 | Amphipoda | Talitridae | . | 7 | 3.70 | 0.50 | -26.04 | 0.58 | 9.88 | 0.99 |
| MM-W | INVERT | MW_2 | ORTHOPTERA | Tettigoniidae | . | 2 | 2.57 | 0.37 | -25.96 | 0.69 | . | . |
| MM-W | SOIL | MW_1 | | SOIL | . | . | 3.41 | . | -27.13 | . | -4.16 | 0.34 |
| MM-W | SOIL | MW_2 | | SOIL | . | . | 0.55 | . | -26.82 | . | 9.32 | 0.40 |
| MM-W | VEG | MW_1 | | VEGETATION | . | . | 2.91 | 0.10 | -24.49 | 0.53 | -0.78 | 0.27 |
| MM-W | VEG | MW_2 | | VEGETATION | . | . | 1.83 | 0.09 | -27.33 | 0.17 | 0.88 | 0.35 |

**Appendix 16 - 10b. Summary statistics for the wetland food web at Mendall Marsh West. Total Hg and methyl Hg for marsh birds and invertebrates collected in 2009.**

| AREA | GROUP | SITE ID | ORDER | SPECIES /FAMILY | AGE CLASS | N | MEAN THg ug/g ww | SD THg ug/g ww | MEAN THg ug/g dw | SD THg ug/g dw | MEAN MeHg ug/g dw | MeHg SD ug/g dw | mean WEIGHT g | SD weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MM-W | BIRD | MM-Southwest | . | NESP | AHY | 11 | 3.192 | 1.718 | . | . | . | . | . | . |
| MM-W | BIRD | MM-Southwest | . | RWBL | HY | 11 | 0.890 | 0.670 | . | . | . | . | . | . |
| MM-W | BIRD | MM-Southwest | . | RWBL | AHY | 14 | 4.401 | 3.261 | . | . | . | . | . | . |
| MM-W | BIRD | MM-Southwest | . | SOSP | AHY | 2 | 0.546 | 0.287 | . | . | . | . | . | . |
| MM-W | BIRD | MM-Southwest | . | SWSP | AHY | 2 | 3.330 | 0.325 | . | . | . | . | . | . |
| MM-W | BIRD | MM-Southwest | . | VIRA | AHY | 6 | 2.919 | 2.219 | . | . | . | . | . | . |
| MM-W | INVERT | MW_1 | Homoptera | Cicadellidae | . | 2 | . | . | 0.023 | 0.006 | 0.009 | 0.011 | 0.0086 | 0.0002 |
| MM-W | INVERT | MW_1 | Diptera | Dolichopodidae | . | 1 | . | . | 0.833 | . | 0.548 | . | 0.0009 | . |
| MM-W | INVERT | MW_1 | Homoptera | Fulgoroidea | . | 1 | . | . | 0.020 | . | 0.001 | . | 0.0047 | . |
| MM-W | INVERT | MW_1 | Diptera | Tabanidae | . | 1 | . | . | 3.322 | . | 2.787 | . | 0.0733 | . |
| MM-W | INVERT | MW_1 | Amphipoda | Talitridae | . | 11 | . | . | 0.662 | 0.227 | 0.515 | 0.189 | 0.0625 | 0.0202 |
| MM-W | INVERT | MW_1 | ARANAEA | Tetragnathidae | . | 3 | . | . | 0.687 | 0.230 | 0.403 | 0.066 | 0.0116 | 0.0069 |
| MM-W | INVERT | MW_2 | Homoptera | Cicadellidae | . | 1 | . | . | 0.046 | . | 0.001 | . | 0.0030 | . |
| MM-W | INVERT | MW_2 | ARANAEA | Lycosidae | . | 1 | . | . | 1.718 | . | 1.880 | . | 0.0253 | . |
| MM-W | INVERT | MW_2 | Homoptera | Membracidae | . | 1 | . | . | 0.023 | . | 0.030 | . | 0.0055 | . |
| MM-W | INVERT | MW_2 | Diptera (Larvae) | Tabanidae | . | 1 | . | . | 1.063 | . | 0.924 | . | . | . |
| MM-W | INVERT | MW_2 | Amphipoda | Talitridae | . | 7 | . | . | 0.863 | 0.256 | 0.647 | 0.157 | 0.0910 | 0.0156 |
| MM-W | INVERT | MW_2 | ORTHOPTERA | Tettigoniidae | . | 2 | . | . | 0.166 | 0.061 | 0.170 | 0.069 | 0.0219 | 0.0020 |
| MM-W | SOIL | MW_1 | | SOIL | . | . | . | . | 0.782 | . | 0.038 | . | . | . |
| MM-W | SOIL | MW_2 | | SOIL | . | . | . | . | 0.094 | . | 0.000 | . | . | . |
| MM-W | VEG | MW_1 | | VEGETATION | . | . | . | . | . | . | . | . | . | . |
| MM-W | VEG | MW_2 | | VEGETATION | . | . | . | . | . | . | . | . | . | . |

**Appendix 16 - 11a. Summary statistics for the wetland food web at Scarborough Marsh. Carbon, nitrogen and sulfur stable isotope signatures for marsh birds and invertebrates collected in 2009.**

| AREA | GROUP | SITE ID | ORDER | SPECIES /FAMILY | AGE CLASS | N | mean $\delta^{15}N$ ‰ | SD $\delta^{15}N$ ‰ | mean $\delta^{13}C_{raw}$ ‰ | SD $\delta^{13}C_{raw}$ ‰ | mean $\delta^{34}S$ ‰ | SD $\delta^{34}S$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SM | BIRD | Scarborough | . | NESP | AHY | 11 | 6.61 | 0.80 | -15.09 | 0.71 | -0.99 | 2.74 |
| SM | BIRD | Scarborough | . | VIRA | AHY | 7 | 8.63 | 0.97 | -19.88 | 3.34 | 6.53 | 2.85 |
| SM | INVERT | SM_2 | Homoptera | Cercopidae | . | 1 | 6.34 | . | -11.33 | . | -3.41 | . |
| SM | INVERT | SM_2 | Homoptera | Cicadellidae | . | 2 | 3.25 | 0.02 | -12.35 | 0.28 | -6.06 | 0.37 |
| SM | INVERT | SM_2 | Homoptera | Fulgoroidea | . | 1 | 3.44 | . | -12.88 | . | . | . |
| SM | INVERT | SM_2 | ARANAEA | Lycosidae | . | 1 | 6.93 | . | -15.34 | . | . | . |
| SM | INVERT | SM_2 | Diptera (Larvae) | Tabanidae | . | 4 | 5.50 | 0.38 | -16.29 | 0.20 | 7.06 | 0.24 |
| SM | INVERT | SM_2 | Diptera | Tachinidae | . | 1 | 11.35 | . | -17.06 | . | 4.79 | . |
| SM | INVERT | SM_2 | Amphipoda | Talitridae | . | 5 | 4.79 | 1.34 | -18.13 | 3.05 | 12.03 | 1.86 |
| SM | INVERT | SM_2 | ARANAEA | Tetragnathidae | . | 3 | 5.86 | 0.75 | -16.74 | 0.11 | -0.07 | 0.79 |
| SM | INVERT | SM_2 | ORTHOPTERA | Tettigoniidae | . | 1 | 5.24 | . | -13.92 | . | -4.82 | . |
| SM | INVERT | SM_2 | Diptera | Ulidiidae | . | 3 | 6.93 | 0.59 | -13.55 | 0.11 | -8.38 | 0.86 |
| SM | SOIL | SM_2 | | SOIL | . | 1 | 1.72 | . | -15.17 | . | 1.95 | 0.31 |
| SM | VEG | SM_2 | | VEGETATION | . | 3 | 2.84 | 0.18 | -12.93 | 0.21 | -7.03 | 0.06 |

**Appendix 16 - 12b. Summary statistics for the wetland food web at Scarborough Marsh. Total Hg and methyl Hg for marsh birds and invertebrates collected in 2009.**

| AREA | GROUP | SITE ID | ORDER | SPECIES /FAMILY | AGE CLASS | N | MEAN THg ug/g ww | SD THg ug/g ww | MEAN THg ug/g dw | SD THg ug/g dw | MEAN MeHg ug/g dw | MeHg SD ug/g dw | mean WEIGHT g | SD weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SM | BIRD | Scarborough | . | NESP | AHY | 11 | 0.784 | 0.529 | . | . | . | . | . | . |
| SM | BIRD | Scarborough | . | VIRA | AHY | 7 | 0.159 | 0.060 | . | . | . | . | . | . |
| SM | INVERT | SM_2 | Homoptera | Cercopidae | . | 1 | . | . | 0.026 | . | 0.015 | . | 0.0142 | . |
| SM | INVERT | SM_2 | Homoptera | Cicadellidae | . | 2 | . | . | 0.016 | 0.003 | 0.001 | . | 0.0026 | 0.0003 |
| SM | INVERT | SM_2 | Homoptera | Fulgoroidea | . | 1 | . | . | 0.015 | . | 0.001 | . | 0.0013 | . |
| SM | INVERT | SM_2 | ARANAEA | Lycosidae | . | 1 | . | . | 0.105 | . | 0.083 | . | 0.0060 | . |
| SM | INVERT | SM_2 | Diptera (Larvae) | Tabanidae | . | 4 | . | . | 0.162 | 0.040 | 0.122 | 0.047 | 0.0845 | 0.0077 |
| SM | INVERT | SM_2 | Diptera | Tachinidae | . | 1 | . | . | 0.112 | . | 0.041 | . | 0.0121 | . |
| SM | INVERT | SM_2 | Amphipoda | Talitridae | . | 5 | . | . | 0.100 | 0.016 | 0.042 | 0.040 | 0.0614 | 0.0315 |
| SM | INVERT | SM_2 | ARANAEA | Tetragnathidae | . | 3 | . | . | 0.100 | 0.023 | 0.105 | 0.022 | 0.0091 | 0.0083 |
| SM | INVERT | SM_2 | ORTHOPTERA | Tettigoniidae | . | 1 | . | . | 0.035 | . | 0.020 | . | 0.0720 | . |
| SM | INVERT | SM_2 | Diptera | Ulidiidae | . | 3 | . | . | 0.042 | 0.017 | 0.026 | 0.008 | 0.0078 | 0.0040 |
| SM | SOIL | SM_2 | | SOIL | . | 1 | . | . | 0.037 | . | 0.002 | . | . | . |
| SM | VEG | SM_2 | | VEGETATION | . | 3 | . | . | . | . | . | . | . | . |

**Appendix 16 - 13a. Summary statistics for the wetland food web at W17. Carbon, nitrogen and sulfur stable isotope signatures for marsh birds and invertebrates collected in 2009 in Penobscot Bay.**

| AREA | GROUP | SITE ID | ORDER | SPECIES / FAMILY | AGE CLASS | N | mean $\delta^{15}N$ ‰ | SD $\delta^{15}N$ ‰ | mean $\delta^{13}C_{raw}$ ‰ | SD $\delta^{13}C_{raw}$ ‰ | mean $\delta^{34}S$ ‰ | SD $\delta^{34}S$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W17 | BIRD | W-17-N | . | NESP | AHY | 7 | 6.93 | 0.87 | -21.85 | 1.00 | 4.83 | 2.25 |
| W17 | BIRD | W-17-N | . | RWBL | AHY | 1 | 6.53 | . | -21.54 | . | 1.71 | . |
| W17 | BIRD | W-17-N | . | RWBL | HY | 5 | 6.30 | 0.37 | -23.88 | 0.67 | 2.85 | 3.11 |
| W17 | BIRD | W-17-N | . | SOSP | AHY | 5 | 6.38 | 1.18 | -22.78 | 0.98 | 8.96 | 2.06 |
| W17 | BIRD | W-17-N | . | SOSP | HY | 3 | 7.04 | 1.57 | -23.65 | 0.54 | 6.69 | . |
| W17 | BIRD | W-17-N | . | SWSP | AHY | 3 | 5.01 | 0.37 | -25.02 | 0.13 | 6.93 | . |
| W17 | BIRD | W-17-N | . | SWSP | HY | 1 | 5.53 | . | -28.27 | . | . | . |
| W17 | BIRD | W-17-N | . | VIRA | AHY | 1 | 7.13 | . | -24.73 | . | 5.34 | . |
| W17 | BIRD | W-17-S | . | NESP | AHY | 2 | 7.35 | 0.21 | -20.21 | 0.18 | . | . |
| W17 | BIRD | W-17-S | . | SOSP | AHY | 2 | 7.86 | 0.62 | -20.60 | 0.83 | 8.83 | 0.04 |
| W17 | INVERT | W17_1 | ARANAEA | Araneidae | . | 1 | 7.26 | . | -22.15 | . | . | . |
| W17 | INVERT | W17_1 | Homoptera | Cicadellidae | . | 3 | 5.71 | 0.34 | -25.36 | 1.53 | -1.36 | 1.42 |
| W17 | INVERT | W17_1 | Diptera | Dolichopodidae | . | 1 | 7.25 | . | -22.68 | . | . | . |
| W17 | INVERT | W17_1 | Hymenoptera | Ichneumonidae | . | 1 | 6.40 | . | -23.28 | . | . | . |
| W17 | INVERT | W17_1 | ARANAEA | Lycosidae | . | 2 | 7.44 | 0.78 | -22.95 | 0.87 | 12.62 | 0.61 |
| W17 | INVERT | W17_1 | Diptera | Syrphidae | . | 1 | 5.81 | . | -18.48 | . | . | . |
| W17 | INVERT | W17_1 | Diptera | Tabanidae | . | 1 | 5.52 | . | -24.61 | . | 11.58 | . |
| W17 | INVERT | W17_1 | Diptera (Larvae) | Tabanus | . | 1 | 6.22 | . | -24.47 | . | 7.02 | . |
| W17 | INVERT | W17_1 | Amphipoda | Talitridae | . | 5 | 3.65 | 0.80 | -23.44 | 0.60 | 17.56 | 0.90 |
| W17 | INVERT | W17_1 | ARANAEA | Tetragnathidae | . | 1 | 6.68 | . | -23.29 | . | 0.00 | 0.00 |
| W17 | INVERT | W17_1 | ORTHOPTERA | Tettigoniidae | . | 3 | 3.71 | 1.00 | -24.34 | 2.25 | 5.08 | 0.40 |
| W17 | INVERT | W17_2 | ORTHOPTERA | Acrididae | . | 1 | 1.78 | . | -16.61 | . | . | . |
| W17 | INVERT | W17_2 | ARANAEA | Araneidae | . | 1 | 4.66 | . | -24.81 | . | 8.70 | . |
| W17 | INVERT | W17_2 | ARANAEA | Araneidae+Lycosida | . | 1 | 5.64 | . | -21.23 | . | 4.66 | . |
| W17 | INVERT | W17_2 | Homoptera | Cicadellidae | . | 2 | 1.54 | 0.26 | -11.80 | 0.38 | -5.78 | 1.45 |
| W17 | INVERT | W17_2 | Diptera | Dolichopodidae | . | 1 | 5.71 | . | -25.13 | . | . | . |
| W17 | INVERT | W17_2 | Diptera | Tabanidae | . | 3 | 7.68 | 2.75 | -23.19 | 1.11 | 7.88 | 4.58 |
| W17 | INVERT | W17_2 | Amphipoda | Talitridae | . | 6 | 2.34 | 0.67 | -22.49 | 1.91 | 15.73 | 1.58 |
| W17 | INVERT | W17_2 | ARANAEA | Tetragnathidae | . | 1 | 5.28 | . | -22.49 | . | . | . |
| W17 | INVERT | W17_2 | ORTHOPTERA | Tettigoniidae | . | 10 | 2.61 | 0.35 | -21.51 | 3.34 | 5.18 | 1.99 |
| W17 | SOIL | W17_1 | | SOIL | . | 1 | 3.04 | . | -27.05 | . | 1.88 | 0.06 |
| W17 | SOIL | W17_2 | | SOIL | . | 1 | 0.84 | . | -20.12 | . | 0.89 | 0.29 |
| W17 | VEG | W17_1 | | VEGETATION | . | 3 | 2.51 | 0.06 | -26.41 | 0.28 | 1.46 | 0.40 |
| W17 | VEG | W17_2 | | VEGETATION | . | 3 | 0.88 | 0.05 | -13.62 | 0.36 | -3.88 | 0.30 |

**Appendix 16 - 14b. Summary statistics for the wetland food web at W17. Total Hg and methyl Hg for marsh birds and invertebrates collected in 2009 in Penobscot Bay.**

| AREA | GROUP | SITE ID | ORDER | SPECIES /FAMILY | AGE CLASS | N | MEAN THg ug/g ww | SD THg ug/g ww | MEAN THg ug/g dw | SD THg ug/g dw | MEAN MeHg ug/g dw | MeHg SD ug/g dw | mean WEIGHT g | SD weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W17 | BIRD | W-17-N | . | NESP | AHY | 7 | 4.949 | 2.416 | . | . | . | . | . | . |
| W17 | BIRD | W-17-N | . | RWBL | AHY | 1 | 4.254 | . | . | . | . | . | . | . |
| W17 | BIRD | W-17-N | . | RWBL | HY | 5 | 2.215 | 1.716 | . | . | . | . | . | . |
| W17 | BIRD | W-17-N | . | SOSP | AHY | 5 | 1.523 | 0.633 | . | . | . | . | . | . |
| W17 | BIRD | W-17-N | . | SOSP | HY | 3 | 0.833 | 0.870 | . | . | . | . | . | . |
| W17 | BIRD | W-17-N | . | SWSP | AHY | 3 | 1.633 | 0.803 | . | . | . | . | . | . |
| W17 | BIRD | W-17-N | . | SWSP | HY | 1 | 0.520 | . | . | . | . | . | . | . |
| W17 | BIRD | W-17-N | . | VIRA | AHY | 1 | 2.914 | . | . | . | . | . | . | . |
| W17 | BIRD | W-17-S | . | NESP | AHY | 2 | 4.613 | 0.677 | . | . | . | . | . | . |
| W17 | BIRD | W-17-S | . | SOSP | AHY | 2 | 1.864 | 0.606 | . | . | . | . | . | . |
| W17 | INVERT | W17_1 | ARANAEA | Araneidae | . | 1 | . | . | 1.125 | . | 0.974 | . | 0.0232 | . |
| W17 | INVERT | W17_1 | Homoptera | Cicadellidae | . | 3 | . | . | 0.056 | 0.004 | 0.054 | 0.004 | 0.0111 | 0.0027 |
| W17 | INVERT | W17_1 | Diptera | Dolichopodidae | . | 1 | . | . | 0.845 | . | 0.730 | . | 0.0044 | . |
| W17 | INVERT | W17_1 | Hymenoptera | Ichneumonidae | . | 1 | . | . | 0.201 | . | 0.102 | . | 0.0040 | 0.0038 |
| W17 | INVERT | W17_1 | ARANAEA | Lycosidae | . | 2 | . | . | 1.055 | 0.169 | 0.885 | 0.065 | 0.0154 | 0.0026 |
| W17 | INVERT | W17_1 | Diptera | Syrphidae | . | 1 | . | . | 0.022 | . | 0.006 | . | 0.0105 | . |
| W17 | INVERT | W17_1 | Diptera | Tabanidae | . | 1 | . | . | 2.928 | . | 3.480 | . | 0.0754 | . |
| W17 | INVERT | W17_1 | Diptera (Larvae) | Tabanus | . | 1 | . | . | 1.251 | . | 1.168 | . | 0.0651 | . |
| W17 | INVERT | W17_1 | Amphipoda | Talitridae | . | 5 | . | . | 0.957 | 0.233 | 0.749 | 0.166 | 0.0747 | 0.0373 |
| W17 | INVERT | W17_1 | ARANAEA | Tetragnathidae | . | 1 | . | . | 1.820 | . | 1.956 | . | 0.0046 | . |
| W17 | INVERT | W17_1 | ORTHOPTERA | Tettigoniidae | . | 3 | . | . | 0.179 | 0.061 | 0.146 | 0.040 | 0.0526 | 0.0197 |
| W17 | INVERT | W17_2 | ORTHOPTERA | Acrididae | . | 1 | . | . | 0.066 | . | 0.066 | . | 0.0263 | . |
| W17 | INVERT | W17_2 | ARANAEA | Araneidae | . | 1 | . | . | 2.842 | . | 1.910 | . | 0.0222 | . |
| W17 | INVERT | W17_2 | ARANAEA | Araneidae+Lycosida | . | 1 | . | . | 2.571 | . | 2.080 | . | 0.0212 | . |
| W17 | INVERT | W17_2 | Homoptera | Cicadellidae | . | 2 | . | . | 0.074 | 0.004 | 0.069 | 0.016 | 0.0104 | 0.0084 |
| W17 | INVERT | W17_2 | Diptera | Dolichopodidae | . | 1 | . | . | 2.118 | . | 1.467 | . | 0.0058 | . |
| W17 | INVERT | W17_2 | Diptera | Tabanidae | . | 3 | . | . | 2.626 | 1.787 | 2.355 | 1.610 | 0.0595 | 0.0152 |
| W17 | INVERT | W17_2 | Amphipoda | Talitridae | . | 6 | . | . | 1.475 | 0.245 | 1.112 | 0.397 | 0.0744 | 0.0241 |
| W17 | INVERT | W17_2 | ARANAEA | Tetragnathidae | . | 1 | . | . | 2.767 | . | 2.318 | . | 0.0056 | . |
| W17 | INVERT | W17_2 | ORTHOPTERA | Tettigoniidae | . | 10 | . | . | 0.166 | 0.051 | 0.166 | 0.036 | 0.0673 | 0.0319 |
| W17 | SOIL | W17_1 | | SOIL | . | 1 | . | . | 0.812 | . | 0.082 | . | . | . |
| W17 | SOIL | W17_2 | | SOIL | . | 1 | . | . | 0.360 | . | 0.039 | . | . | . |
| W17 | VEG | W17_1 | | VEGETATION | . | 3 | . | . | . | . | . | . | . | . |
| W17 | VEG | W17_2 | | VEGETATION | . | 3 | . | . | . | . | . | . | . | . |

**Appendix 16 - 15a. Summary statistics for the wetland food web at sites in the lower Penobscot and along the outer coast. Carbon, nitrogen and sulfur stable isotope signatures for marsh birds collected in 2009.**

| AREA | GROUP | SITE ID | ORDER | SPECIES /FAMILY | AGE CLASS | N | mean $\delta^{15}N$ ‰ | SD $\delta^{15}N$ ‰ | mean $\delta^{13}C$raw ‰ | SD $\delta^{13}C$raw ‰ | mean $\delta^{34}S$ ‰ | SD $\delta^{34}S$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BH | BIRD | Bald Hill Cove No | . | SOSP | AHY | 2 | 5.79 | 0.86 | -23.14 | 0.95 | 8.10 | 2.27 |
| BH | BIRD | Bald Hill Cove No | . | SOSP | HY | 1 | 8.14 | . | -19.68 | . | -0.52 | . |
| BS | BIRD | Bass Harbor | . | SWSP | AHY | 1 | 7.80 | . | -26.96 | . | . | . |
| LP | BIRD | Leaches Point-LP | . | SOSP | AHY | 2 | 5.85 | 0.11 | -24.75 | 0.45 | 6.69 | . |
| LP | BIRD | Leaches Point-Gr | . | SOSP | AHY | 2 | 6.67 | 1.01 | -24.73 | 0.31 | 7.78 | . |
| LP | BIRD | Leaches Point-Or | . | SOSP | AHY | 4 | 5.02 | 0.78 | -24.13 | 0.43 | 0.38 | 7.98 |
| LP | BIRD | Leaches Point-LP | . | SWSP | AHY | 3 | 7.16 | 0.26 | -26.00 | 0.70 | 10.55 | . |
| MM-CAR | BIRD | MM-Car dealer | . | RWBL | AHY | 1 | 5.95 | . | -22.73 | . | 4.68 | . |
| MM-CAR | BIRD | MM-Car dealer | . | SWSP | AHY | 2 | 6.40 | 1.28 | -25.39 | 0.23 | 6.00 | 3.39 |
| MM-CAR | BIRD | MM-Car dealer | . | VIRA | AHY | 1 | 6.74 | . | -25.08 | . | 11.87 | . |
| MM-JETTI | BIRD | MM-Jetti | . | NESP | AHY | 2 | 8.82 | 1.48 | -20.71 | 2.63 | . | . |
| MM-JETTI | BIRD | MM-Jetti | . | SOSP | AHY | 1 | 7.70 | . | -22.67 | . | 3.64 | . |
| MM-JETTI | BIRD | MM-Jetti | . | SWSP | AHY | 3 | 7.38 | 0.84 | -24.32 | 3.41 | 7.43 | 1.45 |
| MM-JETTI | BIRD | MM-Jetti | . | VIRA | AHY | 4 | 7.23 | 0.43 | -25.04 | 0.38 | 10.92 | 1.18 |
| MM-S174 | BIRD | MM-south-174 | . | NESP | AHY | 9 | 6.11 | 0.75 | -23.57 | 0.83 | 10.43 | 1.24 |
| MM-S174 | BIRD | MM-south-174 | . | RWBL | HY | 4 | 6.90 | 0.19 | -24.91 | 0.94 | 5.02 | 1.60 |
| MM-S174 | BIRD | MM-south-174 | . | RWBL | AHY | 6 | 6.39 | 0.56 | -23.96 | 0.77 | 3.73 | 2.59 |
| MM-S174 | BIRD | MM-South-174 | . | SOSP | AHY | 1 | 8.57 | . | -25.40 | . | 8.26 | . |
| MM-S174 | BIRD | MM-South-174 | . | SWSP | HY | 2 | 5.27 | 0.15 | -24.67 | 1.03 | . | . |
| MM-S174 | BIRD | MM-South-174 | . | SWSP | AHY | 7 | 6.67 | 1.32 | -23.34 | 0.65 | 5.80 | . |
| MM-S174 | BIRD | MM-South-174 | . | VIRA | AHY | 3 | 7.12 | 1.01 | -29.03 | 3.49 | 9.85 | 3.48 |
| MM-TREAT | BIRD | MM-Treat Pt. | . | VIRA | AHY | 4 | 7.27 | 0.47 | -25.16 | 0.49 | 10.41 | 0.93 |
| RCNWR | BIRD | RCNWR | . | NESP | AHY | 4 | 8.13 | 0.68 | -15.47 | 0.76 | . | . |
| TREMONT | BIRD | TREMONT | . | NESP | AHY | 1 | 5.63 | . | -17.65 | . | . | . |
| TREMONT | BIRD | Tremont | . | SOSP | HY | 1 | 5.37 | . | -24.58 | . | 6.77 | . |

**Appendix 16 - 16b. Summary statistics for the wetland food web at sites in the lower Penobscot and along the outer coast. Carbon, nitrogen and sulfur stable isotope signatures for marsh birds collected in 2009.**

| AREA | GROUP | SITE ID | ORDER | SPECIES /FAMILY | AGE CLASS | N | MEAN THg ug/g ww | SD THg ug/g ww | MEAN THg ug/g dw | SD THg ug/g dw | MEAN MeHg ug/g dw | MeHg SD ug/g dw | mean WEIGHT g | SD weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BH | BIRD | Bald Hill Cove No | . | SOSP | AHY | 2 | 0.114 | 0.019 | . | . | . | . | . | . |
| BH | BIRD | Bald Hill Cove No | . | SOSP | HY | 1 | 0.052 | . | . | . | . | . | . | . |
| BS | BIRD | Bass Harbor | . | SWSP | AHY | 1 | 1.190 | . | . | . | . | . | . | . |
| LP | BIRD | Leaches Point-LP | . | SOSP | AHY | 2 | 0.184 | 0.046 | . | . | . | . | . | . |
| LP | BIRD | Leaches Point-Gr | . | SOSP | AHY | 2 | 0.064 | 0.027 | . | . | . | . | . | . |
| LP | BIRD | Leaches Point-Or | . | SOSP | AHY | 4 | 0.186 | 0.073 | . | . | . | . | . | . |
| LP | BIRD | Leaches Point-LP | . | SWSP | AHY | 3 | 0.593 | 0.296 | . | . | . | . | . | . |
| MM-CAR | BIRD | MM-Car dealer | . | RWBL | AHY | 1 | 0.734 | . | . | . | . | . | . | . |
| MM-CAR | BIRD | MM-Car dealer | . | SWSP | AHY | 2 | 0.460 | 0.170 | . | . | . | . | . | . |
| MM-CAR | BIRD | MM-Car dealer | . | VIRA | AHY | 1 | 1.816 | . | . | . | . | . | . | . |
| MM-JETTI | BIRD | MM-Jetti | . | NESP | AHY | 2 | 3.209 | . | . | . | . | . | . | . |
| MM-JETTI | BIRD | MM-Jetti | . | SOSP | AHY | 1 | 2.188 | . | . | . | . | . | . | . |
| MM-JETTI | BIRD | MM-Jetti | . | SWSP | AHY | 3 | 2.250 | 0.964 | . | . | . | . | . | . |
| MM-JETTI | BIRD | MM-Jetti | . | VIRA | AHY | 4 | 2.871 | 1.635 | . | . | . | . | . | . |
| MM-S174 | BIRD | MM-south-174 | . | NESP | AHY | 9 | 4.122 | 1.685 | . | . | . | . | . | . |
| MM-S174 | BIRD | MM-south-174 | . | RWBL | HY | 4 | 0.317 | 0.198 | . | . | . | . | . | . |
| MM-S174 | BIRD | MM-south-174 | . | RWBL | AHY | 6 | 2.005 | 1.722 | . | . | . | . | . | . |
| MM-S174 | BIRD | MM-South-174 | . | SOSP | AHY | 1 | 0.033 | . | . | . | . | . | . | . |
| MM-S174 | BIRD | MM-South-174 | . | SWSP | HY | 2 | 1.035 | 0.106 | . | . | . | . | . | . |
| MM-S174 | BIRD | MM-South-174 | . | SWSP | AHY | 7 | 1.109 | 0.447 | . | . | . | . | . | . |
| MM-S174 | BIRD | MM-South-174 | . | VIRA | AHY | 3 | 1.295 | 0.146 | . | . | . | . | . | . |
| MM-TREAT | BIRD | MM-Treat Pt. | . | VIRA | AHY | 4 | 2.170 | 1.184 | . | . | . | . | . | . |
| RCNWR | BIRD | RCNWR | . | NESP | AHY | 4 | 0.485 | 0.076 | . | . | . | . | . | . |
| TREMONT | BIRD | TREMONT | . | NESP | AHY | 1 | 0.631 | . | . | . | . | . | . | . |
| TREMONT | BIRD | Tremont | . | SOSP | HY | 1 | 0.024 | . | . | . | . | . | . | . |