IDENTIFYING BYCATCH OF SHORT-FINNED PILOT WHALES (*Globicephala macrorhynchus*) IN A LONGLINE FISHERY:

CEPHALOPOD IDENTIFICATION AND STABLE ISOTOPE REVIEW

by

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Short-finned pilot whales (*Globicephala macrorhynchus*) generally forage on cephalopods in the mesopelagic zone, sometimes diving to over 1000m in depth in pursuit of prey. However, pilot whales and several other species of odontocetes have learned to target longline fishing vessels to depredate (prey upon) hooked fish. These odontocetes may gain energetic benefits due to the high calorie prey and relatively little effort involved in depredation. Each year, hundreds of short-finned pilot whales become hooked due to depredation attempts and even if they break free they can become injured by trailing gear. In order to understand and reduce these interactions, basic questions still need to be answered, including which segments of the population are preying upon hooked fish? Stable isotope analysis is a powerful tool used to study trophic interactions and can potentially identify pilot whales that are depredating on tuna. This requires stable isotope values of the pilot whales, tuna, and cephalopod prey of both the pilot whales and tuna to enable estimates of trophic relationships. Stable isotope values of cephalopods are lacking in the western North Atlantic.

Regarding cephalopod prey, the only stomach content analysis (SCA) study of short-finned pilot whales in this region was of 27 whales that stranded on the coast of North Carolina. The most important cephalopod prey families were Brachioteuthidae, Cranchiidae, and Histiooteuthidae, followed by several others. The primary cephalopod taxa are not caught in commercial fisheries, and offshore sampling is logistically and financially difficult. Considering those challenges, this study aims to use SCA of several tuna species to determine if tuna, and which species in particular, can be used as biological samplers to obtain the same deep-water cephalopod taxa that short-finned pilot whales prey upon.

Two bigeye (*Thunnus obesus*), nine yellowfin (*T. albacares*), and four blackfin (*T. atlanticus*) tuna were collected between July and November, 2015, by recreational charter vessels off of Manteo and Morehead City, NC. Stomachs were examined and the lower beaks of cephalopods were separated for identification. 91 lower beaks were identified to the lowest possible taxa. The bigeye tuna collected were longer (Fork Length = 152 – 180cm) than both yellowfin (FL = 69 – 130cm) and blackfin (FL = 60 – 66cm) tuna. In total, 78 of the 91 lower beaks belonged to the family Ommastrephidae, of which six species are found in the western North Atlantic. Examining the cephalopod prey by predator type, bigeye tuna stomachs contained 15 lower beaks of a diverse range of taxa, including at least 5 families. They contained at least four specimens from the Cranchiidae and Histiooteuthidae families; both families are commonly found in the mesopelagic and bathypelagic zones, from 200m to 1,800m. The bigeye stomachs also contained eight Ommastrephidae specimens, which are often found in the epipelagic zone, though they are encountered in deeper waters as well. The yellowfin stomachs were mostly empty of cephalopod prey; only three lower beaks were found, of which two were Ommastrephidae. Blackfin tuna had 73 lower beaks, of which 68 belonged to the Ommastrephidae family.

Despite the limited sample sizes in this study, the distribution of cephalopod taxa among the tuna species agrees with studies from other oceans and the limited literature in the western North Atlantic. Bigeye tuna have greater thermoregulatory abilities than yellowfin or blackfin.
tuna, allowing them to forage deeper into the mesopelagic zone. Thus bigeye tuna often have greater occurrences of Histiooteuthidae, Cranchiidae, Enoploteuthidae, and other mesopelagic cephalopod families. Ontogenetic shifts have been demonstrated in yellowfin tuna, showing that larger individuals are able to forage into the mesopelagic zone. However, yellowfin and blackfin tuna are generally restricted to the epipelagic zone and thus Ommastrephids make up a majority of their diet. A large study of 13 pelagic fish predators in the western North Atlantic found Ommastrephids to dominate their diets, along with varied fish and crustacean spp.

In addition to the one SCA study of short-finned pilot whales, other SCA studies of deep diving marine mammals in the western North Atlantic, including long-finned pilot whales (G. melas) and pygmy (Kogia breviceps) and dwarf (K. sima) sperm whales, have revealed the importance of Histiooteuthidae (specifically Histiooteuthis reversa) and Cranchiidae spp in their diets. This preliminary study and the limited literature available on tuna diets in the western North Atlantic suggests that tuna, specifically bigeye tuna, are appropriate biological samplers for obtaining the target cephalopod species. The overlap isn’t complete, especially given the generalist foraging strategies of the predators involved. However, a large sample size of bigeye tuna should contain an appropriate number of Histiooteuthid, Cranchiid, and other target cephalopod taxa to obtain representative stable isotope values.

**Introduction**

Bycatch, the unintended capture of animals in fishing gear, is the largest threat facing marine mammals (Read et al., 2006). Many marine mammals become entangled because they simply swim into gear they don’t perceive. However, some marine mammals have learned to seek out specific types of fishing gear because they have learned how to depredate (i.e. prey upon) bait or caught fish. Depredation has become increasingly common in longline fisheries throughout the world’s oceans and involves many species of odontocetes, including killer whales (Orcinus orca), sperm whales (Physeter macrocephalus), false killer whales (Pseudorca crassidens), and pilot whales (Globicephala spp) (Hamer et al., 2012).

Odontocetes benefit from depredating catch by decreased energy expenditures or access to prey that may otherwise be too large or fast to catch (Aoki et al., 2012; Soto et al., 2008; Hamer et al., 2012). However, these benefits may be offset by the increased risk of mortality from entanglement or, if released alive, chronic sub-lethal impacts (Angliss and DeMaster, 1998).

The Atlantic pelagic longline fishery operates in the continental shelf and slope waters off of the U.S. East Coast and primarily targets bigeye (Thunnus obesus) and yellowfin (T. albacares) tuna
and swordfish (*Xiphias gladius*) (Angliss and DeMaster 1998, Walsh and Garrison, 2006). The Pelagic Longline Take Reduction Team (PLTRT) was convened by NOAA Fisheries in 2005 to address interactions and entanglement of odontocetes in this fishery: primarily pilot whales (*Globicephala* spp.) and Risso’s dolphins (*Grampus griseus*) (Garrison, 2007). Most of these interactions result from animals depredating catch or bait (Angliss and DeMaster, 1998; Garrison, 2007). Short-finned (*Globicephala macrorhynchus*) and long-finned pilot whales (*G. melas*) co-occur in some areas, but the Atlantic pelagic longline fishery primarily interacts with short-finned pilot whales (PLTRT, 2012). Management efforts by the PLTRT to reduce interactions of short-finned pilot whales are impeded by a lack of knowledge of the prevalence and distribution of depredation by the whales. Currently, little is known about demographic factors influencing depredation, including which sexes, age classes, social groups, or individuals engage in depredation.

Stable isotopes of carbon and nitrogen can be used to answer many questions surrounding foraging ecology, habitat use, diet composition, and trophic ecology (Kelly, 2000; Newsome et al., 2010). The isotopic composition of an animal’s tissues reflects the average composition of its assimilated diet, although different tissues reflect different assimilation periods, depending on the animal and turnover rates in the tissue (DeNiro and Epstein, 1978; Estrada et al., 2005). The ratio of $^{13}$C/$^{12}$C ($\delta^{13}$C) changes little (~1%) with trophic level, but provides information on the source of primary production of the food web that the organism has been feeding on, allowing inferences of past spatial utilization (e.g. coastal vs. oceanic or low vs. high latitude) (DeNiro and Epstein, 1981; Inger and Bearhop, 2008; Peterson and Fry, 1987). In contrast, the ratio of $^{15}$N/$^{14}$N ($\delta^{15}$N) exhibits a stepwise trophic enrichment, increasing ~3-4% per trophic level in marine food webs, and thus allows an estimate of trophic position for an organism (Minagawa and Wada, 1984; Peterson & Fry, 1987; Post, 2002; Layman et al., 2012).

The use of stable isotope analysis (SIA) to evaluate trophic relationships requires an understanding of the prey field of the predator, which is typically studied through stomach content analysis (SCA) (Chipps et al., 2007; Garvey and Chipps, 2013). The current knowledge of short-finned pilot whale diet in the North Atlantic is limited to one SCA study of 27 whales which mass stranded in North Carolina in 2005 (Mintzer et al., 2008). Mintzer and colleagues
found that cephalopods comprised most of the prey of these stranded whales, but the proportions of cephalopod families in their diet differed greatly from short-finned pilot whale SCA in the Pacific, eastern North Atlantic, and Japanese waters (Sinclair, 1992; Seagars and Henderson, 1985; Hernandez and Martin, 1994; Kubodera and Miyazaki, 1994).

A number of studies have looked at bigeye and yellowfin tuna diets in other oceans, but relatively few large-scale studies have attempted to characterize the diets of bigeye and yellowfin tuna in the North Atlantic (Poland, 2014; Rudershausen et al., 2010; Sabatié et al., 2003; Logan and Lutcavage, 2012; Logan et al., 2013). These SCA studies show that cephalopods make up a significant proportion of bigeye and yellowfin tuna diets (Poland, 2014; Rudershausen et al., 2010; Sabatié et al., 2003; Potier et al., 2004; Staudinger et al., 2013). To interpret variation in δ^{15}N and δ^{13}C values between pilot whales, tuna, and their prey, more data is needed on the cephalopod prey overlap of pilot whales, bigeye tuna, and yellowfin tuna.

Obtaining cephalopod stable isotope values can be difficult, as most species are not commercially caught, and offshore sampling via traditional fisheries sampling methods is expensive and logistically challenging (Clarke, 2006; Staudinger et al., 2013). Often, traditional sampling gear captures a subset of the cephalopods present due to limitations of the gear (eg. cephalopods evading the trawl) (Staudinger et al., 2013). Using predators such as odontocetes and teuthophagus pelagic fish (eg tunas) as biological samplers is an alternative sampling method that can be used to supplement traditional methods (Spitz et al., 2011; Staudinger et al., 2013). In this study, several tuna species are examined via SCA to determine if tuna (and which species in particular) can be used as biological samplers to obtain cephalopod taxa that overlap with our limited knowledge of short-finned pilot whale diets in the western North Atlantic. To supplement short-finned pilot whale diet data, cephalopod prey taxa from Mintzer and colleagues are compared to cephalopods found in other sympatric deep-diving odontocetes (2008).

Methods (2015-2016 Cephalopod Collection, Identification, and Stable Isotope Analysis)

Sample Collection
Fifteen tuna were sampled in total. Two bigeye tuna and nine yellowfin tuna were collected between July 16th and September 18th, 2015, from a commercial fish house that serviced recreational daily charter catch in Manteo, NC. Four blackfin tuna (T. atlanticus) were collected on November 11th, 2015, from a daily recreational charter boat out of Morehead City, NC. For each tuna, length, girth and weight were recorded. Additionally, dorsal muscle tissue was collected near the second dorsal fin, and a cut was made just posterior to the beginning of the esophagus to remove the stomach. All samples were frozen immediately at -20°C.

Stomach Processing

Stomachs were thawed and then weighed twice: first intact with prey inside and then again excluding stomach contents. Stomachs were then rinsed through 1mm sieves. Whole squid or partial squid with mantle attached were refrozen at -20°C. Cephalopod beaks were placed in 70% ethanol. Any beaks with tissue attached were separated and the beaks were placed in ethanol while the tissue was refrozen. All other stomach contents were refrozen.

Cephalopod Identification

Whole or partial cephalopods, as well as cephalopod beaks, were examined for any defining morphological characteristics using expert knowledge, online and print resources. Upper and lower beaks were separated, and lower beaks were grouped by size and shape. Lower rostral length of squid beaks and the lower hood length of octopod beaks were measured, and each set of similar lower beaks were examined using a cephalopod beak key and comparing the beak to online and print resources. A reference collection of beaks was also used to compare sampled beaks to known species. Upper beaks are usually not useful for identification and were stored for potential future use.

Results

The 15 stomachs yielded 179 beaks (91 lower and 79 upper beaks), either from whole or partial cephalopods, or as beaks only. Most lower beaks were from sub-adult squid, identified by their lower levels of chitinization and relatively small lateral rostral lengths, which ranged from 0.1 –
3.5mm, although most were ~1.0mm in length. Table 2 shows the taxonomic identity of the lower beaks; 88 squid beaks and 3 octopod beaks were identified, at least to the family level. The squid beaks all fell within five families (Cranchiidae, Histiooteuthidae, Mastigoteuthidae, Ommastrephidae, and Onychoteuthidae), except for one unknown beak. One octopod beak was identified to species level, and the other two octopod beaks could only be identified as pelagic octopods.

Table 1: Morphometrics from tuna sampled for stomach content analysis along the coast of North Carolina

<table>
<thead>
<tr>
<th>Species</th>
<th>Fork length (cm)</th>
<th>Weight (kg)</th>
<th>Species</th>
<th>Fork length (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bigeye tuna</td>
<td>152.0</td>
<td>64.9</td>
<td>Yellowfin tuna</td>
<td>69.2</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>180.0</td>
<td>98.9</td>
<td></td>
<td>101.6</td>
<td>20.2</td>
</tr>
<tr>
<td>Blackfin tuna</td>
<td>60.0</td>
<td>--</td>
<td></td>
<td>105.4</td>
<td>21.3</td>
</tr>
<tr>
<td></td>
<td>60.1</td>
<td>--</td>
<td></td>
<td>118.0</td>
<td>30.4</td>
</tr>
<tr>
<td></td>
<td>64.1</td>
<td>--</td>
<td></td>
<td>119.3</td>
<td>27.2</td>
</tr>
<tr>
<td></td>
<td>66.0</td>
<td>--</td>
<td></td>
<td>120.7</td>
<td>30.8</td>
</tr>
<tr>
<td></td>
<td>121.9</td>
<td>29.9</td>
<td></td>
<td>122.0</td>
<td>31.8</td>
</tr>
<tr>
<td></td>
<td>129.5</td>
<td>35.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Only two bigeye tuna stomachs were sampled, but they contained a diverse assemblage of 15 cephalopod beaks (Table 2). The nine yellowfin tuna sampled contained several large unidentified fish species, but most stomachs were empty and yielded only three lower beaks. Two of the four blackfin tuna stomachs contained a diverse variety of prey, including small seahorses, monofilament fishing line, fish, whole cephalopods, and Sargassum, suggesting recent feeding at or near the surface. The blackfin tuna cephalopod prey was heavily dominated by squid from the family Ommastrephidae. (Table 2). The high number of Ommastrephids found in blackfin tuna stomachs skew the total cephalopod distribution toward Ommastrephids, which included 78 of the 91 beaks examined.
Table 2: Lower beaks of cephalopod prey identified by predator species

<table>
<thead>
<tr>
<th>Cephalopod Taxa</th>
<th>Bigeye tuna (N=2)</th>
<th>Yellowfin tuna (N=9)</th>
<th>Blackfin tuna (N=4)</th>
<th>Total number of specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranchiidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Cranchia scabra</em></td>
<td>3</td>
<td>--</td>
<td>--</td>
<td>3</td>
</tr>
<tr>
<td>Unclassified</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>Histioteuthidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unclassified</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>Mastigoteuthidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Mastigoteuthis magna</em></td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>Ommastrephidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ornithoteuthis antillarum</em></td>
<td>--</td>
<td>1</td>
<td>46</td>
<td>47</td>
</tr>
<tr>
<td><em>Illex sp.</em></td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>Unclassified</td>
<td>7</td>
<td>1</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>Onychoteuthidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Onychoteuthis banksii</em></td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Unclassified</td>
<td>--</td>
<td>--</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Unknown Squid</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>Octopoda (Order)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Haliphron atlanticus</em></td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>Unclassified</td>
<td>--</td>
<td>--</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total # of lower beaks</td>
<td>15</td>
<td>3</td>
<td>73</td>
<td>91</td>
</tr>
</tbody>
</table>

Discussion

*Cephalopods in Bigeye and Yellowfin Tuna Diets in the North Atlantic*

Bigeye, yellowfin, and blackfin tuna prey on fish, crustaceans, and cephalopods (Poland, 2014; Logan et al., 2013). The importance of cephalopods in their diets varies with size (for yellowfin tuna), season, latitude, species, and other factors (Poland, 2014; Logan et al., 2013; Staudinger et al., 2013). The diet of bigeye tuna is less well studied in the North Atlantic than that of yellowfin or blackfin tuna (Poland, 2014; Staudinger et al., 2013). Logan and colleagues’ examination of cephalopod prey in bigeye tuna diets found Ommastrephidae to be the primary contributor, followed by Octopoda, Enoploteuthidae, Architeuthidae, and Histioteuthidae (2013). Poland found yellowfin tuna to be the most teuthophagous predator, with shortfin
squid (*Illex illecebrosus*), an Ommastrephid, being the dominant cephalopod prey found in their diets (2014). However, schooling fish were still the most dominant prey of yellowfin tuna by mass, abundance, and occurrence (Poland, 2014). Logan et al. also found the cephalopod prey of yellowfin tuna to be dominated by Ommastrephidae, followed by Octopoda, and Histiotethidae (2013). Poland found blackfin tuna to be less piscivorous than yellowfin tuna, with crustaceans, cephalopods, and other molluscs contributing the majority of the mass and number of prey recovered (2014). Poland also found that while blackfin tuna were less teuthophagous, they still contained a significant number of cephalopod prey, primarily of the families Argonautidae, Loliginidae and Ommastrephidae (2014).

Ommastrephids dominated the cephalopod prey of tunas in this study (Table 2), similar to the results of other North Atlantic SCA studies of bigeye, yellowfin, and blackfin tuna diets described above (Poland, 2014; Staudinger et al., 2013; Logan et al., 2013). There are six Ommastrephidae spp. which are encountered in the western North Atlantic: *Illex coindetti*, *Illex illecebrosus*, *Illex oxygonius*, *Ommastrephes bartramii*, *Ornithoteuthis antillarum*, and *Sthenoteuthis pteropus* (Vecchione, 2015). The unclassified Ommastrephidae spp. in Table 2 are likely one of the six previously listed species, excluding *O. antillarum* which is easily distinguished by the lateral wall ridge.

**Foraging Differences between Bigeye and Yellowfin Tuna**

In multiple ocean basins, bigeye tuna consume larger larger prey, including cephalopods, than yellowfin, blackfin, and albacore (*Thunnus alalunga*) tunas (Staudinger et al., 2013; Ménard et al., 2006; Young et al., 2010). The physiological adaptations of bigeye tuna allow them to forage at deeper depths and follow the diel migration of the deep scattering layer (DSL), which supports greater diversity and size ranges of cephalopod prey, compared with yellowfin tuna which are often restricted to the epipelagic zone (Brill, 1994; Dagorn et al., 2000; Ménard et al., 2006; Pusineri et al., 2008). Many tagging studies, including one in the central North Atlantic, have consistently recorded bigeye tuna diving to ~300-500m (dependent on the depth of the DSL) during the day and remaining in the upper 100m during the night (Howell et al., 2010; Matsumoto et al., 2005). More studies of bigeye tuna with larger sample sizes are needed to
draw definitive conclusions on prey composition and feeding behaviors in the western North Atlantic (Staudinger et al., 2013).

Yellowfin tuna, while often restricted to the epipelagic zone, demonstrate ontogenetic shifts in vertical habitat use and concomitant variation in feeding strategies (Graham et al., 2007; Vaske et al., 2003). In the Pacific, yellowfin tuna exhibit a shift in diet at approximately 50 cm fork length, from crustaceans to larger invertebrates and fish (Graham et al., 2007). The yellowfin stomachs in this study contained relatively few cephalopod prey, but their fork lengths were above this length threshold; thus they could be expected to be feeding on relatively large prey. Tagging records reveal that yellowfin tuna occasionally dive to 300-500m and even occasionally >1,000m, but they are thought to primarily feed in the epipelagic or just below (Dagorn et al., 2006; Schaefer et al., 2007; Weng et al., 2009).

*Marine Mammal Cephalopod Prey in western North Atlantic*

As mentioned above, knowledge of short-finned pilot whale prey in the western North Atlantic is limited to one SCA study of 27 animals that mass stranded on the North Carolina coast. Only 11 of the forestomachs of these whales contained prey hard parts (Mintzer et al., 2008). The main cephalopod taxa represented in the prey were the families Brachioteuthidae, Histioteuthidae, and several other deep water, oceanic taxa (Mintzer et al., 2008). As discussed, this is in contrast to short-finned pilot whale SCA studies in other oceans and even the eastern North Atlantic, which suggested regional preferences for neritic (e.g. *Loligo spp.*) or deeper cephalopods (e.g. *Cranchiidae* spp.), respectively (as per Mintzer et al., 2008). This demonstrates the need for additional regional studies of the trophic ecology of these predators.

Long-finned pilot whales caught incidentally as bycatch in the western North Atlantic mid-water trawl fishery had been feeding on the neritic squid family Loliginidae as their primary prey (Gannon et al., 1997). The correspondence of the prey of these whales taken as bycatch and the target species of this fishery is perhaps unsurprising. Little else is known about long-finned pilot whale diet in the western North Atlantic. However, SCA in the eastern North Atlantic
suggests Octopodidae and Ommastrephidae to be primary contributors, which further necessitates additional western and eastern North Atlantic diet studies (Santos et al., 2014).

A study of pygmy (Kogia breviceps) and dwarf (K. sima) sperm whales in the western North Atlantic determined that their primary prey includes the families Histiotethidae, Cranchidae, Ommastrephidae, and Enoplooteuthidae (Staudinger et al., 2014). The diets of these cryptic odontocetes suggested that they feed on a wide range of cephalopod families occurring from 200m to 1,800m (Staudinger et al., 2014), including both oceanic and benthic species.

The study by Staudinger et al. provides further evidence that Histiotethis reversa, Enoplooteuthis spp., and Illex illecebrosus are important prey items of deep diving odontocetes in the western North Atlantic (2014). H. reversa was also found to be a significant prey item in long-finned pilot whales (Gannon et al., 1997), and appears to be generally important in the diets of large predators in the western North Atlantic (Staudinger et al., 2013).

**Review of Tuna Stable Isotope Values in the central and western North Atlantic**

Table 3: Bigeye and yellowfin tuna N and C muscle tissue isotopes from the central North Atlantic and western North Atlantic. Values reported are Mean ± SD.

<table>
<thead>
<tr>
<th>Study</th>
<th>Species</th>
<th>Season</th>
<th>N</th>
<th>$\delta^{15}N$</th>
<th>$\delta^{13}C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teffer et al., 2015. Western North Atlantic.</td>
<td>Yellowfin</td>
<td>Summer-Fall</td>
<td>21</td>
<td>10.4 ± 0.7</td>
<td>-17.9 ± 0.5</td>
</tr>
<tr>
<td>Poland, 2014 (unpublished): Western North Atlantic</td>
<td>Yellowfin</td>
<td>Total</td>
<td>111</td>
<td>9.6 ± 0.7</td>
<td>-17.0 ± 0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring</td>
<td>31</td>
<td>9.7 ± 0.8</td>
<td>-17.1 ± 0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Summer</td>
<td>73</td>
<td>9.5 ± 0.7</td>
<td>-17.0 ± 0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fall</td>
<td>7</td>
<td>9.7 ± 0.7</td>
<td>-16.7 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>Bigeye</td>
<td>Total</td>
<td>2</td>
<td>12.4 ± 0.5</td>
<td>-16.4 ± 0.1</td>
</tr>
<tr>
<td>Logan et al., 2013. Central North Atlantic.</td>
<td>Yellowfin</td>
<td>Summer</td>
<td>52</td>
<td>9.6 ± 0.6</td>
<td>-17.1 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>Bigeye</td>
<td>Summer</td>
<td>30</td>
<td>10.3 ± 0.7</td>
<td>-16.8 ± 0.3</td>
</tr>
<tr>
<td>Waples &amp; Read (unpublished). Western North Atlantic.</td>
<td>Yellowfin</td>
<td>Total</td>
<td>30</td>
<td>10.1 ± 0.6</td>
<td>-17.8 ± 0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring</td>
<td>15</td>
<td>9.8 ± 0.3</td>
<td>-17.7 ± 0.3</td>
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<tr>
<td></td>
<td></td>
<td>Fall</td>
<td>15</td>
<td>10.4 ± 0.6</td>
<td>-17.9 ± 0.3</td>
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<tr>
<td></td>
<td>Bigeye</td>
<td>Total</td>
<td>30</td>
<td>11.9 ± 0.4</td>
<td>-17.3 ± 0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring</td>
<td>15</td>
<td>11.8 ± 0.4</td>
<td>-17.3 ± 0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fall</td>
<td>15</td>
<td>12.0 ± 0.4</td>
<td>-17.3 ± 0.2</td>
</tr>
</tbody>
</table>

Table 3 summarizes $\delta^{15}N$ and $\delta^{13}C$ values for muscle of bigeye and yellowfin tuna in the central
and western North Atlantic. The $\delta^{15}N$ values are similar for yellowfin tuna in all four studies. Bigeye tuna in Logan et al.’s study have lower $\delta^{15}N$ values than corresponding values from the other studies, although it should be noted that Poland only examined two bigeye tuna (Poland, 2014; Logan et al., 2013). The Teffer, Poland, and Logan studies used mass balance equations from Logan et al., 2008, to correct $\delta^{13}C$ values \textit{a posteriori}, and the $\delta^{13}C$ values reported in Waples and Read represent lipid extracted values. However, if the same mass balance equations are applied to the uncorrected $\delta^{13}C$ values in Waples and Read, the results are very similar to the other two studies. Logan found that in general, the pelagic teleosts sampled in the central North Atlantic study had lower $\delta^{15}N$ values and higher $\delta^{13}C$ values than their counterparts in the eastern and western North Atlantic (2013). Logan also noted that many of these large pelagic predators move great distances and their study detected latitudinal increases in muscle $\delta^{15}N$ for yellowfin tuna and dolphin fish (\textit{Coryphaena hippurus}), which correlates with those of zooplankton; $N_2$ fixation is most prevalent in the Caribbean and Sargasso Sea and thus $\delta^{15}N$ values often increase with latitude as the distance from $^{15}N$ waters increases (2013). Therefore, nitrogen and carbon isotopic baselines must be kept in mind for migratory predators, including many tuna species (Logan et al., 2013).

\textit{Review of Cephalopod Stable Isotope Values in North Atlantic:}

Navarro and colleagues conducted a review of studies that measured cephalopod $\delta^{15}N$ and $\delta^{13}C$ values in all major oceans (2013). In the supplementary materials, 42 sets of values are presented from cephalopods in the Atlantic Ocean, though 16 are \textit{Loligo} spp. and 7 are \textit{Illex} spp (Navarro et al., 2013). There are several overlapping species with deep-diving odontocete prey in the western North Atlantic, yet additional cephalopod SIA studies are needed (Navarro et al., 2013).

Poland found \textit{Illex illecebrosus} $\delta^{15}N$ values in the western North Atlantic to be at the lower range of \textit{I. illecebrosus} $\delta^{15}N$ values in Navarro et al. (2014). Poland also reported $\delta^{15}N$ and $\delta^{13}C$ values for paper nautiluses (\textit{Argonauta} spp.), which were not represented in the 2014 review by Navarro and colleagues (2014). Logan and Lutcavage present $\delta^{15}N$ and $\delta^{13}C$ values for many beaks and several mantle specimens collected in the central North Atlantic, which were not included in Navarro and colleagues’ 2014 review (2012). Monteiro and colleagues determined
$\delta^{15}$N and $\delta^{13}$C values for several Histioteuthidae and Ommastrephidae spp. from the eastern North Atlantic (2015). While intra-family variability does exist, one study found Octopoda and Histioteuthidae to have the lowest $\delta^{15}$N values of those examined; Ommastrephidae had higher $\delta^{15}$N values but it should be noted that Cranchiidae spp. were not examined (Logan and Lutcavage, 2012). Overall, the lack of stable isotope studies in the western North Atlantic and the sometimes large intra-species variation in $\delta^{15}$N and $\delta^{13}$C values for which there are studies, demonstrates the need for more stable isotope analyses to draw conclusions for the less studied odontocete cephalopod prey (Navarro et al., 2013).

**Conclusion**

Despite limited sample sizes of bigeye tuna examined in this study and in other studies in the western North Atlantic, their cephalopod prey suggests they would be ideal biological samplers for obtaining specimens of squid and octopods found in marine mammal diets. The fact that they forage in the mesopelagic realm and the occurrence of a significant amount of cephalopod prey in their diet suggests they are ideal for obtaining samples of the cephalopod species found in the diet of short-finned pilot whales. The diets of yellowfin and blackfin tuna contain a greater proportion of epipelagic prey. Thus, these two species are less effective biological samplers for the purposes of obtaining cephalopod specimens of marine mammals that forage primarily in the mesopelagic zone.

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Literature Cited


