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Feeding Habits of the Blue Shark (*Prionace glauca*) in the Northwestern Pacific Based on Stomach Contents and Stable Isotope Ratios[1]

Yuki Fujinami,[2] *Sayaka Nakatsuka*,[3] *and Seiji Ohshimo*[2,4]

Abstract: The blue shark, *Prionace glauca* (L.), is one of the most abundant pelagic sharks, and determining their feeding habits is important for understanding the ocean ecosystem. Generally, stomach contents analysis has been used to evaluate its feeding habits; however simply analyzing stomach contents reveals short-term feeding habits. In this study, we examined feeding habits of blue sharks in the Northwestern Pacific based on results of both stomach contents and stable isotope analyses. The most dominant species and taxonomic group in the stomach were identified as anchovy and Oegopsida species, respectively. Mean $\delta^{13}C$ and $\delta^{15}N$ values of blue sharks were 18.5‰ and 12.1‰, respectively, which were higher than those of the prey items. Estimated proportional distribution of prey species varied according to discrimination factors used for stable carbon and nitrogen isotope ratios. Proportion of neritic or mesopelagic nekton, such as anchovy and lanternfish, was higher than that of other prey items including squids. We conclude that blue sharks capture prey ranging from neritic to mesopelagic animals through diel vertical migration.

The blue shark, *Prionace glauca* (L.), is widely distributed in oceanic waters, from tropical to temperate areas (Compagno 1984). As one of the most abundant pelagic sharks, large numbers of blue sharks are caught by the world's fisheries, principally as bycatch on longlines and in gill nets (Nakano and Stevens 2008). This species is also abundant in the Northwestern Pacific, where the catch rate declined in the early 1980s but subsequently increased in the 1990s (ISC 2014; Hiraoka et al. 2016; Ohshimo, Fujinami, et al. 2016). Juveniles and semiadults of sharks such as blue shark and shortfin mako (*Isurus oxyrhinchus*) are distributed north of the Kuroshio–Oyashio transition zone, which is a highly productive area (Nakano 1994, Kai et al. 2015). Sharks play a major role in the exchange of energy between the upper and lower trophic levels in the marine environment (Markaida and Sosa-Nishizaki 2010).

The feeding habits of blue sharks based on stomach contents analysis have been reported from the Northwestern Pacific (Kubodera et al. 2007), Northeastern Pacific (Markaida and Sosa-Nishizaki 2010, Preti et al. 2012, Hernández-Aguilar et al. 2015), South Pacific (Lopez et al. 2010), and the Atlantic Ocean (Stevens 1973, Clarke et al. 1996, McCord and Campana 2003). Those previous studies suggested that blue sharks feed on a large variety of fishes and cephalopods; however, they were conducted in coastal areas or limited by season. To describe the comprehensive feeding habits of blue sharks, samples should be analyzed from a wide area and from a range of shark sizes, as well as from all seasons. In addition, large fluctuations in the population dynamics of small pelagic species, such as anchovy and sardine, have been observed in the Northwestern Pacific and adjacent waters (e.g., Komatsu et al. 2002, Ohshimo et al. 2009). Therefore, the feeding habits of sharks could change owing to such a regime shift in

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the pelagic ecosystem. A regime shift is a persistent change in an ecosystem's structure and function, which can be abrupt and difficult to reverse.

Some authors have criticized stomach contents analyses for being merely a snapshot sample (e.g., Basker et al. 2014), and some biases have occurred from regurgitation during capture (Vignon and Dierking 2011). Therefore, analyzing stomach contents reveals only the short-term feeding habits of animals. In contrast, stable isotope analyses provide information relating to long-term trophic interaction patterns (e.g., MacNeil et al. 2005). Stable carbon and nitrogen isotope ratios are commonly used to determine food web and trophic positions of sharks (e.g., Logan and Lutcavage 2010, Cardona et al. 2012, Malpica-Cruz et al. 2013). These stable isotope ratios provide considerably more robust results when quantifying feeding preferences compared with the stomach contents approach. Recently, Hernández-Aguilar et al. (2015) reported the diet composition of blue sharks off the west coast of Baja California Sur, Mexico, based on results of both stomach content and stable isotope analyses.

In this study, we investigated the feeding habits of blue sharks caught in the Northwestern Pacific from 1999 to 2015 based on combined stomach content and stable isotope analyses to describe the quantitative importance of various prey items in the blue shark diet.

MATERIALS AND METHODS

Sampling and Measurements

Blue shark samples for the stomach contents analysis were collected by longline ($n = 399$), midwater trawling ($n = 58$), and drift net ($n = 3$) fisheries operated in the Northwestern Pacific from 1999 to 2014 (Figure 1). The blue shark samples used for the stable isotope analysis were collected by longline ($n = 101$) and midwater trawling ($n = 19$) from 2010 to 2015 (Figure 1). The longline bait was mackerel (*Scomber* sp.) and Japanese sardine (*Sardinops melanostictus*). Sex was determined by the presence of the copulatory organ. Precaudal length (PCL: length from the tip of the nose to the precaudal pit) and dorsal length (DL: length between the origin of first and second dorsal fin) of blue sharks were measured to the nearest centimeter. As the head and viscera were removed from sharks caught by the commercial vessels, DL was converted to PCL using a conversion equation (male: PCL = 2.51 DL + 12.33; female: PCL = 2.62 DL + 7.48) (Fujinami et al. 2017). The whole stomachs of all blue sharks were removed on board and frozen immediately for the stomach contents analysis. Similarly, the white muscles of sharks were excised and frozen for the stable isotope analysis.

Although the items in the stomach were identified in this study, in many cases the items were almost completely digested, making them unsuitable for the stable isotope analysis. Therefore, the prey species ($n = 64$) were collected by midwater trawling from 2014 to 2015 (Figure 1). These samples were collected at night when the prey moved to the surface layer and possibility of catch was higher. The net measured 30 m high by 30 m wide, and the towing speed and duration were about 3 knots (5.6 km/hr) and 30 min, respectively. After the trawl net was retrieved, the captured specimens were sorted by species and frozen in seawater. The specimens were brought to the laboratory and measured for body length (standard length for fish and mantle length for squid) and body weight. The muscle of fish or mantle of squid was removed and frozen for the stable isotope analysis.

Stomach Contents Analysis

A total of 460 specimens (303 males, 139 females, and 18 sharks with no sex recorded) was collected for the stomach contents analysis. The size of males ranged from 62.3 to 224.0 cm PCL, and that of females from 60.9 to 209.0 cm PCL (Figure 2). Each stomach was thawed and weighed before its contents were identified. The stomach contents were placed in a plastic pan, and the inner wall of the stomach was rinsed carefully to collect all prey remnants. In some cases, the stomach was empty, and the number of such sharks was

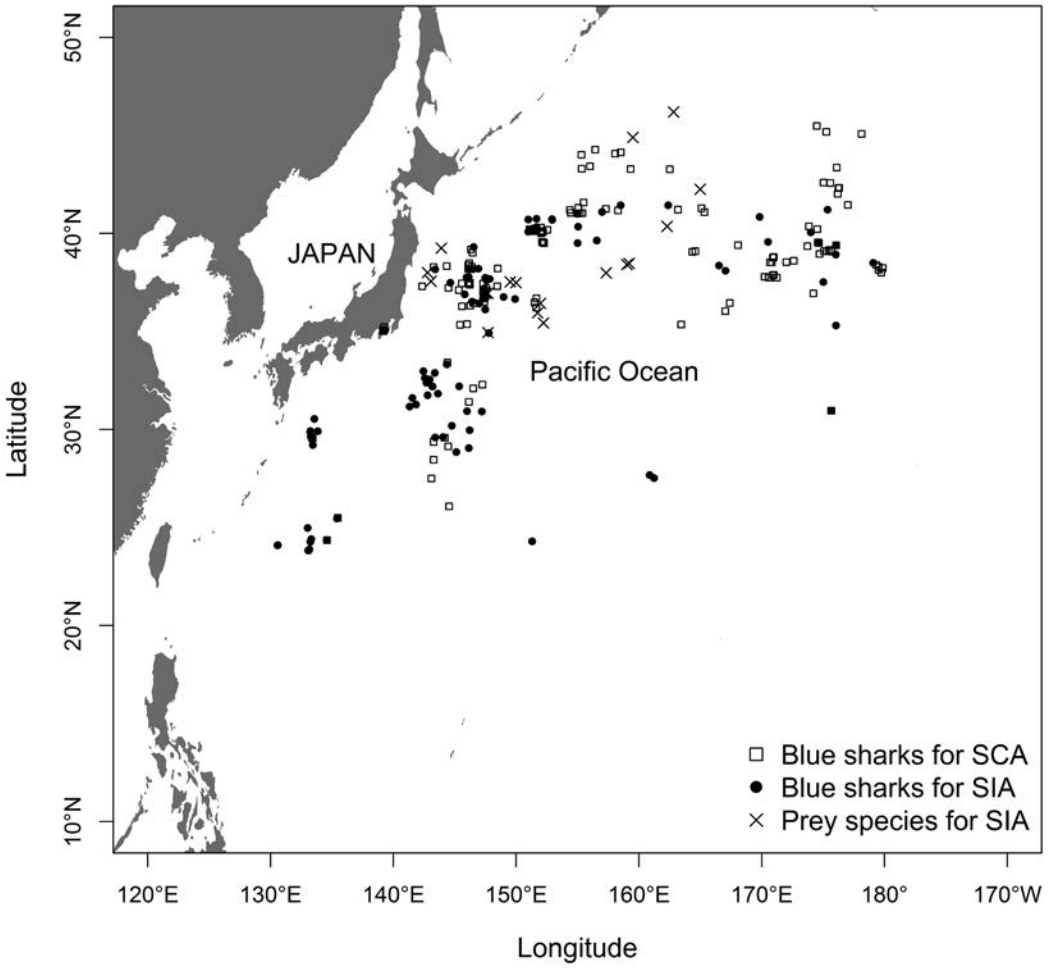

FIGURE 1. Blue shark and prey species sampling sites in the Northwestern Pacific. Squares denote blue shark samples for stomach contents analysis (SCA), black circles denote blue shark samples for stable isotope analysis (SIA), and crosses denote prey species for SIA, respectively.

recorded. Undigested and partially digested fish and cephalopods were sorted and identified to the lowest taxonomic level possible based on external morphology, and digested prey items were identified based on the otoliths in fish and the lower beak of cephalopods (Clarke 1986, Rodhouse and Yeatman 1990, Lu and Ickeringill 2002, Xavier and Cherel 2009).

After identifying the species in the stomachs, we calculated the mean number and weight of prey items monthly and annually, the percentage composition by number (%N), the weight percentage (%W), and the percentage frequency of occurrence (%F). The main food items were identified using the index of relative importance (IRI) proposed by Pinkas et al. (1971) and the percentage IRI (%IRI) (Cortés 1997):

$$IRI_i = (\%N_i + \%W_i) \times \%F_i \quad (1)$$

$$\%IRI_i = (IRI_i / \sum IRI_i) \times 100 \quad (2)$$

where i represents species i.

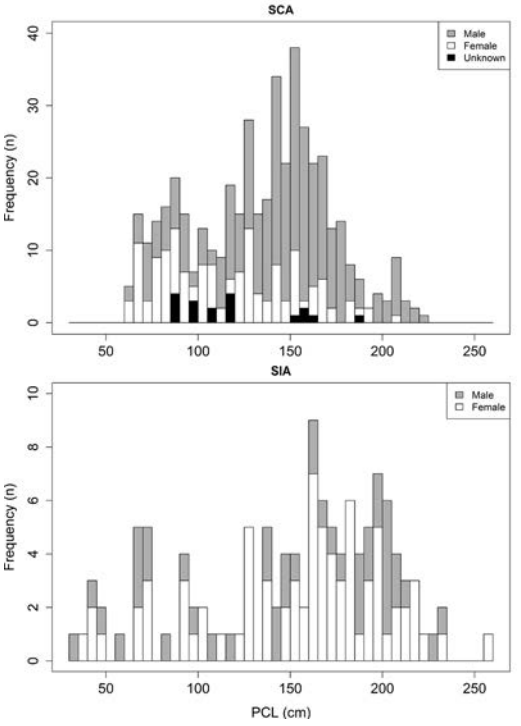

FIGURE 2. Length distribution of blue sharks in the Northwestern Pacific for the stomach contents analysis (SCA: *above*) and for the stable isotope analysis (SIA: *below*), respectively.

A randomized cumulative prey curve (Ferry and Cailliet 1996) was constructed using the vegan package (Oksanen et al. 2010) in R statistical software to determine whether the number of analyzed stomach samples was sufficient to describe the blue shark diet.

Stable Isotope Analysis

Blue sharks for the stable isotope analysis ranged from 33.4 to 230.7 cm PCL for males and from 37.2 to 256.4 cm PCL for females (Figure 2). The sampled lateral white muscle of fish and mantle of squid were freeze-dried, smashed, and placed in a centrifuge tube for the defatting procedure. Subsequently, the samples were treated with a 2 : 1 chloroform-methanol solution and methanol to remove lipids and minimize the differences in ^{13}C caused by the variable fatty tissue content among individuals (Schoeninger and DeNiro 1984). The shark tissues were thoroughly rinsed in deionized water for 15 min to remove urea (Kim and Koch 2012, Carlisle et al. 2017).

After removing the lipids and urea, each sample was air-dried at 60°C overnight, and a 1 mg subsample was analyzed. The stable carbon and nitrogen isotope ratios were analyzed at the Isotope Research Institute (Yokohama, Japan) using a stable isotope ratio mass spectrometer (Delta V Advantage, Thermo Fisher Scientific, Yokohama, Japan). The stable isotope ratios are presented as the per mil (‰) deviation from the respective international standards, calculated using the following equation:

$$\delta^{15}N \text{ or } \delta^{13}C = [(R_{sample} / R_{standard}) - 1] \times 1{,}000 \quad (3)$$

where R is the ratio of $^{15}N/^{14}N$ or $^{13}C/^{12}C$. Atmospheric nitrogen and Vienna Pee Dee Belemnite limestone (V-PDB) were used as the nitrogen and carbon standards, respectively. Analytical precision of isotope analyses was ±0.20‰ for both $\delta^{15}N$ and $\delta^{13}C$.

Mixing Model

To calculate the relative contribution of potential prey species to the blue shark diet, we used the Bayesian mixing model Stable Isotope Analysis in R (SIAR) (Parnell et al. 2010). The SIAR model parameters were the isotope ratios and the elemental concentrations of potential food sources, the tissue isotope ratio, and the carbon and nitrogen trophic shift (i.e., isotopic enrichment) from prey to predator. Prey-to-predator isotopic discrimination factors for fish, mammals, and loggerhead sea turtles were taken from Reich et al. (2008) and Caut et al. (2009). Although SIAR incorporates uncertainty about diet-tissue isotopic discrimination factors ($\Delta^{13}C$ and $\Delta^{15}N$) in the form of a standard deviation, we used three combinations of the discrimination factor from Kim et al. (2012) ($\Delta^{13}C$ = 1.7‰, $\Delta^{15}N$ = 3.7‰), Hussey et al. (2009) ($\Delta^{13}C$ = 0.9‰, $\Delta^{15}N$ = 2.3‰), and DeNiro and Epstein (1981) ($\Delta^{13}C$ = 1.1‰, $\Delta^{15}N$ = 3.4‰).

RESULTS

Stomach Contents Analysis

Of the 460 blue shark stomachs that were assessed, 221 (48.0%) contained prey items (Table 1). Few shark specimens were collected during January and March, and the fraction of individuals with empty stomachs ranged from 16.7% in August to 76.9% in July (Table 1). The cumulative prey curve that was created to describe the increasing trend did not reach full asymptotic stabilization (Figure 3).

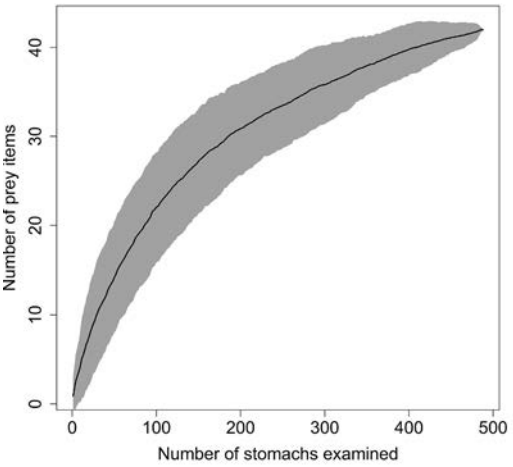

FIGURE 3. Randomized cumulative prey curve for the blue shark.

Five classes of animals were found in the stomachs of blue sharks: Mammalia, Chondrichthyes, Actinopterygii, Cephalopoda, and Malacostraca. The most abundant prey species was anchovy (*Engraulis japonicus*), followed by krill (Euphausiacea). In this study, krill (euphausiids), amphipods, and decapods were presumed to be secondary prey consumed by the other prey species. The prey species with the greatest percentage weight was mackerel (Table 2); however, because mackerel and Japanese sardine were used as longline bait in this study, these prey species were removed from the analysis. Anchovy and neon flying squid (*Ommastrephes bartramii*) were the highest percentage prey species by weight (Table 2). The monthly mean number and weight of prey items were calculated, and the highest values were recorded in August (Table 1) and September (Table 2), respectively. Few blue shark specimens were captured in 2001, 2002, and 2014 (Supplemental Table S1 and Table S2). Anchovy was the prey consumed in the largest number in 2006. The highest mean number and weight of prey items were observed in 2006. In addition, there was no strong variation in prey composition among sampling areas and growth stages (Supplemental Tables S3–S6).

Authors' Note: Supplemental materials available online at BioOne (http://www.bioone.org/toc/pasc/current) and Project MUSE (http://muse.jhu.edu/journal/166).

Figure 4 illustrates the %N, %W, and %F of four categories of prey species consumed by blue sharks: anchovy (Clupeiformes), Myctophiformes (lanternfishes), Oegopsida (squids), Octopoda (octopuses), and others. The %N values for anchovy and Oegopsida were 64.7% and 22.5%, respectively. However, the %W value for anchovy (14.0%) was lower than that for Oegopsida (61.1%). The highest IRI species value was for anchovy (410.7), and the IRI prey category value for Oegopsida was 2618.9 (Table 3). In addition, the %IRI anchovy and Oegopsida values were 12.7% and 80.7%, respectively. However, the IRI and %IRI of Oegopsida species values were relatively low except for unidentified Oegopsida. The important prey items in the diets of males and females were similar: the highest %IRI values of prey species for males were Oegopsida (89.5%), anchovy (3.9%), and Octopoda (2.6%) and those for females were Oegopsida (79.0%), anchovy (9.0%), and Myctophiformes (6.9%).

Stable Isotopes Analysis

The mean $\delta^{13}C$ and $\delta^{15}N$ values for blue sharks were –18.5‰ and 12.1‰, respectively (Table 4). The stable nitrogen isotope ratios of all prey species were lower than those of blue sharks, whereas the carbon isotope ratio of some cephalopods was larger than that of blue sharks. In addition, the stable isotope ratios of Oegopsida were generally higher

TABLE 1

Monthly Number of Prey Items Recorded in the Stomach of Blue Sharks in the Northwestern Pacific

Class	Order	Family	Species	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Mammalia	Carnivora	Unidentified Carnivora		0	0	0	0	0	0	0	0	1	0	0	0	1
Chondrichthyes	Carcharhiniformes	Carcharhinidae	Unidentified Carcharhinidae	0	0	0	0	0	0	0	0	0	1	0	0	1
Actinopterygii	Clupeiformes	Engraulidae	*Engraulis japonicus*	0	0	0	3	1	0	1	900	77	0	0	18	1000
	Clupeiformes	Clupeidae	*Sardinops melanostictus*	0	0	0	0	0	0	1	0	2	6	0	0	9
	Myctophiformes	Myctophidae	*Notoscopelus* sp.	0	0	0	0	0	0	0	1	0	0	0	0	1
	Myctophiformes	Myctophidae	*Ceratoscopelus warmingii*	0	0	0	18	9	0	0	1	1	0	0	0	29
	Myctophiformes	Myctophidae	Unidentified Myctophidae	0	0	0	6	4	2	1	39	25	3	0	4	84
	Aulopiformes	Paralepididae	Unidentified Paralepididae	0	0	0	0	0	0	0	0	2	0	0	0	2
	Aulopiformes	Alepisauridae	*Alepisaurus ferox*	0	0	0	1	1	1	0	0	0	0	0	0	3
	Perciformes	Bramidae	*Brama japonica*	0	0	0	0	0	0	0	0	1	0	0	0	1
	Perciformes	Scombridae	*Auxis rochei*	0	0	0	0	0	0	0	0	0	0	2	0	2
	Perciformes	Scombridae	*Scomber* sp.	0	0	1	9	7	12	0	12	4	0	8	15	68
	Perciformes	Scombridae	*Katsuwonus pelamis*	0	0	0	0	0	0	0	0	0	1	0	0	1
	Perciformes	Scombridae	*Thunnus* sp.	0	0	0	0	0	0	0	0	0	1	0	0	1
	Perciformes	Gempylidae	*Gempylus serpens*	0	0	0	0	0	0	1	0	0	0	0	0	1
	Perciformes	Carangidae	Unidentified Carangidae	0	0	0	0	0	1	0	0	1	0	0	0	2
	Perciformes	Tetragonuridae	*Tetragonurus cuvieri*	0	0	0	0	0	0	1	0	0	0	0	0	1
	Perciformes	Molidae	*Mola* sp.	0	0	0	0	1	0	0	0	0	0	0	0	1
	Salmoniformes	Salmonidae	*Oncorhychus kisutch*	0	0	0	0	0	0	0	1	0	0	0	0	1
Cephalopoda	Oegopsida	Ommastrephidae	*Ommastrephes bartramii*	0	0	0	0	0	0	0	5	7	0	0	0	12
	Oegopsida	Ommastrephidae	Unidentified Ommastrephidae	0	0	0	0	0	0	0	1	3	0	0	17	21
	Oegopsida	Ommastrephidae	*Eucleoteuthis luminosa*	0	0	0	0	0	1	0	1	3	3	0	0	8
	Oegopsida	Histioteuthidae	*Histioteuthis boylei*	0	0	0	2	0	0	0	0	0	1	0	0	3
	Oegopsida	Histioteuthidae	*Histioteuthis corona inermis*	0	0	0	0	0	0	0	0	0	0	7	0	7
	Oegopsida	Histioteuthidae	Unidentified Histioteuthidae	0	0	0	2	7	11	0	3	3	5	0	10	41
	Oegopsida	Ancistrocheiridae	*Ancistrocheirus lesueurii*	0	0	0	0	0	5	0	1	0	0	0	0	6
	Oegopsida	Gonatidae	*Gonatopsis borealis*	0	0	0	0	1	0	1	1	0	0	0	3	6
	Oegopsida	Gonatidae	*Gonatopsis* sp.	0	0	0	0	0	0	0	1	1	1	0	0	3
	Oegopsida	Gonatidae	*Gonatus pyros*	0	0	0	4	4	1	1	1	3	1	3	3	21

	Oegopsida	Gonatidae	*Gonatus berryi*	0	0	0	0	0	1	1	0	0	0	0	1	3
	Oegopsida	Gonatidae	Unidentified Gonatidae	0	0	0	2	3	4	0	8	4	5	3	28	57
	Oegopsida	Octopoteuthidae	*Taningia danae*	0	0	0	0	0	0	0	0	0	2	0	0	2
	Oegopsida	Octopoteuthidae	Unidentified Octopoteuthidae	0	0	0	0	1	3	1	3	0	0	2	2	12
	Oegopsida	Onychoteuthidae	*Onychoteuthis banksii*	0	0	0	0	0	0	0	0	5	0	0	0	5
	Oegopsida	Onychoteuthidae	Unidentified Onychoteuthidae	0	0	0	0	7	3	0	11	3	4	1	0	29
	Oegopsida	Chiroteuthidae	*Grimalditeuthis* sp.	0	0	0	1	3	1	0	0	0	0	0	1	6
	Oegopsida	Enoploteuthidae	*Watasenia scintillans*	0	0	0	0	0	0	0	13	2	0	0	0	15
	Oegopsida	Enoploteuthidae	Unidentified Enoploteuthidae	0	0	0	0	0	15	0	1	2	0	0	0	18
	Oegopsida	Unidentified Oegopsida		0	0	0	10	11	8	6	14	7	24	3	7	90
	Octopoda	Octopodidae	Unidentified Octopodidae	0	0	0	8	7	4	2	3	2	1	2	3	32
	Octopoda	Bolitanaenidae	*Japetella diaphana*	0	0	0	0	0	0	0	0	0	4	0	4	8
	Octopoda	Unidentified Octopoda		0	0	0	0	1	0	0	0	0	4	2	2	9
Malacostraca	Euphausiacea	Unidentified Euphausiacea		0	0	0	0	0	0	611	15	0	0	0	0	626
	Amphipoda	Unidentified Amphipoda		0	0	0	0	0	2	0	0	0	1	0	1	4
	Decapoda	Unidentified Decapoda		0	0	0	0	1	1	0	0	0	0	2	0	4
Total				0	0	1	66	69	76	628	1036	159	68	35	119	2257
Average number				—	—	1	4	3	4	35	35	7	2	3	3	10
Empty stomach				0	1	1	23	20	19	60	6	13	69	7	20	239
Total specimen number				0	1	2	41	42	40	78	36	36	100	19	65	460

TABLE 2

Monthly Weight (g) of Prey Items Recorded in the Stomach of Blue Sharks in the Northwestern Pacific

Class/Order	Family	Species	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Mammalia															
Carnivora	Unidentified Carnivora		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.0	0.0	0.0	0.0	95.0
Chondrichthyes															
Carcharhiniformes	Carcharhinidae	Unidentified Carcharhinidae	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
Actinopterygii															
Clupeiformes	Engraulidae	*Engraulis japonicus*	0.0	0.0	0.0	54.8	13.2	0.0	4.4	2605.7	1037.0	0.0	0.0	0.0	3715.1
Clupeiformes	Clupeidae	*Sardinops melanostictus*	0.0	0.0	0.0	0.0	0.0	0.0	83.6	0.0	310.4	1361.6	0.0	0.0	1755.6
Myctophiformes	Myctophidae	*Notoscopelus* sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	1.8
Myctophiformes	Myctophidae	*Ceratoscopelus warmingii*	0.0	0.0	0.0	0.0	3.8	0.0	0.0	2.0	6.7	0.0	0.0	0.0	12.5
Myctophiformes	Myctophidae	Unidentified Myctophidae	0.0	0.0	0.0	5.0	0.0	10.3	2.4	178.4	97.9	11.9	0.0	0.0	305.9
Aulopiformes	Paralepididae	Unidentified Paralepididae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.5	0.0	0.0	0.0	23.5
Aulopiformes	Alepisauridae	*Alepisaurus ferox*	0.0	0.0	0.0	212.9	99.9	187.7	0.0	0.0	0.0	0.0	0.0	0.0	500.5
Perciformes	Bramidae	*Brama japonica*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1126.1	0.0	0.0	0.0	1126.1
Perciformes	Scombridae	*Auxis rochei*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	865.0	0.0	865.0
Perciformes	Scombridae	*Scomber* sp.	0.0	0.0	155.3	1477.0	584.2	1871.6	0.0	819.1	443.4	0.0	1043.1	2079.9	8473.6
Perciformes	Scombridae	*Katsuwonus pelamis*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	897.0	0.0	0.0	897.0
Perciformes	Scombridae	*Thunnus* sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	542.7	0.0	0.0	542.7
Perciformes	Gempylidae	*Gempylus serpens*	0.0	0.0	0.0	0.0	0.0	0.0	53.0	0.0	0.0	0.0	0.0	0.0	53.0
Perciformes	Carangidae	Unidentified Carangidae	0.0	0.0	0.0	0.0	0.0	5.5	0.0	0.0	2.4	0.0	0.0	0.0	7.9
Perciformes	Tetragonuridae	*Tetragonurus cuvieri*	0.0	0.0	0.0	0.0	0.0	0.0	270.9	0.0	0.0	0.0	0.0	0.0	270.9
Perciformes	Molidae	*Mola* sp.	0.0	0.0	0.0	0.0	306.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	306.9
Salmoniformes	Salmonidae	*Oncorhychus kisutch*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	664.8	0.0	0.0	0.0	0.0	664.8
Cephalopoda															
Oegopsida	Ommastrephidae	*Ommastrephes bartramii*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2419.0	2078.7	0.0	0.0	0.0	4497.7
Oegopsida	Ommastrephidae	Unidentified Ommastrephidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	649.0	0.0	0.0	1115.0	1764.1
Oegopsida	Ommastrephidae	*Eucleoteuthis luminosa*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	839.9	104.4	0.0	0.0	944.4
Oegopsida	Histioteuthidae	*Histioteuthis hoylei*	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	136.3	0.0	0.0	136.5

Oegopsida	Histioteuthidae	*Histioteuthis corona inermis*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3
Oegopsida	Histioteuthidae	Unidentified Histioteuthidae	0.0	0.0	0.0	0.4	0.6	0.8	0.0	0.1	0.1	0.5	0.0	0.8	3.3
Oegopsida	Ancistrocheiridae	*Ancistrocheirus lesueurii*	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.7
Oegopsida	Gonatidae	*Gonatopsis borealis*	0.0	0.0	0.0	0.0	0.2	0.0	493.4	123.8	0.0	0.0	0.0	0.0	617.4
Oegopsida	Gonatidae	*Gonatopsis* sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.4	0.0	0.0	0.6
Oegopsida	Gonatidae	*Gonatus pyros*	0.0	0.0	0.0	0.3	0.4	0.1	0.1	0.1	0.2	0.0	0.1	2.4	3.7
Oegopsida	Gonatidae	*Gonatus berryi*	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.3
Oegopsida	Gonatidae	Unidentified Gonatidae	0.0	0.0	0.0	0.0	0.1	18.0	0.0	14.7	2.5	1.2	0.1	1.0	37.6
Oegopsida	Octopoteuthidae	*Taningia danae*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	751.0	0.0	0.0	751.0
Oegopsida	Octopoteuthidae	Unidentified Octopoteuthidae	0.0	0.0	0.0	0.0	0.4	0.7	0.1	0.2	0.0	0.0	1.9	0.5	3.8
Oegopsida	Onychoteuthidae	*Onychoteuthis banksii*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.4	0.0	0.0	0.0	57.4
Oegopsida	Onychoteuthidae	Unidentified Onychoteuthidae	0.0	0.0	0.0	0.0	89.9	0.7	0.0	5.1	0.4	0.6	0.0	0.0	96.7
Oegopsida	Chiroteuthidae	*Grimalditeuthis* sp.	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
Oegopsida	Enoploteuthidae	*Watasenia scintillans*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	1.8	0.0	0.0	0.0	15.3
Oegopsida	Enoploteuthidae	Unidentified Enoploteuthidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	3.2
Oegopsida	Unidentified Oegopsida		0.0	0.0	0.0	22.5	29.8	16.9	864.0	380.6	1415.8	4866.3	37.8	130.9	7764.6
Octopoda	Octopodidae	Unidentified Octopodidae	0.0	0.0	0.0	0.4	0.5	0.0	7.6	0.8	0.0	0.5	0.2	0.1	10.1
Octopoda	Bolitanaenidae	*Japetella diaphana*	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
Octopoda	Unidentified Octopoda		0.0	0.0	0.0	0.0	197.2	0.0	0.0	0.0	0.0	0.1	204.5	0.1	401.9
Malacostraca															
Euphausiacea	Unidentified Euphausiacea		0.0	0.0	0.0	0.0	0.0	0.0	90.0	2.0	0.0	0.0	0.0	0.0	92.0
Amphipoda	Unidentified Amphipoda		0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.2	0.0	0.4	2.9
Decapoda	Unidentified Decapoda		0.0	0.0	0.0	0.0	0.9	0.4	0.0	0.0	0.0	0.0	3.9	0.0	5.2
Total			0.0	0.0	155.3	1773.6	1328.0	2115.8	1869.6	7232.1	8191.6	8674.6	2156.8	3331.2	36828.7
Average weight (g)			—	—	155.3	98.5	60.4	100.8	103.9	241.1	356.2	279.8	179.7	74.0	166.6
Empty stomach			0	1	1	23	20	19	60	6	13	69	7	20	239
Total specimen number			0	1	2	41	42	40	78	36	36	100	19	65	460

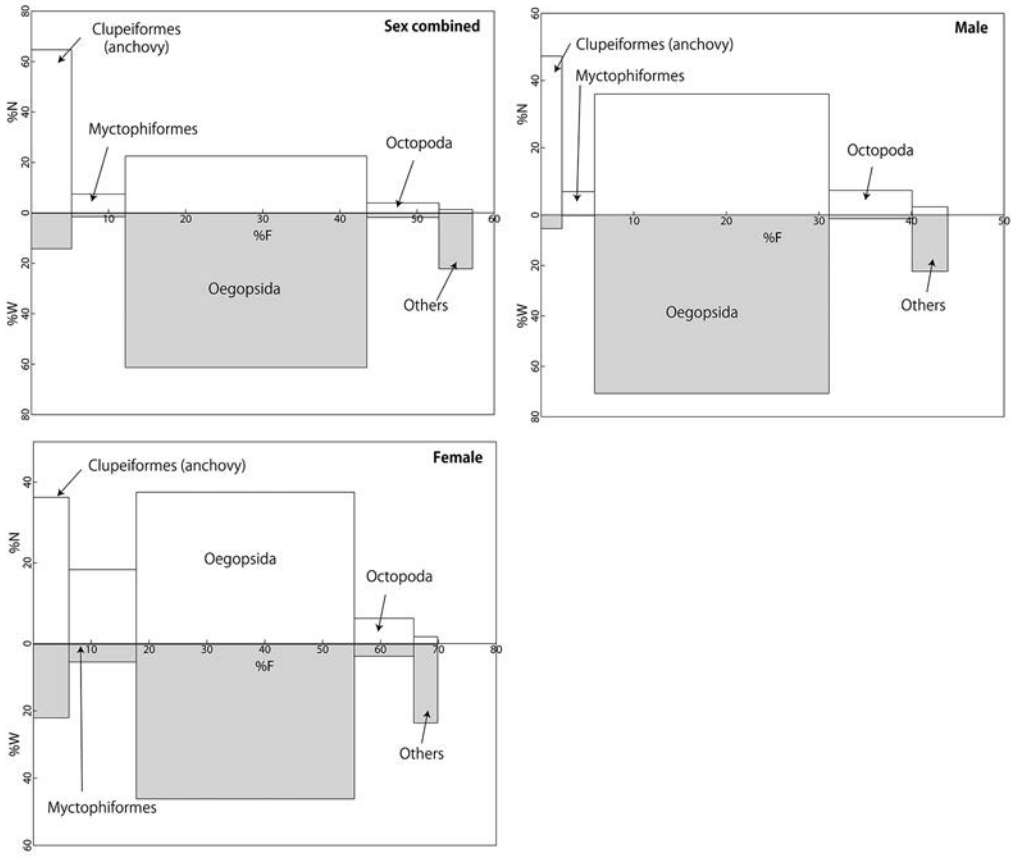

FIGURE 4. Percentage by number (%N), percentage by weight (%W), and percentage frequency of occurrence (%F) of the blue shark stomach contents in the Northwestern Pacific.

than those of fish (Figure 5). The prey species with the lowest mean δ^{15}N value was anchovy (9.3‰), and that with the lowest mean δ^{13}C was *Gonatus pyros* (–19.9‰). The prey species with the highest mean δ^{13}C was *Gonatus berryi* (–17.8‰), and the highest mean δ^{15}N value was for *Taningia danae* (11.5‰).

The feasible contribution of each prey species to the diet of blue sharks was calculated using the SIAR package. The proportions of anchovy, Warming's lantern fish (*Ceratoscopelus warmingii*), and prickly lanternfish (*Myctophum asperum*) were higher than those of other species (Figure 6) for all combinations of the carbon and nitrogen discrimination factors. The proportions of these species were almost 0.2; however, the other species were below 0.1 even though Oegopsida was often observed in the blue shark stomachs.

DISCUSSION

Kubodera et al. (2007) reported on the feeding habits of blue and salmon sharks in the transition region of the North Pacific during 1999 and 2000 based on stomach contents analysis. They reported that the important prey species for blue sharks were meso- to bathypelagic cephalopods (e.g., *Chiroteuthis calyx*, *Haliphron atlanticus*, *Histioteuthis dofleini*, and *Belonella borealis*) and small myctophid fish (e.g., *Maurolicus imperatorius*). Our stomach contents analysis indicated that the most

important prey for blue sharks was anchovy and Oegopsida. Kubodera et al. (2007) surveyed sharks during April–May, whereas anchovy were observed mainly in August and September in our study. Murase et al. (2012) reported that anchovy were widely distributed in the Kuroshio–Oyashio transition zone, and anchovy was the most abundant pelagic species in this region in the 2000s. Thus, it is likely that the discrepancy between the findings of Kubodera et al. (2007) and this study resulted from differences in the survey area and sampling season. In addition, the number of fish sampled in our study ($n = 460$) was much larger than that of Kubodera et al. (2007) ($n = 70$). Therefore, the stomach contents of blue sharks captured in this study may be more representative.

Reported important prey items of blue sharks based on stomach contents analysis varies among studies. For example, Clarke et al. (1996) and Markaida and Sosa-Nishizaki (2010) reported that the most important prey were cephalopods in the waters off the Azores, and in the waters off Ensenada, Baja California, Mexico, respectively. In contrast, McCord and Campana (2003) reported that blue sharks off Nova Scotia feed primarily on pelagic teleost fishes. They also suggested that the differences of prey importance among studies would be due to a seasonal factor or abundance of prey species. In conclusion, blue sharks seem to feed on the spatial-temporally abundant prey species; thus, blue sharks are considered to be opportunistic feeders.

Stable isotope carbon and nitrogen ratios for blue sharks in the Northwestern Pacific have been reported (Takai et al. 2007; Ohshimo, Tanaka et al. 2016). The δ^{15}N (12.0‰) and δ^{13}C (–18.1‰) values reported by Takai et al. (2007) are similar to those of this study (δ^{15}N: 12.1‰, δ^{13}C: –18.5‰), whereas Ohshimo, Tanaka, et al. (2016) reported a higher δ^{15}N value (13.8‰) for the East China Sea. Tanaka et al. (2008) studied differences in the stable isotope ratios of anchovy among sampling areas and found that values in the offshore area of the Pacific were significantly lower than those in coastal areas. In addition, several authors reported geographical differences in δ^{15}N value between the Western and Eastern Pacific (e.g., Madigan et al. 2014) and showed that the δ^{15}N value in the Western Pacific was lower than that in the Eastern Pacific. The δ^{15}N value in our study was also lower than that reported in the Eastern Pacific [15.2‰: Madigan et al. (2012); 16.5‰: Hernández-Aguilar et al. (2015)]. Although the baseline zooplankton δ^{15}N value varies annually and seasonally (e.g., McMahon et al. 2013), the effect of baseline fluctuations should be analyzed in the future. In addition, to take into account these baseline fluctuations, fine-scale sampling of prey species both temporally and spatially would be valuable.

The Δ^{13}C and Δ^{15}N values are important for calculating trophic position and estimating predator-prey interactions (Hussey et al. 2014) because the discrimination factor highly affects the proportion of prey item calculated by SIAR (Bond and Diamond 2011). Usually, Δ^{13}C and Δ^{15}N values of about 1.0‰ and 3.0–4.0‰, respectively, are used (e.g., DeNiro and Epstein 1981). However, Caut et al. (2009) reviewed Δ^{13}C and Δ^{15}N in animals and found that those values have negative relationships with stable isotope ratios. Hussey et al. (2009) reported that Δ^{13}C and Δ^{15}N values in lipid-extracted muscle of large sharks were 0.9‰ and 2.3‰, respectively. In this study, we evaluated the proportion of prey items in the blue shark diet using three combinations of Δ^{13}C and Δ^{15}N (DeNiro and Epstein 1981, Hussey et al. 2009; Kim et al. 2012), and all results were similar. In all combinations of discrimination factors, our results indicated that the relative contributions of anchovy and small mesopelagic myctophids were higher than that of Oegopsida species, although the results from stomach contents analyses indicated that the %IRI values of anchovy and Oegopsida were high. The stable isotope analysis can predict the actual feeding habits of blue sharks; however, we measured the stable isotope values of only 15 species. Although sampling the other species, such as epipelagic and mesopelagic fish and squid, in the open ocean is difficult, we plan to measure Δ^{13}C and Δ^{15}N values for these other potential prey in the future.

TABLE 3

Proportions of Prey Items Recorded in the Stomach of Blue Sharks in the Northwestern Pacific

Class	Order	Family	Species	%N	%W	%F	IRI	%IRI
Mammalia	Carnivora	Unidentified Carnivora		0.06	0.36	0.22	0.09	0.01
Chondrichthyes	Carcharhiniformes	Carcharhinidae	Unidentified Carcharhinidae	0.06	0.00	0.22	0.01	0.00
Actinopterygii	Clupeiformes	Engraulidae	*Engraulis japonicus*	64.69	14.02	5.22	410.67	33.47
	Clupeiformes	Clupeidae	*Sardinops melanostictus*					
	Myctophiformes	Myctophidae	*Notoscopelus* sp.	0.06	0.01	0.22	0.02	0.00
	Myctophiformes	Myctophidae	*Ceratoscopelus warmingii*	1.91	0.05	1.96	3.83	0.31
	Myctophiformes	Myctophidae	Unidentified Myctophidae	5.37	1.15	5.87	38.31	3.12
	Aulopiformes	Paralepididae	Unidentified Paralepididae	0.13	0.09	0.22	0.05	0.00
	Aulopiformes	Alepisauridae	*Alepisaurus ferox*	0.19	1.89	0.65	1.36	0.11
	Perciformes	Bramidae	*Brama japonica*	0.06	4.25	0.22	0.94	0.08
	Perciformes	Scombridae	*Auxis rochei*	0.13	3.26	0.22	0.74	0.06
	Perciformes	Scombridae	*Scomber* sp.					
	Perciformes	Scombridae	*Katsuwonus pelamis*	0.06	3.38	0.22	0.75	0.06
	Perciformes	Scombridae	*Thunnus* sp.	0.06	2.05	0.22	0.46	0.04
	Perciformes	Gempylidae	*Gempylus serpens*	0.06	0.20	0.22	0.06	0.00
	Perciformes	Carangidae	Unidentified Carangidae	0.13	0.03	0.43	0.07	0.01
	Perciformes	Tetragonuridae	*Tetragonurus cuvieri*	0.06	1.02	0.22	0.24	0.02
	Perciformes	Molidae	*Mola* sp.	0.06	1.16	0.22	0.27	0.02
	Salmoniformes	Salmonidae	*Oncorhychus kisutch*	0.06	2.51	0.22	0.56	0.05
Cephalopoda	Oegopsida	Ommastrephidae	*Ommastrephes bartramii*	0.78	16.97	1.30	23.15	1.89
	Oegopsida	Ommastrephidae	Unidentified Ommastrephidae	1.36	6.66	4.57	36.60	2.98
	Oegopsida	Ommastrephidae	*Eucleoteuthis luminosa*	0.52	3.56	1.52	6.21	0.51
	Oegopsida	Histioteuthidae	*Histioteuthis hoylei*	0.19	0.52	0.43	0.31	0.03
	Oegopsida	Histioteuthidae	*Histioteuthis corona inermis*	0.45	0.00	0.22	0.10	0.01
	Oegopsida	Histioteuthidae	Unidentified Histioteuthidae	2.65	0.01	6.52	17.39	1.42
	Oegopsida	Ancistrocheiridae	*Ancistrocheirus lesueurii*	0.39	0.00	1.30	0.51	0.04
	Oegopsida	Gonatidae	*Gonatopsis borealis*	0.39	2.33	0.87	2.36	0.19
	Oegopsida	Gonatidae	*Gonatopsis* sp.	0.19	0.00	0.65	0.13	0.01
	Oegopsida	Gonatidae	*Gonatus pyros*	1.36	0.01	4.13	5.67	0.46
	Oegopsida	Gonatidae	*Gonatus berryi*	0.19	0.00	0.65	0.13	0.01
	Oegopsida	Gonatidae	Unidentified Gonatidae	3.69	0.14	6.74	25.82	2.10
	Oegopsida	Octopoteuthidae	*Taningia danae*	0.13	2.83	0.43	1.29	0.11
	Oegopsida	Octopoteuthidae	Unidentified Octopoteuthidae	0.78	0.01	2.61	2.06	0.17
	Oegopsida	Onychoteuthidae	*Onychoteuthis banksii*	0.32	0.22	0.22	0.12	0.01
	Oegopsida	Onychoteuthidae	Unidentified Onychoteuthidae	1.88	0.36	5.00	11.21	0.91
	Oegopsida	Chiroteuthidae	*Grimalditeuthis* sp.	0.39	0.00	1.09	0.42	0.03
	Oegopsida	Enoploteuthidae	*Watasenia scintillans*	0.97	0.06	1.30	1.34	0.11

	Oegopsida	Enoploteuthidae	Unidentified Enoploteuthidae	1.17	0.01	0.87	1.02	0.08
	Oegopsida	Unidentified Oegopsida		5.83	29.30	17.61	618.53	50.41
	Octopoda	Octopodidae	Unidentified Octopodidae	2.07	0.04	5.22	11.01	0.90
	Octopoda	Bolitanaenidae	*Japetella diaphana*	0.52	0.00	0.87	0.45	0.04
	Octopoda	Unidentified Octopoda		0.58	1.52	1.30	2.74	0.22
Malacostraca	Euphausiacea	Unidentified Euphausiacea						
	Amphipoda	Unidentified Amphipoda						
	Decapoda	Unidentified Decapoda						

Stomach contents analysis has been criticized as providing only a snapshot of predator diet (e.g., Basker et al. 2014). In our study, blue sharks were caught mainly by longline at night. A hooked blue shark cannot capture additional prey, and the prey could be digested. Actually, the cumulative prey curve did not reach an asymptotic value, so our sample size was insufficient despite being much larger than that used in previous studies. In addition, the calculated mean number or weight of blue shark prey items was underestimated because most prey items were already digested. The digestion rate depends on prey type and size (Macdonald et al. 1982). In general, larger and bony fish take longer to digest, and fish otoliths and the squid beak cannot be digested, so squid were more likely to be recorded in the stomach, indicating that squid (Oegopsida) in the stomach contents tended to be overestimated as an important prey species.

Chavez et al. (2003) reviewed the relationships between climate change and population fluctuations of small pelagic fish in the genera *Engraulis* and *Sardinops* in the Pacific Ocean. They reported that environmental conditions in the Pacific changed from a cool "anchovy regime" to a warm "sardine regime" in the 1970s, and a shift back to an anchovy regime occurred in the mid- to late 1990s. Murase et al. (2012) reported that 1.5–3.4 million tons of Japanese anchovy were present in the offshore area of the Northwestern Pacific between 2004 and 2007. Some larval Japanese anchovy that hatch on the coastal side of the Kuroshio are believed to be transported offshore by the Kuroshio Extension, where they migrate northward into the Kuroshio–Oyashio transition region (Takasuka and Aoki 2002). Japanese anchovy were mainly observed in blue shark stomachs in August and September. Therefore, although this species is important, it is a seasonally abundant prey item for blue sharks. No reports are available on the stock sizes of lanternfish or squid in the current survey area, but these are mesopelagic taxa and would likely have large stock size. Diel vertical migration of blue sharks has been reported by an electronic tagging study (e.g., Campana et al. 2011), but there are no

TABLE 4

Stable Isotope Values of Prey Items and Blue Sharks in the Northwestern Pacific

Class	Species	Mean $\delta^{15}N \pm SD$	Range	Mean $\delta^{13}C \pm SD$	Range	*n*	Abbreviation
Actinopterygii	*Myctophum asperum*	9.7 ± 0.7	8.6 to 10.3	−19.7 ± 0.2	−19.9 to −19.5	5	MYC(MA)
	Ceratoscopelus warmingii	9.7 ± 0.9	8.9 to 10.9	−19.6 ± 0.2	−19.9 to −19.6	5	MYC(CW)
	Notoscopelus resplendens	10.3 ± 1.1	9.7 to 12.3	−19.1 ± 0.5	−19.8 to −18.6	5	MYC(NR)
	Engraulis japonicus	9.3 ± 0.6	8.4 to 10.2	−19.1 ± 0.8	−19.7 to −17.6	6	ANC
	Lestrolepis japonica	10.7 ± 0.7	10.0 to 11.8	−18.8 ± 0.8	−19.3 to −17.5	5	BAR
Cephalopoda	*Gonatus pyros*	11.3 ± 0.4	11.0 to 11.8	−19.9 ± 0.3	−20.2 to −19.5	4	SQ(GP)
	Eucleoteuthis luminosa	10.5 ± 1.1	9.1 to 11.5	−19.2 ± 0.3	−19.4 to −18.6	5	SQ(EL)
	Gonatus onyx	10.1 ± 0.8	9.7 to 11.0	−18.6 ± 0.2	−18.7 to −18.4	3	SQ(GO)
	Gonatopsis makko	10.8 ± 0.7	9.9 to 11.5	−18.7 ± 0.4	−19.0 to −18.1	5	SQ(GM)
	Octopoteuthis sicula	11.1 ± 0.7	9.9 to 11.8	−18.6 ± 0.6	−19.3 to −17.6	5	SQ(OS)
	Thysanoteuthis rhombus	11.0	10.7 to 11.2	−18.4	−18.8 to −18.1	2	SQ(TR)
	Enoploteuthis chunii	10.5 ± 0.8	9.7 to 11.5	−18.3 ± 0.4	−18.7 to −17.8	5	SQ(EC)
	Ancistrocheirus lesueurii	10.4 ± 0.7	9.6 to 11.1	−18.1 ± 0.4	−18.5 to −17.5	5	SQ(AL)
	Taningia danae	11.5	11.4 to 11.5	−17.9	−18.0 to −17.9	2	SQ(TD)
	Gonatus berryi	11.4	11.3 to 11.6	−17.8	−17.9 to −17.8	2	SQ(GB)
Chondrichthyes	*Prionace glauca*	12.1 ± 0.8	10.3 to 14.0	−18.5 ± 0.6	−19.6 to −17.1	120	

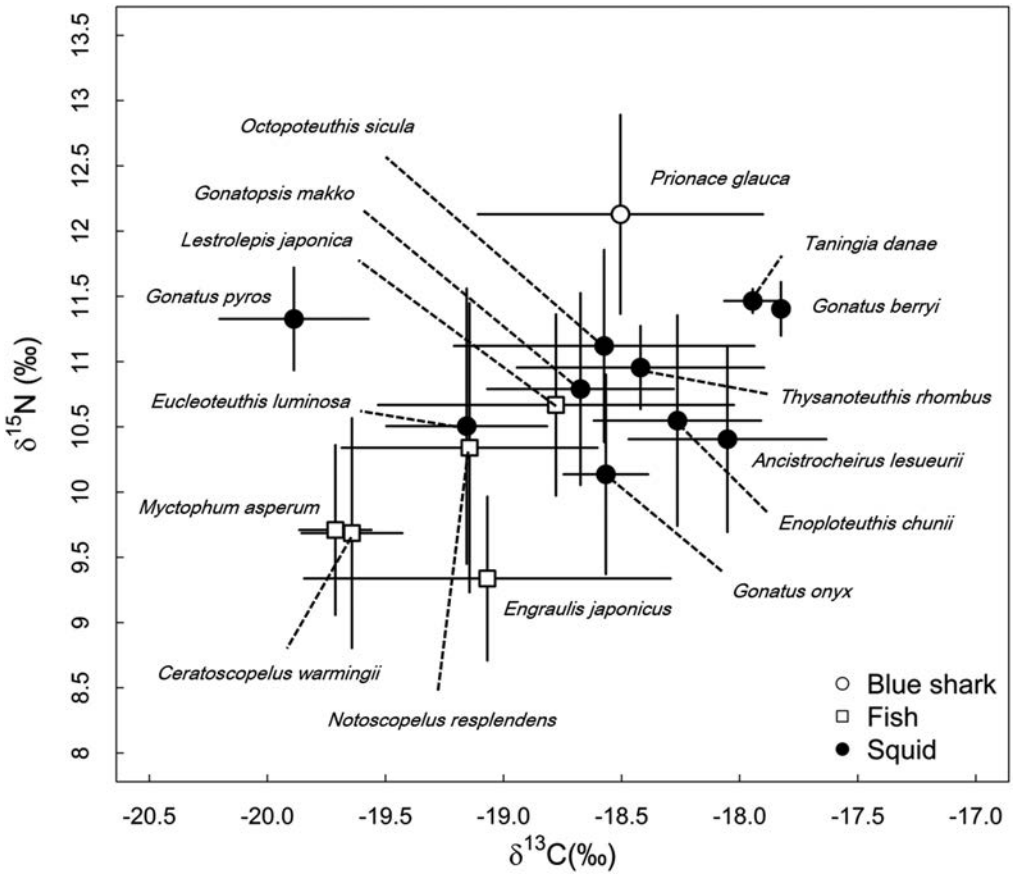

FIGURE 5. Relationship between δ^{15}N and δ^{13}C values of blue shark and its prey items. White circles, black circles, and white squares represent mean stable isotope ratios for blue shark, squid, and other fish, respectively. Vertical and horizontal bars represent standard deviations.

reports on the horizontal migration of blue sharks in the Northwestern Pacific. Thus, future research should include surveys on blue shark behavior and the horizontal and vertical distributions of its prey items.

CONCLUSION

Based on our observations of the stomach contents of blue sharks in the Northwestern Pacific, the main prey items were anchovy and squids. The stable isotope ratio analyses with a mixing model indicated that the main blue shark prey species were anchovy and myctophid fish. Our stomach analysis results demonstrated that a large number of samples is needed to describe the overall trophic diversity of the blue shark diet. On the other hand, the stable isotope analysis showed a result similar to that of the stomach contents analysis despite the small sample size. The combination of stomach contents and stable isotope analyses was a better method to avoid observation error bias. The large IRI value of anchovy reflected the capture of this species in summer, when the distribution area of anchovy expands in the North Pacific, and this species was seasonally abundant for blue sharks. We conclude that blue sharks capture prey ranging from neritic to mesopelagic animals through diel vertical migration.

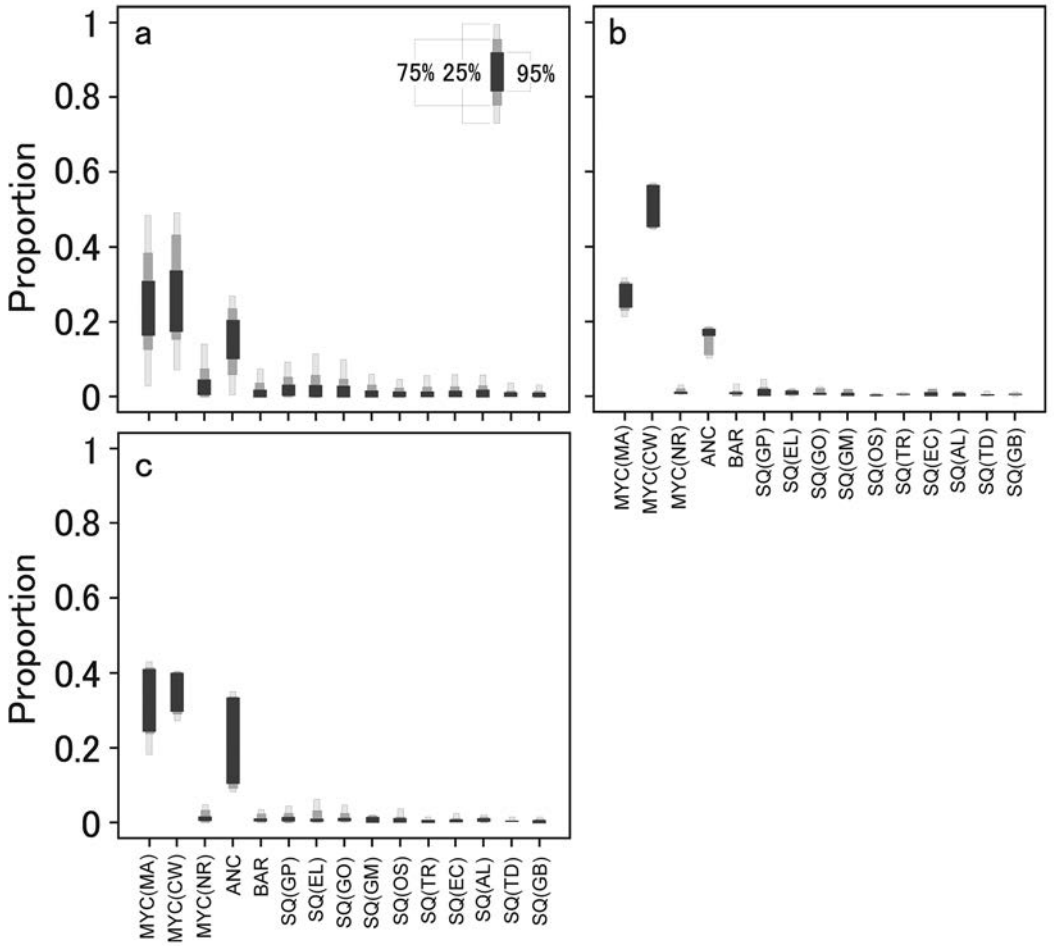

FIGURE 6. Contribution of potential prey to the diet of blue sharks according to the Stable Isotope Analysis in R (SIAR) and three different discrimination factors: *a*, Kim et al. (2012); *b*, Hussey et al. (2009); *c*, DeNiro and Epstein (1981). Results are shown as 95%, 75%, and 25% credible intervals for each prey taxon. Abbreviations are defined in Table 4.

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SUPPLEMENTAL TABLE S1

Annual Number of Prey Species Recorded in the Stomach of Blue Sharks in the Northwestern Pacific

Class	Order	Family	Species	1999	2001	2002	2006	2010	2011	2012	2013	2014	Total
Mammalia	Carnivora	Unidentified Carnivora		0	0	0	1	0	0	0	0	0	1
Chondrichthyes	Carcharhiniformes	Carcharhinidae	Unidentified Carcharhinidae	0	0	0	0	1	0	0	0	0	1
Actinopterygii	Clupeiformes	Engraulidae	*Engraulis japonicus*	0	0	0	977	1	0	19	3	0	1000
	Clupeiformes	Clupeidae	*Sardinops melanostictus*	0	0	0	0	4	5	0	0	0	9
	Myctophiformes	Myctophidae	*Notoscopelus* sp.	0	0	0	1	0	0	0	0	0	1
	Myctophiformes	Myctophidae	*Ceratoscopelus warmingii*	0	0	0	2	0	0	21	6	0	29
	Myctophiformes	Myctophidae	Unidentified Myctophidae	3	0	0	66	0	0	10	5	0	84
	Aulopiformes	Paralepididae	Unidentified Paralepididae	0	0	0	2	0	0	0	0	0	2
	Aulopiformes	Alepisauridae	*Alepisaurus ferox*	0	0	0	0	0	0	3	0	0	3
	Perciformes	Bramidae	*Brama japonica*	0	0	0	1	0	0	0	0	0	1
	Perciformes	Scombridae	*Auxis rochei*	0	0	0	0	0	0	0	2	0	2
	Perciformes	Scombridae	*Scomber* sp.	0	0	0	15	0	0	39	13	1	68
	Perciformes	Scombridae	*Katsuwonus pelamis*	1	0	0	0	0	0	0	0	0	1
	Perciformes	Scombridae	*Thunnus* sp.	0	0	0	0	0	0	0	1	0	1
	Perciformes	Gempylidae	*Gempylus serpens*	0	0	0	0	1	0	0	0	0	1
	Perciformes	Carangidae	Unidentified Carangidae	0	0	0	0	0	0	0	2	0	2
	Perciformes	Tetragonuridae	*Tetragonurus cuvieri*	0	0	0	1	0	0	0	0	0	1
	Perciformes	Molidae	*Mola* sp.	0	0	0	0	0	0	1	0	0	1
	Salmoniformes	Salmonidae	*Oncorhychus kisutch*	0	0	0	1	0	0	0	0	0	1
Cephalopoda	Oegopsida	Ommastrephidae	*Ommastrephes bartramii*	0	0	0	12	0	0	0	0	0	12
	Oegopsida	Ommastrephidae	Unidentified Ommastrephidae	0	0	0	3	0	1	17	0	0	21
	Oegopsida	Ommastrephidae	*Eucleoteuthis luminosa*	1	0	0	1	0	0	2	4	0	8
	Oegopsida	Histioteuthidae	*Histioteuthis hoylei*	0	0	0	0	0	0	0	3	0	3
	Oegopsida	Histioteuthidae	*Histioteuthis corona inermis*	0	0	0	0	0	0	0	7	0	7
	Oegopsida	Histioteuthidae	Unidentified Histioteuthidae	5	0	0	4	0	1	22	9	0	41
	Oegopsida	Ancistrocheiridae	*Ancistrocheirus lesueurii*	0	0	0	1	0	0	4	1	0	6
	Oegopsida	Gonatidae	*Gonatopsis borealis*	0	0	0	1	1	0	4	0	0	6
	Oegopsida	Gonatidae	*Gonatopsis* sp.	0	0	0	2	0	1	0	0	0	3
	Oegopsida	Gonatidae	*Gonatus pyros*	0	0	0	3	1	2	12	3	0	21
	Oegopsida	Gonatidae	*Gonatus berryi*	0	0	0	1	0	0	2	0	0	3
	Oegopsida	Gonatidae	Unidentified Gonatidae	4	0	0	12	0	1	37	3	0	57
	Oegopsida	Octopoteuthidae	*Taningia danae*	0	0	0	0	0	2	0	0	0	2
	Oegopsida	Octopoteuthidae	Unidentified Octopoteuthidae	0	0	0	5	0	0	3	4	0	12
	Oegopsida	Onychoteuthidae	*Onychoteuthis banksii*	0	0	0	5	0	0	0	0	0	5
	Oegopsida	Onychoteuthidae	Unidentified Onychoteuthidae	1	0	0	12	1	3	10	2	0	29
	Oegopsida	Chiroteuthidae	*Grimalditeuthis* sp.	0	0	0	0	0	0	3	3	0	6

	Oegopsida	Enoploteuthidae	*Watasenia scintillans*	0	0	0	15	0	0	0	0	0	15
	Oegopsida	Enoploteuthidae	Unidentified Enoploteuthidae	0	0	0	3	0	0	1	14	0	18
	Oegopsida	Unidentified Oegopsida		8	0	0	19	7	12	28	16	0	90
	Octopoda	Octopodidae	Unidentified Octopodidae	0	0	0	4	1	2	13	12	0	32
	Octopoda	Bolitanaenidae	*Japetella diaphana*	4	0	0	0	0	0	4	0	0	8
	Octopoda	Unidentified Octopoda		4	0	0	0	0	0	4	1	0	9
Malacostraca	Euphausiacea	Unidentified Euphausiacea		0	0	0	15	611	0	0	0	0	626
	Amphipoda	Unidentified Amphipoda		1	0	0	0	0	0	0	3	0	4
	Decapoda	Unidentified Decapoda		0	0	0	0	0	0	2	2	0	4
Total				32	0	0	1185	629	30	261	119	1	2257
Average number				2.7	—	—	24.7	30.0	2.1	2.7	4.1	1.0	10.2
Empty stomach				4	0	0	9	109	16	72	27	2	239
Total specimen number				16	0	0	57	130	30	168	56	3	460

SUPPLEMENTAL TABLE S2

Annual Weight of Prey Species Recorded in the Stomach of Blue Sharks in the Northwestern Pacific

Class	Order	Family	Species	1999	2001	2002	2006	2010	2011	2012	2013	2014	Total
Mammalia	Carnivora	Unidentified Carnivora		0.0	0.0	0.0	95.0	0.0	0.0	0.0	0.0	0.0	95.0
Chondrichthyes	Carcharhiniformes	Carcharhinidae	Unidentified Carcharhinidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Actinopterygii	Clupeiformes	Engraulidae	*Engraulis japonicus*	0.0	0.0	0.0	3642.7	4.4	0.0	13.2	54.8	0.0	3715.1
	Clupeiformes	Clupeidae	*Sardinops melanostictus*	0.0	0.0	0.0	0.0	674.6	1081.0	0.0	0.0	0.0	1755.6
	Myctophiformes	Myctophidae	*Notoscopelus* sp.	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	1.8
	Myctophiformes	Myctophidae	*Ceratoscopelus warmingii*	0.0	0.0	0.0	8.7	0.0	0.0	3.8	0.0	0.0	12.5
	Myctophiformes	Myctophidae	Unidentified Myctophidae	11.9	0.0	0.0	289.0	0.0	0.0	5.0	0.0	0.0	305.9
	Aulopiformes	Paralepididae	Unidentified Paralepididae	0.0	0.0	0.0	23.5	0.0	0.0	0.0	0.0	0.0	23.5
	Aulopiformes	Alepisauridae	*Alepisaurus ferox*	0.0	0.0	0.0	0.0	0.0	0.0	500.5	0.0	0.0	500.5
	Perciformes	Bramidae	*Brama japonica*	0.0	0.0	0.0	1126.1	0.0	0.0	0.0	0.0	0.0	1126.1
	Perciformes	Scombridae	*Auxis rochei*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	865.0	0.0	865.0
	Perciformes	Scombridae	*Scomber* sp.	0.0	0.0	0.0	1115.1	0.0	0.0	5401.6	1801.6	155.3	8473.6
	Perciformes	Scombridae	*Katsuwonus pelamis*	897.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	897.0
	Perciformes	Scombridae	*Thunnus* sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	542.7	0.0	542.7
	Perciformes	Gempylidae	*Gempylus serpens*	0.0	0.0	0.0	0.0	53.0	0.0	0.0	0.0	0.0	53.0
	Perciformes	Carangidae	Unidentified Carangidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9	0.0	7.9
	Perciformes	Tetragonuridae	*Tetragonurus cuvieri*	0.0	0.0	0.0	270.9	0.0	0.0	0.0	0.0	0.0	270.9
	Perciformes	Molidae	*Mola* sp.	0.0	0.0	0.0	0.0	0.0	0.0	306.9	0.0	0.0	306.9
	Salmoniformes	Salmonidae	*Oncorhychus kisutch*	0.0	0.0	0.0	664.8	0.0	0.0	0.0	0.0	0.0	664.8
Cephalopoda	Oegopsida	Ommastrephidae	*Ommastrephes bartramii*	0.0	0.0	0.0	4497.7	0.0	0.0	0.0	0.0	0.0	4497.7
	Oegopsida	Ommastrephidae	Unidentified Ommastrephidae	0.0	0.0	0.0	649.0	0.0	0.0	1115.0	0.0	0.0	1764.0
	Oegopsida	Ommastrephidae	*Eucleoteuthis luminosa*	102.0	0.0	0.0	0.1	0.0	2.5	839.7	0.2	0.0	944.5
	Oegopsida	Histioteuthidae	*Histioteuthis hoylei*	0.0	0.0	0.0	0.0	136.3	0.0	0.2	0.0	0.0	136.5
	Oegopsida	Histioteuthidae	*Histioteuthis corona inermis*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3
	Oegopsida	Histioteuthidae	Unidentified Histioteuthidae	0.5	0.0	0.0	0.2	0.0	0.1	1.5	1.0	0.0	3.3
	Oegopsida	Ancistrocheiridae	*Ancistrocheirus lesueurii*	0.0	0.0	0.0	0.1	0.0	0.0	0.5	0.1	0.0	0.7

	Oegopsida	Gonatidae	*Gonatopsis borealis*	0.0	0.0	0.0	123.8	493.4	0.0	0.2	0.0	0.0	617.4
	Oegopsida	Gonatidae	*Gonatopsis* sp.	0.0	0.0	0.0	0.2	0.0	0.4	0.0	0.0	0.0	0.6
	Oegopsida	Gonatidae	*Gonatus pyros*	0.0	0.0	0.0	0.2	0.1	0.1	0.8	2.4	0.0	3.6
	Oegopsida	Gonatidae	*Gonatus berryi*	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.0	0.0	0.4
	Oegopsida	Gonatidae	Unidentified Gonatidae	0.2	0.0	0.0	17.2	0.0	0.9	1.1	18.1	0.0	37.5
	Oegopsida	Octopoteuthidae	*Taningia danae*	0.0	0.0	0.0	0.0	0.0	751.0	0.0	0.0	0.0	751.0
	Oegopsida	Octopoteuthidae	Unidentified Octopoteuthidae	0.0	0.0	0.0	0.5	0.0	0.0	0.5	2.9	0.0	3.9
	Oegopsida	Onychoteuthidae	*Onychoteuthis banksii*	0.0	0.0	0.0	57.4	0.0	0.0	0.0	0.0	0.0	57.4
	Oegopsida	Onychoteuthidae	Unidentified Onychoteuthidae	0.0	0.0	0.0	5.2	0.1	0.6	90.6	0.2	0.0	96.7
	Oegopsida	Chiroteuthidae	*Grimalditeuthis* sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
	Oegopsida	Enoploteuthidae	*Watasenia scintillans*	0.0	0.0	0.0	15.3	0.0	0.0	0.0	0.0	0.0	15.3
	Oegopsida	Enoploteuthidae	Unidentified Enoploteuthidae	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	3.2
	Oegopsida	Unidentified Oegopsida		84.7	0.0	0.0	639.9	672.2	5290.1	208.9	868.9	0.0	7764.7
	Octopoda	Octopodidae	Unidentified Octopodidae	0.0	0.0	0.0	1.0	7.4	0.5	0.9	0.3	0.0	10.1
	Octopoda	Bolitanaenidae	*Japetella diaphana*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Octopoda	Unidentified Octopoda		0.1	0.0	0.0	0.0	0.0	0.0	401.5	0.3	0.0	401.9
Malacostraca	Euphausiacea	Unidentified Euphausiacea		0.0	0.0	0.0	2.0	90.0	0.0	0.0	0.0	0.0	92.0
	Amphipoda	Unidentified Amphipoda		0.2	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	2.8
	Decapoda	Unidentified Decapoda		0.0	0.0	0.0	0.0	0.0	0.0	1.2	3.9	0.0	5.1
Total				1096.5	0.0	0.0	13250.9	2131.6	7127.3	8893.9	4173.3	155.3	36828.7
Average weight (g)				91.4	—	—	276.1	101.5	509.1	92.6	143.9	155.3	166.6
Empty stomach				4	0	0	9	109	16	72	27	2	239
Total specimen number				16	0	0	57	130	30	168	56	3	460

SUPPLEMENTAL TABLE S3

Prey Species Composition by Precaudal Length (25 cm) Recorded in the Stomach of Blue Sharks in the Northwestern Pacific

Class	Order	Family	Species	50	75	100	125	150	175	200	Total
Mammalia	Carnivora	Unidentified Carnivora		0	0	1	0	0	0	0	1
Chondrichthyes	Carcharhiniformes	Carcharhinidae	Unidentified Carcharhinidae	0	0	0	1	0	0	0	1
Actinopterygii	Clupeiformes	Engraulidae	*Engraulis japonicus*	6	24	429	13	528	0	0	1000
	Clupeiformes	Clupeidae	*Sardinops melanostictus*	0	0	1	3	4	0	1	9
	Myctophiformes	Myctophidae	*Notoscopelus* sp.	0	0	1	0	0	0	0	1
	Myctophiformes	Myctophidae	*Ceratoscopelus warmingii*	0	2	20	1	7	0	0	30
	Myctophiformes	Myctophidae	Unidentified Myctophidae	0	23	9	24	28	0	0	84
	Aulopiformes	Paralepididae	Unidentified Paralepididae	0	0	0	2	0	0	0	2
	Aulopiformes	Alepisauridae	*Alepisaurus ferox*	0	0	1	2	0	0	0	3
	Perciformes	Bramidae	*Brama japonica*	0	0	1	0	0	0	0	1
	Perciformes	Scombridae	*Auxis rochei*	0	0	0	0	0	0	2	2
	Perciformes	Scombridae	*Scomber* sp.	3	18	17	8	17	3	2	68
	Perciformes	Scombridae	*Katsuwonus pelamis*	0	0	0	0	1	0	0	1
	Perciformes	Scombridae	*Thunnus* sp.	0	0	0	0	0	0	1	1
	Perciformes	Gempylidae	*Gempylus serpens*	0	0	0	1	0	0	0	1
	Perciformes	Carangidae	Unidentified Carangidae	0	0	0	1	1	0	0	2
	Perciformes	Tetragonuridae	*Tetragonurus cuvieri*	0	0	1	0	0	0	0	1
	Perciformes	Molidae	*Mola* sp.	0	0	0	0	1	0	0	1
	Salmoniformes	Salmonidae	*Oncorhychus kisutch*	0	0	0	0	1	0	0	1
Cephalopoda	Oegopsida	Ommastrephidae	*Ommastrephes bartramii*	0	0	11	1	0	0	0	12
	Oegopsida	Ommastrephidae	Unidentified Ommastrephidae	14	4	1	1	0	1	0	21
	Oegopsida	Ommastrephidae	*Eucleoteuthis luminosa*	0	1	0	1	3	1	2	8
	Oegopsida	Histioteuthidae	*Histioteuthis hoylei*	0	0	0	2	1	0	0	3
	Oegopsida	Histioteuthidae	*Histioteuthis corona inermis*	0	0	0	0	0	7	0	7
	Oegopsida	Histioteuthidae	Unidentified Histioteuthidae	3	6	8	6	10	4	4	41
	Oegopsida	Ancistrocheiridae	*Ancistrocheirus lesueurii*	0	1	2	2	1	0	0	6
	Oegopsida	Gonatidae	*Gonatopsis borealis*	0	3	1	2	0	0	0	6
	Oegopsida	Gonatidae	*Gonatopsis* sp.	0	0	0	2	1	0	0	3
	Oegopsida	Gonatidae	*Gonatus pyros*	3	2	2	7	3	3	1	21
	Oegopsida	Gonatidae	*Gonatus berryi*	0	1	1	1	0	0	0	3
	Oegopsida	Gonatidae	Unidentified Gonatidae	10	23	8	9	4	3	0	57
	Oegopsida	Octopoteuthidae	*Taningia danae*	0	0	0	1	1	0	0	2
	Oegopsida	Octopoteuthidae	Unidentified Octopoteuthidae	1	4	0	3	3	0	1	12
	Oegopsida	Onychoteuthidae	*Onychoteuthis banksii*	0	5	0	0	0	0	0	5
	Oegopsida	Onychoteuthidae	Unidentified Onychoteuthidae	0	4	4	7	10	4	0	29
	Oegopsida	Chiroteuthidae	*Grimalditeuthis* sp.	1	0	1	0	4	0	0	6
	Oegopsida	Enoploteuthidae	*Watasenia scintillans*	0	2	2	2	9	0	0	15
	Oegopsida	Enoploteuthidae	Unidentified Enoploteuthidae	0	1	1	2	14	0	0	18

	Oegopsida	Unidentified Oegopsida		3	13	14	21	30	5	4	90
	Octopoda	Octopodidae	Unidentified Octopodidae	3	3	7	5	7	4	3	32
	Octopoda	Bolitanaenidae	*Japetella diaphana*	0	4	1	2	1	0	0	8
	Octopoda	Unidentified Octopoda		2	0	3	0	4	0	0	9
Malacostraca	Euphausiacea	Unidentified Euphausiacea		0	1	14	609	2	0	0	626
	Amphipoda	Unidentified Amphipoda		0	0	0	0	2	1	1	4
	Decapoda	Unidentified Decapoda		0	0	1	1	1	0	1	4
Total				49	145	563	743	698	36	23	2257
Average weight (g)				2.0	3.3	13.7	16.2	15.2	3.3	2.9	10.2
Empty stomach				6	25	26	69	77	26	10	239
Total specimen number				31	69	67	115	123	37	18	460

SUPPLEMENTAL TABLE S4

Weight of Prey Species by Precaudal Length (25 cm) Recorded in the Stomach of Blue Sharks in the Northwestern Pacific

Class	Order	Family	Species	50	75	100	125	150	175	200	Total
Mammalia	Carnivora	Unidentified Carnivora		0.0	0.0	95.0	0.0	0.0	0.0	0.0	95.0
Chondrichthyes	Carcharhiniformes	Carcharhinidae	Unidentified Carcharhinidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Actinopterygii	Clupeiformes	Engraulidae	*Engraulis japonicus*	0.0	195.3	2965.8	104.6	449.4	0.0	0.0	3715.1
	Clupeiformes	Clupeidae	*Sardinops melanostictus*	0.0	0.0	444.5	240.3	963.5	0.0	107.3	1755.6
	Myctophiformes	Myctophidae	*Notoscopelus* sp.	0.0	0.0	1.8	0.0	0.0	0.0	0.0	1.8
	Myctophiformes	Myctophidae	*Ceratoscopelus warmingii*	0.0	2.0	3.8	6.7	0.0	0.0	0.0	12.5
	Myctophiformes	Myctophidae	Unidentified Myctophidae	0.0	40.8	54.6	93.9	116.6	0.0	0.0	305.9
	Aulopiformes	Paralepididae	Unidentified Paralepididae	0.0	0.0	0.0	23.5	0.0	0.0	0.0	23.5
	Aulopiformes	Alepisauridae	*Alepisaurus ferox*	0.0	0.0	187.7	312.8	0.0	0.0	0.0	500.5
	Perciformes	Bramidae	*Brama japonica*	0.0	0.0	1126.1	0.0	0.0	0.0	0.0	1126.1
	Perciformes	Scombridae	*Auxis rochei*	0.0	0.0	0.0	0.0	0.0	0.0	865.0	865.0
	Perciformes	Scombridae	*Scomber* sp.	270.1	2617.1	1971.4	995.8	1584.7	692.8	341.7	8473.6
	Perciformes	Scombridae	*Katsuwonus pelamis*	0.0	0.0	0.0	0.0	897.0	0.0	0.0	897.0
	Perciformes	Scombridae	*Thunnus* sp.	0.0	0.0	0.0	0.0	0.0	0.0	542.7	542.7
	Perciformes	Gempylidae	*Gempylus serpens*	0.0	0.0	0.0	53.0	0.0	0.0	0.0	53.0
	Perciformes	Carangidae	Unidentified Carangidae	0.0	0.0	0.0	5.5	2.4	0.0	0.0	7.9
	Perciformes	Tetragonuridae	*Tetragonurus cuvieri*	0.0	0.0	270.9	0.0	0.0	0.0	0.0	270.9
	Perciformes	Molidae	*Mola* sp.	0.0	0.0	0.0	0.0	306.9	0.0	0.0	306.9
	Salmoniformes	Salmonidae	*Oncorhychus kisutch*	0.0	0.0	0.0	0.0	664.8	0.0	0.0	664.8
Cephalopoda	Oegopsida	Ommastrephidae	*Ommastrephes bartramii*	0.0	0.0	3806.7	691.0	0.0	0.0	0.0	4497.7
	Oegopsida	Ommastrephidae	Unidentified Ommastrephidae	923.6	191.5	648.8	0.1	0.0	0.0	0.0	1764.0
	Oegopsida	Ommastrephidae	*Eucleoteuthis luminosa*	0.0	0.1	0.0	102.0	842.2	0.0	0.2	944.5
	Oegopsida	Histioteuthidae	*Histioteuthis hoylei*	0.0	0.0	0.0	0.2	136.3	0.0	0.0	136.5
	Oegopsida	Histioteuthidae	*Histioteuthis corona inermis*	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3
	Oegopsida	Histioteuthidae	Unidentified Histioteuthidae	0.2	0.2	0.8	0.6	1.0	0.1	0.5	3.4
	Oegopsida	Ancistrocheiridae	*Ancistrocheirus lesueurii*	0.0	0.1	0.2	0.2	0.2	0.0	0.0	0.7
	Oegopsida	Gonatidae	*Gonatopsis borealis*	0.0	0.0	123.7	493.7	0.0	0.0	0.0	617.4
	Oegopsida	Gonatidae	*Gonatopsis* sp.	0.0	0.0	0.0	0.4	0.2	0.0	0.0	0.6
	Oegopsida	Gonatidae	*Gonatus pyros*	0.1	0.1	0.2	0.5	2.4	0.2	0.1	3.6
	Oegopsida	Gonatidae	*Gonatus berryi*	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.4
	Oegopsida	Gonatidae	Unidentified Gonatidae	0.4	3.0	14.6	0.5	18.9	0.1	0.0	37.5
	Oegopsida	Octopoteuthidae	*Taningia danae*	0.0	0.0	0.0	750.7	0.3	0.0	0.0	751.0
	Oegopsida	Octopoteuthidae	Unidentified Octopoteuthidae	0.0	0.4	0.0	0.3	2.8	0.0	0.4	3.9
	Oegopsida	Onychoteuthidae	*Onychoteuthis banksii*	0.0	57.4	0.0	0.0	0.0	0.0	0.0	57.4
	Oegopsida	Onychoteuthidae	Unidentified Onychoteuthidae	0.0	0.9	0.8	4.5	90.0	0.5	0.0	96.7
	Oegopsida	Chiroteuthidae	*Grimalditeuthis* sp.	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
	Oegopsida	Enoploteuthidae	*Watasenia scintillans*	0.0	2.4	1.4	1.8	9.7	0.0	0.0	15.3

	Oegopsida	Enoploteuthidae	Unidentified Enoploteuthidae	0.0	0.0	0.0	3.2	0.0	0.0	0.0	3.2
	Oegopsida	Unidentified Oegopsida		62.7	192.5	108.1	773.1	6589.9	22.3	16.1	7764.7
	Octopoda	Octopodidae	Unidentified Octopodidae	0.1	0.0	1.2	8.0	0.7	0.1	0.0	10.1
	Octopoda	Bolitanaenidae	*Japetella diaphana*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Octopoda	Unidentified Octopoda		0.1	0.0	0.0	0.0	401.8	0.0	0.0	401.9
Malacostraca	Euphausiacea	Unidentified Euphausiacea		0.0	0.1	1.9	29.0	61.0	0.0	0.0	92.0
	Amphipoda	Unidentified Amphipoda		0.0	0.0	0.0	0.0	0.6	0.2	2.0	2.8
	Decapoda	Unidentified Decapoda		0.0	0.0	0.3	2.8	0.9	0.0	1.1	5.1
Total				1257.3	3304.1	11830.5	4698.8	13144.3	716.6	1877.1	36828.7
Average weight (g)				50.3	75.1	288.5	102.1	285.7	65.1	234.6	166.6
Empty stomach				6	25	26	69	77	26	10	239
Total specimen number				31	69	67	115	123	37	18	460

SUPPLEMENTAL TABLE S5

Number of Prey Species by Area (boundary: 40° N, 155° E) Recorded in the Stomach of Blue Sharks in the Northwestern Pacific

Class	Order	Family	Species	NW	NE	SW	SE	Total
Mammalia	Carnivora	Unidentified Carnivora		0	1	0	0	1
Chondrichthyes	Carcharhiniformes	Carcharhinidae	Unidentified Carcharhinidae	0	1	0	0	1
Actinopterygii	Clupeiformes	Engraulidae	*Engraulis japonicus*	238	757	4	1	1000
	Clupeiformes	Clupeidae	*Sardinops melanostictus*	0	2	0	7	9
	Myctophiformes	Myctophidae	*Notoscopelus* sp.	0	1	0	0	1
	Myctophiformes	Myctophidae	*Ceratoscopelus warmingii*	0	2	28	0	30
	Myctophiformes	Myctophidae	Unidentified Myctophidae	5	65	14	0	84
	Aulopiformes	Paralepididae	Unidentified Paralepididae	0	2	0	0	2
	Aulopiformes	Alepisauridae	*Alepisaurus ferox*	0	0	3	0	3
	Perciformes	Bramidae	*Brama japonica*	0	1	0	0	1
	Perciformes	Scombridae	*Auxis rochei*	0	0	2	0	2
	Perciformes	Scombridae	*Scomber* sp.	16	15	36	1	68
	Perciformes	Scombridae	*Katsuwonus pelamis*	0	0	1	0	1
	Perciformes	Scombridae	*Thunnus* sp.	0	0	1	0	1
	Perciformes	Gempylidae	*Gempylus serpens*	0	0	0	1	1
	Perciformes	Carangidae	Unidentified Carangidae	0	0	2	0	2
	Perciformes	Tetragonuridae	*Tetragonurus cuvieri*	0	1	0	0	1
	Perciformes	Molidae	*Mola* sp.	0	0	1	0	1
	Salmoniformes	Salmonidae	*Oncorhychus kisutch*	0	1	0	0	1
Cephalopoda	Oegopsida	Ommastrephidae	*Ommastrephes bartramii*	0	12	0	0	12
	Oegopsida	Ommastrephidae	Unidentified Ommastrephidae	12	3	5	1	21
	Oegopsida	Ommastrephidae	*Eucleoteuthis luminosa*	0	1	5	2	8
	Oegopsida	Histioteuthidae	*Histioteuthis hoylei*	0	1	2	0	3
	Oegopsida	Histioteuthidae	*Histioteuthis corona inermis*	0	0	7	0	7
	Oegopsida	Histioteuthidae	Unidentified Histioteuthidae	4	4	31	2	41
	Oegopsida	Ancistrocheiridae	*Ancistrocheirus lesueurii*	0	1	5	0	6
	Oegopsida	Gonatidae	*Gonatopsis borealis*	0	1	4	1	6
	Oegopsida	Gonatidae	*Gonatopsis* sp.	0	2	0	1	3
	Oegopsida	Gonatidae	*Gonatus pyros*	4	3	11	3	21
	Oegopsida	Gonatidae	*Gonatus berryi*	1	1	1	0	3
	Oegopsida	Gonatidae	Unidentified Gonatidae	22	12	22	1	57
	Oegopsida	Octopoteuthidae	*Taningia danae*	0	0	0	2	2
	Oegopsida	Octopoteuthidae	Unidentified Octopoteuthidae	2	4	5	1	12
	Oegopsida	Onychoteuthidae	*Onychoteuthis banksii*	0	5	0	0	5
	Oegopsida	Onychoteuthidae	Unidentified Onychoteuthidae	2	10	13	4	29
	Oegopsida	Chiroteuthidae	*Grimalditeuthis* sp.	0	0	6	0	6
	Oegopsida	Enoploteuthidae	*Watasenia scintillans*	0	15	0	0	15
	Oegopsida	Enoploteuthidae	Unidentified Enoploteuthidae	0	3	15	0	18

	Oegopsida	Unidentified Oegopsida		5	18	49	18	90
	Octopoda	Octopodidae	Unidentified Octopodidae	3	4	22	3	32
	Octopoda	Bolitanaenidae	*Japetella diaphana*	4	0	4	0	8
	Octopoda	Unidentified Octopoda		2	0	7	0	9
Malacostraca	Euphausiacea	Unidentified Euphausiacea		15	0	0	611	626
	Amphipoda	Unidentified Amphipoda		0	0	4	0	4
	Decapoda	Unidentified Decapoda		0	0	4	0	4
Total				335	949	314	660	2257
Average weight (g)				7.0	23.7	8.7	6.8	10.2
Empty stomach				25	15	112	87	239
Total specimen number				73	55	148	184	460

SUPPLEMENTAL TABLE S6

Weight of Prey Species by Area (Boundary: 40° N, 155° E) Recorded in the Stomach of Blue Sharks in the Northwestern Pacific

Class	Order	Family	Species	NW	NE	SW	SE	Total
Mammalia	Carnivora	Unidentified Carnivora		0.0	95.0	0.0	0.0	95.0
Chondrichthyes	Carcharhiniformes	Carcharhinidae	Unidentified Carcharhinidae	0.0	0.0	0.0	0.0	0.0
Actinopterygii	Clupeiformes	Engraulidae	*Engraulis japonicus*	664.0	2978.7	68.0	4.4	3715.1
	Clupeiformes	Clupeidae	*Sardinops melanostictus*	0.0	532.7	0.0	1222.9	1755.6
	Myctophiformes	Myctophidae	*Notoscopelus* sp.	0.0	1.8	0.0	0.0	1.8
	Myctophiformes	Myctophidae	*Ceratoscopelus warmingii*	0.0	8.7	3.8	0.0	12.5
	Myctophiformes	Myctophidae	Unidentified Myctophidae	7.3	281.7	16.9	0.0	305.9
	Aulopiformes	Paralepididae	Unidentified Paralepididae	0.0	23.5	0.0	0.0	23.5
	Aulopiformes	Alepisauridae	*Alepisaurus ferox*	0.0	0.0	500.5	0.0	500.5
	Perciformes	Bramidae	*Brama japonica*	0.0	1126.1	0.0	0.0	1126.1
	Perciformes	Scombridae	*Auxis rochei*	0.0	0.0	865.0	0.0	865.0
	Perciformes	Scombridae	*Scomber* sp.	2443.8	1115.1	4775.9	138.8	8473.6
	Perciformes	Scombridae	*Katsuwonus pelamis*	0.0	0.0	897.0	0.0	897.0
	Perciformes	Scombridae	*Thunnus* sp.	0.0	0.0	542.7	0.0	542.7
	Perciformes	Gempylidae	*Gempylus serpens*	0.0	0.0	0.0	53.0	53.0
	Perciformes	Carangidae	Unidentified Carangidae	0.0	0.0	7.9	0.0	7.9
	Perciformes	Tetragonuridae	*Tetragonurus cuvieri*	0.0	270.9	0.0	0.0	270.9
	Perciformes	Molidae	*Mola* sp.	0.0	0.0	306.9	0.0	306.9
	Salmoniformes	Salmonidae	*Oncorhychus kisutch*	0.0	664.8	0.0	0.0	664.8
Cephalopoda	Oegopsida	Ommastrephidae	*Ommastrephes bartramii*	0.0	4497.7	0.0	0.0	4497.7
	Oegopsida	Ommastrephidae	Unidentified Ommastrephidae	623.0	649.0	492.0	0.0	1764.0
	Oegopsida	Ommastrephidae	*Eucleoteuthis luminosa*	0.0	0.1	102.3	842.1	944.5
	Oegopsida	Histioteuthidae	*Histioteuthis boylei*	0.0	136.3	0.2	0.0	136.5
	Oegopsida	Histioteuthidae	*Histioteuthis corona inermis*	0.0	0.0	0.3	0.0	0.3
	Oegopsida	Histioteuthidae	Unidentified Histioteuthidae	0.1	0.2	2.9	0.1	3.3
	Oegopsida	Ancistrocheiridae	*Ancistrocheirus lesueurii*	0.0	0.1	0.6	0.0	0.7
	Oegopsida	Gonatidae	*Gonatopsis borealis*	0.0	123.8	0.2	493.4	617.4
	Oegopsida	Gonatidae	*Gonatopsis* sp.	0.0	0.2	0.0	0.4	0.6
	Oegopsida	Gonatidae	*Gonatus pyros*	0.2	0.2	3.0	0.2	3.6
	Oegopsida	Gonatidae	*Gonatus berryi*	0.1	0.1	0.1	0.0	0.4
	Oegopsida	Gonatidae	Unidentified Gonatidae	0.7	17.2	18.7	0.9	37.5
	Oegopsida	Octopoteuthidae	*Taningia danae*	0.0	0.0	0.0	751.0	751.0
	Oegopsida	Octopoteuthidae	Unidentified Octopoteuthidae	0.1	0.4	3.3	0.2	3.9
	Oegopsida	Onychoteuthidae	*Onychoteuthis banksii*	0.0	57.4	0.0	0.0	57.4
	Oegopsida	Onychoteuthidae	Unidentified Onychoteuthidae	3.9	1.3	90.8	0.7	96.7
	Oegopsida	Chiroteuthidae	*Grimalditeuthis* sp.	0.0	0.0	0.1	0.0	0.1
	Oegopsida	Enoploteuthidae	*Watasenia scintillans*	0.0	15.3	0.0	0.0	15.3
	Oegopsida	Enoploteuthidae	Unidentified Enoploteuthidae	0.0	3.2	0.0	0.0	3.2

	Oegopsida	Unidentified Oegopsida		174.5	573.2	1072.9	5944.1	7764.7
	Octopoda	Octopodidae	Unidentified Octopodidae	0.1	1.0	1.1	7.9	10.1
	Octopoda	Bolitanaenidae	*Japetella diaphana*	0.0	0.0	0.0	0.0	0.0
	Octopoda	Unidentified Octopoda		0.1	0.0	401.8	0.0	401.9
Malacostraca	Euphausiacea	Unidentified Euphausiacea		2.0	0.0	0.0	90.0	92.0
	Amphipoda	Unidentified Amphipoda		0.0	0.0	2.8	0.0	2.8
	Decapoda	Unidentified Decapoda		0.0	0.0	5.1	0.0	5.1
Total				3919.9	13175.6	10182.7	9550.1	36828.7
Average Weight (g)				81.7	329.4	282.9	98.5	166.6
Empty Stomach				25	15	112	87	239
Total specimen number				73	55	148	184	460