# Tropical Scombrid Feeding Habits in the Central Pacific

Kevin McLean
S-199
Stanford@SEA
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**Abstract**

The feeding habits of tropical scombrid species was conducted through analysis of stomach contents of specimens collected in Hawaii and the Line Islands. Background research of scombrid feeding habits throughout the world led to expectations that the primary food source among specimens collected would be fish and cephalopods. A total of 44 fish were collected from Captain Cook, Hawaii, Christmas Island, and Palmyra Atoll. Yellowfin tuna were the most abundant species collected, though skipjack tuna, rainbow runners, and wahoo were also collected. Diets consisted primarily of megalops and other invertebrates, with fish and cephalopods as secondary or negligible food sources. The few specific prey species that were observed suggested possible selective feeding behavior in the Deep Scattering Layer. Disparity of composition of stomach contents from net tows sampling the Deep Scattering Layer also provided supporting evidence for selective feeding.

**Introduction**

Considering our vast history of exploratory endeavors and the tools at our disposal today, relatively little is known about the world's oceans. Conservation and management efforts to support fisheries in the Atlantic Ocean have instigated notable amounts of research on its ecosystems. The Pacific Ocean, though under heavy fishing pressure from nations across the globe, experiences significantly lower levels of protection and correspondingly the research conducted in this region is less extensive. In order to understand the Pacific Ocean ecosystems, comprehensive investigation and analysis of the ecosystem and trophic structure must be performed. Through studies of the diets of predatory fish within this ecosystem, a more accurate perception of the complexity of the pelagic environment can be discerned.

Work that has been carried out in the Pacific Ocean has provided a rough outline of the ecological network. The diets of predatory species are representative of both the availability of and preference for certain prey species. The scombrid family, which includes tunas and mackerels, are opportunistic feeders whose stomach contents include the prey species that are available in the environment in which they are feeding (Bernard et al. 1985). According to stomach content analysis of three species of tuna in waters surrounding French Polynesia, fish, crustaceans, cephalopods, and gelatinous organisms observed represented upwards of fifty taxa. Furthermore, the percentage distribution of organisms was similar to that of the net tow samples collected. (Bertrand et al. 2002). The diversity of the diets of apex predators in oceanic environments provides the support for the top-down trophic cascading effect that occurs when these animals are removed from an ecosystem (Shiomoto et al. 1997; Estes et al. 1998; Verheye and Richardson 1998 in Olson 2001), making research and management of these organisms increasingly critical.

In combination with the organisms found in stomachs of predatory fish, insight into their feeding habits can be gained through knowledge of where individual species are generally most active in the water column. Vertical position is regarded as indicative of where the fish are feeding in the water column. Several studies have been conducted on the diving behavior of tuna using various types of archival tags to detect depth. This research supported the knowledge that in tropical regions yellowfin, blackfin, and longtail tunas prefer the mixed layer above the thermocline (Carey and Olson 1982; Holland et al. 1990 in Block et al. 1997). Feeding behavior of bigeye and yellowfin tuna is described by Bertrand et al. (1998) for the French Polynesian ecosystem. Individual yellowfin and bigeye tuna specimens were tagged with sonic tracking devices with pressure and temperature sensors to record their position in the water column. Upon comparison to the apparent positions of prey species based on interpretation of echogram data, the vertical movement of the tuna was shown to follow that of the prey species. Both species concentrated a majority of their time near the deep scattering layer where prey species would be feeding on planktonic organisms. Research on yellowfin tuna in the tropical Pacific using light-sensing archival tags to determine depth has shown similar diving behavior during they day when they are believed to be most actively feeding (Brill et al. 1998).

While there has been research conducted in the Central Pacific regarding the stomach content analysis and feeding behavior of apex predators as well as the vertical migration patterns, there has been little focus on how feeding habits of scombrids vary in relation to specific island chains, namely the Hawaiian Islands and the Line Islands. In the Bernard et al. (1985) study of scombrid feeding habits the sampling region was associated with the southern California coast as well as the open ocean off shore from this region. The Block et al. study of yellowfin tuna (1997) sampled a similar range. The Bertrand study of tuna feeding habits (2002) sampled waters in French Polynesia, which could be considered similar, but by no means the same, as the Hawaiian and Line Islands and did not include collections in the open ocean. Collecting specimens near the Hawaiian Islands and Line Islands will give a new perspective on how land formations influence the availability and dietary dependence on various prey species.

Due to elevated levels of productivity near the Line Islands and Hawaiian Islands, these waters are expected to sustain a diverse community of prey species. The waters surrounding the Hawaiian Islands tend to have high productivity due to the nutrients associated with the local upwelling that occurs near the islands. The Line Islands are also likely to have high primary productivity in association with the nutrient upwelling within the intertropical convergence zone (ITCZ). Primary productivity can be used to gauge where many organisms will congregate, as oceanic ecosystems depend on this base of production to support the trophic ladder. Because of the characteristically high levels of productivity associated with the ITCZ, fish collected in the Line Islands were expected to have the highest diversity of prey species in their stomachs. The diets of the specimens collected were also expected to be composed primarily of fish and cephalopods with crustaceans as a secondary food source. In addition, due to the opportunistic feeding behavior observed in pelagic predators, the planktonic organisms found in the stomachs of the specimens collected are expected to be comparable to the percent composition present in the net tow.

**Materials and Methods**

Collection of scombrid specimens was conducted off of the southwestern coast of the island of Hawaii, as well as at Christmas Island and Palmyra Atoll in the Line Islands. Fish were caught by trolling at the surface using artificial lures as recommended by local fishermen as well as Simon and Schuster (1992). The specimens were collected during the time of day when resources were available. In Hawaii collection took place during the late morning, during the mid afternoon at Christmas Island, and in the late afternoon to early evening at Palmyra.

After collection, specimens were kept on ice for a short period of time until they could be dissected. The stomachs were removed and either frozen immediately or the contents emptied and kept frozen until they could be analyzed on land in Palmyra. The contents of the stomachs collected was organized and separated and counted based on the lowest identifiable taxonomic group. Diet composition among all specimens collected was calculated based on the number of organisms in each taxonomic group found and identified in relation to the total number of organisms found in the stomach.

Net tows were also collected near Palmyra at the surface and in the deep scattering layer as defined by the Acoustic Doppler Current Profiler (ADCP), providing a ratio of organisms present. These ratios were compared to the ratios of organisms found in the stomach contents in order to determine whether the planktonic prey species represented are comparable to that which is actually present in the water column.

**Results**

A total of 44 specimens of four different species were taken from the one collection site in the Hawaiian Islands and two sites in the Line Islands. Collection off of the island of Hawaii produced 21 yellowfin tuna (*Thunnus albacares*) between 43 and 49 centimeters in length, eight skipjack tuna (*Katsuwonus pelamis*) between 42 and 57 centimeters, three rainbow runners (*Elegantis bipinnulatus*) between 40 and 45 centimeters, and one wahoo (*Acanthocybium solandri*) measuring 110 centimeters. Upon dissection of these specimens, two yellowfin tuna, seven skipjack tuna, and the one wahoo were found to have completely empty stomachs. In Christmas Island two yellowfin tuna were collected measuring fifty-eight and seventy-six centimeters and one wahoo measuring 117 centimeters in length. One of the yellowfin and the wahoo had completely empty stomachs. At Palmyra Atoll eight yellowfin tuna specimens were collected, all between eighty and eighty-six centimeters (see Table 1).

Analysis of the stomachs of yellowfin tuna specimens collected from Hawaii showed that they were composed of approximately 47.2% megalops, 17% stomatopods, 9.6% fish longer than 5 cm (large fish), and 8.7% fish shorter than 5 cm (small fish), and 5.7% cephalopods. The remaining percentage was composed of various invertebrates including euphausiid shrimp, lobster larvae, mysid shrimp, amphipods, and pteropods (see Figure 1). In the fish collected from Palmyra stomach contents was composed of 71.9% megalops, 22.2% euphausiid shrimp, and 3.1% fish shorter than 5 cm, with the remaining percentage consisting of stomatopods, pteropods, cephalopods, and isopods (see Figure 2). In the stomachs of the rainbow runners collected, the contents were made up of 35% megalops, 25% pteropods, with the remaining percentages distributed amongst euphausiid shrimp, cephalopods, fish, copepods, chaetagnaths, amphipods, and mysid shrimp (see Figure 3).

Comparison of individual yellowfin specimens collected in Hawaii showed that there was great variation in percent diet composition. While megalops made up a majority of the collective diet of all specimens, the dietary composition of megalops in each fish ranged from 6% to 100%, stomatopods ranged from 0% to 78%, and fish longer that 5 cm ranged from 0% to 90% (see Figure 4). Total number of organisms found in stomachs of the Hawaii specimens that were not empty had a mean of 12 and ranged from 3 to 27 organisms. In the Palmyra yellowfin, megalops were consistently most abundant in the stomachs of individual specimens, accounting for 57% to 80% of the total stomach contents. Euphausiid shrimp also made up a significant portion of the contents, ranging from 10% to 35%, while fish shorter than 5 cm made up 1.5% to 6.5% of the total composition (see Figure 5). The mean number of organisms found in each stomach in Palmyra was 693 with a range between 349 and 1196 organisms. A statistical similarity analysis (SIMPER) of the yellowfin stomachs from Hawaii and Palmyra showed using the specimens collected as separate communities Hawaii had an average similarity of 38%, while Palmyra had an average similarity of 84%.

There were four morphological types of megalops found in the stomachs of the specimens collected from Hawaii and Palmyra. The first type was purple in color with a hard shell. There were also red, white, and black varieties that did not have hard shells. The white variety was by far the most abundant in all of the specimens. It is unclear weather these morphological variations are different species, different stages of development, or different stages of digestion within the stomach.

There were two net tows taken approximately 1.5 miles south of Palmyra, the Neuston net at the surface and the meter net at 50 meters below the surface. A random sample taken from the Neuston net biomass was made up of 72% ostracods, 19% copepods, 3% mysid shrimp, 3% pteropods, 2% chaetognaths, and 1% salps (see Figure 6). The meter net that was deployed contained 62% copepods, 20 % ostracods, and the remaining percentage divided amongst pteropods, amphipods, euphausiid shrimp, stomatopods, mysid shrimp, chaetagnaths and other invertebrates (see Figure 7).

The organisms that were identified from the stomachs of the specimens collected were identified to the lowest possible trophic level. Due to the stage in digestion and the length of time which some samples were frozen identification was not always possible for every organism present. Also, diet composition figures were calculated based on number of organisms counted and did not take biomass into account. However, with the exception of the fish greater than 5 cm, the prey species identified were largely similar in size. Additionally, the varying collection times at the different sites could have affected the number of organisms found in the stomachs. The depth of the meter net tow was determined based on the estimated depth of the Deep Scattering Layer (DSL) as shown by the ADCP. Due to the sea conditions during sampling it is unclear whether the net was deployed at the appropriate depth in order to accurately represent the composition of organisms in the DSL. These sources of error, however, were not significant enough to drastically affect the trends observed in the stomach contents as a whole.

**Discussion**

Based on current knowledge of the diving habits of yellowfin tuna, it is well understood that they feed in the DSL. The similarities of species present in the meter net tow off Palmyra supports that this belief, though the percent compositions of the net tow versus the stomach samples were drastically different. This difference abundance of certain organisms, namely megalops, suggests that the fish are selectively feeding on these particular prey species within the DSL. Further support for the possibility of selective feeding behavior is the fact that the yellowfin in both Hawaii and Palmyra were heavily dependent on megalops in their diets. This similarity in prey species suggests selectivity for these specific organisms. However, the relative uniformity in size of the organisms found in the stomachs of all specimens with the exception of those containing large fish (>5 cm) provides evidence that yellowfin select for size rather than by specific organism. If this is the case, then percent composition of net tows should be similar to those found in the stomachs of collected specimens. The single net tow that was deployed in the DSL at Palmyra did not show the same high abundance of megalops, which suggests species-based selectivity in feeding.

The dietary dependence on fish and cephalopods amongst the scombrid specimens collected was strongly overshadowed by the clear preference for crustaceans. Though fish and cephalopods were incorporated in the diets of most specimens, the fish collected are clearly more dependent on planktonic organisms in the DSL. This is likely a result of the nutrient rich character of the waters associated with both island chains. These waters are able to support a constant source of easily obtainable prey, which reduces the need to spend valuable energy foraging for free-swimming organisms.

The difference in the number of organisms found in the Hawaiian specimens versus the Palmyra specimens could be attributed to the time of day in which they were caught. The fish collected in Hawaii were caught in the morning, while in Palmyra all specimens were caught in the late afternoon. Yellowfin tuna are believed to feed primarily during the day, as exhibited by their diving behavior during daylight hours (Brill et al. 1998). Thus, the specimens that were collected in the morning had not been feeding nearly as long as the specimens collected later in the day and did not have as much contents in their stomachs.

High diversity of prey species was also expected in association with the island chains with nutrient-rich waters. While a greater number of species was found in the Hawaiian Islands, specimens from both sites were dependent primarily on only a few different prey species. Despite the biologically rich resources available in the productive Hawaiian and equatorial waters, the consistent tropical conditions provide a stable food source on which yellowfin tuna, as well as other species like the rainbow runners collected in Hawaii, have grown dependent. This dietary preference for crustaceans is an interesting divergence from the related bluefin tuna found in more temperate waters, which feed primarily on fish and other free-swimming prey. In addition to the difference in dietary preference the keratin found in the shells of these crustaceans may also give yellowfin tuna their characteristic yellow hue that is not present in the bluefin species (pers com B. Block). While the expected results in terms of prey diversity and species dependence were not observed in the feeding habits of scombrid specimens collected, the valuable insight obtained into the feeding habits of yellowfin tuna in the Central Pacific add to the growing knowledge of tropical tuna biology.

**Conclusion**

The literary research on the feeding habits of tuna and other pelagic predators led to a hypothesis that the nutrient-rich waters associated with the coastal upwelling in the Hawaiian Islands and the equatorial upwelling in the Line Islands would result in a diverse diet among scombrid specimens primarily dependent on fish and cephalopods. After collection and analysis of 44 fish from four different species, 31 of which were yellowfin tuna, crustaceans were found to be the primary food source for tropical yellowfin tuna and rainbow runners in the Hawaiian Islands and for yellowfin tuna in the Line Islands. Diversity of prey species was not high in either site, and high dependence on crustaceans provided evidence of selective feeding in the DSL of the productive tropical waters was observed. For future attempts to study tropical yellowfin tuna feeding behavior, further sampling of DSL organisms is highly recommended. Accurate approximation of the depth of the DSL is critical, and sampling during various times of the day would also be useful. Observation of diversity within size classes of planktonic organisms in the DSL would allow for study of whether size or species is more important in the selective feeding behavior. In addition, collection of fish in the open ocean would provide a contrast to the diets observed in fish collected in nutrient-rich waters associated with island chains.

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**Table 1**

| Specimen | Species | Date Caught | Time | Length (cm) | Location | Comments |
|---|---|---|---|---|---|---|
| 1 | YFT | 5/11/2005 | Morning | 45.8 | Captain Cook, Hawaii | |
| 2 | Skipjack | 5/11/2005 | Morning | 56.8 | Captain Cook, Hawaii | stomach empty |
| 3 | Rainbow Runner | 5/11/2005 | Morning | 40.8 | Captain Cook, Hawaii | |
| 4 | Rainbow Runner | 5/11/2005 | Morning | 41.5 | Captain Cook, Hawaii | |
| 5 | YFT | 5/11/2005 | Morning | 47.3 | Captain Cook, Hawaii | |
| 6 | YFT | 5/11/2005 | Morning | 46 | Captain Cook, Hawaii | |
| 7 | Skipjack | 5/11/2005 | Morning | 49 | Captain Cook, Hawaii | stomach empty |
| 8 | YFT | 5/11/2005 | Morning | 47 | Captain Cook, Hawaii | |
| 9 | YFT | 5/11/2005 | Morning | 47 | Captain Cook, Hawaii | |
| 10 | YFT | 5/11/2005 | Morning | 47.5 | Captain Cook, Hawaii | |
| 11 | YFT | 5/11/2005 | Morning | 47 | Captain Cook, Hawaii | |
| 12 | YFT | 5/11/2005 | Morning | 48 | Captain Cook, Hawaii | |
| 13 | YFT | 5/11/2005 | Morning | 44 | Captain Cook, Hawaii | |
| 14 | YFT | 5/11/2005 | Morning | 45.5 | Captain Cook, Hawaii | |
| 15 | Skipjack | 5/11/2005 | Morning | 46 | Captain Cook, Hawaii | stomach empty |
| 16 | Skipjack | 5/11/2005 | Morning | 44 | Captain Cook, Hawaii | stomach empty |
| 17 | Skipjack | 5/11/2005 | Morning | 49 | Captain Cook, Hawaii | stomach empty |
| 18 | Rainbow Runner | 5/11/2005 | Morning | 45 | Captain Cook, Hawaii | |
| 19 | YFT | 5/11/2005 | Morning | 45.8 | Captain Cook, Hawaii | |
| 20 | YFT | 5/11/2005 | Morning | 45.5 | Captain Cook, Hawaii | |
| 21 | YFT | 5/11/2005 | Morning | 45 | Captain Cook, Hawaii | |
| 22 | YFT | 5/11/2005 | Morning | 54 | Captain Cook, Hawaii | |
| 23 | YFT | 5/11/2005 | Morning | 45 | Captain Cook, Hawaii | |
| 24 | YFT | 5/11/2005 | Morning | 43 | Captain Cook, Hawaii | |
| 25 | YFT | 5/11/2005 | Morning | 46 | Captain Cook, Hawaii | |
| 26 | YFT | 5/11/2005 | Morning | 48.2 | Captain Cook, Hawaii | stomach empty |
| 27 | Skipjack | 5/11/2005 | Morning | 42 | Captain Cook, Hawaii | stomach empty |
| 28 | Skipjack | 5/11/2005 | Morning | 31.2 | Captain Cook, Hawaii | |
| 29 | YFT | 5/11/2005 | Morning | 56 | Captain Cook, Hawaii | stomach empty |
| 30 | YFT | 5/11/2005 | Morning | 78 | Captain Cook, Hawaii | |
| 31 | YFT | 5/11/2005 | Morning | 48.5 | Captain Cook, Hawaii | |
| 32 | Skipjack | 5/11/2005 | Morning | 44 | Captain Cook, Hawaii | stomach empty |
| 33 | Wahoo | 5/11/2005 | Morning | 110 | Captain Cook, Hawaii | stomach empty |
| 34 | Wahoo | 5/22/2005 | Afternoon | 117 | Christmas Island | stomach empty |
| 35 | YFT | 5/22/2005 | Afternoon | 58 | Christmas Island | stomach empty |
| 36 | YFT | 5/22/2005 | Afternoon | 76 | Christmas Island | |
| 37 | YFT | 5/29/2005 | Evening | 83 | Palmyra | |
| 38 | YFT | 5/29/2005 | Evening | 83 | Palmyra | |
| 39 | YFT | 5/29/2005 | Evening | 81 | Palmyra | |
| 40 | YFT | 5/29/2005 | Evening | 80 | Palmyra | |
| 41 | YFT | 5/29/2005 | Evening | 83 | Palmyra | |
| 42 | YFT | 5/29/2005 | Evening | 81.5 | Palmyra | |
| 43 | YFT | 5/29/2005 | Evening | 85.2 | Palmyra | |
| 44 | YFT | 5/29/2005 | Evening | 84 | Palmyra | |

**Figure 1**

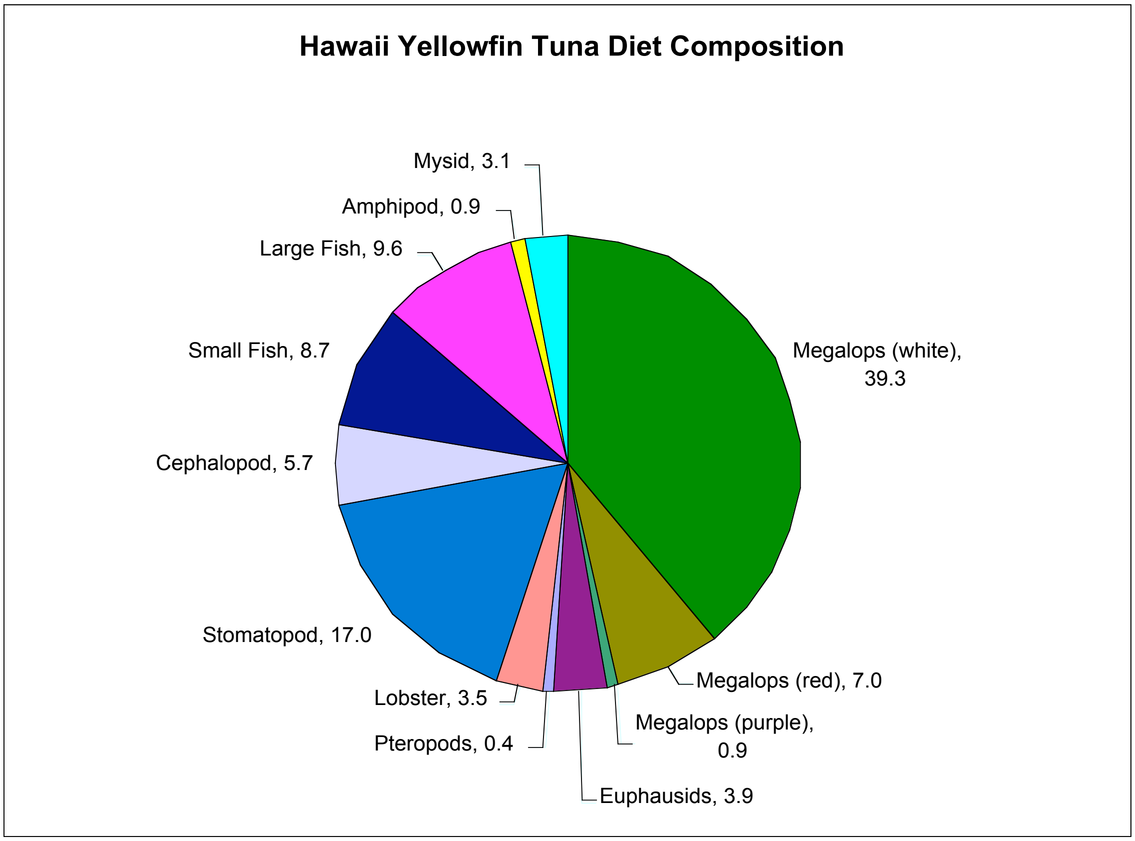
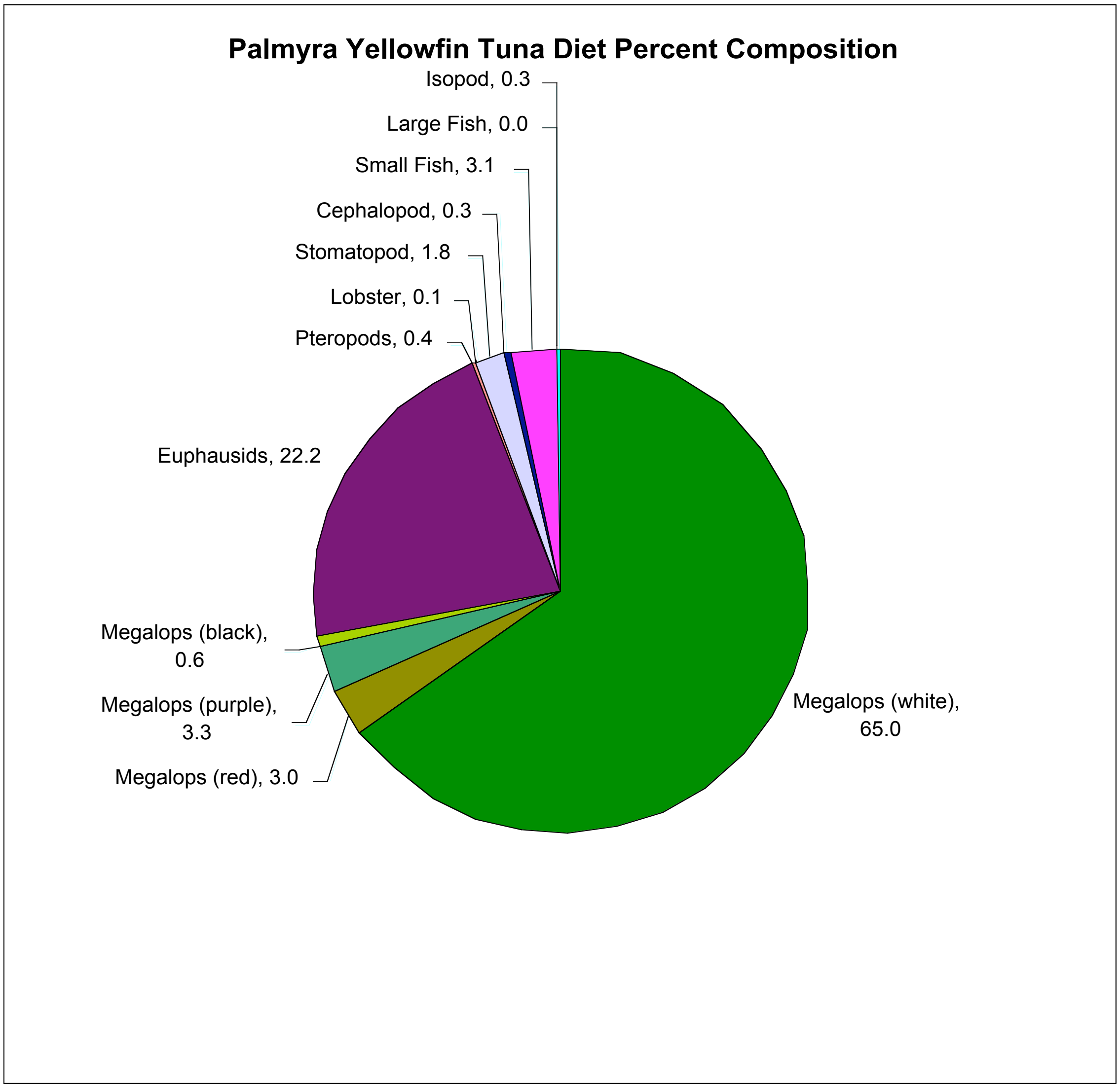
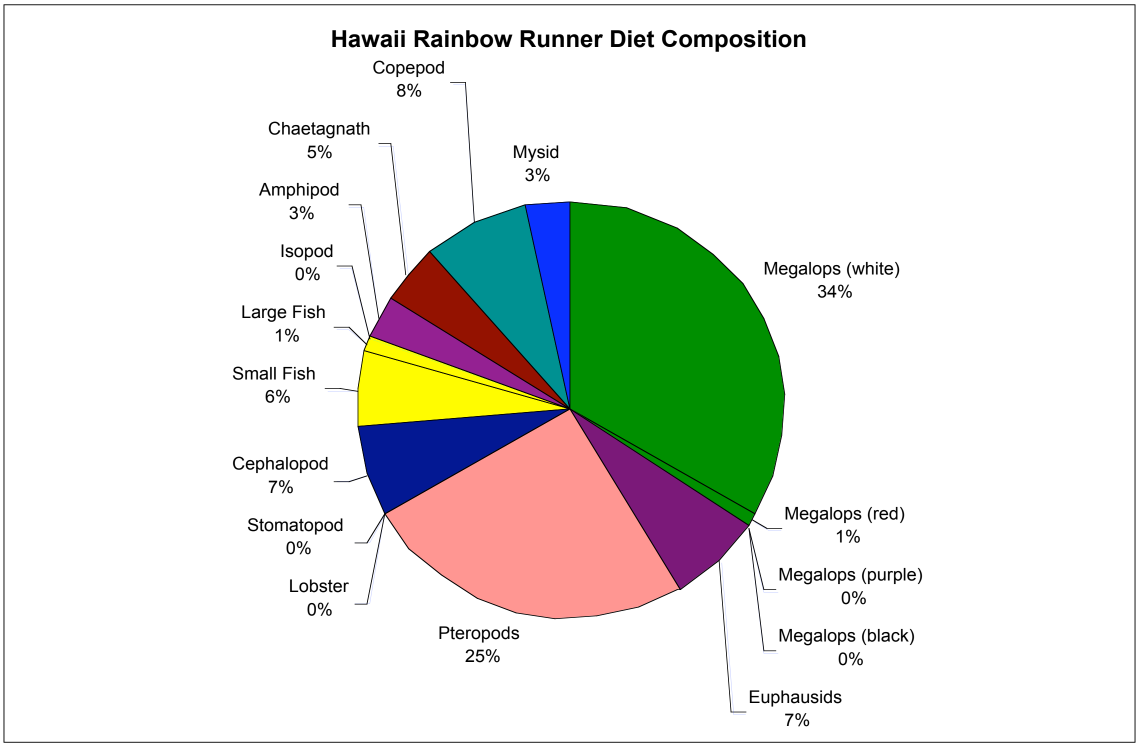

Hawaii Yellowfin Tuna Diet Composition
Mysid, 3.1
Amphipod, 0.9
Large Fish, 9.6
Small Fish, 8.7
Cephalopod, 5.7
Stomatopod, 17.0
Lobster, 3.5
Pteropods, 0.4
Euphausids, 3.9
Megalops (purple), 0.9
Megalops (red), 7.0
Megalops (white), 39.3

**Figure 2**



Palmyra Yellowfin Tuna Diet Percent Composition
Isopod, 0.3
Large Fish, 0.0
Small Fish, 3.1
Cephalopod, 0.3
Stomatopod, 1.8
Lobster, 0.1
Pteropods, 0.4
Euphausids, 22.2
Megalops (black), 0.6
Megalops (purple), 3.3
Megalops (red), 3.0
Megalops (white), 65.0

## Figure 3




## Figure 4

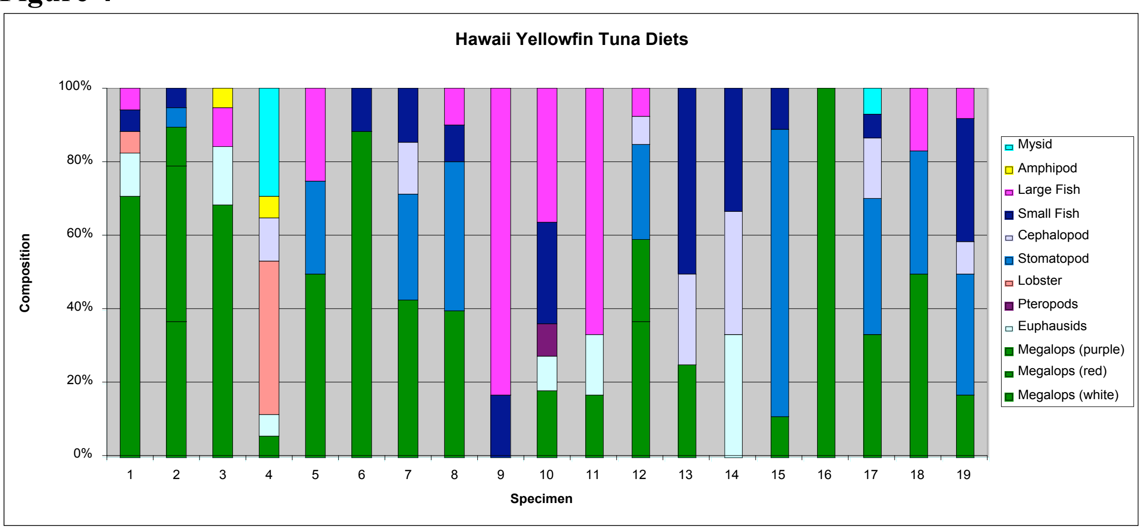


**Figure 5**

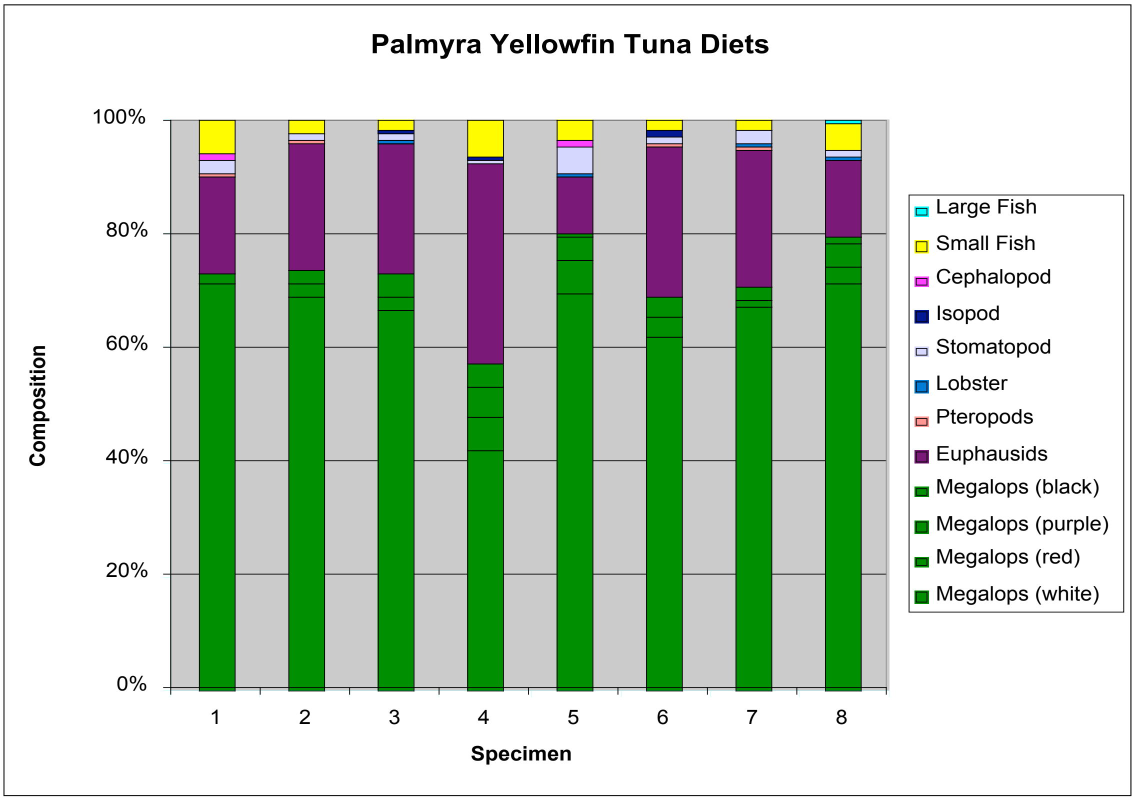
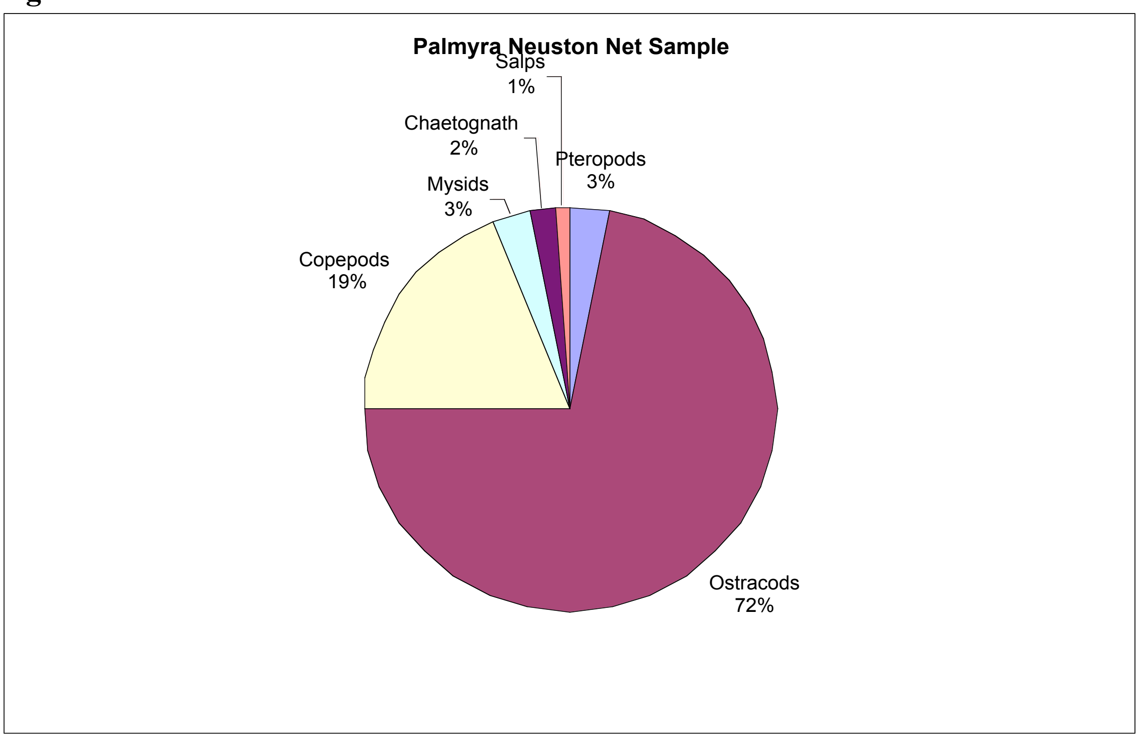
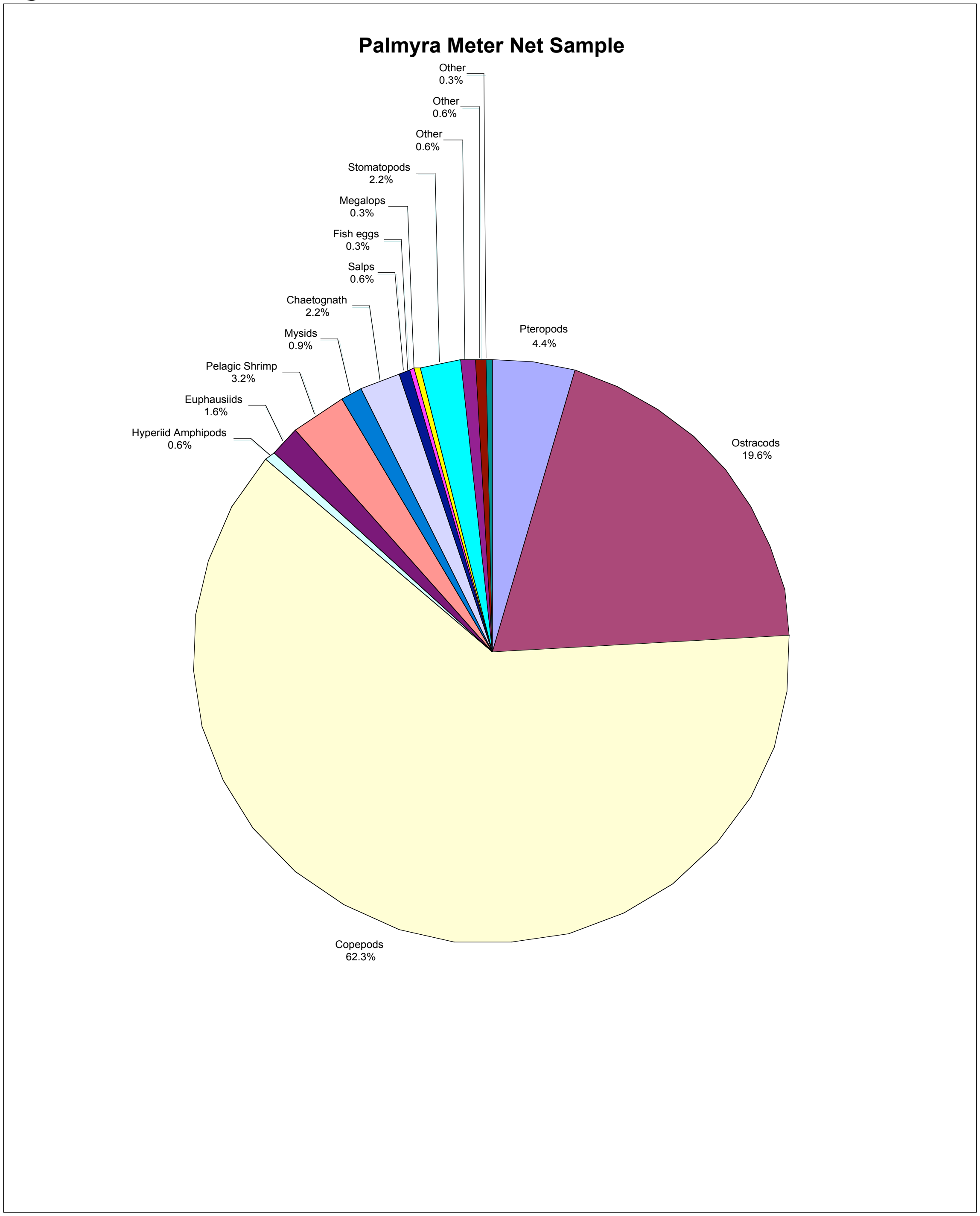



**Figure 6**



## Figure 7



Palmyra Meter Net Sample
Other 0.3%
Other 0.6%
Other 0.6%
Stomatopods 2.2%
Megalops 0.3%
Fish eggs 0.3%
Salps 0.6%
Chaetognath 2.2%
Mysids 0.9%
Pelagic Shrimp 3.2%
Euphausiids 1.6%
Hyperiid Amphipods 0.6%
Pteropods 4.4%
Ostracods 19.6%
Copepods 62.3%

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