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In the western Atlantic Ocean, northern bluefin tuna *Thunnus thynnus* are distributed from Labrador and Newfoundland to the Gulf of Mexico, Caribbean Sea, and off Venezuela and Brazil. The northern bluefin tuna is epipelagic and usually oceanic, but seasonally strays near the coast (Collette and Nauen 1983). During June through October, these tuna are common off the eastern United States and Canada (Squire 1962) and support both commercial and recreational fisheries. From the end of May to August, many pods of small school bluefin tuna (<100 kg) migrate past Virginia on their way to more northern feeding grounds. These tuna are caught 30 to 60 km off the Virginia coast in the vicinity of numerous shoals or "hills," by recreational anglers trolling dead bait or lures on or near the surface (Figley 1984). In 1986, 886 boats participated with some degree of regularity in the recreational fishery for tuna and billfish out of Virginia ports (Bochenek and Lucy In press). Further north, there is a recreational fishery for giant (>200 kg) and medium (100–200 kg) bluefin tuna, and, to a lesser extent, school bluefin tuna (Figley 1984).

Bluefin tuna are opportunistic predators that prey upon fishes, mollusks, crustaceans, and salps (Crane 1936; Bigelow and Schroeder 1953; Krumholz 1959; Dragovich 1969, 1970; Mason 1976; Matthews et al. 1977; Holliday 1978). Pacific bluefin tuna *Thunnus thynnus orientalis* caught off California and Baja California preferred the same prey as the Atlantic Ocean subspecies *Thunnus thynnus thynnus* (Pinkas 1971).

The spawning stock of the western Atlantic bluefin tuna has declined sharply since 1970, and both recruitment and juvenile stock size are still substantially lower than in 1970 (ICCAT 1987). Thus, information about life-history characteristics, such as trophic habits, is essential for developing sound management plans for this important commercial and recreational fish. Mason (1976) and Holliday (1978) studied the feeding behavior of school bluefin tuna captured along the eastern coast of the United States; however, only 68 bluefin tuna stomachs were collectively examined from fish caught off or near the Virginia coast (lat 36–38°N and long. 75°W). Therefore, knowledge of the feeding habits of school bluefin tuna off the Virginia coast is relatively sparse. The present paper describes the findings of stomach content analysis for juvenile bluefin tuna collected during the summer of 1986 by recreational fishermen along the mid-Atlantic coast off Virginia.

Methods and materials

During June and July 1986, stomach samples of 97 bluefin tuna were obtained from recreational fishermen as they landed their catch at Rudee Inlet, Virginia Beach, and at Wachapreague on the eastern shore of Virginia. Curved fork length (mm) and the area of capture (Fig. 1) were recorded for each fish. Fish that could not be identified with a specific area of capture were eliminated from the sample. Weights (kg) were recorded for tuna officially weighed on certified marina scales. Stomachs were removed and placed in 10% buffered formalin. Stomachs were opened and designated in the laboratory as either containing food or empty. Stomachs containing only parasites were classified as empty. Stomach contents were rinsed in water and stored in 10% ethanol until identification.

Prey items were sorted into major food groups (fishes, crustaceans, mollusks, and unidentifiable remains), enumerated, and identified to the lowest possible taxon with the aid of a binocular dissecting scope. Volumes were determined by water displacement using a graduated cylinder and measured to the nearest 0.5 mL. Fishes too far digested for certain identification were placed in an unidentified teleost category and used in estimating total prey volume. The majority of unidentified teleost material resembled remnants of sand lance (*Ammodytes* spp.) more than any other recognizable species.

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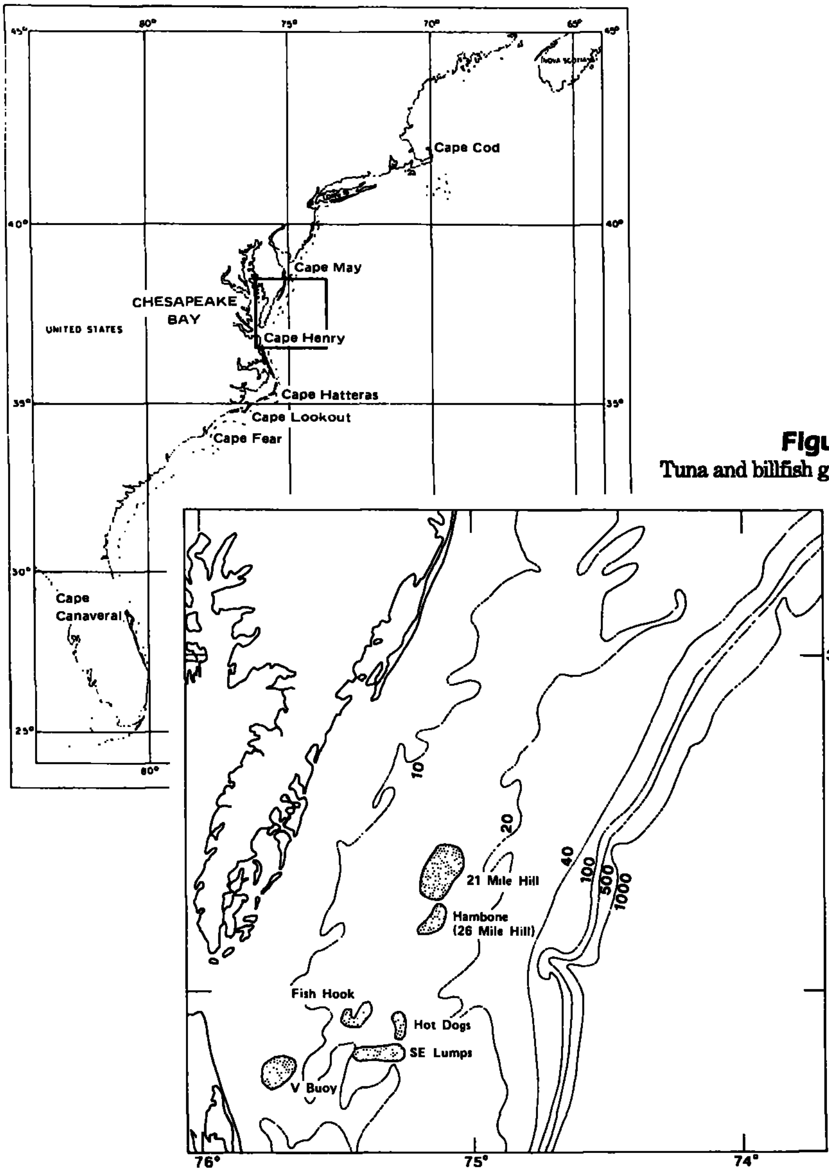

Figure 1
Tuna and billfish grounds off Virginia.

To help evaluate the relationship of the various food items found in stomachs we employed an index of relative importance (*IRI*) (Pinkas 1971):

$$IRI = (N + V)\,F,$$

where N = numerical percentage, V = volumetric percentage, and F = frequency of occurrence percentage. Percent *IRI* consisted of the *IRI* value of each prey category (unidentified fish and cephalopods excluded) divided by the sum of the *IRI* values (unidentified fish and cephalopods excluded). To determine if the quantity of the key trophic group differed by area of capture (Fig. 1), displacement volume was compared against three areas sampled with a one-way ANOVA model (with displacement volume as the dependent variable and area of capture as the independent factor). The key trophic group was composed of pooled volumetric contributions of both identified and unidentified teleost remains. The three areas were: (1) the "Hot Dog," (2) "'Fish hook" and "S.E. Lumps," and (3) "21 Mile Hill." The "Fish hook" and "S.E. Lumps" areas were pooled because boat captains generally fished both areas during the same trip. The remaining areas, "26 Mile Hill" and "V-Buoy," were both eliminated from the hypothesis test because of low sample sizes ($N = 2$ for both). Significant differences were contrasted by a Student-Neuman-Kuels (SNK) multiple range test set at an experiment-wise error rate (EWER) of 0.05 (Zar 1984). Tests for normality and equality of variance (Zar 1984)

Table 1

List of prey species or class groups occurring in stomachs of juvenile bluefin tuna *Thunnus thynnus* from the Mid-Atlantic Bight, Virginia, 1986.

	No. of individual prey items from 72 stomachs	Percent by number	Volume (mL)	Percent volume	% Frequency of occurrence based on stomachs containing food (*N* = 72)	Index of relative importance (*IRI*)	% *IRI*
Teleosts							
Ammodytes spp. (sand lance)	403	84.1	1028.0	30.75	48.6	5583.2	0.968
Peprilus triacanthus (butterfish)	11	2.3	84.0	2.51	2.8	13.5	0.002
Hippocampus erectus (lined seashore)	9	1.9	2.5	0.07	1.4	2.7	0.0004
Aluterus scriptus (scrawled filefish)	1	0.2	1.5	0.04	1.4	0.4	0.00006
Unidentified teleosts (primarily sand lance)	NA	NA	1653.5	49.46	75.0	NA	NA
Cephalopods							
Lolliguncula brevis (Atlantic brief squid)	48	10.0	432.0	12.92	6.9	158.3	0.027
Loligo pealeii (longfin squid)	2	0.4	124.0	3.71	2.8	11.6	0.002
Unidentified cephalopods	NA	NA	5.0	0.15	1.4	NA	NA
Miscellaneous							
Salpidae			12.3	0.37	8.3	NA	NA
Idotea sp. (Isopod)	5	1.0	0.5	0.01	1.4	1.5	0.0002
Totals	479		3343.3			5771.0	1.0
Total stomachs analyzed	97						
No. (%) containing food materials (identified and unidentified)	72(74.2)						
No. (%) empty	25(25.8)						

indicated that the logarithmically transformed volumes were appropriate for ANOVA.

Results

Food analysis

Of the 97 juvenile bluefin tuna stomachs examined, 72 (74%) contained food. These tuna averaged 21.3 kg ($n = 7$, SD 7.7, range 15–39 kg) with a mean fork length of 90 cm ($n = 85$, SD 13, range 70–132 cm). Stomach contents consisted of two primary food groups: teleosts and cephalopods. Teleosts contributed over five times the percent volume to the diet (82.8%) compared with cephalopods (16.8%) (Table 1). Teleosts occurred in 91% of those stomachs containing food items and accounted for 86% of the total identified prey items (Table 1). Major subgroups of identifiable teleosts by percent frequency of occurrence (based on number of stomachs containing food), *IRI*, and percent *IRI*, listed in decreasing order were sand lance, butterfish *Peprilus triacanthus*, lined seahorse *Hippocampus erectus*, and scrawled filefish *Aluterus scriptus* (Table 1). Sand lance was the predominant teleost occurring in stomachs, especially considering that the unidentified teleost category (probably primarily sand lance) contributed the greatest volume of all prey species found (Table 1).

Cephalopods occurred in 14.4% of those stomachs containing food (Table 1). This group was represented by two species, the Atlantic brief squid *Lolliguncula brevis* and the longfin squid *Loligo pealeii*. Unidentified cephalopod remains accounted for the lowest percent volume (0.2%) of prey items in stomachs containing food, whereas Atlantic brief squid contributed the highest (12.9%) (Table 1).

A third, miscellaneous prey category included salps and one immature species of isopod. A cigarette wrapper and piece of *Sargassum* weed were each present in two of the stomachs.

The combined volumetric contributions of teleost remains to the gut were significantly affected by area of capture (ANOVA; $F = 8.93$, df 2, 82, $P < 0.0003$). Stomach contents of tuna landed from "21 Mile Hill" had significantly higher volumes of teleost remains than did stomachs taken from either the "Hot Dog"

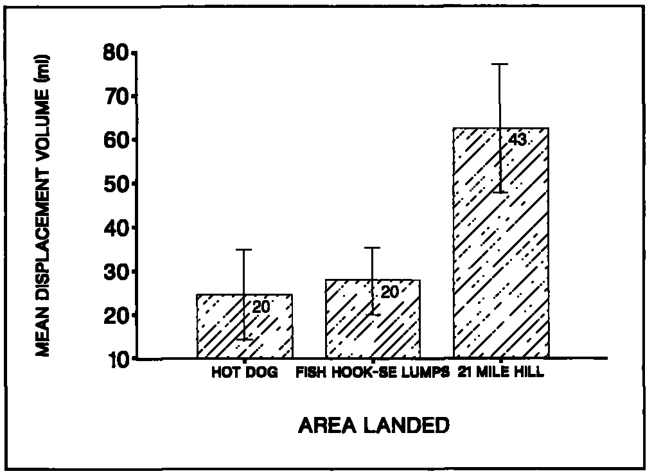

Figure 2
Mean combined displacement volume of identified and unidentified teleost remains from stomachs of bluefin tuna collected from three different areas off Virginia. Numbers within each bar indicate number of specimens sampled; vertical lines indicate ±1 SE.

or "Fish hook and S.E. Lumps" areas (SNK: EWER 0.05) (Fig. 2).

Digenetic trematodes *Hirudinella ventricosa* were found in 8 (11.1%) of the stomachs and averaged 10 mm in length and 2–3 mm in width. The worms were never attached to the lining of the stomach and were typically found at the posterior end. The number of worms per stomach ranged from 1 to 2 with a mean of 1.14 *H. ventricosa* per individual stomach. The possible effects of area landed on the number of trematodes occurring in the stomachs were not evaluated because of the relatively low rate of parasitism.

Discussion

Diet

This study indicates that school bluefin tuna, captured off the Virginia coast, feed predominantly on the sand lance. Mason (1976) was the first to report sand lance as a prey item of school bluefin tuna caught off the U.S. East Coast. He also reported sand lance to be the most important prey of school bluefin tuna caught off Virginia, but for fish taken north of Virginia, mackerel (*Scomber* spp.) replaced sand lance as the dominant prey. Holliday (1978) also found the sand lance to be the predominant food item for bluefin tuna captured by trolling along the U.S. East Coast. The *IRI* of sand lance in this study (*IRI* = 5583) is very similar to that reported by Holliday (1978) (*IRI* = 4896).

Sand lance form dense schools over New England and mid-Atlantic Continental Shelf areas. They occur throughout the water column during daylight hours, and are available to tuna predation at various depths (Meyer et al. 1979, Auster and Stewart 1986). Tuna predation on sand lance may affect the populations of this important forage species off Virginia. Reproducing populations of sand lance, as indicated by egg and larvae counts, exist on the Virginia shelf (Norcross et al. 1961); hence, the Virginia coast is an important habitat to the species. The sand lance serves as an important link between secondary producers and higher trophic-level fish and mammals in marine food chains (Bigelow and Schroeder 1953); thus, extensive predation by tuna could affect marine mammal populations. A cause-and-effect relationship may exist between low mackerel and herring stocks (resulting from heavy fishing mortality) and the observed population explosion of sand lance larvae in the mid- to late 1970s (Sherman et al. 1981); thus, tuna predation on sand lance could be beneficial to the return of mackerel and herring stock abundance.

The Atlantic brief squid was the second most important item consumed by school bluefin tuna examined in our study. Mason (1976) found two squid in the 20 fish he examined from Virginia waters. Holliday (1978) also reported similar species of cephalopods in stomach contents of the bluefin tuna taken off the U.S. East Coast. Krumholz (1959), working near the Bahamas, reported salps as the second most important food item. In the western North Atlantic, Dragovich (1970) noted molluscs (mainly cephalopods) as second in trophic importance. Similarly, Matthews et al. (1977) also reported cephalopods, pteropods, and heteropods as being the most frequent invertebrate forage group after fishes. For California bluefin tuna, the second most important food item was the California market squid *Loligo opalescens* or the pelagic swimming crab *Pleuroncodes planipes*, depending upon the area of capture (Pinkas 1971).

The butterfish, lined seahorse, and scrawled filefish were found in very few stomachs, being rare contributors to the diet of bluefin tuna in this study. These prey species demonstrate considerable diversity in their foraging locations, including nearsurface, mesopelagic, and demersal habitats. It is possible that the butterfish, lined seahorse, and scrawled filefish are associated with drifting *Sargassum* weed; thus, tuna may feed in part around drifting *Sargassum* communities. Other miscellaneous items found in the stomachs were salps, the isopod *Idotea* spp., a cigarette wrapper, and *Sargassum* weed. Holliday (1978) also reported the occurrence of *Idotea* spp. in stomachs of bluefin tuna caught trolling near *Sargassum* communities. He hypothesized that the isopod and *Sargassum* weed were accidently ingested by the tuna while pursuing other prey.

Parasites

The digenetic trematode *Hirudinella ventricosa* occurred in 11% of the stomachs examined in this study. Mason (1976) also found an annulated hemiurid trematode in 2% of the bluefin tuna stomachs he examined from the western Atlantic Ocean. The trematodes in Mason's (1976) study were found in both empty stomachs and stomachs which contained food. Crane (1936) reported *Distoma*-like worms in 25% of giant bluefin tuna stomachs he examined off Maine. *Hirudinella ventricosa* (= *marina*) occurred in 9% of school bluefin tuna and 48% of giant bluefin tuna stomachs collected from North Carolina to Massachusetts (Holliday 1978).

Giant trematodes of the genus *Hirudinella* frequently parasitize scombroid fishes (Nigrelli and Stunkard 1947, Nakamura and Yuen 1961, Watertor 1973, Manooch and Hogarth 1983). Adult parasites typically attach to the stomach lining and remain near the site of attachment throughout this life-stage (Manooch and Hogarth 1983). These digenetic endoparasites have complicated life cycles involving an alternation of generations and hosts; however, the life cycle of *Hirudinella* spp. is still unknown (Manooch and Hogarth 1983).

Attempts to evaluate the incidence of parasitism by size and sex of the host and by geographical area of collection have demonstrated mixed results (Nakamura and Yuen 1961, Manooch and Hogarth 1983). Nakamura and Yuen (1961) examined the occurrence of the parasite *H. ventricosa* (= *marina*) in the stomachs of skipjack tuna *Euthynnus pelamis* collected from Hawaii and off the Marquesas. They concluded that significant differences in the occurrence of trematodes collected from these two areas were attributable to time (year of collection) rather than area. Manooch and Hogarth (1983) reported distinct differences in the incidence of parasitism by *H. ventricosa* between wahoo *Acanthocybium solanderi* from the coast of Florida-South Florida and wahoo from the rest of the southeastern Atlantic. They suggested that this difference may reflect two subpopulations of wahoo along the southeastern U.S. coast: a northern population characterized by high incidence of trematodes, and a southern population with a much lower incidence.

Watertor (1973) examined 258 bluefin tuna captured off the East Coast of the United States (lat. 35–40°N; long. 65–75°W) and off the northeast coast of South America (lat. 0–18°N; long. 50–82°W). Of these, 51 were infected with *H. ventricosa* (= *marina*), nearly twice the infection rate noted in this study. There are two possible explanations for this difference. First, the parasites described by Watertor (1973) were pooled from both the eastern U.S. and northeastern South American samples. Inclusion of a South American group, with possibly a higher prevalence of parasitism, similar in nature to that described for wahoo by Manooch and Hogarth (1983), might have biased the values reported by Watertor (1973). Secondly, Watertor (1973) did not report the overall size ranges of bluefin tuna used in his study. Inclusion of giant bluefin tuna, with a higher prevalence of parasitism (see Crane 1936) may also contribute to apparent differences in levels of infection.

Area effects

Environmental factors such as temperature and oceanographic frontal zones have been shown to markedly influence the distribution, abundance and catchability of tunas (Murphy 1959, Uda 1973, Laurs and Lynn 1977, Rockford 1981, Sund et al. 1981, Laurs et al. 1984). Murphy (1959) suggested that the aggregation of albacore *Thunnus alalunga* in clear water on the oceanic side of fronts in nearshore areas may reflect an inability to efficiently capture large, mobile prey in turbid coastal waters. This same mechanism may help to explain the higher combined displacement volumes of sand lance and unidentified teleost remains in the stomachs of tuna taken from the "21 Mile Hill" compared with the "Hot Dog" or "Fishook and S.E. Lumps" areas (Fig. 2). Turbidity associated with effluent from Chesapeake Bay might have reduced the ability of bluefin tuna to detect mobile forage such as the sand lance and other teleosts. The effluent from the Chesapeake Bay appears in shelf waters as a lens of freshened water (with high concentrations of bay water constituents) extending offshore and towards the south as a part of the general shelf circulation (Ruzecki 1981). The three areas in question are directly offshore of the Chesapeake Bay mouth (Fig. 1). Differences in the diet of bluefin tuna have also been attributed to depth of capture, availability and type of food in a given area, time of day or year, spawning, atmospheric conditions, physiological conditions of predator fish, size of prey, and size of the bluefin tuna (Dragovich 1970).

We conclude that the sand lance is the most important forage of school bluefin tuna off the Virginia coast and suggest that this prey species, as well as teleosts in general, may become more vulnerable to tuna predation in areas least affected by the turbid waters of the Chesapeake Bay plume. In addition, the occurrence of the digenetic trematode *Hirudinella ventricosa* in a small but significant number of bluefin tuna off Virginia suggests that variation in infestation rates of this parasite might provide a mechanism to help distinguish among possible subpopulations of bluefin tuna occurring in the Western Atlantic.

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