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Food and Feeding of Northern Bluefin Tuna (Thunnus thynnus) and Yellowfin Tuna (Thunnus albarcares): A Comparative Study of the Food and Feeding Habits of the Northern Bluefin Tuna off the Coast of Virginia

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FOOD AND FEEDING OF NORTHERN BLUEFIN TUNA (THUNNUS THYNNUS) AND YELLOWFIN TUNA (THUNNUS ALBACARES)

A COMPARATIVE STUDY OF THE FOOD AND FEEDING HABITS OF THE NORTHERN BLUEFIN TUNA AND YELLOWFIN TUNA OFF THE COAST OF VIRGINIA.

A Thesis
Presented to
The Faculty of the School of Marine Science
The College of William and Mary in Virginia

In Partial Fullfillment
Of the Requirements for the Degree of
Master of Arts

by
Charles G. Barr
1991
This thesis is submitted in partial fulfillment of
the requirements for the degree of

Master of Arts

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To my parents, Charles and Mary,
who were always there with love and support.
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ABSTRACT

A two year study was conducted examining the food and feeding strategies of bluefin tuna (Thunnus thynnus) and yellowfin tuna (Thunnus albacares) as they occur off the coast of Virginia. Stomach samples from 220 bluefin and 259 yellowfin were collected from the recreational fishery from June through September 1988 and 1989. Data was collected on tuna catch locations, sea surface temperatures at time of capture and tuna length/weight. Stomach contents were measured volumetrically using water displacement and food items were counted and identified to the lowest possible taxon.

Results of the length/weight data indicated the average bluefin and yellowfin tuna were 2-3 year old fish. Bluefin averaged 10.8 kgs. in weight with an average fork length of 84 cm. Yellowfin averaged 14.8 kgs. in weight with an average fork length of 94 cm.

The diets of the bluefin and yellowfin were grouped into three categories: fish, squid and crustaceans. Fish comprised the largest portion of both tuna diets by number, volume and frequency of occurrence. The data show the importance of the sand lance, Ammodytes dubius as a primary food source for both bluefin and yellowfin tuna. The yellowfin diet exhibited greater diversity of prey fish with 21 families represented. The bluefin diet consisted almost exclusively of A. dubius, however 8 fish families were represented. Squid were represented in both bluefin and yellowfin tuna by a single species, Illex illecebrosus (short finned squid). Crustaceans (mainly amphipods, isopods, megalopae and mysids) were common in both bluefin and yellowfin stomachs.

Differences in feeding strategies between the bluefin and yellowfin tuna were evident based on dietary differences and feeding in distinctly different marine habitats. Yellowfin were found in areas with warmer sea surface temperatures and strong thermocline which restricts them to feeding in the upper water column. Surface feeding was evident by a high frequency of floating plant material found in their stomachs. The high prey diversity found in yellowfin stomachs was also indicative of feeding in areas of upwelling found along thermal fronts. Bluefin were found in areas characterized by cooler temperatures, shallower thermoclines and lack of thermal fronts. Bluefin feeding most frequently occurred in the lower water column. This was evident by a low occurrence of floating plant material, the occurrence of gravel and small shells found in some stomachs, low prey diversity and the presence of benthic and demersal prey.
FOOD AND FEEDING OF NORTHERN BLUEFIN TUNA (THUNNUS THYNNUS)

AND YELLOWFIN TUNA (THUNNUS ALBACARES)
INTRODUCTION

Bluefin tuna (Thunnus thynnus) and yellowfin tuna (Thunnus albacares) are members of the family Scombridae. This family consists of 15 genera and 48 species (Collette 1978). It contains all of the tunas as well as bonitos, mackerels, seerfishes (Spanish mackerels), and the butterfly kingfish (Klawe 1977).

The northern bluefin tuna and the yellowfin tuna are epipelagic, oceanic species which exhibit seasonal migrations. The northern bluefin tuna migrations occur in the Atlantic and Pacific Oceans as well as the Mediterranean Sea. In the western Atlantic, bluefin tuna may range as far north as Labrador and Newfoundland and south to Brazil (Collette and Nauen 1983). Yellowfin tuna, which are more frequently associated with more tropical and sub-tropical regions, are found worldwide except in the Mediterranean Sea (Collette and Nauen 1983). In the western Atlantic the yellowfin tuna seasonally range from Massachusetts to Brazil (Manooch 1984; Collette and Nauen 1983). During the summer months schools of young bluefin and yellowfin tuna concentrate in the coastal waters of the Mid-Atlantic Bight for feeding (Bochenek and Lucy 1990; Bochenek 1989; Bochenek, et al. 1989; Figley 1984).

Off the coast of Virginia, the summer feeding of one to three year old tuna is concentrated at well defined feeding grounds. These discrete areas are found within a band from 30 to 130 kilometers offshore extending to the edge of the continental shelf. Most of the
feeding grounds share the unique feature of being rises in elevation on the seafloor. Commonly they are called "the hills" or "the lumps" by local fishermen. Geologically, these sites are the remnants of ancient land features submerged by the postglacial rise of sea level that began ten thousand years ago (Swift, et al. 1976; Goldsmith, et al. 1974).

The annual influx and abundance of young tunas off the coast of Virginia from June through September supports a multimillion dollar recreational fishery (Bochenek and Lucy 1990; Bochenek 1989; Bochenek, et al. 1989; Lucy, et al. 1988; 1989; 1990; Figley 1984). In 1987, it was estimated that Virginia's recreational tuna fishing fleet was comprised of approximately 1100 boats (Lucy, Bochenek and Chartier 1988) mainly located at Rudee Inlet in Virginia Beach and Wachapreague on the Eastern Shore of Virginia.
NORTHERN BLUEFIN TUNA (Thunnus thynnus)

DISTRIBUTION AND MOVEMENTS:

Northern bluefin tuna can tolerate a wide range of temperatures (Collette and Nauen 1983). They prefer moderately warm seas (Bigelow and Schroeder 1953) which are found in the tropical and temperate oceans of the world. The preferred temperature range for bluefin tuna is between 16°C-19°C though they have been found in water temperatures as low as 6°C and as high as 27°C (Roffer 1987; O'Hara 1985; Magnuson 1963).

Spawning of Atlantic bluefin occurs in only two locations, in the Gulf of Mexico west of the Straits of Florida and in the Gulf of Guinea off the coast of Africa (Richards 1975; Richards and Pothoff 1980; Baglin 1975). Bluefin enter the Gulf of Mexico as early as February and spawning takes place for about 60 days (Richards 1975). In the Gulf of Guinea spawning occurs in February, March and August (Richards 1975). There is no evidence of spawning occurring anywhere else in the Atlantic. The mean age of the spawning stock in the Gulf of Mexico is about twelve years old (Baglin 1975) with an average individual weight of 260 kilograms (573 lbs.). By the first or second week in May, bluefin begin to appear on the eastern side of the Straits of Florida (Bigelow and Schroeder 1953) as they begin their post spawning northerly movements. In June, bluefin are found off the coasts of New Jersey, Long Island, southern New England, and in Cape Cod Bay. By late June or
early July, schools of bluefin arrive in the Gulf of St. Lawrence.

Bluefin tuna spawned in the western Atlantic tend to follow rather well defined distributional patterns according to the size of the fish (Rivas 1979). Age zero bluefin undertake fairly long migrations from their spawning/nursery grounds in the Gulf of Mexico and concentrate in the Mid-Atlantic Bight during or soon after the end of their first year (Mather 1980). They remain in this area at least through their second summer, alternating between summer feeding in coastal waters and winter feeding over the adjacent continental slope off the New York Bight and Georges Bank. According to Mather (1980), in some years large contingents of small fish 3-44 kgs. (6-97 lbs.) cross the Atlantic during the cool season following the Gulf Stream to the Bay of Biscay. Similar seasonal movements of medium size bluefin 45-130 kgs. (99-286 lbs.) also occur but extend northward into the Gulf of Maine and the waters of Nova Scotia in the summer and fall. During winter, medium size fish extend their movements much farther east between Nova Scotia and Georges Banks to the Gulf Stream.

Even more extensive movements are noted for giant bluefins, greater than 130 kgs. (>286 lbs.). During summer and fall, their feeding range extends from New Jersey to the Gulf of St. Lawrence and Newfoundland. Their winter habitat is extremely large, extending from Bermuda to the Equatorial Current. The giant bluefins then gather for spring spawning in the Gulf of Mexico and then begin their northward migrations again.

An interesting aspect of bluefin movement is their tendency to travel in schools segregated by size (Magnuson 1963). By the time bluefin have reached giant size, schooling ends and they become solitary oceanic wanderers.
FOOD AND FEEDING BEHAVIOR:

Bluefin prey on a wide variety of forage organisms, mainly small schooling fishes, macrozooplankton, mollusks (cephalopods) and some benthic organisms (Dragovich 1970; Bigelow and Schroeder 1953; Krumholtz 1959; Pinkas 1971). Seasonal feeding migrations of adult bluefin, after spawning (April to June), extend as far as 4500 kilometers in a month while the young move distances as far as 400 kilometers (Dragovich 1970a).

Bluefin are opportunistic, feeding on small fish or other organisms which are locally abundant (Bigelow and Schroeder 1953). In the Gulf of Maine they feed on large and small herring, mackerel and silver hake. South of Cape Cod they prey on menhaden. Off the Bahama Islands, Dragovich (1970a) examined one bluefin stomach containing 104 Diodon sp. and another containing 97 worm eels, Ahlia egmontis. Pelagic crustaceans were also found in large numbers especially the amphipod, *Phrosina semilunata* (Dragovich 1970a).

Butler and Mason (1977) examined the feeding behavior, food selectivity and daily food consumption of captive giant bluefin (>225 kgs.) confined to impoundment nets for 2 to 3 months. The tuna were normally fed approximately 18 kgs. of food per day, which was considerably less than the maximum amount these tuna were capable of eating. It was determined that maximum food consumption (42 kgs. of fish/day) occurred when the confined giant bluefins were fed at 4 hour intervals. Upon examination of stomach contents at various times after feeding, Butler and Mason (1977) found complete digestion occurred in approximately 18-20 hours (i.e., stomach empty other than viscous liquid).
Bluefin behavior is strongly influenced by feeding. They react to both olfactory and visual stimuli. Bluefin have been observed schooling in a parabolic feeding formation with the concave side of the parabola forward. The tuna apparently work together to drive schools of prey between the outstretched ends of the parabola, then surround and consume the prey (Partridge 1982). In the North Sea, bluefin which were located below a thermocline by sonar (where temperatures of 6° to 8°C were present) were attracted by chum to the surface (with temperatures of 14°-16°C) to feed (Magnuson 1963). Butler and Mason (1977) observed that tuna visually sighted their food and aligned themselves for the approach with their mouth opened slightly more than in the normal swimming configuration, yet not wide enough to engulf prey. Just as it approached its prey the tuna suddenly opened their opercular plates, rapidly sucking in the food. Almost all of the water was exited over the gill arches while the food was ingested. During feeding, individuals generally fed with equal activity with no dominance apparent. Butler and Mason (1977) also found that bluefin fed during early morning, mid-day, and dusk, and could be very selective about their diet. Magnuson (1963) observed association behavior in bluefin which is possibly related to feeding. Bluefin in the northwestern Atlantic were found in association with sargassum weed patches. They passed from patch to patch and would make dashes through the patches while chasing prey such as butterfish, *Peprilus triacanthus*. 
YELLOWFIN TUNA (Thunnus albacares)

DISTRIBUTION AND MOVEMENTS:

The yellowfin tuna are found worldwide in tropical and sub-tropical regions but are absent in the Mediterranean Sea (Collette and Nauen 1983; Olson and Boggs 1986). Yellowfin prefer a temperature range of roughly 18°-24°C (68°-74°F). Their vertical distribution in the water column is influenced by the thermal structure of the water. During feeding the yellowfin spend most of their time in the mixed layer near the top of the thermocline. During non-feeding or migration they tend to be found near the thermocline (Hunter, et al. 1986). Yellowfin are essentially confined to the upper 100 meters of the water column in areas with marked oxyclines. Oxygen concentrations of less than 2 ml/l found below the thermocline as well as the strong thermocline gradient act as a strong barrier (Collette and Nauen 1983).

Information on yellowfin movement and migrations along the eastern coast of the United States is scarce. Extensive studies have been conducted on yellowfin movements in the Pacific which may be applicable in theory to the western Atlantic (Manooch 1984). Nakamura (1969) believed that yellowfin distribution and movements are not based on tuna seeking out suitable temperatures, but on seeking out a suitable ecological habitat. Such a habitat can be defined as an area bounded by a suitable range of temperature, optimum oxygen concentrations and abundance of prey (Roffer 1987; Nakamura 1969). As temperature changes,
habitats can expand or contract resulting in the concentration or dispersion of yellowfin. These pelagic habitats also seem to be specific to the stage of development of the tuna and their related environmental needs. In the Atlantic, Reintjes and King (1953) found that large yellowfin (greater than 130 cm FL or greater than 43 kgs.) were scarce in surface waters but abundant at subsurface levels. Small fish (less than 100 cm FL or less than 20 kgs.) were most abundant in surface waters near shore, uncommon in surface waters offshore and rarely found in subsurface waters. Medium sized yellowfin (100-130 cm FL.) existed throughout the ranges of both smaller and larger fish.

This distribution and abundance is probably not determined by the occurrence of specific food items but is influenced by the total amount of food present in an area. It was found in the Pacific that late post larval and first year juvenile tuna (less than 15 mm long) enter coastal waters. In the western Atlantic, the juveniles (age 0) prefer the neritic waters which occur in the coastal areas of the Caribbean and the northeastern coast of South America. Adolescent yellowfin (age 1+) leave the waters of the Caribbean for feeding in the waters off the east coast of the U.S. and Bermuda.

Yellowfin exhibit seasonal migration. Throughout the summer, they move steadily northward along the east coast of the U.S. taking advantage of food concentrations (Longhurst and Pauly 1987; Nakamura 1969). As coastal waters cool in the late summer some yellowfin move farther out to sea spending the rest of the year in the warm waters of the west boundary of the Gulf Stream. Sexually mature yellowfin, those over 120 cm. (47 in.), take a mid-ocean southern route back to the Caribbean, Gulf of Mexico and northeastern South America where spawning
takes place from January to March (Davidoff 1963; Kikawa and Nishikawa 1979).

Yellowfin tuna, like the bluefin tuna, also exhibit schooling behavior. Schooling of yellowfin primarily occurs by size in near surface waters, however, schools may be made up of multispecific groups.

An universal attraction to flotsam such as floating wooden boards, logs or rafts of seaweed is exhibited by yellowfin (Longhurst and Pauly 1987). The reason is not known. It is unclear if tuna orienting behavior is feeding related. In many cases the tuna will leave the association to feed elsewhere and then return (Brill 1988, personal communication).

**FOOD AND FEEDING BEHAVIOR:**

The yellowfin tuna, like most tunas, is an opportunistic, generalist predator (Olson and Boggs 1986) feeding on a great variety of organisms (Reintjes and King 1973). Yellowfin are capable of capturing swift and relatively large prey or straining small, near surface items from the water using their gill apparatus (Manooch and Mason 1983). The great variability of food organisms in the diet suggests that yellowfin are voracious, non-selective feeders (Hida 1973; Manooch and Mason 1983) and will eat most any living organism available. Despite the great variability of food organisms consumed by yellowfin, the food is able to be primarily categorized into three significant groups: fish, mollusks, and crustaceans (Hida 1973; Ronquillo 1953; Dragovich 1970a).

Along the east coast of the United States, fish are the most important food item by both volume and frequency of occurrence (Dragovich 1970a; Manooch and Mason 1983; Hida 1973; Ronquillo 1953;
Manooch and Mason (1983) found fish occurred in 77% of the yellowfin stomachs that contained food. From these tuna stomachs, they were able to identify members of 23 different finfish families. Finfish were primarily older larval and juvenile forms often associated with sargassum weed. Dragovich (1970b) and Ronquillo (1953) reported similar findings. Dragovich (1970b) found fish from 15 different families in the stomachs of yellowfin along the U.S. east coast with the scombrids and serranids (primarily juvenile and larval forms) constituting the most important food by frequency of occurrence and by volume. The most numerous of the scombrids found was Auxis sp.

A wide variety of forms of crustaceans were found in the stomachs of yellowfin with a fork length range of 40 cm. to 155 cm. (Dragovich 1970b). Larval macrozooplankton forms made up the bulk of crustaceans in all areas. Along the eastern coast of the U.S., crustaceans found in the stomachs of yellowfin consisted of hyperiid amphipods and megalopal stages of Brachyura; one group of megalopae, Raninidae, was identified to family in Dragovich's (1970b) study. Manooch and Mason (1983) found that crustaceans were second in importance only to fish, being found in 52% of the yellowfin examined. The majority of these crustaceans were immature stages - larvae, megalopae, and glaucothae. On one occasion a stomach contained hundreds of crustaceae larvae. Due to their small size, however, they only accounted for 5.9% of total food volume found in the stomach. Reintjes and King (1953) found yellowfin (88 cm. to 136 cm. FL.) caught in the vicinity of an extremely large aggregation of crab megalopae were gorged and regurgitated large amounts of the larvae when landed. They averaged about 1500 larvae (180 cc.) per stomach. Crustaceans occurred in 24.8% of all yellowfin stomachs they studied.
Cephalopods (Teuthidida and Octopodida) constituted almost all of the molluskan food in the Reintjes and King (1953) study. The Teuthoids (squids) were most important by frequency of occurrence (50.5%) and by volume (41.0%) in yellowfin (Manooch and Mason 1983). Squid composed 26.2%, by number, in the Reintjes and King (1953) study. Three genera of squid were identified by Manooch and Mason (1983): *Loligo*, *Sepioteuthis*, and *Illex*. Dragovich (1970b) found squid to be the most numerous of the mollusks in yellowfin stomachs, however, they were considerably fewer in number than fish and crustaceans.

Yellowfin ingest a wide variety of items accidentally with natural foods. Non-food items such as *Sargassum*, *Zostera*, *Thalassia*, *Spartina*, feathers, globs of tar and plastics occurred with 31.6% frequency, by number (Manooch and Mason 1983).

Different studies throughout the world’s oceans generally suggest that as tuna grow larger their diets change (Manooch and Mason 1983). Small tuna feed predominantly on crustacean larvae. Medium tuna mainly feed on fish and squid. This is substantiated by Reintjes and King (1953), Nakamura (1965), and Batts (1972) for skipjack tuna. In yellowfin, however, Manooch and Mason (1983) found size of food items in tuna stomachs showed little change as fish size increased (or decreased). The occurrence of floating plant material decreased for larger yellowfin. This may be explained by longline catch data which shows larger yellowfin are caught at greater depths (suggesting that feeding of larger yellowfin occurs well below the surface where plant material is not found). Manooch and Mason contradict Dragovich (1970b), who found yellowfin size does effect size of food items. Dragovich found the size of prey fish increased with an increase in yellowfin
Nakamura (1969) also stated that yellowfin in the Pacific search out new habitats as they grow larger in order to satisfy their changing dietary requirements.

The volume of stomach contents of yellowfin tuna has received much attention over the years. Magnuson (1969) estimated the maximum stomach capacity of yellowfin at 7% of the weight of the fish. Dragovich (1970b) found the volume of stomach contents in 85% of the yellowfin examined to be less than 20 ml. Reintjes and King (1953) found food volume in yellowfin was less than 25 ml. in 58% of the stomachs. Manooch and Mason (1983) found the displacement volume for food found in yellowfin averaged 67.9 ml. The differences between the two former studies versus the latter study may be attributed to three possible factors: the number of fish sampled, the size of the fish caught and the area of sampling. Dragovich examined 611 yellowfin, 78% of which were caught in the Atlantic off the coast of Africa. Manooch and Mason examined 206 yellowfin caught in the Atlantic off the southeastern coast of the United States.

Reintjes and King (1953) offered some possible explanations for variations in volume of stomach contents based on rate of digestion or feeding habits. Tunas sampled from different habitats and of different size schools may exhibit variations in volume of stomach contents. For example fish coming from surface schools have a higher percentage of empty stomachs as compared to fish from poorly defined schools (individuals or small aggregations). The large percentage of empty or almost empty stomachs found may also be related to tunas' rapid rate of digestion. Another possibility may be that yellowfin depend on occasional opportunities to gorge themselves on large aggregations of
food items. Reintjes and King (1953) also found that the mean food volume increased with increased fork length, but the average stomach content by volume per unit of body weight (cc/lb.) decreased as weight of fish increased.

Diurnal feeding fluctuations may be another explanation for the high percentage of empty stomachs. Nakamura (1965) suggested a diurnal feeding pattern of skipjack was based on the availability of food (movement of zooplankton and forage organisms during the mid-day period of maximum illumination to depths beyond the reach of skipjack and yellowfin) or the satiation of tuna after a heavy morning feeding period. Feeding of yellowfin also occurs at night however, according to Olson and Boggs (1986).

DIGESTION AND GASTRIC EVACUATION:

Olson and Boggs (1986) examined the digestion and gastric evacuation of yellowfin tuna. They found that yellowfin took about 30 minutes to feed to satiation and the relative meal size averaged 8.53% of wet body weight. This is higher than the 7% of the body weight established by Magnuson (1969). Reintjes and King (1953) found some yellowfin stomachs greatly distended by large single feedings on large carangid and scombrid fishes. One stomach from a yellowfin (136 cm. FL.) contained a skipjack 40 cm. in length. The discovery of vertebral remains suggest prey of this size are not uncommon. The maximum size of food organisms is estimated at approximately one third the length of the yellowfin.

Digestion is rapid in tuna. Olson and Boggs (1986) provided evidence that yellowfin tuna evacuate food from the stomach faster than
most scrombroid and non-scombroid fishes studied. The type of prey organism ingested significantly affects the rate at which food is passed from the stomach. Mackerel were evacuated significantly slower than squid and smelt (Olson and Boggs 1986). Yellowfin can empty their stomachs of smelt in an average of 10.4 and 12 hours respectively (Magnuson 1969). One reason hypothesized for this rapid processing of food is to keep up with the high energy demand required by the constant swimming of yellowfin in order to maintain their hydrostatic equilibrium and to maintain ventilation of their gills.

Yellowfin are abundant in tropical seas where primary production is low and food distribution is patchy. It is advantageous for tropical tunas to have the ability to process large volumes of food in a short time when food is available. The more rapidly food is digested and evacuated, the more food a tuna can acquire from what may be a short lived aggregation of food. After metabolic demands are met energy is used for growth or stored as body lipids for reproduction and migration.

**REACTIONS OF YELLOWFIN TO STIMULI:**

Yellowfin tuna have developed strong visual acuity as well as a highly developed olfactory system. Studies by Atema, et al. (1980) suggest tuna use a low threshold olfactory sense to respond to specific qualitative differences in mixtures of compounds which occur in the secretions of their prey. It seems unlikely that internal body juices of prey constitute frequently encountered stimuli even during a feeding frenzy since tuna swallow their prey whole. The prey secretions of greatest benefit to a tuna would be the external secretions or metabolic residues of intact prey. These external secretions and residues of prey
consist of oils, proteins and amino acids found in the protective mucus layers of fishes and squids. A tuna can detect a single amino acid assuming uniform dilution of around 10 Molar.

Tuna use their olfactory acuity in tracking secretion trails of specific prey schools which are seasonally or locally abundant but well out of visual range (Atema, et al. 1980). Once a prey secretion is detected by a yellowfin, it stimulates an active search response. This response is characterized by a sudden stall in movement or a burst of speed which was then followed by a general increase in swimming speed, changes in overall swimming pattern and a breakdown of coordinated swimming of the fish in the "school" (Atema, et al. 1980). A strong response culminated in behavior such as jaw snapping, display of feeding bars (dark vertical stripes often seen on the flanks of feeding tuna) and sometimes tight circling in the area of the secretions. Upon approaching the prey, the increased intensity of the secretion stimulus coupled with a strong visual stimulus creates a voracious feeding response in the tuna.

In a study conducted by Miyake (in Tester 1952), attraction of yellowfin to sound was tested. No positive results were found in attracting tuna by broadcasting low frequency (100 cycle to 70 kilocycle per second) but there were some positive reactions to complex sounds of low frequency. It is interesting to note that many boat captains have expressed the opinion that the sounds given off by the engines of certain boats attract fish while others may repel.
STOMACH CONTENT ANALYSIS

There are various systems for analysis of stomach contents reviewed by Reintjes and King (1953). They group them into three general systems: the numerical system, frequency of occurrence analysis, and the volumetric system.

The numerical system is based on the count of organisms present. Each food element is evaluated as a percent of the total number of all elements. This method is extremely simple but has some serious inherent problems. This method over-emphasizes the importance of organisms with digestion resistant parts. Organisms such as squid and small fish which digest quickly may be downgraded in importance while digestion resistant crustaceans and large fish may be over emphasized. Foods finely broken up can only provide a rough estimate of number. This method does not take into account the size of the food items and conveys little importance of the relative size of separate components in terms of biomass.

In frequency of occurrence analysis each food item is also expressed as a percentage. This is derived by dividing the number of stomachs containing the food (regardless of amount) by the total number of stomachs examined. This method provides a rough but useful index to overall availability or desirability of the food items.

In the volumetric analysis system the importance of individual food items is based on the percentage of volume. This method reduces the
bias associated with food organisms with more durable parts, but is
still affected by variable rates of digestion. It yields the most
reliable information on recent food, but may not adequately account for
largely digested food which has been in the stomach for a long period.
Size of individual items is taken into account only by this type of
analysis. This method has often been considered the best of the three
(Reintjes and King 1953).

The volumetric analysis method can be calculated in several ways.
One such use is an aggregate-total-volume method where the percentage of
each kind of food is obtained by dividing the total volume of all foods
of each kind by the total volume of the stomach contents of all fish
sampled. The variation in the total volume of food from each stomach
influences the final result in direct proportion to that value. This
method reflects the true volumetric importance of a particular food
organism regardless of whether much or little of other food is present.

Another application of the volumetric analysis system is an average
percent method. The percentage of total volume is calculated for each
food item within each individual stomach and averaged across the sample.
The individual variation in total volume of food present does not
influence the results. Fish stomachs containing very little food exert
the same influence on results as do well-filled stomachs.

Various combinations of the three basic systems of analysis have
been used to present a more complete picture of food habits. Tester
(1932) combined volumetric and frequency of occurrence methods for a
graphic representation of food habits. The relative importance of each
kind of food was demonstrated graphically by a rectangle in which
percent frequency of occurrence was the vertical line. The vertical
scale was set at 40 percent of the horizontal to give volume of food more weight. Food items which ranked high in volume and high in frequency of occurrence were important foods at the time and for the area sampled.
OBJECTIVES

The purpose of this study was to examine the food, feeding habits and trophic interaction of the northern bluefin tuna (*Thunnus thynnus*) and the yellowfin tuna (*Thunnus albacares*) as they occur in the Atlantic Ocean off the coast of Virginia. Knowledge of food and feeding habits is important to the understanding of the biology, abundance and distribution of tuna species. Since bluefin and yellowfin can co-occur off Virginia and may even be found in proximity to each other (Bochenek 1990), it is worthwhile to determine whether distinctions in diets occur. Relatively few studies pertaining to the feeding of bluefin and yellowfin tuna have been conducted in the Atlantic (Manooch and Mason 1983). Data from feeding studies provide important information regarding food web relationships and feeding ecology which is useful for fisheries management. This type of study takes on added importance with recent warnings from members of the U.S. delegation to the International Commission for the Conservation of Atlantic Tunas (ICCAT) stating that the northern bluefin stock is in danger of being overfished (Drumm 1989). By understanding the biological and ecological requirements of the tunas, in particular the bluefin tuna, we can work to safeguard important food resources and protect important habitats such as spawning and feeding grounds to ensure the existence of the species.
Hypothesis

It is hypothesized that there are spatial and temporal differences, interspecifically and intraspecifically, in the prey composition of the bluefin and yellowfin tuna.

To test this hypothesis: 1) the relative importance of the individual prey organisms consumed by the bluefin and yellowfin tuna was determined, and 2) the significance of the differences in spatial and temporal composition of prey was examined.
METHODS

Field Collection

The primary ports for tuna fishing in Virginia are located at Rudee Inlet in Virginia Beach and at Wachapreague on the Eastern Shore of Virginia. Samples were obtained from the recreational catch at these locations from May through September of 1988 and 1989. As catches were brought into these locations by recreational fishermen, those which were to be cleaned at the facility were identified. They were then weighed to the nearest half pound (later converted to kilograms) and measured to the nearest millimeter along the curved fork length from tip of the lower jaw to the fork of the tail. Data on location of capture and sea surface temperature were obtained through a brief interview with either the mate or captain of the boat (satellite sea surface temperature data were also examined). Each tuna was then assigned an identification number which was attached to the caudal peduncle by a rubber band, and the fish sent to the cleaning station (for filleting or steaking). After the tuna were cleaned, the remains, which had been numbered, were set aside by cooperating fish cleaners. The stomach of each tuna could then be easily extracted and matched to the corresponding length, weight and catch data. Stomachs and identification numbers were then placed in individual "zip-lock" plastic bags and packed in ice for transportation back to the lab.
Laboratory Analysis

Tuna stomachs were handled in one of three ways: analyzed immediately; frozen for later analysis; or preserved in 10% buffered formalin. Those stomachs which were to be preserved in formalin were removed from the plastic bags, punctured several times to allow easy penetration of the formalin and placed in individual storage jars. After analysis, items which were to be saved for future identification were fixed in 10% formalin (if not previously in formalin) for two days then transferred to 50% isopropyl alcohol for storage and later identification.

The tuna stomachs were opened and the contents were examined. The contents were thoroughly rinsed with water onto a number 60 mesh sieve (0.2489 mm) and attention was paid to the degree of distention of the stomach. Occasionally an empty or near empty stomach would be found yet a definite distention of the stomach walls would be evident. This indicated that the stomach contents had probably been regurgitated during capture. This is reported to be a common occurrence by fishermen. The stomach contents were measured by volumetric water displacement to the nearest milliliter in a graduated cylinder. Items found in the stomachs were identified to the lowest taxon, counted, and recorded per individual stomach. Representative small percoids were cleared and stained and identified to the lowest possible taxon using the methods described by Simons and Van Horn (1971), and Dingerkus and Uhler (1977) in Pothoff (1984).
Statistical Analysis

In order to produce an accurate, realistic picture of the dietary importance of various food items, the number, volume or weight, and frequency of occurrence of the items should be represented (Hyslop 1980). Pinkas, Oliphant and Iverson (1971) developed an "index of relative importance" (IRI) which takes these key characteristics of diet into account. The index is calculated as: \( \text{IRI} = (N + V)F \), where \( N \) = numerical percentage of a food, \( V \) = volumetric percentage and \( F \) = percentage frequency of occurrence (Manooch and Mason 1983).

The differences between the bluefin and yellowfin diets were evaluated using the Spearman Rank Correlation Coefficients (Fritz 1974) method applied to IRI values. This nonparametric test requires no assumption of normality with regard to distribution of the variables (Manooch and Mason 1983). Cailliet and Barry (in Manooch and Mason 1983) warn against the use of this method if 1) a large number of ties occur, 2) a considerable non-overlap of prey items is evident, 3) high diversity is present. The Spearman rank correlation coefficients are calculated using either of two equations (Fritz 1974).

\[
\begin{align*}
    r_s &= 1.0 - \frac{6 \sum d^2}{N^3 - N} \\
    \text{or with tied ranks: } \quad r_s &= \frac{\sum x^2 + \sum y^2 - \sum d^2}{2\sqrt{\sum x^2 \sum y^2}} \\
    \text{where } \quad \sum x^2 &= \frac{N^3 - N - \sum Tx}{N} \\
    \text{and } \quad \sum y^2 &= \frac{N^3 - N - \sum Ty}{N} \\
    \text{and } \quad T &= \frac{(t^3 - t)}{N}
\end{align*}
\]
where $r_s = \text{Spearman rank correlation coefficient}$, $N = \text{number of ranks}$, $d = \text{difference between ranks}$, $T = \text{correction factor for ties}$, and $t = \text{number of observations tied at a given rank}$ ($x, y, \text{etc.}$). The first equation is used for comparing data in which no ranks are tied and the second equation is used when some ranks are tied.

Bluefin and yellowfin stomach samples were collected from boats fishing many fishing/feeding grounds in order to examine any spatial differences in feeding habits. Diet composition from northern feeding areas for bluefin tuna such as the 21 Mile Hill and the 26 Mile Hill were compared to more southerly areas such as the Fishhook and Hotdog. This same northern region versus southern region comparison was also applied to yellowfin tuna. Data from the northerly region were pooled as were data from the southern region. These data were ranked and comparisons were performed using the Mann-Whitney test (Elliott 1983; Zar 1984) to examine similarities and differences.

The Mann-Whitney test is a powerful non-parametric test whose power-efficiency is never less than 86% (Elliott 1983). The IRI numerical data from each area were ranked from highest to lowest or from lowest to highest. These ranks were then used in the calculation of the Mann-Whitney statistic,

$$U = n_1n_2 + n_1(n_1 + 1) - R_1$$

where $n_1$ and $n_2$ are the numbers of observations from the different locations and $R_1$ is the sum of the ranks of the observations of sample 1 (Zar 1984).

The Mann-Whitney analysis may also be applied in a similar manner to the spatial examination of tuna diets. This test was used to reveal any intra-specific differences in diets of the bluefin and yellowfin tuna as they feed in different regions.
RESULTS AND DISCUSSION

Samples from 220 bluefin and 259 yellowfin tuna were collected from Rudee Inlet at Virginia Beach and Wachapreague on Virginia's Eastern Shore. From these two locations, recreational fishermen targeted bluefin and yellowfin tuna at over eleven different fishing sites located from 20 to 80 nautical miles offshore. Most of the tunas landed from Virginia's offshore fishing sites were juveniles. Bluefin tuna sampled averaged 10.8 kgs. (24 lbs.) in weight with a range from 3.4 to 53.6 kgs. (8 to 118 lbs.). Bluefin lower jaw fork length ranged from 54.4 to 142.1 cm. (21.2 to 55.4 in.) with an average length of 84 cm. (38.3 in.). Examination of bluefin length frequencies (FIGURE 1) showed 32% (range: 51 to 80 cm.) were approximately two year old fish and 58% (range: 81 to 100 cm.) were approximately three year old fish (Parrack and Phares 1978; Mather 1980a). Yellowfin tuna sampled during this study weighed from 1.6 to 43.9 kgs. (3.6 to 96.9 lbs.) with an average weight of 14.8 kgs. (33 lbs.). Yellowfin lower jaw fork length ranged from 60.4 to 135.5 cm. (23.6 to 52.8 in.) with an average length of 94 cm. (36.6 in.). Examination of yellowfin length frequencies (FIGURE 1) showed 56% (range: 81 to 100 cm.) were approximately two year old fish and 31% (range: 101 to 120 cm.) were three year olds (Wild 1986).

An early attempt was made to sex both bluefin and yellowfin tuna samples. This proved to be impossible since gonadal development was not evident in either bluefin or yellowfin tuna until they reached a weight of approximately 27 kgs. (60 lbs.).
FIGURE 1
TUNA LENGTH FREQUENCIES
1988-1989

PERCENT

LENGTH (CM.)

BLUEFIN  
YELLOWFIN

(BLUEFIN N=219, YELLOWFIN N=255)
COMPOSITION OF STOMACH CONTENTS:

Stomach samples from the bluefin and yellowfin tunas were collected from June through September 1988 and 1989. These samples yielded 8437 food items which were grouped into four categories: fish, cephalopods (squid), crustaceans, and miscellaneous. Data were collected on numbers of individual food items, volume and frequency of occurrence from each tuna species. Number and volume percentages were determined, and an index of relative importance was calculated for each category (TABLE 1). The index of relative importance for the four basic categories is represented in FIGURE 2. Data from TABLE 1 was then partitioned with respect to the most frequently occurring identified food species (TABLE 2).

Non-food items were also found in many of the tuna stomachs and these were noted separately. These items included parasites, shell fragments, gravel, plant material, insects, and a variety of plastics.

Each tuna stomach was subjectively judged for fullness based on the criteria described in TABLE 3. The results of this analysis were similar for both bluefin and yellowfin tuna (TABLE 4). Of the bluefin, 73.4% of all stomachs were rated as less than 50% full and 16.3% of the bluefin stomachs were full and distended with food. Of the yellowfin 70.2% were rated as less than 50% full and 20% were full and distended with food. Occasionally a stomach would be found which was distended but empty. This most likely indicated stomach content regurgitation. The regurgitation of stomach contents occasionally occurs when tunas are being landed (by fishermen) or while in the fish well of the boat. Evidence of distended, empty stomachs was very rare in the samples of
this study and no quantitative data was collected regarding the occurrence of this situation.
TABLE 1

RESULTS OF BLUEFIN (BF) AND YELLOWFIN (YF) STOMACH ANALYSIS\(^1\)

<table>
<thead>
<tr>
<th></th>
<th>NUMBER</th>
<th>NUMBER %</th>
<th>VOLUME (ML.)</th>
<th>VOLUME %</th>
<th>FREQUENCY OF OCCURRENCE</th>
<th>INDEX OF RELATIVE IMPORTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BF</td>
<td>YF</td>
<td>BF</td>
<td>YF</td>
<td>BF</td>
<td>YF</td>
</tr>
<tr>
<td>FISH</td>
<td>3888.0</td>
<td>3080.0</td>
<td>91.9%</td>
<td>73.2%</td>
<td>7560.0</td>
<td>10809.8</td>
</tr>
<tr>
<td>CEPHALOPODS (^2)</td>
<td>166.0</td>
<td>571.0</td>
<td>3.9%</td>
<td>13.6%</td>
<td>155.4</td>
<td>3926.1</td>
</tr>
<tr>
<td>CRUSTACEANS (^3)</td>
<td>151.0</td>
<td>518.0</td>
<td>3.6%</td>
<td>12.3%</td>
<td>16.6</td>
<td>94.2</td>
</tr>
<tr>
<td>MISCELLANEOUS (^4)</td>
<td>24.0</td>
<td>39.0</td>
<td>0.6%</td>
<td>0.9%</td>
<td>6.1</td>
<td>10.0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4229.0</td>
<td>4208.0</td>
<td>7738.1</td>
<td>14840.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) DATA ARE THE RESULT OF THE ANALYSIS OF 220 BLUEFIN TUNA AND 259 YELLOWFIN TUNA STOMACH SAMPLES.

\(^2\) CEPHALOPODS CONSIST OF SQUID OF THE FAMILY OMMASTREPHIDAE, GENUS ILLEX.

\(^3\) CRUSTACEANS REPRESENTS ALL CRUSTACEANS AND MEGALOPAE.

\(^4\) MISCELLANEOUS REPRESENTS ISOPODS AND SALPS.
FIGURE 2
INDEX OF RELATIVE IMPORTANCE (IRI)

YELLOWFIN TUNA
(THUNNUS ALBACARES)

BLUEFIN TUNA
(THUNNUS THYNNUS)

FISH

SQUID

CRUSTACEANS

OTHERS - PREY ITEMS LESS THAN 2%
<table>
<thead>
<tr>
<th>Species</th>
<th>Number BF</th>
<th>Number %</th>
<th>Volume (mL) BF</th>
<th>Volume %</th>
<th>Frequency of Occurrence BF</th>
<th>Index of Relative Importance BF</th>
<th>Number YF</th>
<th>Volume %</th>
<th>Frequency of Occurrence YF</th>
<th>Index of Relative Importance YF</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMMODYTES SP.</td>
<td>3530.0</td>
<td>83.47%</td>
<td>6715.90</td>
<td>59.74%</td>
<td>86.79%</td>
<td>55.38%</td>
<td>2514.0</td>
<td>59.74%</td>
<td>86.79%</td>
<td>55.38%</td>
</tr>
<tr>
<td>PEPRILUS SP.</td>
<td>213.0</td>
<td>5.04%</td>
<td>655.00</td>
<td>5.04%</td>
<td>8.46%</td>
<td>3.58%</td>
<td>121.0</td>
<td>5.04%</td>
<td>8.46%</td>
<td>3.58%</td>
</tr>
<tr>
<td>HIPPOCAMPUS SP.</td>
<td>80.0</td>
<td>1.89%</td>
<td>28.50</td>
<td>0.37%</td>
<td>0.37%</td>
<td>0.37%</td>
<td>120.0</td>
<td>1.89%</td>
<td>0.37%</td>
<td>0.37%</td>
</tr>
<tr>
<td>MONOCANTHUS SP.</td>
<td>1.0</td>
<td>0.02%</td>
<td>9.60</td>
<td>0.02%</td>
<td>0.02%</td>
<td>0.02%</td>
<td>9.0</td>
<td>0.02%</td>
<td>0.02%</td>
<td>0.02%</td>
</tr>
<tr>
<td>PRIACANTHUS SP.</td>
<td>5.0</td>
<td>0.12%</td>
<td>3.90</td>
<td>0.05%</td>
<td>0.05%</td>
<td>0.05%</td>
<td>2.0</td>
<td>0.12%</td>
<td>0.05%</td>
<td>0.05%</td>
</tr>
<tr>
<td>UNSPECIFIED TELEOSTS</td>
<td>59.0</td>
<td>1.40%</td>
<td>147.10</td>
<td>1.90%</td>
<td>12.96%</td>
<td>17.73%</td>
<td>314.0</td>
<td>7.46%</td>
<td>1923.90</td>
<td>12.96%</td>
</tr>
<tr>
<td>CEPHALOPODS</td>
<td>166.0</td>
<td>3.93%</td>
<td>155.40</td>
<td>2.01%</td>
<td>26.46%</td>
<td>24.09%</td>
<td>571.0</td>
<td>3.93%</td>
<td>3926.10</td>
<td>26.46%</td>
</tr>
<tr>
<td>MEGALOPOAE</td>
<td>8.0</td>
<td>0.19%</td>
<td>3.90</td>
<td>0.05%</td>
<td>0.05%</td>
<td>0.05%</td>
<td>444.0</td>
<td>10.55%</td>
<td>42.60</td>
<td>0.05%</td>
</tr>
<tr>
<td>CRUSTACEANS</td>
<td>143.0</td>
<td>3.38%</td>
<td>12.70</td>
<td>0.16%</td>
<td>0.16%</td>
<td>0.16%</td>
<td>74.0</td>
<td>1.76%</td>
<td>51.60</td>
<td>0.16%</td>
</tr>
<tr>
<td>ISOPODS</td>
<td>24.0</td>
<td>0.53%</td>
<td>6.10</td>
<td>0.13%</td>
<td>0.06%</td>
<td>1.36%</td>
<td>39.0</td>
<td>0.92%</td>
<td>10.00</td>
<td>0.13%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>4229.0</td>
<td></td>
<td>7738.10</td>
<td></td>
<td></td>
<td></td>
<td>4208.0</td>
<td></td>
<td>14840.10</td>
<td></td>
</tr>
</tbody>
</table>

1. Data are the result of the analysis of 220 bluefin tuna and 259 yellowfin tuna stomach samples.
2. Unspecified teleosts consist of unidentified and identified fish of low quantities.
3. Cephalopods consist of squid of the family ommastrephidae, genus Illex.
4. Crustaceans represent various unidentified amphipods, mysids, euphausids, and 1 Ovalipes sp. crab.
5. Isopods consist of members of Idotea sp.
<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>Completely empty stomach</td>
</tr>
</tbody>
</table>
| 25%        | Volume up to 25% of stomach capacity.  
Very digested remains (only fragmented skeletal material).  
Few small items such as individual megalopae, amphipods, squid beaks. |
| 50%        | Volume 25% to 50% of stomach capacity.  
Digested remains (flesh & skeletal material).  
Some fresh (no or light digestion) specimens.  
Nearly complete small fish, crustaceans and squid. |
| 75%        | Volume 50% to 75% of stomach capacity.  
Mixture of fresh and partially digested specimens.  
Most specimens easily identifiable. |
| 90%        | Stomach full.  
Freshly consumed specimens.  
All specimens easily identifiable. |
| 100%       | Full distended stomach.  
Stomach gorged on freshly consumed prey. |
TABLE 4

PERCENT STOMACH FULLNESS

<table>
<thead>
<tr>
<th></th>
<th>0%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BLUEFIN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO.</td>
<td>60</td>
<td>70</td>
<td>31</td>
<td>10</td>
<td>13</td>
<td>36</td>
</tr>
<tr>
<td>% TOTAL</td>
<td>27.2%</td>
<td>31.8%</td>
<td>14.0%</td>
<td>4.5%</td>
<td>5.9%</td>
<td>16.3%</td>
</tr>
<tr>
<td>n</td>
<td>220</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>0%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>YELLOWFIN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO.</td>
<td>53</td>
<td>73</td>
<td>56</td>
<td>9</td>
<td>17</td>
<td>52</td>
</tr>
<tr>
<td>% TOTAL</td>
<td>20.4%</td>
<td>28.2%</td>
<td>21.6%</td>
<td>3.4%</td>
<td>6.6%</td>
<td>20.0%</td>
</tr>
<tr>
<td>n</td>
<td>259</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**FISH:**

Fish comprised the largest portion of the bluefin and yellowfin diets by number, volume and frequency of occurrence. Small, schooling fish primarily *Ammodytes* sp., the sand lance, were present in both species of tuna. The yellowfin diet exhibited a greater diversity of prey fish with 21 families represented (APPENDIX I). The bluefin diet consisted almost exclusively of *Ammodytes* sp., however, 8 fish families were represented (APPENDIX II).

Fish constituted 73.2% by number and 72.8% by volume of the yellowfin diet (TABLE 1). The index of relative importance (IRI) ranked fish of greatest importance followed by squid and crustaceans (FIGURE 2). Of the 21 fish families consumed by yellowfin only two of these families (*Ammodytidae* and *Syngnathidae*) had adult representatives. The remaining families were represented by post-larvae (*Lophius* sp. in transition between pelagic larvae and benthic juveniles; *Chaetodon* sp. exhibiting armored head plates) and juveniles. Many of these post-larval and juvenile fish were associated with floating seagrass, sargassum and/or flotsam which was simultaneously found in the yellowfin stomachs. Most of the juveniles were found singularly in stomachs containing low volumes of food. This indicates that the yellowfin were picking lone individuals from among the floating vegetation during a period of orienting to these seagrass rafts. One yellowfin stomach contained seahorses still clinging by their prehensile tails to strands of *Zostera*, eelgrass. The fish families represented in the yellowfin stomachs are characteristically found from the surface to midwater depths. The only two possible exceptions were *Lophius americanus*, the goosefish (monkfish), and *Ammodytes* sp. The single specimen of *L. americanus* was
a prejuvenile measuring approximately 35 mm. Goosefish are normally thought of as benthic, however, Bigelow and Schroeder (1953) suggest that juveniles less than 63.5 mm (2.5 inches) are pelagic. *Ammodytes* sp. may be found throughout the entire water column over the continental shelf. The characteristics of the fish families preyed upon by the yellowfin indicated feeding takes place exclusively in the upper water column. There was no indication of yellowfin feeding on the bottom.

The bluefin diet exhibited much less diversity of fish prey than the yellowfin diet. Fish constituted 91.9% by number and 97.6% by volume of the bluefin diet (TABLE 1). The high quantities of fish in the bluefin diet also resulted in a high index of relative importance (IRI) shown in FIGURE 2. Of the fish consumed by the bluefin, the *Ammodytes* sp. (sand lance) constituted 90.8% of the number and 88.8% of the volume. Many bluefin stomachs were literally gorged with *Ammodytes* sp. Of the 8 families of fish consumed by the bluefin, only 2 families (*Ammodytidae* and *Syngnathidae*) had adult representatives. The remaining 6 families were represented by post-larvae and juveniles. As in the yellowfin stomachs, post-larvae and juvenile fish were usually found singularly in conjunction with seagrasses and flotsam. An example of the consumption of small individual prey in relation to floating seagrasses was evident in a single bluefin stomach which contained *Zostera* and 43 *Hippocampus erectus* (lined seahorses) all at varying stages of digestion.

The bluefin prey fish are characteristic of midwater, lower water column and benthic species. *Ammodytes* are found throughout the water column but will quickly retreat to the bottom when attacked or pursued (Auster and Stewart 1986). The butterfish, *Peprilus triacanthus*. 
congregate near the bottom during the daylight feeding on small fish, squid, crustacea (amphipods, copepods and shrimp) and annelid worms (Murawski, et al. 1978). Pieces of coarse sand, gravel, small shells and shell fragments were found among the contents of bluefin stomachs. The ability to tolerate cooler water temperatures (such as temperatures found below the thermocline) and the relative shallow depths (less than 10 m. at some of the bluefin feeding areas) make the bottom accessible to the bluefin.

**Cephalopods:**

Cephalopods were represented in the diets of both bluefin and yellowfin tuna by a single species of squid, *Illex illecebrosus* (the short finned squid). Identification was based on fin lengths which ranged from 30.0% to 35.5% of mantle length. These percentages correspond to the range established by Squire (1957). There was evidence of squid in 49.8% of all yellowfin but in only 24.0% of all bluefin. Indication of 571 squid were found in yellowfin constituting a total volume of 3926.1 ml. Evidence of 166 squid with a total volume of 155.4 ml. were found in the bluefin. Squid constituted 26.4% of the volume of the yellowfin diet but only 2.0% of the volume of the bluefin diet (TABLE 1).

The digestion rate of squid in the stomachs of tunas appears to be quite rapid. As a result, the majority of the squid were heavily digested or only evident by disarticulated beaks. This accounts for the relatively large numbers of squid and relatively low volume of food mass. Squid identification (genus and species) was based on whole, intact squid which were occasionally found in the tuna stomachs and an
attempt was also made to identify squid genera based on beak morphology. In stomach samples where only squid beaks were found, counts were based on upper and lower beak component pairs (1 pair counted as 1 squid) or if lone beak components were found, they would indicate one squid (1 unmatched upper beak or 1 unmatched lower beak counted as 1 squid).

**CRUSTACEANS:**

Crustaceans were common in both bluefin and yellowfin stomachs. Yellowfin exhibited the greatest variety with 10 genera represented. These crustaceans ranged in size from small Hyperid sp. amphipods (which most likely were an accidental catch) to a complete Ovalipes sp. crab. The bluefin had evidence of five different genera with amphipods constituting the greatest numbers. Due to the small size of these amphipods it is most likely that they were consumed accidentally while in pursuit of other prey.

Crustaceans constituted 0.2% of the total bluefin diet based on volume (TABLE 1). Many of the crustaceans were very small (5-10 mm) and found singularly or in small numbers in the bluefin stomachs. Their nutritional value appears to be very low, but there may be some as of yet undescribed significance if intentional feeding is occurring. There was one example of an 18 kg. (40 lb.) bluefin that contained approximately 250 amphipods in its stomach. The total displaced volume of these amphipods was only 8.4 ml. It seems unlikely that a large number of organisms such as this would have been consumed accidentally, however they were probably ingested incidentally with other food organisms. This same stomach also contained five Hippocampus erectus, 10 Ammodytes and strands of Zostera. This bluefin was probably
orienting to a seagrass raft which provided the seahorses and a swarm of amphipods which were readily consumed. The seagrass rafts encourage or carry with them a diverse collection of crustaceans. The black isopod, *Idotea baltica*, was commonly found in conjunction with *Zostera* in both bluefin and yellowfin stomachs. The isopod, *I. baltica*, is considered a lower intertidal resident of *Zostera* beds (Gosner 1978). Megalopae were also commonly found in both bluefin and yellowfin.

Another interesting discovery in the stomachs of two bluefins was the presence of *Homarus americanus* (the American lobster). These juvenile specimens were approximately 20 mm in length and were probably accidentally consumed by the bluefin while feeding on *Ammodytes* near the bottom. Yellowfin stomachs contained only examples of pelagic postlarval *H. americanus* which were either taken from the water column or off of seagrass rafts.

The yellowfin stomachs yielded a more diverse collection of crustaceans. This can be attributed to a greater period of time spent by yellowfin, orienting to seagrass rafts. Most of the crustaceans were very small (<15 mm) such as amphipods, mysids, juvenile *Squilla* sp. (mantis shrimp) and juvenile *Acestes* sp. (lucifer shrimp). Their nutritional importance may not be significant when these organisms appear in the stomachs in small numbers, however intentional feeding on these small organisms may suggest some dietary requirement. Yellowfin, as with bluefin, exhibited some evidence of intentional feeding on small crustaceans. A yellowfin weighing 16.6 kg. (37.0 lbs.) contained 33 megalopae. Their total displaced volume equalled only 3.4 ml. This amount of food seems insignificant for a 16.6 kg. fish, however, these megalopae do not appear to be incidentally consumed. This particular
yellowfin's stomach contained the remains of two heavily digested *Peprilus* (displacing 5.0 ml.) and strands of *Zostera* and *Spartina*. Megalopae which occasionally form dense swarms may trigger the feeding response of the tuna especially in areas of low prey density.
NON-FOOD ITEMS:

Many non-food items found in the stomachs of the bluefin and yellowfin tuna (APPENDIX III) are linked to the tuna's orienting behavior to rafts of seagrass and flotsam. Plant material consisted mainly of Zostera marina, a submerged aquatic plant which grows in the high salinities of the lower Chesapeake Bay and the inshore waters of the Atlantic coastline (Hurley 1990). Wave and storm action uproot Zostera along the coast. These plants are then transported offshore by wind and currents forming seagrass rafts and wind rows. Other inshore plant species ingested by the tunas include Ruppia maritima and Spartina alterniflora. On very rare occasions Sargassum sp. was found. Plant material appeared in 22% of all yellowfin and 6% of all bluefin.

Wind gathered flotsam in the form of plastics were also ingested by bluefin and yellowfin tuna usually in conjunction with seagrass. Plastics (APPENDIX III) were found in 12% of all yellowfin and 3% of all bluefin. There never appeared to be any indication of a hindrance to the digestive process caused by the plastics in the stomachs of the tunas. Materials such as plastic braided rope, however, surely pose the threat of intestinal blockages.

Gravel, shell fragments and small shells were found in 3 bluefin tunas. This material was not found in any of the yellowfins examined. The presence of gravel and shells, which could only have been picked up off the seafloor, provides evidence of occasional bottom feeding by bluefins. In a conversation with Capt. Steve Haase of the charter boat Our Dream, it is a common occurrence to find gravel and shell bits while cleaning out the fish storage wells on the boat after unloading a catch.
of bluefins. Capt. Haase stated that this material was regurgitated by the bluefins along with sand lances, *Ammodytes*.

An interesting collection of insects were also found in the tuna stomachs (APPENDIX III). These insects were always found in conjunction with seagrass material and were most likely accidentally consumed by the tunas. The insects represented seven different families (one insect sample from each family listed was found).

A digenetic trematode, *Hirudinella ventricosa* (Overstreet 1978; Eggleston and Bochenek 1989), was present in the stomachs of both the bluefin and yellowfin. This parasitic stomach worm is reported to reach a large size in billfish and other pelagic fishes (Overstreet 1978). The specimens found during this investigation were rather small, the largest being 25 mm long. There did not appear to be any injury or damage caused to the stomachs by these parasites. These worms usually occurred singularly at the posterior end of the tuna stomach. Occasionally two *H. ventricosa* would occur in the same stomach but never more than two. Samples of *H. ventricosa* were found in 15% of the yellowfin and 5% of the bluefin sampled.
COMPARISON OF FOOD

INDEX OF RELATIVE IMPORTANCE (IRI):

The index of relative importance was calculated for the major prey items found in both bluefin and yellowfin stomachs (TABLE 2). Calculations of the IRI values were performed as described by Manooch and Mason (1983).

The IRI values are graphically displayed in FIGURE 3 for the complete diets of the bluefin and yellowfin tuna. In the side by side comparison, the importance of the Ammodytes in the diet becomes evident. In the bluefin tuna, Ammodytes is ranked highest in IRI. Ammodytes constituted 83.47% of total prey numbers and 86.8% of the total prey volume with 66.8% frequency of occurrence (TABLE 2). In the yellowfin, Ammodytes also ranked highest. Ammodytes constituted 59.74% of total prey number, and 55.4% of the prey volume with 41.3% frequency of occurrence (TABLE 2). The prey importance of squid to the yellowfin is evident (FIGURE 3). Squid ranked second based on the IRI. Squid composed 13.57% of total yellowfin prey numbers and 26.4% of yellowfin prey volume with 49.8% frequency of occurrence. In bluefin, squid ranked third in IRI (TABLE 2). Squid constituted only 3.93% of total bluefin prey number and only 2.0% of the bluefin prey volume with a frequency of occurrence of 24.0%.

An examination of the prey items other than Ammodytes was performed to further examine differences in bluefin and yellowfin tuna diets
(FIGURE 4). Once the *Ammodytes* were removed from the bluefin diet, *Peprilus triacanthus* became evident as a secondarily important food source to the bluefin based on its IRI. *Peprilus* represented 8.46% of the total prey volume of the bluefin tuna diet and represented 64% of the volume of prey after *Ammodytes* were removed (FIGURE 5). Squid, unidentifiable fish and *Hippocampus* sp. followed *Peprilus* in order of IRI. In yellowfin diet with the *Ammodytes* removed, squid (*Illex illecebrosus*) became evident as a secondarily important prey based on IRI, followed by *Peprilus*, unidentifiable fish, and crustaceans. *Illex* squid represented 26.46% of the total prey volume of the yellowfin tuna diet and represented 59.2% of the volume of prey after *Ammodytes* were removed (FIGURE 5). The differences which occurred in the secondarily important prey of the bluefin and yellowfin were most likely due to benthic characteristics of tuna feeding locations ("hills", canyons, etc.), water temperatures (depth and strength of thermocline) and varying water depths (FIGURE 6 and TABLE 5). These habitat forming characteristics resulted in fairly well segregated feeding areas for the bluefin and yellowfin tuna. The bluefin tended to be found closer inshore in areas of shallower depths (providing access to the bottom) and cooler waters where there are a greater availability of *Peprilus*. The yellowfin tend to feed farther offshore on the continental shelf and slope in deeper depths and in closer proximity to the warm Gulf Stream currents. In these offshore areas *Illex* squid, are in greater abundance feeding on euphausiids, other squid and small fish (Maurer and Bowman 1985; Zaborski 1980) and are more readily available to the yellowfin.
FIGURE 3
INDEX OF RELATIVE IMPORTANCE (IRI)

BLUEFIN TUNA
(THUNNUS THYNNUS)

YELLOWFIN TUNA
(THUNNUS ALBACARES)

AMMODYTES

OTHERS

AMMODYTES

OTHERS

UNID. FISH
MEGALOPAE
SQUID

OTHERS - PREY ITEMS LESS THAN 2%
FIGURE 4
INDEX OF RELATIVE IMPORTANCE (IRI)
PREY COMPARISON OMITTING AMMODYTES

BLUEFIN TUNA
(THUNNUS THYNNUS)

YELLOWFIN TUNA
(THUNNUS ALBACARES)

SQUID  CRUSTACEANS

OTHERS  UNID.FISH

PEPRILUS

OTHERS - PREY ITEMS LESS THAN 2%
FIGURE 5
PERCENT VOLUME
SECONDARY PREY - AMMODYTES REMOVED

BLUEFIN TUNA
(THUNNUS THYNNUS)

YELLOWFIN TUNA
(THUNNUS ALBACAARES)

OTHERS • PREY ITEMS LESS THAN 2%
Tuna and Billfish Grounds Off Virginia
With Bluefin (B) and Yellowfin (Y) Catches Per Area, 1988-89

1. Jackspot
2. The Fingers
3. Poor Man's Canyon
4. Lumps
5. First Lump
6. Second Lump
7. Rockpile
8. 29 Fathom Lumps
9. 20 Fathom Fingers
10. 21 Mile Hill
11. No Name
12. 26 Mile Hill (Hambone)
13. The Fingers
14. Triangle Wrecks
15. Fishhook
16. Hot Dog
17. Southeast Lumps
18. Horseshoe
19. Boomerang
20. V Buoy
21. 4A Buoy
22. Cigar
23. Honey Hole
24. Washington Canyon
25. Norfolk Canyon
26. 10 Fathom Lump
TABLE 5

NUMBER OF BLUEFIN (BF) / YELLOWFIN (YF) CATCHES PER LOCATION
INCLUDING DEPTH (FA.)

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>BF</th>
<th>YF</th>
<th>DEPTH</th>
<th>LOCATION</th>
<th>BF</th>
<th>YF</th>
<th>DEPTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 MILE HILL</td>
<td>26</td>
<td>0</td>
<td>10</td>
<td>CIGAR</td>
<td>4</td>
<td>76</td>
<td>18</td>
</tr>
<tr>
<td>26 MILE HILL</td>
<td>67</td>
<td>3</td>
<td>10</td>
<td>WASHINGTON CANYON</td>
<td>1</td>
<td>18</td>
<td>100+</td>
</tr>
<tr>
<td>FINGERS</td>
<td>2</td>
<td>43</td>
<td>22</td>
<td>NORFOLK CANYON</td>
<td>8</td>
<td>64</td>
<td>100+</td>
</tr>
<tr>
<td>FISHHOOK</td>
<td>24</td>
<td>0</td>
<td>10</td>
<td>NORTHERN LUMPS</td>
<td>0</td>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td>HOTDOG</td>
<td>69</td>
<td>5</td>
<td>10</td>
<td>POOR MAN'S CANYON</td>
<td>1</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>SE. LUMPS</td>
<td>3</td>
<td>6</td>
<td>10</td>
<td>20 FATHOM FINGERS</td>
<td>7</td>
<td>17</td>
<td>22</td>
</tr>
<tr>
<td>HORSESHOE</td>
<td>6</td>
<td>0</td>
<td>9</td>
<td>29 FATHOM FINGERS</td>
<td>2</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>40 FATHOM FINGERS</td>
<td>0</td>
<td>4</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BLUEFIN (BF) N = 220
YELLOWFIN (YF) N = 240 (19 YF SAMPLES HAD UNSPECIFIED LOCATIONS)
SPEARMAN RANK CORRELATION COEFFICIENTS:

Differences between the bluefin and yellowfin diets were evaluated using the Spearman rank correlation coefficients (Fritz 1974) applied to the IRI values of the total diet (TABLE 7). The null hypothesis ($H_0$: the bluefin and yellowfin diets are the same.) was tested at the 0.05 level. Coefficients were assigned to all IRI values of TABLE 2 with the exception of Monocanthurus sp. and Pliacanthus sp. These two prey items were eliminated due to their very low IRI values. The result of the analysis yielded no significant difference in the diets between the two species of tuna. This was mainly due to the high IRI values of the Ammodytes for both bluefin and yellowfin. The bluefin and yellowfin diets differed significantly ($0.05 > P > 0.02$) when Ammodytes IRI values were removed and secondary prey IRI's were compared.

Diet comparisons were also performed using the Spearman Rank Correlation Coefficients for three feeding locations of both bluefin and yellowfin tuna (TABLE 7). Feeding of the two species of tuna was not concurrent. Temporal differences as much as a month occurred. This may have affected prey availability at the feeding sites which would greatly affect the tuna diets. These areas were the Norfolk Canyon, the 20 Fathom Fingers and the Hotdog. At the Norfolk Canyon, the bluefin and yellowfin diets were significantly different at the 0.05 level. In the bluefin, unidentifiable fish ranked highest followed by Ammodytes. Unidentifiable fish, Ammodytes, Peprilus and squid were all closely ranked in IRI value of the bluefin in this area. In yellowfin, Ammodytes ranked highest followed by squid. The Ammodytes and unidentifiable fish constituted the greatest proportion of the bluefin and yellowfin diet with squid also highly ranked. At the 20 Fathom
Fingers the bluefin and yellowfin diets were statistically indistinguishable. *Ammodytes* ranked highest followed by squid for both species. At the Hotdog, diets proved to be significantly different. The bluefin at the Hotdog fed nearly exclusively on *Ammodytes*. The yellowfin diet consisted mostly of *Ammodytes* but also many megalopae, unidentifiable fish and squid. The diet comparison at the Hotdog was based on 69 bluefin samples and only 5 yellowfin samples.
TABLE 6

SPEARMAN RANK CORRELATION
BLUEFIN VS. YELLOWFIN DIET COMPARISONS

\[ H_0: \text{BLUEFIN AND YELLOWFIN DIETS NOT SIGNIFICANTLY DIFFERENT} \]
\[ \text{SIGNIFICANCE LEVEL: } 0.05 \]

TOTAL DIETS: ALL AREAS POOLED (N = 220 BF; 259 YF)
\[ r_s = 0.619 \]
\[ r_s(.05)(2)(8) = 0.738 \]
\[ P > 0.05 \]
CONCLUSION: NO SIGNIFICANT DIFFERENCE

NORFOLK CANYON: (N = 8 BF; 64 YF)
\[ r_s = 0.734 \]
\[ r_s(.05)(2)(9) = 0.70 \]
\[ 0.05 > P > 0.02 \]
CONCLUSION: DIETS SIGNIFICANTLY DIFFERENT

20 FATHOM FINGERS: (N = 7 BF; 17 YF)
\[ r_s = 0.669 \]
\[ r_s(.05)(2)(8) = 0.738 \]
\[ P > 0.05 \]
CONCLUSION: NO SIGNIFICANT DIFFERENCE

HOTDOG: (N = 69 BF; 5 YF)
\[ r_s = 0.698 \]
\[ r_s(.05)(2)(10) = 0.648 \]
\[ 0.05 > P > 0.02 \]
CONCLUSION: DIETS SIGNIFICANTLY DIFFERENT
Mann-Whitney Test:

Intra-specific diet comparisons were performed for both bluefin and yellowfin tuna using the Mann-Whitney test to examine any differences between tuna feeding in the northern regions versus feeding in the more southern regions of the Virginia waters. This test was conducted to examine any feeding differences possibly attributed to the impact of the Chesapeake Bay plume which, according to Roffer (1987), may effect tuna prey availability. The diets of bluefin caught at the 21 Mile Hill and the 26 Mile Hill were pooled. (n=93 samples) to represent feeding in the northern regions and were compared to the pooled data from bluefin caught at the Hotdog and Fishhook (n=93 samples) to represent feeding in the southern region. Bluefin diets from these two regions showed no significant difference at the 0.05 level. The diets of yellowfin caught at the 20 Fathom Fingers (n=17 samples) representing the northern region were compared to yellowfin caught at the Cigar (n=76 samples) in the southern region. This comparison also revealed no significant difference between the yellowfin diets at the 0.05 level. The results of these comparisons give no indication of the Chesapeake Bay water plume effecting tuna prey availability or prey distribution.
The data collected during this study shows the importance of *Ammodytes* in the feeding of bluefin and yellowfin tuna off the coast of Virginia. *Ammodytes* are described as planktivorous, forming large daytime schools of up to tens of thousands of individuals (Auster and Stewart 1986; Meyer, et al. 1979), and are a major link between the zooplankton and commercially important fish such as the tuna (Auster and Stewart 1986; Smigielski, et al. 1984; Scott 1968; Meyer et al. 1979). *Ammodytes* occur throughout the water column over well oxygenated substrates of sand, sand with crushed shell and fine gravel into which they burrow (Meyer, et al. 1979). Sand with crushed shell and fine gravel is typical of what is found at the hills and lumps, the tuna feeding/fishing grounds. As a result, large numbers of *Ammodytes* are also found at the hills and lumps, attracting bluefin and yellowfin for feeding. Fine gravel and shells were occasionally found in the stomachs of some bluefin.

It is believed that two species of the genus *Ammodytes* which exist in the Mid-Atlantic Bight, *A. americanus* and *A. dubius* (Richards 1982; Scott 1968; Auster and Stewart 1986). The identification of these two species is usually distinguished by their distributional range, length, and meristic and morphometric characters. *Ammodytes americanus*, usually considered the inshore sand lance, have low to intermediate meristic counts while *A. dubius*, considered the offshore sand lance, have
intermediate to high counts (Scott 1968; Auster and Stewart 1986; Nizinski, et al. 1990). Much confusion has arisen in separating these two species mainly due to considerable overlap of the meristic and morphometric characteristics.

An examination was performed on the meristics of 18 Ammodytes taken from the stomachs of the tunas. Data indicated yellowfin tuna were feeding on larger Ammodytes than bluefin (FIGURE 7) suggesting the presence of A. americanus and A. dubius existing off the coast of Virginia. A meristic examination was performed on six specimens of Ammodytes taken from bluefin stomachs, six taken from yellowfin and six taken from indistinguishable bluefin and yellowfin tuna stomachs. The samples were cleared and stained in preparation for meristic analysis using methods described by Simons and Van Horn (1971) and Dingerkus and Uhler (1977) in Pothoff (1984). Meristic counts were made of the dorsal fin rays, anal fin rays and vertebral column (TABLE 7).

The results of the Ammodytes meristic analysis showed no variation between tuna species. The dorsal fin rays averaged 62.1 (std. dev. ±1.0); anal fin rays averaged 30.4 (std. dev. ±1.8); vertebral counts averaged 71.5 (std. dev. ±1.0). The low standard deviations indicated that there was only one species of Ammodytes found in the stomach contents of the tunas examined. After comparison to the meristic results found in the Ammodytes literature (TABLE 8), the meristic analysis yielded counts in the high end of the meristics range. These counts most closely compare to A. dubius.

Ammodytes length data (total length) from tuna stomachs was recorded and analyzed. A total of 3604 Ammodytes were identified in the tuna stomachs but only 935 were in good enough condition to record
lengths. Accompanying the *Ammodytes* length data was also information on
date and location of tuna capture, consuming tuna length and tuna
species.
FIGURE 7
AMMODYTES LENGTH FREQUENCIES
STOMACH CONTENT ANALYSIS

NUMBER

LENGTH (CM.)

BLUEFIN  YELLOWFIN
TABLE 7

Meristic Composition of Sand Lance (Ammodytes sp.) Collected From Stomach Contents of Bluefin Tuna (Thunnus thynnus) and Yellowfin Tuna (Thunnus albacares) Off the Coast of Virginia.

Ammodytes sp. (collected from bluefin stomachs):

<table>
<thead>
<tr>
<th>Length (cm.)</th>
<th>Dorsal Fin Rays</th>
<th>Anal Fin Rays</th>
<th>Vertebrae</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) 9.2</td>
<td>63</td>
<td>32</td>
<td>72 (45+27)</td>
</tr>
<tr>
<td>2) 9.1</td>
<td>61</td>
<td>31</td>
<td>72 (46+26)</td>
</tr>
<tr>
<td>3) 10.8</td>
<td>62</td>
<td>28</td>
<td>72 (46+26)</td>
</tr>
<tr>
<td>4) 10.1</td>
<td>62</td>
<td>28</td>
<td>72 (46+26)</td>
</tr>
<tr>
<td>5) 9.2</td>
<td>63</td>
<td>32</td>
<td>72 (46+26)</td>
</tr>
<tr>
<td>6) 9.8</td>
<td>61</td>
<td>29</td>
<td>72 (48+24)</td>
</tr>
</tbody>
</table>

Ammodytes sp. (collected from yellowfin stomachs):

<table>
<thead>
<tr>
<th>Length (cm.)</th>
<th>Dorsal Fin Rays</th>
<th>Anal Fin Rays</th>
<th>Vertebrae</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) 10.8</td>
<td>63</td>
<td>32</td>
<td>72 (46+26)</td>
</tr>
<tr>
<td>2) 10.0</td>
<td>64</td>
<td>31</td>
<td>74 (48+26)</td>
</tr>
<tr>
<td>3) 14.9</td>
<td>61</td>
<td>31</td>
<td>72 (47+25)</td>
</tr>
<tr>
<td>4) 12.3</td>
<td>62</td>
<td>29</td>
<td>70 (45+25)</td>
</tr>
<tr>
<td>5) 12.5</td>
<td>63</td>
<td>30</td>
<td>72 (46+26)</td>
</tr>
<tr>
<td>6) 14.0</td>
<td>62</td>
<td>30</td>
<td>71 (45+26)</td>
</tr>
</tbody>
</table>

Ammodytes sp. (unspecified bluefin and yellowfin stomachs):

<table>
<thead>
<tr>
<th>Length (cm.)</th>
<th>Dorsal Fin Rays</th>
<th>Anal Fin Rays</th>
<th>Vertebrae</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) 12.7</td>
<td>62</td>
<td>31</td>
<td>71 (47+24)</td>
</tr>
<tr>
<td>2) 12.2</td>
<td>63</td>
<td>30</td>
<td>71 (47+24)</td>
</tr>
<tr>
<td>3) 11.8</td>
<td>62</td>
<td>31</td>
<td>71 (45+26)</td>
</tr>
<tr>
<td>4) 9.8</td>
<td>60</td>
<td>29</td>
<td>69 (45+24)</td>
</tr>
<tr>
<td>5) 14.7</td>
<td>61</td>
<td>31</td>
<td>71 (46+25)</td>
</tr>
<tr>
<td>6) 9.0</td>
<td>63</td>
<td>31</td>
<td>71 (47+24)</td>
</tr>
</tbody>
</table>

Mean (Std.Dev.): 62.1(+1.0)  30.4(+1.8)  71.5(+1.0)
n=18
TABLE 8

Meristic values of Northwest Atlantic species of *Ammodytes*
(adapted from Auster and Stewart 1986)

<table>
<thead>
<tr>
<th>Species</th>
<th>Vertebrae</th>
<th>Dorsal fin</th>
<th>Anal fin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Range</td>
<td>Range</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------</td>
<td>------------</td>
<td>----------</td>
</tr>
<tr>
<td><em>Ammodytes americanus</em> (Backus 1957) Labrador</td>
<td>62-69</td>
<td>56-60</td>
<td>28-31</td>
</tr>
<tr>
<td>A. <em>americanus</em> (Meyer et al. 1979) Stellwagen Bank, Cape Cod</td>
<td>67-72</td>
<td>60-63</td>
<td>30-31</td>
</tr>
<tr>
<td>A. <em>americanus</em> (Winters and Dalley 1988) Labrador</td>
<td>63-72</td>
<td>51-61</td>
<td>26-34</td>
</tr>
<tr>
<td>A. <em>americanus</em> (Nizinski et al. 1990) Labrador to Delaware</td>
<td>62-70</td>
<td>52-61</td>
<td>26-33</td>
</tr>
<tr>
<td>A. <em>dubius</em> (Leim and Scott 1966) East coast of Canada</td>
<td>71-75</td>
<td>62-68</td>
<td>30-35</td>
</tr>
<tr>
<td>A. <em>dubius</em> (Winters and Dalley 1988) Labrador</td>
<td>70-78</td>
<td>60-68</td>
<td>30-36</td>
</tr>
</tbody>
</table>

The Ammodytes data was compared to data from the U.S. National Marine Fisheries Service (NMFS) Groundfish Trawl Survey (described in Grosslein 1969) conducted in the Mid-Atlantic Bight. Samples from the NMFS survey were collected during March and September 1988 and 1989. Sixteen sites were sampled in 1988 and 20 sites were sampled in 1989 between $38^\circ$N and $36^\circ$N latitude. Catch and length data (total length) on 6715 Ammodytes were recorded during the 1988 cruise and 295 Ammodytes were collected in 1989. Samples were collected using a "36 Yankee" trawl with a 1.25 cm. (0.5 in.) stretched mesh liner in the codend and upper belly.

The examination of the Ammodytes length data was designed to determine size selectivity by the tunas and to determine any temporal and spatial Ammodytes size differences. Of the Ammodytes collected from the bluefin tuna, 416 were measurable (digestion had not effected the length of the specimen). Ammodytes lengths from the bluefin ranged from 7.2 cm. to 19.1 cm. (mean 9.8 cm., std. dev. 1.480). Measurable Ammodytes collected from yellowfin tuna totaled 519 individuals. Ammodytes lengths from the yellowfin ranged from 7.7 cm. to 20.7 cm. (mean 12.4 cm., std. dev. 2.019).

Ammodytes length frequencies from the NMFS trawl survey and the stomachs of bluefin and yellowfin tunas were plotted for March, June, July, August and September 1988 (FIGURES 8-10). Data from the NMFS trawl survey indicated two year classes were present during March 1988 (FIGURE 8). The March NMFS data indicated a 1+ year class (11-15 cm.) and a 2+ year class (17-19 cm.). The 0-1 year class of Ammodytes does not appear in the NMFS data. This is most likely due to gear size selectivity (1.25 cm. stretched mesh liner) which allows the smallest
Ammodytes to escape capture. Ammodytes collected during June 1988 (FIGURE 8) from the stomachs of tunas showed evidence of heavy feeding, especially by the bluefin, on the 0-1 year class (7-11 cm.) which were spawned during the previous December and January. The July 1988 data (FIGURE 9) again showed heavy tuna feeding on the 0-1 year class and the 1+ year class of Ammodytes. There was also some indication of yellowfin consuming some Ammodytes of the 2+ year class. The June and July data also provided evidence of yellowfin tuna consuming larger Ammodytes than bluefin tuna. The bluefin tuna fed heaviest on the 0-1 year class Ammodytes and the yellowfin fed heaviest on the 1+ year class.
FIGURE 8
AMMODYTES LENGTH FREQUENCIES
MARCH AND JUNE 1988

PERCENT

LENGTH (CM.)

BLUEFIN  YELLOWFIN  NMFS TRAWL

NMFS TRAWL DATA FROM MARCH 1988
FIGURE 9
AMMODYTES LENGTH FREQUENCIES
JULY 1988

PERCENT

LENGTH (CM.)

BLUEFIN  YELLOWFIN
August 1988 the bluefin tuna had moved out of the Virginia waters. The Ammodytes samples from August (FIGURE 10) were collected solely from yellowfin stomachs. These data were very similar to the July data. Ammodytes of the 0-1 year class and the 1+ year class were strongly represented as well as some indication of feeding on the 2+ year class of Ammodytes. The NMFS trawl data from September 1988 (FIGURE 10) revealed the presence of the 0-1 year class which had grown to lengths 10-15 cm. These were the Ammodytes which were apparently not catchable by the trawl in March of that year. The 1+ year class of Ammodytes was evident in the 16-17 cm. range. The NMFS data from September 1988 showed no evidence of the 2 year class of Ammodytes which was indicated in the NMFS data from March 1988.

The 0-1+ year class of Ammodytes preyed upon by the bluefin and yellowfin tuna are considered juveniles (Scott 1968). Scott (1968) suggested that Ammodytes are not sexually mature until their second year at which time they attain a length of approximately 20 cm. The high quantities of juvenile Ammodytes and juvenile fish of other species may indicate a strong selectivity for juvenile fish of all species by the tunas.

The examination of the Ammodytes revealed some interesting results. Many of the Ammodytes were very heavily digested to the point of being nearly unidentifiable upon removal from the tuna stomachs. Identification of these Ammodytes was performed through the recognition of their digestive tracts. The elongated stomach, duodenum and intestines of the Ammodytes were highly resistant to the gastric action of the tuna stomachs. Upon dissection of a complete stomach from an intact Ammodytes and comparison to the unidentified free stomachs found
in the tuna stomachs, it was confirmed that indeed these free stomachs were from *Ammodytes*. Counting the distinct
FIGURE 10
AMMODYTES LENGTH FREQUENCIES
AUGUST AND SEPTEMBER 1988

LENGTH (CM.)

PERCENT

NMFS TRAWL DATA SEPTEMBER 1988

YELLOWFIN NMFS TRAWL
free stomachs of the *Ammodytes* proved to be a useful tool in obtaining an accurate count of otherwise unidentifiable *Ammodytes*. This technique was also applied to the unique stomach characteristics of *Peprius triacanthus* (the butterfish).

Many of the complete *Ammodytes* specimens removed from tuna stomachs had full stomachs of their own. Examination of the stomach contents of the *Ammodytes* revealed many were gorged with copepods (Order: Calanoida) and amphipods (*Hyperia* sp.). The presence of these zooplankton in the stomachs of the *Ammodytes* clearly shows the importance of *Ammodytes* as a major link between the plankton and top of the food chain predators such as tunas.
SEA SURFACE TEMPERATURE DATA

Data on sea surface temperatures at location of tuna capture was provided for 167 bluefin and 219 yellowfin (FIGURE 11). These temperatures were measured by charter boat captains whose boats were equipped with temperature gauges. The charter captain or mate provided the temperature data during the post-trip dockside interview.

Sea surface temperatures at the time of bluefin capture ranged from 17.8°C to 27.2°C (64°F to 81°F). The greatest numbers of bluefin were caught in water temperatures between 20.0°C to 23.3°C (68°F to 74°F). This range closely matches the "preferred habitat" temperature range of 19°C to 23°C proposed by Roffer (1987).

Sea surface temperatures at time of yellowfin capture ranged from 20.0°C to 27.8°C (68°F to 82°F). Yellowfin concentrations were greatest at temperatures between 22.2°C to 23.3°C (72°F to 74°F) and 26.1°C to 27.8°C (79°F to 82°F).

The sea surface temperature ranges recorded for bluefin and yellowfin tuna exhibited considerable overlap. This overlap may not be indicative of the water temperatures in the lower water column where the bluefin are located. The first seasonal appearance of the bluefin occurred at the Hotdog in early June, 1988 and 1989. The sea surface temperature at the Hotdog at that time was 19.4°C to 20.0°C (67°F to 68°F) in 1988 and 22.2°C to 22.8°C (72°F to 73°F) in 1989. The yellowfin tuna made their first seasonal appearance at the end of June.
at the Norfolk Canyon and on the first of July at the Cigar. The sea surface temperatures at these areas ranged from 20.0°C to 21.1°C (68°F to 70°F) in 1988 and approximately 24.4°C (76°F) in 1989. The closeness and overlap of sea surface temperatures at the time of bluefin and yellowfin appearances suggested that temperature alone may not be the only factor governing their initial movements into the waters off Virginia.
FIGURE 11
TUNA CATCH DATA
BY SEA SURFACE TEMPERATURE 1988-1989

(SEA SURFACE TEMP. (°C))

# OF TUNA

(BLUEFIN = 167  YELLOWFIN = 219)

(BLUEFIN  ■  167  YELLOWFIN  ■  219)
SUMMARY AND CONCLUSION

The diets of the bluefin and yellowfin tuna can be grouped into three basic categories: fish, squid and crustaceans (Hida 1973; Ronquillo 1953; Dragovich 1970a). Fish composed the largest portion of the bluefin and yellowfin diets by number, volume and frequency of occurrence. Similar results were also found by Dragovich 1970a, Manooch and Mason 1983, Hida 1973, Ronquillo 1953, and Reintjes and King 1953. Squid (Illex illecebrosus) were consumed by both bluefin and yellowfin, with yellowfin having a greater percent of frequency of occurrence (yellowfin 49.8% versus bluefin 24.0% frequency of occurrence). Crustaceans such as amphipods (Hyperid sp.), isopods (Idotea baltica) and crab megalopae were commonly found in the stomachs of both tuna species but made negligible contribution to total biomass. Yellowfin exhibited the greatest variety of crustaceans (10 genera versus 5 genera found in bluefin). Larval macrozooplankton constituted the greatest numbers of crustaceans in both bluefin and yellowfin diets. Similar findings were reported in Dragovich (1970b).

Comparisons of the bluefin and yellowfin diets were performed based on the index of relative importance (IRI) of major prey items. The complete diets of the bluefin and yellowfin were evaluated based on the IRI's using the Spearman rank correlation coefficients. The results of this analysis yielded no significant differences in the diets of the two species of tuna at the 0.05 level. This result was not surprising due
to the high quantities of *Ammodytes* consumed by both bluefin and yellowfin tuna. *Ammodytes*, *Peprilus* and *Illex* constituted the greatest proportion of the diets of both bluefin and yellowfin tuna. The combined numbers and volumes of *Ammodytes*, *Peprilus* and *Illex* amounted to 92% by number and 95% by volume of the total bluefin diet versus 92% by number and 85% by volume in the total yellowfin diet.

An examination of prey items other than *Ammodytes* was performed revealing only minor differences in secondary food items. The butterfish, *Peprilus triacanthus* ranked second in the bluefin diet based on the index of relative importance (IRI) followed by squid, unidentifiable fish and crustaceans. For yellowfin, squid ranked second in IRI followed by *Peprilus*, unidentifiable fish and crustaceans.

Spatial diet comparisons were performed for three common feeding locations of bluefin and yellowfin tuna. These areas were the Norfolk Canyon, the 20 Fathom Fingers and the Hotdog. Feeding of the bluefin and yellowfin in those areas was not concurrent. Temporal differences as much as one month occurred. The Norfolk Canyon showed significant differences in the bluefin and yellowfin diets. In the bluefin from the Norfolk Canyon, unidentifiable fish ranked highest in IRI followed by *Ammodytes*, *Peprilus* and squid. In Norfolk Canyon yellowfin, *Ammodytes* ranked highest in IRI followed by squid. At the 20 Fathom Fingers bluefin and yellowfin diets showed no significant difference. *Ammodytes* constituted the greatest number, volume and frequency of occurrence in both bluefin and yellowfin. At the Hotdog, bluefin and yellowfin diets showed significant differences. The bluefin diet consisted almost exclusively of *Ammodytes*. The yellowfin diet was mostly *Ammodytes*, but many megalopae, unspecified teleosts and squid were also present.
Intra-specific diet comparisons of bluefin and yellowfin tunas were performed using the Mann-Whitney Test. This test examined tunas feeding in the northern end of their Virginia range versus feeding in more southern regions of the Virginia waters. Diets of bluefins caught at the 21 Mile Hill and the 26 Mile Hill were pooled (northern region) and compared to diets of bluefin caught at the Hotdog and the Fishhook (southern region). No significant differences appeared due to the high consumption of Ammodytes in all of the areas. The diet of yellowfin tuna caught at the 20 Fathom Fingers (northern region) were compared to yellowfin caught at the Cigar (southern region). This comparison also yielded no significant differences. The major prey items, in particular Ammodytes, are found throughout the entire range of the tunas off Virginia. Ammodytes are also found in great abundance throughout the entire water column particularly at the hills and lumps. The great abundance of the common prey species which were available to both bluefin and yellowfin tuna accounted for their similar diets.

The results of this study show the great importance of the sand lance, Ammodytes as a major prey source for both bluefin and yellowfin tuna as they occurred off Virginia. The results of meristic analysis revealed that the tunas were likely feeding on one species of sand lance, Ammodytes dubius. Ammodytes lengths consumed by bluefin ranged from 7.2 cm. to 19.1 cm. (mean 9.8 cm.). Ammodytes lengths consumed by yellowfin ranged from 7.7 cm. to 20.1 cm. (mean 12.4 cm.). Ammodytes length differences can be attributed to temporal differences in bluefin and yellowfin feeding off the coast of Virginia. The difference in mean length of Ammodytes found between bluefin and yellowfin closely
corresponds to the growth rate described by Scott (1968) for *A. dubius* over a period of 1+ months in *A. dubius* 9 to 13 cm in length.

The fish prey consumed by bluefin and yellowfin tuna was composed almost entirely of small juvenile schooling fish. Of the 21 fish families consumed by the yellowfin, only 2 families had adult representatives. The bluefin diet was represented by only 8 fish families with juvenile *Ammodytes* constituting the greatest quantities by number, volume and frequency of occurrence. The predominance of small, juvenile fish may indicate size selectivity of prey by the tunas.

The presence of plant material, mainly *Zostera*, in the stomachs of the bluefin and yellowfin tuna provided evidence of tuna orienting to and feeding in relation to floating rafts of seagrass. Plant material appeared in 22% of all yellowfin and 3% of all bluefin. This suggested yellowfin tend to orient and feed near rafts of seagrass more frequently than bluefin.

Incidental consumption of non-food items such as plastics and insects was evident. Wind blown flotsam and debris accumulates in the floating seagrasses and was likely consumed accidentally by tunas. Plastics were found in 12% of all yellowfin due to their frequent association with the seagrass rafts while only 3% of all bluefin contained plastics. A small collection of insects were also incidentally consumed by the tunas while feeding in relation to seagrasses.

Sea surface water temperatures at time of tuna capture were recorded. Bluefin tuna were caught in temperatures ranging from 17.8°C to 27.2°C. Yellowfin tuna were caught in temperatures ranging from 20.0°C to 27.8°C. Despite the overlap in surface temperature ranges,
lower water column temperatures may be quite different at the time of capture, this may be partially responsibly for bluefin and yellowfin segregation in their spatial and temporal appearance off Virginia.

The results of this study provide evidence of bluefin and yellowfin tuna feeding in distinctly different marine habitats. These habitats are very similar to those described by Nakamura (1969) and are responsible for species segregation. The yellowfin tuna are found in areas with warmer sea surface temperatures and areas of greater prey diversity. The warmer sea surface temperatures result in the development of a strong thermocline which restricts yellowfin to the upper water column. Movements below the thermocline are only possible for short periods of time (Holland, et al. 1990) due to the cold water temperatures and low concentrations of oxygen (Collette and Nauen 1983). Yellowfin feeding in the upper water column is evident by 22% of all yellowfin containing floating plant material and no evidence of any benthic prey, gravel, sand or shell fragments in their stomachs. The great diversity of prey items in particular, juvenile fish, may be associated with feeding in relation to upwelling zones near thermal fronts (Laurs, et. al. 1984; Laurs and Lynn 1977). Bluefin tuna occur in a habitat characterized by cooler water temperatures, a shallower thermocline and a lack of thermal fronts. Bluefin feeding most frequently occurs in the lower water column. This behavior is evident in the bluefin stomach contents by a low occurrence of floating plant material (3% frequency of occurrence), the occurrence of gravel, sand and shell fragments and the occurrence of benthic and lower water column prey (Homarus americanus, Lophius sp. and Peprilus triacanthus). This behavior is consistent with Magnuson (1963) who attracted bluefin to the
surface waters to feed from below a thermocline in the North Sea where water temperatures were 6° to 8°C. Low prey diversity indicates bluefin rarely feed at upwelling zones associated with thermal fronts.

The large numbers of Ammodytes which inhabited the continental shelf off the coast of Virginia, provided a primary prey source for both the bluefin and yellowfin tuna. The great importance of the Ammodytes to the feeding of the juvenile tunas, should provide an interesting topic for future research. Topics for future research could involve how fluctuations in Ammodytes population densities may effect the feeding patterns, diet characteristics and numbers of juvenile tunas. Another question which arises is how diet characteristics will be effected during years of high populations of Peprilus or Illex squid. It would also be interesting to track bluefin and yellowfin movements through the use of sonic tracking devices as the tunas occur off the coast of Virginia. All of these suggested topics may provide insights into bluefin and yellowfin behavior and movements which could prove useful in tuna management and conservation.
APPENDIX I

PREY SPECIES LIST

YELLOWFIN TUNA (Thunnus albacares):

FISH:

Family Acanthuridae:
  * Acanthurus sp. (surgeonfish - juvenile)

Family Ammodytidae:
  Ammodytes sp. (sandlance)

Family Argentinidae:
  Argentine silus (Atlantic argentine - juvenile)

Family Balistidae:
  Monocanthurus hispidus (planehead filefish - juvenile)

Family Belonidae:
  Strongylura sp. (needlefish - juvenile)

Family Bramidae:
  Brama brama (Atlantic pomfret - juvenile)

Family Carangidae:
  * Selene vomer (lookdown - juvenile)
    Decapterus punctatus (round scad - juvenile)

Family Chaetodontidae:
  * Chaetodon sp. (butterflyfish - prejuvenile)

Family Clupeidae:
  Etrumeus teres (round herring - juvenile)

Family Coryphaenidae:
  Coryphaena hippurus (dolphin - juvenile)

Family Dactylopteridae:
  Dactylopterus volitans (flying gunard - juvenile)

Family Diodontidae:
  Diodon hystrix (porcupinefish - juvenile)

Family Gadidae:
  Merluccius bilinearis (silver hake - juvenile)
Family Lophiidae:
   Lophius americanus (goosefish - prejuvenile)

Family Ostraciidae:
   Lactophrys trigonus (trunkfish - juvenile)

Family Priacanthidae:
   * Priacanthus cruentatus (glasseye snapper - juvenile)
   * Priacanthus sp. (bigeye - juvenile)

Family Scombridae:
   Scomber sp. (mackerel - juvenile)
   Thunnus thynnus (bluefin tuna - juvenile)

Family Stromateidae:
   Pepriulus triacanthus (butterfish - juvenile)

Family Syngnathidae:
   Hippocampus erectus (lined seahorse)
   Syngnathus sp. (pipefish)

Family Tetradontidae:
   Spheroides sp. (puffer - juvenile)

Family Trichiuiridae:
   Trichiurus lepturus (Atlantic cutlassfish - juvenile)

CEPHALOPODS:
   Illex illecebrosum (boreal squid)

CRUSTACEANS:
   Homarus americanus (American lobster - post larval)
   Ocypode quadrata (ghost crab - megalopae)
   Portunus sp. (portunid crab - megalopae)
   Portunus sp. (portunid crab - juvenile)
   Idotea baltica (black isopod)
   Hyperia sp. (hyperid amphipod)
   Ovalipes stephensoni (ovalipes crab)
   Cancer irroratus (cancer crab)
   Squilla empusa (mantis shrimp)
   Acetes americanus (lucifer shrimp)
   Neomysis americana (mysid)

TUNICATES:
   Salpa sp. (salp)

* Identified by clearing and staining technique.
APPENDIX II

PREY SPECIES LIST

BLUEFIN TUNA (Thunnus thynnus):

FISH:
Family Ammodytidae:
   Ammodytes sp. (sandlance)

Family Balistidae:
   Monocanthurus hispidus (planehead filefish - juvenile)

Family Lophiidae:
   Lophius americanus (goosefish - prejuvenile)

Family Priacanthidae:
   * Priacanthus crucenatus (glasseye snapper - juvenile)
   * Pristigenys alta (short bigeye - juvenile)

Family Scombridae:
   * Scomberomorus regalis (cero mackerel - juvenile)

Family Stomateidae:
   Peprius triacanthus (butterfish - juvenile)

Family Syngnathidae:
   Hippocampus erectus (lined seahorse)

Family Trichiuridae:
   Trichiurus lepturus (Atlantic cutlassfish - juvenile)

CEPHALOPODS:
   Illex illecebrus (boreal squid)

CRUSTACEANS:
   Homarus americanus (American lobster - juvenile)
   Homarus americanus (American lobster - post larval)
   Ocypode quadrata (ghost crab - megalopae)
   Idotea baltica (black isopod)
   Hyperia sp. (hyperid amphipod)

* Identified by clearing and staining technique.
APPENDIX III

NON-PREY ITEMS REPRESENTED IN TUNA STOMACH CONTENTS

INSECT FAMILIES: (Each family represented by a single example.)

Order Orthoptera - Grasshoppers, katydids, crickets, etc.
   Family Acrididae - Short-horned grasshoppers (locusts)
Order Hymenoptera - Wasps, ants, and bees
   Family Ichneumonidae - Ichneumon wasps (parasitic)
Order Diptera - Flies
   Family Tipulidae - Crane flies
   Family Anthomyiidae - Dung flies
Order Coleoptera - Beetles and weevils
   Family Curculionidae - Snout beetles (weevils)
   Family Histeridae - Hister beetles
   Family Carabidae - Ground beetles

PLANTS:

Zostera marina
Ruppia maritima
Spartina alterniflora
Sargassum sp.

PLASTICS:

Plastic rope (1/8" & 1/4" dia.)
   Colors: yellow, grey, orange
Cellophane cassette tape wrapper
   Colors: orange, white, yellow, clear
Plastic bag material
   Colors: white, green, blue, black, clear, grey
Rubber band
   Color: brown
Balloon - knotted end only
   Color: yellow
Monofilament fishing line
   Colors: black, yellow, clear, orange

* Insect identifications performed with the assistance of
  Dr. Norman J. Fashing, Professor of Biology - College of William
  and Mary.

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