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# Diet Composition of Young-of-The-Year Bluefish, Pomatomus saltatrix, in the Lower Chesapeake Bay and Virginia's Coastal Ocean

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# DIET COMPOSITION OF YOUNG-OF-THE-YEAR BLUEFISH, *POMATOMUS SALTATRIX*, IN THE LOWER CHESAPEAKE BAY AND VIRGINIA'S COASTAL OCEAN

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# ABSTRACT

Although the young-of-the-year (YOY) bluefish, *Pomatomus saltatrix,* diet has been described a number of times in the past, there is no information from the Lower Chesapeake Bay and Virginia's coastal ocean. Age-0 bluefish were therefore collected from the Lower Bay and coastal ocean in the summers of 1999 and 2000 for gut content analysis. The main objectives of this project were to 1) provide a general diet description 2) identify the size at which these fish became mainly piscivorous and 3) describe spatial, inter-annual and intra-annual variations in the diet.

Small pelagic and littoral schooling fishes, mostly bay anchovy (*Anchoa mitchilli*) and Atlantic silverside (*Menidia menidia*), were the main prey of age-0 bluefish in this region. Striped anchovy (*Anchoa hepsetus*) and Atlantic menhaden (*Brevoortia tyrannus*) were of secondary importance. Invertebrates were a minor component of the diet and were mainly represented by portunid crab megalope (*Callinectes spp.*) and sand shrimp (*Crangon septemspinossa*). Age-0 bluefish appeared to be feeding on the most abundant prey available in the Lower Bay and coastal ocean at this time, but their diet may have also reflected size selectivity for small prey.

YOY bluefish were mainly piscivorous throughout the size range collected (33 mm fork length to 290 mm fork length). The smallest size corresponds to the size at which these fish recruit to the Chesapeake region and the largest to the size of the spring-spawn fish when they begin their southerly fall migration. Since bluefish may grow larger and have higher survival probabilities in nursery areas where they feed mainly on fish, further study quantifying this region's contribution to the US Atlantic Coast stock is warranted.

The diet of age-0 bluefish collected from Virginia's coastal ocean differed from that of fish collected in the Lower Chesapeake Bay, and the diet in each of these areas varied by month. The diet in 1999 was not significantly different from that in 2000. In the coastal ocean, the Atlantic silverside was the main prey in the late spring and early summer, while the bay and striped anchovies were the dominant prey types from mid summer to autumn. Portunid crab megalope and sand shrimp composed a substantial portion of the diet in mid summer. The bluefish may have shifted from Atlantic silverside to the anchovies and invertebrates as the young of the latter recruited to this area in mid summer.

In the Lower Bay, Atlantic silverside was again the dominant prey type in the late spring and early summer and the anchovies were the main prey from mid summer to fall. Atlantic menhaden were fairly important in the Lower Bay diet from mid summer to fall as well, and bluefish consumed the YOY of the economically valuable striped bass (*Morone saxatilis*) in June. Although the Atlantic menhaden was important in the general diet description, they were only found in the Lower Bay diet. The reason for their absence from the coastal ocean diet is unknown. While YOY bluefish do consume age-0 striped bass in this region, their impact on striped bass recruitment due to direct predation is probably minimal, since they only accounted for a minor portion of the diet.

# DIET COMPOSITION OF YOUNG-OF-THE-YEAR BLUEFISH, *POMATOMUS SALTATRIX*, IN THE LOWER CHESAPEAKE BAY AND VIRGINIA'S COASTAL OCEAN

# INTRODUCTION

The bluefish (*Pomatomus saltatrix*) is the only species in the genus *Pomatomus*. These fish are migratory coastal pelagics, occurring in temperate and subtropical estuarine and continental shelf waters throughout the world's oceans with the exception of the Eastern Pacific. In the United States, bluefish are found seasonally from Maine to South Florida, and according to a genetic analysis, these fish probably comprise a single stock and are managed as such (Lassiter 1962; Wilk 1977; Graves et al. 1992). A smaller population occurs in the Northern Gulf of Mexico (Ditty and Shaw 1995).

Bluefish support commercial and recreational fisheries throughout their range. The annual recreational bluefish harvest from US East Coast waters far exceeds their commercial catch in this area, accounting for 80% of the bluefish biomass taken from this region (ASMFC 1998). These fish are sought by recreational anglers for their superior fighting abilities and dominated recreational landings by weight from 1979 to 1987. About 75% of the bluefish biomass harvested by shore and private boat anglers fishing in US Atlantic Coast estuaries and coastal ocean zones are age-0[*] fish, which are preferred by many over the adults as their meat has a lighter texture and sweeter taste (Creaser and Perkins 1994; ASMFC 1998).

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* Unless otherwise stated, age-0 bluefish refers to those in the juvenile stage of development.

Commercial and recreational bluefish landings have declined along the US Atlantic Coast. The recreational catch-per-unit-effort has fallen from 5.9 kg / angler / day in 1981 to 2.2 kg / angler / day in 1995 (Figure 1) (ASMFC1998). Spawning stock biomass estimates also decreased from 270,000 t in 1982 to 110,000 t in 1995 (Figure 2) (ASMFC 1998). Young-of-the-year (YOY)* bluefish recruitment indices and landings have declined and become quite variable in many areas, including the Chesapeake Bay region, beginning in the late 1980's and persisting throughout the 1990's (Austin and Seaver 1996; Austin et al. 1997; Clark 1998; Munch and Conover 2000). The Atlantic Coast bluefish stock fishing mortality rate has exceeded that which gives maximum sustainable yield since 1981, so it is likely that this excessive fishing mortality has played a role in this decline (ASMFC 1998). Natural fluctuations in their abundance have been observed since at least the mid 1800's, so factors other than fishing may also be partly responsible for the current status of the stock (Baird 1873; Creaser and Perkins 1994; McBride et al. 1995).

Much of the contemporary bluefish research has focused on the recent fluctuations and declines in YOY bluefish landings and abundance indices as well as possible linkages to the present condition of the US Atlantic Coast stock. It is well known that the highly variable mortality rates during the egg and larval stages of development have a significant impact on year-class strength and the future abundances of many coastal species (Hjort 1914; Houde 1989). Recent studies have shown that the juvenile stage may also be critical for certain fishes

* Unless otherwise stated, YOY bluefish refers to those in the juvenile stage of development.

Figure 1. Recreational catch-per-unit-effort (CPUE - expressed as kg / angler / day) of bluefish for the US Atlantic Coast from 1981 to 1995 (ASMFC 1998).

# Atlantic Coast Bluefish Recreational CPUE

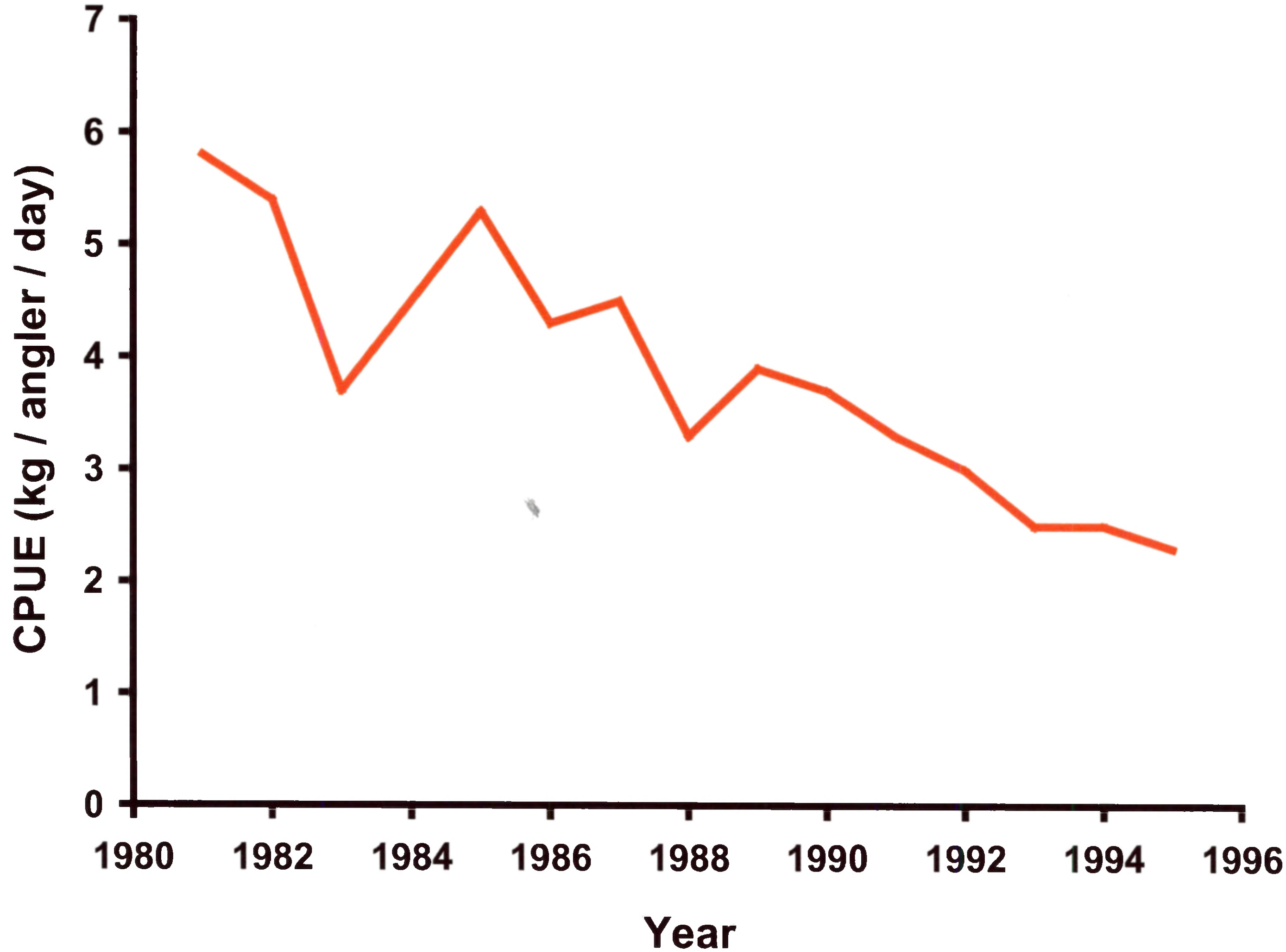
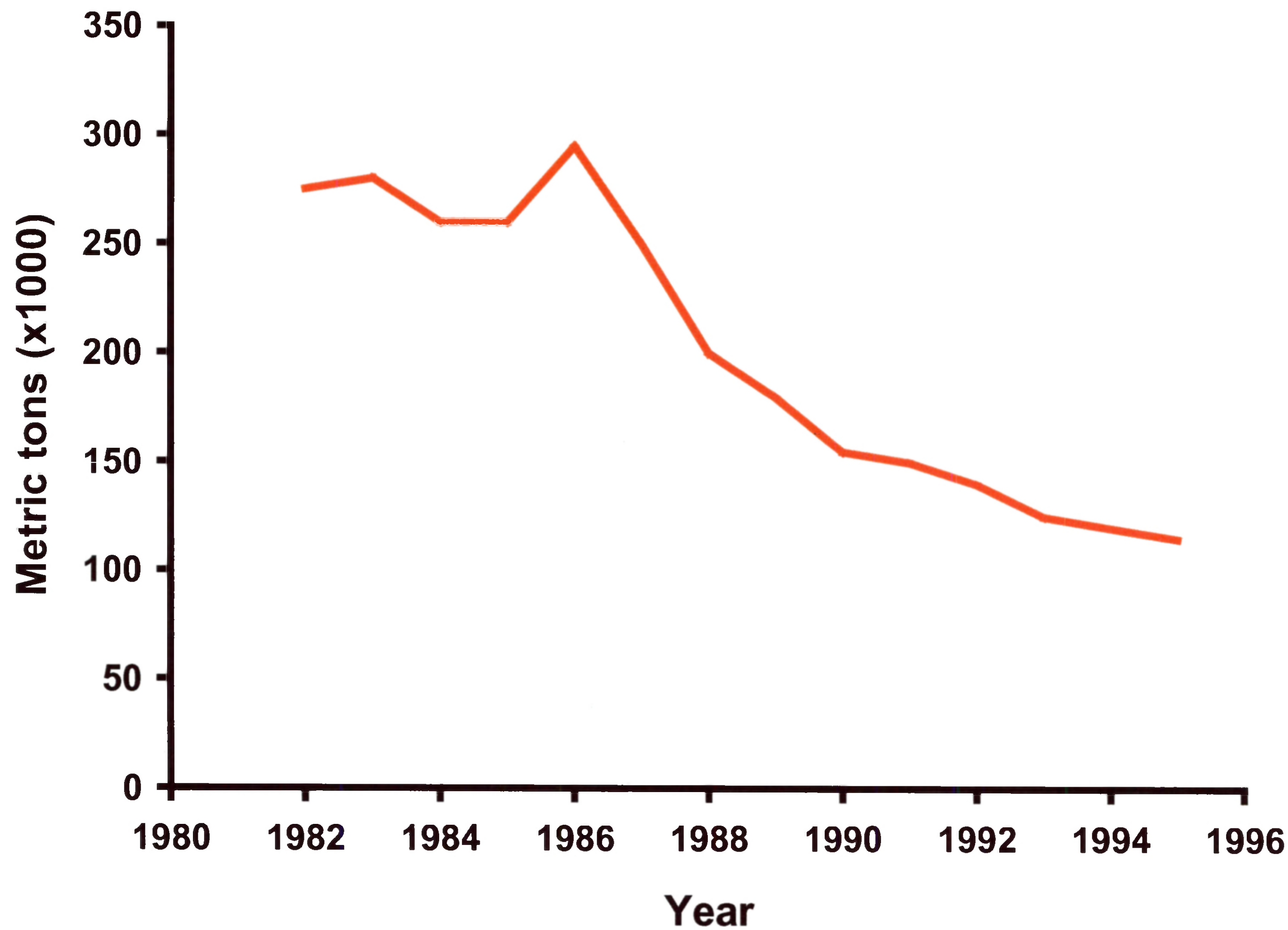


Figure 2. Estimates of Atlantic Coast bluefish spawning stock biomass (1982 – 1995) expressed in metric tons (t) (ASMFC 1998).

# Atlantic Coast Bluefish Spawning Stock Biomass



such as the Arctic cod (*Gadus morhua*) (Helle et al. 1999), Norwegian spring-spawning herring (*Clupea harengus*) (DeBarros and Toresen 1995) and weakfish (*Cynoscion regalis*) (Grecay and Targett 1996).

Biotic and abiotic factors such as predation, competition, temperature, salinity and circulation patterns can influence juvenile natural mortality rates, and in turn, year-class strength and future adult abundances (Hare and Cowen 1996; Buckel et al. 1998). It has been suggested that prey availability during the juvenile stage may also play a crucial role, as a dearth of prey can lead to either starvation or reduced growth rates, rendering the juveniles more susceptible to predation and increasing natural mortality (Friedland et al. 1988; Juanes and Conover 1994; Scharf et al. 1997; Buckel et al. 1998; Buckel et al. 1999a). Adams et al. (1982) suggested that juvenile largemouth bass (*Micropterus salmoides*) survival and recruitment success in the Watts Bar Reservoir, Tennessee, may have been closely related to prey availability. Similar bottom-up controls may be driving the recent trends in age-0 bluefish abundance and perhaps even the changes in the US Atlantic Coast stock (McBride et al. 1995). Multispecies models, such as bioenergetic and multispecies virtual population analysis models, can be used to determine whether prey availability during the YOY stage may be responsible for the declines in bluefish recruitment, and this information would be timely in light of the current interest in developing ecosystem based multispecies management plans (Rothschild 1991; Houde et al. 1998; NMFS 1999). Before these modeling and management efforts can be undertaken, however, YOY bluefish trophic interactions must be quantified by analyzing their diet composition.

Most of the YOY bluefish diet studies in US waters have focused on identifying their main prey in estuaries and coastal ocean zones. The earliest investigations were conducted in North Carolina estuaries and reported that fishes such as juvenile Atlantic silverside (*Menidia menidia*), butterfish (*Peprilus tricanthus*) and pinfish (*Lagodon rhomboids*) composed a substantial portion of the diet (Linton 1905; Lassiter 1962). Crustaceans were also present, but were of lesser importance. These studies appear to be the only age-0 bluefish diet investigations in southern US waters.

The majority of the bluefish research over the past 20 years has examined the diet composition in New Jersey and New York waters. A study in Sandy Hook Bay, New Jersey, showed that crustaceans were more important than fish prey in two of three years (Friedland et al. 1988). Diet investigations in the Lower Hudson River in the late 1980's and early 1990's discovered that economically valuable anadromous fishes, including striped bass, American shad (*Alosa sapidissma*) and blueback herring (*Alosa aestivalis*), were the main prey in this region (Juanes et al. 1993; Buckel et al. 1999a). Juanes and Conover (1995) collected YOY bluefish from nearby Great South Bay about the same time period that Juanes et al. (1993) conducted the Hudson River study and found the diet to be dominated by Atlantic silverside and bay anchovy (*Anchoa mitchilli*). The diet variability among these studies was likely due to ecological and environmental differences among the nursery areas, indicating that these predators are flexible in their feeding behavior as well as emphasizing the importance of quantifying the diet in each nursery area, rather than assuming that findings from one region apply to all.

The Lower Chesapeake Bay and near shore Virginia waters are an important nursery area for YOY bluefish. It is generally believed that age-0 bluefish are produced annually in three distinct spawning events, although some evidence indicates that spawning is continuous but appears as separate episodes due to variations in survival (Lassiter 1962; Kendall and Walford 1979; Chiarella and Conover 1990; Hare and Cowen 1993; Smith et al. 1994). YOY bluefish from two of these events recruit to the Chesapeake region (Austin and Seaver 1996; Austin et al. 1997).

Spawning commences in March along the inshore edge of the Gulf Stream between Cape Hatteras, North Carolina, and Cape Canaveral, Florida. The pelagic eggs and larvae from this spring spawn are advected northward by the Gulf Stream, and the transition from larvae to juvenile occurs offshore at approximately 20 mm standard length (SL) (Wilk 1977; Kendall and Walford 1979; Chiarella and Conover 1990; Marks and Conover 1992). YOY bluefish then cross the continental shelf probably by swimming and advection by both warm core ring streamers and wind driven currents as shelf water temperatures warm to 15 to 20°C (Hare and Cowen 1996). These fish enter the estuaries and near shore oceanic zones of the southern Middle Atlantic Bight (MAB), including Virginia's waters, in mid to late May (approximately 30 mm to 60 mm fork length

(FL)) while they recruit to the more northern coastal areas (eg, New Jersey and New York waters) in mid June.

Adult bluefish migrate north and inshore after the spring spawn and feed along the coast of the MAB throughout the summer and early fall. The second spawn occurs over the continental shelf of the MAB in June and July (Kendall and Walford 1979; Chiarella and Conover 1990). This summer-spawn cohort also recruits to estuaries and coastal ocean zones, including the Chesapeake Bay region, as juveniles in late July and early August. Summer-spawn recruitment was less than that of the spring-spawn cohort in the 1980's and throughout the 1990's (McBride et al. 1995; Austin et al. 1997; Munch and Conover 2000).

Both cohorts use these coastal waters as nursery areas throughout the summer and early autumn, where they encounter abundant food supplies, warm temperatures and protection from predators. These conditions allow YOY bluefish to grow rapidly (1 to 2 mm / day) during their first summer and attain a larger size at age-1 than most other temperate fishes (Friedland et al. 1988; Juanes and Conover 1994). Spring-spawn fish reach approximately 280 mm FL and summer-spawn fish are about 120 mm FL when temperature and photoperiod changes and prey migrations trigger an exodus to their overwintering grounds south of Cape Hatteras (Lund and Maltezos 1970; Wilk 1977; Buckel et al. 1999b). The rapid growth rate and large size at the end of the first growing season increase survival probabilities by affording the age-0 bluefish a partial refuge from predation during the southern migration (Friedland et al. 1988; Hartman and Brandt 1995a; Buckel et al. 1998).

Adult bluefish also migrate to the South Atlantic Bight in the fall, and the third spawning event occurs at this time. These fall-spawn fish recruit to the estuaries and coastal ocean zones of the South Atlantic Bight (Chiarella and Conover 1990). There is no evidence of recruitment to the Chesapeake Bay region, and this cohort is believed to contribute little to the US Atlantic Coast bluefish stock (McBride et al. 1995; Austin and Seaver 1996; ASMFC 1998).

The Chesapeake Bay and Virginia's coastal ocean are inhabited by at least 270 species of freshwater, estuarine, marine, anadromous and catadromous fishes (Baird and Ulanowicz 1989; Murdy et al. 1997). Diet composition has been quantified for the YOY of many economically and ecologically important fishes in this region, including striped bass (Ruderhausen 1994; Walter 1999), white perch (*Morone americana*) (Ruderhausen 1994), weakfish (Chao 1976) and Atlantic croaker (*Micropogonias undulatus*) (Chao and Musick 1977). Hartman and Brandt (1995b) examined the age-0 bluefish diet in the Chesapeake Bay in the early 1990's, but their sample size was small and fish were only collected from Maryland's portion of this estuary. The YOY bluefish diet composition has otherwise received little attention in this area and has yet to be quantified in the Lower Bay and near shore Virginia waters.

The feeding habits and diet composition of many freshwater and marine fishes such as the brook trout (*Salvelinus fontinalis*) (Magnan et al. 1994), roach (*Rutilus rutilus*) (Mehner et al. 1998), Lake Tanganyika sardine (*Limnothrissa* *moidon*) (Mandima 2000), skipjack tuna (*Katsuwonus pelamis*) (Dragovich 1970), yellowfin tuna (*Thunnus albarcares*) (Dragovich 1970) and weakfish (Grecay and Targett 1996) changed as biotic and abiotic conditions varied. In previous bluefish studies, the diet differed among nursery areas also probably due to variations in particular ecological and environmental factors (Friedland et al. 1988; Juanes et al. 1993; Juanes and Conover 1995; Buckel et al. 1999a). In terms of its biotic environment, the Chesapeake region is unique in that it serves as the northernmost boundary for numerous tropical and subtropical fishes and the southern boundary for many boreal species. These fishes, along with the temperate species found throughout the MAB, comprise one of the most diverse finfish faunas along the Atlantic coast (Murdy et al. 1997). Thus, age-0 bluefish encounter predator, prey and competitor assemblages in this region that differ from those in other estuaries, which may alter their feeding behavior and diet composition (Creaser and Perkins 1994).

This region's physical environment is also unique due to its location. These waters occupy the transition area between the boreal / temperate climate zone to the north and the temperate / subtropical climate zone to the south. As a result, the Bay and adjacent coastal waters warm earlier in the spring and cool later in the fall than Maine, New York and New Jersey waters (McBride and Conover 1991; Creaser and Perkins 1994). Since the age-0 bluefish migrations into and out of their nursery areas are partly triggered by temperature, YOY bluefish in the Chesapeake Bay region may experience a longer period of estuarine residency than those in more northern environments. Average summer water temperatures in the Lower Bay and near shore Virginia waters are also greater than those further north (Murdy et al. 1997). Either or both of these factors may influence YOY bluefish feeding behavior (consumption rates, prey selectivity, feeding periodicity, gastric evacuation rate, etc.) causing diet composition to differ from that observed elsewhere (Hathaway 1927; Buckel et al. 1995; Buckel and Conover 1996).

Factors that may influence the age-0 bluefish diet differ between this and the other nursery areas. Furthermore, ecological and environmental conditions in this region have fluctuated since Hartman and Brandt (1995b) examined the diet in the early 1990's. Quantifying the YOY bluefish diet composition in the Lower Chesapeake Bay and Virginia's coastal ocean at this time and comparing these findings with those from other regions as well as with the initial Chesapeake Bay study will improve the understanding of age-0 bluefish foraging ecology. Again, identifying the main prey of these bluefish in one of their largest nursery areas will provide timely information necessary for the development of multispecies models and management plans (McBride et al. 1995; NMFS 1999). By incorporating this data into multispecies models, it may be possible to determine whether changes in the availability of certain prey types are responsible for the recent trends in the age-0 bluefish landings and abundance indices and whether measures should to be taken to ensure that certain prey species are available to the YOY bluefish in this region (Hartman and Brandt 1995a; Houde et al. 1998; Whipple et al. 2000). This approach may also indicate the degree to which fluctuations in prey availability during the YOY stage may influence future adult populations.

Besides potentially identifying bottom-up controls in this ecosystem, YOY bluefish diet information can be used to determine whether these predators exert top-down controls in the Chesapeake Bay region. Predator feeding habits may alter the community structure of an ecosystem by affecting the abundance, size structure and spatial distribution of forage species and must be understood for sound management of predator and prey fisheries (Grant 1962; Safina and Burger 1989; Daan and Sissenwine 1991; Scharf et al. 1997). Although there are many examples from freshwater ecosystems, few researchers have examined top-down controls in marine environments and fewer still have attempted to elucidate the role of age-0 predators in these systems (Cadwallader 1975; Kushlan 1976; Carpenter et al. 1985; Wright et al. 1993; Buckel et al. 1999a). For most fishes, the total prey biomass consumed by YOY fish exceeds that of the older cohorts since the former usually have greater weight specific consumption rates and total biomass (Buckel and Conover 1996; Buckel et al. 1999c).

YOY bluefish are highly mobile, voracious predators with relatively high consumption and gastric evacuation rates (10% to 25% body weight / day and 5 to 7 hours, respectively), and thus have the potential to drastically affect prey populations (Marks and Conover 1992; Juanes et al. 1993; Juanes and Conover 1994; Buckel and Conover 1997). Buckel et al. (1999a) used YOY bluefish diet composition data from the Hudson River, along with consumption and biomass estimates and striped bass biomass and natural mortality rates, to calculate that 51-129% of YOY striped bass natural mortality in this river could be attributed to age-0 bluefish predation. Thus, these predators can have a substantial impact on prey recruitment. Using bioenergetic models, Hartman and Brandt (1995a) showed that YOY bluefish consume more prey biomass per individual than either of their major competitors, age-0 striped bass and YOY weakfish, in Maryland's portion of the Chesapeake Bay. Bluefish therefore have the greatest potential on a per individual basis to significantly reduce the abundance, alter the size structure and influence the spatial distribution of prey in this system as well as to outcompete other predators.

The Lower Chesapeake Bay and Virginia's coastal ocean are important nursery grounds for a number of economically valuable species besides bluefish, including striped bass, American shad, summer flounder (*Paralichthys dentatus*), weakfish, Atlantic menhaden (*Brevoortia tyrannus*) and blue crab (*Callinectes sapidus*). Each of these have been consumed by age-0 bluefish in other nursery areas and may be preyed upon by YOY bluefish in this region as well (Friedland et al. 1988; Juanes et al. 1993; Austin et al. 1997). Once the main prey in the YOY bluefish diet in this area are identified, this information can eventually be incorporated into predator / prey models along with consumption rate and abundance estimate data, leading to a thorough understanding of the extent to which these bluefish exert top-down controls on forage species, limit food availability to competitors through direct competition or resource depletion and compete with local and regional fisheries (Schoener 1974; Hartman and Brandt 1995b; Buckel et al. 1999a; Buckel et al. 1999c; Whipple et al. 2000).

A thorough YOY bluefish diet study in the Chesapeake Bay region should focus not only on providing a general diet description, but also on identifying the size at which these fish shift to piscivory and quantifying spatial and temporal diet variations. Copepods and other planktonic invertebrates are the main prey of larval and early juvenile bluefish in the continental shelf waters, and a switch to piscivory usually occurs sometime after they recruit to the summer nursery areas (Marks and Conover 1992). Piscivorous age-0 bluefish have higher growth rates than non-piscivorous individuals (Juanes and Conover 1994; Buckel et al. 1998). A shift early in the YOY stage should thus yield a higher growth rate and in turn, larger fish with higher survival probabilities throughout their estuarine residency and subsequent fall migration. Therefore, nursery areas may contribute more to the Atlantic Coast bluefish stock when YOY bluefish switch to piscivory earlier (at a smaller size) than later in their summer nursery period. Identifying the size at which the shift occurs in the Chesapeake region may aid in the evaluation of this area's contribution to the Atlantic Coast stock (Friedland et al. 1988).

Examining spatial and temporal diet variations is essential as it not only provides a comprehensive insight into the nature of age-0 bluefish foraging ecology, but also valuable information for future modeling and management efforts (Daan and Sissenwine 1991). Past studies have shown that the YOY bluefish diet can vary within a nursery area as well as among and within years, likely due to differences in the biotic and abiotic environment experienced by these fish (Naughton and Saloman 1984; Creaser and Perkins 1994; Juanes and Conover 1994; Juanes and Conover 1995). While some investigations have focused on the spatial differences in the age-0 bluefish diet and others on the temporal changes, few have examined both. The Lower Chesapeake Bay and Virginia's coastal ocean are dynamic ecosystems as their physical, chemical and biological properties vary in both space and time. It is therefore quite likely that the YOY bluefish diet within this region exhibits spatial and temporal differences.

By investigating spatial variations in the age-0 bluefish diet composition, it is possible to identify regions where significant predator / prey interactions occur as well as how the magnitudes of these interactions vary with location. Recent interest in the identification of essential fish habitat and the establishment of marine reserves requires a thorough understanding of the spatial variations in the type and intensity of predator / prey interactions to locate essential habitat and optimize the placement of the reserve areas (Grecay and Tagett 1996; NMFS 1999).

Examining inter-annual variations in the diet indicates whether the intensity of the trophic interactions between age-0 bluefish and their prey change from year to year, as seen in the Hudson River estuary, as well as if the prey composition of the YOY bluefish diet varies annually (Juanes et al. 1993). In the latter case, multispecies models become highly complex as does the determination of whether bottom-up controls influence YOY bluefish year-class strength and the development of integrated ecosystem based multispecies management plans. Identifying intra-annual variations in age-0 bluefish trophic interactions may prove useful in the management of these predators and their prey. For example, the harvest of a particular prey species may be limited during a time of the year when they are the main YOY bluefish prey to ensure that sufficient prey are available to the predators at that time. This approach may also prevent the collapse of prey stocks by limiting harvest when natural mortality rates may be high due to predation (Magnusson and Palsson 1991). Again, this information is extremely useful for mulitspecies modeling and management efforts since the majority of these models, such as the bioenergetic and MSVPA models, require temporally explicit diet information.

In light of these considerations, the three objectives of this thesis were to

(1) Provide a general description of the YOY bluefish diet composition in the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000

(2) Determine the size at which age-0 bluefish became mainly piscivorous in this region

(3) Describe spatial, inter-annual, and intra-annual diet variations

# METHODS

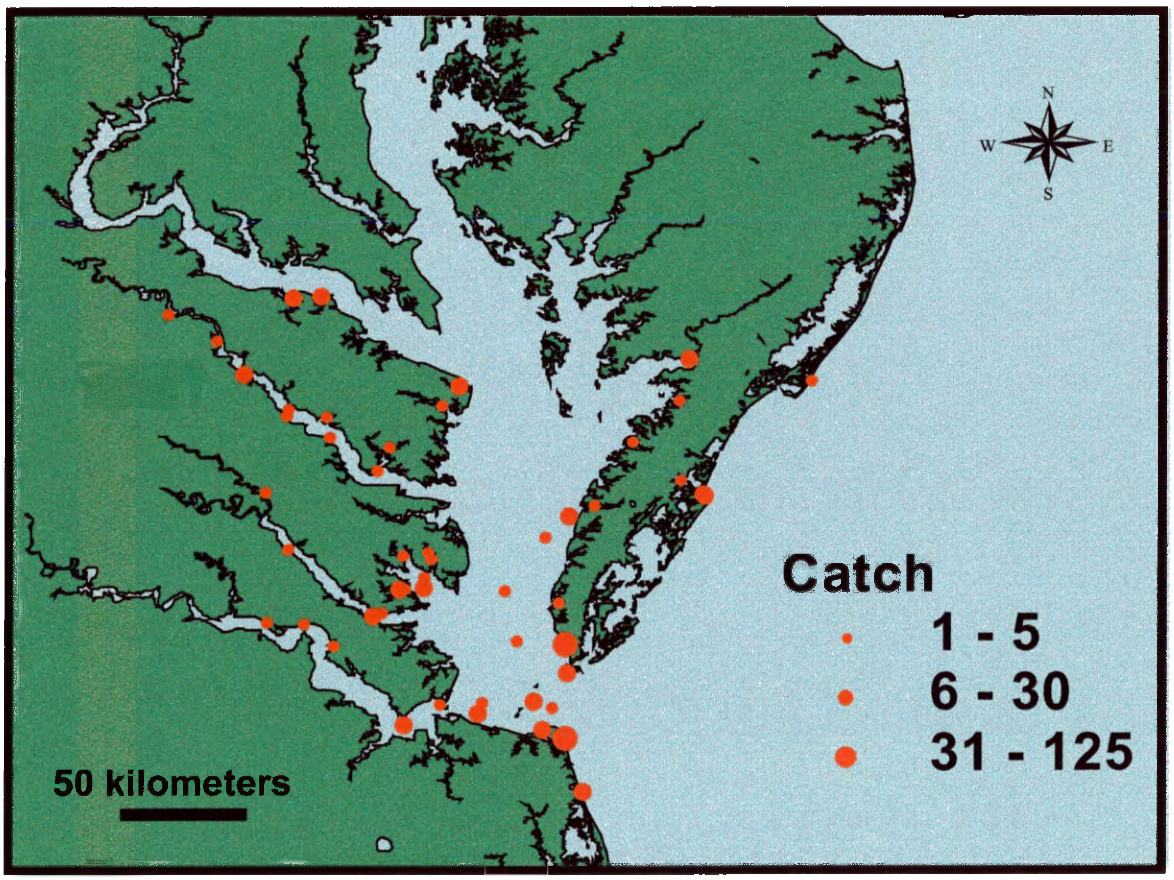
## Field

YOY bluefish were collected from the Lower Chesapeake Bay and Virginia's coastal ocean in the summers of 1999 and 2000 (Figure 3). Sampling was conducted fortnightly in 1999 (from 25 May to 24 September, the time when age-0 bluefish occupy this region) at 10 fixed stations on Virginia's Eastern Shore and Southside beaches using a 30.5 m x 1.8 m bag seine (6.4 mm bar mesh) (Austin and Seaver 1996; Austin et al. 1997). Specimens were also collected biweekly in 2000 from 24 May to 20 September. Additional sites were added on the Eastern Shore, Southside beaches, Western Shore and tributaries to augment sample size.

At each station, the seine was fished by staking one brail pole on the beach, extending the net perpendicular to the shore, sweeping down current and hauling back to the beach. Alternatively, the seine was carried to a depth of 1.2 m, set parallel to the shore and hauled to the beach. This method was used when currents were strong or winds caused the net to 'balloon' (Austin and Seaver 1996; Austin et al. 1997). At least two hauls were completed at each station. Sampling always occurred during daylight hours, since YOY bluefish occupy shore zones during the day and move offshore at night (Olla and Studholme 1971; Juanes and Conover 1994; Buckel and Conover 1997). All

Figure 3. Spatial distribution of sampling sites in the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. The size of a circle corresponds to the number of YOY bluefish collected at that station.

# Distribution of Sampling Sites



age-0 bluefish were immediately fixed in 10% buffered Formalin to minimize digestive losses. Preserving with Formalin is the most effective way to halt the digestive process and facilitates prey identification as it hardens tissues, keeping partially digested prey intact (Creaser and Perkins 1994).

YOY bluefish were also collected opportunistically in 1999 and 2000 from the VIMS juvenile finfish trawl survey (1999: September to November; 2000: August to October), the *Pfeisteria* Cohort Study (1999: September to October; 2000: June to October) and the Striped Bass Seine Survey (1999: July to August; 2000: July to September). The VIMS trawl survey tows a 9.1 m semi-balloon otter trawl with a 38.1 mm stretched mesh body and a 6.4 mm stretched mesh cod end liner along the bottom for five minutes at each station (Geer and Austin 2000). The *Pfeisteria* Cohort Study sets three anchored gill nets (25 mm to 88 mm stretched mesh) in 1 m of water at each sampling site. Soak time is 90 minutes (Hata, pers. comm.). Both surveys capture bluefish ranging from age-0 to age-2. YOY bluefish were distinguished from the older fish on the basis of length, and the latter were returned to the water. The Striped Bass Seine Survey samples 40 stations on the James, York and Rappahannock River systems at approximately five biweekly intervals from July through September. This survey uses a 30.5 m x 1.2 m bagless seine (6.4 mm bar mesh) and occasionally captures age-0 bluefish (Austin et al. 2001). YOY bluefish taken by trawl, gill net and striped bass seine were held on ice to minimize digestive losses, transported to the laboratory and then preserved in 10% buffered Formalin.

## Laboratory

In the laboratory, each specimen was removed from Formalin and rinsed with fresh water. Fork length was measured to the nearest millimeter. The fish was blotted with a paper towel to remove excess moisture, and wet weight was recorded to the nearest 0.001 g. The stomach was then extracted by making a longitudinal mid-ventral incision with a scalpel and severing the alimentary canal anterior to the stomach and posterior to the pylorus. Each stomach was opened individually and the inner walls scraped with the tip of a scalpel to remove all contents. Prey encountered in the esophagus and buccal cavity were also included in the diet analysis, while those in the intestines were ignored since the rapid digestion rates of YOY bluefish precluded the identification of these items. All prey items were identified to the lowest possible taxon and enumerated. The wet weight (0.001 g) of each item was also recorded.

YOY bluefish have well developed teeth, which enables them to consume their prey in pieces, as well as rapid digestion rates, so prey identification was sometimes difficult. Items were often compared to specimens in the VIMS fish collection and analysis of mouth morphology, scales, spine and fin placement, ray counts, vertebral counts, peritoneum coloration, otoliths and other hard parts aided in identification. For example, bay anchovy could usually be distinguished from striped anchovy by examining the snout morphology, and many Atlantic menhaden were positively identified by their characteristic scales, distinctive gizzard shape and black peritoneum (Manooch 1973). Sciaenids were often distinguished by examining their otoliths. Identification of crustaceans was sometimes possible through microscopic examination of the rostrum (Gosner 1971).

## Analysis

### General Diet Description (Objective 1)

A general description of the YOY bluefish diet in the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000 was generated by first constructing a cumulative prey curve. These curves have been used to evaluate a posteriori whether a sufficient number of stomachs have been collected and examined to adequately characterize a predator's diet (Gelsleichter et al. 1999; Walter 1999; Lucena et al. 2000). They are constructed by randomizing the order in which stomachs were analyzed 10 times and plotting the mean cumulative number of new prey types encountered (along with ± standard deviation) against the cumulative number of stomachs examined (Ferry and Calliet 1996). If the curve reaches an asymptote, all of the main prey types probably have been encountered, so a sufficient number of stomachs have been processed (in other words, an adequate number of predators have been collected and examined). Analyzing additional guts should only yield rare prey types. More specimens must be collected to properly characterize the diet if there is no asymptote since it is likely that all of the main prey types have yet to be discovered. Unfortunately, the determination of whether an asymptote has been reached is often subjective.

When constructing a cumulative prey curve, each stomach is assumed to be independent. The guts examined in this study may not have been independent, however, as a number of age-0 bluefish (and consequently stomachs) were collected from a single school in certain instances. This could have lead to a false stabilization of the curve, and the conclusion that an adequate number of stomachs had been collected when in fact they had not. The cumulative prey curve was therefore used to determine whether the number of guts examined was insufficient (no asymptote reached) or if an adequate number of stomachs (YOY bluefish) may have been collected to adequately characterize the diet (asymptote reached). The length-frequency distribution of the bluefish and the percentage of stomachs with and without food were also reported.

Many diet indices have been developed to identify a predator's main prey. Those most commonly used in previous YOY bluefish diet studies include percent frequency of occurrence (%F), percent number (%N) and percent weight (%W) (Friedland et al. 1988; Juanes et al. 1993; Buckel et al. 1999a). Each was designed to measure a different aspect of a predator's feeding habits and diet composition.

Percent F for prey type i is given by

$$\%F_i = (S_i / S) * 100$$

where $S_i$ is the number of stomachs containing prey type i and S is the total number of stomachs with food (Bowen 1996). This index characterizes population, rather than individual, feeding habits. %F has been criticized since it fails to account for the amount of each prey type consumed. Thus, a small prey type that occurs singly in all stomachs will have a greater index value and appear more important than larger, more abundant prey that are encountered in slightly fewer stomachs (Hyslop 1980).

The equation to calculate %N for prey type i is expressed as

$$\%N_i = (N_i / \Sigma N_i) * 100$$

where $N_i$ is the total number of prey type i in all guts and $\Sigma N_i$ is the total number of all prey items. This index provides insight into a predator's foraging behavior and identifies prey populations that may be severely affected by the predator's feeding. Its unilateral use has received criticism when the sizes of the different prey types vary drastically, as %N will overemphasize the importance of small numerous prey relative to larger, less abundant prey (Bowen 1996).

Percent W identifies the prey types of greatest nutritional value to the predator and is calculated by

$$\%W = (W_i / \Sigma W_i) * 100$$

where $W_i$ is the total wet weight of the prey type i encountered in all stomachs and $\Sigma W_i$ is the sum of the wet weights of all prey items (Bowen 1996). In contrast to %N, %W overestimates the importance of single, bulky prey types relative to smaller, more numerous prey when prey size differences are large as well as the importance of indigestible materials such as crustacean and mollusk shells (Hyslop 1980).

Due to the limitations of the aforementioned measures, compound diet indices have been developed that combine %F, %N and %W to circumvent biases associated with each and avoid the loss of information that occurs when only one is reported. The index of relative importance (IRI) is among the most commonly used compound indices and is given by

$$IRI_i = (\%N_i + \%W_i) * \%F_i$$

where $IRI_i$ is the IRI for prey type i (Pinkas et al. 1971; Burke 1995; Grover 1997; Walter 1999). A recent modification proposed by Cortes (1997) is

$$\%IRI_i = (IRI_i / \Sigma IRI_i) * 100$$

where $\Sigma IRI_i$ is the sum of the IRI values of all prey types. This index was designed to serve as a standard for diet studies. %IRI was used in this investigation to identify the main prey types in the YOY bluefish diet.

In this study, a %IRI, %F, %N, and %W value was calculated for each prey type encountered in the diet for each station in which YOY bluefish were collected for each fortnightly sampling interval. A mean index value was then calculated for each prey type for each diet index by

$$\overline{X}_i = (\Sigma X_{iab}) / n$$

where $\overline{X}_i$ is the mean index value (index X) for prey type i, $X_{iab}$ is the index value (index X) for prey type i at station a in sampling interval b and n is the total number of station / sampling interval combinations in which bluefish were collected (Zar 1999). Standard errors were calculated by

$$S_{\bar{x}_i} = S / (n^{0.5})$$

where $S_{\bar{x}_i}$ is the standard error estimate for $\overline{X}_i$ and S is the standard deviation of the mean (Zar 1999).

Many investigators have calculated these diet indices by combining the gut contents of all specimens collected throughout the study rather than using this averaging approach. In this investigation, YOY bluefish catches ranged from only one or two fish at certain stations in some sampling intervals to over 50 at others. Stations where many fish were collected do not bias the overall general diet description in this study since all stations were weighted equally with this averaging approach. An assumption of this method is that the numbers of bluefish in the environment at each station in which YOY bluefish were collected for each sampling interval were fairly similar, which is not unreasonable for a schooling fish like the bluefish. Thus, the variability in the catches represented differences in the percentage of the school captured, rather than spatial differences in bluefish abundance.

**Shift to Piscivory (Objective 2)**

The shift to piscivory was said to occur at the smallest size in which the bluefish diet was fish-dominated. Binary logistic regression was used to calculate the probability of a fish-dominated diet at a given fork length. In general, logistic regression is used to predict the probability of the occurrence of an event (probability of a fish-dominated diet) as a function of a continuous or categorical independent variable (fork length) using the model

$$p = (e^{(b + a*X + \varepsilon)}) / (1 + e^{(b + a*X + \varepsilon)})$$

where p is the probability of the event occurring, b is the intercept term, a is the coefficient of the independent variable, X is the independent variable and $\varepsilon$ is the random error term (Hosmer 2000). The intercept and coefficient terms are estimated by using the logit transform to convert the above equation to

$$\text{logit}(p) = b + a*X + \varepsilon$$

where logit(p) is the natural log of the odds ratio (p / 1-p). Once the intercept and coefficient (b and a) are estimated from the latter equation, they are applied to the untransformed model (first equation) to calculate the probability of the event occurring as a function of the independent variable.

The size at which fish prey began to dominate the YOY bluefish diet numerically was identified by first assigning a value of one to a station in a given sampling interval if the total gut contents of all age-0 bluefish collected from that station contained a greater number of fish than invertebrate prey, and zero if the number of invertebrate prey was greater than or equal to the number of fish prey. The average fork length of bluefish collected at that station was also calculated. This was done for each station in which bluefish were collected. The logistic regression was constructed on a station rather than an individual basis since stations, not individuals, were the independent units in this study. The logistic regression model was constructed using Minitab©, with fork length as the predictor variable and the binary variable (fish or invertebrate dominated diet) as the response (Minitab Inc., 1998). The likelihood ratio test was used to determine whether the regression was significant (Hosmer 2000). Probability values were then calculated and plotted against average fork lengths, and the size at which fish prey began to dominate the diet numerically was defined as the smallest average size at which the probability of a fish-dominated diet was greater than 50%. This method was also used to identify the size at which fish began to dominate the bluefish diet by weight.

**Spatial, Inter-annual and Intra-annual Diet Differences (Objective 3)**

*Correspondence analysis*

Correspondence analysis (CA), an exploratory multivariate ordination technique similar to Principal Components Analysis, was used to identify spatial variations in the YOY bluefish diet by examining the associations among the diets from stations at which specimens were collected. The %IRI values (by station for each sampling interval) for the five main prey types identified by this index in the general diet description were entered into Minitab© (Minitab Inc., 1998). Since CA was designed for discrete data, all percentage values were rounded to the nearest integer to satisfy this requirement (Davis 1986). In CA, row (station) and column (prey type) principal components (PCs) are calculated using eigenanalysis (Davis 1986). Biplots were constructed using the first and second component station and prey type PCs and examined for spatial patterns in the diet. Any observed spatial patterns were tested using parametric statistics (described in next section). This technique was also used to identify possible spatial differences in the bluefish diet using the %F, %N, and %W diet indices.

*Multivariate Analysis of Variance (MANOVA)*

A three-way MANOVA was used to test for significant spatial and temporal variations in the %IRI values of the five main prey types identified by this index in the general diet description (Zar 1999). Temporal differences in the YOY bluefish diet were identified by comparing the diet in 1999 to that in 2000 (inter-annual) as well as among those months in which fish were collected (intra-annual). Monthly intervals were chosen since this was the finest time scale in which an adequate number of specimens were collected in each interval to characterize the diet.

Each month / year / location cell contained a number of %IRI values for the top five prey types, where each represented the %IRI value of a prey type from a single station in a sampling interval in that month / year / location combination. The arcsin transformation, commonly applied to percentage data, was used to satisfy the assumptions of multivariate normality and homogeneity of variance-covariance (Zar 1999). Pillai's trace test statistic was calculated to identify which factors (location / year / month) and interaction terms, if any, had a significant effect on the response variables (%IRI values). The MANOVA is similar to the univariate ANOVA in that it only tests for significant differences in the data and does not indicate where these differences occur. Three-way MANOVAs were also used to identify spatial, inter-annual and intra-annual variations in the diet using the %F, %N and %W indices.

*Detailed Diet Description*

If the three-way MANOVAs identified significant spatial, inter-annual or intra-annual variations in the YOY bluefish diet, additional diet descriptions were generated to elucidate these differences. Age-0 bluefish were separated according to the significant factors (by location, year, month or any combination of these), and a diet description was provided for each group of bluefish similar to the general description. A cumulative prey curve was constructed for each set of bluefish, and a length-frequency distribution along with the percentage of stomachs with and without food were reported. %IRI, %F, %N and %W were then calculated for each prey type to identify the main prey using the averaging approach described previously.

# RESULTS

## General Diet Description (Objective 1)

Five hundred fifteen YOY bluefish ranging from 33 mm to 290 mm FL* were collected for stomach content analysis from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000 (Figure 4). The smallest FL corresponds to their size when they recruit to coastal waters and the largest to the approximate length of spring-spawn fish at the outset of the autumn migration. The mean FL was 108.0 mm (±55.4 mm SD), and most of the fish were between 70 mm and 180 mm. A few seine hauls in early August 2000 yielded a large number of bluefish ranging from 40 mm to 60 mm, which accounts for the peak in the length-frequency distribution in this range.

Prey were encountered in 406 of the 515 age-0 bluefish (78.8%). Empty stomachs were examined to determine whether this condition may have been due to regurgitation. Only two of 109 (1.8%) empty guts had smooth stomach walls indicative of recent regurgitation. There were twenty-two identifiable prey types, 14 fish species and eight invertebrate species, in the diet (Table 1). The cumulative prey curve reached a reasonable asymptote, indicating that an adequate number of guts may have been collected (Figure 5). The curve ascended rapidly up to about 125 cumulative stomachs, indicating that

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* All bluefish length measurements are fork length unless otherwise specified.

Figure 4. Length-frequency distribution of YOY bluefish collected in 1999 and 2000 from the Lower Chesapeake Bay and Virginia's coastal ocean. Lengths are fork lengths in millimeters (mm).

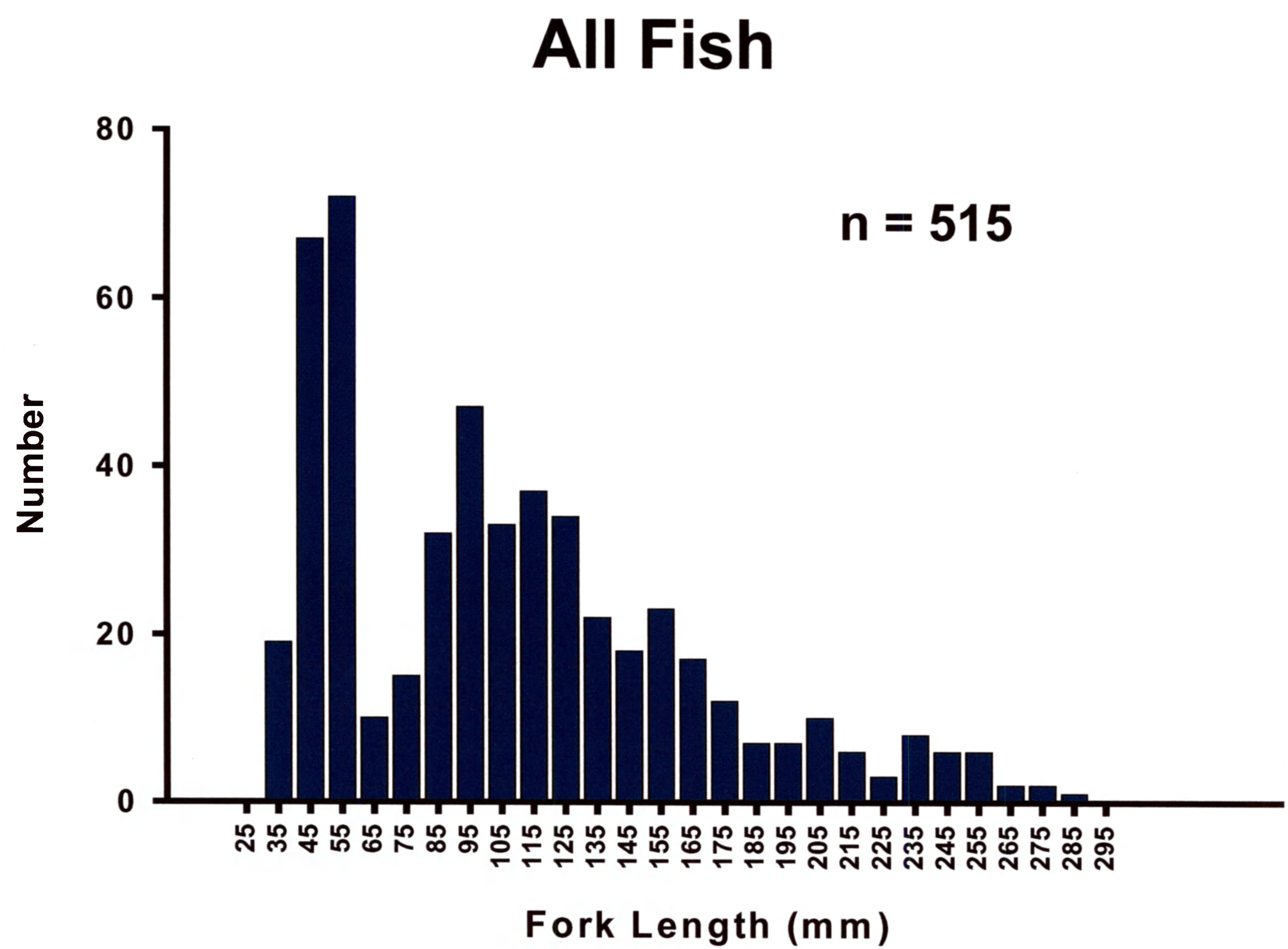
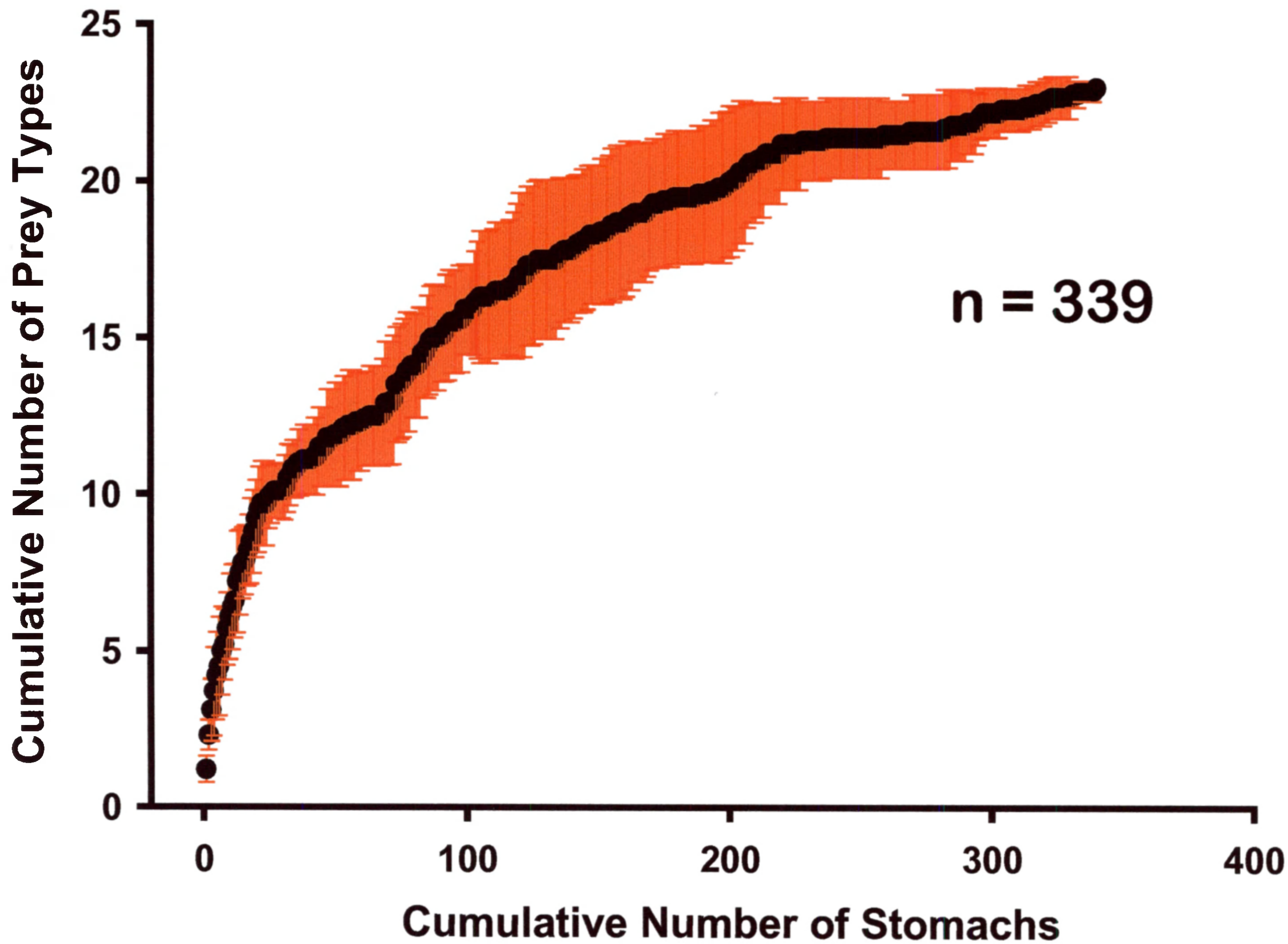

All Fish
n = 515
Number
80
60
40
20
0
25 35 45 55 65 75 85 95 105 115 125 135 145 155 165 175 185 195 205 215 225 235 245 255 265 275 285 295
Fork Length (mm)

Table 1. Common and scientific names of prey encountered in the age-0 bluefish guts collected in 1999 and 2000 from the Lower Chesapeake Bay and Virginia's coastal ocean.

| COMMON NAME | SCIENTIFIC NAME |
|---|---|
| **Vertebrates** | |
| Atlantic menhaden | *Brevoortia tyrannus* |
| Atlantic herring | *Clupea harengus* |
| Atlantic silverside | *Menidia menidia* |
| Banded killifish | *Fundulus diaphanus* |
| Bay anchovy | *Anchoa mitchilli* |
| Bluefish | *Pomatomus saltatrix* |
| Kingfish spp. | *Menticirrhus spp.* |
| Mummichog | *Fundulus heteroclitus* |
| Rough silverside | *Membras martinica* |
| Spotted seatrout | *Cynoscion nebulosus* |
| Striped anchovy | *Anchoa hepsetus* |
| Striped bass | *Morone saxatilis* |
| White mullet | *Mugil curema* |
| White perch | *Morone americana* |
| **Invertebrates** | |
| Gammarid amphipod | *Gammarus spp.* |
| Isopod | *Lironeca ovalis* |
| Lady crab | *Ovalipes ocellatus* |
| Opossum shrimp | *Neomysis americana* |
| Polychaete worm | *Nereis spp.* |
| Portunid crab megalope | *Callinectes spp.* |
| Sand shrimp | *Crangon septemspinosa* |
| Unidentified squid | Class Cephalopoda |

Figure 5. Cumulative prey curve for all age-0 bluefish collected from the Lower Chesapeake Bay and near shore Virginia waters in 1999 and 2000 that contained identifiable prey in their gut. Points are mean values and error bars are ± SD.

## All Fish



Cumulative Number of Prey Types
25
20
15
10
5
0
0
100
200
300
400
Cumulative Number of Stomachs
n = 339

the main prey types were probably identified in the first 125 stomachs examined. The curve continued to ascend at a much slower and more or less steady rate thereafter, since rarer prey types were gradually identified as additional stomachs were examined.

Bay anchovy was the main prey of these YOY bluefish. This small forage fish had a %IRI value of 26.2%, occurred in an average of 26.1% of stomachs with food and composed 24.6% and 26.7% of the diet by number and weight, respectively (Table 2, Figure 6, Figure 7). Atlantic silverside was only slightly less important, accounting for 23.7% by %IRI, 23.9% by %F, 22.6% by %N and 25.3% by %W. Striped anchovy (*Anchoa hepsetus*) and YOY Atlantic menhaden were practically of equal importance with %IRI values of 9.2% and 8.1%, respectively. Portunid crab megalope (*Callinectes spp.*) was the main invertebrate prey in the diet, having a %IRI value of 4.5%. Their contribution was much greater by number than weight because large numbers of small megalope (sometimes as many as 50) were encountered in a few stomachs. Sand shrimp (*Crangon septemspinosa*) was the only other common invertebrate prey (%IRI – 2.6).

Unidentified categories (especially unidentified fish and unidentified meat) comprised a substantial portion of the diet since, as mentioned previously, the shearing dentition and rapid digestion rates of these predators precluded the identification of many prey items. Seventeen prey types had %IRI values <2%, indicating the generalist nature of the bluefish feeding habits. These

Table 2. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000.

| Species | % IRI | %F | %N | %W |
|---|---|---|---|---|
| Bay anchovy | 26.2 (± 3.6) | 26.1 (± 3.5) | 24.6 (± 3.5) | 26.7 (± 3.7) |
| Atlantic silverside | 23.7 (± 3.4) | 23.9 (± 3.3) | 22.6 (± 3.3) | 25.3 (± 3.5) |
| Unidentified fish | 9.7 (± 2.2) | 12.4 (± 2.4) | 10.5 (± 2.2) | 9.8 (± 2.4) |
| Striped anchovy | 9.2 (± 2.2) | 11.7 (± 2.5) | 9.1 (± 2.2) | 11.5 (± 2.5) |
| Atlantic menhaden | 8.1 (± 2.3) | 8.7 (± 2.4) | 7.8 (± 2.2) | 8.0 (± 2.3) |
| Port. crab megalope | 4.5 (± 1.6) | 5.4 (± 1.8) | 6.0 (± 1.9) | 2.5 (± 1.2) |
| Sand shrimp | 2.6 (± 1.1) | 4.3 (± 1.5) | 3.0 (± 1.1) | 2.3 (± 1.2) |
| Unidentified meat | 2.5 (± 1.0) | 4.5 (± 1.4) | 3.0 (± 1.1) | 2.0 (± 1.0) |
| Mummichog | 2.0 (± 1.0) | 1.7 (± 1.0) | 2.0 (± 1.1) | 2.1 (± 1.1) |
| White perch | 1.5 (± 0.9) | 1.4 (± 0.7) | 1.3 (± 0.7) | 2.0 (± 0.9) |
| Gammarid amphipod | 1.4 (± 0.7) | 1.3 (± 0.7) | 2.2 (± 1.1) | 0.4 (± 0.3) |
| Opossum shrimp | 1.1 (± 0.6) | 1.9 (± 1.0) | 1.9 (± 1.0) | 0.5 (± 0.3) |
| Striped bass | 0.9 (± 0.6) | 0.9 (± 0.6) | 0.4 (± 0.3) | 1.0 (± 0.7) |
| White mullet | 0.9 (± 0.8) | 0.9 (± 0.8) | 0.9 (± 0.8) | 0.9 (± 0.8) |
| Unidentified egg | 0.7 (± 0.7) | 0.8 (± 0.8) | 0.8 (± 0.8) | 0.5 (± 0.5) |
| Bluefish | 0.5 (± 0.4) | 0.5 (± 0.4) | 0.5 (± 0.4) | 0.7 (± 0.5) |
| Anchovy spp. | 0.5 (± 0.3) | 1.2 (± 0.5) | 0.9 (± 0.5) | 0.4 (± 0.2) |
| Polychaete worm | 0.4 (± 0.4) | 0.4 (± 0.4) | 0.7 (± 0.7) | 0.2 (± 0.1) |
| Unidentified invert. | 0.4 (± 0.3) | 0.7 (± 0.4) | 0.6 (± 0.3) | 0.4 (± 0.3) |
| Spotted seatrout | 0.4 (± 0.4) | 0.4 (± 0.4) | 0.2 (± 0.2) | 0.6 (± 0.6) |
| Kingfish spp. | 0.4 (± 0.4) | 0.4 (± 0.4) | 0.1 (± 0.1) | 0.6 (± 0.6) |
| Lady crab | 0.3 (± 0.3) | 0.8 (± 0.8) | 0.3 (± 0.3) | 0.4 (± 0.4) |
| Unidentified squid | 0.3 (± 0.3) | 0.2 (± 0.2) | 0.2 (± 0.2) | 0.8 (± 0.7) |
| Isopod | 0.1 (± 0.1) | 0.5 (± 0.3) | 0.3 (± 0.2) | 0.1 (± 0.1) |
| Atlantic herring | 0.1 (± 0.1) | 0.3 (± 0.3) | 0.2 (± 0.2) | 0.2 (± 0.1) |
| Banded killifish | 0.1 (± 0.1) | 0.2 (± 0.2) | 0.1 (± 0.1) | 0.1 (± 0.1) |
| Rough silverside | 0.1 (± 0.1) | 0.3 (± 0.3) | 0.1 (± 0.1) | 0.2 (± 0.2) |

Figure 6. Percent IRI values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000.

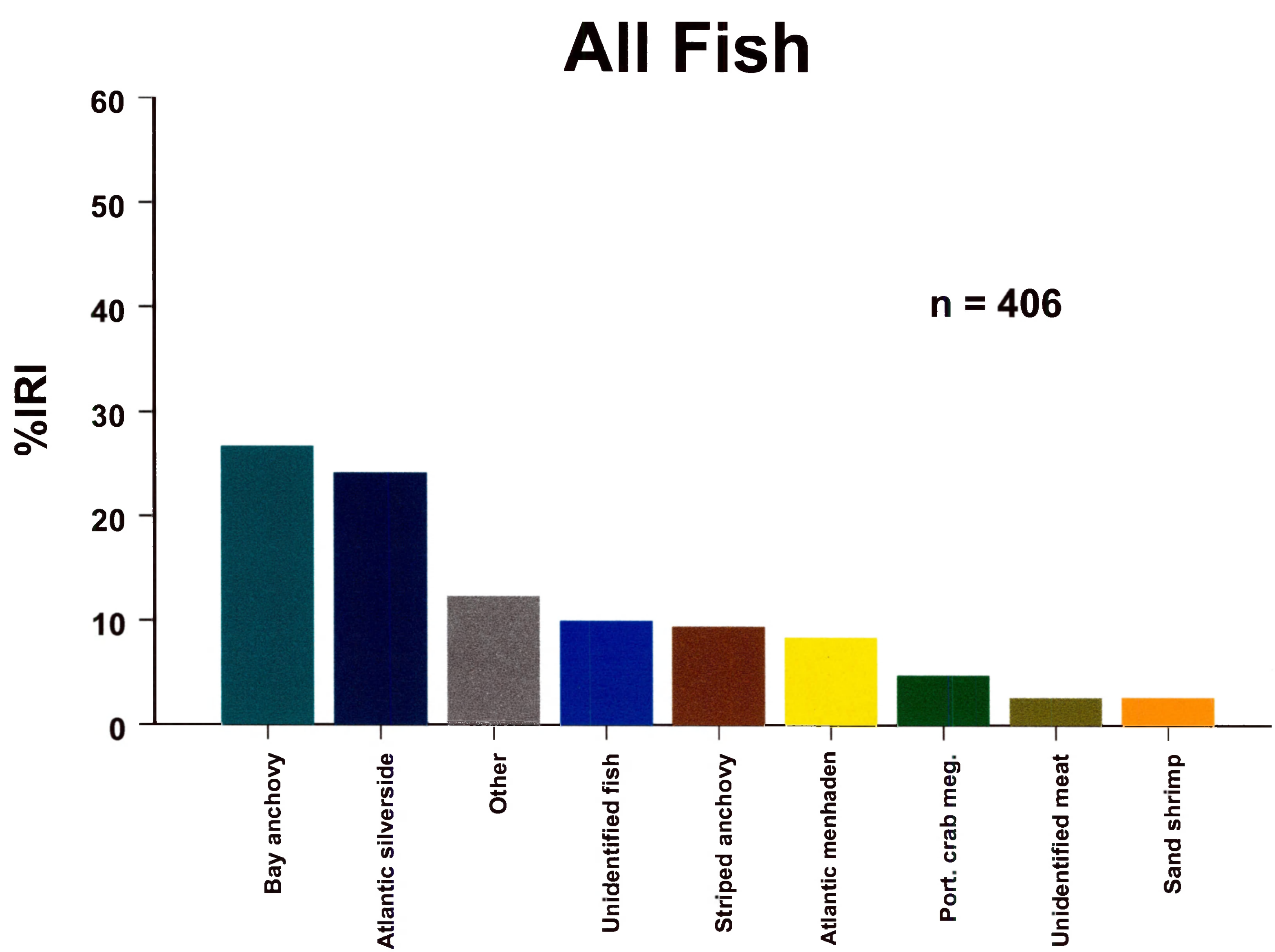
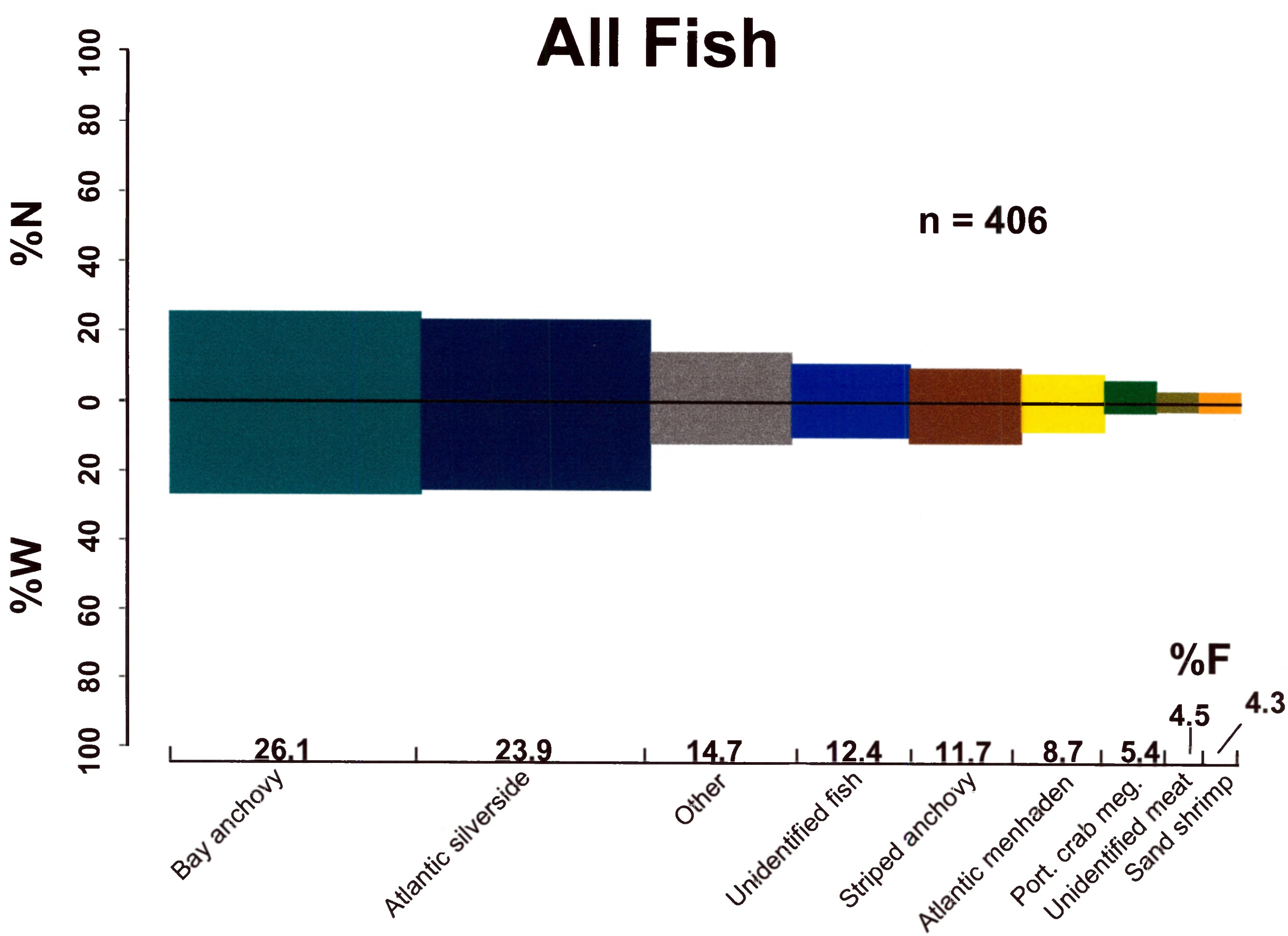

All Fish
n = 406
%IRI
60
50
40
30
20
10
0
Bay anchovy
Atlantic silverside
Other
Unidentified fish
Striped anchovy
Atlantic menhaden
Port. crab meg.
Unidentified meat
Sand shrimp

Figure 7. %F, %N and %W values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F.


All Fish
n = 406
%N
%W
%F
100
80
60
40
20
0
20
40
60
80
100
26.1
23.9
14.7
12.4
11.7
8.7
5.4
4.5
4.3
Bay anchovy
Atlantic silverside
Other
Unidentified fish
Striped anchovy
Atlantic menhaden
Port. crab meg.
Unidentified meat
Sand shrimp

prey were lumped into the 'other' category to facilitate graphical representation. For many of these, including spotted seatrout (*Cynoscion nebulosus*), kingfish spp. (*Menticirrhus spp.*), lady crab (*Ovalipes ocellatus*), banded killifish (*Fundulus diaphanous*), Atlantic herring (*Clupea harengus*) and rough silverside (*Membras martinica*), only one individual was encountered.

**Shift to Piscivory (Objective 2)**

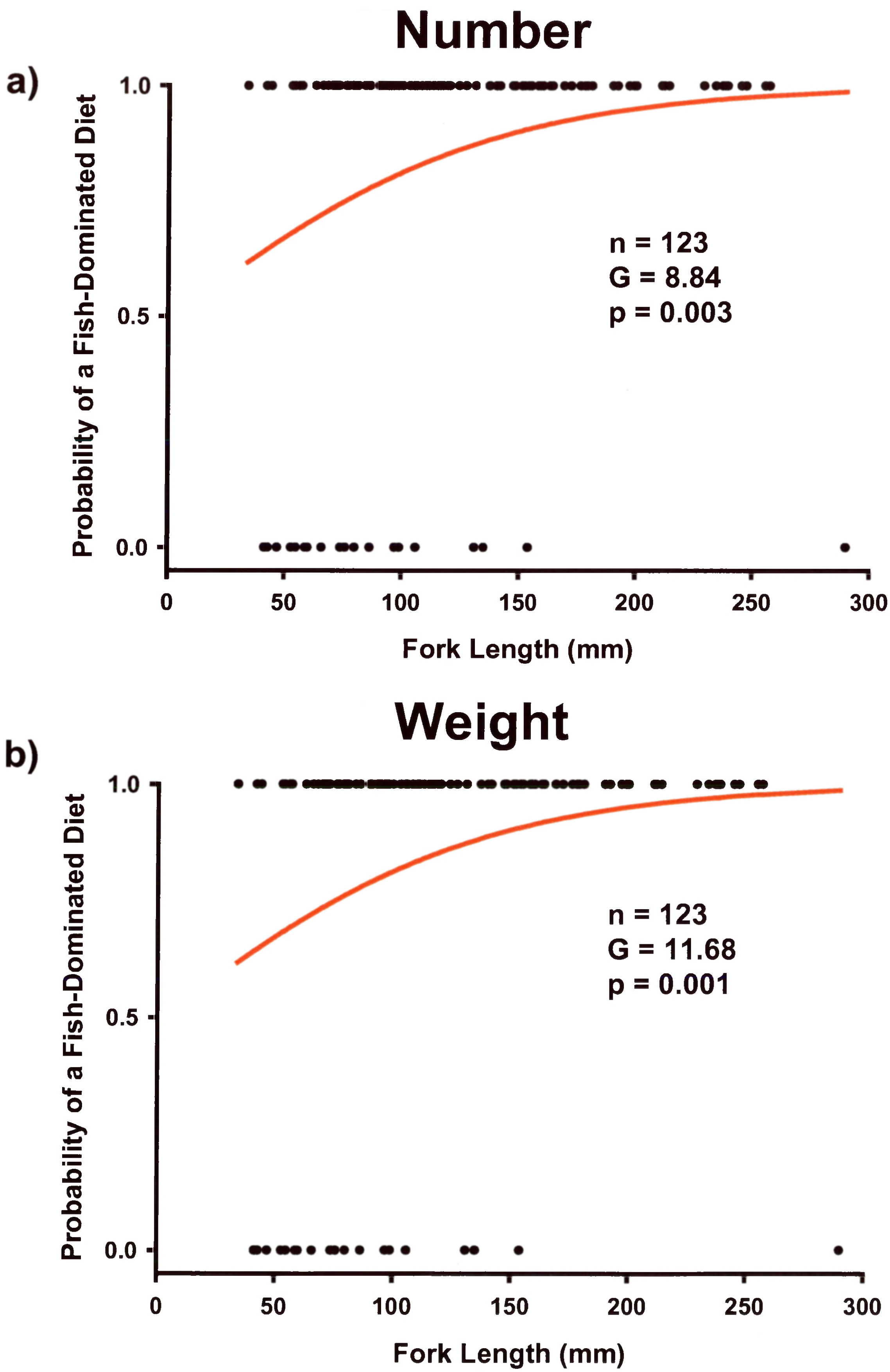
The probability of a fish-dominated diet increased, both numerically and by weight, as the average bluefish fork length at a station increased. Both logistic regressions were significant (Figure 8). Even for the smallest average FL (33 mm), the probability of a fish-dominated diet by number or weight was greater than 50% (61.8% by number; 64.8% by weight). YOY bluefish therefore switched from a planktivorous to a piscivorous diet either before or shortly after they recruited to the Chesapeake Bay region. The probability of a fish-dominated diet when the average bluefish size at a station was greater than 200 mm was nearly 100% (by number or weight).

**Spatial, Inter-annual and Intra-annual Diet Differences (Objective 3)**

*Correspondence Analysis*

The diet of age-0 bluefish collected from the coastal ocean may have differed from that of fish captured in the Lower Bay and its tributaries according to the CA for each diet index. Most of the station separation occurred along component 2, which is common with 'noisy' gut content data (Crow 1981). The majority of the ocean stations scored negatively on component 2 (bay anchovy

Figure 8. Probability of fish dominating the YOY bluefish diet a) numerically and b) by weight versus bluefish fork length in millimeters (mm). The results of the logistic regression (G statistic and p value) are given for each plot.


Number
a)
1.0
0.5
0.0
Probability of a Fish-Dominated Diet
n = 123
G = 8.84
p = 0.003
0
50
100
150
200
250
300
Fork Length (mm)
Weight
b)
1.0
0.5
0.0
Probability of a Fish-Dominated Diet
n = 123
G = 11.68
p = 0.001
0
50
100
150
200
250
300
Fork Length (mm)

and Atlantic menhaden vs. striped anchovy, portunid crab megalope and Atlantic silverside) in the CA using the %IRI data (Figure 9 a,b). A few ocean stations had positive PCs and some Bay stations had negative PCs, which was expected with highly variable gut content data. There appeared, however, to be sufficient evidence to justify a statistical Bay versus ocean diet comparison. The CA for %F, %N and %W each showed similar results except the majority of the ocean stations had positive PCs for component 2 (bay anchovy and Atlantic menhaden vs. Atlantic silverside, portunid crab megalope and striped anchovy) while only a few had negative PCs (Figures 10-12 a,b).

*MANOVA*

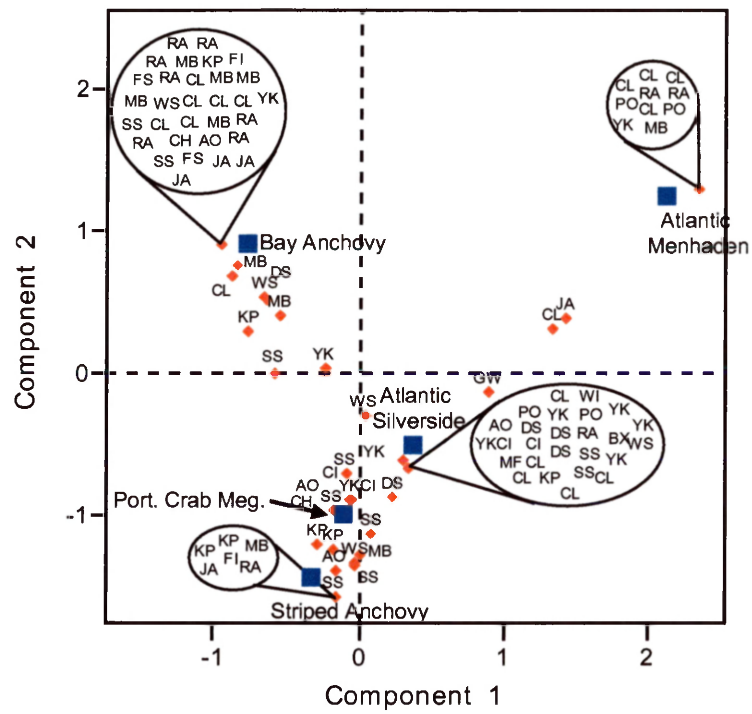
Bay anchovy, Atlantic silverside, striped anchovy, Atlantic menhaden and portunid crab megalope indices were used in each of the three-way MANOVAs. These five prey types accounted for 72.9%, 70.4%, 70.1% and 74.0% of the diet according to %IRI, %F, %N and %W, respectively. May, October and November data were excluded from these analyses, since only a few bluefish were collected in these months. The results of each MANOVA were similar, so only the %IRI MANOVA is described in detail to avoid redundancy.

Location and month explained a significant percentage of the variability in the %IRI values for these five prey types (Table 3). Thus, the diet composition in the Lower Chesapeake Bay and its tributaries differed from that in Virginia's coastal ocean (spatial variation), and the diet in each of these regions varied by month (intra-annual variation). Year did not have a significant effect on the %IRI

Figure 9. Biplot of station and prey type principal components (PCs) for component 1 and component 2 of a correspondence analysis using %IRI data by station from each sampling interval for the five main prey types identified by this index in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. Station PCs are represented by a) abbreviated station name and b) station type (bay vs. ocean).

# %IRI Correspondence Analysis

**a)**




**b)**

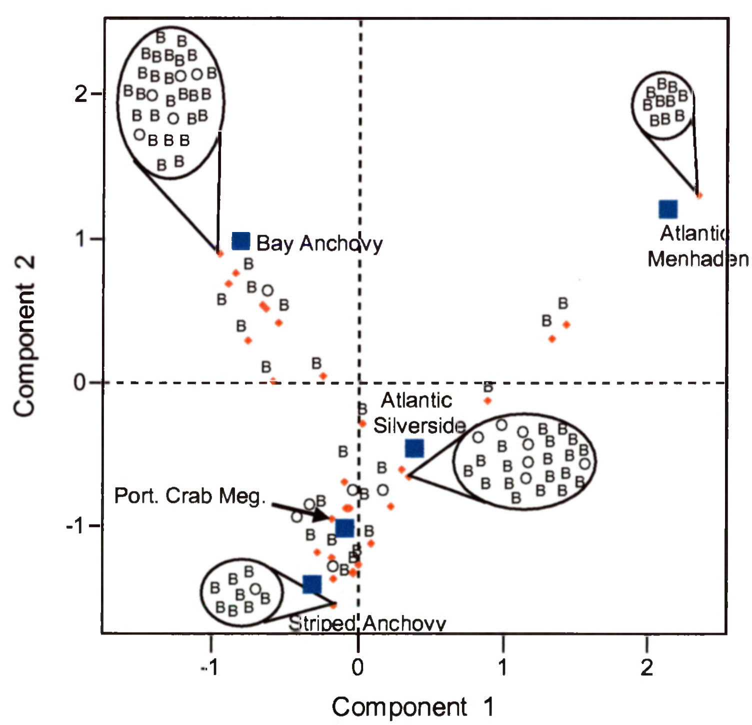


Figure 10. Biplot of station and prey type principal components (PCs) for component 1 and component 2 of a correspondence analysis using %F data by station from each sampling interval for the five main prey types identified by this index in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. Station PCs are represented by a) abbreviated station name and b) station type (bay vs. ocean).

# %F Correspondence Analysis

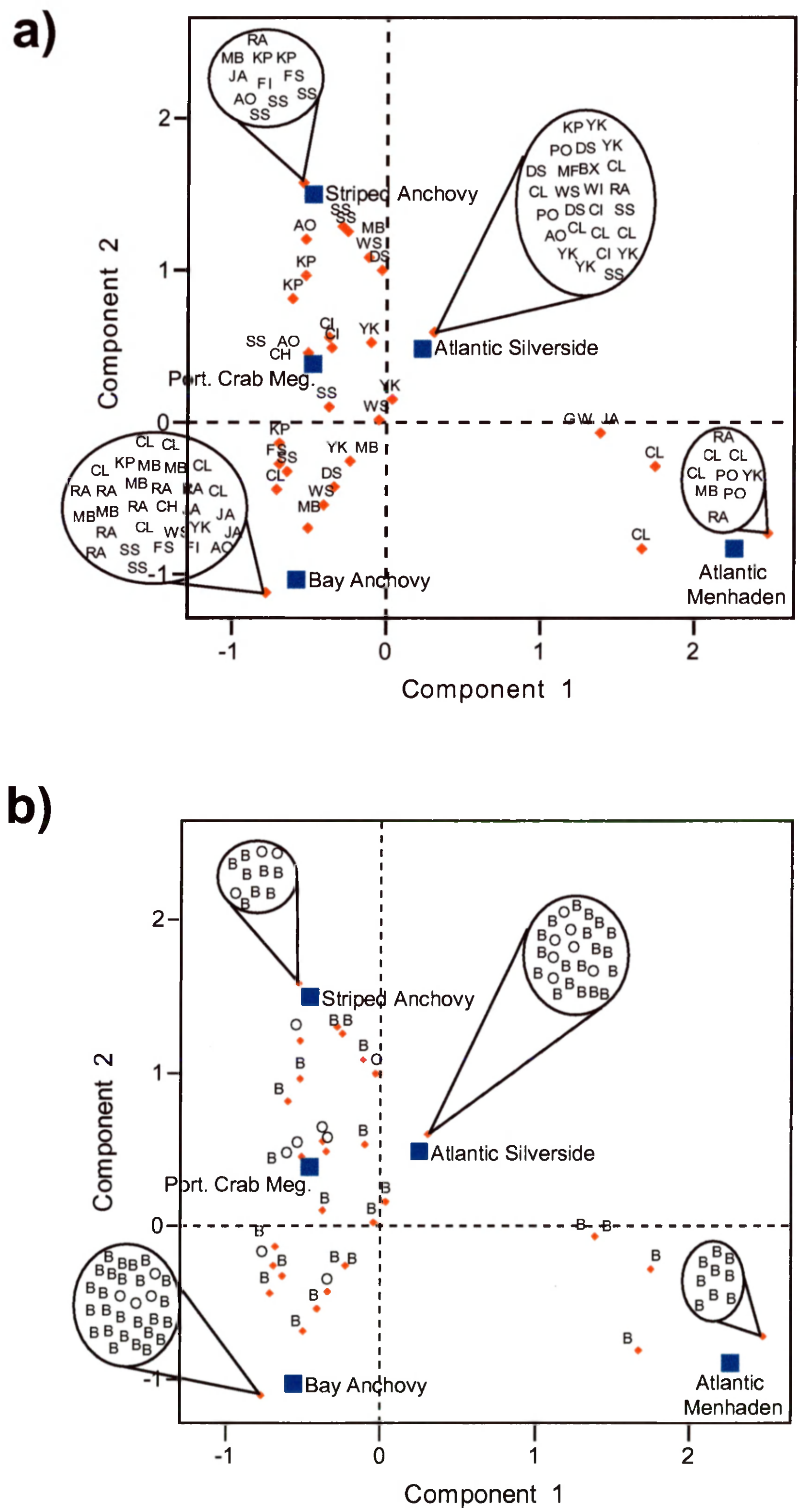
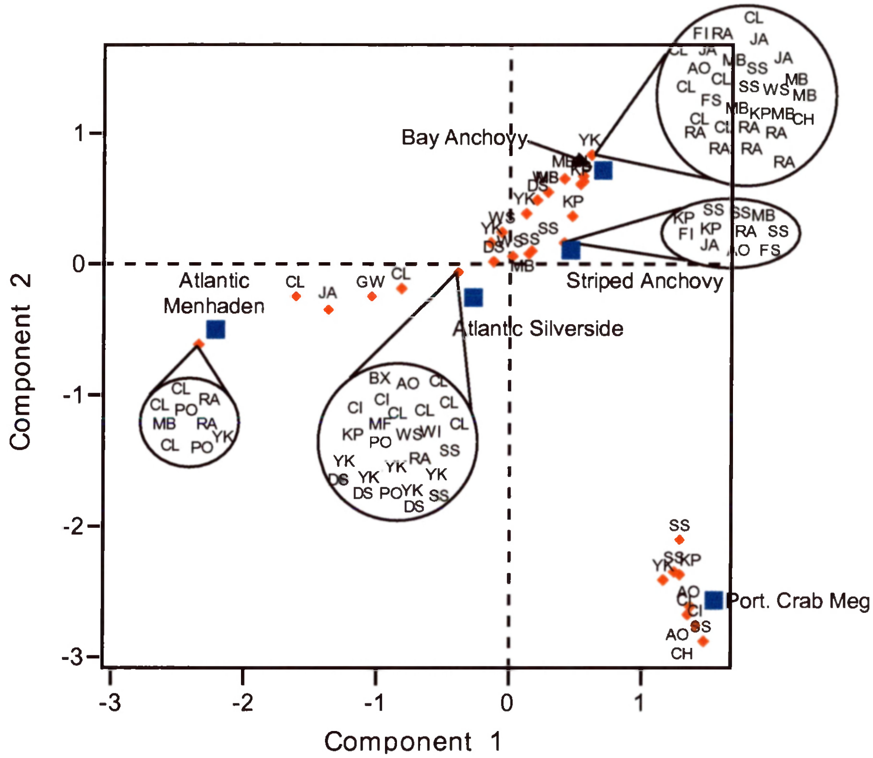


Figure 11. Biplot of station and prey type principal components (PCs) for component 1 and component 2 of a correspondence analysis using %N data by station from each sampling interval for the five main prey types identified by this index in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. Station PCs are represented by a) abbreviated station name and b) station type (bay vs. ocean).

# %N Correspondence Analysis

a)




b)

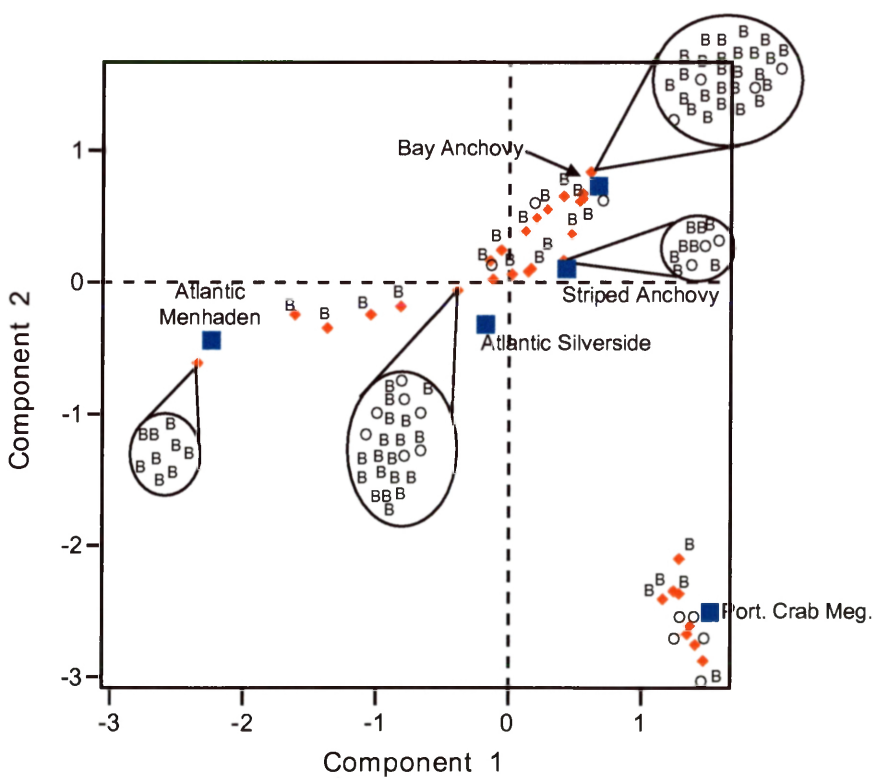


Figure 12. Biplot of station and prey type principal components (PCs) for component 1 and component 2 of a correspondence analysis using %W data by station from each sampling interval for the five main prey types identified by this index in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. Station PCs are represented by a) abbreviated station name and b) station type (bay vs. ocean).

# %W Correspondence Analysis

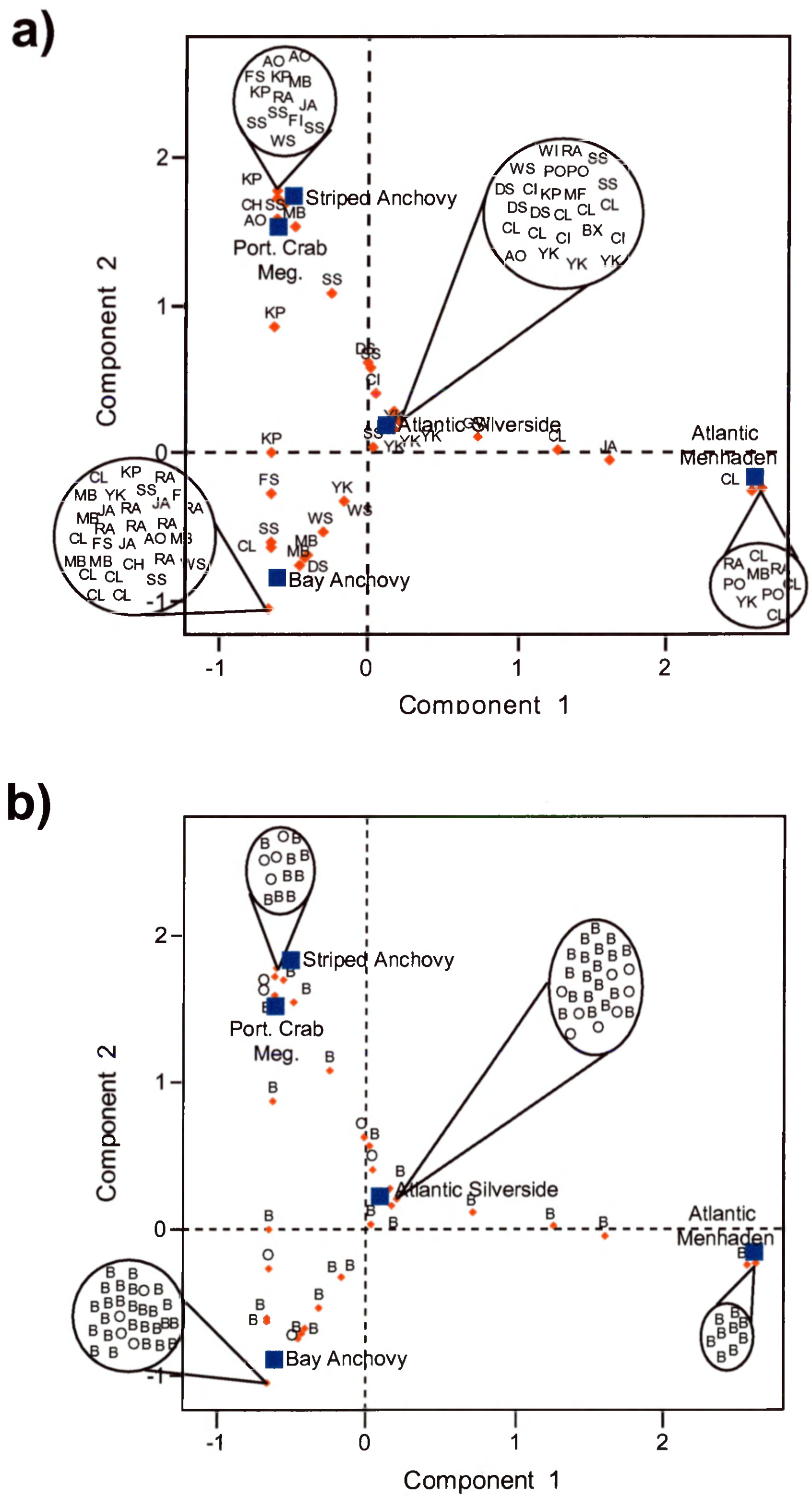


Table 3. Results of a three-way MANOVA where location, year and month were factors and the responses were %IRI values (by station for each sampling interval) for each of the five main prey types identified by this index in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. Factors and interaction terms were significant when $p \leq 0.05$.

**Three-Way MANOVA Results - %IRI**

| Factor | Pillai'sTrace | $F_{n,d}$ | p Value |
|---|---|---|---|
| Location | 0.1516 | $3.00_{5,84}$ | ***0.015*** |
| Year | 0.1016 | $1.90_{5,84}$ | 0.103 |
| Month | 0.4143 | $2.76_{15,258}$ | ***0.001*** |
| **Interaction** | **Pillai'sTrace** | $F_{n,d}$ | **p Value** |
| Location x Year | 0.0679 | $1.22_{5,84}$ | 0.305 |
| Location x Month | 0.2127 | $1.31_{15,258}$ | 0.194 |
| Year x Month | 0.2542 | $1.59_{15,258}$ | 0.076 |
| Location x Year x Month | 0.1164 | $0.69_{15,258}$ | 0.789 |

values of the five prey types, so the diet in 1999 was not different from that in 2000 (no inter-annual variation). None of the interaction terms were significant. The results of the three-way MANOVAs for the other diet indices are found in Tables 4-6.

*Detailed Diet Description*

Each MANOVA indicated that the YOY bluefish diet varied spatially and intra-annually. The following sections therefore provide by month diet descriptions for fish collected in 1) the coastal ocean and 2) the Lower Bay and its tributaries. A length-frequency distribution, percent of stomachs containing food and cumulative prey curve (when more than one identifiable prey type was encountered) was given for each location / month combination along with the four diet indices and standard errors for each prey type. Although May, October and November were excluded from the statistical analyses, they were included here for completeness. No YOY bluefish were collected, however, from Virginia's coastal ocean in November.

***Ocean***

*May*

Two YOY bluefish (49 mm and 57 mm) were collected from Virginia's coastal ocean in May 1999 and 2000. Since both specimens had only consumed Atlantic silverside, this prey type composed 100% of the diet according to each of the four indices.

Table 4. Results of a three-way MANOVA where location, year and month were factors and the responses were %F values (by station for each sampling interval) for each of the five main prey types identified by this index in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. Factors and interaction terms were significant when $p \leq 0.05$.

**Three-Way MANOVA Results - %F**

| Factor | Pillai'sTrace | $F_{n,d}$ | p Value |
|---|---|---|---|
| Location | 0.1302 | $2.51_{5,84}$ | ***0.036*** |
| Year | 0.0538 | $0.96_{5,84}$ | 0.450 |
| Month | 0.3660 | $2.39_{15,258}$ | ***0.003*** |
| **Interaction** | **Pillai'sTrace** | $F_{n,d}$ | **p Value** |
| Location x Year | 0.0327 | $0.57_{5,84}$ | 0.723 |
| Location x Month | 0.2025 | $1.25_{15,258}$ | 0.238 |
| Year x Month | 0.2400 | $1.50_{15,258}$ | 0.107 |
| Location x Year x Month | 0.0812 | $0.48_{15,258}$ | 0.950 |

Table 5. Results of a three-way MANOVA where location, year and month were factors and the responses were %N values (by station for each sampling interval) for each of the five main prey types identified by this index in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. Factors and interaction terms were significant when $p \leq 0.05$.

**Three-Way MANOVA Results - %N**

| Factor | Pillai's Trace | $F_{n,d}$ | p Value |
|---|---|---|---|
| Location | 0.1459 | $2.87_{5,84}$ | ***0.019*** |
| Year | 0.0977 | $1.81_{5,84}$ | 0.118 |
| Month | 0.3579 | $2.33_{15,258}$ | ***0.004*** |
| **Interaction** | **Pillai's Trace** | **$F_{n,d}$** | **p Value** |
| Location x Year | 0.0713 | $1.29_{5,84}$ | 0.276 |
| Location x Month | 0.1872 | $1.15_{15,258}$ | 0.317 |
| Year x Month | 0.2422 | $1.51_{15,258}$ | 0.101 |
| Location x Year x Month | 0.1073 | $0.64_{15,258}$ | 0.842 |

Table 6. Results of a three-way MANOVA where location, year and month were factors and the responses were %W values (by station for each sampling interval) for each of the five main prey types identified by this index in the diet of YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. Factors and interaction terms were significant when $p \leq 0.05$.

**Three-Way MANOVA Results - %W**

| **Factor** | **Pillai'sTrace** | $F_{n,d}$ | **p Value** |
|---|---|---|---|
| Location | 0.1407 | $2.75_{5,84}$ | ***0.024*** |
| Year | 0.0362 | $0.63_{5,84}$ | 0.677 |
| Month | 0.3839 | $2.52_{15,258}$ | ***0.002*** |
| **Factor** | **Pillai'sTrace** | $F_{n,d}$ | **p Value** |
| Location x Year | 0.0368 | $0.64_{5,84}$ | 0.669 |
| Location x Month | 0.2389 | $1.49_{15,258}$ | 0.109 |
| Year x Month | 0.2192 | $1.36_{15,258}$ | 0.170 |
| Location x Year x Month | 0.1098 | $0.65_{15,258}$ | 0.828 |

*June*

Sampling the near shore oceanic waters in June yielded six age-0 bluefish. These specimens ranged from 56 mm to 97 mm (Figure 13). Only one stomach (16.7%) was empty. As in May, Atlantic silverside dominated the diet, since each fish with food in its gut had consumed a single silverside.

*July*

Eighteen bluefish were collected from the coastal ocean in July. Most of the specimens ranged from 33 mm to 50 mm, while the smallest was 33 mm and the largest was 124 mm (Figure 14a). Fifteen fish (83.3%) had prey in their gut, but the cumulative prey curve did not reach an asymptote, indicating that an insufficient number of stomachs were analyzed to adequately characterize the diet (Figure 14b).

Atlantic silverside was the main prey once again, composing 24.1%, 22.8%, 21.2% and 38.2% by %IRI, %F, %N and %W (Table 7, Figure 15, Figure 16). Striped anchovy was the second most important prey type. They accounted for 20.0% of the diet by each of the four indices. Invertebrates were also prevalent, as portunid crab megalope and sand shrimp had %IRI values of 14.7% and 9.4%, respectively. The crab megalope owed their importance to their numerical abundance rather than their weight contribution. Numerous, small individuals were encountered in approximately 10% of the stomachs. Most of the fish that had consumed these megalope were less than 50 mm. Bay anchovy accounted for 14.6% by %IRI at this time. A large component of the diet was unidentified fish. This category's contribution by occurrence and number

Figure 13. Length-frequency distribution of YOY bluefish collected in June 1999 and 2000 from Virginia's coastal ocean. Lengths are fork lengths in millimeters (mm).

# Ocean – June 1999 & 2000

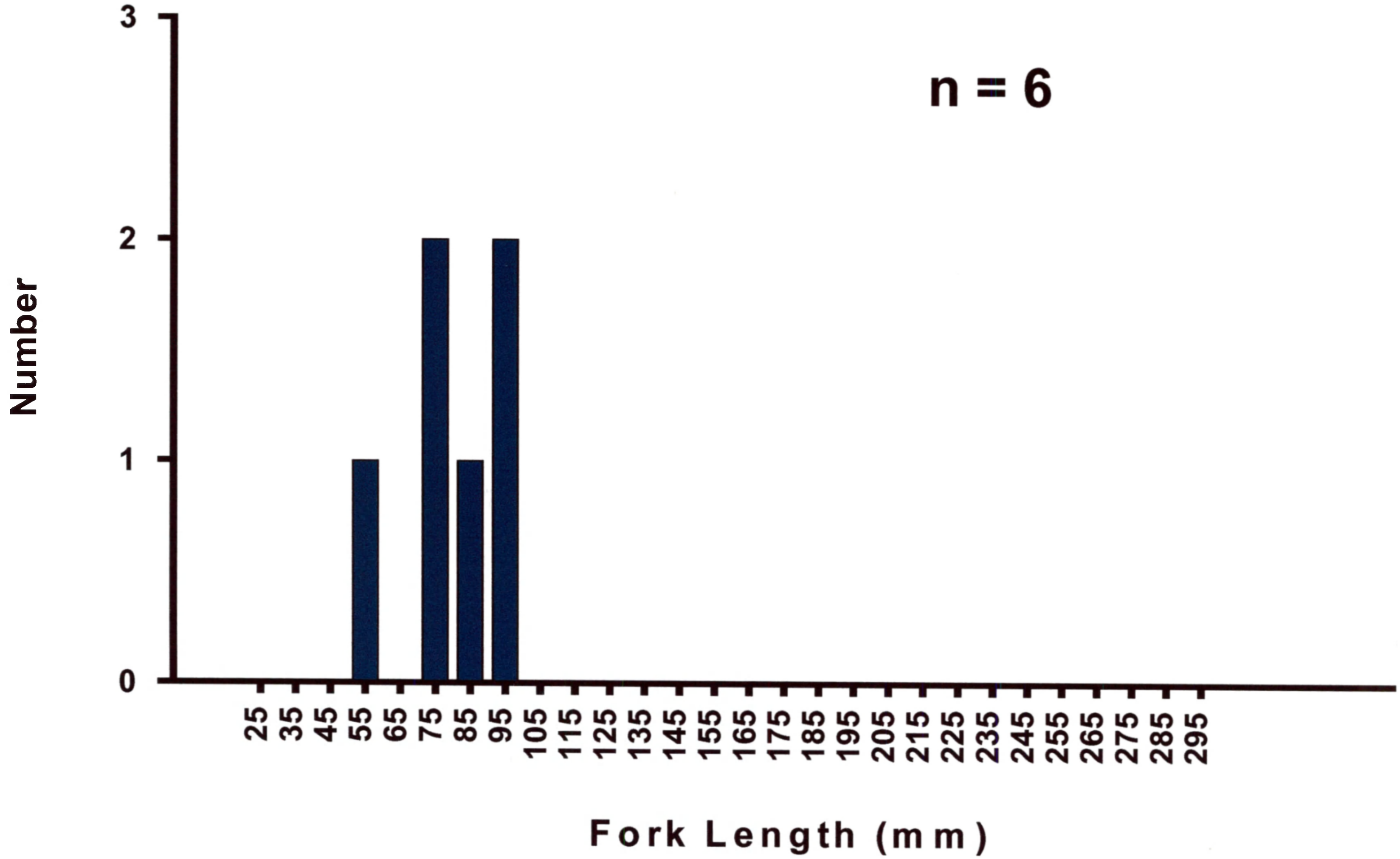
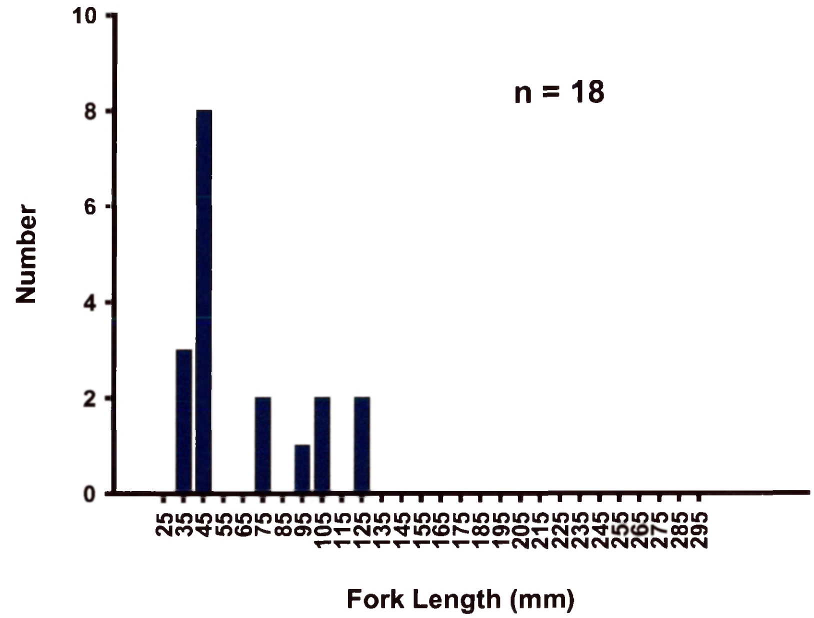


Figure 14a. Length-frequency distribution of YOY bluefish collected in July 1999 and 2000 from Virginia's coastal ocean. Lengths are fork lengths in millimeters (mm).

Figure 14b. Cumulative prey curve for YOY bluefish collected in July 1999 and 2000 from Virginia's coastal ocean. Points are mean values and error bars are ± SD.

# Ocean – July 1999 & 2000

a)




b)

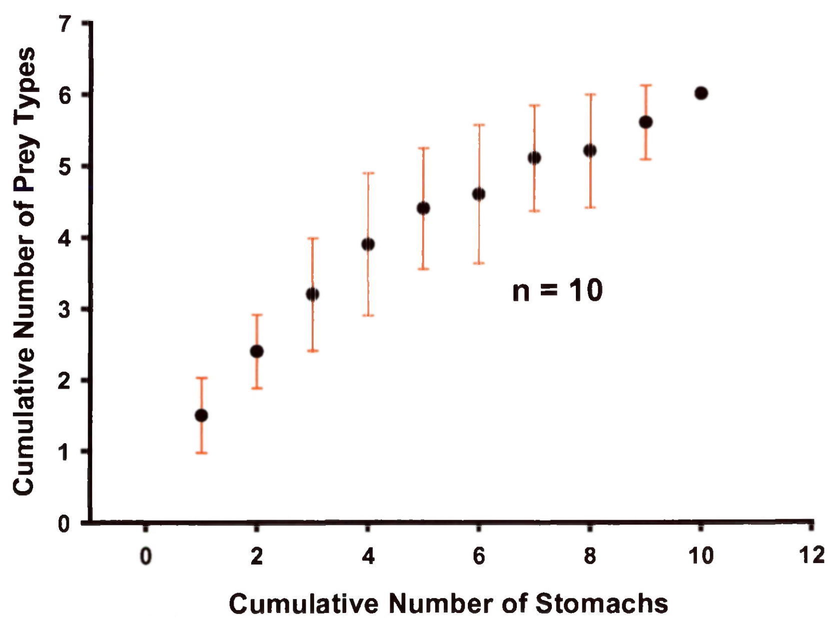


Table 7. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected in July 1999 and 2000 from Virginia's coastal ocean.

| Species | % IRI | %F | %N | %W |
|---|---|---|---|---|
| Atlantic silverside | 24.1 (±19.4) | 22.8 (±19.5) | 21.2 (±19.7) | 38.2 (±23.4) |
| Striped anchovy | 20.0 (±20.0) | 20.0 (±20.0) | 20.0 (±20.0) | 20.0 (±20.0) |
| Unidentified fish | 16.1 (±10.7) | 20.0 (±12.2) | 20.0 (±12.2) | 12.3 (±11.2) |
| Port. crab. meg. | 14.7 (±14.7) | 11.4 (±11.4) | 16.3 (±16.3) | 1.0 (±1.0) |
| Bay anchovy | 14.6 (±14.5) | 10.0 (±10.0) | 10.0 (±10.0) | 19.2 (±19.2) |
| Sand shrimp | 9.4 (±9.3) | 12.9 (±9.7) | 10.6 (±9.9) | 8.6 (±8.6) |
| Unidentified meat | 0.8 (±0.8) | 5.7 (±5.7) | 1.3 (±1.3) | 0.7 (±0.7) |
| Opossum shrimp | 0.2 (±0.1) | 2.9 (±2.9) | 0.6 (±0.6) | 0.1 (±0.1) |

Figure 15. Percent IRI values for prey types in the diet of YOY bluefish collected from Virginia's coastal ocean in July 1999 and 2000.

# Ocean – July 1999 & 2000

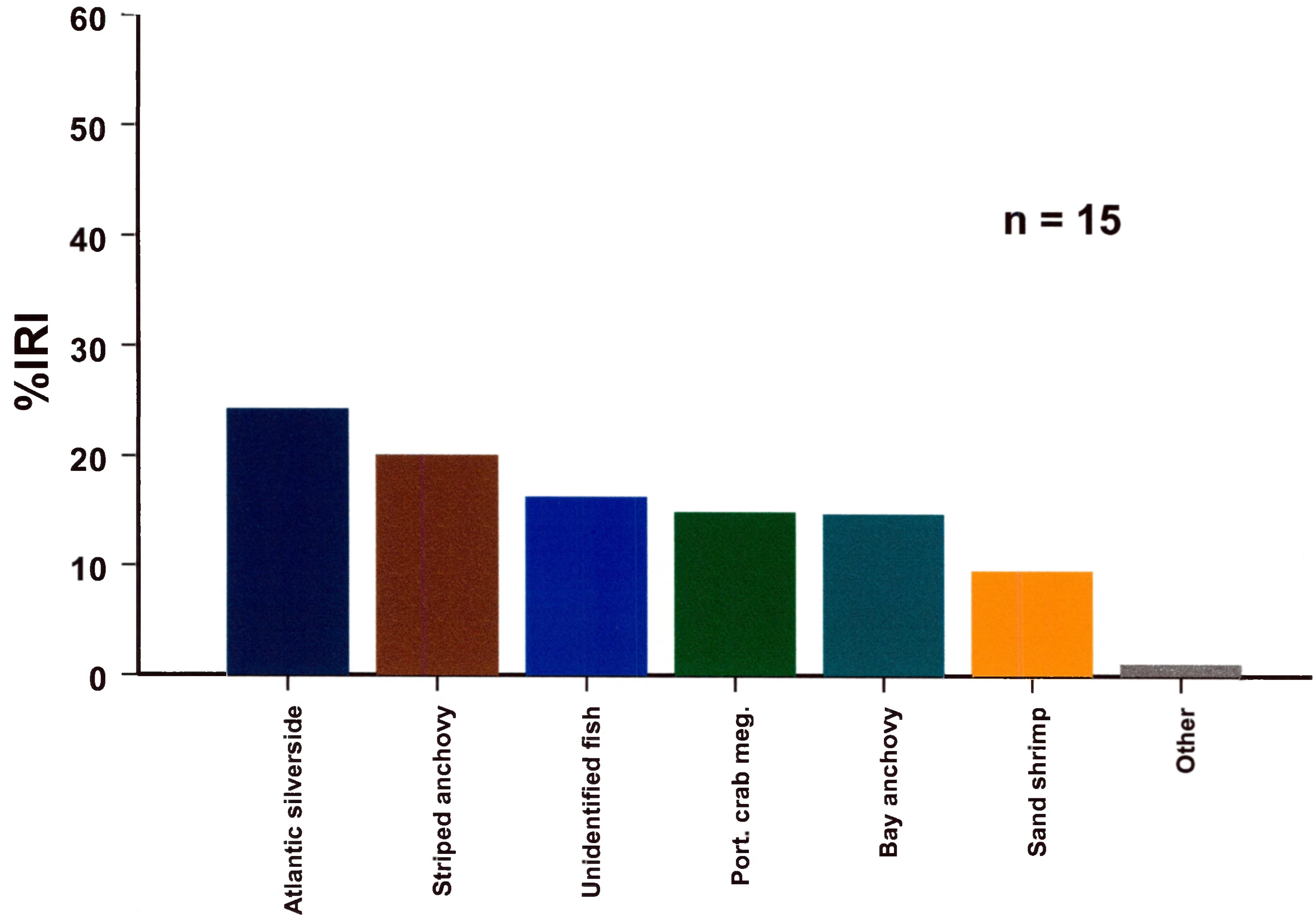
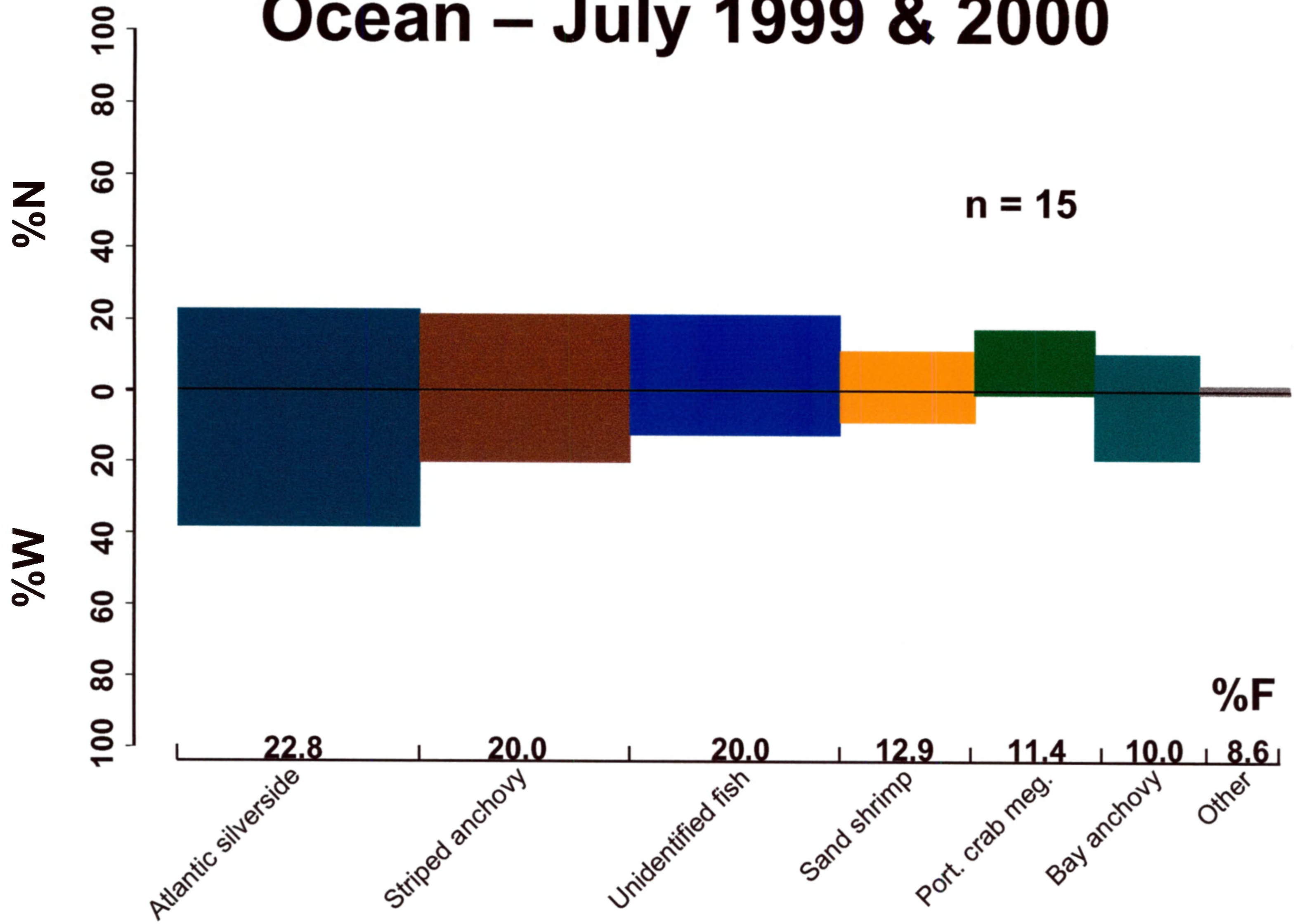


Figure 16. %F, %N and %W values for prey types in the diet of YOY bluefish collected from Virginia's coastal ocean in July 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F.

# Ocean – July 1999 & 2000



exceeded that by weight since well digested fish remains, such as vertebrae and other bony structures, were encountered in many stomachs.

*August*

The 71 bluefish sampled from Virginia's coastal ocean in August 1999 and 2000 ranged from 43 mm to 133 mm, but most were 40 mm to 60 mm (Figure 17a). Prey were encountered in 56 stomachs (78.9%), and the cumulative prey curve reached an asymptote (Figure 17b).

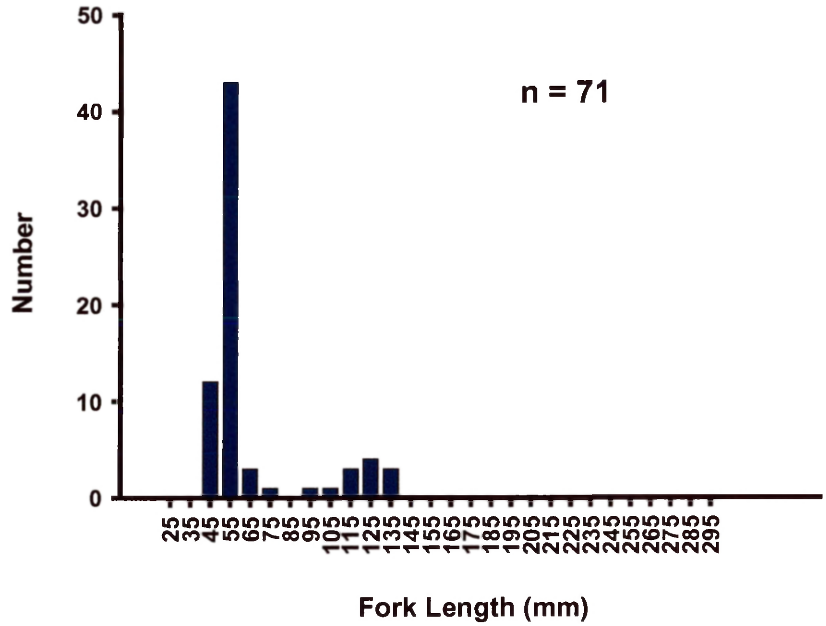
Portunid crab megalope increased in importance and were the main prey in August (Table 8, Figure 18, Figure 19). The %IRI value for these crustaceans was 38.7%, and their numerical contribution was again much greater than that by weight. Although all of the bluefish that had consumed these crabs in July were less than 50 mm, most of those with megalope in their gut in August were about 100 mm. Atlantic silverside continued to decline in importance with a %IRI value of 14.1%. Bay anchovy had the third highest contribution to the diet according to %IRI (13.2%) and %W (10.5%). Gammarid amphipod (*Gammarus spp.*) and opossum shrimp (*Neomysis americana*) accounted for 7.7% and 7.0% by %IRI. Similar to portunid crab megalope, the gammarid amphipod contribution was far greater numerically than by weight because a large number of these small prey had been consumed. Striped anchovy, anchovy spp. and bluefish were also found and had %IRI values of 3.3%, 2.3% and 2.0%, respectively. The presence of age-0 bluefish in the diet confirms that bluefish are cannibalistic and will even prey on members of their own year-class. The highest prey type diversity in the coastal ocean YOY bluefish diet occurred at this time.

Figure 17a. Length-frequency distribution of YOY bluefish collected in August 1999 and 2000 from Virginia's coastal ocean. Lengths are fork lengths in millimeters (mm).

Figure 17b. Cumulative prey curve for YOY bluefish collected in August 1999 and 2000 from Virginia's coastal ocean. Points are mean values and error bars are $\pm$ SD.

# Ocean – August 1999 & 2000

a)




b)

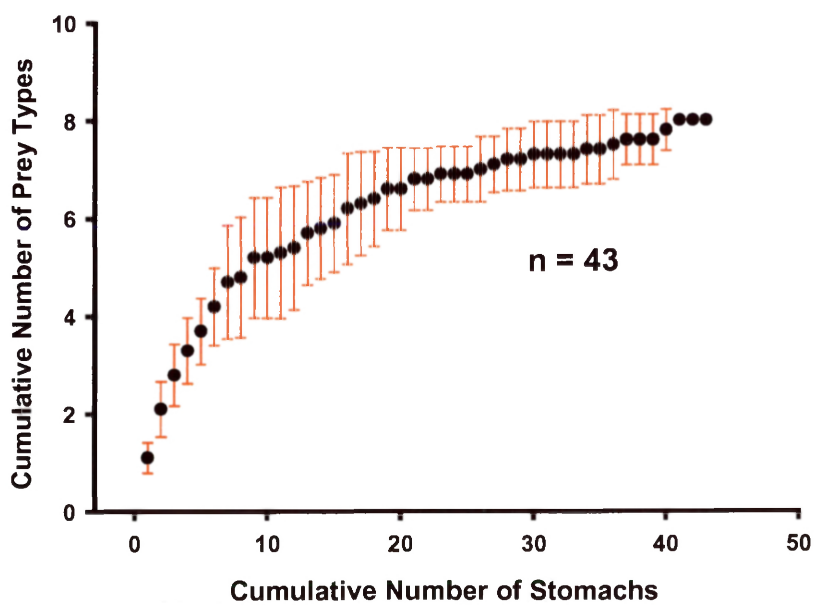


Table 8. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected in August 1999 and 2000 from Virginia's coastal ocean.

| Species | % IRI | %F | %N | %W |
|---|---|---|---|---|
| Port. crab meg. | 38.7 (±18.1) | 42.6 (±20.2) | 40.5 (±19.4) | 29.3 (±17.6) |
| Atlantic silverside | 14.1 (±10.4) | 10.9 (±7.4) | 7.0 (±6.6) | 19.9 (±13.2) |
| Bay anchovy | 13.2 (±13.1) | 8.4 (±6.5) | 6.5 (±6.3) | 10.5 (±9.9) |
| Gammarid amphipod | 7.7 (±7.7) | 5.5 (±5.5) | 11.9 (±11.9) | 3.6 (±3.7) |
| Opossum shrimp | 7.0 (±7.0) | 16.7 (±16.6) | 8.3 (±8.3) | 5.5 (±5.5) |
| Unidentified meat | 6.6 (±5.8) | 10.8 (±5.0) | 5.2 (±2.5) | 10.4 (±9.4) |
| Striped anchovy | 3.3 (±2.9) | 8.5 (±5.4) | 6.5 (±3.9) | 7.3 (±4.0) |
| Unidentified invert. | 3.0 (±3.0) | 5.5 (±5.5) | 2.4 (±2.4) | 3.6 (±3.6) |
| Anchovy spp. | 2.3 (±2.2) | 6.7 (±4.3) | 3.7 (±3.4) | 2.7 (±2.4) |
| Unidentified fish | 2.1 (±1.3) | 7.3 (±3.4) | 6.4 (±3.9) | 0.6 (±0.3) |
| Bluefish | 2.0 (±2.0) | 2.4 (±2.4) | 1.7 (±1.7) | 6.5 (±6.4) |

Figure 18. Percent IRI values for prey types in the diet of YOY bluefish collected from Virginia's coastal ocean in August 1999 and 2000.

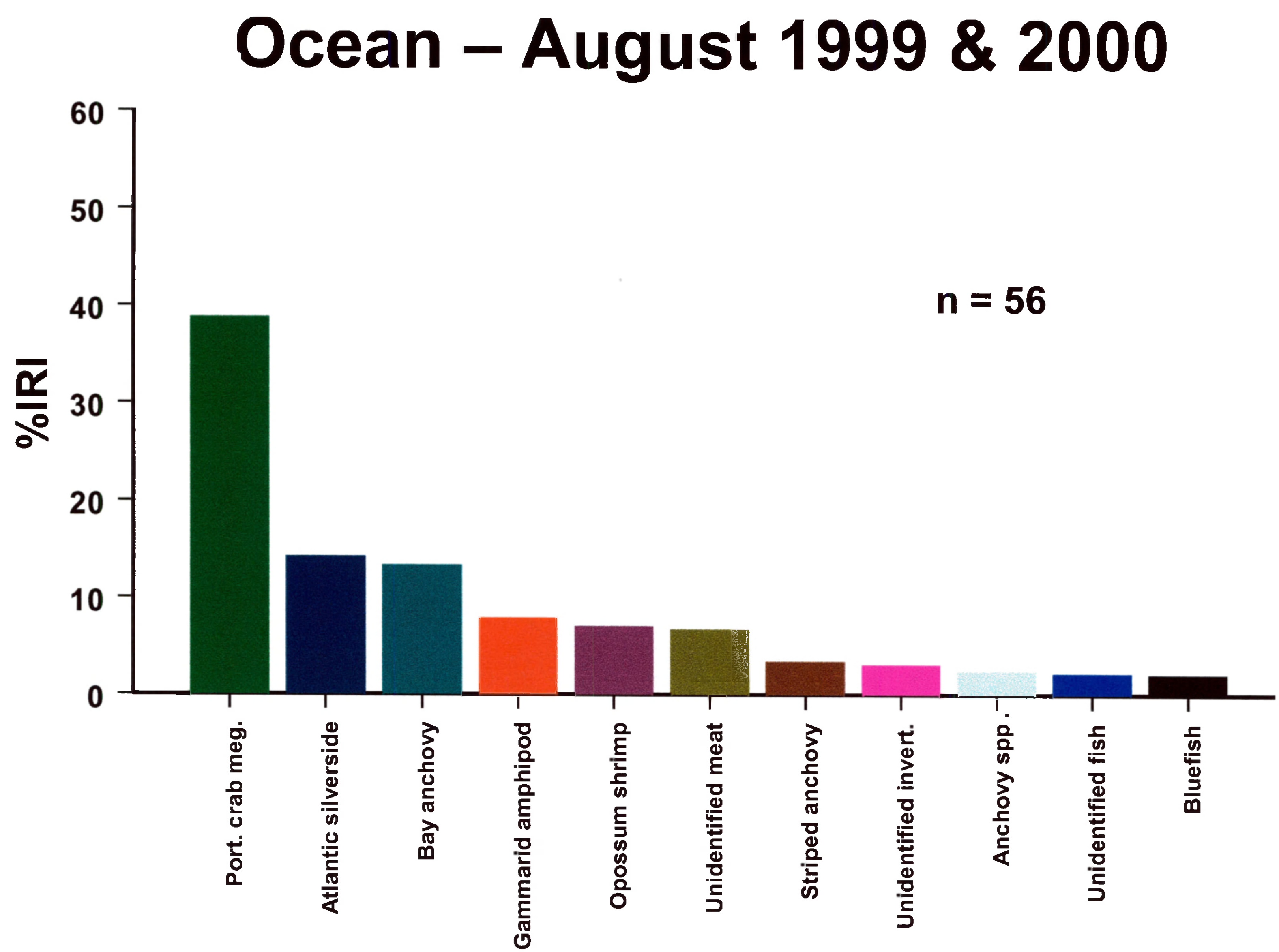
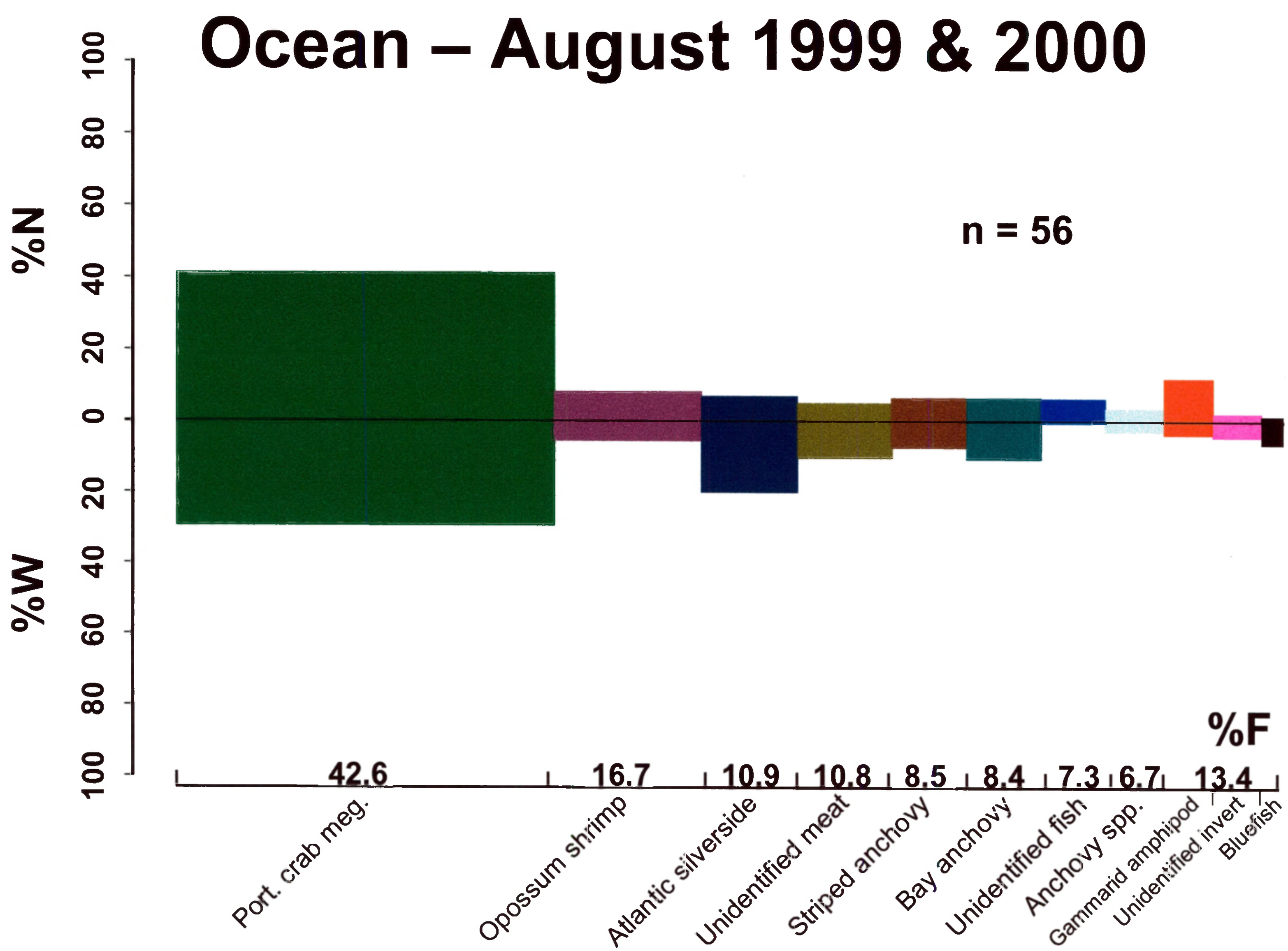

Ocean – August 1999 & 2000
%IRI
60
50
40
30
20
10
0
n = 56
Port. crab meg.
Atlantic silverside
Bay anchovy
Gammarid amphipod
Opossum shrimp
Unidentified meat
Striped anchovy
Unidentified invert.
Anchovy spp .
Unidentified fish
Bluefish

Figure 19. %F, %N and %W values for prey types in the diet of YOY bluefish collected from Virginia's coastal ocean in August 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F.


Ocean – August 1999 & 2000
n = 56
%N
%W
100
80
60
40
20
0
20
40
60
80
100
%F
42.6
16.7
10.9
10.8
8.5
8.4
7.3
6.7
13.4
Port. crab meg.
Opossum shrimp
Atlantic silverside
Unidentified meat
Striped anchovy
Bay anchovy
Unidentified fish
Anchovy spp.
Gammarid amphipod
Unidentified invert
Bluefish

*September*

Thirty-four YOY bluefish, ranging from 49 mm to 159 mm, were collected from the near shore oceanic waters in September (Figure 20a). The largest percentage of empty stomachs in the coastal ocean collections occurred at this time, as 11 (32.4%) were empty. The cumulative prey curve reached an asymptote (Figure 20b). Striped anchovy increased in importance relative to the August diet and were the main prey with a %IRI of 30.0% (Table 9, Figure 21). Percent IRI values for the morphologically similar bay anchovy and Atlantic silverside were 26.1% and 24.5%, respectively. Striped anchovy dominated by %F and %W, while the Atlantic silverside had the highest %N value (Figure 22). The contributions by the top three prey types were more equal in September than in August. Portunid crab megalope declined in importance, composing only 3.3% by %IRI. The contribution by number (10.1%) was again much greater than by weight (0.2%).

October

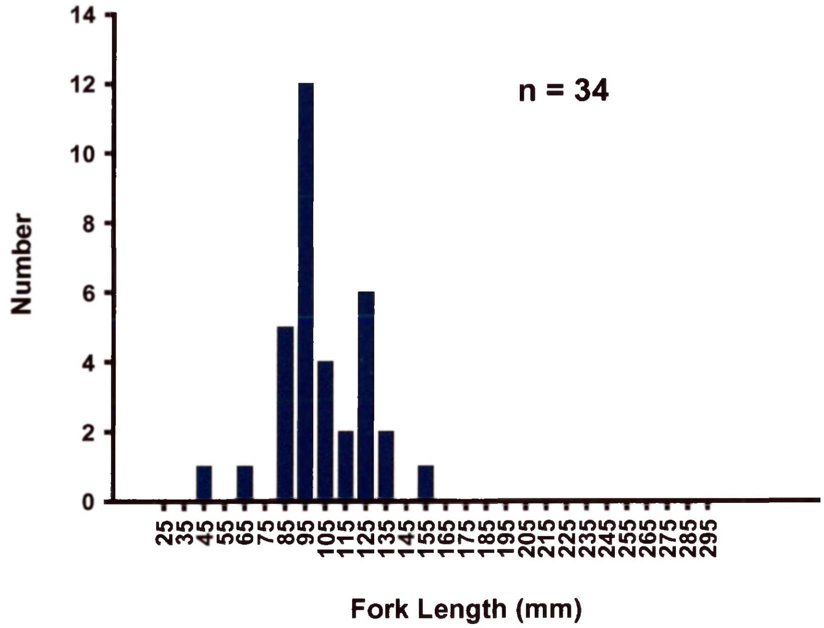
The five age-0 bluefish collected from Virginia's coastal ocean in October spanned from 113 mm to 151 mm. Four fish (80.0%) had prey in their gut. Since each bluefish only had bay anchovy in its gut, this schooling, pelagic forage fish composed 100.0% of the diet by %IRI, %F, %N and %W.

Figure 20a. Length-frequency distribution of YOY bluefish collected in September 1999 and 2000 from Virginia's coastal ocean. Lengths are fork lengths in millimeters (mm).

Figure 20b. Cumulative prey curve for YOY bluefish collected in September 1999 and 2000 from Virginia's coastal ocean. Points are mean values and error bars are ± SD.

# Ocean – September 1999 & 2000

a)




b)

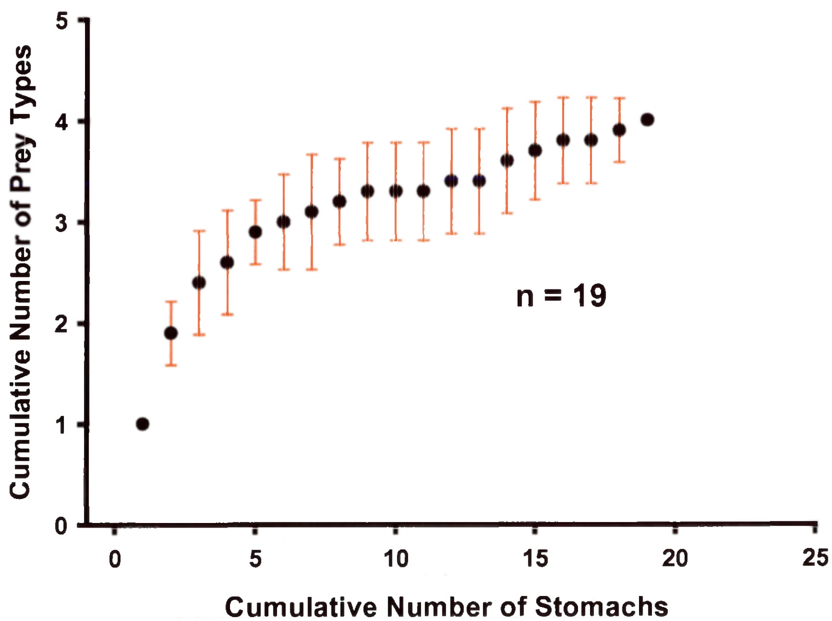


Table 9. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected in September 1999 and 2000 from Virginia's coastal ocean.

| Species | % IRI | %F | %N | %W |
|---|---|---|---|---|
| Striped anchovy | 30.0 (±15.3) | 29.6 (±15.1) | 23.2 (±14.5) | 33.2 (±16.6) |
| Bay anchovy | 26.1 (±13.4) | 21.4 (±11.9) | 21.4 (±11.9) | 28.5 (±14.7) |
| Atlantic silverside | 24.5 (±14.4) | 25.4 (±14.4) | 25.4 (±14.4) | 24.7 (±14.4) |
| Unidentified fish | 13.2 (±11.0) | 14.3 (±11.2) | 14.3 (±11.2) | 13.1 (±11.0) |
| Port. crab meg. | 3.3 (±3.3) | 3.7 (±3.7) | 10.1 (±10.1) | 0.2 (±0.2) |
| Unidentified meat | 3.0 (±3.0) | 5.6 (±5.6) | 5.5 (±5.6) | 0.4(±0.4) |

Figure 21. Percent IRI values for prey types in the diet of YOY bluefish collected from Virginia's coastal ocean in September 1999 and 2000.

# Ocean – September 1999 & 2000

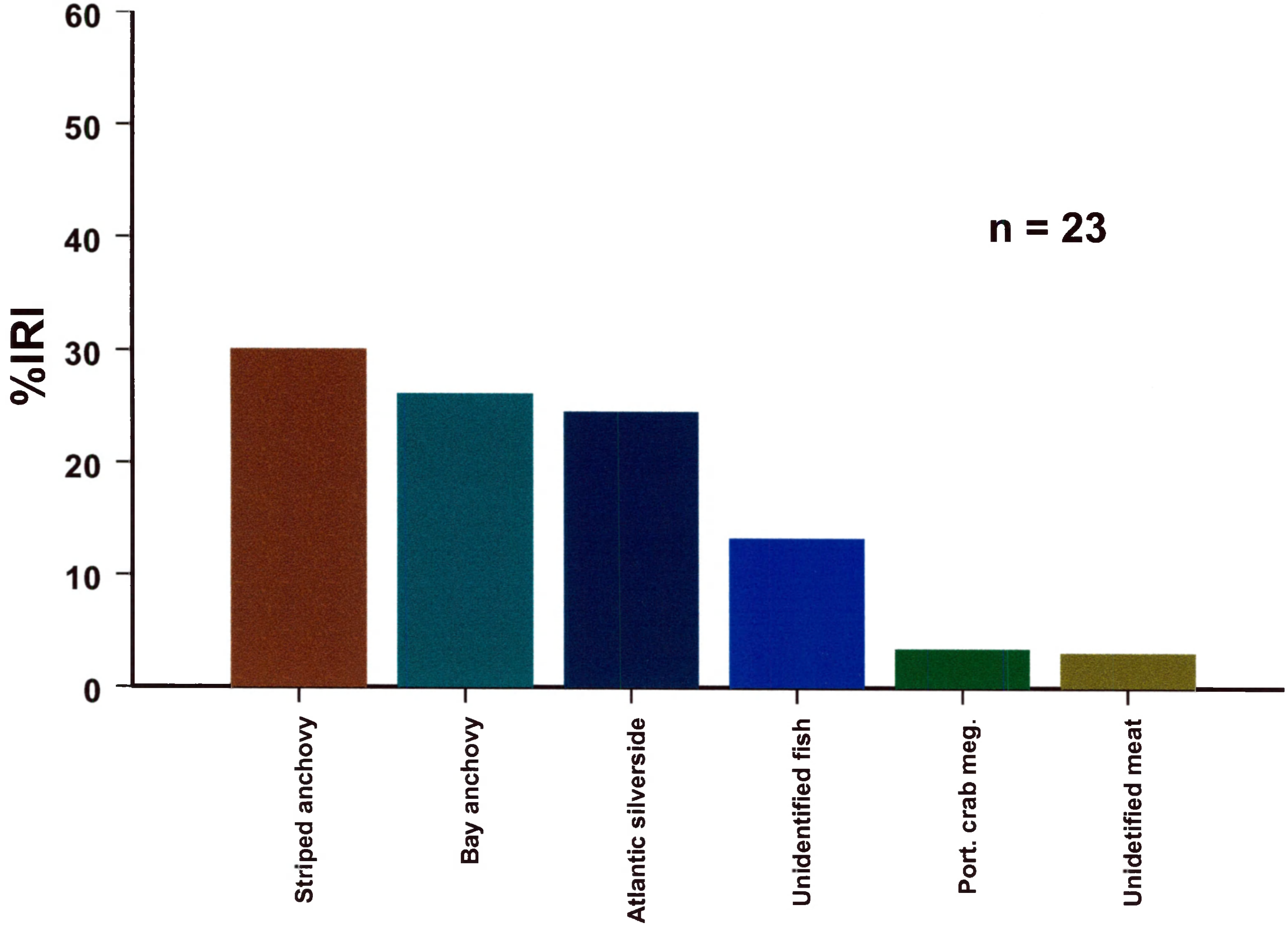
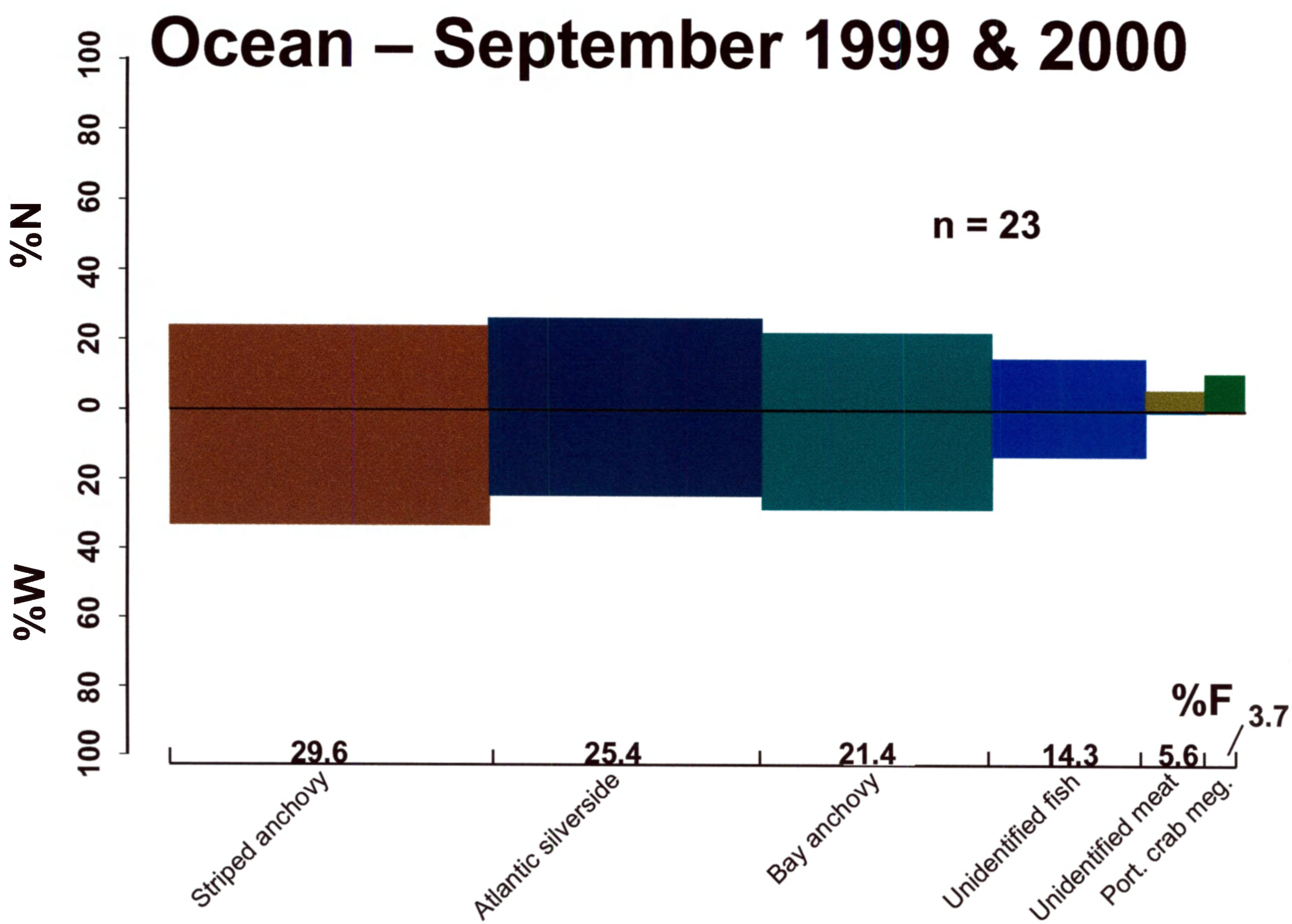


Figure 22. %F, %N and %W values for prey types in the diet of YOY bluefish collected from Virginia's coastal ocean in September 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F.


Ocean – September 1999 & 2000
n = 23
%N
%W
100
80
60
40
20
0
20
40
60
80
100
%F
29.6
25.4
21.4
14.3
5.6
3.7
Striped anchovy
Atlantic silverside
Bay anchovy
Unidentified fish
Unidentified meat
Port. crab meg.

## ***Bay***

*May*

Sampling the Lower Chesapeake Bay in May 1999 and 2000 yielded four YOY bluefish. These fish ranged from 39 mm to 50 mm, and 75.0% had food in their stomach (Figure 23). Only a single bluefish had identifiable prey in its gut, so a cumulative prey curve could not be constructed to assess whether this diet description was sufficient. Unlike the May ocean diet, portunid crab megalope was the main prey, and they accounted for 50.0% by %IRI, %F, %N and %W, respectively (Table 10, Figure 24, Figure 25). Unidentified eggs were also consumed and had a %IRI value of 44.5%. Attempts to identify these eggs were unsuccessful, since most were crushed or partly digested. Unidentified meat composed the remainder of the diet.

*June*

Of the 60 age-0 bluefish collected from the Lower Bay in June 1999 and 2000, which ranged from 34 mm to 129 mm, 80.0% contained prey (Figure 26a). The cumulative prey curve reached an asymptote, so the number of guts collected may have been sufficient (Figure 26b).

As in the June ocean diet, Atlantic silverside had the highest %IRI value (54.9%) and also dominated by %F, %N and %W (Table 11, Figure 27, Figure 28). Sand shrimp and bay anchovy were also important with %IRI values of 9.4% and 8.2%, respectively. Striped bass (4.9%), striped anchovy (4.4%), mummichog (*Fundulus heteroclitus*) (3.0%) and opossum shrimp (2.2%) were part of the June Lower Bay diet. Other prey types were consumed, but

Figure 23. Length-frequency distribution of YOY bluefish collected in May 1999 and 2000 from the Lower Chesapeake Bay. Lengths are fork lengths in millimeters (mm).

# Bay – May 1999 & 2000

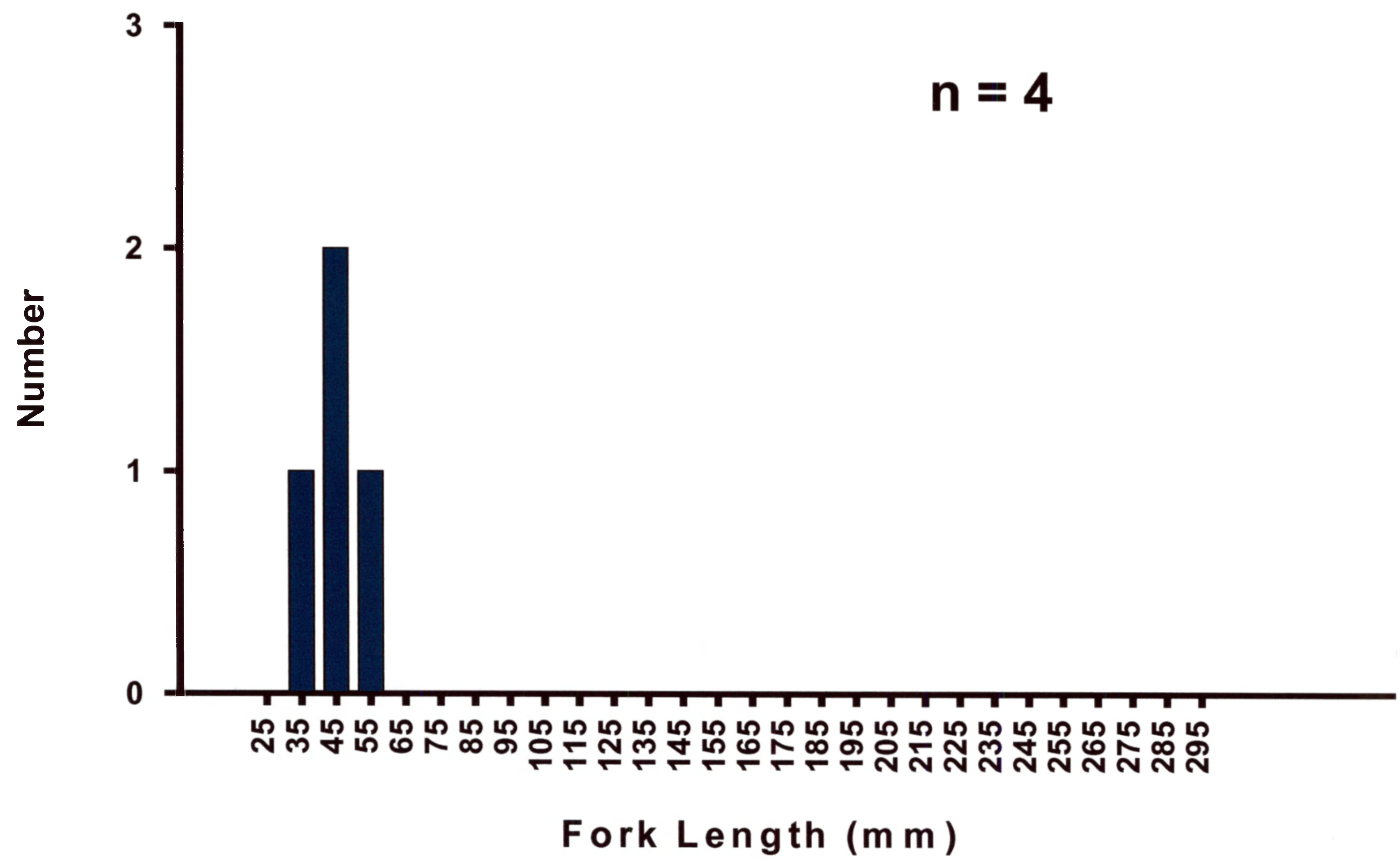


Table 10. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected in May 1999 and 2000 from the Lower Chesapeake Bay.

| **Species** | **% IRI** | **%F** | **%N** | **%W** |
|---|---|---|---|---|
| Port. crab meg. | 50.0 (± 50.0) | 50.0 (± 50.0) | 50.0 (± 50.0) | 50.0 (± 50.0) |
| Unidentified egg | 44.5 (± 44.5) | 50.0 (± 50.0) | 49.2 (± 49.1) | 31.0 (± 31.0) |
| Unidentified meat | 5.5 (± 5.5) | 25.0 (± 25.0) | 0.9 (± 0.9) | 19.0 (± 19.0) |

Figure 24. Percent IRI values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in May 1999 and 2000.

# Bay – May 1999 & 2000

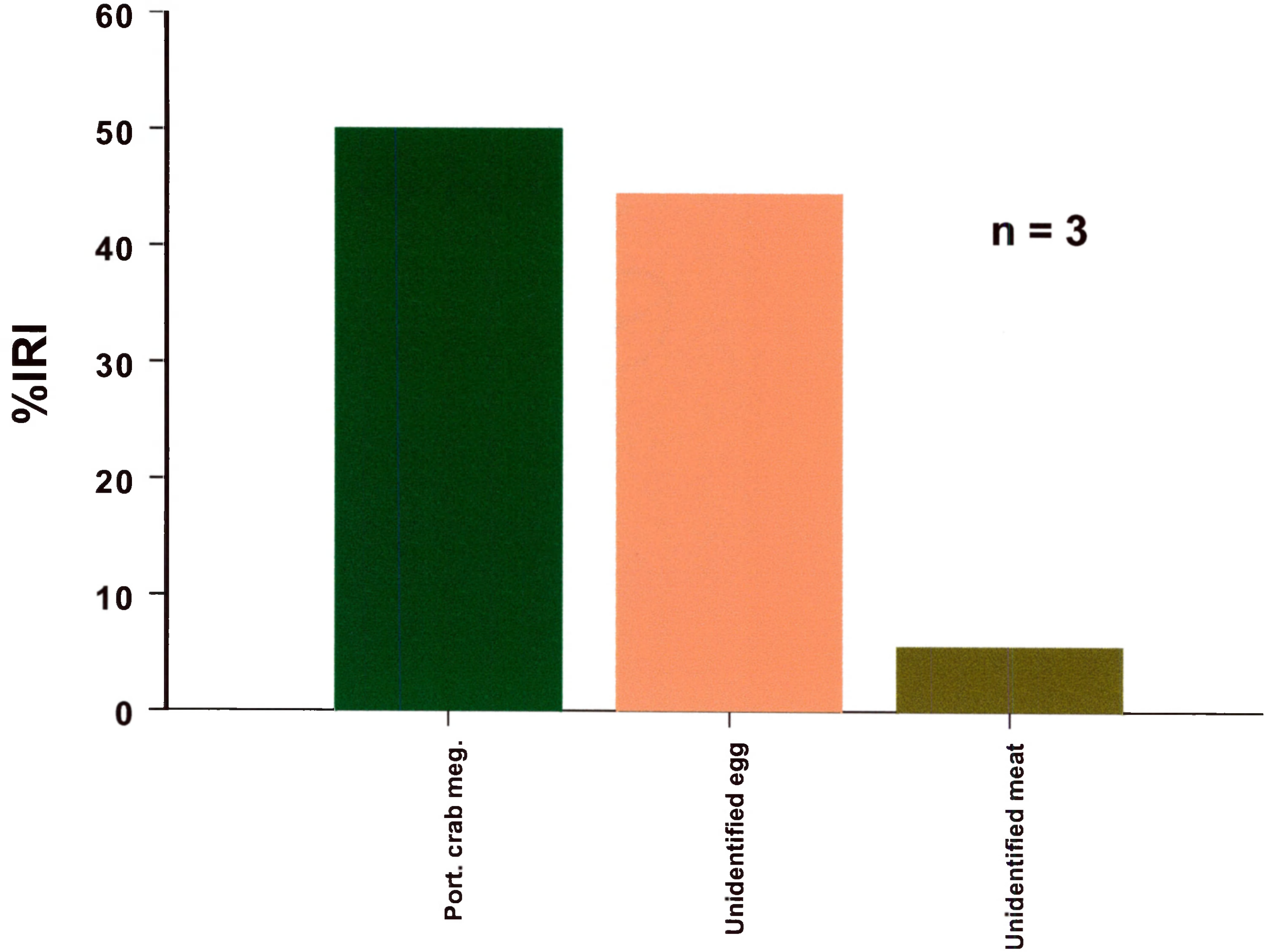


Figure 25. %F, %N and %W values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in May 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F

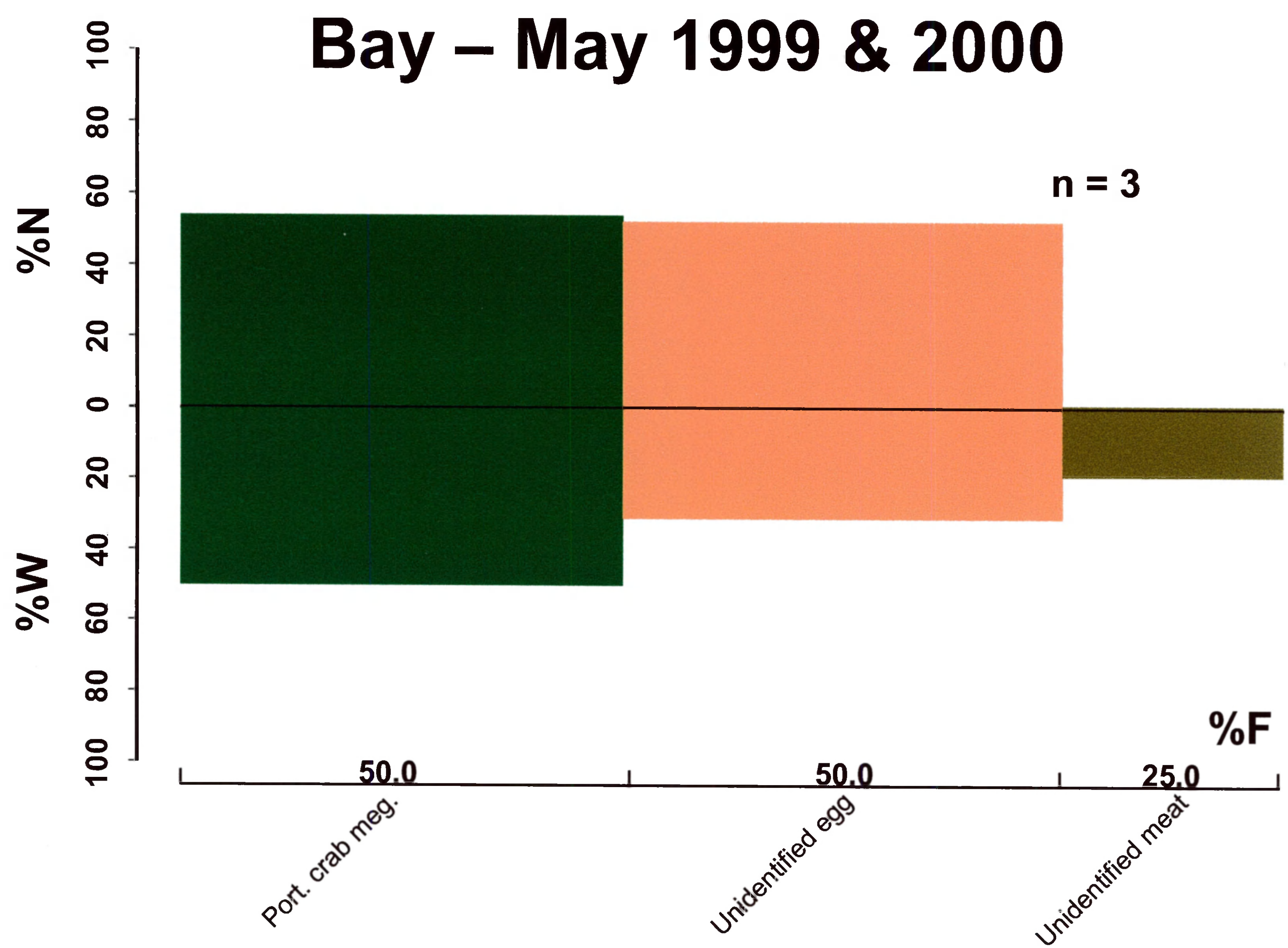
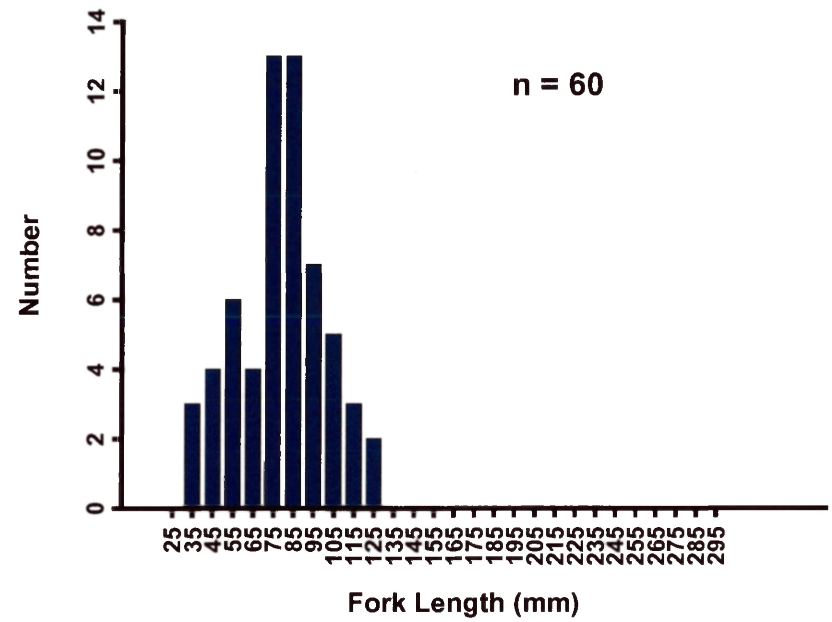

Bay – May 1999 & 2000
n = 3
%N
%W
100
80
60
40
20
0
20
40
60
80
100
%F
50.0
50.0
25.0
Port. crab meg.
Unidentified egg
Unidentified meat

Figure 26a. Length-frequency distribution of YOY bluefish collected in June 1999 and 2000 from the Lower Chesapeake Bay. Lengths are fork lengths in millimeters (mm).

Figure 26b. Cumulative prey curve for YOY bluefish collected in June 1999 and 2000 from the Lower Chesapeake Bay. Points are mean values and error bars are ± SD.

# Bay – June 1999 & 2000

a)




b)

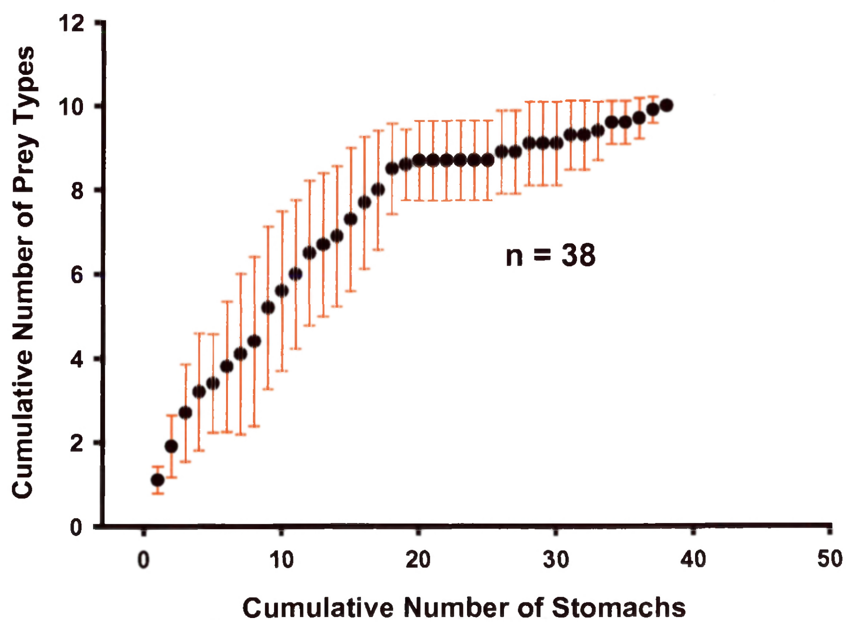


Table 11. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected in June 1999 and 2000 from the Lower Chesapeake Bay.

| Species | % IRI | %F | %N | %W |
|---|---|---|---|---|
| Atlantic silverside | 54.9 (± 9.6) | 53.9 (± 9.3) | 51.2 (± 9.6) | 53.2 (± 9.9) |
| Sand shrimp | 9.4 (± 5.4) | 10.1 (± 5.2) | 9.1 (± 5.0) | 10.1 (± 6.0) |
| Bay anchovy | 8.2 (± 4.7) | 10.1 (± 5.0) | 9.3 (± 4.9) | 8.4 (± 4.8) |
| Unidentified fish | 6.6 (± 3.4) | 10.5 (± 3.6) | 7.5 (± 3.0) | 7.2 (± 4.1) |
| Striped bass | 4.9 (± 3.5) | 5.0 (± 3.5) | 2.2 (± 1.6) | 5.7 (± 4.3) |
| Striped anchovy | 4.4 (± 4.3) | 4.3 (± 4.3) | 4.4 (± 4.3) | 4.4 (± 4.3) |
| Mummichog | 3.0 (± 3.0) | 2.2 (± 2.2) | 2.9 (± 2.0) | 3.0 (± 3.0) |
| Opossum shrimp | 2.2 (± 1.8) | 2.9 (± 2.0) | 4.6 (± 3.5) | 1.1 (± 1.1) |
| White perch | 1.9 (± 1.9) | 2.2 (± 2.2) | 1.4 (± 1.4) | 1.9 (± 2.0) |
| Unidentified invert. | 1.4 (± 1.2) | 2.5 (± 1.8) | 2.2 (± 1.6) | 1.0 (± 1.0) |
| Unidentified squid | 1.4 (± 1.4) | 1.1 (± 1.1) | 1.1 (± 1.1) | 4.1 (± 4.0) |
| Unidentified meat | 1.1 (± 1.1) | 2.2 (± 2.2) | 2.2 (± 2.2) | 0.1 (± 0.1) |
| Port. crab meg. | 0.6 (± 0.6) | 1.4 (± 1.4) | 2.0 (± 2.0) | 0.1 (± 0.1) |

Figure 27. Percent IRI values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in June 1999 and 2000.

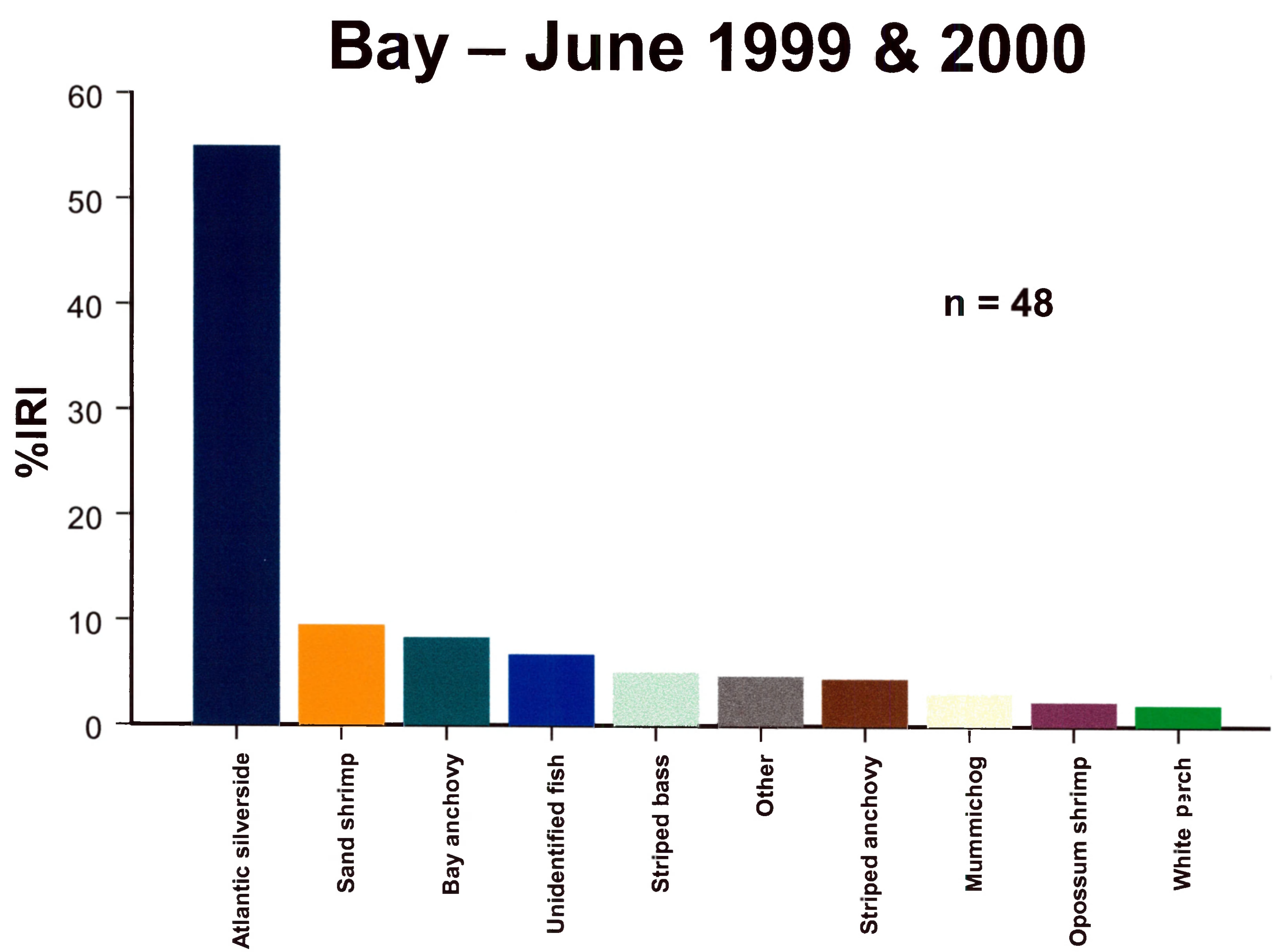
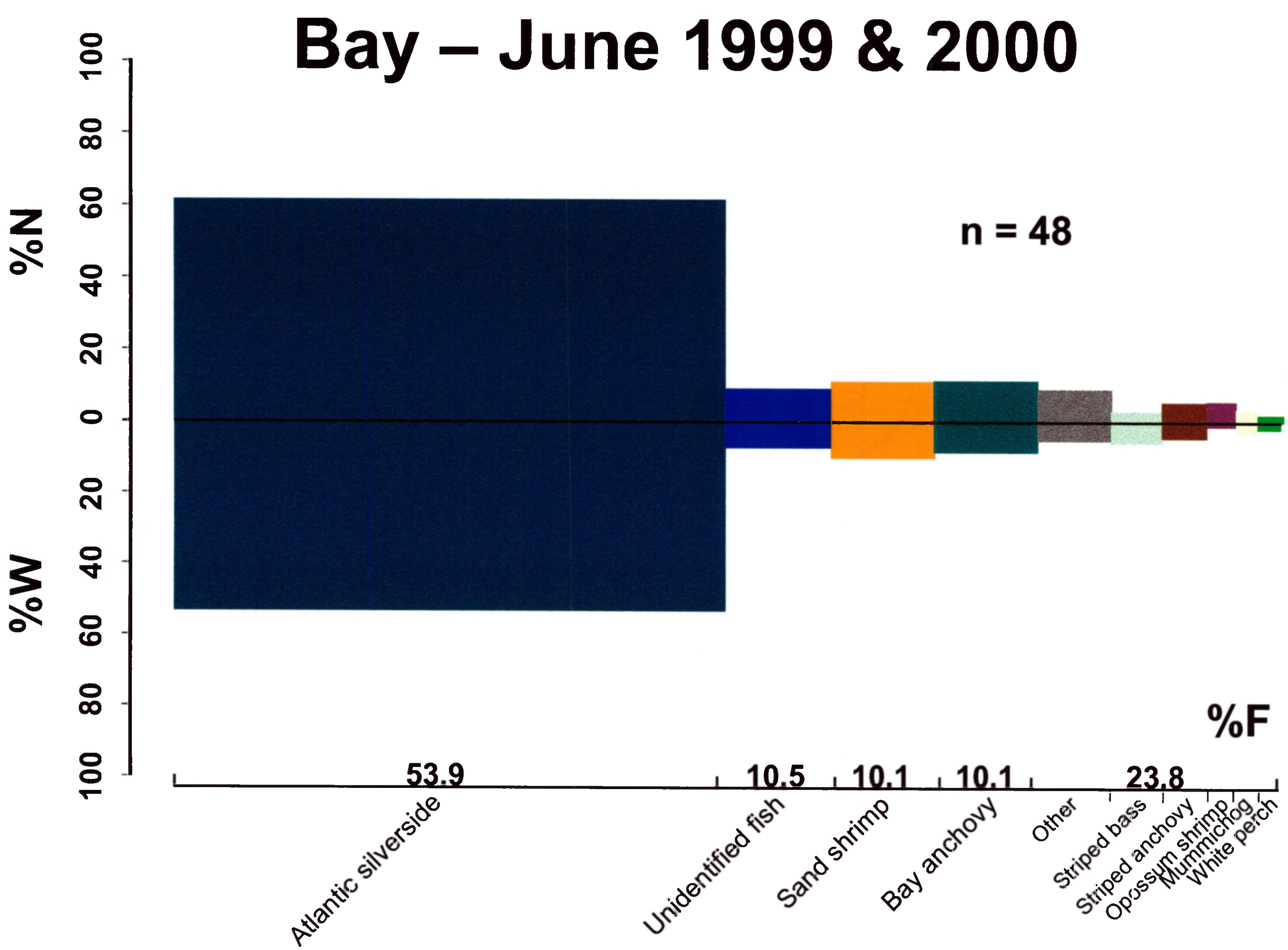

Bay – June 1999 & 2000
n = 48
%IRI
0
10
20
30
40
50
60
Atlantic silverside
Sand shrimp
Bay anchovy
Unidentified fish
Striped bass
Other
Striped anchovy
Mummichog
Opossum shrimp
White perch

Figure 28. %F, %N and %W values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in June 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F.


Bay – June 1999 & 2000
n = 48
%N
%W
%F
100
80
60
40
20
0
20
40
60
80
100
53.9
10.5
10.1
10.1
23.8
Atlantic silverside
Unidentified fish
Sand shrimp
Bay anchovy
Other
Striped bass
Striped anchovy
Opossum shrimp
Mummichog
White perch

all had %IRI values <2.0%. These included white perch, unidentified squid and portunid crab megalope. With the exception of the Atlantic silverside, none of these prey types occurred in the June ocean diet.

*July*

Sixty age-0 bluefish (37 mm to 201 mm) were collected from the Bay in July. Two distinct size classes were apparent in the length-frequency distribution: 40 mm to 70 mm and 130 mm to 180 mm (Figure 29a). Approximately 73% of the stomachs contained prey, the smallest percentage for any month in the Lower Bay. The cumulative prey curve reached a well-defined asymptote (Figure 29b).

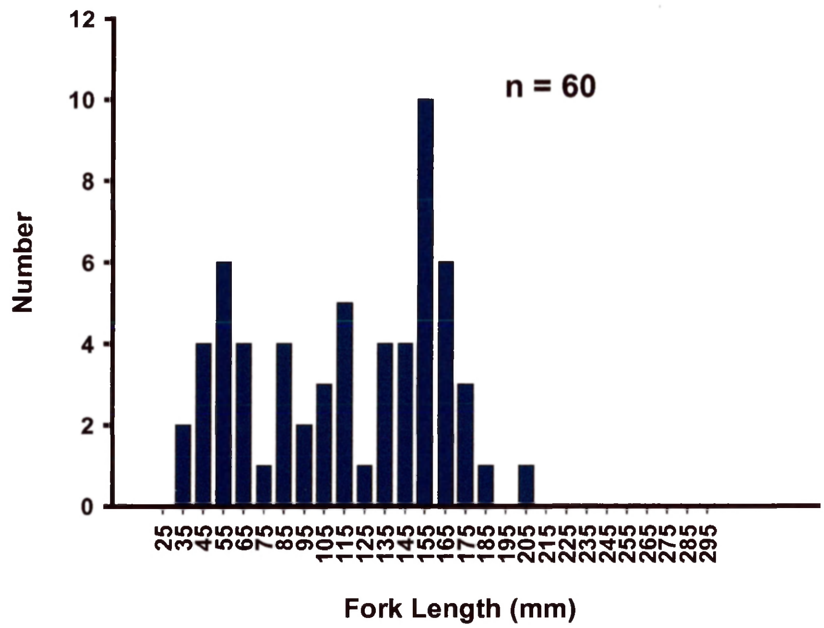
Similar to the June Bay diet and the July ocean diet, Atlantic silverside was the main prey type. These fish accounted for 27.8%, 28.5% 25.2% and 32.8% by %IRI, %F, %N and %W, respectively (Table 12, Figure 30, Figure 31). Atlantic menhaden, a prey type that was absent from the coastal ocean diet, first appeared in the Bay diet in July with a %IRI of 14.1%. White perch, striped anchovy, portunid crab megalope and bay anchovy composed 9.0%, 7.2%, 4.9% and 2.8% of the diet (%IRI). Except for bay anchovy, all increased in importance relative to the June Bay diet. Bluefish (2.4% - %IRI) and gammarid amphipod (2.0% - %IRI) were encountered in the guts, the former providing further evidence that bluefish occasionally engage in cannibalistic behavior. Opossum shrimp and Atlantic herring each accounted for less than 2% by %IRI. The Atlantic herring was found in a single bluefish collected in late July 2000.

Figure 29a. Length-frequency distribution of YOY bluefish collected in July 1999 and 2000 from the Lower Chesapeake Bay. Lengths are fork lengths in millimeters (mm).

Figure 29b. Cumulative prey curve for YOY bluefish collected in July 1999 and 2000 from the Lower Chesapeake Bay. Points are mean values and error bars are ± SD.

# Bay – July 1999 & 2000

a)




b)

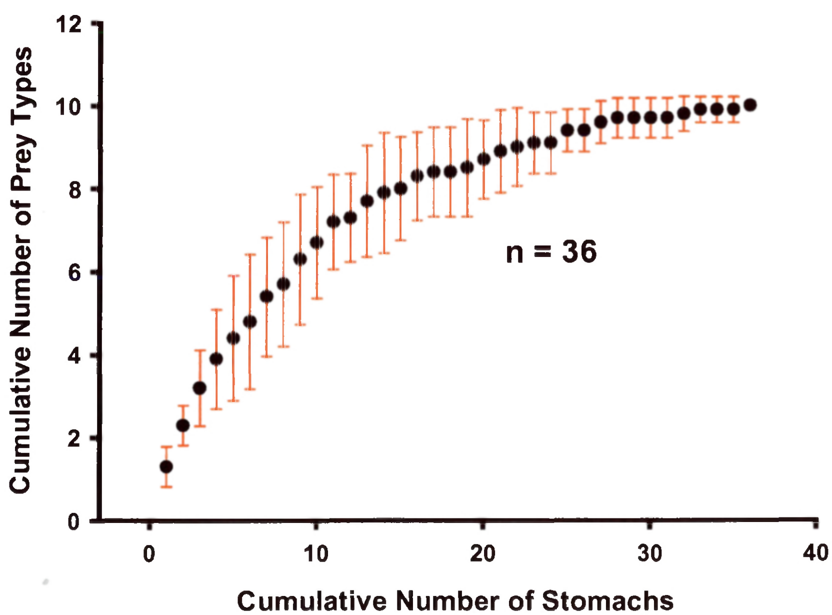


Table 12. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected in July 1999 and 2000 from the Lower Chesapeake Bay.

| Species | % IRI | %F | %N | %W |
|---|---|---|---|---|
| Atlantic silverside | 27.8 (± 8.7) | 28.5 (± 8.5) | 25.2 (± 8.5) | 32.8 (± 9.2) |
| Unidentified fish | 17.8 (± 7.7) | 20.5 (± 8.5) | 16.8 (± 7.6) | 18.8 (± 8.3) |
| Atlantic menhaden | 14.1 (± 7.5) | 15.1 (± 7.5) | 19.7 (± 8.4) | 13.9 (± 7.5) |
| Unidentified meat | 9.3 (± 6.3) | 12.1 (± 6.8) | 8.0 (± 5.6) | 9.2 (± 6.3) |
| White perch | 9.0 (± 5.8) | 6.0 (± 3.5) | 5.6 (± 3.4) | 9.4 (± 6.0) |
| Striped anchovy | 7.2 (± 4.2) | 10.8 (± 6.1) | 5.0 (± 3.1) | 6.8 (± 4.2) |
| Port. crab meg. | 4.9 (± 3.4) | 8.0 (± 5.6) | 7.4 (± 5.1) | 0.9 (± 0.8) |
| Bay anchovy | 2.8 (± 2.4) | 5.7 (± 4.0) | 1.4 (± 1.0) | 4.6 (± 3.8) |
| Bluefish | 2.4 (± 2.4) | 2.3 (± 2.3) | 2.3 (± 2.3) | 2.5 (± 2.5) |
| Gammarid amphipod | 2.0 (± 2.0) | 2.0 (± 2.0) | 3.9 (± 3.9) | 0.1 (± 0.1) |
| Opossum shrimp | 1.9 (± 1.9) | 2.3 (± 2.3) | 3.6 (± 3.6) | 0.2 (± 0.2) |
| Atlantic herring | 0.7 (± 0.7) | 1.5 (± 1.5) | 1.1 (± 1.1) | 0.8 (± 0.8) |

Figure 30. Percent IRI values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in July 1999 and 2000.

# Bay – July 1999 & 2000

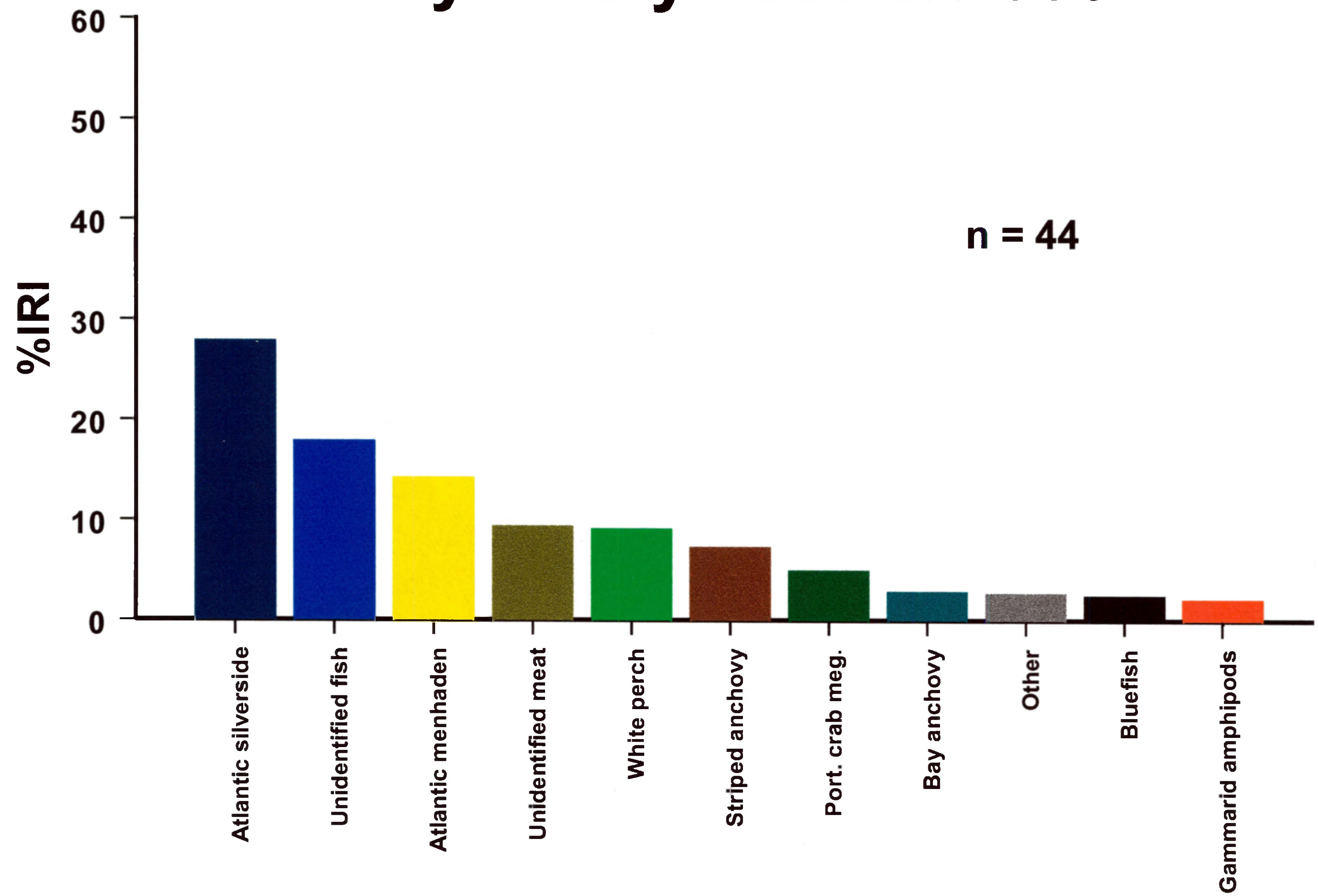
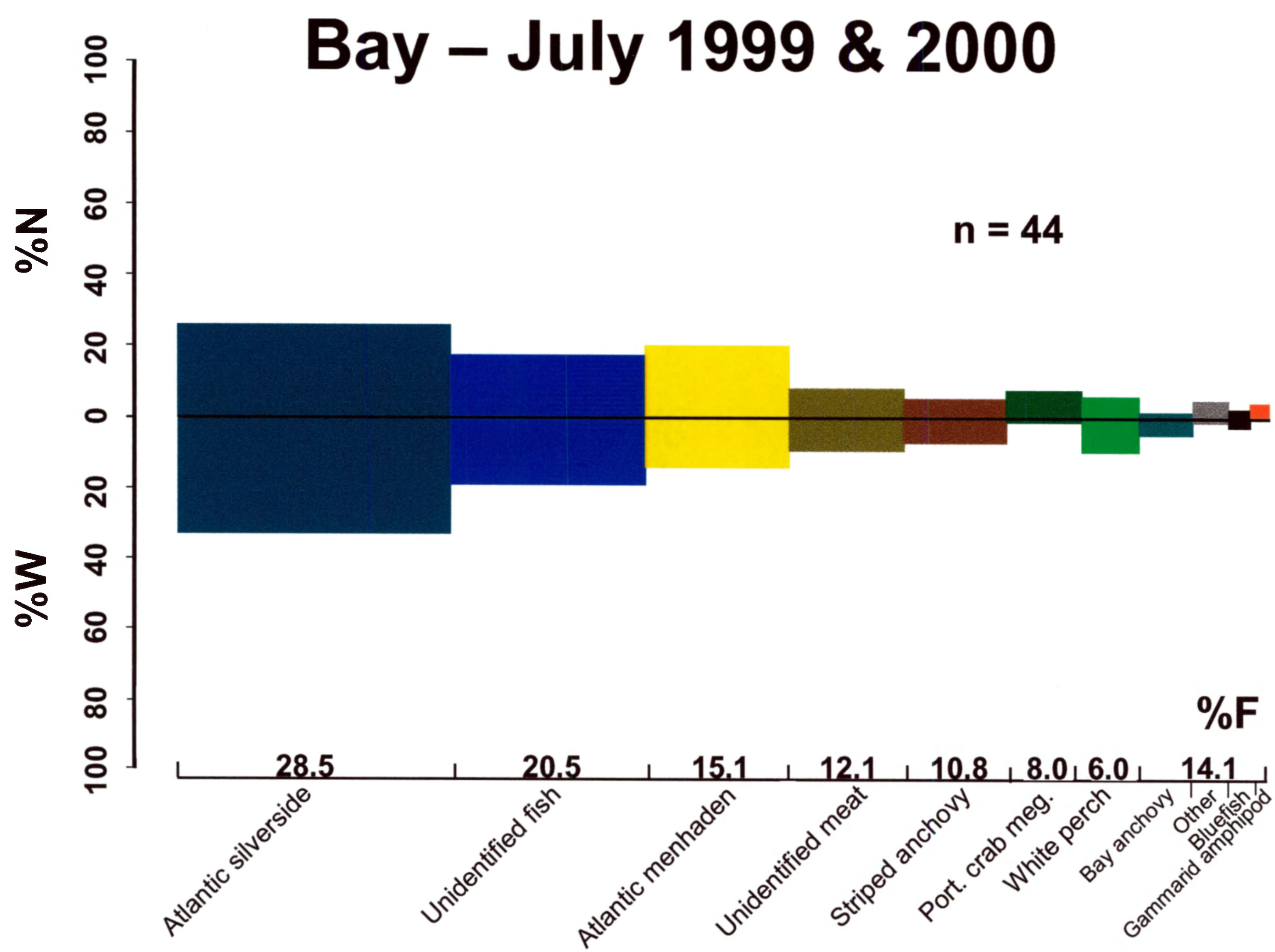


Figure 31. %F, %N and %W values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in July 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F.


Bay – July 1999 & 2000
n = 44
%N
%W
%F
100
80
60
40
20
0
20
40
60
80
100
28.5
20.5
15.1
12.1
10.8
8.0
6.0
14.1
Atlantic silverside
Unidentified fish
Atlantic menhaden
Unidentified meat
Striped anchovy
Port. crab meg.
White perch
Bay anchovy
Other
Bluefish
Gammarid amphipod

*August*

Most of the 104 YOY bluefish sampled from the Bay in August were either between 40 mm and 60 mm or 150 mm and 180 mm. The smallest specimen collected was 33 mm, and the largest was 229 mm (Figure 32a). Prey items occurred in 78.8% of the guts, and the cumulative prey curve reached an asymptote (Figure 32b).

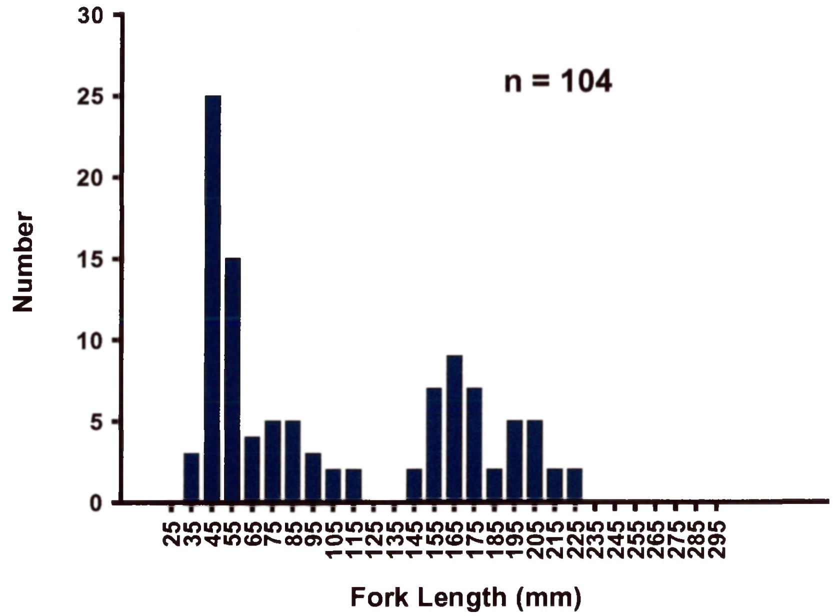
Bay anchovy increased in importance relative to the July Bay diet and was the main prey type with a %IRI value of 25.6%. These small, pelagic fish dominated by %F, %N and %W as well (Table 13, Figure 33, Figure 34). Other important prey included Atlantic menhaden (18.1% - %IRI), striped anchovy (17.5% - %IRI), Atlantic silverside (9.5% - %IRI), white mullet (*Mugil curema*) (4.8% - %IRI) and gammarid amphipod (3.7% - %IRI). The %F, %N and %W indices for these six prey types exhibited the same order of importance. Atlantic menhaden were more important in the diet of the larger (150 mm to 180 mm) bluefish. All prey, except for Atlantic silverside, were more important in the Bay diet in August than in July. A variety of prey types had %IRI values less than 2.0%, including lady crab, mummichog, anchovy spp., portunid crab megalope, sand shrimp, banded killifish, rough silverside, isopod (*Lironeca ovalis*) and opossum shrimp. Although portunid crab megalope were the main prey in the August coastal ocean diet, they contributed very little to the YOY bluefish Bay diet during this time. The greatest prey type diversity in the Lower Bay diet occurred in August.

Figure 32a. Length-frequency distribution of YOY bluefish collected in August 1999 and 2000 from the Lower Chesapeake Bay. Lengths are fork lengths in millimeters (mm).

Figure 32b. Cumulative prey curve for YOY bluefish collected in August 1999 and 2000 from the Lower Chesapeake Bay. Points are mean values and error bars are ± SD.

# Bay – August 1999 & 2000

a)




b)

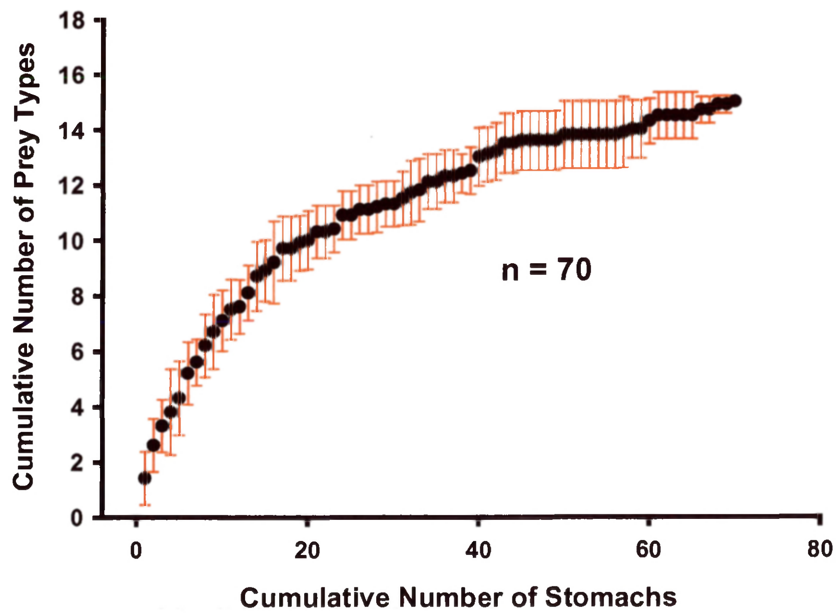


Table 13. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected in August 1999 and 2000 from the Lower Chesapeake Bay.

| Species | % IRI | %F | %N | %W |
|---|---|---|---|---|
| Bay anchovy | 25.6 (± 8.5) | 26.6 (± 8.3) | 25.8 (± 8.3) | 24.7 (± 8.6) |
| Atlantic menhaden | 18.1 (± 7.2) | 20.7 (± 7.8) | 15.3 (± 6.5) | 18.0 (± 7.3) |
| Striped anchovy | 17.5 (± 6.8) | 19.0 (± 7.1) | 14.5 (± 6.1) | 19.2 (± 7.2) |
| Unidentified fish | 13.2 (± 6.2) | 17.3 (± 6.5) | 13.7 (± 6.2) | 14.4 (± 6.7) |
| Atlantic silverside | 9.5 (± 4.2) | 12.0 (± 5.4) | 11.1 (± 4.8) | 8.3 (± 4.3) |
| White mullet | 4.8 (± 4.4) | 5.2 (± 4.4) | 4.8 (± 4.3) | 5.1 (± 4.4) |
| Gammarid amphipod | 3.7 (± 2.9) | 4.0 (± 2.8) | 5.3 (± 3.7) | 1.2 (± 1.2) |
| Lady crab | 1.9 (± 1.9) | 4.3 (± 4.3) | 1.4 (± 1.4) | 2.3 (± 2.3) |
| Mummichog | 1.9 (± 1.9) | 0.9 (± 0.9) | 1.7 (± 1.7) | 2.9 (± 2.9) |
| Anchovy spp. | 1.7 (± 1.7) | 3.4 (± 2.4) | 3.1 (± 2.3) | 1.4 (± 0.9) |
| Port. crab meg. | 0.8 (± 0.8) | 1.4 (± 1.4) | 1.3 (± 1.3) | 0.8 (± 0.8) |
| Sand shrimp | 0.5 (± 0.3) | 2.3 (± 1.6) | 1.5 (± 1.0) | 0.1 (± 0.1) |
| Banded killifish | 0.4 (± 0.4) | 0.9 (± 0.9) | 0.4 (± 0.4) | 0.4 (± 0.4) |
| Rough silverside | 0.3 (± 0.3) | 1.4 (± 1.4) | 0.2 (± 0.2) | 0.8 (± 0.8) |
| Isopod | 0.2 (± 0.2) | 1.1 (± 1.1) | 0.7 (± 0.7) | 0.1 (± 0.1) |
| Unidentified meat | 0.1 (± 0.1) | 0.6 (± 0.6) | 0.1 (± 0.1) | 0.3 (± 0.3) |
| Opossum shrimp | 0.1 (± 0.1) | 0.3 (± 0.3) | 0.1 (± 0.1) | 0.1 (± 0.1) |

Figure 33. Percent IRI values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in August 1999 and 2000.

# Bay – August 1999 & 2000

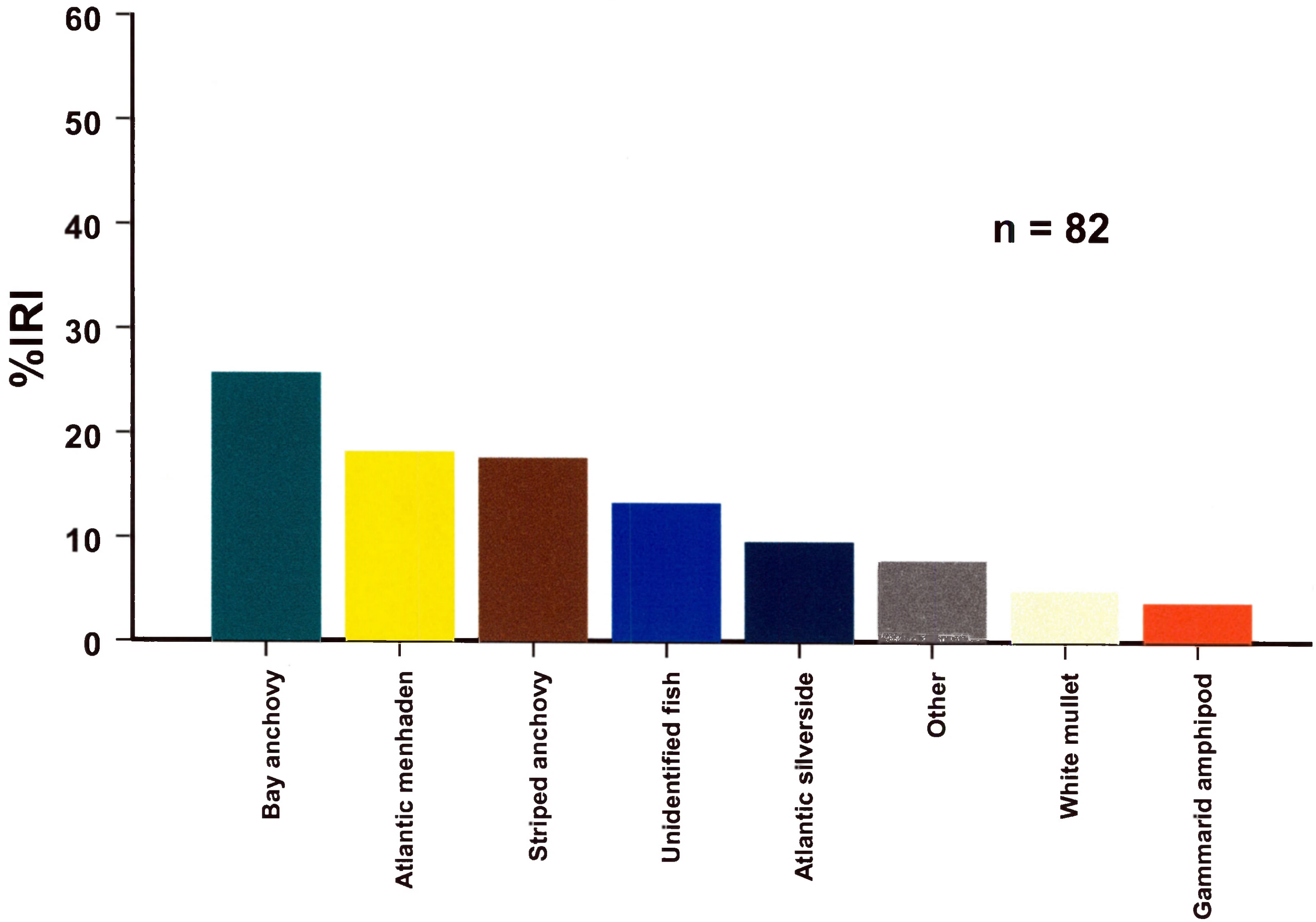
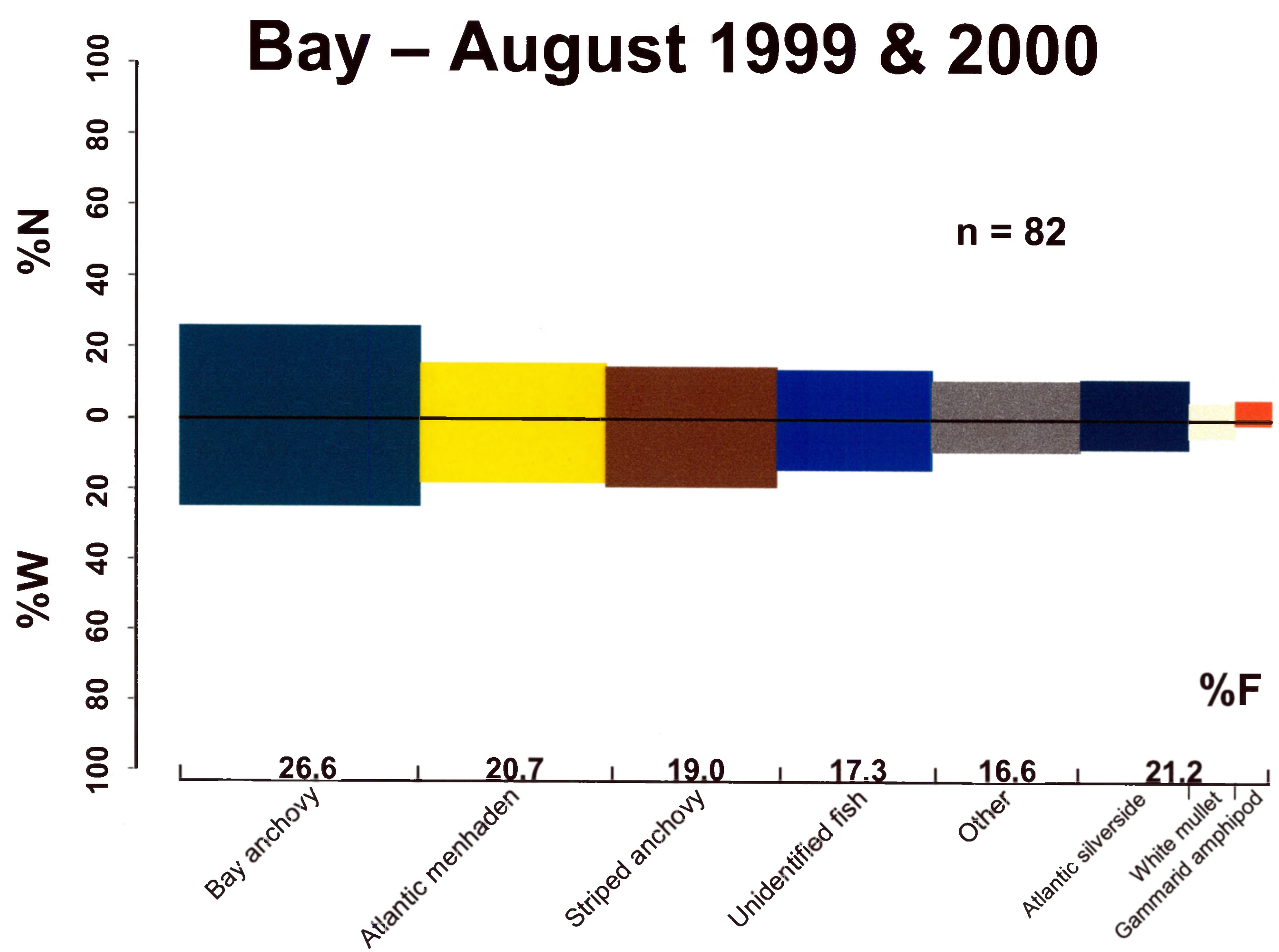


Figure 34. %F, %N and %W values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in August 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F.


Bay – August 1999 & 2000
n = 82
%N
%W
%F
100
80
60
40
20
0
20
40
60
80
100
26.6
20.7
19.0
17.3
16.6
21.2
Bay anchovy
Atlantic menhaden
Striped anchovy
Unidentified fish
Other
Atlantic silverside
White mullet
Gammarid amphipod

*September*

Seventy-three bluefish (73 mm to 264 mm) were sampled from the Bay in September. Most of these fish were 80 mm to 130 mm, and there was a second, smaller group that ranged from 230 mm to 260 mm (Figure 35a). Of these bluefish, 75.3% had food in their gut. A sufficient number of stomachs may have been collected since the cumulative prey curve reached a well-defined asymptote (Figure 35b).

Bay anchovy was the main prey by %F, %N and %W once again, and these fish also dominated by %IRI (40.2%) (Table 14, Figure 36, Figure 37). Atlantic menhaden, striped anchovy and Atlantic silverside had %IRI values of 20.0%, 15.2% and 10.9%, and this order of importance was the same as in the August Bay diet. Atlantic menhaden were again more prevalent in the diet of the larger (230 mm to 260 mm) fish, while the bay anchovy and striped anchovy were more important in the diet of the smaller fish (80 mm to 130 mm). Bay anchovy, striped anchovy and Atlantic silverside were also the main prey in the September ocean diet, but the order differed. Mummichog composed 6.7% by %IRI while anchovy spp. only 0.8%. Unidentified fish and unidentified meat accounted for the remainder.

*October*

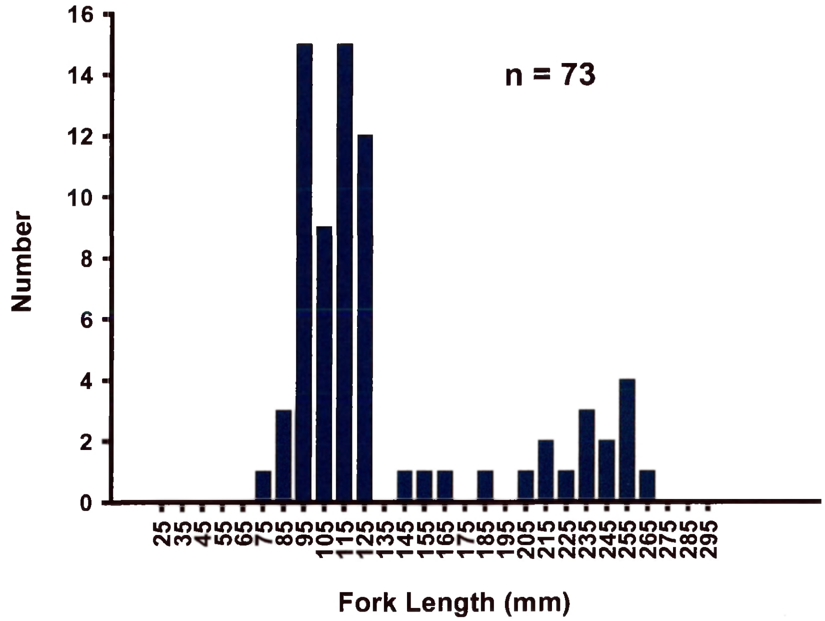
Collections in the Lower Chesapeake Bay in October 1999 and 2000 produced 46 bluefish. The smallest was 94 mm while the largest was 273 mm. Most fell into one of two distinct size ranges: 90 mm to 160 mm or 230 mm to

Figure 35a. Length-frequency distribution of YOY bluefish collected in September 1999 and 2000 from the Lower Chesapeake Bay. Lengths are fork lengths in millimeters (mm).

Figure 35b. Cumulative prey curve for YOY bluefish collected in September 1999 and 2000 from the Lower Chesapeake Bay. Points are mean values and error bars are ± SD.

# Bay – September 1999 & 2000

a)




b)

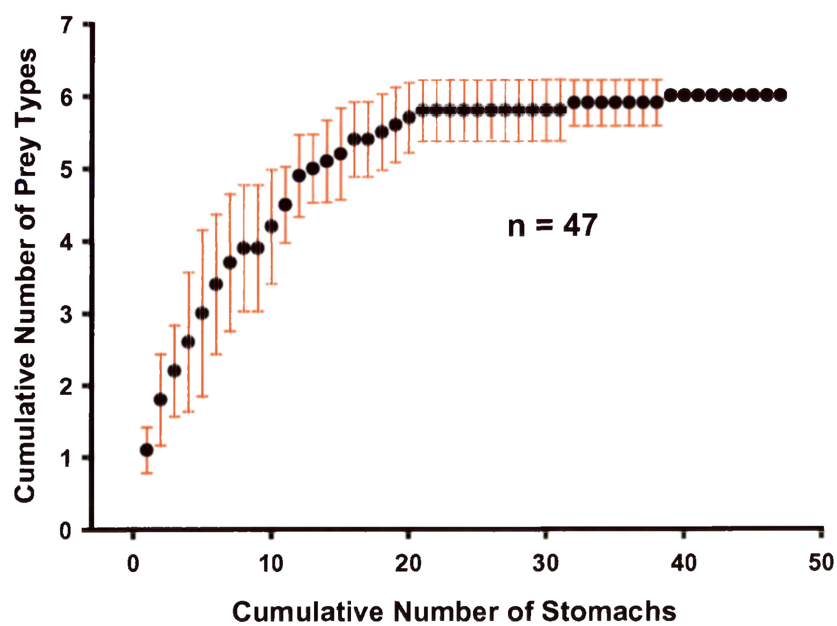


Table 14. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected in September 1999 and 2000 from the Lower Chesapeake Bay.

| Species | % IRI | %F | %N | %W |
|---|---|---|---|---|
| Bay anchovy | 40.2 (± 11.9) | 36.3 (± 11.6) | 37.3 (± 11.5) | 38.8 (± 11.6) |
| Atlantic menhaden | 20.0 (± 10.7) | 20.0 (± 10.9) | 20.0 (± 10.7) | 20.0 (± 10.7) |
| Striped anchovy | 15.2 (± 7.7) | 14.2 (± 7.4) | 14.1 (± 7.4) | 17.5 (± 8.4) |
| Atlantic silverside | 10.9 (± 6.8) | 12.7 (± 7.0) | 12.4 (± 6.7) | 11.3 (± 7.0) |
| Mummichog | 6.7 (± 6.7) | 6.7 (± 6.7) | 6.7 (± 6.7) | 6.7 (± 6.7) |
| Unidentified fish | 4.1 (± 3.1) | 5.7 (± 3.6) | 5.3 (± 3.5) | 3.4 (± 2.7) |
| Unidentified meat | 2.1 (± 2.1) | 2.6 (± 2.2) | 2.6 (± 2.2) | 2.0 (± 2.0) |
| Anchovy spp. | 0.8 (± 0.8) | 1.9 (± 1.7) | 1.5 (± 1.3) | 0.4 (± 0.3) |

Figure 36. Percent IRI values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in September 1999 and 2000.

# Bay – September 1999 & 2000

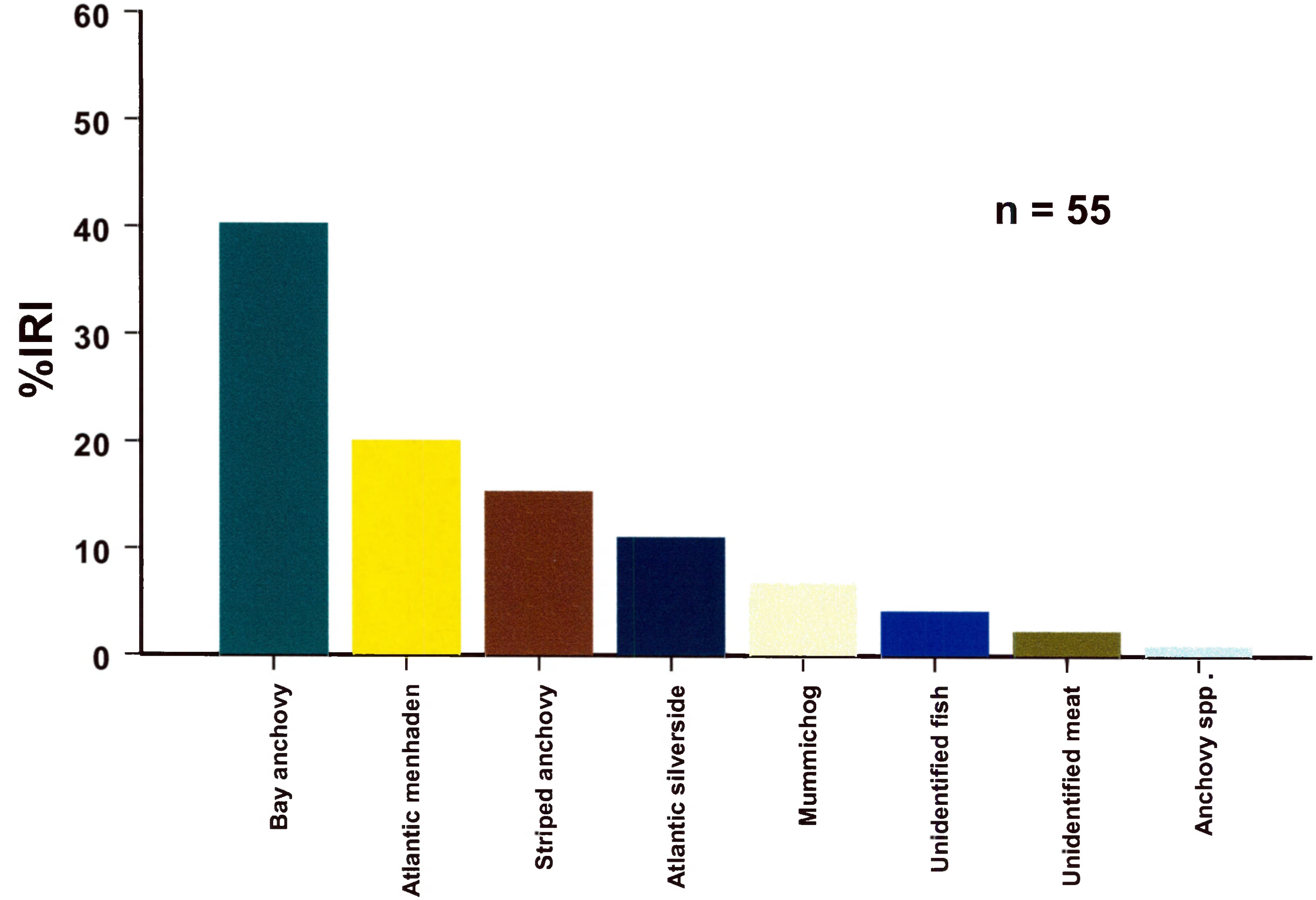
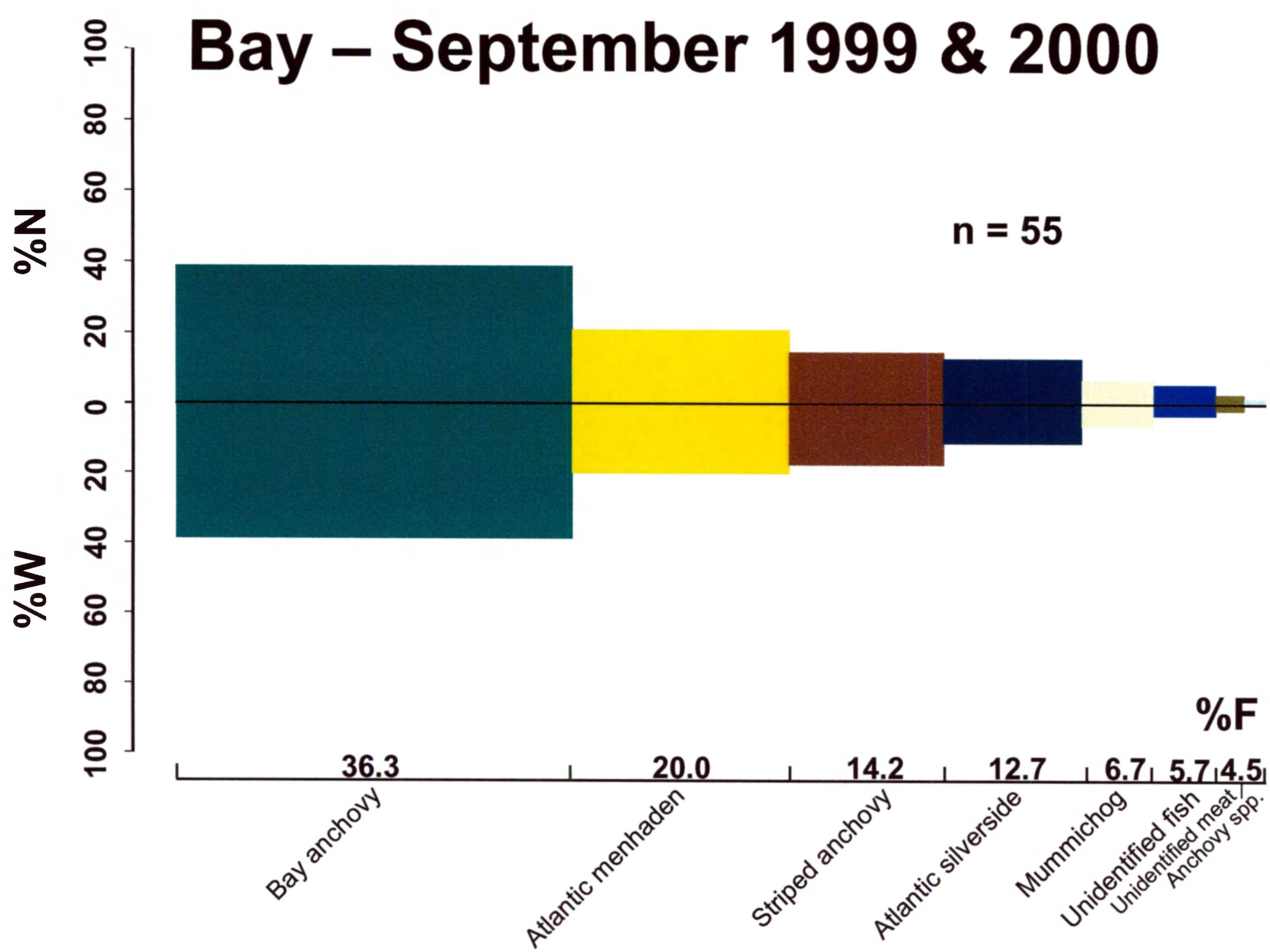


Figure 37. %F, %N and %W values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in September 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F.


Bay – September 1999 & 2000
n = 55
%N
%W
%F
100
80
60
40
20
0
20
40
60
80
100
36.3
20.0
14.2
12.7
6.7
5.7
4.5
Bay anchovy
Atlantic menhaden
Striped anchovy
Atlantic silverside
Mummichog
Unidentified fish
Unidentified meat
Anchovy spp.

280 mm (Figure 38a). Prey were encountered in 89.1% of the guts, but the cumulative prey curve did not reach an asymptote (Figure 38b).

Bay anchovy was again the main prey type, composing 54.7% of the diet by %IRI and dominating by %F (55.6%), %N (54.9%) and %W (56.9%) (Table 15, Figure 39, Figure 40). These fish were also the main prey in the October ocean diet. Striped anchovy was the second most important prey type by %IRI (8.3%) only. Polychaete worm (*Nereis spp.*), spotted seatrout and kingfish spp. were encountered in the stomachs and had %IRI values of 5.1%, 5.0% and 4.9%, respectively. Their importance may have been overemphasized as all six worms were found in only one bluefish, and a large kingfish and spotted seatrout occurred singly in separate stomachs. Each of these prey types were consumed by larger (230 mm to 280 mm) bluefish. Atlantic silverside declined in importance, composing only 3.9% by %IRI, while mummichog accounted for 3.8%. Many prey types had %IRI values less than 2.0% including sand shrimp, isopod, unidentified squid, anchovy spp. and rough silverside. Each of these, with the exception of bay anchovy, was absent from the October ocean diet.

*November*

Thirty-two bluefish were collected from the Lower Bay in November. These fish ranged from 121 mm to 285 mm, and 87.5% had food in their gut (Figure 41a). The cumulative prey curve once again failed to reach an asymptote (Figure 41b). Similar to the August, September and October Bay diets, bay anchovy was the dominant prey, accounting for 95.6% by %IRI, 97.2% by %F, 91.8% by %N and 95.9% by %W (Table 16, Figure 42, Figure 43). Sand

Figure 38a. Length-frequency distribution of YOY bluefish collected in October 1999 and 2000 from the Lower Chesapeake Bay. Lengths are fork lengths in millimeters (mm).

Figure 38b. Cumulative prey curve for YOY bluefish collected in October 1999 and 2000 from the Lower Chesapeake Bay. Points are mean values and error bars are ± SD.

# Bay – October 1999 & 2000

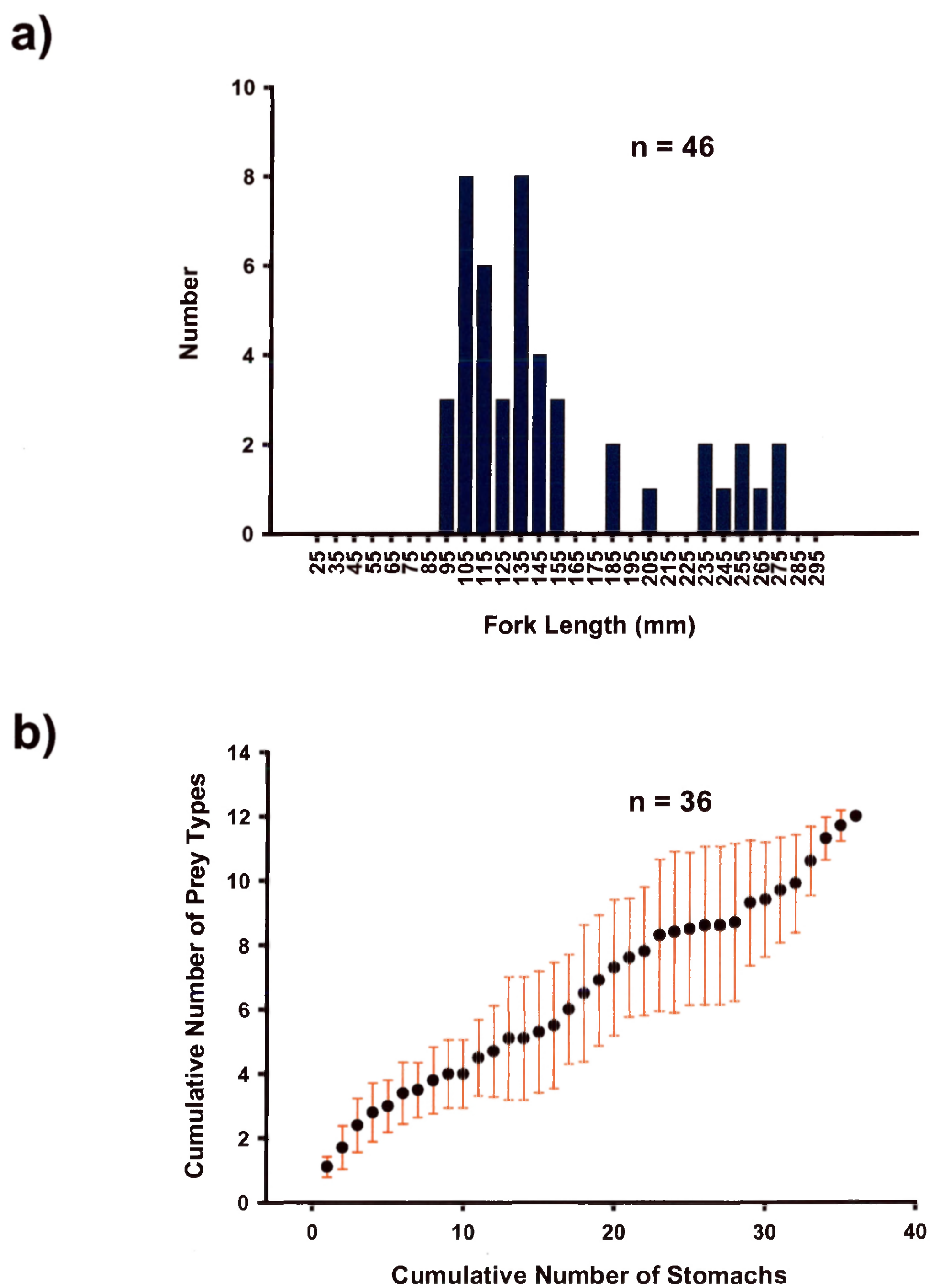
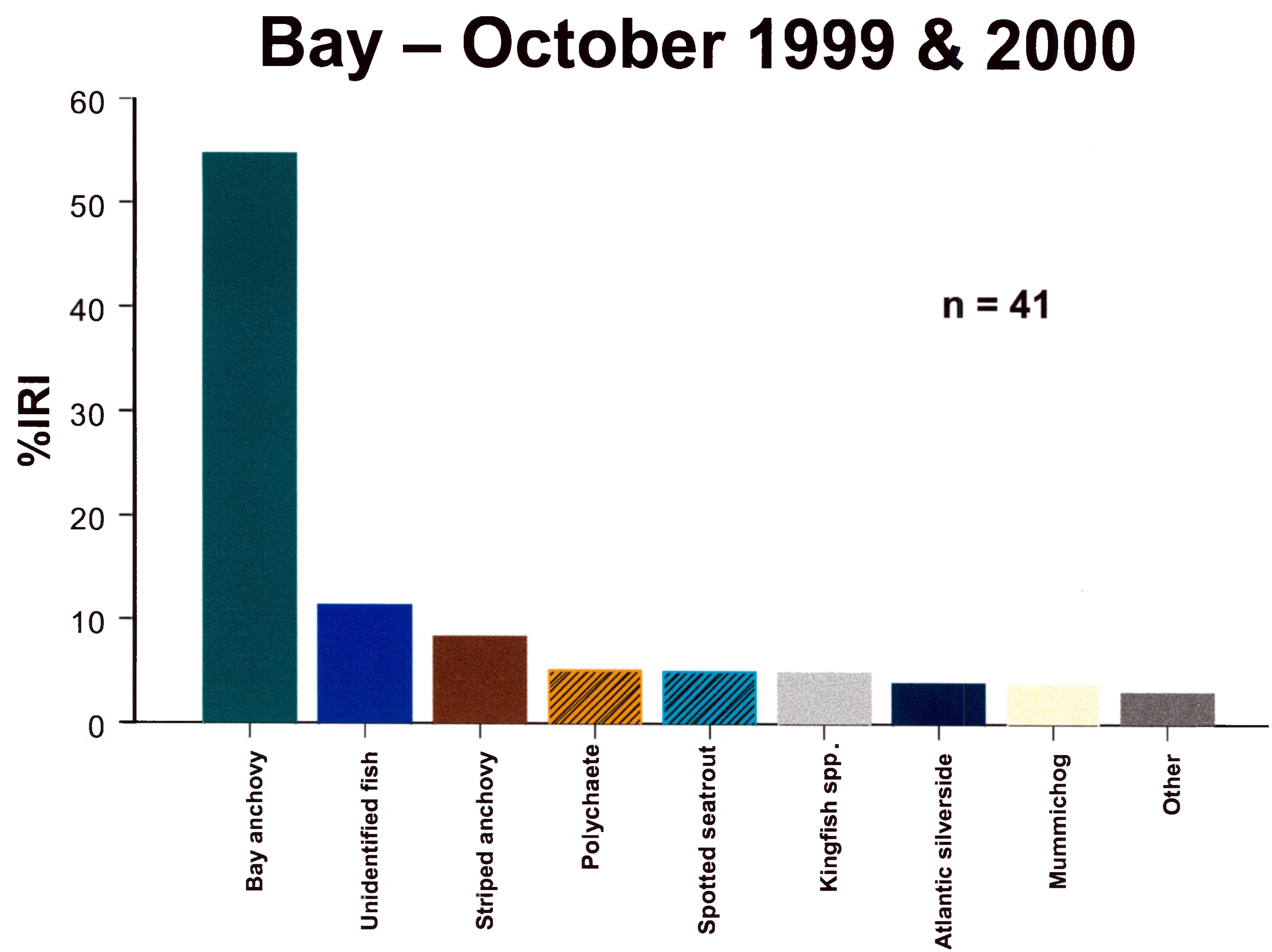


Table 15. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected in October 1999 and 2000 from the Lower Chesapeake Bay.

| Species | % IRI | %F | %N | %W |
|---|---|---|---|---|
| Bay anchovy | 54.7 (± 15.4) | 55.6 (± 15.2) | 54.9 (± 15.3) | 56.9 (± 14.9) |
| Unidentified fish | 11.3 (± 9.9) | 15.8 (± 10.6) | 13.0 (± 10.0) | 10.1 (± 10.0) |
| Striped anchovy | 8.3 (± 8.3) | 5.8 (± 5.8) | 5.4 (± 5.4) | 6.5 (± 6.5) |
| Polychaete worm | 5.1 (± 5.1) | 10.0 (± 10.0) | 8.3 (± 8.3) | 1.9 (± 1.9) |
| Spotted seatrout | 5.0 (± 5.0) | 5.0 (± 5.0) | 2.5 (± 2.5) | 7.5 (± 7.5) |
| Kingfish spp. | 4.9 (± 5.0) | 10.0 (± 10.0) | 1.7 (± 1.7) | 8.1 (± 8.1) |
| Atlantic silverside | 3.9 (± 3.9) | 3.3 (± 3.3) | 2.5 (± 2.5) | 5.3 (± 5.3) |
| Mummichog | 3.8 (± 3.8) | 5.0 (± 5.0) | 5.0 (± 4.5) | 2.5 (± 2.5) |
| Sand shrimp | 1.7 (± 1.6) | 3.3 (± 3.3) | 2.5 (± 2.5) | 0.8 (± 0.8) |
| Isopod | 1.3 (± 1.3) | 3.3 (± 3.3) | 2.5 (± 2.5) | 0.1 (± 0.1) |
| Unidentified invert. | 0.1 (± 0.1) | 0.4 (± 0.4) | 0.5 (± 0.5) | 0.1 (± 0.1) |
| Unidentified squid | 0.1 (± 0.1) | 0.4 (± 0.4) | 0.3 (± 0.3) | 0.2 (± 0.2) |
| Anchovy spp. | 0.1 (± 0.1) | 0.4 (± 0.4) | 0.3 (± 0.3) | 0.1 (± 0.1) |
| Rough silverside | 0.1 (± 0.1) | 0.4 (± 0.4) | 0.3 (± 0.3) | 0.1 (± 0.1) |
| Unidentified meat | 0.1 (± 0.1) | 0.4 (± 0.4) | 0.3 (± 0.3) | 0.1 (± 0.1) |

Figure 39. Percent IRI values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in October 1999 and 2000.



Bay – October 1999 & 2000
n = 41
%IRI
60
50
40
30
20
10
0
Bay anchovy
Unidentified fish
Striped anchovy
Polychaete
Spotted seatrout
Kingfish spp.
Atlantic silverside
Mummichog
Other

Figure 40. %F, %N and %W values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in October 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F.

# Bay – October 1999 & 2000

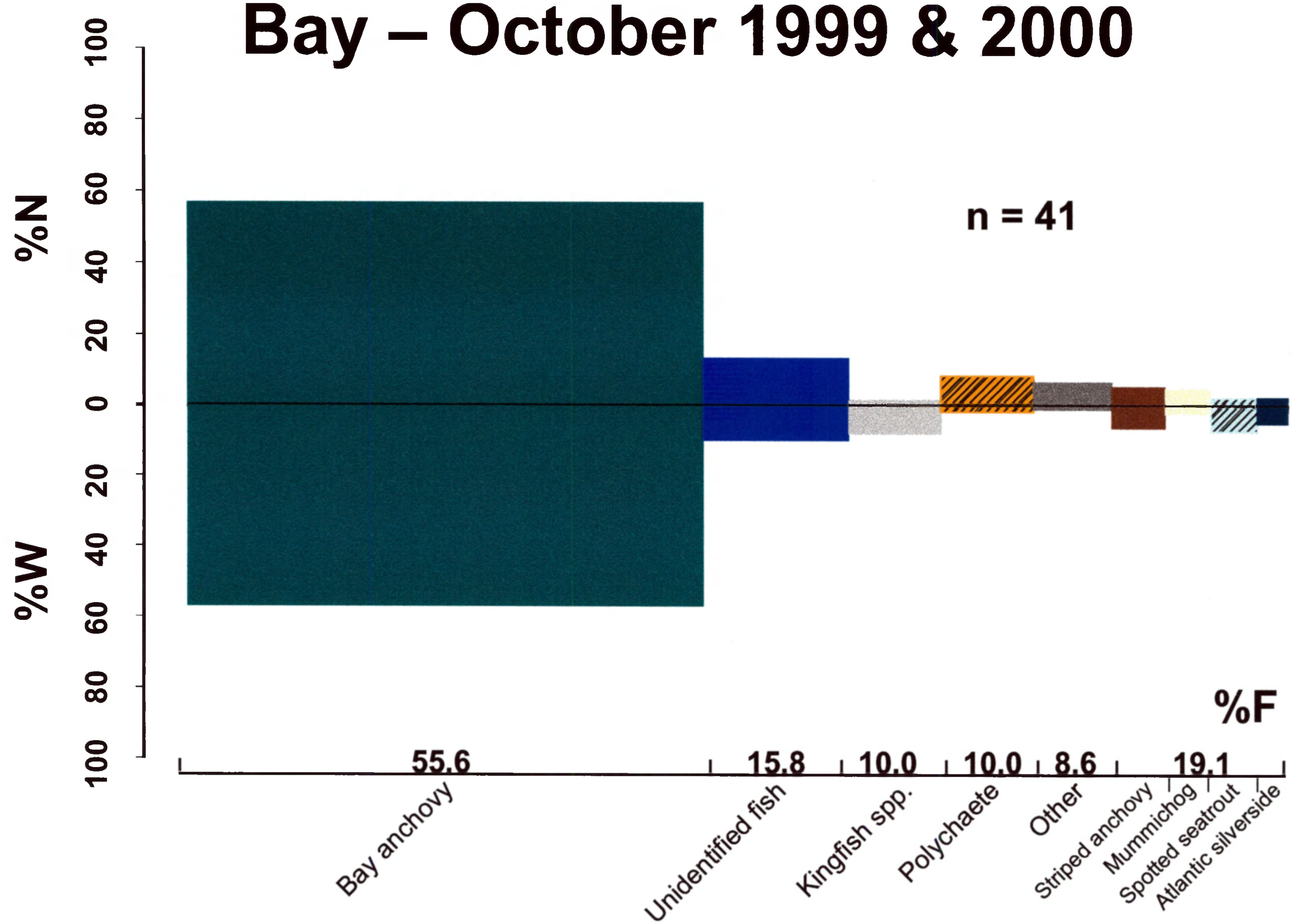
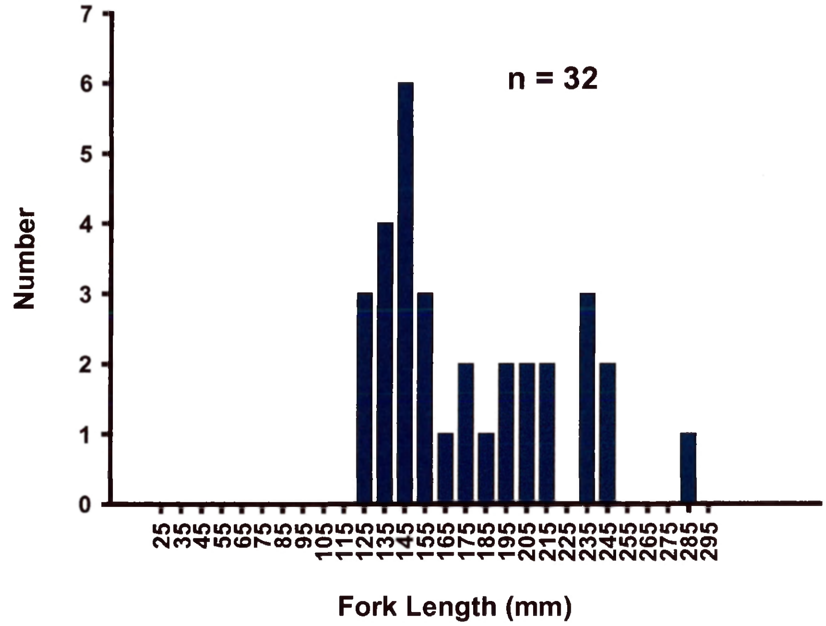


Figure 41a. Length-frequency distribution of YOY bluefish collected in November 1999 and 2000 from the Lower Chesapeake Bay. Lengths are fork lengths in millimeters (mm).

Figure 41b. Cumulative prey curve for YOY bluefish collected in November 1999 and 2000 from the Lower Chesapeake Bay. Points are mean values and error bars are ± SD.

# Bay – November 1999 & 2000

a)




b)

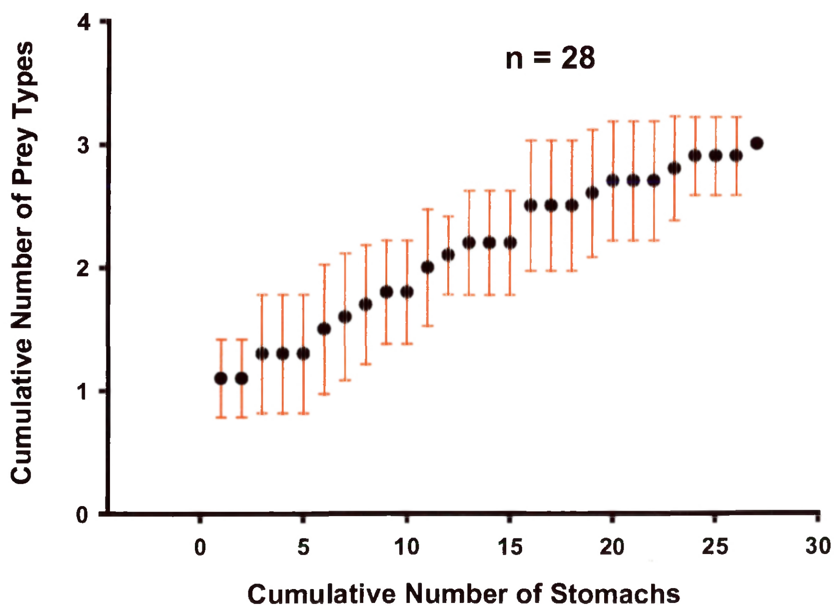


Table 16. Percent IRI, %F, %N and %W (with standard errors) for prey types in the diet of YOY bluefish collected in November 1999 and 2000 from the Lower Chesapeake Bay.

| Species | % IRI | %F | %N | %W |
|---|---|---|---|---|
| Bay anchovy | 95.6 (± 3.4) | 97.2 (± 2.8) | 91.8 (± 5.7) | 95.9 (± 2.7) |
| Sand shrimp | 3.4 (± 3.3) | 13.0 (± 11.0) | 6.0 (± 5.5) | 1.4 (± 1.2) |
| Atlantic silverside | 1.0 (± 1.0) | 2.8 (± 2.8) | 2.2 (± 2.2) | 2.7 (± 2.7) |

Figure 42. Percent IRI values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in November 1999 and 2000.

## Bay – November 1999 & 2000

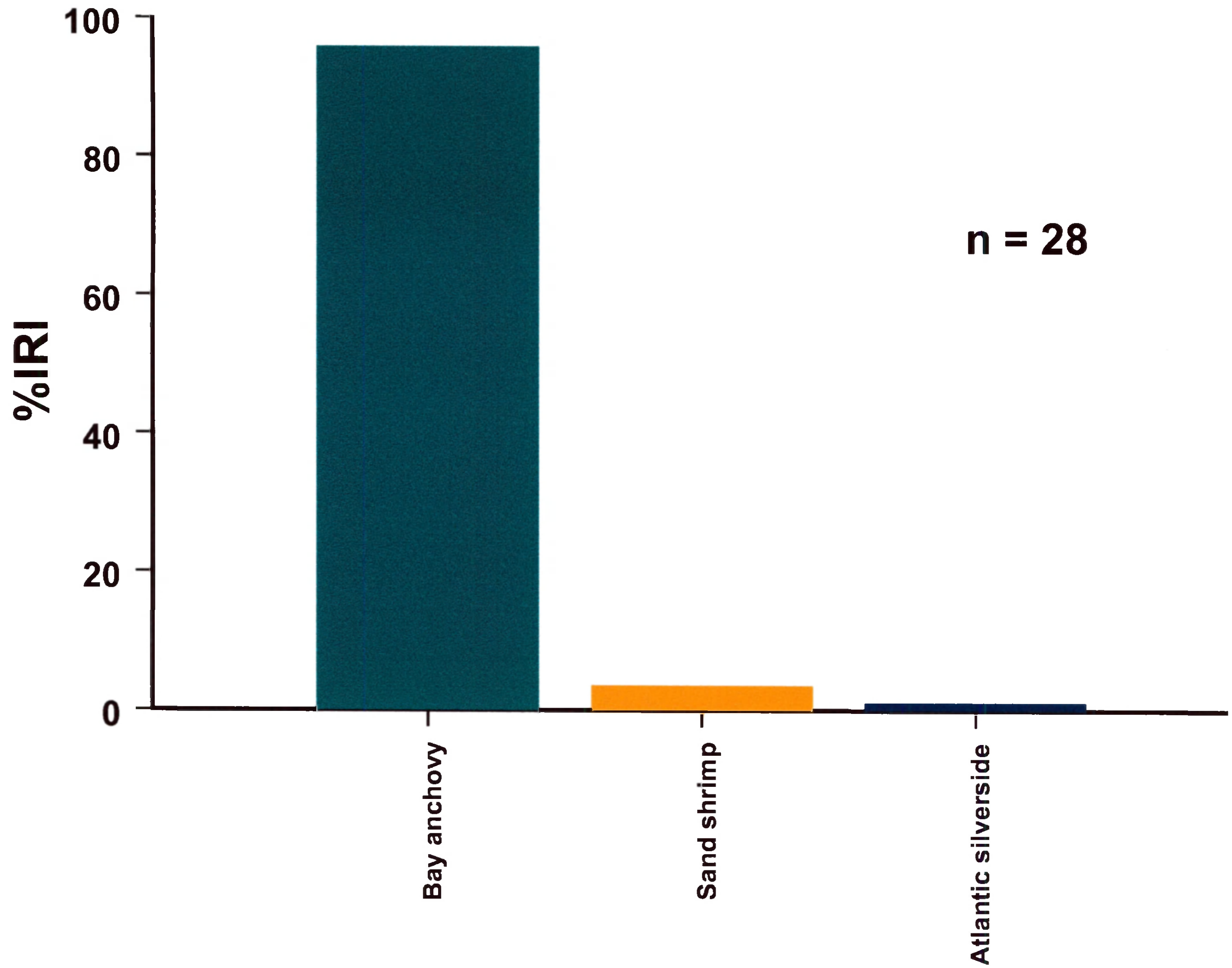
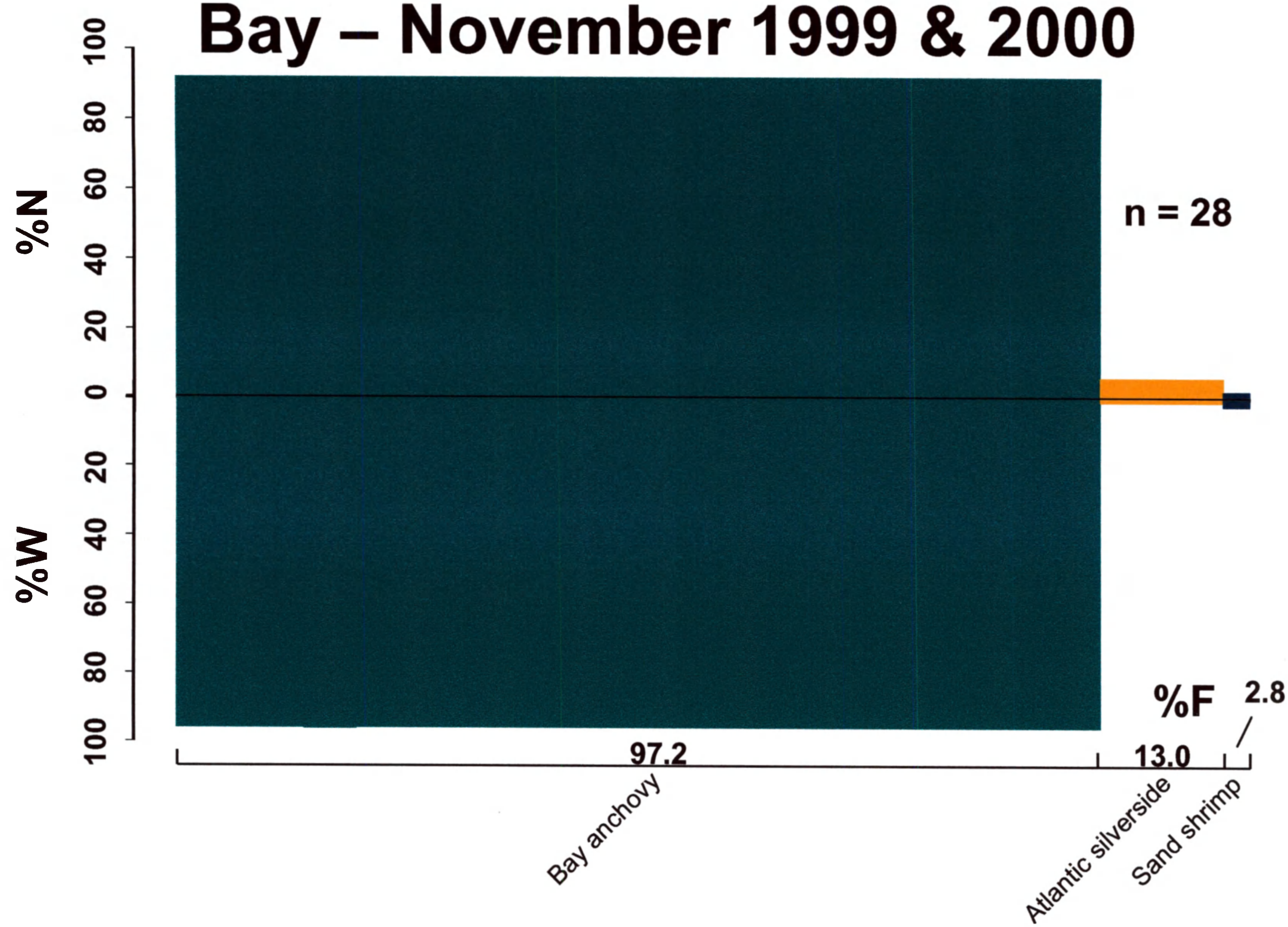


Figure 43. %F, %N and %W values for prey types in the diet of YOY bluefish collected from the Lower Chesapeake Bay in November 1999 and 2000. The height of a bar above the black centerline represents the contribution of a particular prey type to the diet by %N while the depth below the line represents the contribution by %W. The width of a bar represents the contribution by %F.

# Bay – November 1999 & 2000



shrimp had a %IRI value of 3.4% and contributed more to the diet by number than weight. Atlantic silverside continued to decrease in importance with a %IRI value of 1.0%.

# DISCUSSION

## General Diet Description (Objective 1)

Small pelagic and littoral schooling fishes dominated the diet of the YOY bluefish collected from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000. The bay anchovy and Atlantic silverside were the main prey according to all four diet indices. Striped anchovy and Atlantic menhaden were of secondary and near equal importance. Of the 14 fish species encountered in the guts, only kingfish spp. is frequently associated with the bottom (Murdy et al. 1997). These bluefish fed on the age-0 and age-1 bay anchovy, striped anchovy and Atlantic silverside cohorts, while only YOY were consumed for the rest of the fish species identified in the diet.

YOY bluefish preyed upon several invertebrate species in the Lower Bay and coastal ocean. Portunid crab megalope was the main invertebrate prey but was less important than the main fish prey. Sand shrimp, gammarid amphipod and opossum shrimp were also consumed. The general description probably provided an accurate depiction of the age-0 bluefish diet in the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000, since these predators were collected from numerous localities in the Bay, it's tributaries and the coastal ocean. Furthermore, the cumulative prey curve did reach a reasonably well-defined asymptote.

The general diet description confirmed what many researchers had found regarding the YOY bluefish diet in coastal waters; pelagic and littoral fishes were the main prey and invertebrates, mostly crustaceans, were of secondary importance. Linton (1905) and Lassiter (1962) caught age-0 bluefish in some North Carolina estuaries and reported that bay anchovy, Atlantic silverside, butterfish and pinfish dominated the diet by volume while invertebrates contributed little. Breeder (1922) found that age-0 butterfish was the main prey of 31 YOY bluefish collected from a pound net in New Jersey's coastal ocean. Disparities in the most important fish prey among these studies likely reflect differences in the types of prey available among these regions. The results of Grant's (1962) study in the Indian River, Delaware, were quite similar to those presented here as the bay anchovy, mummichog, Atlantic menhaden, Atlantic silverside and inland silverside (*Menidia berrylina*) were the predominant fish prey while the crab megalope and opossum shrimp were the most important invertebrates. Except for the inland silverside, each of these species was identified in my investigation and three of the Indian River bluefish five main prey types were also the main prey of the bluefish that I collected from Virginia's waters.

The age-0 bluefish diet in Sandy Hook Bay, New Jersey, may differ from that in the Lower Chesapeake Bay and Virginia's coastal ocean. Bluefish consumed bay anchovy, Atlantic silverside, opossum shrimp and sand shrimp in both regions. Invertebrate prey dominated the diet in two of three years in the Sandy Hook study, but they were of minor importance in my investigation

(Friedland et al. 1988). Although these incongruities may have resulted from differences in bluefish feeding preferences between these areas, differences in prey availability are a more likely explanation.

The YOY bluefish diet descriptions for New York's Hudson River and for the Chesapeake Bay region were similar. The size ranges of bluefish collected in the Juanes et al. (1993) study and in my investigation were comparable. Bay anchovy was the main prey in both studies, but YOY of several economically important anadromous fishes including the striped bass, American shad and blueback herring were of secondary importance in the Hudson River. Striped bass were a minor component of the diet in my investigation. American shad and blueback herring were not encountered in the guts. Although their absence from the diet in my study may have been due to inadequate sampling, it is also possible that this predator / prey interaction was minimal in the Chesapeake region since age-0 bluefish are rarely encountered in the upper and middle tributary nursery areas inhabited by these YOY anadromous fishes (Austin et al. 2001).

Hudson River studies in the mid and late 1990's gave YOY bluefish diet descriptions similar to that reported by Juanes et al. in 1993 (Buckel and Conover 1997; Buckel et al. 1999a). These Hudson River diet descriptions, along with the results from my study, showed that the bay anchovy was an important food for age-0 bluefish at various locations along the US East Coast. Furthermore, although some of the main prey types varied between these nursery areas, all were usually small, pelagic and littoral age-0 and age-1 fishes, and the diet differences likely reflected variations in the types of prey available in these regions. The YOY bluefish diet in Great South Bay, New York, resembled that of bluefish sampled from the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000, as Juanes et al. (1994) and Juanes and Conover (1995) reported that bay anchovy and Atlantic silverside were the main prey by weight.

Hartman and Brandt's (1995b) bluefish diet study included only a few fish, all of which were collected from the Upper Chesapeake Bay, but the diet was similar to that described here. Age-0 bluefish once again preyed on small pelagic, schooling fishes. Bay anchovy dominated the diet and was consumed almost exclusively in the spring and early summer, while YOY Atlantic menhaden became important in the late summer and early autumn (Hartman and Brandt 1995b). The diet was less diverse in their study than in my investigation however, and some of the main prey in my study (Atlantic silverside, striped anchovy and portunid crab megalope) were either of minor importance or absent from Hartman and Brandt's (1995b) description. These incongruities may reflect differences in YOY bluefish feeding preferences between the Upper Bay and the Lower Bay and Virginia's coastal ocean, variations in prey availability between these regions or with time, or inadequacies in the sample size used to characterize the diet in the Upper Bay. Of these, the latter two explanations seem more reasonable.

When considering the age-0 bluefish morphology, it is not surprising that these fish preyed mainly upon small pelagic and littoral, schooling fishes in the

Lower Chesapeake Bay and near shore Virginia waters. Age-0 bluefish have long, fusiform bodies and consequently a fitness ratio of about 4.5, which is common among fishes that feed primarily on non-benthic prey (Blake 1983). Furthermore, these fish have a terminal mouth, well-developed interdigited conical teeth and excellent vision, all of which are advantageous when feeding on mobile prey in the water column (Molye and Cech 2000). Correlations between predator morphology and feeding behavior have also been noted for a number of Chesapeake Bay's sciaenids (Chao and Musick 1977). Although the bluefish diet included some prey types commonly associated with the bottom (kingfish spp. and gammarid amphipod) these prey may have been consumed away from the bottom, either driven up in response to low dissolved oxygen levels at the deepwater stations in the mainstem Bay and tributaries or disturbed from their benthic habitat in the high energy shore zones. YOY bluefish have been reported to forage along the bottom at times however, as evidenced by specimens with gravel in their gut, so the occurrence of demersal prey in this investigation may have resulted from age-0 bluefish feeding on the bottom (Grant 1962; Lassiter 1962; Juanes et al. 1993).

Bay anchovy, Atlantic silverside and striped anchovy were the main YOY bluefish prey in this study and the most abundant forage fishes in the Lower Bay and coastal ocean at this time (Geer and Austin 2000; Austin, Unpublished data). YOY bluefish fed at random in many estuaries, meaning that the proportions of the various prey types in the diet were similar to those in the environment (Juanes et al. 1993; Buckel et al. 1999a; Buckel et al. 1999b). Thus, the predominance of these three prey types in the diet may have resulted from YOY bluefish feeding at random in the Chesapeake region as well. Without accurate estimates of prey abundances in the environment at the exact times and places that the bluefish were collected for my study however, it was impossible to determine whether these predators were feeding randomly in the Lower Bay and coastal ocean or were selecting for these forage fishes.

Another explanation for the predominance of these small schooling fishes in the diet relies on the optimal foraging theory. This theory basically states that a predator's feeding behavior should maximize energy intake while minimizing energy expenditures (Pyke et al. 1977). Four of the five main prey have the highest weight specific caloric content values of all of the prey types identified in the diet (Steimle and Terranova 1985). Furthermore, the energy required to chase and capture these small prey is probably less than that needed to consume larger, more mobile fishes such as striped bass, white perch and spotted seatrout or forage along the bottom for amphipods and kingfish, a realm to which these YOY predators are not as well adapted. Hence, the age-0 bluefish diet in the Lower Bay and coastal ocean may have reflected a feeding strategy that maximized their energetic gain to energetic cost ratio.

Finally, the anchovy and silverside dominated diet may have resulted from size selectivity for small prey. Numerous field studies have shown that YOY bluefish often select for the smallest prey available (Juanes et al. 1993; Juanes et al. 1994; Juanes and Conover 1995; Scharf et al. 1997; Buckel et al. 1999a; Buckel et al. 1999b). Juanes and Conover (1994) reported that YOY bluefish attacked all potential prey in proportion to their abundance in laboratory experiments, but were most successful in capturing the smallest individuals (passive size selection for small prey). The main prey fish species of age-0 bluefish in the Lower Bay and coastal ocean were smaller than the less important prey types. Furthermore, the anchovies and silversides encountered in the guts were often near the lower extreme of the size ranges of these species available in the environment (Geer and Austin 2000; Austin, Unpublished data). YOY bluefish were capable of consuming larger prey, as evidenced by their presence in the diet. Since the diet was dominated by smaller prey species however, and of these, the bluefish tended to consume the smaller individuals, size selection is not an unreasonable explanation for the observed diet composition.

Other interesting aspects of the YOY bluefish diet in the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000 included the abundance of portunid crab megalope, the presence of age-0 bluefish and the absence of rough silverside. Portunid crab megalope was the main invertebrate prey and the fifth most important prey type overall. These crustaceans were commonly found in bluefish collected from the Lower Bay and coastal ocean littoral zones, and individual fish (many smaller than 100 mm) often had 40 to 50 in their gut. These prey were probably consumed opportunistically as the bluefish encountered swarms of megalope recruiting to this region.

Although these crustaceans were a *Callinectes spp.*, it was impossible to determine whether they were *Callinectes sapidus* or *Callinectes similes,* since distinguishing characteristics are few and were destroyed probably during consumption or digestion. Furthermore, megalope of both species recruit to the coast at about the same time of year, so a species could not be ruled out based on when the megalope were encountered in the guts (Sandifer 1975; Johnson 1985). Considering the importance of the commercial and recreational *C. sapidus* fisheries in the Chesapeake Bay area as well as the current interest in identifying sources of natural mortality for this species, future YOY bluefish diet studies in this region should include plankton collections at each sampling site to obtain intact megalope for specific identification and comparison, which should aid in determining which of these species are consumed by YOY bluefish in this area.

The presence of age-0 bluefish in the diet confirmed that these fish exhibit cannibalistic behavior. Bluefish were also found in the stomachs of YOY bluefish collected from North Carolina, Long Island Sound and US Atlantic Coast continental shelf waters (Lassiter 1962; Austin and Amish 1974; Buckel et al. 1999b). Cannibalism is not uncommon among age-0 piscivorous fishes, as it has also been observed in walleye pollock (*Theragra chalcogramma*) (Sogard and Olla 1994), largemouth bass (*Micropterus salmoides*) (Johnson and Post 1996) and Atlantic cod (*Gadus morhua*) (Blom and Folkvard 1997). The incidence of YOY bluefish cannibalism is probably minor in the Lower Chesapeake Bay and Virginia's coastal ocean however, as these predators accounted for an insignificant fraction of their own diet.

The almost complete absence of the rough silverside from the diet was puzzling. Rough silverside is closely related to the Atlantic silverside (a main prey type) and was frequently collected along with the latter and YOY bluefish from the coastal ocean (Austin, unpublished data). This prey rivaled Atlantic silverside in terms of abundance, and yet only a single rough silverside was found in all of the guts examined. Rough silversides may have been excluded from the diet as a result of size selectivity, since they were usually larger than the main prey types in the field collections.

**Shift to Piscivory (Objective 2)**

The binary logistic regressions showed that the probability of fish being the dominant prey type in the bluefish diet was greater than 50% for the smallest average bluefish FL and increased with increasing bluefish length. The smallest average size was 33 mm, which is their approximate size when they recruit to the coast. My results support Marks and Conover's (1992) hypothesis that these fish become mainly piscivorous either before or shortly after recruitment to the nursery areas. The probability of a fish-dominated diet approached 100% as the average FL reached about 200 mm. Thus, invertebrates would not have been expected to be the dominant prey of any bluefish larger than 200 mm, which was the case except for a single 290 mm specimen that only had six polychaete worms in its gut.

My results agree with past YOY bluefish diet studies that reported fish-dominated diets throughout the summer nursery period and invertebrates, when present, occurring mostly in the guts of the smaller bluefish (Grant 1962; Juanes et al. 1993; Juanes et al. 1994; Juanes and Conover 1995; Buckel et al. 1999a). The fact that bluefish were mainly piscivorous from the time that they were believed to recruit to the Chesapeake region has important management implications for this area. Other factors being equal, piscivorous bluefish have higher growth rates than nonpiscivorous individuals (Buckel et al. 1998). Higher growth rates yield larger bluefish with greater survival probabilities during estuarine residency and the fall migration, since bigger fish are better able to both avoid predation and forage. These fish should also have higher fecundities and therefore contributions to future population sizes later in life (Friedland et al. 1988). The Chesapeake region's contribution to the Atlantic Coast stock may therefore be greater than that of nursery areas where the diet shift to piscvory does not occur until later in the summer, if at all. Furthermore, YOY bluefish may reach a larger size before the fall migration begins and therefore enjoy higher survival rates than those inhabiting more northern nursery areas since, due to the fact that water temperatures in the Chesapeake region warm earlier and cool later than those in northern coastal zones, bluefish in this area may experience a longer summer nursery period. Thus, the Chesapeake Bay region's input to the Atlantic Coast stock could be greater than that of the more northern nursery areas as well. Future YOY bluefish studies should focus on abundance, growth rate, size at the end of summer residency and survival in the Chesapeake Bay area in an effort to quantify this region's contribution to the Atlantic Coast stock and make comparisons with other nursery areas.

**Spatial, Inter-annual and Intra-annual Diet Differences (Objective 3)**

Each correspondence analysis suggested that the YOY bluefish diet in the Lower Chesapeake Bay differed from that in Virginia's coastal ocean, warranting a comparison of the Bay and ocean diets using parametric multivariate statistics. Since predator and prey assemblages, water temperatures, beach profiles and wave energies vary dramatically between Bay and ocean sampling stations, it was not surprising that the diet may have differed between these regions (Austin and Seaver 1996; Austin et al. 1997; Holmquist 2001).

The diet differences between the Lower Bay and coastal ocean, as well as inter-annual and intra-annual variations, were tested for significance for each diet index using the three-way MANOVA. All MANOVAs gave the same result, the YOY bluefish diet in the Lower Bay was significantly different from that in the coastal ocean, and there was a significant difference among those months in which bluefish were collected (intra-annual variation). Seldom have the spatial variations in the age-0 bluefish diet within a particular nursery area been investigated, and statistical analyses have never been used to rigorously test these differences in the few cases where they have been identified. Creaser and Perkins (1994) sampled YOY bluefish from three localities along Maine's coast and found that invertebrates were the main prey in one area while fish prey dominated the diet in the other two. The diet composition differed between the latter two locations as well. The size ranges of bluefish collected from these three regions were not comparable, which may have confounded the results. On the other hand, these results may reflect true spatial differences in the bluefish diet within a nursery area, as was observed in my investigation.

Many studies have reported intra-annual variation in the YOY bluefish diet, but again, none applied statistical tests to identify significant differences. Each of the three studies conducted in the Lower Hudson River found that Atlantic silverside and bay anchovy were important early in the summer while striped bass, blueback herring and American shad became the main prey by mid summer (Juanes et al. 1993; Buckel and Conover 1997; Buckel et al. 1999a). It was suggested that this shift reflected age-0 bluefish feeding on larger prey as the bluefish grew. In both Great South Bay studies, bluefish fed primarily on Atlantic silverside in the early summer and bay anchovy in the later summer and fall (Juanes et al. 1994; Juanes and Conover 1995). In Hartman and Brandt's (1995b) Chesapeake Bay study, bay anchovy was consumed almost exclusively until late summer, at which time Atlantic menhaden gained importance.

According to each three-way MANOVA, the YOY bluefish diet in 1999 was not significantly different from that in 2000. Grant (1962), Juanes et al. (1994), Creaser and Perkins (1994), Hartman and Brandt (1995b) and Buckel and Conover (1997) also found that the bluefish diet did not change dramatically from year to year. Friedland et al. (1998) and Buckel et al. (1999a) reported inter-annual variability. Unfortunately, none of the above investigations used statistical analyses to confirm whether these differences were significant. Future gut content studies should use exploratory multivariate techniques such as correspondence analysis and principal components analysis to identify spatial and temporal variations in a predator's diet, which can then be tested for significance using multivariate parametric statistics such as MANOVA. Using this approach, it will be possible to determine whether observed diet differences are statistically significant or are merely a result of 'noisy' data.

Since the three-way MANOVAs indicated that the age-0 bluefish diet differed between the Lower Chesapeake Bay and Virginia's coastal ocean and also by month, a diet description was provided for each location by month to elucidate these variations. Unfortunately, the cumulative prey curves for the July diet in the ocean and the May, October and November Bay diets did not reach asymptotes, so their descriptions were probably incomplete. Diet descriptions for the May, June and October ocean diets may also have been incomplete, since only a few bluefish were collected in each of these months, and all bluefish collected within each month only consumed one prey type.

The coastal ocean diet was dominated by Atlantic silverside in the late spring / early summer (May and June), soon after the bluefish recruited to the coastal zone. Atlantic silverside decreased in importance as the summer progressed and were no longer the main prey by August. Bay anchovy and striped anchovy increased in importance over this period. Portunid crab megalope and sand shrimp were first encountered in the guts in July, and by August the megalope was the main prey. The highest prey type diversity in the ocean diet occurred in August. By September, bay and striped anchovies became the main prey types, Atlantic silverside was of secondary importance and megalope comprised a small fraction of the diet. Age-0 bluefish only consumed bay anchovy in October.

The general pattern of a silverside dominated diet in the late spring / early summer followed by a switch to anchovy by mid summer was also observed by Juanes et al. (1994) and Juanes and Conover (1995) in Great South Bay.

Hartman and Brandt (1995b) found that the diet was dominated by bay anchovy and Atlantic menhaden in late summer as well. Similar to my study, Buckel et al. (1999a) encountered portunid crabs in the age-0 bluefish diet, and these crustaceans were most important in mid-summer. Few other YOY bluefish diet studies reported intra-annual variations.

An explanation for the observed intra-annual diet patterns may lie in the spawning and recruitment times of the various prey types. Atlantic silversides spawn in the spring, and juveniles are abundant in the littoral zone when the YOY bluefish recruit to the coast (Holmquist 2001). These silversides grow as the summer progresses. The young of bay anchovy, striped anchovy and many invertebrate species, including portunid crabs and sand shrimp, recruit to this region in mid summer (Sandifer 1975; Haefner 1976; Murdy et al. 1997; Rilling and Houde 1999). The diet may have shifted from juvenile Atlantic silverside in the early summer to these smaller, recently spawned prey by mid summer either because the latter became more abundant than the juvenile silversides and/or as a result of size selectivity for the smaller prey. A similar explanation for the shift from Atlantic silverside to bay anchovy in the Great South Bay was offered by Junaes and Conover (1995).

The complete lack of Atlantic menhaden from the coastal ocean diet was puzzling, since age-0 menhaden were often caught along with bluefish in seine hauls from this region (Austin, Unpublished data). Breeder (1922) and Buckel et al. (1999b) collected YOY bluefish from New Jersey's coastal ocean and the Middle Atlantic Bight continental shelf waters, respectively, and also found that

Atlantic menhaden were absent from the diet. The reason for the lack of this abundant, energy-rich, pelagic prey in the YOY bluefish ocean diet are unknown and deserve exploration in future studies.

The Lower Bay diet showed both similarities to and differences from that in the coastal ocean. Unlike the May ocean diet, the May Bay diet was dominated by portunid crab megalope and unidentified eggs. Megalope were absent from the guts in June, and Atlantic silverside was the main prey. Other important prey included sand shrimp, bay anchovy, striped anchovy and striped bass. As in the ocean diet, the importance of Atlantic silverside declined in July. Atlantic menhaden were first encountered at this time and accounted for a substantial portion of the diet. The August and September diets were fairly similar as bay anchovy, Atlantic menhaden and striped anchovy were the main prey while Atlantic silverside was of secondary importance. Bay anchovy and striped anchovy were the most important prey in October, and Atlantic menhaden was absent. Kingfish spp. and spotted seatrout were found in the stomachs at this time. By November, bluefish fed on bay anchovy almost exclusively.

These intra-annual Bay diet variations were consistent with those reported by Juanes et al. (1994) and Juanes and Conover (1995) who also observed a dietary shift from Atlantic silverside to bay anchovy by mid summer. My study's results were also similar to those of Hartman and Brandt (1995b) as anchovies were the main prey throughout most of the summer nursery period, while Atlantic menhaden became important in the late summer and early fall. Hartman and Brandt (1995b) did not observe the early summer dominance of Atlantic silverside described in my study nor the diversity of prey types encountered here, possibly due either to their small sample sizes or to differences in prey availability.

The bluefish Bay diet showed some similarities to that in the ocean. Atlantic silverside was the main prey type in the late spring / early summer while the anchovy dominance began in mid summer and extended throughout the fall. This again may have reflected a feeding shift from recently spawned Atlantic silverside to recently spawned anchovies as they became available. Although silversides were not encountered in the May Bay diet, the diet description for this month may have been incomplete. The appearance of juvenile striped bass in the June diet confirmed that bluefish did feed on this economically valuable species in the Chesapeake region, but the relatively low diet index values and the absence from the diet in all other months suggested that, unlike in the Hudson River estuary, striped bass were probably not a major component of the YOY bluefish diet in this area.

The Atlantic menhaden first appeared in the July Bay diet, which probably reflected bluefish becoming large enough to consume this highly mobile, pelagic prey. Menhaden's absence from the October and November diets was unexpected, since they should have been available to the bluefish at that time (Austin, Unpublished data). Cumulative prey curves indicated that the diet descriptions in these later months were probably incomplete, so Atlantic menhaden may have remained important. The occurrence of larger prey, such as age-0 spotted seatrout and YOY kingfish spp., in the October diet again probably resulted from the bluefish reaching a size large enough to consume these prey.

Based on the results of my study, further investigation of the YOY bluefish diet in the Lower Chesapeake Bay and Virginia's coastal ocean is warranted. Future studies should collect bluefish as randomly as possible. The lack of random sampling in my investigation, due to time and financial constraints, made it difficult to determine how well my diet descriptions applied to the YOY bluefish population in this area. Specimens were only collected during daylight hours, which also may have biased the results if the diet composition changed after nightfall. Although Buckel and Conover (1997) found that the Hudson River bluefish diet at night was quite similar to that during the day, a future YOY bluefish diet study in the Chesapeake region comparing the diet of fish collected during the day to that of specimens taken at night would confirm whether it was possible to obtain an accurate description by sampling solely during daylight hours.

Future attempts to quantify spatial and temporal diet variations should also include intense sampling in May, June, October and November to obtain an adequate number of specimens for these months. Finally, since YOY bluefish have extremely rapid digestion rates, the contribution of easily digested, soft-bodied invertebrates to the diet may have been underestimated (Buckel and Conover 1996). A series of diel collections that sample bluefish every hour or two could help to determine the extent to which these invertebrates may have been underrepresented in the diet.

Overall, there were four general conclusions from my investigation

(1) Small pelagic and littoral, schooling prey, including the bay anchovy, Atlantic silverside, striped anchovy and Atlantic menhaden, were the main YOY bluefish prey in the Lower Chesapeake Bay and Virginia's coastal ocean in 1999 and 2000, while invertebrates such as portunid crab megalope and sand shrimp were of secondary importance.

(2) Age-0 bluefish were mainly piscivorous throughout the size range sampled in my study (33 mm to 290 mm), with the smallest size corresponding to the size at recruitment to this region and the largest to the size of spring-spawn fish when the fall migration begins.

(3) The diets in the Lower Bay and coastal ocean differed, and also varied in each region by month. The diet in 1999 was not significantly different from that in 2000.

(4) The YOY bluefish diet shifted from mainly Atlantic silverside to predominantly anchovies by mid summer in both the Lower Bay and coastal ocean. Prey type diversity was greater in the Bay diet and included Atlantic menhaden, which was completely absent from the coastal ocean diet. While YOY bluefish did consume age-0 striped bass in the Lower Bay, they are probably not a major component of the diet.

Two major questions regarding YOY bluefish in their summer nursery areas are 1) does the availability of certain prey types affect the survival probabilities and therefore year-class strength of these fish? and 2) what impact do these bluefish have on prey populations? Bay anchovy, Atlantic silverside, striped anchovy and Atlantic menhaden may be crucial to age-0 bluefish survival and year-class strength in the Chesapeake region. A decline in the abundances of these prey would probably not result in mass bluefish starvation since these predators have a flexible foraging behavior and would likely shift to other prey species, but the reduction or loss of these prey may lead to decreased growth rates, and consequently survival probabilities, during the summer nursery period and subsequent fall migration. This study provides the fine scale diet data needed for future modeling efforts addressing these questions.

My investigation also identified those prey species that are most likely to be substantially impacted by YOY bluefish feeding. Once the bluefish consumption rates, abundance estimates and prey population sizes are determined in future studies, the dietary proportions of each prey type reported in my study can be coupled with these data to determine the effect of age-0 bluefish foraging on the various prey populations. This information will be valuable since some prey (bay anchovy, striped anchovy and Atlantic silverside) are also consumed by bluefish competitors including striped bass and weakfish, each of which support important commercial and recreational fisheries in the Chesapeake region, others such as striped bass, white perch and portunid crabs support valuable fisheries themselves, and some, namely the Atlantic menhaden, are consumed by competitors and support a fishery.

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