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ECOLOGY AND CONSERVATION OF VIRGINIA SHARK SPECIES.

Analysis of thirty years of Virginia long-line shark census data, 1974-2004.

A Dissertation

Presented to

The Faculty of the Department of Fisheries Science
Virginia Institute of Marine Science/ School of Marine Science
The College of William and Mary in Virginia

In Partial Fulfillment

Of the Requirements for the Degree of

Doctor of Philosophy

by

Daniel Stuart Ha

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APPROVAL

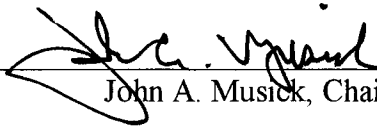
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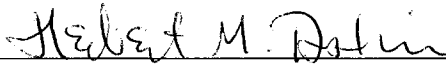


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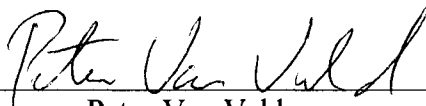
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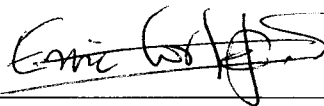
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To my family- Mom, Dad, Jim, Renee, Steve, Sharon, Tom, Maria,
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ABSTRACT

Sharks of the Atlantic coast of the United States have suffered increased fishing pressure in last three decades. Commercial and recreational catches jumped in the mid to late 1980's, leading to regulation by the National Marine Fisheries Service in the early 1990's. The Virginia Institute of Marine Sciences' shark long-line survey, begun in 1974, and continuing to the present day, is thus well positioned to look at the effects of this fishing mortality on sharks. Using GAM modelling, six of ten shark species analyzed, including the most common species, *Carcharhinus plumbeus*, suffered declines of from 98-99% of early abundances in the survey. Only two species showed no significant trends, and only one (*C. obscurus*) showed signs of recovery. Analysis of size changes showed that both *C. plumbeus* and *C. obscurus* have suffered declines in both mean and variance of their size distribution since 1974. Analyses of mass changes showed that five of thirteen species have shown biologically significant declines in mass per shark since 1974. Six of the remaining eight showed no trend in mass per shark.

Habitat analyses showed that few species showed effects of climate scale variables such as the North Atlantic Oscillation index, Chesapeake Bay discharge, or the Palmer Drought Index. Many species showed significant changes in patterns in abundance with local environmental variables, such as temperature, salinity, and water depth. These patterns, when combined, revealed several groupings of species, including deep-water species, Bay-abundant species, and near-shore species. Another group consisted of species that occur only as they move north and south en route to more northerly areas for summer months. One group was made up of two species (*S. acanthias* and *M. canis*) that occurred almost exclusively in cold water (April and May).

Analysis of New Jersey long-line data from 1961-62 with a resample of many of the same sites revealed that abundances off New Jersey show a trend in both mass and abundance similar to that found in the VIMS survey data. Overall, this study demonstrated many trends in shark distribution and ecology not previously shown in any way other than anecdotally.

Ecology and Conservation of Virginia Shark Species.

Chapter 1: Introduction, Literature Review, and Objectives

Elasmobranchs in general and sharks in particular have become increasingly a target of fisheries since the Second World War (Baum et al., 2003; Bonfil, 1994; Castro et al., 1999; Musick et al., 1993). Elasmobranchs have also become increasingly threatened due to their role as bycatch in other fisheries, which has also increased (Bonfil, 1994; Camhi et al., 1998). Lack of research into the harvest of sharks prior to the 1960's was perhaps caused by their relatively low market value (Bonfil, 1994), or by the small scale of their fisheries (Camhi et al., 1998; Castro et al., 1999). As research progressed, it became apparent that many elasmobranchs and especially sharks are highly K-selected. Characteristics of K-selection in elasmobranchs include slow growth, late maturity, and low fecundity. Such attributes lead to low intrinsic rates of population increase and low resilience to fishing (Castro et al., 1999; Hoenig and Gruber, 1990; Musick et al., 2000a; Smith et al., 1998). These common elasmobranch characteristics, especially in combination with other factors, make it essential for fisheries managers to take steps to protect these species before they become over-fished. Evidence suggests that many populations of elasmobranch species, such as the California soupfin shark (*Galeorhinus galeus*), the New England porbeagle shark (*Lamna nasus*), the English basking shark (*Cetorhinus maximus*), the California thresher shark (*Alopias vulpinus*), the Irish Sea common skate (*Raja batis*), and the western North Atlantic barndoor skate

(*Raja laevis*: Brander, 1981; Casey and Myers, 1998; Castro et al., 1999) have already become severely over-fished.

Hoff and Musick (1990) surveyed western North Atlantic shark fisheries and documented a rapid expansion in shark fisheries during the 1980's, as well as increased bycatch as a result of increasing swordfish and tuna fisheries. They also analyzed the information gaps, and found many areas of need, such as life history information, fisheries information (such as landings by species and estimates of effort), and assessment/ management information (such as fisheries-independent measures of shark population abundance).

Baum et al. (2003) analyzed relative abundance data from eight shark species or species groups taken as bycatch in the oceanic long-line fishery in the northwest Atlantic ocean, and found all species/species groups except makos have declined more than 50% in the past 8-15 years. They concluded that overfishing is occurring for most large coastal and pelagic sharks in the area, and that the magnitude of the recent declines suggests that several species of sharks are at risk of large-scale extirpation if protection measures are not taken soon. Though Burgess et al. (2005) disputed these extreme decline levels they acknowledged that shark populations have declined in many cases. They also stressed the importance of more work on assessing shark population levels and their biology.

In U.S. Atlantic waters, a management plan is in place to restore large coastal sharks and recovery has begun for some species (NMFS, 2003; NMFS, 1992; NMFS, 1999). However, much of the basic information needed for management, such as

Essential Fish Habitat (EFH) and a better knowledge of physical factors that affect shark distribution are not available. The National Marine Fisheries Service (NMFS) has outlined further research needs, including determining shark habitat relationships such as seasonal and spatial temperature and salinity patterns, and developing spatially consistent databases of environmental conditions throughout the sharks' ranges (NMFS, 2003). The Food and Agriculture Organization (FAO) of the U. N. has also outlined information gaps, such as lack of biological data that impede effective shark fisheries management (Castro et al., 1999).

Conservation Status

Currently, only one species of elasmobranch (*Pristis pectinata*) is listed under the 1973 Endangered Species Act (ESA), and none that occur presently in Virginia, although *P. pectinata* once did (Hildebrand and Schroeder, 1928). Three species (*Carcharhinus obscurus*, *Carcharias taurus*, and *Carcharhinus signatus*) are listed as "Species of Concern" (SOC), which has no legal status under the ESA. Each was placed on this list after being denied an official status under the ESA.

The International Union for the Conservation of Nature (IUCN) evaluates conservation status of elasmobranchs (among others), and its scope is broader than the USA's ESA. The IUCN regularly updates and publishes its "Red List" of threatened and endangered species from around the world. The Shark Specialist Group (SSG) concerns itself with the Red List for all chondrichthyans (the name is slightly misleading), and is currently engaged in reviewing and expanding the chondrichthyan listings. Two species

of sharks from the Virginia Institute of Marine Science's (VIMS) 30-year longline survey (see below) are considered vulnerable, *Carcharodon carcharias* and *C. taurus* (Table 71.1). Of these, *C. taurus* is by far more abundant in the survey, being the fifth most abundant species caught. Of the rest, eight are in the Lower Risk/ near threatened category, including four of the eight most abundant species in this survey, *Carcharhinus plumbeus*, *C. obscurus*, *Carcharhinus limbatus*, and *Galeocerdo cuvier*. One other species, *Alopias vulpinus*, has been categorized and it is considered Data Deficient. The revised accounts for shark species in progress will likely broaden to include all the species listed, and may revise the status of some of those already included.

The FAO also has published accounts of the conservation status of the world's sharks (Castro et al., 1999). In this scheme, none of the species present in Virginia have been placed in the highest threat category (category 5) but several have been placed in the next highest category (category 4), including *C. plumbeus*, *C. obscurus*, and *C. taurus* (Table 71.1). Species in category 4, "show substantial historical declines and/or have become locally extinct." Category 3, described as, "Species that are exploited by directed fisheries or bycatch, and have a limited reproductive potential, and/or other life history characteristics that make them especially vulnerable to overfishing, and/or that are being fished in their nursery areas," includes *C. limbatus* and *Sphyrna lewini*, from the most abundant species. The rest are categorized as not declining (category 2) or data deficient (category 1).

The American Fisheries Society (AFS), a professional society of fisheries scientists, also published a conservation evaluation of marine fish stocks, including

elasmobranchs (Musick et al., 2000b). The AFS group established criteria for determining levels of extinction for marine fishes and rejected those used by IUCN because the IUCN criteria often overstated extinction risk (Musick 1999). The paradigm that resulted is considered by many to be more appropriate for almost all marine organisms. The AFS considered *C. obscurus* and *C. taurus* vulnerable (Table 1.1). Only two other species are covered by this scheme, both lower abundance sharks in this survey, *C. carcharias* and *Carcharhinus signatus*, with the former considered conservation dependent, and the latter vulnerable.

Management Status

All species of elasmobranchs in the US fall under the jurisdiction of the NMFS, which was asked by the regional fisheries management councils to develop a shark fishery management plan (FMP), under the authority of the Magnuson-Stevens Fishery Conservation and Management Act. The first shark FMP was implemented in 1993, and it set forth many regulations for management of shark fisheries, the salient points of which are summarized below (NMFS, 1992). The plan divided sharks into three management categories: Large Coastal Sharks (LCS), Small Coastal Sharks (SCS), and Pelagic Sharks (PEL; Table 1.1). The plan also implemented many rules to reduce take, both recreational and commercial, and began a data collection process as well as periodic re-evaluations of the status of species under its aegis. At that time, NMFS concluded that SCS were fully fished, and that LCS were overfished.

The NMFS conducted a LCS stock assessment published in 1996 that led to rulings to reduce the commercial and recreational catch, and established a prohibited species list that included *Rhincodon typus*, *C. maximus*, *C. taurus*, *Odontaspis noronhai*, and *C. carcharias* (NMFS, 1996). This led to the agency being sued by commercial fishing groups, and the delay of implementation of these new quotas, but not implementation of the prohibited species list. Following this, and changes to the Magnuson-Stevens Act, NMFS conducted another LCS stock assessment and followed with the 1999 FMP for Highly Migratory Species (HMS), including sharks (NMFS, 1998; NMFS, 1999). The stock assessment indicated that LCS were overfished (NMFS, 1998), and the HMS FMP changed and implemented many management measures (NMFS, 1999). Along with several measures to reduce recreational and commercial catch, the regulations included dividing LCS into ridgeback (*C. plumbeus*, *Carcharhinus falciformis*, and *G. cuvier*) and non-ridgeback species (*C. limbatus*, *Carcharhinus leucas*, *C. brevipinna*, *Negaprion brevirostris*, *G. cirratum*, *S. lewini*, *Sphyrna tiburo*, and *Sphyrna mokarran*). Regulations also included widening the prohibited species list to 19 species, including species present in the VIMS survey, the *C. taurus*, *C. carcharias* (both listed in 1996), *C. obscurus*, *C. signatus*, *Carcharhinus altimus*, and *Alopias superciliosus*. All these regulations were delayed by a court order relating to the earlier lawsuit, although in June 2000 the court allowed the prohibited species list to go into effect. Later in 2000, a settlement was reached allowing some of the other changes to go through. Various emergency rulings were published, suspending or setting back catch quotas until the 2003 amendment to the HMS FMP (NMFS, 2003), which removed the

ridgeback/non-ridgeback distinction, and set new quotas and other regulations based on the 2002 SCS and LCS stock assessments (Cortés, 2002b; Cortés et al., 2002).

The 2002 SCS and LCS stock assessments provided some of the most recent information on the status of shark species classed as LCS and SCS. The SCS stock assessment indicated that the SCS group, as well as the species *Rhizoprionodon terraenovae* and *Sphyrna tiburo* (not found in present study) were at or above biomass levels that could produce maximum sustainable yield (MSY), and that present levels of fishing mortality could be sustained (Cortés, 2002b). It also indicated that *Carcharhinus acronotus* and *Carcharhinus isodon* (not found in present study) were more resistant to analysis, and therefore it was more difficult to determine whether they were at safe biomass levels (Cortés 2002). The 2003 amendment to the HMS FMP interpreted these conclusions as the *C. acronotus* stock being healthy, and the *C. isodon* stock not overfished, but that overfishing was occurring (NMFS, 2003).

The 2002 LCS stock assessment indicated that the LCS complex was in better condition than in 1998, but that it was overfished and overfishing was occurring (Cortés et al., 2002). However, for *C. plumbeus* and *C. limbatus*, the assessment suggested that both species were at or above the biomass necessary to produce MSY, i.e. they were not overfished. It further suggested that *C. plumbeus* was being overfished, but that was not the case for *C. limbatus*.

NMFS has been collecting landings data on sharks since the early 1970's, and their landings data show that U.S. Atlantic shark catches rose drastically starting in the mid-1980's (Figure 1.1). Their data on landings of the most abundant shark in Virginia

waters, *Carcharhinus plumbeus*, showed a steady rise in landings from the late 1980's and starting to the late 1990's, after the implementation of catch quotas in 1993 (Figure 2). All species except *R. terraenovae* show peaks in landings in the mid-1990's (Figures 1.2-1.5). *Rhizoprionodon terraenovae* shows a peak in the late 1990's (Figure 3). The trends in *C. limbatus* and *G. cuvier* landings show a second peak after 2000, as well, likely a result of redirection by the fishery (J. Musick, personal communication; Figures 1.3 and 1.4). The landings data for *C. obscurus* show a second peak in 2000, with a steep decline after that when NMFS placed the species on the protected list (Figure 5). The landings for *G. cuvier* were broken down by latitude, and showed that landings of this species are far greater south of the Virginia/ North Carolina border (Figure 4).

History of Elasmobranch Exploitation in Virginia

In Virginia, harvest of elasmobranchs and sharks began before the earliest days of European colonization of the New World. DeVry's illustration "The Manner of Fishing in Virginia," clearly shows at least one species of elasmobranch in its depiction (DeBry and Alexander, 1976). Hence, as pointed out by Jackson (2001), no marine ecosystem can be considered pristine after European colonization, a fact overlooked or ignored by many fisheries scientists and managers. Indeed, he cites evidence, from the geological record, of changes to the Chesapeake Bay starting in the late 1700's, finding a seven-fold increase in environmental and biological variability since then. The lack of baseline data, and the ignorance of its lack, hampers complete understanding of many fields of environmental science, including shark population biology. In Virginia, the earliest

information on fishing of any species are derived from fish surveys conducted by the U.S. Fish Commission in the late 1800's, and these surveys did not distinguish shark species until well after 1908 (Anonymous, 1911). Despite the lack of information on the pristine system, and the lack of fisheries data until well into the 20th century, valuable insights can still be gained into the nature of elasmobranch biology as it is now (not to be confused with how it was when pristine).

One of the first references to mention elasmobranchs of the Chesapeake Bay and their fisheries is Hildebrand and Schroeder (1928), who included 10 species of sharks and 14 species of other elasmobranchs in the Chesapeake Bay, as opposed to later accounts, that included 12 shark species and 14 of other elasmobranchs (Hildebrand and Schroeder, 1928; Murdy et al., 1997). Hildebrand and Schroeder (1928) listed three species of sharks, *Ginglymostoma cirratum*, *S. tiburo*, and *Squatina dumeril* that have not been collected in recent VIMS long-line surveys (Musick et al. 1993; Table 11.2). The 1997 edition of Fishes of Chesapeake Bay (Murdy et al., 1997) lists three species of sharks that have not been collected in this survey, the last two above, and *C. maximus*. *Ginglymostoma cirratum* is a tropical species (Compagno et al., 2005), and likely a rare visitor to the Chesapeake Bay. *Sphyrna tiburo* is a small species, and is also an infrequent visitor to the Chesapeake Bay from tropical or sub-tropical waters. Its rarity and the fact that it is likely too small to take our hooks are the likeliest reasons for its absence from the long-line survey. *Squatina dumeril* is a benthic "sit and wait" piscivore, accounting for its absence from our long-line survey. Since *C. maximus* is planktivorous, it is easy to understand why this species would not be collected in the

VIMS survey (Musick et al. 1993). Hildebrand and Schroeder (1928) give little fisheries data of any kind on sharks, except for *Sphyrna zygaena*, which they mentioned having seen caught in pound nets and on hook and line, and *Squalus acanthias*, which they mentioned as of no commercial importance in the Bay.

Hildebrand and Schroeder (1928) included five species of skates and rays that have not been collected in this survey, whereas the later edition of Fishes of Chesapeake Bay (Murdy et al. 1997) listed only two not seen in the VIMS long-line survey, *P. pectinata* and *Manta birostris* (Table 21.3). Fisheries data for skates included capture during the early pound net season (spring), and anecdotally mention of one-day pound net catches of 12-22 individuals in early April. *Raja laevis* is the elasmobranch species with most complete information of all elasmobranchs in Hildebrand and Schroeder (1928). They indicated this species was caught frequently early in the year in pound nets, and the wings removed and shipped to New York. Interestingly, this species was recently the subject of a paper calling it “near extinct,” from bycatch mortality (Casey and Myers, 1998). This species is no longer known from the Chesapeake Bay or Virginia waters. The only other elasmobranch mentioned as being caught by fishermen in the Bay was *Dasyatis say*, but no mention is made of commercial exploitation (Hildebrand and Schroeder, 1928).

VIMS' Shark Longline Survey

The long-term data set (referred to as the survey dataset henceforth) collected by VIMS is very valuable for both describing relative abundance trends of Atlantic coastal shark species and describing life history traits of these species. The survey dataset is composed of results of standardized long-line sets started in 1973 (Musick et al., 1993), and has information on many essential aspects of shark biology that has not yet been abstracted and published. The survey, to date, has set 1043 long-lines on 250 cruises from more than 14 vessels. In the process, 92,060 regular hooks and 17,951 other hooks were set, and lines soaked for more than 3,875 hours. Overall, 8296 individuals of 22 shark species are represented in the survey dataset (Table 1.2). Catch of batoids, only recorded reliably since 1995, includes 1,561 fish in 11 species (Table 21.3).

The VIMS long-line survey has used the same gear type since its inception, and has a fixed set of stations (7) that are always sampled (if possible) on each cruise (Figure 6). The gear used is described below in the methods section. Other stations have been stratified by depth when vessel time allowed (Musick et al., 1993) (Figure 7). The VIMS longline data has supported a number of analyses (Conrath and Musick, 2002; Cortés, 2002b; Cortés et al., 2002; Gelsleichter et al., 1999; Goldman, 2002; Grubbs, 2001; Loefer and Sedberry, 2002; Musick, 2000; Musick et al., 1993; NMFS, 1996; NMFS, 1998; Sminkey and Musick, 1996; Sminkey and Musick, 1995; Branstetter and Musick, 1993; Branstetter and Musick, 1994; Musick and Colvocoresses, 1986) but few have focused on general abundance trends and/or looked for correlations with environmental factors, and none since 1993.

In one of the few published accounts using the survey dataset to date, Musick et al. (1993) examined the VIMS longline survey dataset from 1974 to the 1991 season for trends in CPUE, and, in addition to analyzing the whole dataset, broke it down by species, depth strata, month, and size categories for common species. Due to sampling considerations, some years were pooled to more accurately reflect trends (groups were 1974-79, 1980, 1981, 1982-89, 1990, and 1991). They found that the catch was dominated by the sandbar shark, making up more than half the catch for every year group. They further found that juvenile sandbar sharks were commonly caught in the Chesapeake Bay, reinforcing its status as a nursery ground.

Marked declines in catch per unit effort (CPUE) were found in four of the six most commonly caught shark species (*C. plumbeus*, *C. obscurus*, *C. taurus*, and *G. cuvier*). These patterns were detected in all depth categories over time, except for *C. plumbeus* in the Chesapeake Bay, where catches were made up of juvenile sharks, and in *R. terraenovae* in their preferred depth range (10-20 m). In their analysis of month-stratified data, they found sandbar sharks migrated into the area of the survey in May and began to leave in mid-October.

When Musick et al. (1993) analyzed CPUE for size classes, they found a majority of *C. plumbeus* were juveniles and adolescents (50-150 cm TL) taken in Bay and coastal waters (<10 m), while most larger specimens were taken in deeper waters. In addition, they found the CPUE of all size classes of *C. plumbeus* but the smallest (50-100 cm TL) declined over the course of the study. *Carcharhinus obscurus*, the only other species caught in sufficient numbers to allow this analysis, were found to be more abundant in

deeper water (10-20 m), and the smallest size class (<150 cm TL) was found to be most abundant.

In summary, Musick et al. (1993) found that, with juvenile *C. plumbeus* in the Bay excluded, total shark CPUE had declined roughly four-fold in the 17 years of the study. Under criteria established by the IUCN, the declines shown in Musick et al. (1993) would lead one to declare *C. plumbeus* Endangered, and *C. obscurus*, *C. taurus*, and *G. cuvier* to be Critically Endangered in this area. Under the more fisheries-relevant categories of Musick et al. (2000b), *C. obscurus*, *C. taurus* and *G. cuvier* would all be categorized as Vulnerable, and subject to further evaluation (Musick et al., 2000b).

Musick and Colvocoresses (1986) examined VIMS long-line and other data and found that *S. acanthias* were highly abundant in winter months, while *C. plumbeus* and *C. obscurus* dominated the catch in the summer months. They also described the Chesapeake Bay as a pupping and nursery habitat for *C. plumbeus*, and the nearshore (<10m depth) areas of Virginia as pupping and nursery grounds for *C. obscurus* (Musick and Colvocoresses, 1986).

One other paper has utilized catch information from the survey dataset. Branstetter and Musick (1993) compared the catch efficiencies of traditional “Yankee” gangions and modern monofilament gangions, and found monofilament gangions to be more effective than Yankee gangions in almost all cases (Branstetter and Musick, 1993). Only catch rates of offshore species (*I. oxyrinchus*, *C. altimus*, *C. falciformis*, *P. glauca*, and *A. superciliosus*) were higher on steel gangions than on monofilament. The authors

attributed this to the larger size of these species allowing them to more easily bite through the monofilament leader.

Life History Characteristics of Virginia Elasmobranchs

Life history information may help to explain patterns seen in the analyses presented in this study, but an in-depth discussion of these data is not warranted here. For this reason, life-history information for every shark species collected in this survey has been summarized in a series of tables. The Von Bertalanffy growth characteristics of these species show that, of the eight most abundant species in this survey, *C. plumbeus* and *C. obscurus* have relatively low k values, while the *R. terraenovae*, *M. canis*, and *G. cuvier* have relatively high k values (Table 31.4). In terms of the reproductive characteristics of the most abundant species, *S. acanthias* and *C. taurus* are both relatively slow reproducers, while *G. cuvier*, *M. canis*, *S. lewini*, and *R. terraenovae* all are relatively fast reproducers (Table 41.5). Two publications have compared population growth rates in several shark species, but used different population growth models (Table 51.6; Cortés, 2002a; Smith et al., 1998). In terms of what is known of population growth rates of the most abundant species, *G. cuvier* and *C. limbatus* have relatively high population growth rates, while *C. obscurus* has a relatively low rate of population growth. Food habit studies are rare in Virginia, with only four having published information of feeding habits (Table 61.7). The rest are taken from studies in other areas, and provide little specific information on what sharks may be feeding on in Virginia waters.

Essential Fish Habitat

The 1999 FMP defined Essential Fish Habitat (EFH) for many of the shark species collected in the VIMS survey, and some of these definitions were modified in the amendment (NMFS, 2003; NMFS, 1999). One purpose of the present study is to further and/or refine the definitions of EFH for these species. These NMFS documents defined EFH for each species to the greatest extent possible with the knowledge available at the time. They divided each species into three age classes, young-of-year and juveniles, large juveniles and sub-adults, and adults. They attempted to define EFH for each age class by geographic range, known spawning/nursery areas, known mating areas, and environmental preferences. Due to the complexity of the descriptions of EFH in these documents, they will not be summarized here, but will be cited as necessary in the relevant discussions in following chapters.

Objectives

The main objective of this study is to use the information contained in the VIMS long line data set to analyze trends in abundance in shark species in greater detail and help determine the EFH of Virginia's shark species. The shark data set will be used to complete a number of smaller scale objectives with regard to shark distribution, life history, and exploitation history.

Objective 1: Examine all shark species and species groupings for trends in abundance over the course of the dataset (30 years).

Objective 1(a): Separate species (when possible) into size/ age classes and define trends in abundance.

Objective 2: Examine the data set for effects on shark CPUE's of various environmental parameters, such as depth, salinity, water temperature, and dO.

Objective 2(a): Obtain data on weather conditions, such as atmospheric pressure, wind speed, air temperature, and wave height, and test for effects on shark CPUE.

Objective 2(b): Obtain data on larger-scale effects, such as coastal upwelling, and the North Atlantic Oscillation (NAO) and test for effects on shark CPUE.

Objective 3: Examine long-line records for changes in the size structure and/or mean mass of elasmobranch species over the course of this study.

Objective 4: Obtain long-line sampling records from New Jersey long-line survey performed in 1961 and revisit sites to find trends in abundance and size.

Materials and Methods

Field Methods

Elasmobranchs for this study were collected by bottom long-line sampling starting in 1974, and ending (for this study) in 2004. Long-lines were fished once a month May through October at each of seven standard stations. However, varying levels of support and changing research goals led to certain years being under-sampled. In addition, weather or vessel constraints prevented sampling certain stations or certain months.

The VIMS bottom long-line survey was performed with gear standard to the industry at the inception of the study, and the gear has remained the same throughout the survey. The long-line itself is a 6.4 mm (1/4 inch) hard-laid and tarred nylon mainline anchored at both ends with 3-5 m gangions spaced at approximately 20 m intervals. Buoys are set at twenty-gangion intervals, and ends are marked with radar reflectors raised approximately 3 m above sea level. Standard gangions used are of the type termed “Yankee gangions,” these being a heavy-duty quick-snap (also termed a tuna clip) with an 8/0 swivel, 1-3 m of 3 mm (1/8 inch) hard-laid and tarred nylon line, and 8/0 swivel connecting 1-2 m of 1.6 mm (1/16 “) 1X7 or 7X7 stainless steel wire, and a 9/0 hook. Musick et. al (1993) reported that sonar surveys of the long-line indicated it dropped to no deeper than 80 m, but because of catenary formation, most hooks were on or near bottom. Soak times in this survey range from 2 to 17 hours, with the majority 3-4 hours long. Bait used includes many coastal teleost fishes such as croaker, spot, menhaden,

bluefish and mackerel. Surveys since 1998 have used entirely menhaden as bait. Bait pieces are 0.10 to 0.25 kg each.

Long-Line Dataset

Since all sets do not always have every independent variable recorded, and given the number of instances in which a species were not collected in a set of the long-line, several different techniques for analysis of these data are required. First, however, the variables to be analyzed and the constraints they place on the form of analysis must be described.

This long-line survey collects several types of data, and some of these varied over the course of the study. Data about the set is recorded, and can include date, number of hooks, location, time of deployment of the gear (set time), time of retrieval of the gear (haul time), and the duration of the set (soak time). Physical data are also collected, and can include bottom depth, surface temperature, and bottom temperature. Data about the catch, if any, may include species, pre-caudal length, fork length, total length, sex, and gonad state.

Not all of these data are present for each set, however, leaving gaps in the data. Out of 957 recorded stations during 1974-2003, 201 are missing bottom temperature data and 151 are missing haul time data, to cite the worst. The missing data are skewed to the earlier years, making them less available for analysis. Analyses in the following chapters excluded catch records for sets missing variables being analyzed, and thus sample size varies with the number and type of effects in the individual model. Later, in the 1990

field season, other gangion/hook types were deployed on sets in tandem with standard gangions for a hooking efficiency study (Branstetter and Musick, 1993). In the 1993 field season, CTD casts were made for each station, adding salinity and dO data, and increasing the temperature data available. In addition, in that field season, the systematic recording of batoids caught was begun.

Dependent variables that are available for analysis since the inception of this study include number of sharks caught per long-line set per hour of soak time, which is defined as CPUE for this study. Catch per unit effort is available as a total for all species, or broken down by species, or further to species age groups. The CPUE data can also be aggregated in various ways, such as by NMFS management groups. These data will be used in Chapter 2 to address Objective 1. These data will also be used in Chapter 4 to address Objective 2.

The second dependent variable available is size, analyzed strictly either as size or by comparing size-frequency distributions. These data will be used in Chapter 3 to address Objective 3.

Data from a 1961 shark long-line survey off New Jersey using virtually identical gear as the current VIMS long-line survey have been made available by NMFS. In the summer of 2005, a majority of the stations sampled in 1961 was resampled by the VIMS longline survey. The 1961 survey used a 9/0 Japanese tuna hook, and these were used in our resampling program. Comparison of the samples from these two dates may provide valuable insights and possible corroboration for the findings of the Virginia long-line survey. These data are analyzed in Chapter 5, and will attempt to address Objective 4.

FAO Categories	(Castro et al. 1999)	FAO Reasons
1- Exploited species that cannot be placed in other category due to lack of data		1- Significant as bycatch
2-Species pursued in directed fisheries and/or regularly found in bycatch, whose catches have not decreased historically		2- Lack of Data
3-Species that are exploited by directed fisheries or bycatch, and have limited reproductive potential and/or other life history characteristics that make them vulnerable to overfishing.		3-Low or Limited Reproductive Potential
4- Species in this category show substantial historical declines in catches and/or have become locally extinct		4-Targeted by Fisheries
		5-Slow Growth/ longlived/ limited fecundity
		6-Historical Catch Trends
		7-Aggregates/ Schools
		8-Easily Found/ Caught
		9-Fast-Growing
IUCN Category	IUCN Reasons	(IUCN 2003)
DD- Data Deficient	3.1 Harvesting for Food	
LR/nt- Lower Risk/ near threatened	3.1.3 Harvesting for Food-Regional or International Trade	
A-Population reduction	3.4 Harvesting for Materials	
1-80% decline over 10 years or 3 generations	3.4.3 Harvesting for Materials- Regional or International Trade	
2-80% decline in next 10 years or 3 generations	3.5 Harvesting for Cultural/Scientific/Leisure Activities	
a-based on direct observation	4.1 Accidental Mortality-Bycatch	
b-based on index of abundance	4.1.1 Accidental Mortality-Bycatch, Fisheries Related	
c-based on a decline in area of occupancy, extent of occurrence and/or quality of habitat	9.2 Intrinsic Factors-Poor recruitment/reproduction/regeneration	
d-based on actual or predicted levels of exploitation	9.7 Intrinsic Factors-Slow growth rates	

Table 1.1. Current conservation status of shark species caught in the VIMS longline survey 1976-2003. Current status according to United Nations Food and Agriculture Organization (Castro et al. 1999), the IUCN (IUCN 2003), and the American Fisheries Society (Musick et al. 2000b). Additionally, the management group under the National Marine Fisheries Service Highly Migratory Species Fishery Management Plan is shown for each species (NMFS 2003).

Species Name	FAO		AFS		FMP		IUCN	
	Status	Reason	Category	Reason (low)	Group	Pro.	Category	Reason(s)
<i>Alopias superciliosus</i>	3	1,3,5			PEL	x		
<i>Alopias vulpinus</i>	4	3,4			PEL		DD	3.1.3, 3.4.3, 4.1.1
<i>Carcharhinus acronotus</i>	3	3, 4			SCS			
<i>Carcharhinus altimus</i>	1				LCS	x		
<i>Carcharhinus brevipinna</i>	1	2			LCS		LR/nt	3.1.3, 3.4.3, 3.5
<i>Carcharhinus falciformis</i>	3	2,6			LCS			
<i>Carcharhinus leucas</i>	3	3,4,5			LCS		LR/nt	4.1.1
<i>Carcharhinus limbatus</i>	3	3, 7, 8			LCS		LR/nt	3.1, 3.4, 3.5
<i>Carcharhinus obscurus</i>	4	5, 8	Vul.	k, Tmax, Tmat, r	LCS	x	LR/nt	4.1.1, 9.2, 9.7
<i>Carcharhinus plumbeus</i>	4	5,6			LCS		LR/nt	3.1.3, 3.4.3
<i>Carcharhinus signatus</i>	4	1,2	Vul.	k, Tmax	LCS	x		
<i>Carcharias taurus</i>	4	rare, 5,7	Vul.	fec, r	LCS	x	Vu/ A1ab&2d	3.1.3, 3.4.3
<i>Carcharodon carcharias</i>	3	5, 8	CD	k, Tmax	LCS	x	Vu/ A1cd&2cd	3.1, 3.4, 3.5, 4.1.1, 9.2, 9.7
<i>Galeocerdo cuvier</i>	1	2			LCS		LR/nt	3.1, 3.4, 4.1
<i>Isurus oxyrinchus</i>	4	1,2			PEL			
<i>Mustelus canis</i>	1				UNC			
<i>Negaprion brevirostris</i>	1	2			LCS		LR/nt	
<i>Prionace glauca</i>	3	1			PEL		LR/nt	3.1, 3.4, 3.5, 4.1.1
<i>Rhizoprionodon terraenovae</i>	2	9			SCS			
<i>Sphyrna lewini</i>	3	4,7, 8			LCS			
<i>Sphyrna zygaena</i>	1	2			LCS			
<i>Squalus acanthias</i>	4	3, 6			UNC			

Species Name	Naming Authority	Common Name	Total	1928	1997
<i>Carcharhinus plumbeus</i>	Nardo, 1827	Sandbar	5246	x	x
<i>Rhizoprionodon terraenovae</i>	Richardson, 1836	Atlantic Sharpnose	1169	x	x
<i>Mustelus canis</i>	Mitchill, 1815	Smooth Dogfish	582	x	x
<i>Carcharhinus obscurus</i>	Lesueur, 1818	Dusky	446		x
<i>Carcharias taurus</i>	Rafinesque, 1810	Sand Tiger	225		x
<i>Carcharhinus limbatus</i>	Muller & Henle, 1839	Blacktip	133		
<i>Sphyrna lewini</i>	Griffith and Smith, 1834	Scalloped Hammerhead	102		x
<i>Galeocerdo cuvier</i>	Peron & Lesueur, 1822	Tiger	88		
<i>Squalus acanthias</i>	Linnaeus, 1758	Spiny Dogfish	66	x	x
<i>Carcharhinus brevipinna</i>	Muller & Henle, 1839	Spinner	50		
<i>Carcharhinus altimus</i>	Springer, 1950	Bignose	42		
<i>Prionace glauca</i>	Linnaeus, 1758	Blue	33		
<i>Isurus oxyrinchus</i>	Rafinesque, 1810	Shortfin Mako	31		
<i>Carcharhinus falciformis</i>	Muller & Henle, 1839	Silky	21		
<i>Negaprion brevirostris</i>	Poey, 1868	Lemon	15		
<i>Alopias vulpinus</i>	Bonnaterre, 1788	Thresher	11		
<i>Carcharhinus leucas</i>	Muller & Henle, 1839	Bull	9		x
<i>Carcharhinus signatus</i>	Poey, 1868	Night	9		
<i>Sphyrna zygaena</i>	Linnaeus, 1758	Smooth	9	x	x
<i>Carcharhinus acronotus</i>	Poey, 1860	Blacknose	5		
<i>Alopias superciliosus</i>	Lowe, 1841	Bigeye Thresher	3		
<i>Carcharodon carcharias</i>	Linnaeus, 1758	White	1	x	
<i>Ginglymostoma cirratum</i>	Bonnaterre, 1788	Nurse	-	x	
<i>Sphyrna tiburo</i>	Linnaeus, 1758	Bonnethead	-	x	x
<i>Squatina dumeril</i>	Lesueur, 1818	Atlantic Angelshark	-	x	x
<i>Cetorhinus maximus</i>	Gunnerus, 1765	Basking Shark	-		x

Table 1.2: Species of shark collected in the VIMS long-line survey 1974-2004, in order of abundance. Common names and scientific naming authority is taken from Nelson et al. (2004). This also includes comparisons of sharks present with the first edition of Fishes of Chesapeake Bay, by Hildebrand and Schroeder (1928), and with the new edition, by Murdy et al. (1997).

Species Name	Naming Authority	Common Name	Total	FoCB 1928	FoCB 1997
<i>Raja eglanteria</i>	Bosc, 1800	Clearnose Skate	1295	x	x
<i>Dasyatis americana</i>	Hildebrand and Schroeder 1928	Southern Stingray	71	x	x
<i>Gymnura altavela</i>	Linnaeus, 1758	Spiny Butterfly Ray	61		x
<i>Dasyatis centroura</i>	Mitchill 1815	Roughtail Stingray	58	x	x
<i>Rhinoptera bonasus</i>	Mitchill, 1815	Cownose Ray	45	x	x
<i>Dasyatis sabina</i>	Lesueur 1824	Atlantic Stingray	15	x	x
<i>Dasyatis say</i>	Lesueur 1817	Bluntnose Stingray	5	x	x
<i>Gymnura micrura</i>	Bloch & Schneider 1801	Smooth Butterfly Ray	5	x	x
<i>Myliobatis freminvillei</i>	Lesueur 1824	Bullnose Ray	3	x	x
<i>Leucoraja ocellata</i>	Mitchill 1815	Winter Skate	2	x	x
<i>Leucoraja erinacea</i>	Mitchill 1825	Little Skate	1	x	x
<i>Dipturus laevis</i>	Mitchill, 1818	Barndoor Skate	-	x	
<i>Torpedo nobiliana</i>	Bonaparte 1835	Atlantic Torpedo	-	x	
<i>Pristis pectinata</i>	Latham 1794	Smalltooth Sawfish	-	x	x
<i>Aetobatus narinari</i>	Euphrasen 1790	Spotted Eagle Ray	-	x	
<i>Manta birostris</i>	Walbaum 1792	Atlantic Manta Ray	-	x	x

Table 1.3: Species of other elasmobranchs collected in the VIMS long-line survey 1974-2004, in order of abundance. Common names and scientific naming authority is from Nelson et al. (2004). This also includes comparisons of species present with the first edition of Fishes of Chesapeake Bay, by Hildebrand and Schroeder (1928), and with the new edition, by Murdy et al. (1997).

Table 1.4. Summary of individual growth parameters from Von Bertalanffy growth models of shark species caught in the VIMS long-line survey 1974-2004.

1. (Liu et al., 1998)
2. (Cailliet and Goldman, 2004)
3. (DriggersIII et al., 2004)
4. (Branstetter, 1987c)
5. (Bonfil et al., 1993)
6. (Branstetter and Stiles, 1987)
7. (Branstetter, 1987a)
8. (Natanson et al., 1994)
9. (Sminkey and Musick, 1995)
10. (Goldman, 2002)
11. (Wintner and Cliff, 1999)
12. (Natanson et al., 1999)
13. (Ribot-Carballal et al., 2005)
14. (Conrath and Musick, 2002)
15. (Brown and Gruber, 1988)
16. (Skomal and Natanson, 2003)
17. (Loefer and Sedberry, 2002)
18. (Santana and Lessa, 2004)
19. (Nammack et al., 1985)
20. (Carlson and Baremore, 2005)

Species	Sex	age mat Years	linf cm TL	k 1/year	t0 years	Ref
<i>Alopias superciliosus</i>	♀	12-13	224.6	0.092	-4.21	1
<i>Alopias superciliosus</i>	♂	9-10	218.8	0.088	-4.22	1
<i>Alopias vulpinus</i>	♀	5-8	464.3	0.124	-3.35	2
<i>Alopias vulpinus</i>	♂	5	416.2	0.184	-2.08	2
<i>Carcharhinus acronotus</i>	♀	5	114 FL	0.18	-4.07	3
<i>Carcharhinus acronotus</i>	♂	6	106 FL	0.21	-3.9	3
<i>Carcharhinus altimus</i>		-	-	-	-	
<i>Carcharhinus brevipinna</i>	see 20	6-7 m 7-8 f	214	0.212	-1.94	4
<i>Carcharhinus falciformis</i>		10 m 12 f	311	0.101	-2.72	5
<i>Carcharhinus leucas</i>		14-15 m 18+ f	285	0.076	-3	6
<i>Carcharhinus limbatus</i>		4-5 m 7-8 f	176	0.274	-1.2	7
<i>Carcharhinus obscurus</i>	♀	21	359 FL	0.039	-7.04	8
<i>Carcharhinus obscurus</i>	♂	19	373 FL	0.038	-6.28	8
<i>Carcharhinus plumbeus</i>	♀	15-16	197	0.059	-4.8	9
<i>Carcharhinus plumbeus</i>	♂	15-16	184	0.059	-5.4	9
<i>Carcharhinus signatus</i>		8 m 10 f	270	0.11	-2.7	18
<i>Carcharias taurus</i>	♀	9-10	296 PCL	0.11	-4.2	10
<i>Carcharias taurus</i>	♂	6-7	250 PCL	0.16	-3.4	10
<i>Carcharodon carcharias</i>		8-13	544	0.065	-4.4	11
<i>Galeocerdo cuvier</i>		7	337 FL	0.178	-1.12	12
<i>Isurus oxyrinchus</i>		7 m 15 f	411	0.05	-4.7	13
<i>Mustelus canis</i>	♀	4-7	124	0.292	-1.94	14
<i>Mustelus canis</i>	♂	2-3	105	0.439	-1.52	14
<i>Negaprion brevirostris</i>		11.6 m 12.7 f	317.65	0.057	-2.3	15
<i>Prionace glauca</i>	♀	5	310 FL	0.13	-1.77	16
<i>Prionace glauca</i>	♂	5	282 FL	0.18	-1.35	16
<i>Rhizoprionodon terraenovae</i>	♀	3	74.9 PCL	0.49	-0.94	17
<i>Rhizoprionodon terraenovae</i>	♂	3	74.5 PCL	0.5	-0.91	17
<i>Sphyrna lewini</i>		10 m 15 f	329	0.073	-2.2	4
<i>Sphyrna zygaena</i>		-	-	-	-	
<i>Squalus acanthias</i>	♀	12	100.5	0.1067	-2.9	19
<i>Squalus acanthias</i>	♂	6	82.49	0.148	-2.67	19

Species	Young #/litter	Ref	Reprod. cycle	Ref	Gestation Months	Ref
<i>Alopias superciliosus</i>	2-4	h	-		12	b
<i>Alopias vulpinus</i>	2-4	b	annual?	b	9	b
<i>Carcharhinus acronotus</i>	3-6	c	biennial?	c	8	c
<i>Carcharhinus altimus</i>	7-15		-		-	
<i>Carcharhinus brevipinna</i>	9-17	k	biennial	j	11-12	o
<i>Carcharhinus falciformis</i>	10-12	m	biennial	r	12	r
<i>Carcharhinus leucas</i>	6-12	s	biennial?	a	10-11	l
<i>Carcharhinus limbatus</i>	6-11	u	biennial	n	12-13	u
<i>Carcharhinus obscurus</i>	6-14	l	triennial	cc	16	l
<i>Carcharhinus plumbeus</i>	4-12	p	biennial	p	12	v
<i>Carcharhinus signatus</i>	12-18	l	-		-	
<i>Carcharias taurus</i>	2	g	annual	g	10	g
<i>Carcharodon carcharias</i>	2-14	b	biennial?	b	12?	b
<i>Galeocerdo cuvier</i>	6-56	y	biennial	y	12?	l
<i>Isurus oxyrinchus</i>	4-25	aa	triennial	aa	15-18	aa
<i>Mustelus canis</i>	3-18	e	annual	e	11-12	e
<i>Negaprion brevirostris</i>	5-13	l	biennial	j	12	l
<i>Prionace glauca</i>	11-49	v	biennial	q	12	q
<i>Rhizoprionodon terraenovae</i>	2-10	r	annual	r	10-11	w
<i>Sphyrna lewini</i>	15-31	t	annual	bb	9-10	t
<i>Sphyrna zygaena</i>	29-37		-		-	
<i>Squalus acanthias</i>	1-15	x	biennial	x	18-24	f

Table 1.5: Summary of reproductive parameters for the species caught in this survey.

a] (Castro et al., 1999) b] (Compagno, 2001) c] (Hazin et al., 2002) d] (Conrath and Musick, 2002) e] (Compagno et al., 2005) f] (Gilmore Jr. et al., 2005) g] (Moreno and Morón, 1992) h] (Castro, 1983) i] (Castro, 1993) j] (Allen and Cliff, 2000) k] (Clark and Schmidt, 1965) l] (Bonfil et al., 1993) m] (Castro, 1996) n] (Branstetter, 1981) o] (Musick et al., 1993) p] (Pratt, 1979) q] (Branstetter, 1987b) r] (Cliff and Dudley, 1991) s] (Stevens and Lyle, 1989) t] (Dudley and Cliff, 1993) u] (Stevens and McLoughlin, 1991) v] (Parsons, 1983) w] (Nammack et al., 1985) x] (Simpfendorfer, 1992) y] (Jones and Ugland, 2001) z] (Mollet et al., 2000) aa] (Chen et al., 1988) bb] (Romine, 2004)

Species	r (2m)		λ	
	Value	Rank	Value	Rank
<i>Alopias superciliosus</i>				
<i>Alopias vulpinus</i>	0.069	2	1.125	4
<i>Carcharhinus acronotus</i>				
<i>Carcharhinus altimus</i>				
<i>Carcharhinus brevipinna</i>			1.037	10
<i>Carcharhinus falciformis</i>	0.043	7	1.108	5
<i>Carcharhinus leucas</i>				
<i>Carcharhinus limbatus</i>	0.054	4		
<i>Carcharhinus obscurus</i>			1.030	11
<i>Carcharhinus plumbeus</i>			1.022	12
<i>Carcharhinus signatus</i>				
<i>Carcharias taurus</i>	0.052	5		
<i>Carcharodon carcharias</i>	0.040	9	1.098	6
<i>Galeocerdo cuvier</i>	0.043	8	1.246	2
<i>Isurus oxyrinchus</i>	0.051	6	1.141	3
<i>Mustelus canis</i>				
<i>Negaprion brevirostris</i>			1.064	8
<i>Prionace glauca</i>	0.061	3	1.401	1
<i>Rhizoprionodon terraenovae</i>	0.084	1	1.056	9
<i>Sphyrna lewini</i>			1.086	7
<i>Sphyrna zygaena</i>				
<i>Squalus acanthias</i>				

Table 1.6: Summary of population growth rates for each species in this survey. Dark grey shaded cells indicate low population growth rates, while light gray shaded cells indicate relatively high population growth rates. Values for r (2m) are from Smith et al. (1998), while values for λ are from Cortes (2002a).

Species	Food	Ref
<i>Alopias superciliosus</i>	pelagic fishes	a
<i>Alopias vulpinus</i>	small fishes	a
<i>Carcharhinus acronotus</i>		
<i>Carcharhinus altimus</i>	teleosts, sharks, stingrays and cuttlefish	a
<i>Carcharhinus brevipinna</i>	Primarily Teleosts, stingrays and cephalopods	a
<i>Carcharhinus falciformis</i>	Primarily teleosts, also cephalopods and pelagic crabs	a
<i>Carcharhinus leucas</i>	Teleosts, invertebrates, elasmobranchs, seaturtles, birds, dolphins, whale offal, and terrestrial mammals	a
<i>Carcharhinus limbatus</i>	teleosts (Menhaden), elasmobranchs	a
<i>Carcharhinus obscurus</i>	teleosts, elasmobranchs	a
<i>Carcharhinus plumbeus</i>	teleosts (Flatfish), elasmobranchs (skates), soft blue crabs (Juv)	a
<i>Carcharhinus signatus</i>	small active teleosts, squid, shrimp	a
<i>Carcharias taurus</i>	teleosts, elasmobranchs	b
<i>Carcharodon carcharias</i>	fish and marine mammals	a
<i>Galeocerdo cuvier</i>	teleosts, elasmobranchs (including own pups), sea turtles, sea snakes, marine iguanas, seabirds, marine mammals, carrion and rubbish	a
<i>Isurus oxyrinchus</i>	fishes and squid	a
<i>Mustelus canis</i>	crustaceans, mollusks	b
<i>Negaprion brevirostris</i>	Primarily fishes, also crustaceans and molluscs	a
<i>Prionace glauca</i>	small squid and pelagic fish, also invertebrates, bottom fish and small sharks	a
<i>Rhizoprionodon terraenovae</i>	teleosts, crustaceans	b
<i>Sphyrna lewini</i>	teleosts, sharks, rays, and invertebrates	a
<i>Sphyrna zygaena</i>	teleosts, small sharks, skates, and stingrays	a
<i>Squalus acanthias</i>	teleosts, and invertebrates	a

Table 1.7: Diet summary of species collected in this survey. Virginia-specific data for most of these species does not exist, resulting in the generality of the diet categories in many cases. References: a) Compagno et al. (2005) b) Gelschlechter et al. (1999)

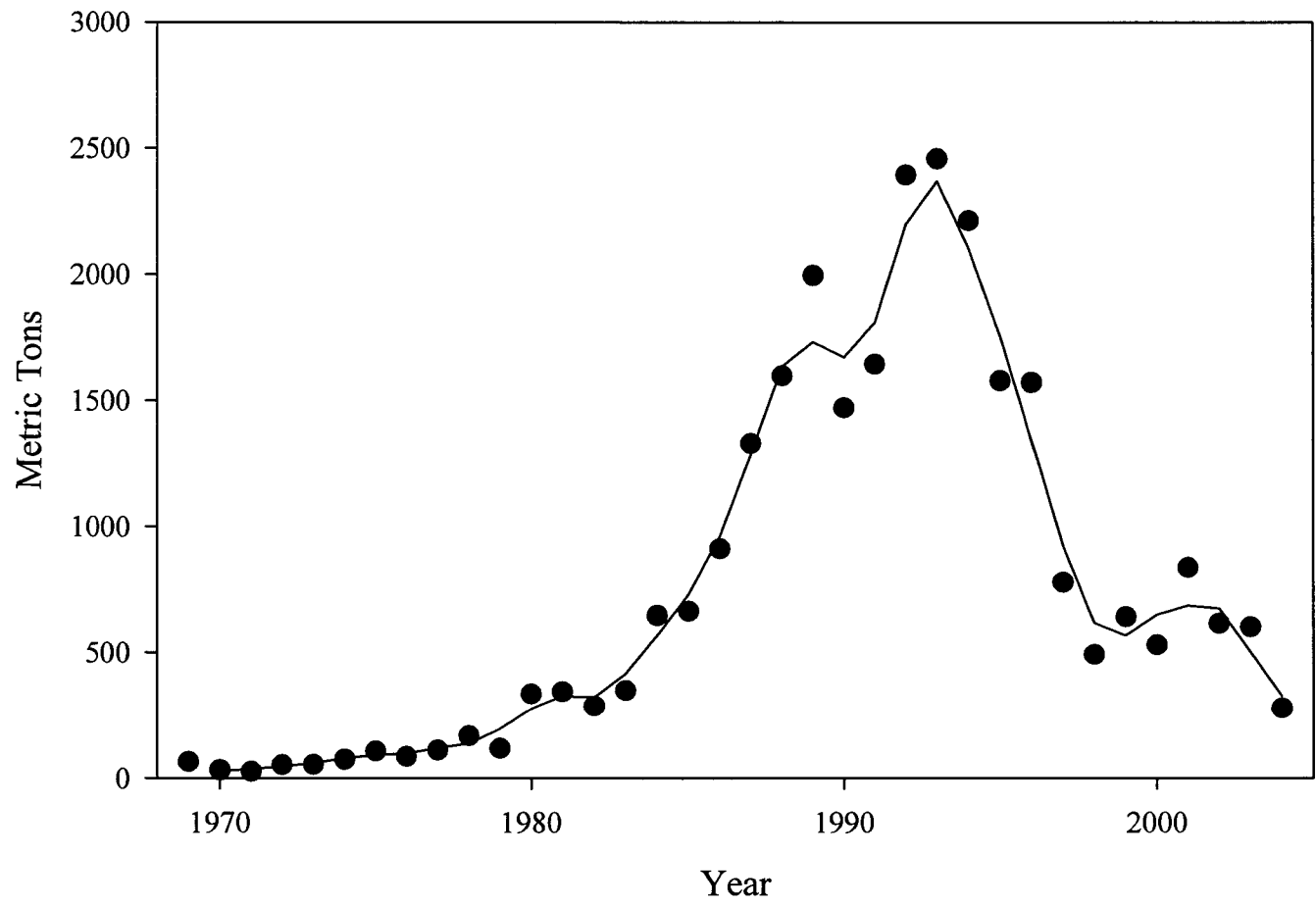


Figure 1.1. Historical commercial landings in metric tons of all shark species for all Atlantic states, with Lowess-smoothed catch curve. Data from NMFS (2006).

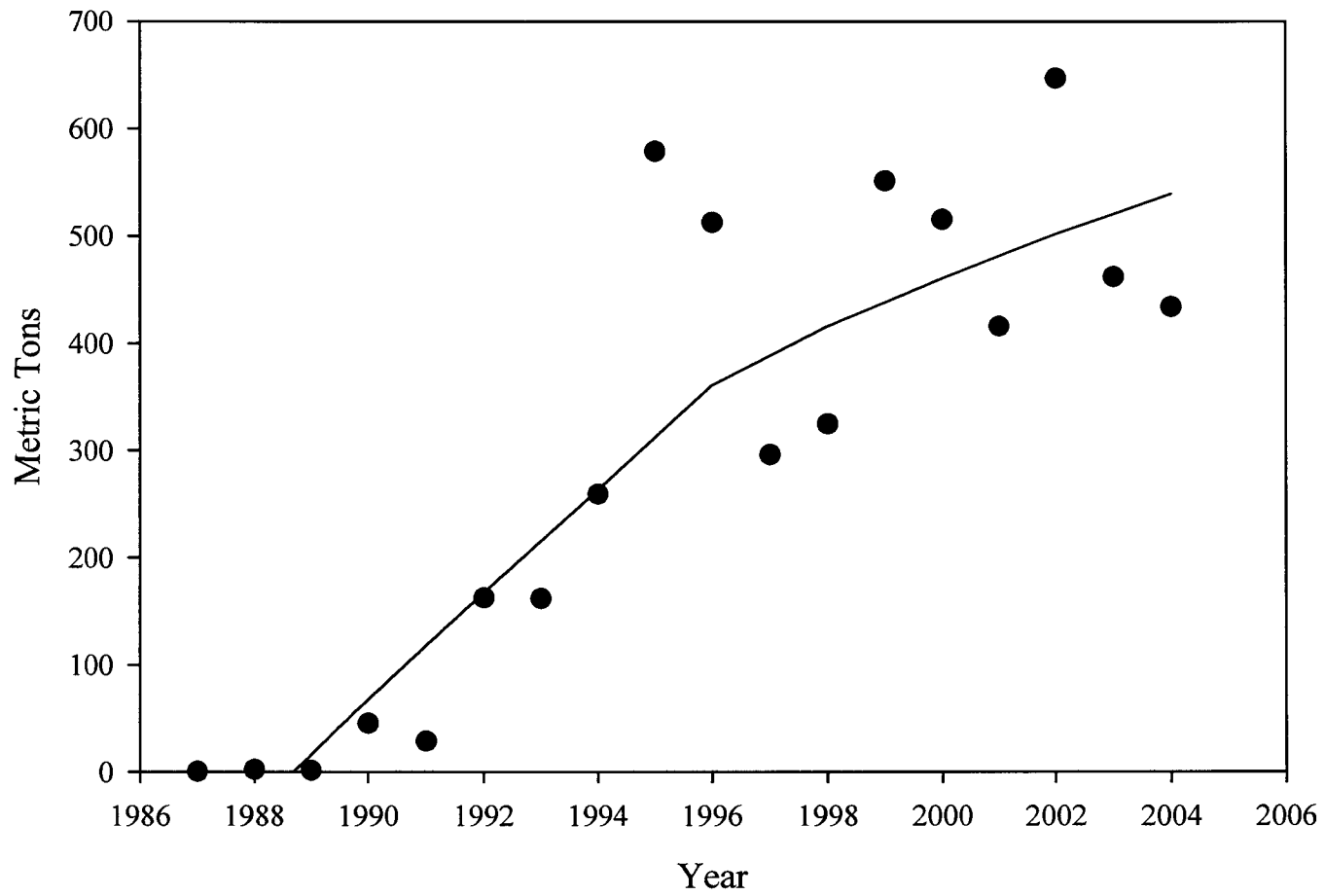


Figure 1.2. Historical commercial U.S. Atlantic coast landings of *C. plumbeus*, with Lowess-smoothed curve. Data from NMFS (2006)

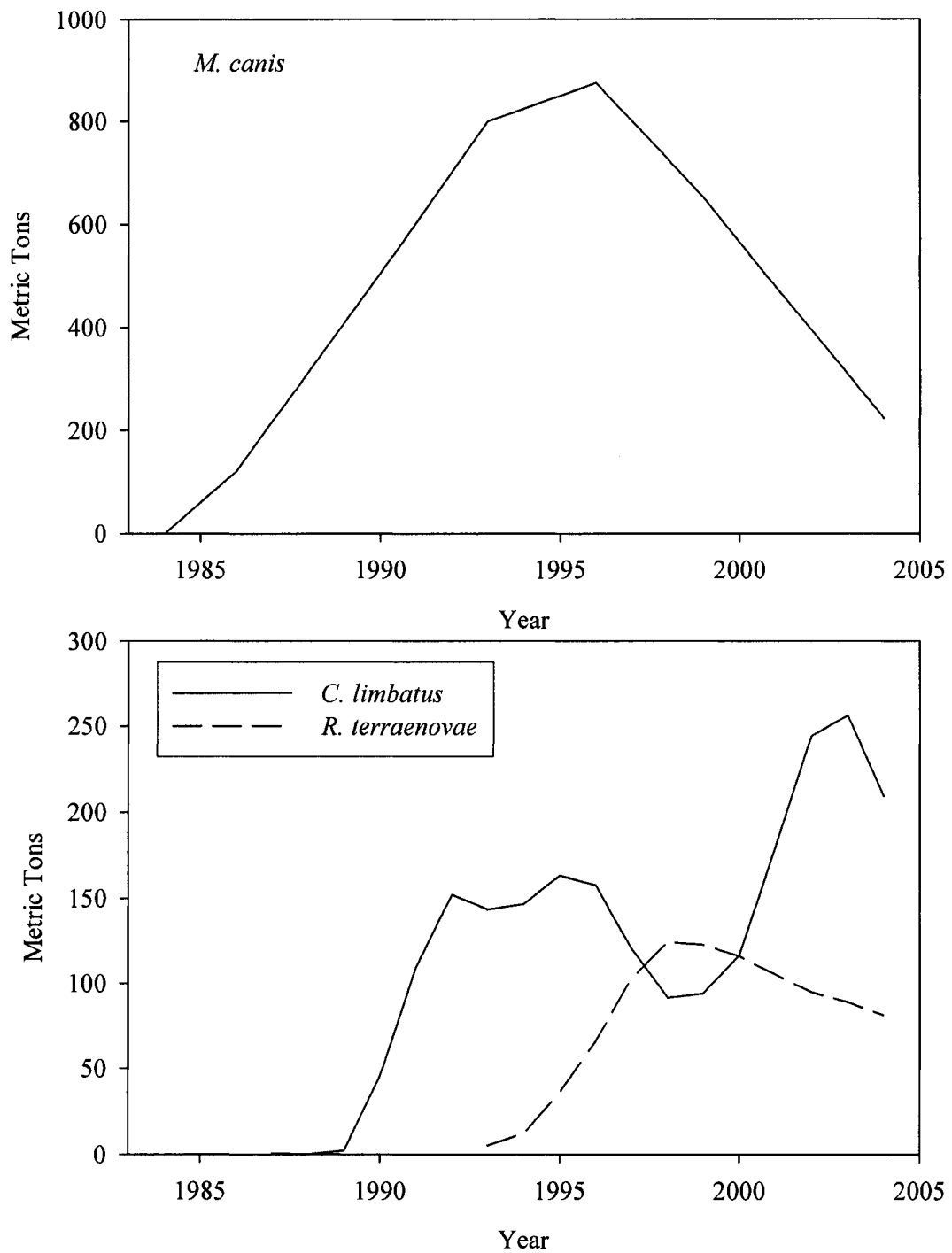


Figure 1.3: Commercial U.S. Atlantic coast landings figures lowess-smoothed for three of the ten most abundant species in this survey. Data from NMFS (2006).

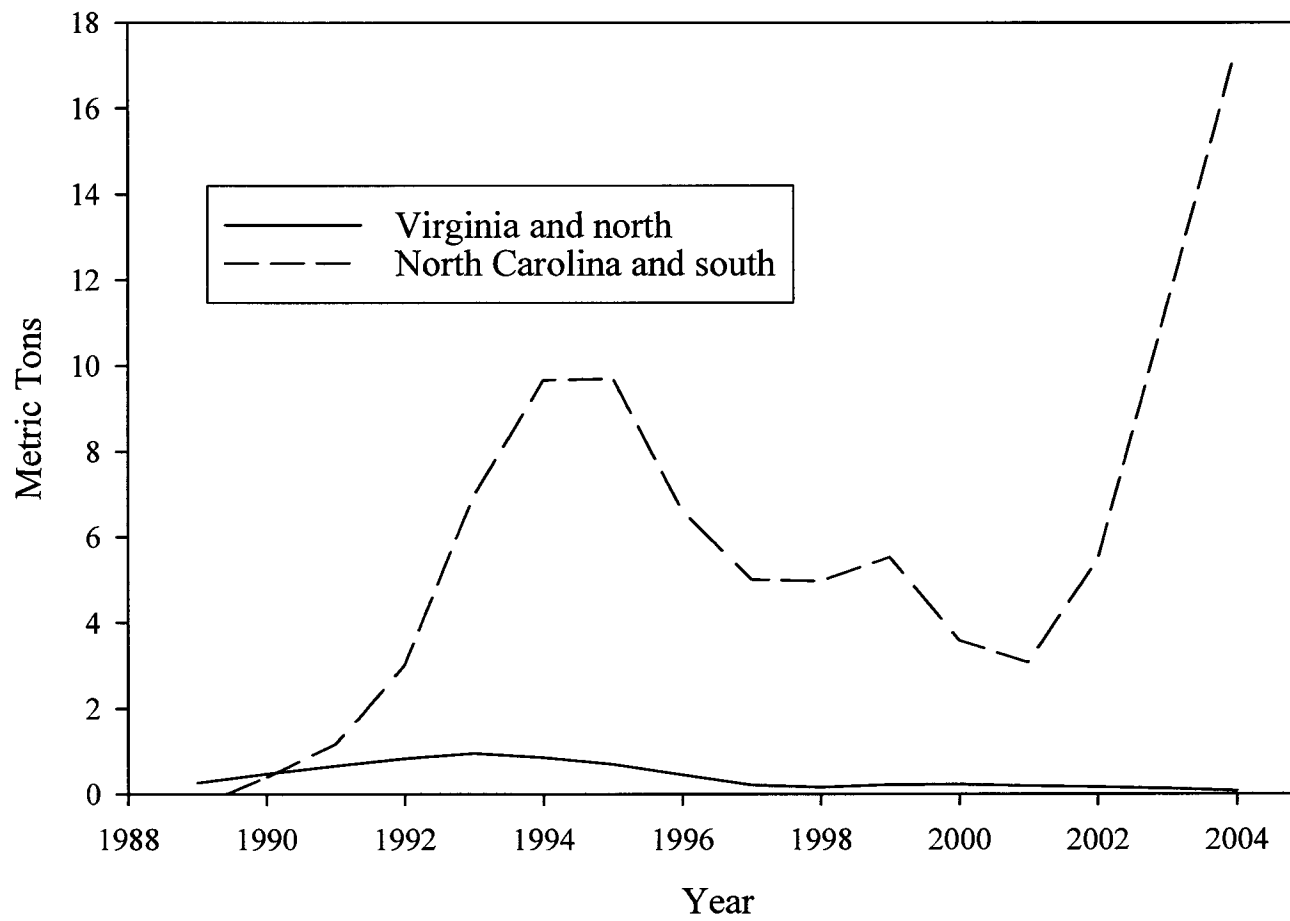


Figure 1.4: Commercial U.S. coastal landings figures from NMFS (2006) for *G. cuvier*, split into Northern and Southern Atlantic components.

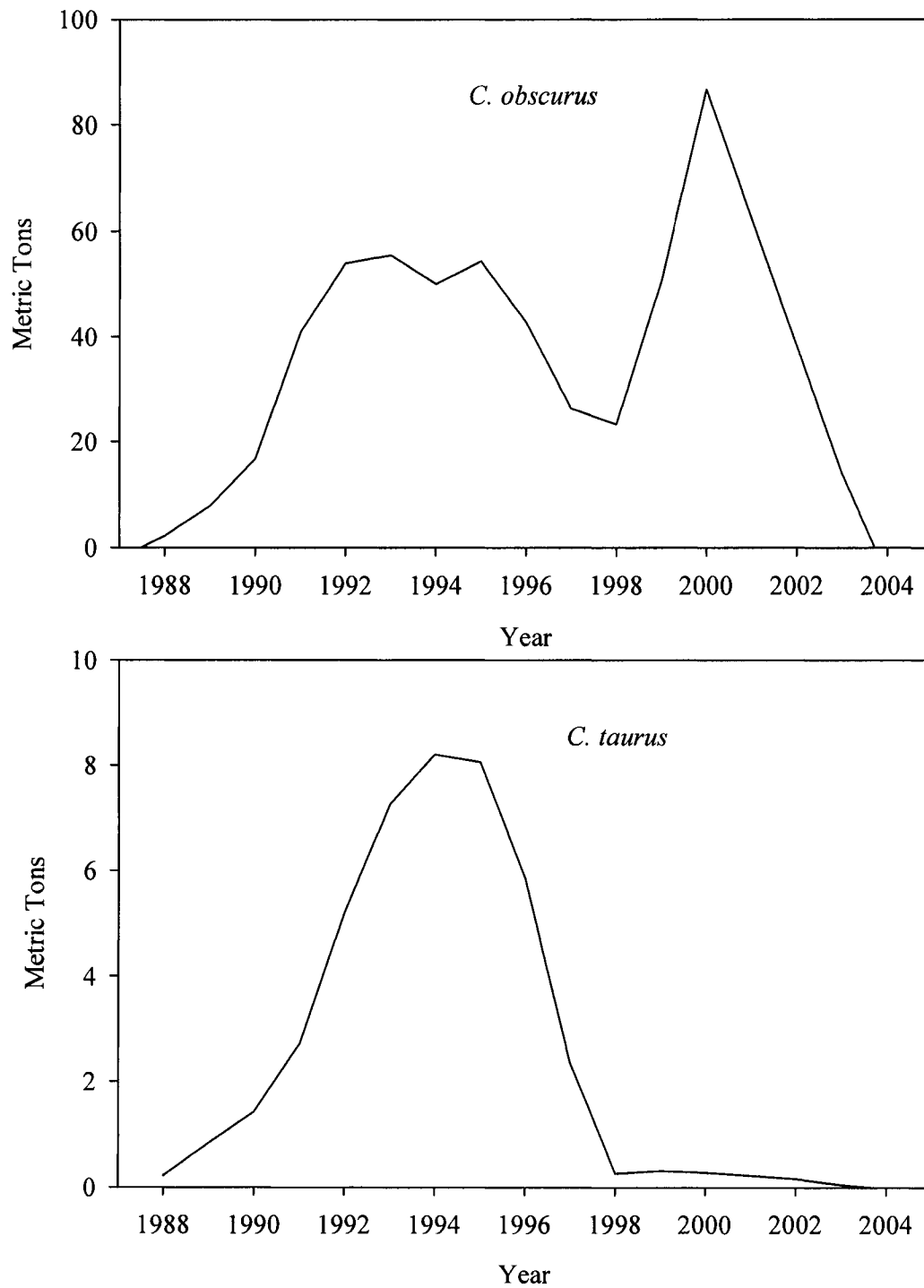


Figure 1.5: Commercial U.S. Atlantic coast landings lowess-smoothed for *C. obscurus* and *C. taurus*, from NMFS (2006).



Figure 1.6: Standard longline stations since 1990. K=Kiptopeke, M=Middleground, C=Chesapeake Bay Lighttower, W=Wreck Island/Sand Shoal Inlet, T=Triangle Wrecks, V=Virginia Beach, L=Smith Island Shoals.

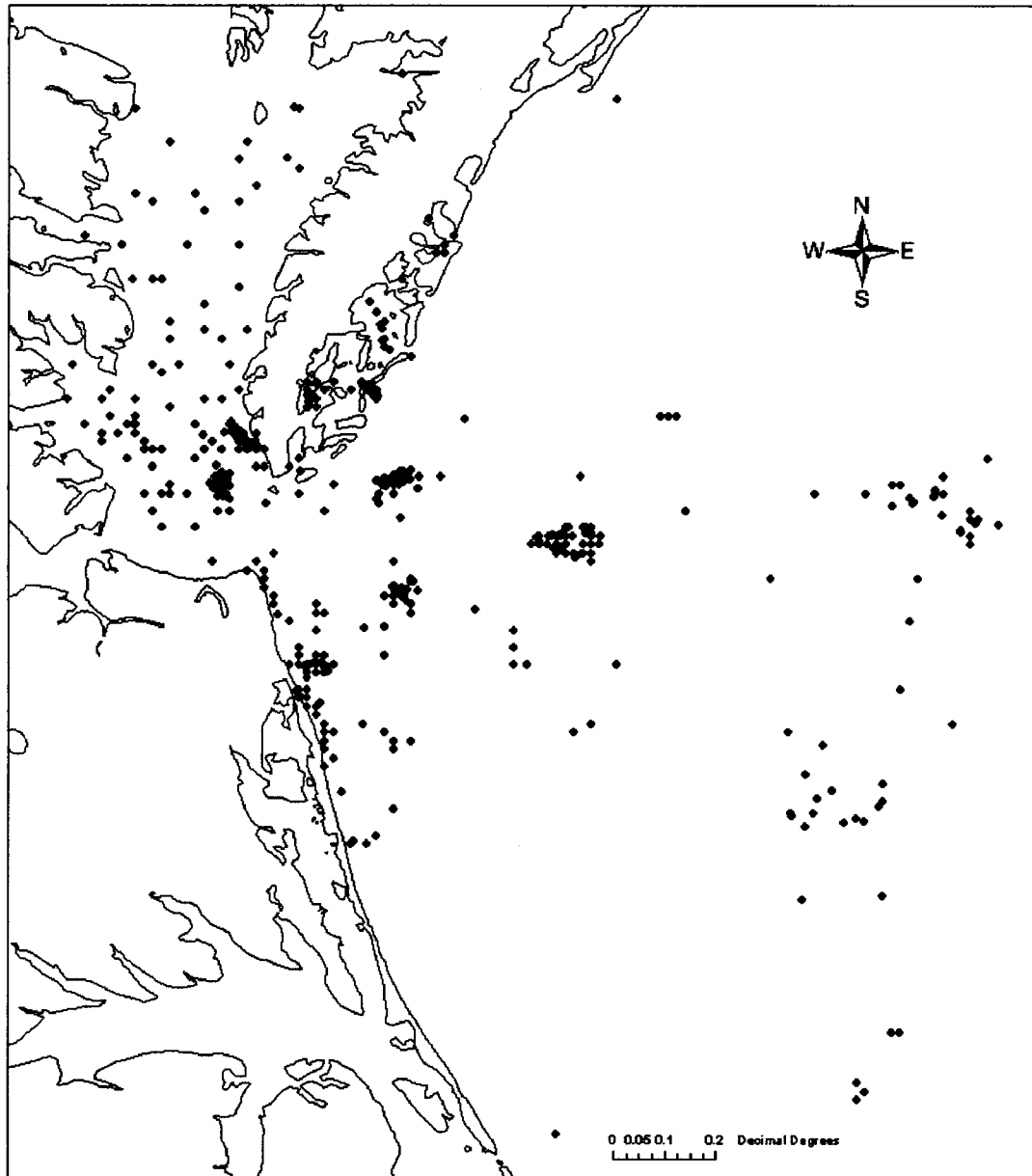


Figure 1.7: Positions of all long-line stations sampled since 1974.

Chapter 2: Trends in Shark CPUE

The goal for this chapter is to examine the VIMS shark long-line dataset for trends in catch-per-unit-effort (CPUE). CPUE for this chapter is defined as the number of sharks caught per hook per hour. CPUE values were calculated for individual species, within-species age groups and sexes, as well as for NMFS management groups.

Methods

Models

Generalized Additive Models (GAM) allow one to fit non-parametric curves to predictor variables, and thus are well suited to post-hoc data exploration (Quinn and Keogh 2002). For this reason, such models were used in this chapter to examine the VIMS data set for patterns in abundance over the course of time. Like Generalized Linear Models (GLM), GAMs allow one to choose a distribution and link function for the response variable, which relaxes the assumption that predictor variables are normally distributed. However, the response variables used in this study were not suited to the distribution/link functions available in the software package (SAS/STAT; SAS Institute 2002). This problem was addressed by transforming the data with an arc-sine/root transform (also known as the angular transform), the most appropriate transform for

proportion data (Sokal and Rohlf, 1995). These transformed data were used in the GAM with a Gaussian distribution and an identity link function.

GAM analyses can be limited in their cross-product terms, also termed interaction effects. The statistical program used for these analyses does not allow such cross-product terms, possibly due to the greater computational resources such effects would require. Venables and Ripley (2002) discussed this issue, and concluded that the best way to handle such cross-product terms, short of including them in the model, is to choose variables that one would not expect to have very large interactions. Especially early in the long-line program, funding and logistics led to some standard stations being under-represented in some years. For this reason, the under-represented years were combined with adjacent years to form year categories so that each standard station was as equally represented as possible in each year category.

GAM analysis allows for simultaneous parametric and non-parametric curve fitting. The general form for a GAM model is

$$\eta = B_0 + f_1(x_1) + f_2(x_2) + \dots + f_p(x_p) \quad (1)$$

where the $f_i(x_i)$ terms are local smoothers, of many different forms, including linear terms as used in GLMs. In this case, the smoothing function used, where applicable, was lowess smoothers. Since month and station in this study are categorical variables, they were fitted to linear parametric terms and a lowess smoothing function fitted to the other variables. Combining the general model with the specific variables used in this analysis, Equation (1) becomes, for each species/ species group:

$$2(\arcsin(\sqrt{\text{catch} / \text{effort}})) = a + bM + cS + lo_1(\text{Year}) + lo_2(\text{depth}) \\ + lo_3(\text{out}) + lo_4(\text{haul}) + lo_5(\text{Sur.Temp.}) + \varepsilon \quad (2)$$

where a , b , and c are constants, M is the month, S is the station, the lowess smoothed terms are as given, and ε is a random error term, with a Gaussian distribution.

Generalized cross validation (GCV) was used to choose the best smoothing parameter. Generalized cross validation is a simplified version of cross validation, which works by leaving out points one at a time, estimating the squared residual for the function based on the remaining points, and choosing a smoothing parameter so as to minimize the sum of the squared residuals (Hastie and Tibshirani, 1990). This model was iterated removing the least significant term (significance defined as $p < 0.05$) at each iteration until all terms in the model were significant.

Logistic Regression Models

The data for categories that could not be normalized as above were transformed into presence/absence data by changing all positive catches into 1, to represent presence. These data were analyzed for trends with a logistic regression analysis (proc Logistic, SAS/STAT, SAS Institute 2002). The same independent variables used above were used in this analysis. The starting model for each species/species group in this analysis was of the form:

$$\ln\left(\frac{\hat{Y}}{1 - \hat{Y}}\right) = \beta_0 + \beta_1(\text{Year})_i + \beta_2(\text{Station})_i + \beta_3(\text{Month})_i \\ + \beta_4(\text{SurfaceTemperature})_i + \beta_5(\text{Depth})_i + \beta_6(\text{Set})_i + \beta_7(\text{Haul})_i \quad (3)$$

where \hat{Y} is the estimated probability of catch, β_0 is the constant, β_1 through β_7 are the partial regression coefficients for each variable in parentheses, for the i th case ($i=1, \dots, n$).

Data

The complete VIMS long-line data set was modified to form a standardized relative index of the CPUE of shark species. Only sharks caught on standard gangions and only standard stations sampled from the beginning of this survey were included in this analysis. A semi-parametric model, as described above, was fitted to the dependent variable against all main effects available from the start of the long-line survey (year, station, month, mean water depth, time out, time in, and surface temperature; SAS, 2002). To achieve the most accurate trend in CPUE with year, all dependent variables except for year were included to remove their effects (if any), in order to remove environmental, spatial, or seasonal variability from the trend in year. The effects of these other variables will be examined in a more rigorous and detailed analysis in chapter 4.

The Chesapeake Bay is the largest known pupping and nursery ground for *C. plumbeus* (Grubbs, 2001; NMFS, 2003). For this reason, the data for *C. plumbeus* were re-analyzed after removing the bay stations (K,M) to avoid any effects of the nursery habitat. In addition, since the species classified as large coastal species (LCS) have changed over time, CPUEs of the LCS group as originally defined [(Table 1.1); NMFS (1992), referred to hereafter as LCS (original)], and the LCS group as currently defined [(Table 1.1) ; NMFS (2003), referred to hereafter as LCS (current)] were analyzed.

These categories were also analyzed with the nursery ground stations removed, as indicated above.

The years grouped together were 1974-76, 1978-79, 1981-84, 1986-89, and 1993-94. The year categories were not necessarily of equal intervals and were represented in analyses as a continuous independent variable by the mean year of all stations in that year category. Thus the year category 1974-76 is 1974.85, 1978-79 is 1978.6, 1981-84 is 1982.04, 1986-89 is 1987.39, and 1993-94 is 1993.11, while all others are simply the year. Although CPUE is defined as number of sharks per hook hour fished, this was simplified for the figures by multiplying by the number of hook*hours in a standard set (100 hooks for 4 hours). This was done to simplify the axes, which now represent number of sharks caught per standard set, rather than true CPUE.

Results

The CPUE for only one species (*C. plumbeus*) was usable under the above criterion, while the transformed CPUE for six species and seven other groups were usable (Table 2.1). Of the remaining 15 species/groups, a further four were available for analysis with logistic regression, while the rest were not caught frequently enough to analyze (Table 2.2). GAM analyses found significant trends in CPUE with year in most cases, while surface temperature, depth, set time and haul time all were found to be significant in at least one case (Table 2.3). These results will not be discussed in this chapter; see chapter 4 for results of analyses of the effects of environmental variables on shark CPUE.

GAM Results

Using generalized additive model analyses, the independent variable year was significant for all species/groups except for *R. terraenovae* (Table 2.3). Since only one other member of the Small Coastal Species (SCS) management category has been caught in this survey (n=9 individuals), the results for SCS were identical to those for *R. terraenovae*. For this reason, the SCS category was not analyzed separately from *R. terraenovae*. Declines in CPUE analyzed in percentage terms showed the strongest declines for adult *C. plumbeus*, *C. taurus*, and *G. cuvier* (Table 2.4).

Species analyzed that are currently classified as Large Coastal Species all suffered significant declines during the course of this study (Figures 2.1-2.2). *Carcharhinus plumbeus* was the largest component of the LCS group, especially in recent years. By 2004, LCS (original) CPUE declined to roughly 21% of that in 1974. LCS (current) CPUE dropped, and mirrors the trend for *C. plumbeus* CPUE even more closely than the broader original definition. By 2004, *C. plumbeus* CPUE had dropped to 18% of that in 1974. The three rarer species also showed declines in CPUE, while *C. obscurus* has shown signs of a rebuilding (Figure 2.2). *Carcharhinus obscurus* CPUE dropped to 4% of its peak abundance by 1992, but rebounded somewhat to 32% by 2004. *Carcharias taurus* CPUE had dropped to 0.18% of its former abundance level by 2004. By 2004, *G. cuvier* CPUE had dropped to 2.5% of that in 1974. Large Coastal Species analyzed without nursery ground stations show less variability (Figure 2.3). The trend in

C. plumbeus CPUE without Chesapeake Bay stations was similar, but below the trend for *C. plumbeus* with Chesapeake Bay stations (Figure 2.4).

The trends in *C. plumbeus* and its age groups, young-of-the-year, juveniles, and adults showed signs of changes in size, and hence age-class structure over the course of this study (Figures 2.5-2.6). CPUE of adults had dropped to 0.07% of early levels by 2003, but the decline was much earlier in the time series. CPUE of juveniles showed an increase in the late 1990's, but had dropped by 2004 to 0.68% of 1974 levels (Figure 2.5). Adult CPUE declined dramatically in the late 1980's, and has shown no sign of recovery since then (Figure 2.6).

GAM results showed early male and female *C. plumbeus* CPUE trends to be different, while later, since 1993, trends showed the sexes mirroring each other (Figure 2.7). Early data also showed that females were much more abundant than males. Males remained in the southern wintering areas after about age eight and thus were unavailable to the VIMS sampling. For this reason, the larger, older individuals caught in this survey were virtually all females (Musick et al. 1993). As the adult CPUE declined, the sex ratio became 50/50 because the catches became dominated by juveniles, since the sex ratio at birth of *C. plumbeus* is 1:1 (Musick et al. 1993). To support this, it is clear that the sex ratio of female *C. plumbeus* to total *C. plumbeus* (only *C. plumbeus* with sex recorded were used for this total) steadily decreased over time, in the results of the GAM model (Figure 2.8).

Mustelus canis was the only species not classified as an LCS that was analyzed and a significant fit with year found. However the pattern was highly variable over the

course of the study, with no steady increasing or decreasing trend (Figure 2.9). Patterns in effort may have caused the variability, as *M. canis* (as shown in Chapter 4) was almost entirely caught in May, and some years of this survey did not include May sampling dates due to budgetary restrictions or adverse weather conditions. In addition, a project studying *M. canis* was going on from 1998-2000, and hence an effort was made to collect this species. For this reason, one cannot reasonably come to any conclusions about biologically significant trends with year.

Non-normalized data

Four of the 22 species (*C. limbatus*, *S. lewini*, *S. acanthias*, and *C. brevipinna*) and one category (PEL) were analyzed via the statistical methodology outlined for species whose catch records could not be normalized (Table 2.2). Logistic modeling only showed significant results with year for two out of the four species (*C. brevipinna* and *S. lewini*), and no significant result for the Pelagics group (Table 2.5). The results showed a decline in probability of catch in *S. lewini* and an increase in *C. brevipinna* (Figure 2.10).

Discussion

Out of the ten species analyzed, three (*C. taurus*, *G. cuvier*, and *C. plumbeus*) showed clear declining trends with no recovery. One species (*C. obscurus*) showed a decline with some sign of recovery, and another species (*M. canis*) showed an equivocal

pattern. *R. terraenovae* showed no significant pattern with time over the course of this study. All sub-groups of the most abundant species, *C. plumbeus*, showed significant trends. Management groups showed mixed results. Large coastal species (driven by *C. plumbeus*) showed a significant decline, while small coastal species (almost entirely *R. terraenovae*) showed no significant pattern.

Discussion of patterns found through logistic regression must be interpreted with care, as probability of catch is a less reliable indicator of abundance than CPUE. Many other factors may be causing the trends seen in *C. brevipinna* and *S. lewini*, other than changes in abundance. For this reason, the results for these two species will be discussed separately from GAM-analyzed species.

Declining species

The CPUE trends for *C. taurus* found in other areas along with landings data (see Figure 1.5) lead one to conclude that the declines seen in this study do reflect the trend for *C. taurus* in the southeastern Atlantic states. In the North Atlantic, Castro et al. (1999), citing a personal communication, stated that *C. taurus* showed a “very severe” population decline in Florida and North Carolina in the early 1990’s.

Further, the decline seen in this study and by Castro et al. (1999) were most likely declines in reproducing adults. Birth in *C. taurus* takes place at depths <50 m on the continental shelf from Cape Canaveral, FL to Cape Hatteras, NC (Gilmore et al., 2005), the area mentioned by Castro et al. (1999). The VIMS survey has caught entirely adult males or adult females in a post-partum or resting stage since its inception (Goldman,

2002). In the only study available on the response of this species to human-induced mortality, Krogh (1994) stated that there have been substantial declines in catches of this species during the course of the beach protection program in Australia. They collected 65 individuals in the 18 year period 1972-1990, while in 1937, 58 were caught in three months.

Recovery in *C. taurus* may be slower than in other shark species, since Cortes (2002a) found *C. taurus* to exhibit one of the slowest population growth rates (λ) of the shark species he surveyed. In addition, their low reproductive potential (Table 1.6) may be indicative of a species with a poor ability to respond to high mortality.

Sphyrna lewini has shown declines in other areas of the western North Atlantic similar to those seen in the present study, leading to the conclusion that the decline in CPUE documented in this study is representative of the overall trend in this species. An independent fishery monitoring program off South Carolina found a 66% decrease in catches between 1983-4 and 1994-5 using nominal catch data (Ulrich, 1996). Pelagic logbook data from the U.S. swordfish fishery (although this lumps 3 species together) suggested that hammerheads had declined 78% between 1986 and 1995 (Cramer, 1996). Australian and South African beach protection programs both found the survival rate of *S. lewini* in their nets to be very low (1.7% and 5% found alive, respectively) (Cliff and Dudley, 1992; Reid and Krogh, 1992). This means that they likely suffer by-catch mortality to a greater degree than other species.

An increase in CPUE of *G. cuvier* observed south of our study area may indicate that the decline in Virginia waters represents a reduction in range rather than a true

decline in population. Burgess (Florida Program for Shark Research; personal communication) has recently found signs of recovery in *G. cuvier* populations in Florida waters. The NMFS definition of the EFH of adult *G. cuvier* is Chesapeake Bay and south to Florida and Puerto Rico (NMFS, 1999). Landings figures support the possibility of a recovery in *G. cuvier* south of this study area, with landings south of the Virginia/North Carolina border much higher than north of the same, especially in recent years (Figure 1.4). In the Australian beach protection program, Simpfendorfer (1992) found no evidence of a decrease in the population size of *G. cuvier* after 22 years of protective netting.

Large Coastal Species showed a decline both as originally defined and as currently defined. In Virginia, *C. plumbeus* comprised the majority of the LCS group, using either definition. Overall the catch of *C. plumbeus* was 82% of the catch of LCS (original), and 92% of LCS (current). Since fishery landings of *C. plumbeus* and other LCS species increased during the same period (Figures 1.2-1.5), the most likely reason for this decline is fishing mortality, especially for *C. plumbeus*.

Without *C. plumbeus* nursery ground stations, the results showed that the recovery seen in *C. obscurus* was reflected in the LCS (original) group as a whole. Since *C. obscurus* was the second most abundant member of the LCS (original) group at 7%, and made up 61% of the prohibited LCS (those species not included in the current definition of LCS), it is not unexpected to see such an effect.

Recovering species

Carcharhinus obscurus is the only species that showed a decline followed by a recovery of more than 5 years, which may be attributable to effective management. The decline coincided with increased landings (Figure 1.5), and thus was likely caused by fishing mortality (Musick et al. 1993). This species was placed on the prohibited species list effectively in June 2000, and the steepest part of the recovery occurred subsequent to that year. This management action is also reflected in the landings data (Figure 1.5). A recent stock assessment of *C. obscurus* off the U.S. Gulf of Mexico and Atlantic found that of five GLM-standardized CPUE series (3 commercial, one recreational, and one fishery-independent, 3 showed highly significant negative trends and one slightly decreasing, non-significant trends (Cortes, personal communication).

Equivocal pattern

Mustelus canis showed no biologically significant trend in abundance over the course of this study, however this may be due to the sampling scheme of this study. Sampling began each year no earlier than May, and *M. canis* is known to prefer cooler water, and was most abundant in this survey in the early months. However, the first long-line sets occurred on different dates due to logistic and funding considerations, and hence some years may not include long-lines during times when water temperatures were low enough to capture *M. canis*. One study found an increase in *M. canis* abundance in Gulf of Mexico research trawls, to 13 times its 1972 abundance by 2002 (Shepherd and Myers, 2005), although the Gulf smooth dogfish may be a separate population. Such

gear is more suited to collecting *M. canis*, a small bodied shark that may be gape-limited in our sampling.

Carcharhinus plumbeus

The dynamics of *Carcharhinus plumbeus* are more detailed, as this was the most abundant species collected in this survey. The overall trend was a decline to roughly 15% of 1974 levels by 2004, with no signs of a recovery. This decline is likely the result of fishing mortality (Figure 1.2). When analyzed with nursery ground stations, the age class makeup of the general trend in *C. plumbeus* seems to be one of reduced adult and young-of-year abundances, and increasing predominance of the juvenile age class. Musick et al. (1993) suggested that increases in CPUE of young-of-year in the late 1980's and early 1990's was a result of higher survivorship due to declines in LCS predators, and this may explain the pattern seen in young-of-year in this study.

In terms of sex composition, the proportion of females declined from the start of the survey to the mid 1990's, and then the sexes neared a 1:1 ratio. This was due to the reduced abundance of adults, which were virtually all females on their way into or out of the nursery area. In recent years, the predominance of juveniles, born in a 1:1 sex ratio (Springer, 1960), and rarity of adults has resulted in an even sex ratio.

Logistic regression

Sphyrna lewini has shown declines in other areas of the western North Atlantic, which may indicate that the decline in probability of catch documented in this study may

be due to decreased abundance. An independent fishery monitoring program off South Carolina found a 66% decrease in catches between 1983-4 and 1994-5 using nominal catch data (Ulrich, 1996). Pelagic logbook data from the U.S. swordfish fishery (although this lumps 3 species together) suggested that hammerheads had declined 78% between 1986 and 1995 (Cramer, 1996). Australian and South African beach protection programs both found the survival rate of *S. lewini* in their nets to be very low (1.7% and 5% found alive, respectively) (Cliff and Dudley, 1992; Reid and Krogh, 1992). This means that they likely suffer by-catch mortality to a greater degree than other species. Unfortunately, no published studies have examined any of the other factors that may have caused the decline in probability of catch seen here, making it impossible to conclude that abundance trends drove this decline.

Carcharhinus brevipinna showed an increase in probability of catch over the course of this survey, which is most likely due to taxonomic identification errors in early years of the survey combined with low sample sizes. This species has only occurred in survey records since 1990. Morphological similarity with *C. limbatus* (Castro, 1983) and frequent interspecific schooling with *C. limbatus* (R. D. Grubbs, personal communication) may imply that some of the early records of *C. limbatus* in this survey were misidentified as *C. brevipinna*. Data from other areas of the world indicate that *C. brevipinna* may be better able to recover from human-induced mortality. The South African beach protection program found no trend in *C. brevipinna* catch rates between 1978 and 1997, although they found high inter-annual variation (Allen and Wintner,

2002). Cortes (2002a) found the population growth rate of this species to be in the mid-range of the shark species he examined.

The Pelagics group showed an equivocal pattern in probability of catch, which may be due to lack of sampling of pelagic habitat in this survey. Most of the sets in this survey were done in areas considered inshore (Figure 1.2), and the members of the Pelagic group are defined as deep-water sharks. Only two stations (I & N) overlap into the pelagic zone off Virginia, and these are not standard stations. Any member of the Pelagics group in this analysis would be a stray coming into fringe, little-used habitats.

Conclusions

In summary, most large sharks in Virginia showed declines in CPUE consistent with data from other areas of the Atlantic coast, and few of these show any signs of recovery. One species, the warmer-water *G. cuvier*, showed a declining trend that may be due to fishing mortality causing a range contraction. Several other species, such as *C. taurus*, *C. plumbeus*, and *C. obscurus*, showed signs that the reductions in CPUE documented here were a direct result of fishing mortality. The protected *C. obscurus* showed signs of a recovery trend, while *G. cuvier* showed signs of recovery south of Cape Hatteras. Two of the smallest species, *R. terraenovae* and *M. canis*, were the only ones that showed little or no trends in abundance over the course of this survey. Both *M. canis* and *S. acanthias* occurred in low numbers in this program, due in large part to the lack of sampling during times of the year when water temperatures were low, since both species are known to prefer colder water. *Rhizoprionodon terraenovae*, a smaller

species, was not as valuable to the fishery, and subject to lower fishing mortality than other shark species (Cortés 2002; Figure 1.3).

Management groups showed trends that corroborate the results of NMFS stock assessments (Cortés, 2002b; Cortés et al., 2002), in that LCS groups showed declines in CPUE, but signs of recovery, while SCS showed no trend. Pelagic species, as yet unassessed by NMFS, showed no trend due to the lack of sampling in habitats preferred by such species.

Table 2.1. Comparison of standard station (stations C,L,K,M,W,T, and S) CPUE (number of sharks per hook*hour) with arcsine-root transformed CPUE for all species, species groups, and species sub-groups available in this study. Names and skewness/kurtosis in bold are those for which the transform successfully reduced to skewness and/or kurtosis to acceptable levels for GAM analysis. Species with missing values were not caught at standard stations.

Species	Before Transformation		After Transformation	
	Skew	Kurt.	Skew	Kurt.
<i>Alopias superciliosus</i>				
<i>Alopias vulpinus</i>	15	237	14	187
<i>Carcharhinus acronotus</i>	18	340	15	244
<i>Carcharhinus altimus</i>				
<i>Carcharhinus brevipinna</i>	6	40	5	21
<i>Carcharhinus falciformis</i>	20	424	19	349
<i>Carcharhinus leucas</i>	14	225	13	172
<i>Carcharhinus limbatus</i>	11	162	6	39
<i>Carcharhinus obscurus</i>	7	59	3	14
<i>Carcharhinus plumbeus</i>	3	10	1	0
<i>Carcharhinus signatus</i>				
<i>Carcharias taurus</i>	7	64	4	17
<i>Carcharodon carcharias</i>	25	638	25	638
<i>Galeocerdo cuvier</i>	7	62	4	19
<i>Isurus oxyrinchus</i>	21	484	17	313
<i>Mustelus canis</i>	4	22	3	10
<i>Negaprion brevirostris</i>	24	580	21	447
<i>Prionace glauca</i>	25	629	23	545
<i>Rhizoprionodon terraenovae</i>	4	16	2	4
<i>Sphyrna lewini</i>	10	129	7	46
<i>Sphyrna zygaena</i>	13	180	13	165
<i>Squalus acanthias</i>	23	546	15	266
Large Coastal Sharks (1993)	2	6	1	0
Large Coastal Sharks (2003)	2	8	1	0
Small Coastal Sharks	4	16	2	4
Pelagics	16	297	11	131
YOY <i>C. plumbeus</i>	6	39	3	9
Juvenile <i>C. plumbeus</i>	3	12	1	1
Adult <i>C. plumbeus</i>	5	24	3	6
Female <i>C. plumbeus</i>	4	32	1	1
Male <i>C. plumbeus</i>	3	7	1	0

Table 2.2. Summary of species by analysis type. Species analyzed with GAM analysis were those with transformed CPUE's with acceptable levels of skewness and/or kurtosis. Species not analyzed were those either not caught at standard stations, or those with an n below five. All other species were analyzed with the secondary protocol, as described in the text. N/C= Species not caught at standard stations.

Species	Total # Fish	GAM	Categorical	Unanalyzed	Reason
<i>Carcharhinus plumbeus</i>	5246	x			
<i>Rhizoprionodon terraenovae</i>	1169	x			
<i>Mustelus canis</i>	582	x			
<i>Carcharhinus obscurus</i>	446	x			
<i>Carcharias taurus</i>	225	x			
<i>Carcharhinus limbatus</i>	133		x		
<i>Sphyrna lewini</i>	102		x		
<i>Galeocerdo cuvier</i>	88	x			
<i>Squalus acanthias</i>	66		x		
<i>Carcharhinus brevipinna</i>	50		x		
<i>Carcharhinus altimus</i>	42			x	N/C
<i>Prionace glauca</i>	33			x	low N
<i>Isurus oxyrinchus</i>	31			x	low N
<i>Carcharhinus falciformis</i>	21			x	low N
<i>Negaprion brevirostris</i>	15			x	low N
<i>Alopias vulpinus</i>	11			x	low N
<i>Carcharhinus leucas</i>	9			x	low N
<i>Carcharhinus signatus</i>	9			x	N/C
<i>Sphyrna zygaena</i>	9			x	low N
<i>Carcharhinus acronotus</i>	5			x	low N
<i>Alopias superciliosus</i>	3			x	N/C
<i>Carcharodon carcharias</i>	1			x	low N

Table 2.3. Results of GAM analysis of those species, species groups, and species sub-groups that were usable after transformation. Significant lowest fits are shown for each variable. Values of smoothing parameter obtained through GCV also shown.

Species	Category	Year		Depth		Surface Temp		Set Time		Haul Time	
		Signif.	Smooth	Signif.	Smooth	Signif.	Smooth	Signif.	Smooth	Signif.	Smooth
<i>C. plumbeus</i>	All	***	0.997			***					
	YOY	*	0.430			***					
	Juveniles	***	0.272			**					
	Adults	***	0.354	***	0.621						
	Females	***	0.449	*	0.443	***				*	0.439
	Males	**	0.217	*	0.456	**					
<i>C. obscurus</i>		***	0.727								
<i>C. taurus</i>		***	0.997	***	0.327		0.032	*	0.603		
<i>G. cuvieri</i>		***	0.892			**	0.007	**	0.985		
<i>M. canis</i>		***	0.246			***					
<i>R. terraenovae</i>						***					
LCS	Original	***	0.691			**				*	0.383
	Current	***	0.829			***					

Table 2.4. Percent declines for each species, species group, and species sub-group analyzed with the primary methodology. Percentages were calculated using the lowest-smoothed values and expressed as (a) the 2004 level as a percentage of the 1974 value (b) the lowest value as a percentage of the highest value, and (c) the lowest value as a percentage of the 1974 value. Years of lowest and highest levels are also given.

Species	Sub-Category	Decline %, 74-04	Year Min. Abun	Year Max. Abun	Min/Max Decline
<i>C. plumbeus</i>	All	18.32	2004	1974	-
	YOY	166.71	1974	1975	7.26
	Juveniles	0.68	2004	1997	-
	Adults	0.07	2003	1982	0.002
	Females	0.28	2004	1974	-
	Males	1.45	2004	1995	0.52
<i>C. obscurus</i>		32.14	1992	1974	4.40
<i>C. taurus</i>		0.18	2004	1974	-
<i>G. cuvieri</i>		2.53	2004	1974	-
<i>M. canis</i>		538.66	1990	1999	0.58
Large Coastal Sharks		21.29	2004	1974	-

Table 2.5. Results of analyses using the secondary methodology on those species and the species group amenable to such analysis. This shows significance levels for all independent variables that were significant at the $p < 0.05$ level for the logistic regression model.

Logistic									
Species	N	Year		Surf. Temp		Depth		Set Time	
<i>C. limbatus</i>	576			<0.0001	***				
<i>S. acanthias</i>	576			<0.0001	***				
<i>S. lewini</i>	639	0.0006	***						
<i>C. brevipinna</i>	576	0.0004	***	0.0103	*				
Pelagics	536			0.0009	***	0.0049	**	0.0163	*

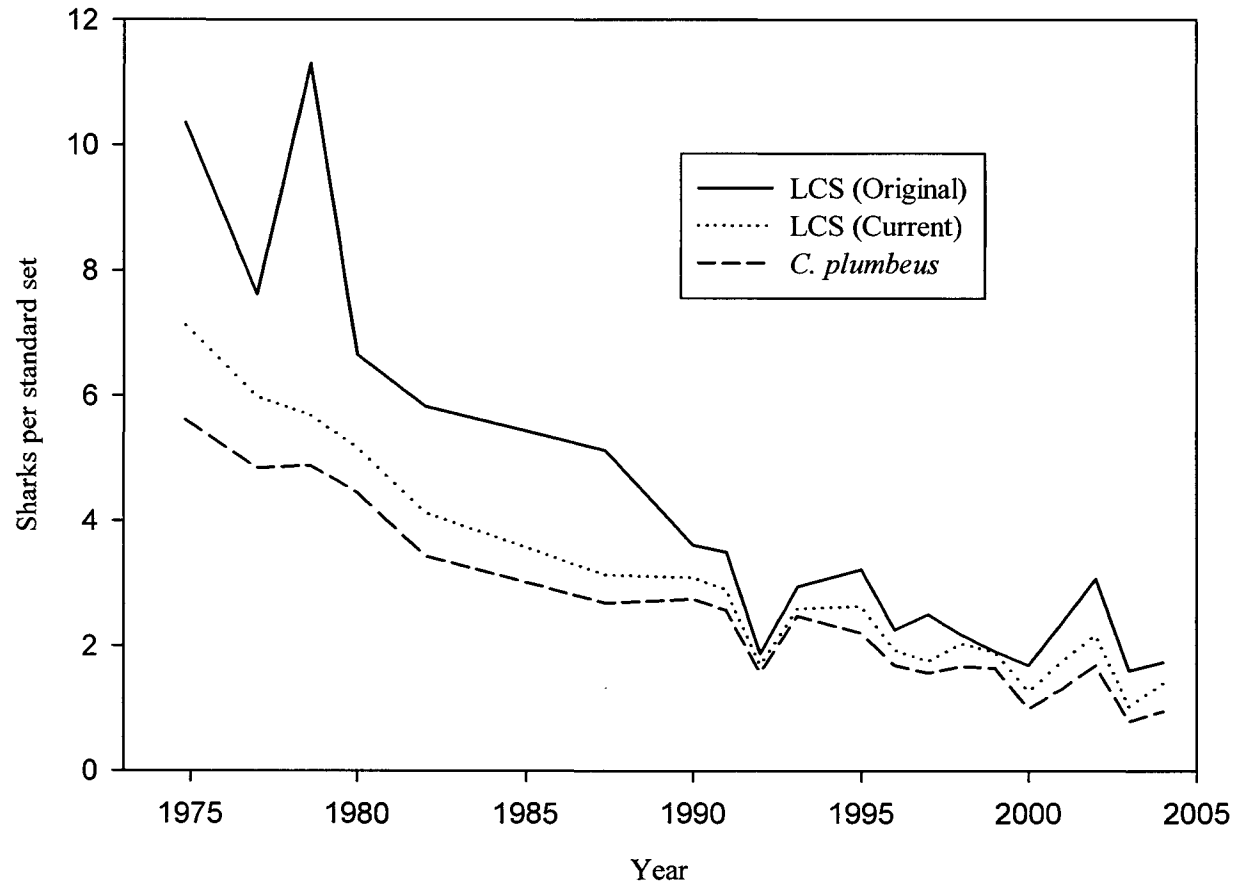


Figure 2.1: Significant Lowess-smoothed trends in transformed cpue data fitted with a GAM model for the large coastal species group and *C. plumbeus*. The Y-axis is back-transformed into sharks per standard set, a standard set being 100 hooks soaking for four hours. The LCS group is shown both as defined originally in 1992 (NMFS 1992) and as defined currently (NMFS 2003). The current definition excludes the white, sand tiger, bignose and night sharks.

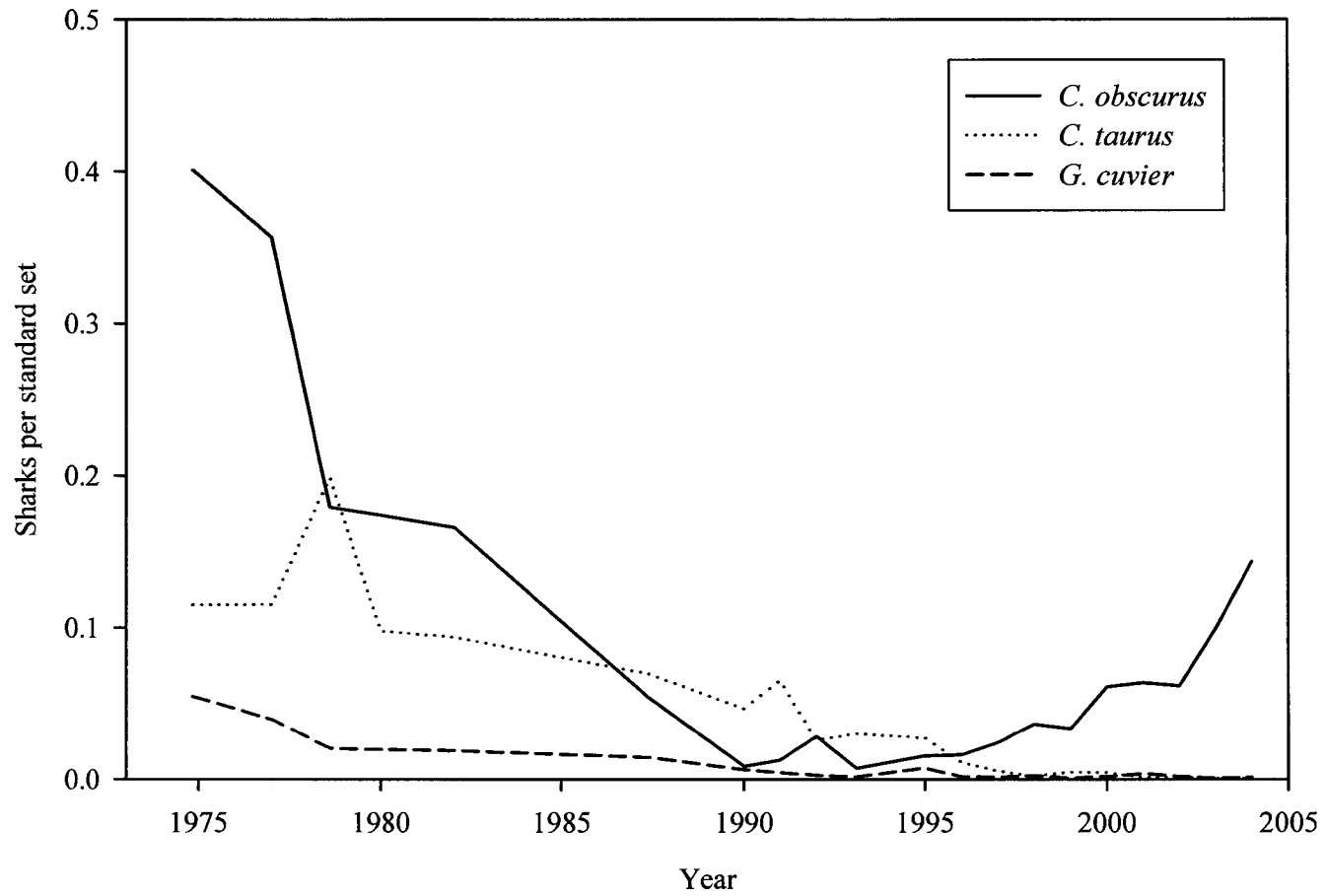


Figure 2.2: Significant Lowess-smoothed trends in abundance for LCS species present in lower abundances. The Y-axis is back-transformed into sharks per standard set, a standard set being 100 hooks soaking for four hours.

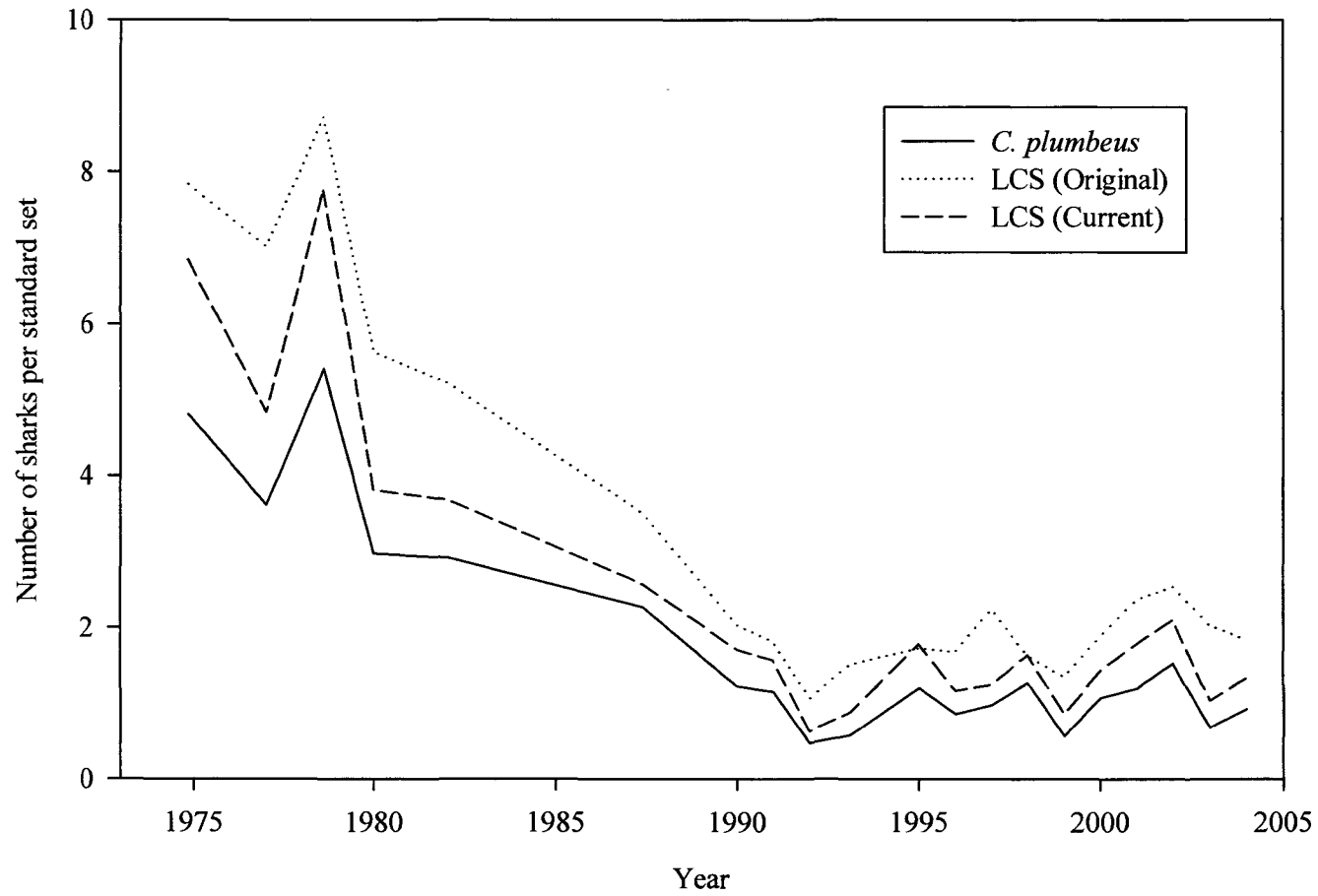


Figure 2.3: Trends in LCS (Original) and LCS (Current) abundance compared to *C. plumbeus* trend when data analyzed exclude stations in the known nursery ground areas of *C. plumbeus*. The Y-axis is back-transformed into sharks per standard set, a standard set being 100 hooks soaking for four hours.

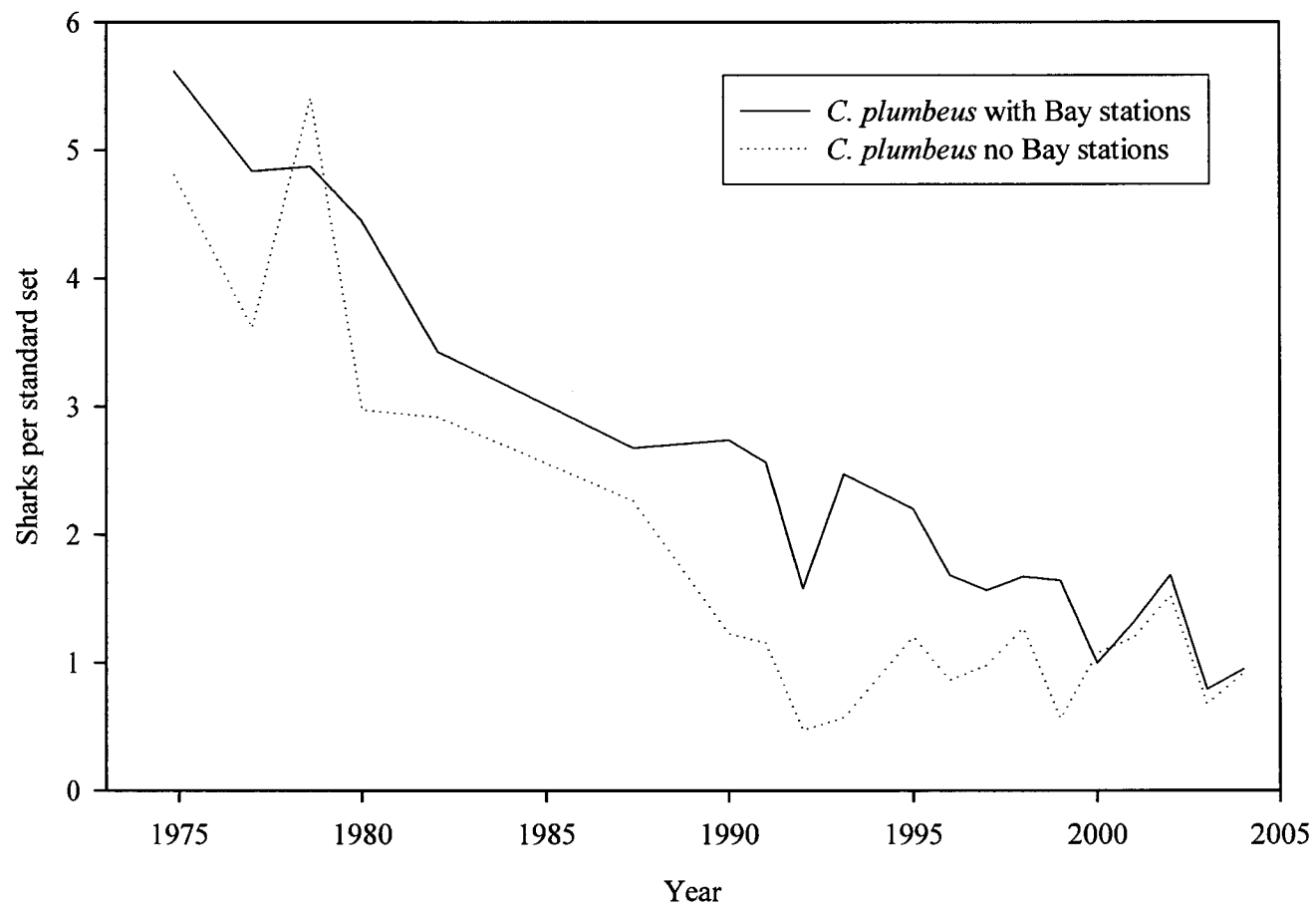


Figure 2.4: Comparison of the significant trends in abundance in *C. plumbeus* with and without the standard stations located in the Chesapeake Bay. The Y-axis is back-transformed into sharks per standard set, a standard set being 100 hooks soaking for four hours.

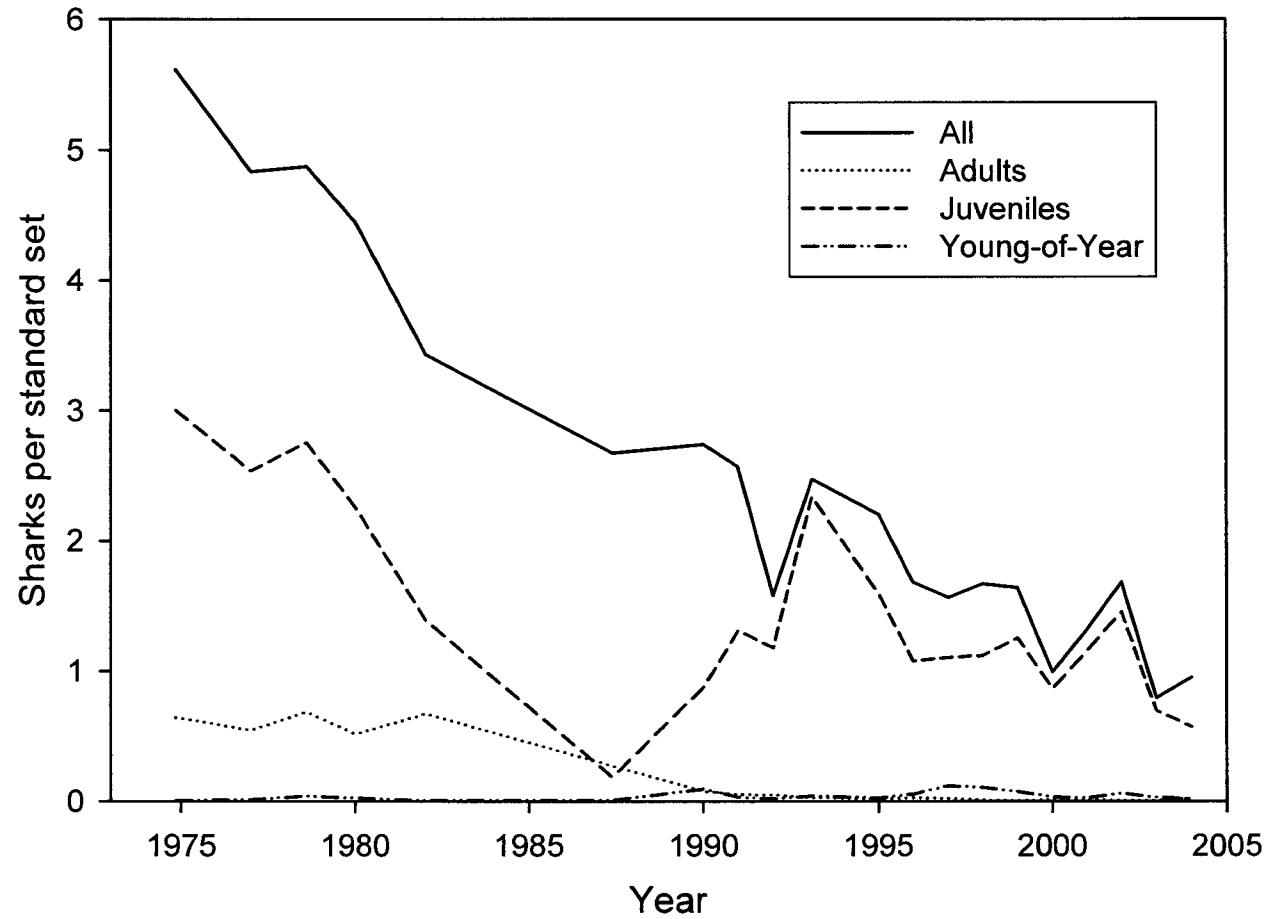


Figure 2.5: Significant lowess-smoothed trends in the three NMFS defined size classes of *C. plumbeus*, compared to the trend in all *C. plumbeus*. The Y-axis is back-transformed into sharks per standard set, a standard set being 100 hooks soaking for four hours.

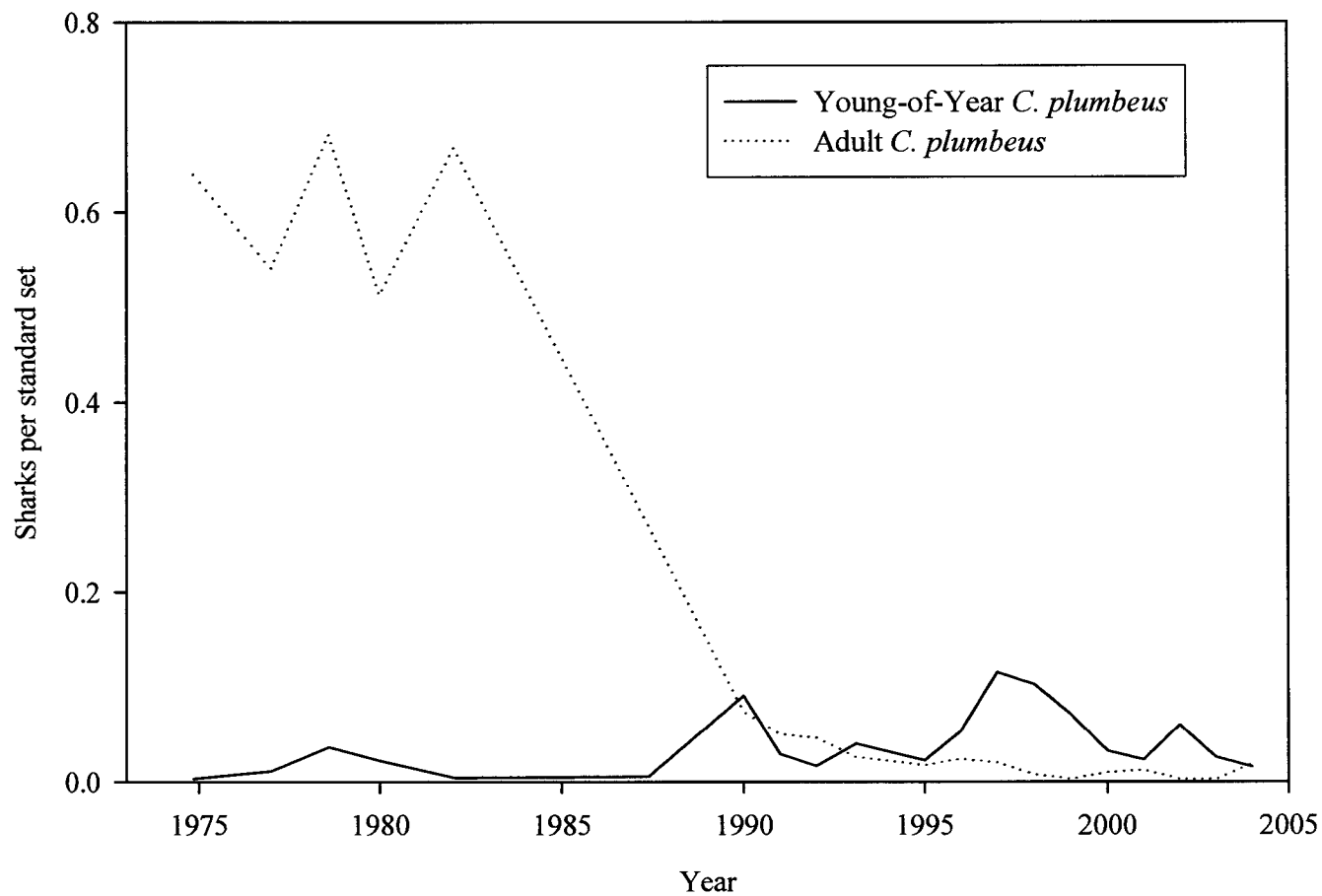


Figure 2.6: The significant lowess smoothed trends in young-of-year and adult *C. plumbeus*, on a smaller Y scale than Figure 2.5, so as to see their patterns in abundance more clearly. The Y-axis is back-transformed into sharks per standard set, a standard set being 100 hooks soaking for four hours.

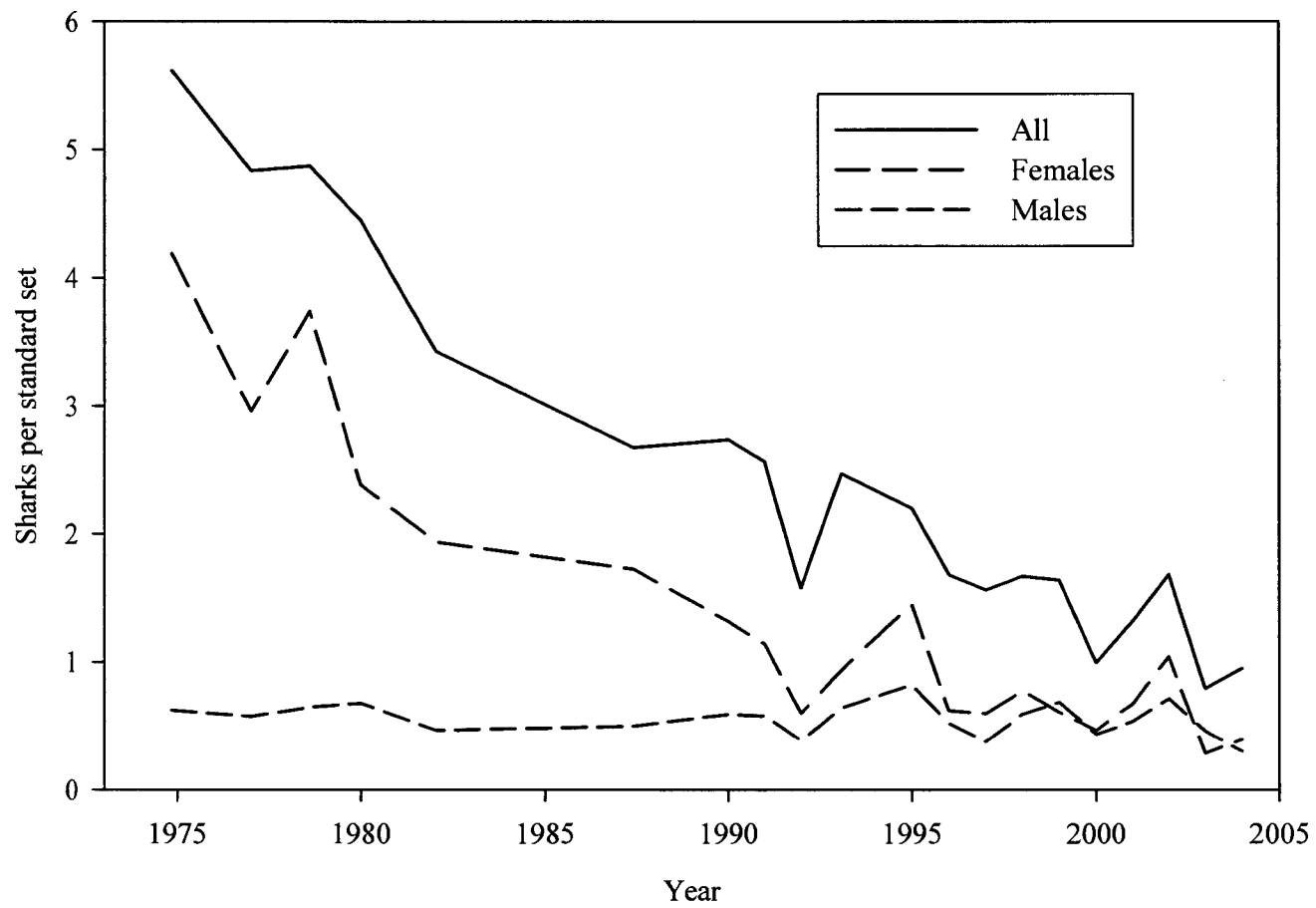


Figure 2.7: Significant lowess-smoothed trends in the sexes of *C. plumbeus*, compared to the trend in all *C. plumbeus*. The Y-axis is back-transformed into sharks per standard set, a standard set being 100 hooks soaking for four hours.

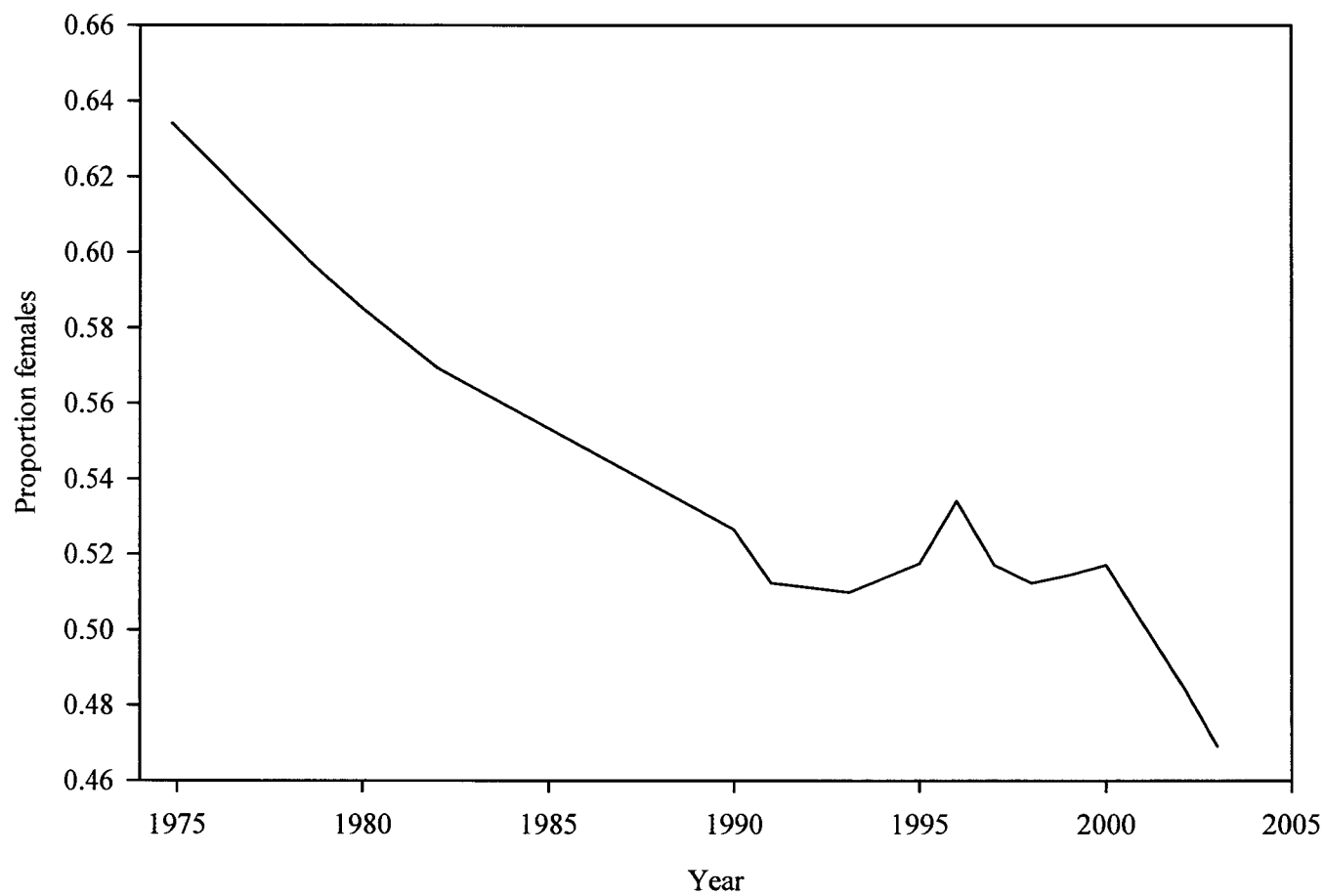


Figure 2.8: Significant lowess smoothed trend in proportion of female *C. plumbeus* to all *C. plumbeus* for all individuals with sex recorded in this survey.

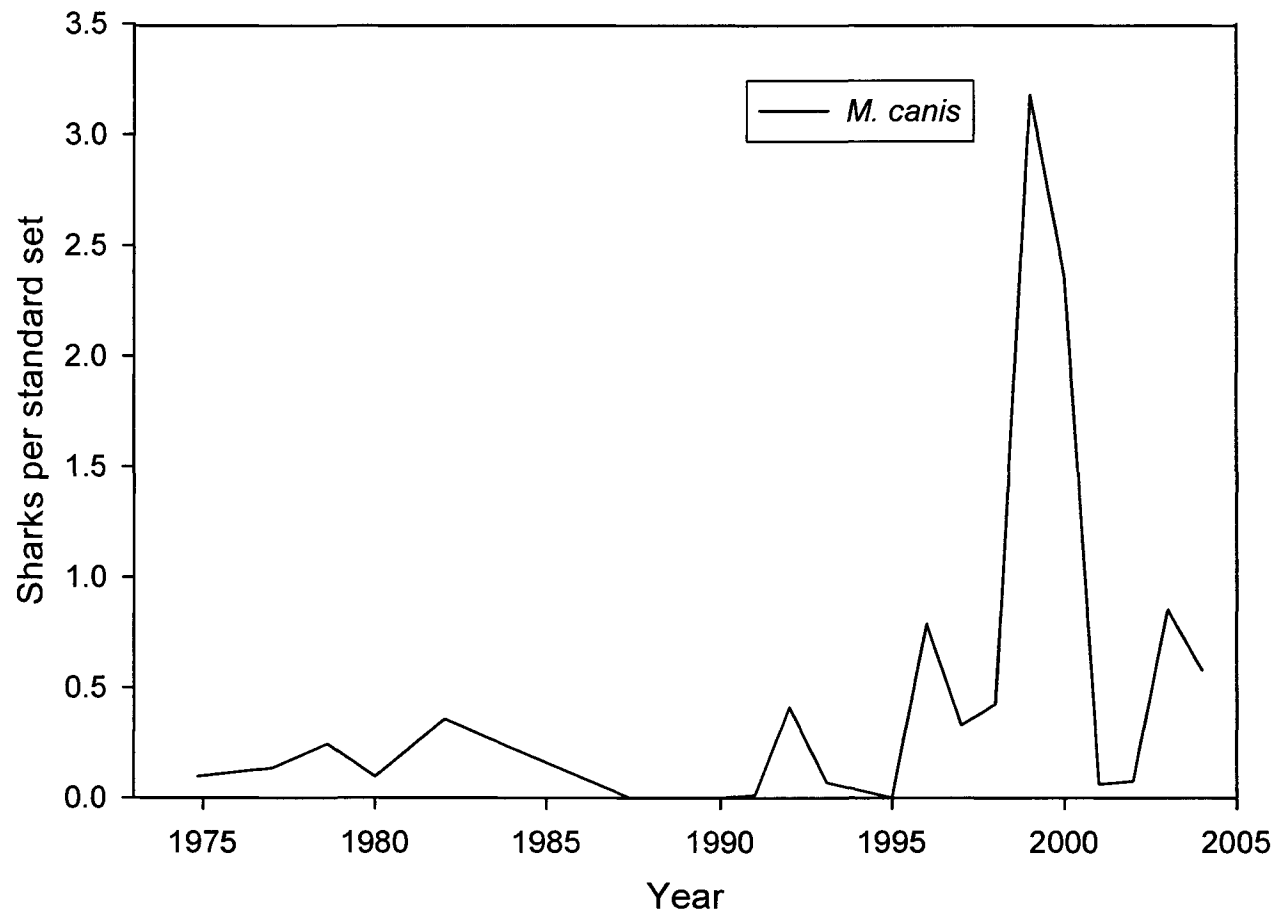


Figure 2.9: Significant lowess-smoothed trends in the only non LCS shark species to show a significant fit to a curve, *Mustelus canis*. The Y-axis is back-transformed into sharks per standard set, a standard set being 100 hooks soaking for four hours.

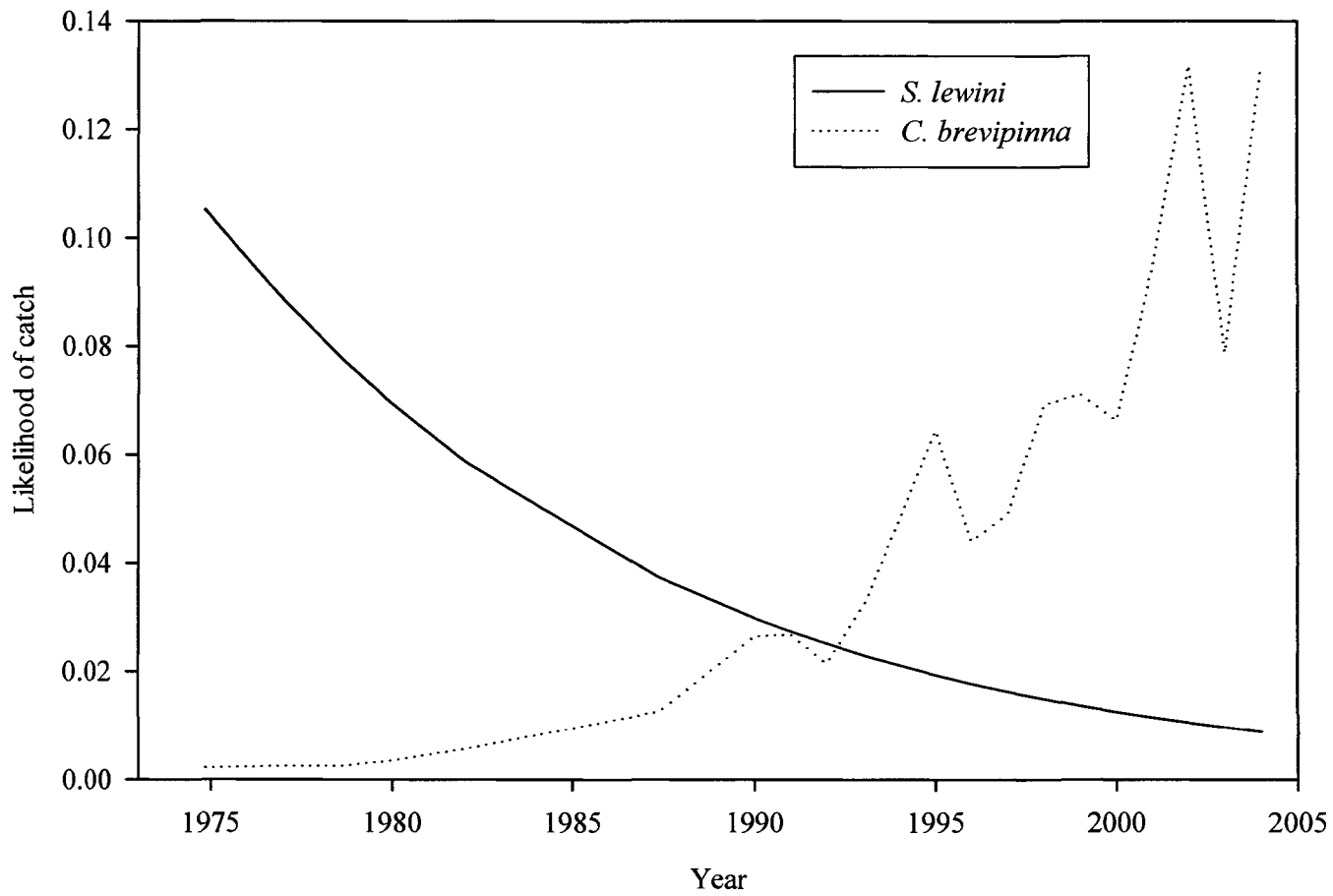


Figure 2.10: Significant trends in abundance from logistic regression analysis of species and species groups with unusable transformed CPUE data.

Chapter 3: Trends in Shark Size

This chapter analyzes sizes and changes in size of sharks caught in the VIMS long-line survey over time, using both a measure of length and biomass as metrics.

Methods

Analysis of size measured as total length (TL) was accomplished using both simple size-frequency distribution graphs and through tests for changes in both the mean and the standard deviation of size-frequency distributions over time. Size-frequency distributions were made for species represented by more than 20 individuals collected during the course of this survey, with the data pooled over the entire time series. The analysis of changes in size frequency distribution (both mean and standard deviation) over time included the four most abundant species in the survey (Table 1.2). In order to increase resolution and maintain acceptable sample sizes, these species were separately broken down into year categories with approximately equal catches of the species. Z-scores, a technique for standardizing data to a specified mean and standard deviation, were then calculated for each year group based on the mean and standard deviation of the first year group for each species. The mean and 95% confidence limits of the z-scores for each year were then calculated, and the results plotted (SAS, 2002; SPSS, 2002). T-tests

comparing each subsequent year/year group to the first year were performed to test for significant differences, and the Bonferroni correction applied to correct for multiple comparisons (Sokal and Rohlf 1995).

Analyses of biomass trends was complicated by the need to back-calculate masses of sharks from lengths, since sharks were weighed when collected only until the early 1990's. Published relationships between length and weight often use different measures of length than are collected in this survey. This discrepancy required using published conversions from measures of length such as TL, pre-caudal length (PCL), and fork length (FL) to convert the length data to the necessary input length format (TL, FL, PCL) for the length-weight equations. No published length to length conversion equations were available for three species, *M. canis*, *S. acanthias*, and *C. taurus*, so VIMS long line data were used in a linear regression model (SAS, 2002).

Published length-weight relationships were used when available to calculate the mass of individual sharks. No published length-weight relationship was found for one species, *C. taurus*, so catch records of this species from the VIMS survey with both weight and length measurements were used to fit a length-weight model (SAS, 2002). This relationship was then used to calculate the mass of individuals of this species without a mass recorded.

The biomass data were analyzed with a GAM model, fitting a Lowess smoothing curve to the data over the time-series, to investigate the changes in the mean weight of individuals of each species. The model was fitted using a Gaussian distribution and a identity link function. This model for each species was of the form:

$$weight = a + lo_1(Year) + e$$

where *weight* is the response variable, *a* is a constant, *lo* indicates a loess smoothing function, and *e* is the error term (with a Gaussian distribution).

Results

The length-frequency histograms for three of the twelve species, show the catch was predominantly adults, these being *C. taurus*, *P. glauca*, and *R. terraenovae* (Figures 3.1-3.3). Two species (*M. canis* and *S. acanthias*) had no size breaks (Figure 3.4). Mainly juveniles and sub-adults of the other eight species were caught (Figures 3.1-3.2, 3.5-3.7), which may indicate that Virginia waters are not breeding grounds and/or preferred habitat of adults.

Size-Frequency changes over time

For the z-score figures, any year group that has both its mean and its 95% confidence limits drop below or rise above zero is a year group in which the size distribution has significantly changed with respect to the previous year (Table 3.1). In the case of rising above zero the size distribution has become broader, whereas in the opposite case, the size distribution has narrowed. The varying sample sizes of these species led to year groupings that were different for each species (Table 3.1). Early in the time series, female *C. plumbeus* of a wide range of sizes were caught, followed by a constriction in the size distribution as smaller individuals became increasingly predominant in catches (Figure 3.8). The pattern for *C. plumbeus* males was similar,

although the total decline in mean z-score was less than that of females, reflecting the rarity of adult male *C. plumbeus* in the survey area during all years (Figure 3.9).

Carcharhinus obscurus females showed a trend that was similar to that of female *C. plumbeus*, but this trend did not drop as low as the pattern in female *C. plumbeus* (Figure 3.10). Male *C. obscurus* had a lower resolution, but a statistically significant decline did occur in the last year category (Figure 3.11). *Rhizoprionodon terraenovae* females (Figure 5 3.12) and males (Figure 63.13) showed no apparent trend in size distribution throughout the time-series. *Mustelus canis* females, the only sex caught in high enough abundances for analysis, also showed no trend in size over years (Figure 73.14).

Weight

Results of mass analyses showed highly species-specific trends (Table 3.2). Three species required length conversion equations to be calculated from the VIMS data (Table 3.3). Only one species required the calculation of a length-weight relationship from the VIMS data (Table 3.4).

Of the thirteen species analyzed, six (*P. glauca*, *R. terraenovae*, *C. limbatus*, *C. taurus*, *M. canis*, and *I. oxyrinchus*) showed no biologically significant changes in size over the course of this sampling program, while two (*C. altimus* and *C. brevipinna*) showed significant increases, and five (*C. plumbeus*, *S. acanthias*, *S. lewini*, *G. cuvier*, and *C. obscurus*) showed significant decreases. Two of the smaller sharks species (*M. canis* and *R. terraenovae*) showed no clear trend in mean biomass per individual through

the study period (Figure 8 3.15). The other, *S. acanthias*, showed signs of decline from a mean of over 5 kg per individual to less than 4 kg per individual (Figure 93.16). Of the LCS (current), *C. limbatus* showed no clear trend in mean weight (Figure 103.15). *Carcharhinus plumbeus*, *S. lewini* and *G. cuvier*, however, showed clear patterns of decline in mean biomass over the course of this study (Figure 10). *Carcharhinus plumbeus* weight decreased from a peak of roughly 20 kg per individual to about 5 kg per individual (Figure 3.16), while *G. cuvier* dropped from 73 kg mean to about 8 kg (Figure 3.17). In prohibited and pelagic species, records for *C. taurus*, *P. glauca* (Figure 83.15) and *I. oxyrinchus* (Figure 103.17) showed no trend in mean biomass, while *C. obscurus* showed a decline (Figure 103.17). Two species of shark showed increases in mean mass per shark over the course of this study. Both *C. altimus* and *C. brevipinna* showed significant increases in mean mass per fish (Figure 113.18).

Discussion

Extending the data from these results and using the results of abundance trends from Chapter 2, a hundred hook long-line soaked for four hours during the period 1974-76 would have caught on average 126 kg of the eight most common species in this survey. The same amount of effort would catch on average 25 kg of the same species in 2004 (Table 3.5). In the following discussion, trends in the shape of the size-frequency distribution were deemed biologically significant if they lasted for multiple year groups and/or showed a marked deviation from the null model (the zero line).

Both *C. plumbeus* and *C. obscurus* show signs of change in size, measured both as reduction in mean mass per fish and as changes in the shape of the size-frequency curve over time. Both species were subjected to heavy fishing pressure historically (see Figures 1.2 and 1.5), as well as bycatch mortality in other fisheries (NMFS, 1999). *Carcharhinus obscurus* was placed on the prohibited species list as of June 2000, but *C. plumbeus* is still fished, and shark long-line catches are at time comprised of 80-90% *C. plumbeus* in some areas (NMFS, 1999). The changes in size documented in both of these species possibly reflect the effects of fishing mortality on these populations. Adults are taken in fisheries, and this drops the mean mass, as well as removing large size classes from the population, resulting in the effects shown here.

Rhizoprionodon terraenovae and *M. canis* are both commonly caught small species with fairly high population growth and reproductive rates (Conrath and Musick, 2002; Parsons, 1983), and therefore likely to be slower in showing effects of fishing mortality. Even though they suffer bycatch mortality, they are not as heavily exploited by commercial fisheries due to their small size (Conrath and Musick, 2002; NMFS, 1999). This would explain the patterns shown in this study, as well as the conclusion that *R. terraenovae* are not overfished made by Cortés (2002b).

Less abundant species

Three of the species not present in sufficient numbers to allow analysis of changes in size-frequency over time showed declines in mean mass per shark over the course of

this survey. In addition to *C. plumbeus* and *C. obscurus*, mentioned above, they were, *G. cuvier*, *S. lewini*, and *S. acanthias*.

Squalus acanthias is a heavily exploited species that has been shown to have suffered reductions in mean size of individuals, as well (Rago et al., 1998). They also found declines in the mean length of *S. acanthias* of both sexes in the northwest Atlantic fishery, but especially in the females, which were targeted by the fishery (95% of the catch since 1982). Data from the NMFS Northeast Fisheries Science Center's spring trawl survey showed an 11% decline between 1982 and 1994 in the yearly mean length of *S. acanthias*, while VIMS data showed a 33% decline in mean mass per shark between 1974 and 2004.

Although *G. cuvier* are relatively rare in our survey, they have shown the most significant decrease in mean mass per fish of the sharks in this survey. Other populations of *G. cuvier* have shown similar responses to human-induced mortality. In Australian beach protection data, Simpfendorfer (1992) found that the mean size of female *G. cuvier* had declined from approximately 300 cm TL to 250 cm TL between 1964 and 1986, a decrease of 17% (Simpfendorfer, 1992). Pepperell (1992) found that size frequency distributions of *G. cuvier* caught by game fish anglers had shifted towards smaller individuals (measured as mass, kg) between the periods 1961-1970, 1971-80 and 1981-90. NMFS defined the essential habitat of adult *G. cuvier* as reaching the northern limit at the mouth of the Chesapeake Bay, and the habitat of the younger stages as reaching much farther north, to Martha's Vineyard (NMFS, 1999). However, early data (1961-2) showed that adults were common as least as far north as Sandy Hook, NJ (Chapter 5).

After this species was fished down in the 1980's and early 1990's (see Figure 1.4), the larger sharks virtually disappeared. As mentioned in the previous chapter, this species has shown signs of recovery in areas of the southern Atlantic U.S., leading one to expect to see smaller individuals first.

Sphyrna lewini showed a habitat pattern similar to that seen in *G. cuvier*. In this case, the VIMS long-line sampling area is entirely contained in the EFH for the juvenile/subadult stage (NMFS, 1999), but our sampling area is on the fringe of the adult EFH for this species. The same pattern may be occurring as described above for *G. cuvier*. One additional factor possibly contributing to the reduction in adults of this species is their high mortality on long-lines (Musick, personal communication).

Species showing no trend

In addition to *R. terraenovae* and *M. canis*, discussed above, four other species showed no biologically significant trend in mean biomass per shark over time, including *I. oxyrinchus*, *P. glauca*, *C. limbatus* and *C. taurus*. *Isurus oxyrinchus* and *Prionace glauca* are similar in that they are pelagic species rarely-caught in this survey. In addition, both species are highly migratory even for sharks (Hazin et al., 1994; Casey and Kohler, 1992). This means our catches likely represent fortuitous catches and are not a representative cross-section of the populations.

Carcharhinus limbatus is another uncommon species in our survey, making conclusions difficult to draw. This species is unusual in that its abundance trend (Chapter 2) shows a decline while its biomass trend shows no discernable trend. This

means that adults occur in Virginia with occasional catches of younger individuals.

NMFS (2003) concluded that *C. limbatus* were currently no longer overfished, and in fact could withstand an increase in total allowable catch of 20-50 percent. The original FMP (NMFS, 1992) delineates the EFH of this species as starting at the Virginia/ North Carolina border and extending south. Fishing pressure may have reduced *C. limbatus* populations in their primary range, and since the abundance has declined over their range, fewer *C. limbatus* come north to Virginia waters in the summer.

Carcharias taurus is also a species that has shown a decline in abundance over the course of the survey while showing no biologically significant trend in mean size. As discussed in Chapter 2, catches were comprised of adults in post-partum or resting stages (58% of the catch), and sub-adults (40%) (Goldman, 2002). The VIMS survey area is being used by a small size range of *C. taurus*, and this size range has not changed over the course of this study, but the overall abundance of this species has. This species has shown a similar response to population depletion in other areas. A shift towards smaller size classes of *C. taurus* over time in shark catches was found in Australian beach protection nets (Reid and Krogh, 1992). However, as discussed in the previous chapter, neonates and early juveniles are rare and have always been rare in this survey.

Increasing Species

Both *C. altimus* and *C. brevipinna*, have shown significant increases in mean mass per fish over the time series of this study. *Carcharhinus altimus* has been protected since June of 2000, but *C. brevipinna* has not. The VIMS long-line survey only samples

a small portion of the range of these species, resulting in low sample sizes, and hence these trends may not be representative of overall trends.

Summary

This chapter showed that several species of sharks found in the survey area showed decreases in size, both as measured by the shape of their size-frequency distributions, and by the changes in mean mass per fish over the duration of this study. In the cases of *C. plumbeus* and *C. obscurus*, such reductions are the logical result of fishing mortality, which targeted the larger adults of a species. Reductions in mean mass per shark in *S. acanthias*, *G. cuvier*, and *S. lewini* were likely due to fishing mortality, although no corroborating evidence exist to support this. Cases in which no trend was evident include a group of species (*R. terraenovae* and *M. canis*) that reproduce relatively quickly, were not as heavily fished, and may be subject to lower predation due to decreased abundances of larger sharks (Gelschlechter et al. 1999). Another group that showed no decline comprises uncommon species, including *I. oxyrinchus* and *P. glauca*, in which there were likely too little data to have shown a trend if any trend existed. The only other species that showed no decline, *C. taurus* and *C. limbatus*, can be explained by the migration patterns of adults post-pupping and the dynamics of recovery after heavy fishing mortality. Species that showed apparent increases were not sampled sufficiently by the VIMS survey to have detected true population trends.

<i>C. plumbeus</i>		<i>R. terraenovae</i>		<i>C. obscurus</i>		<i>M. canis</i>	
Male Group	Female Group	Male Group	Female Group	Male Group	Female Group	Female Group	
1974-79	1974-76	1974-77	1977-81	1974-79	1974-79	1974-80	
1980 *	1977-79 *	1980 *	1988-91 *	1980 *	1980 *	1981 ns	
1981-89 *	1980 ns	1981 *	1992-97 ns	1981 ns	1981-84 ns	1990-93 ns	
1990 ns	1981-89 *	1982-90 ns	1998-04 ns	1990-99 ns	1990-98 *	1996-97 ns	
1991 ns	1990 *	1991 ns		2000-04 *	1999-01 *	1998 ns	
1992 *	1991 *	1992 ns			2002-04 *	1999 ns	
1993-95 ns	1992 *	1995 ns				2000 ns	
1996 ns	1993-95 *	1996-97 *				2001-02 ns	
1997 *	1996 *	1998-99 ns				2003 ns	
1998 *	1997 *	2000-01 ns				2004 *	
1999 *	1998 *	2002-04 ns					
2000 *	1999 *						
2001 *	2000 *						
2002 ns	2001 *						
2003 *	2002 *						
2004 *	2003 *						
	2004 *						

Table 3.1. Groupings of years used to provide even sample sizes for z-score analysis of size frequency distributions of selected shark species, with significance levels from t-tests described in the Methods section. Bonferroni corrected α values were 0.003 for both sexes of *C. plumbeus*, 0.005 for male *R. terraenovae*, 0.02 for female *R. terraenovae*, 0.01 for both sexes of *C. obscurus*, and 0.006 for *M. canis* females. Due to use of the Bonferroni correction, significance is indicated by a single asterisk (*).

	Mean mass per fish				decrease, %
	earliest	year	most recent	year	
<i>G. cuvier</i>	118.79	1976	10.87	2003	91%
<i>S. lewini</i>	27.80	1976	4.05	2004	85%
<i>C. obscurus</i>	39.03	1976	13.82	2004	65%
<i>C. plumbeus</i>	15.71	1976	9.63	2004	39%
<i>S. acanthias</i>	4.09	1980	2.72	2004	33%
<i>C. taurus</i>	61.69	1976	51.51	2003	16%
<i>R. terraenovae</i>	4.64	1976	4.28	2004	8%
<i>C. altimus</i>	11.76	1980	35.88	1998	
<i>C. brevipinna</i>	2.71	1990	7.66	2004	
<i>C. limbatus</i>	20.30	1976	33.28	2004	
<i>I. oxyrinchus</i>	13.91	1980	34.40	2000	
<i>M. canis</i>	6.95	1976	6.97	2004	
<i>P. glauca</i>	33.52	1982	46.03	2000	

Table 3.2. Decline in predicted yearly mean mass (kg) per shark between the mean from the earliest year and the most recent year predicted values are available for. Predicted values used were from a GAM lowess smoothed model of mass of individual fish of each species against year.

Species	a	b	r ²	From	To	Source	n
<i>Carcharhinus altimus</i>	0.8074	7.7694	0.9872	TL	FL	a	
<i>C. obscurus</i>	0.8396	-3.1902	0.9947	TL	FL	a	
<i>C. plumbeus</i>	0.8175	2.5675	0.9933	TL	FL	a	
<i>Galeocerdo cuvier</i>	0.8761	-13.354	0.9887	TL	FL	a	
<i>Prionace glauca</i>	0.8313	1.3908	0.9932	TL	FL	a	
<i>Sphyrna lewini</i>	0.7756	-0.3132	0.9868	TL	FL	a	
<i>Mustelus canis</i>	1.0906	5.0346	0.9762	FL	TL	Present study	109
<i>Squalus acanthias</i>	3.8959	1.0799	0.9896	FL	TL	Present study	42
<i>C. limbatus</i>	1.16	5.71	0.994	FL	TL	b	
<i>R. terraenovae</i> Fem.	0.7819	-23.303	0.99	TL	PCL	c	
Male	0.9302	-10.464	0.99	FL	PCL	c	
<i>Carcharias taurus</i>	0.8362	2.0351	0.9499	TL	FL	Present study	90

Table 3.3. Summary of length-length relationships used to convert lengths as measured by the VIMS survey to length needed as input into length-mass equations. The model parameters given are for the equation $L_2 = a * L_1 + b$. Units for L_1 and L_2 are also shown. New regressions performed using VIMS survey data also show sample size.

a) (Kohler et al., 1995) b) (Branstetter, 1987a) c) (Loefer and Sedberry, 2002)

Species	a	b	r ²	Length	Mass	Source	n
<i>Carcharhinus altimus</i>	0.000001	3.461	0.8958	FL, cm	kg	a	
<i>C. obscurus</i>	0.000032	2.786	0.9649	FL, cm	kg	a	
<i>C. plumbeus</i>	0.000011	3.012	0.9385	FL, cm	kg	a	
<i>Galeocerdo cuvier</i>	0.000003	3.260	0.955	FL, cm	kg	a	
<i>Prionace glauca</i>	0.000003	3.131	0.9521	FL, cm	kg	a	
<i>Sphyrna lewini</i>	0.000008	3.067	0.9255	FL, cm	kg	a	
<i>Mustelus canis</i>	0.000000	3.500	0.95	TL, mm	g	b	
<i>Squalus acanthias</i> F	0.000000	3.607		TL, mm	g	c	
M	0.000002	3.098		TL, mm	g	c	
<i>C. limbatus</i>	0.000014	2.870		TL, cm	kg	d	
<i>R. terraenovae</i> F	0.000000	3.040	0.99	PCL, mm	kg	e	
M	0.000000	2.960	0.99	PCL, mm	kg	e	
<i>Carcharias taurus</i>	0.000087	2.592	0.777	FL, cm	kg	this study	90
<i>C. brevipinna</i> F	0.000005	3.163		PCL, cm	kg	f	
M	0.000007	3.098		PCL, cm	kg	f	

Table 3.4. Summary of length-mass equations used to convert VIMS survey measured lengths into mass by species. The model parameters shown are for the equation $Mass=(a)L^b$. The units of L and mass are given, as well as the parameters a and b, and the r² for the model. For the new model estimated using VIMS survey data, the sample size is also given.

a) (Kohler et al., 1995) b) (Rountree and Able, 1996) c) (Rago et al., 1998) d) (Branstetter, 1987a) e) (Loefer and Sedberry, 2002) f) (Allen and Wintner, 2002)

Species	Abundance		Mean mass		Mean catch, kg	
	1974	2004	1974	2004	1974	2004
<i>C. plumbeus</i>	5.31	0.97	15.71	9.63	83.37	9.37
<i>R. terraenovae</i>	0.46	0.7	4.64	7.28	2.13	5.10
<i>M. canis</i>	0.11	0.58	6.95	6.97	0.75	4.04
<i>C. obscurus</i>	0.38	0.12	39.03	13.82	14.91	1.70
<i>C. taurus</i>	0.13	0.00	61.69	29.04	8.09	0.01
<i>C. limbatus</i>	0.31	0.13	20.3	33.28	6.29	4.33
<i>S. lewini</i>	0.18	0.04	27.8	4.05	5.00	0.16
<i>G. cuvier</i>	0.04	0.00	118.79	10.87	5.00	0.01
			Sum		125.54	24.71

Table 3.5. Mean biomass of the eight most abundant species caught per standard set for the earliest recorded year of this survey (1974) and the most recent year analyzed (2004). Abundance figures are taken from the GAM lowess-smoothed models described in Chapter 2 (results shown in Figures 3.4, 3.5, and 3.6), except for *R. terraenovae*, *S. lewini*, and *C. limbatus*, in which case a simple mean was used. Mean mass (kg) per fish for each year was taken from GAM lowess smoothed models described in the methods section.

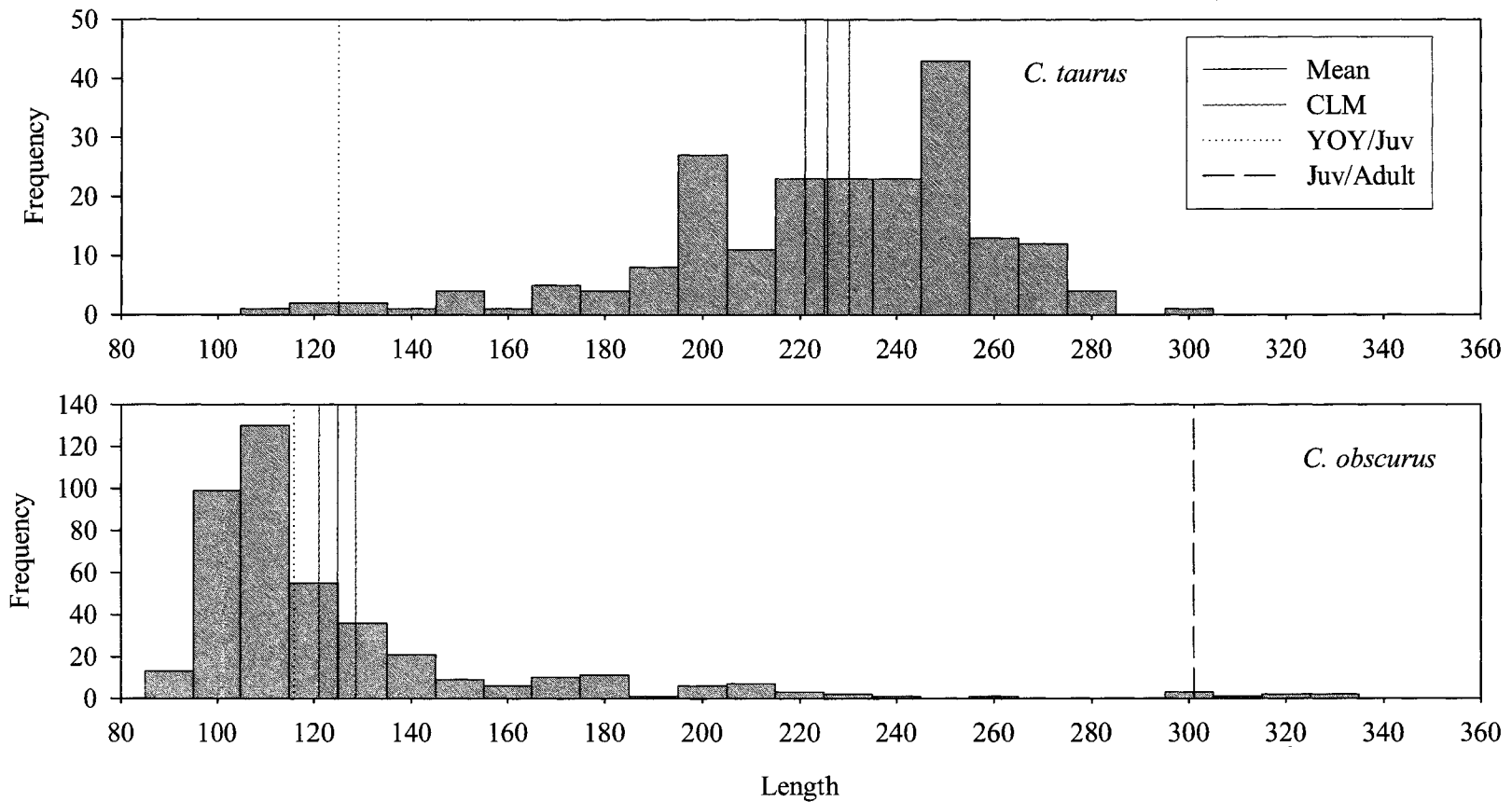


Figure 3.1: Length-frequency histograms in 20 cm TL increments for 2 of the 13 most abundant species in this survey. All species show the mean length (cm TL; red line) and 95% confidence limits of the mean (green lines). All species covered by the NMFS HMS FMP (NMFS 1999) have the NMFS size breaks between young of the year/ early juveniles and late juvenile/subadults and the break between the latter and adults shown.

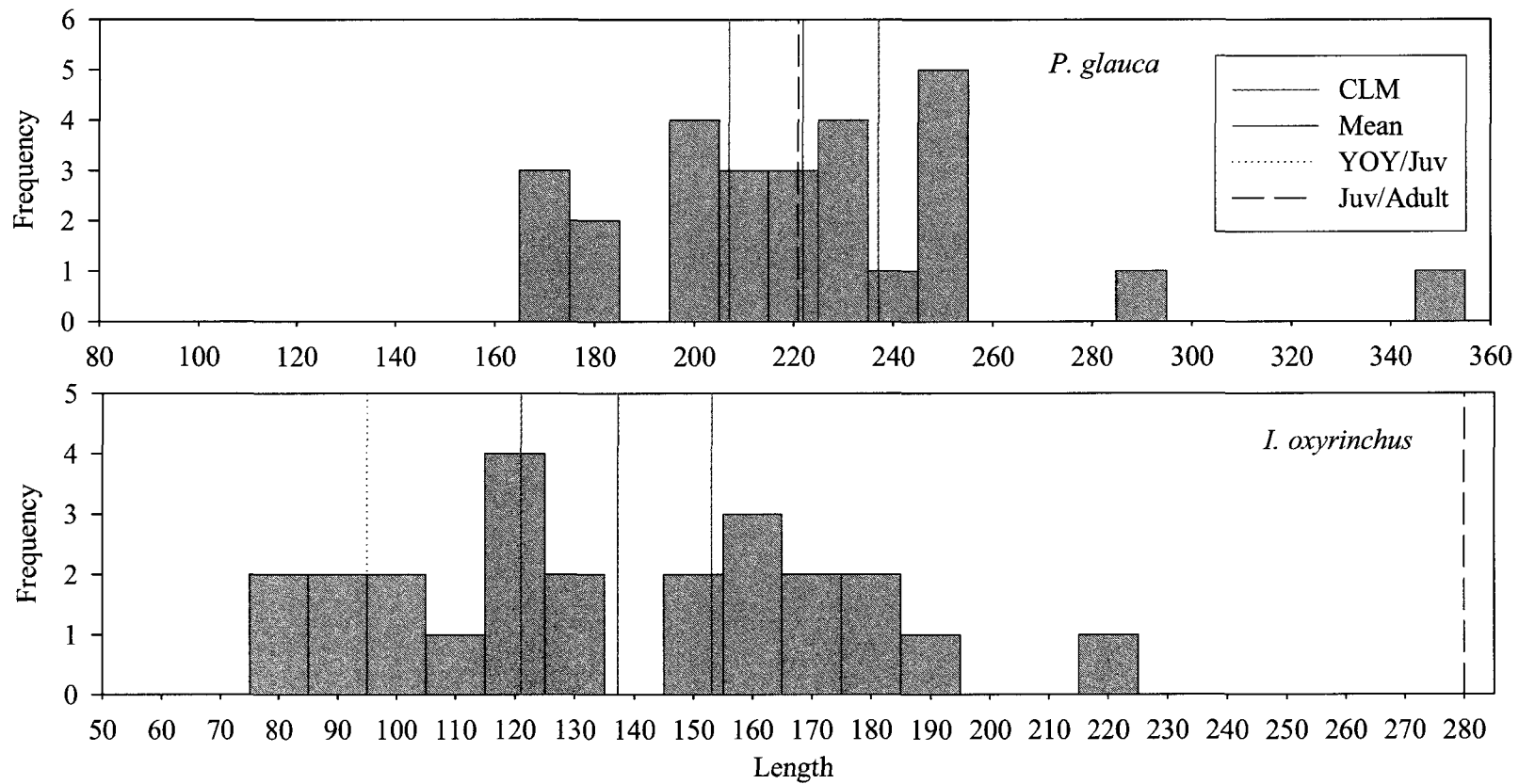


Figure 3.2: Length-frequency histograms for 2 of the 13 most abundant species in this survey. All species show the mean length (cm TL; red line) and 95% confidence limits of the mean (green lines). All species covered by the NMFS HMS FMP (NMFS 1999) have the NMFS size breaks between young of the year/ early juveniles and late juvenile/subadults and the break between the latter and adults shown.

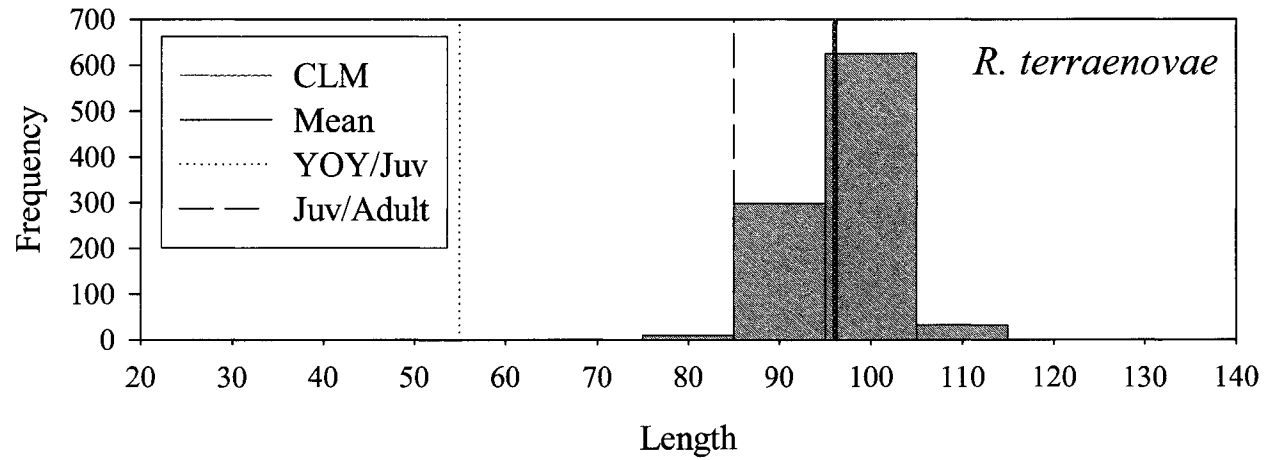


Figure 3.3: Length-frequency histogram in 10 cm TL increments for *R. terraenovae* caught in this survey. All species show the mean length (cm TL; red line) and 95% confidence limits of the mean (green lines). The NMFS HMS FMP (NMFS 1999) size breaks between young of the year/ early juveniles and late juvenile/subadults and the break between the latter and adults are shown.

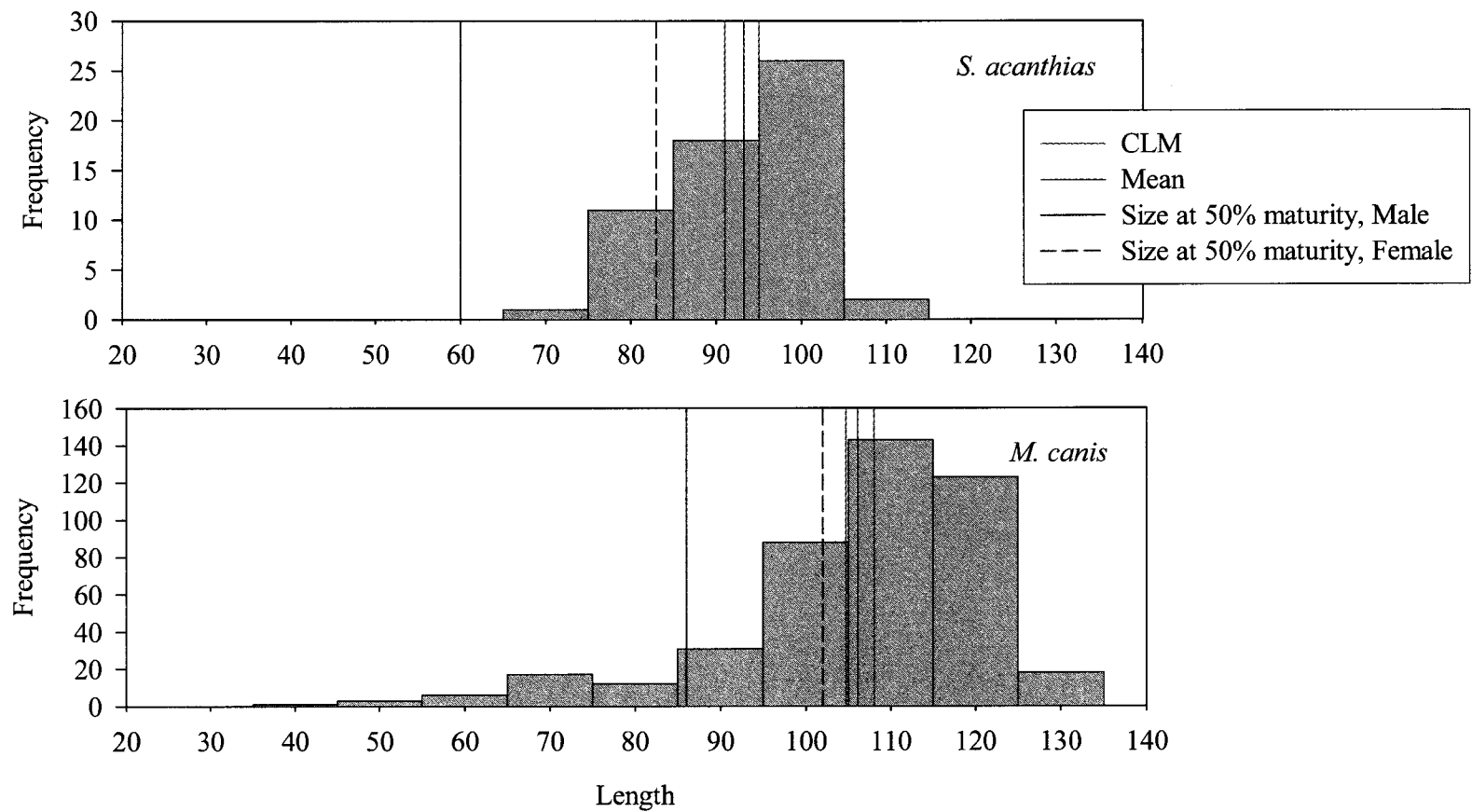


Figure 3.4: Length-frequency histograms in 10 cm TL increments for 2 of the 13 most abundant species in this survey. All species show the mean length (cm TL; red line) and 95% confidence limits of the mean (green lines). The two species not covered by this plan have their size given at 50% maturity by sex. For *M. canis*, Conrath and Musick (2002) was used, while McMillan and Morse (1999) (based on Nammack et al. 1985) was used for *S. acanthias*.

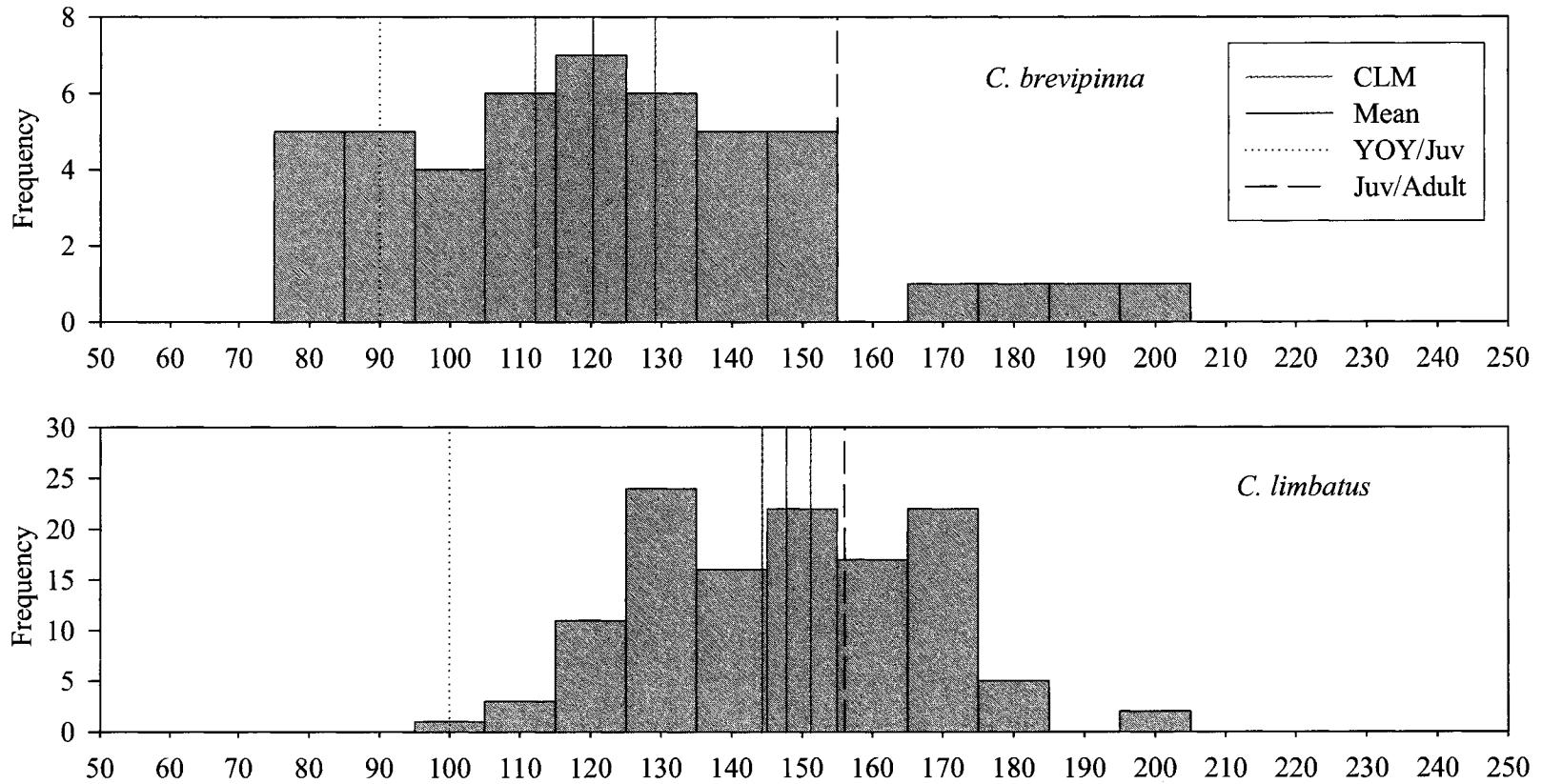


Figure 3.5: Length-frequency histograms in 10 cm TL increments for 2 of the 13 most abundant species in this survey. All species show the mean length (cm TL; red line) and 95% confidence limits of the mean (green lines). All species covered by the NMFS HMS FMP (NMFS 1999) have the NMFS size breaks between young of the year/ early juveniles and late juvenile/subadults and the break between the latter and adults shown.

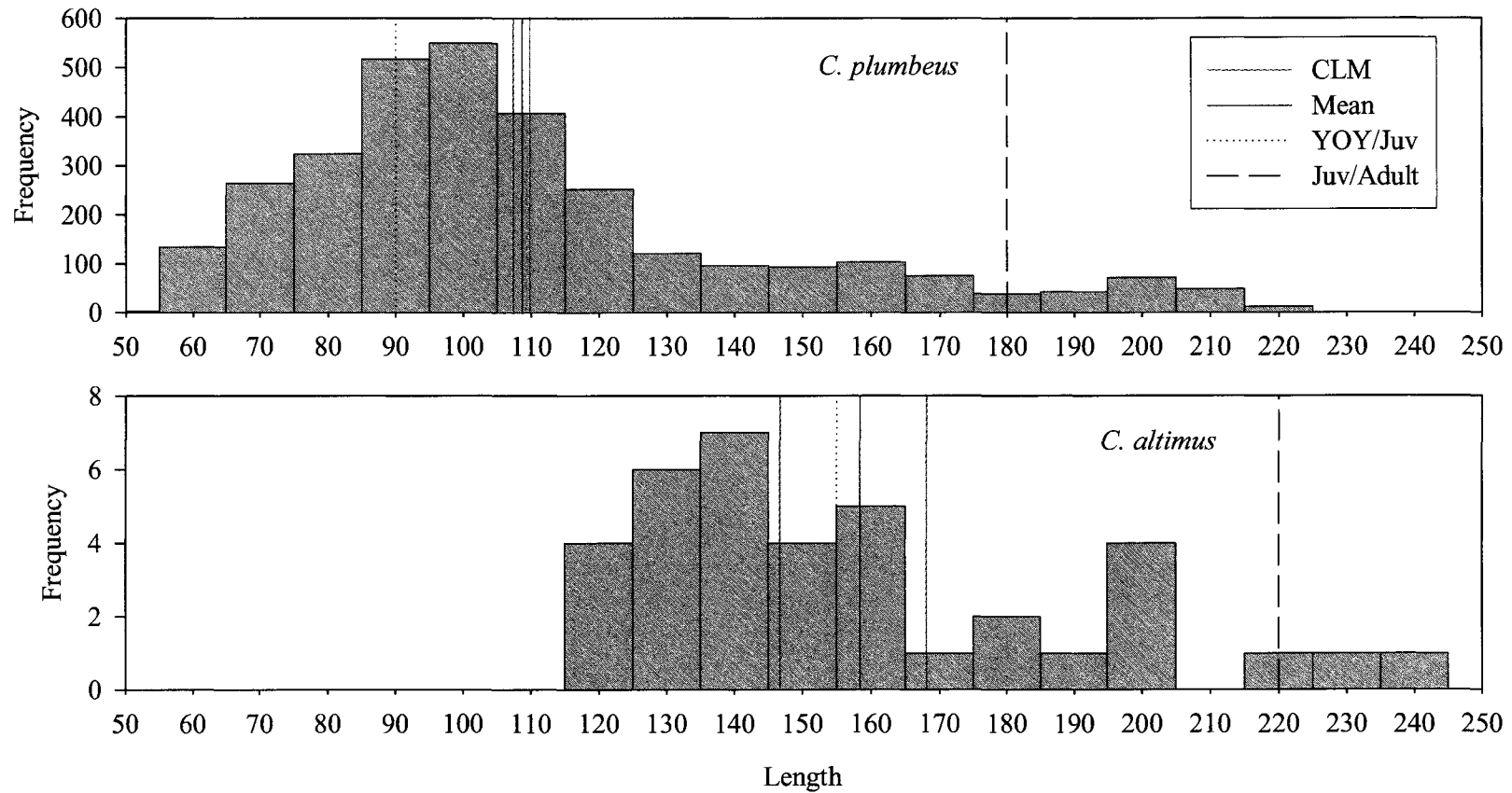


Figure 3.6: Length-frequency histograms in 10 cm TL increments for 2 of the 13 most abundant species in this survey. All species show the mean length (cm TL; red line) and 95% confidence limits of the mean (green lines). All species covered by the NMFS HMS FMP (NMFS 1999) have the NMFS size breaks between young of the year/ early juveniles and late juvenile/subadults and the break between the latter and adults shown.

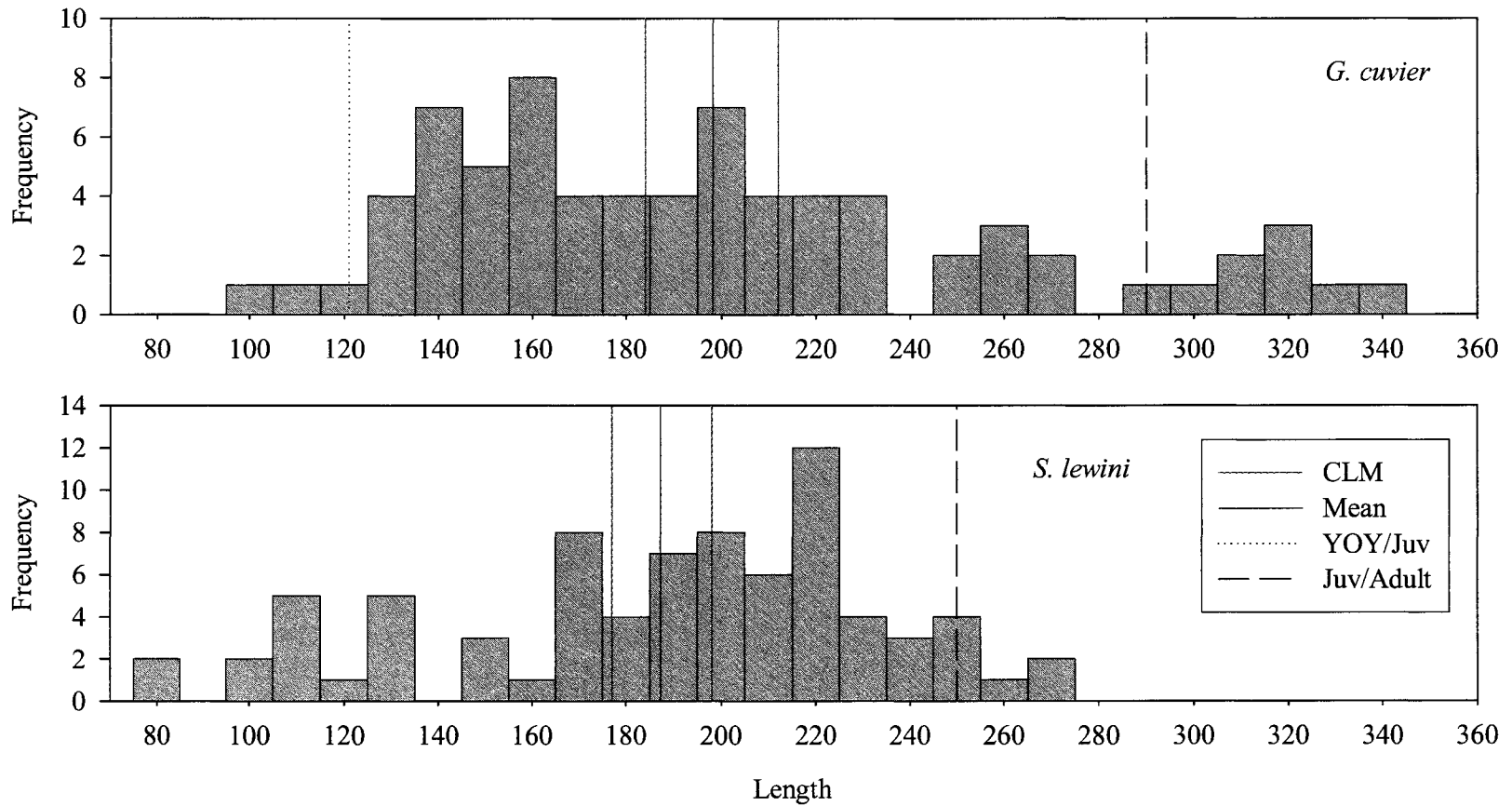


Figure 3.7: Length-frequency histograms in 20 cm TL increments for 2 of the 13 most abundant species in this survey. All species show the mean length (cm TL; red line) and 95% confidence limits of the mean (green lines). All species covered by the NMFS HMS FMP (NMFS 1999) have the NMFS size breaks between young of the year/ early juveniles and late juvenile/subadults and the break between the latter and adults shown.

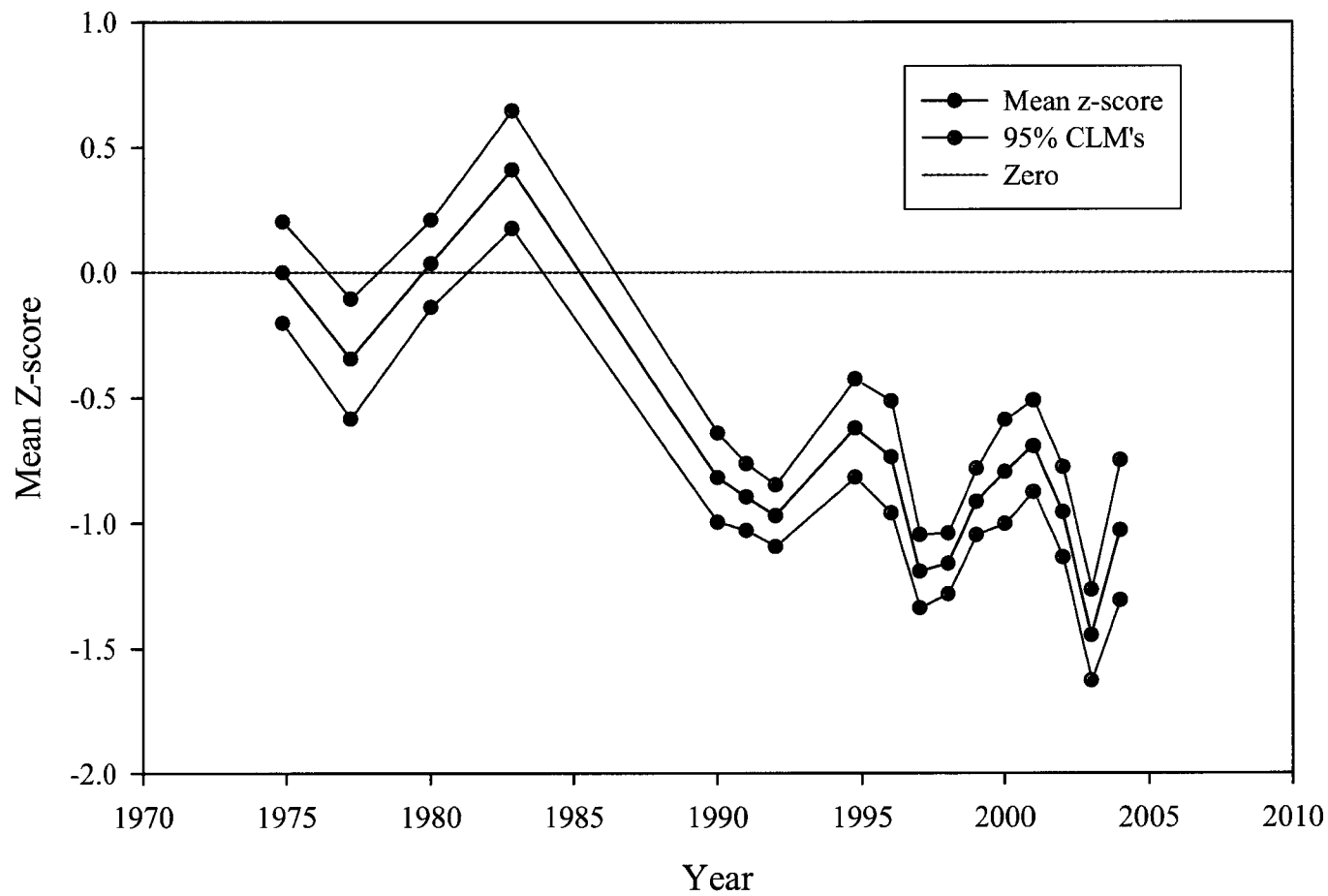


Figure 3.8: Results of z-score transformation analysis of female *C. plumbeus* length data. Black line indicates yearly mean; red lines indicate 95% confidence limits of the means. Green reference line indicates zero, the level which indicates no change in the shape of the size-frequency distribution.

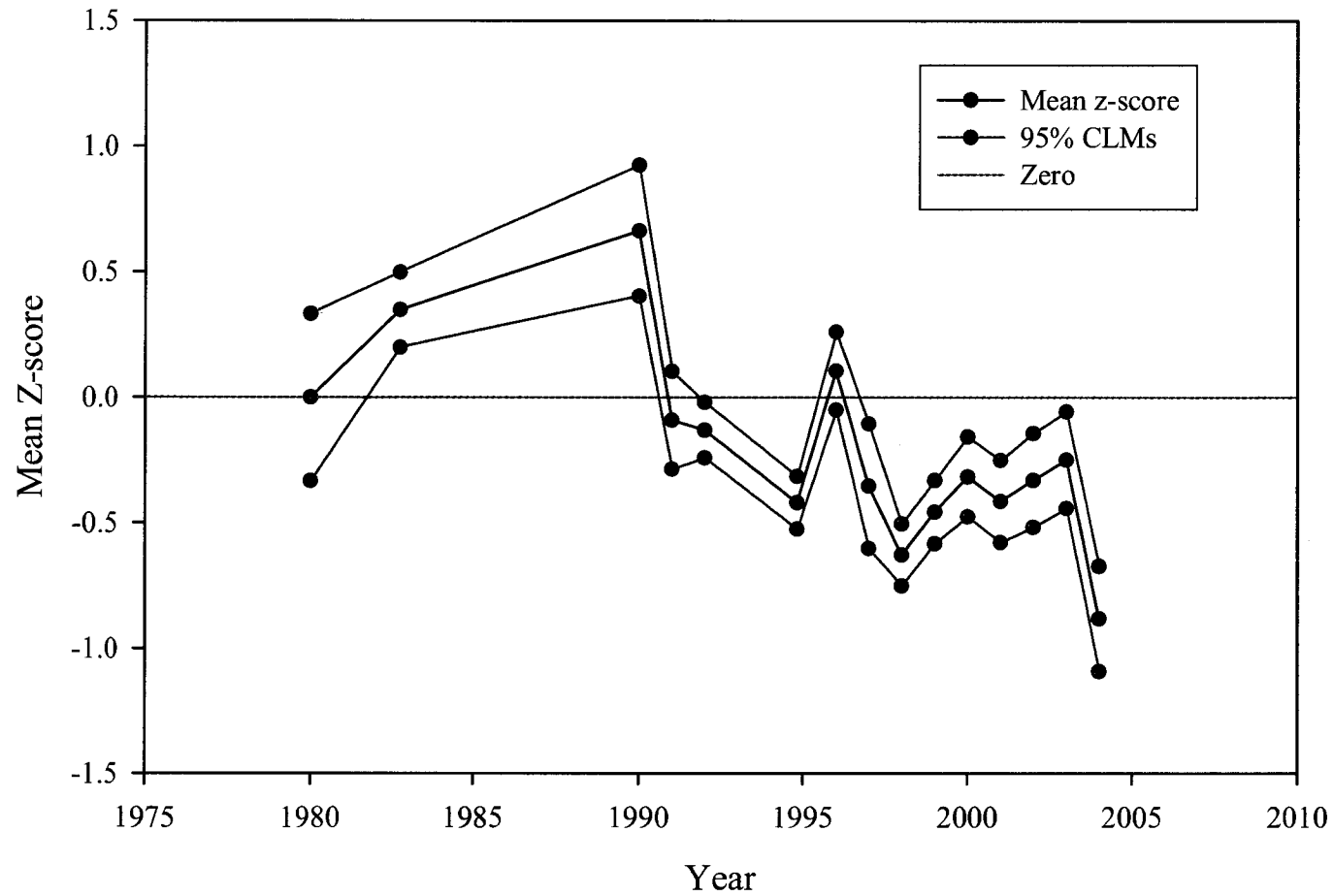


Figure 3.9: Results of z-score transformation analysis of male *C. plumbeus* length data. Black line indicates yearly mean; red lines indicate 95% confidence limits of the means. Green reference line indicates zero, the level which indicates no change in the shape of the size-frequency distribution.

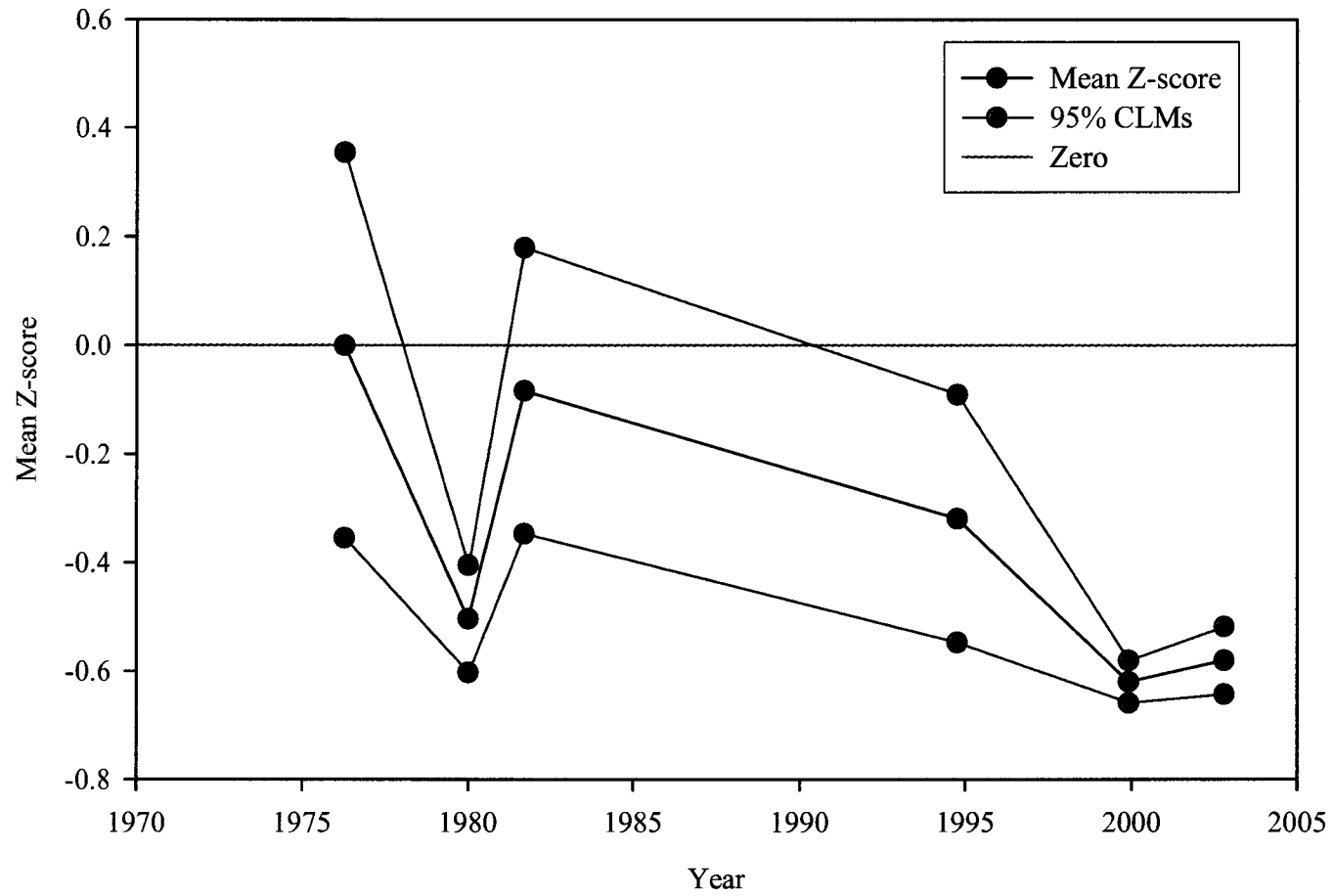


Figure 3.10: Results of z-score transformation analysis of female *C. obscurus* length data. Black line indicates yearly mean; red lines indicate 95% confidence limits of the means. Green reference line indicates zero, the level which indicates no change in the shape of the size-frequency distribution.

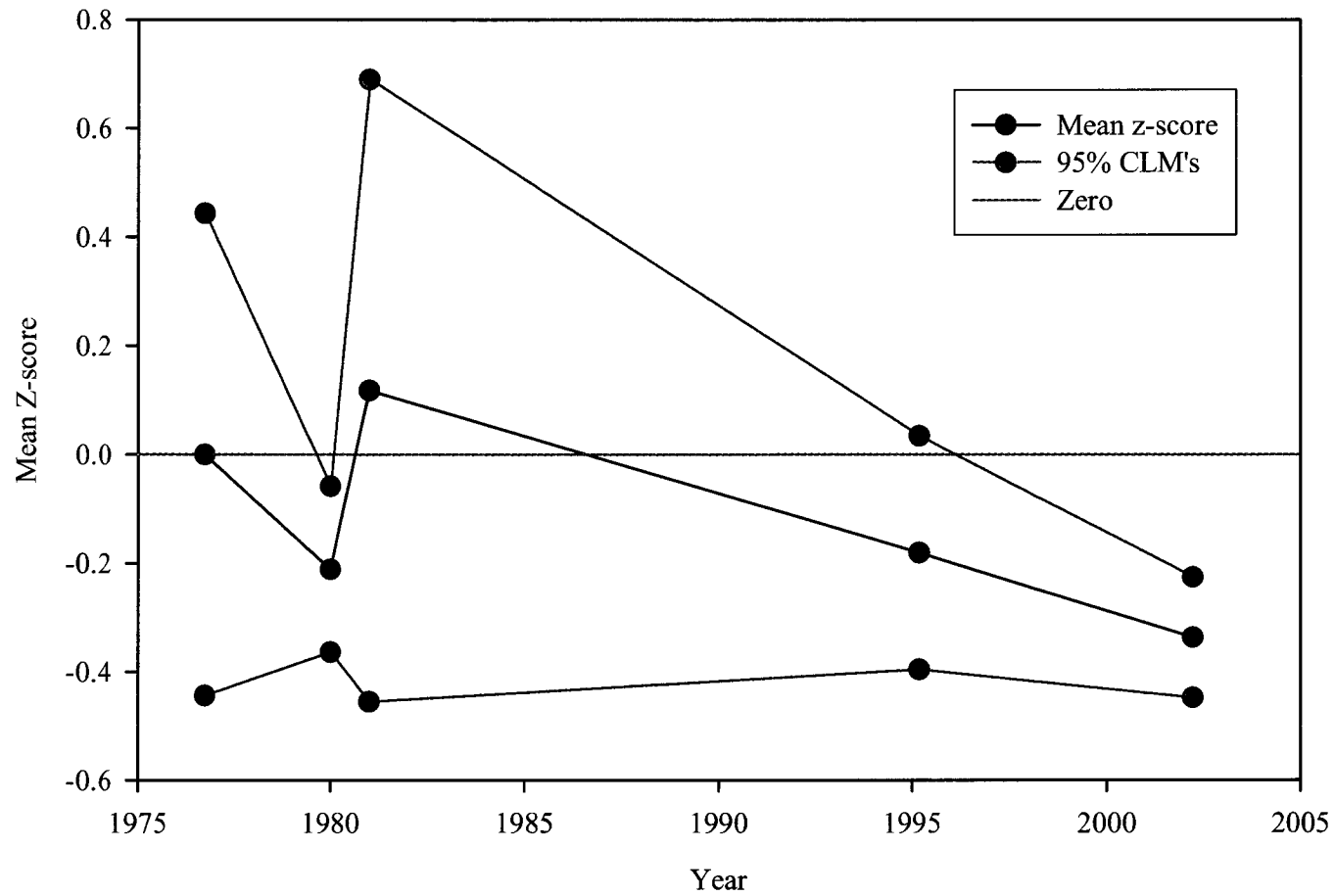


Figure 3.11: Results of z-score transformation analysis of male *C. obscurus* length data. Black line indicates yearly mean; red lines indicate 95% confidence limits of the means. Green reference line indicates zero, the level which indicates no change in the shape of the size-frequency distribution.

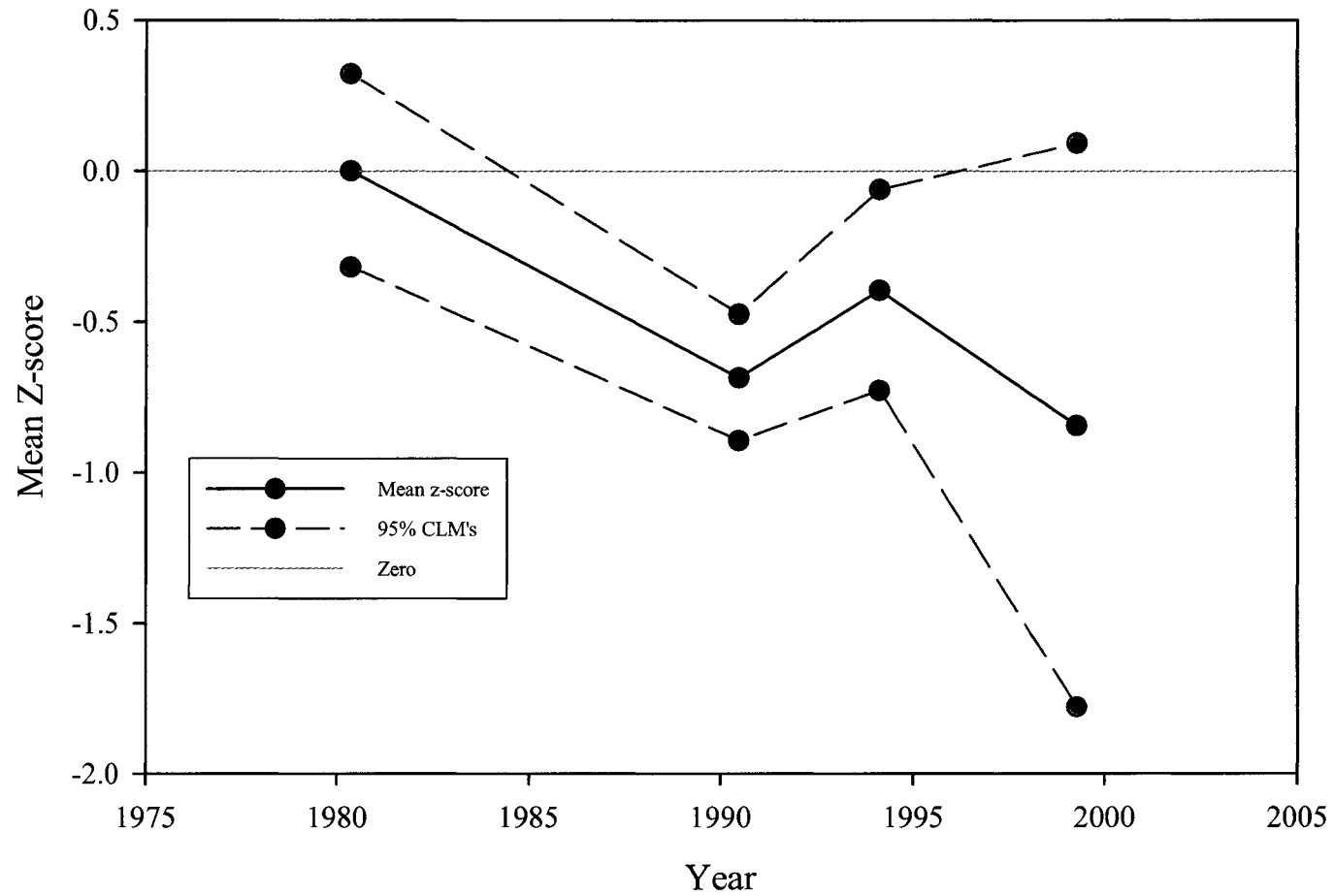


Figure 3.12: Results of z-score transformation analysis of female *R. terraenovae* length data. Black line indicates yearly mean; red lines indicate 95% confidence limits of the means. Green reference line indicates zero, the level which indicates no change in the shape of the size-frequency distribution.

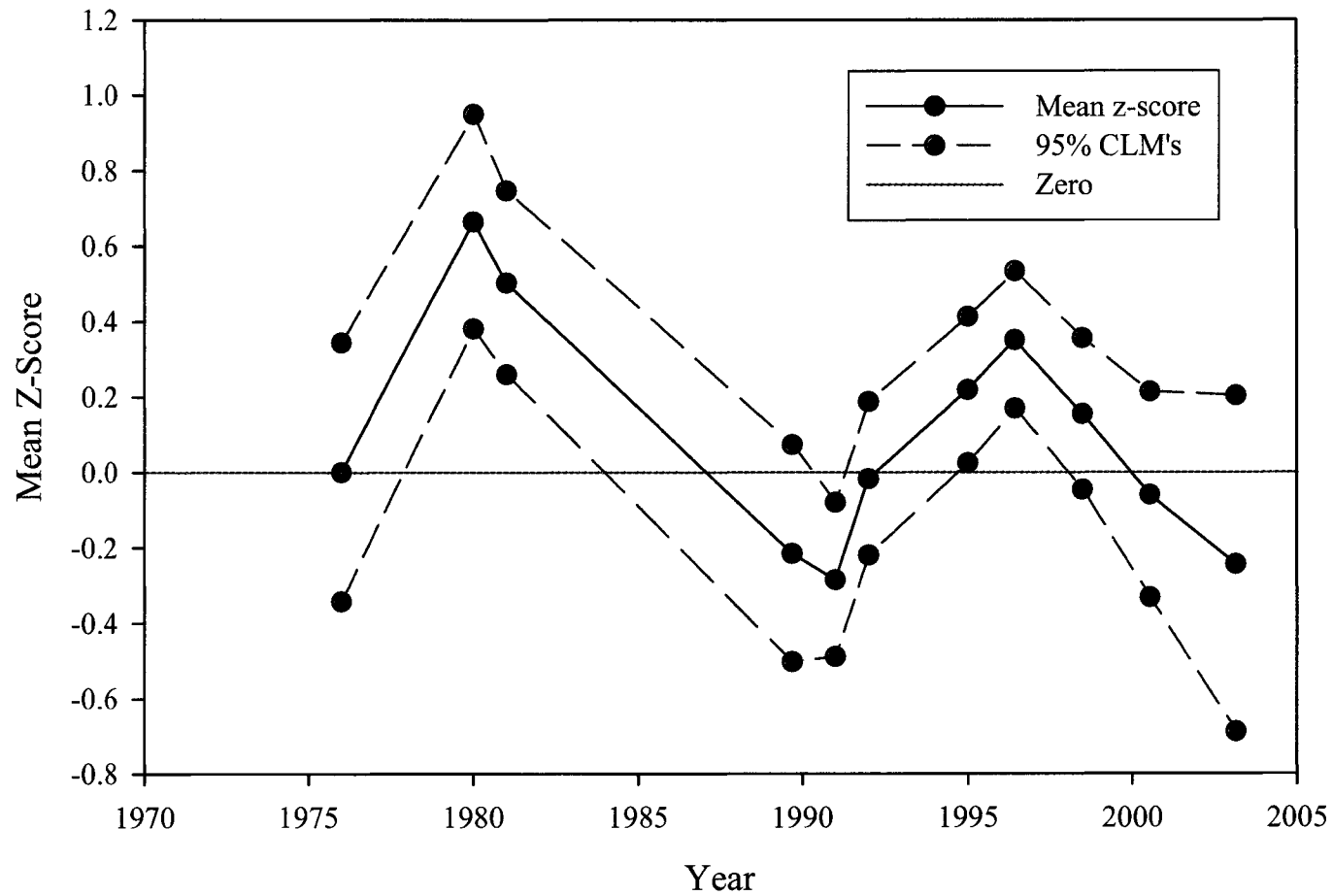


Figure 3.13: Results of z-score transformation analysis of male *R. terraenovae* length data. Black line indicates yearly mean; red lines indicate 95% confidence limits of the means. Green reference line indicates zero, the level which indicates no change in the shape of the size-frequency distribution.

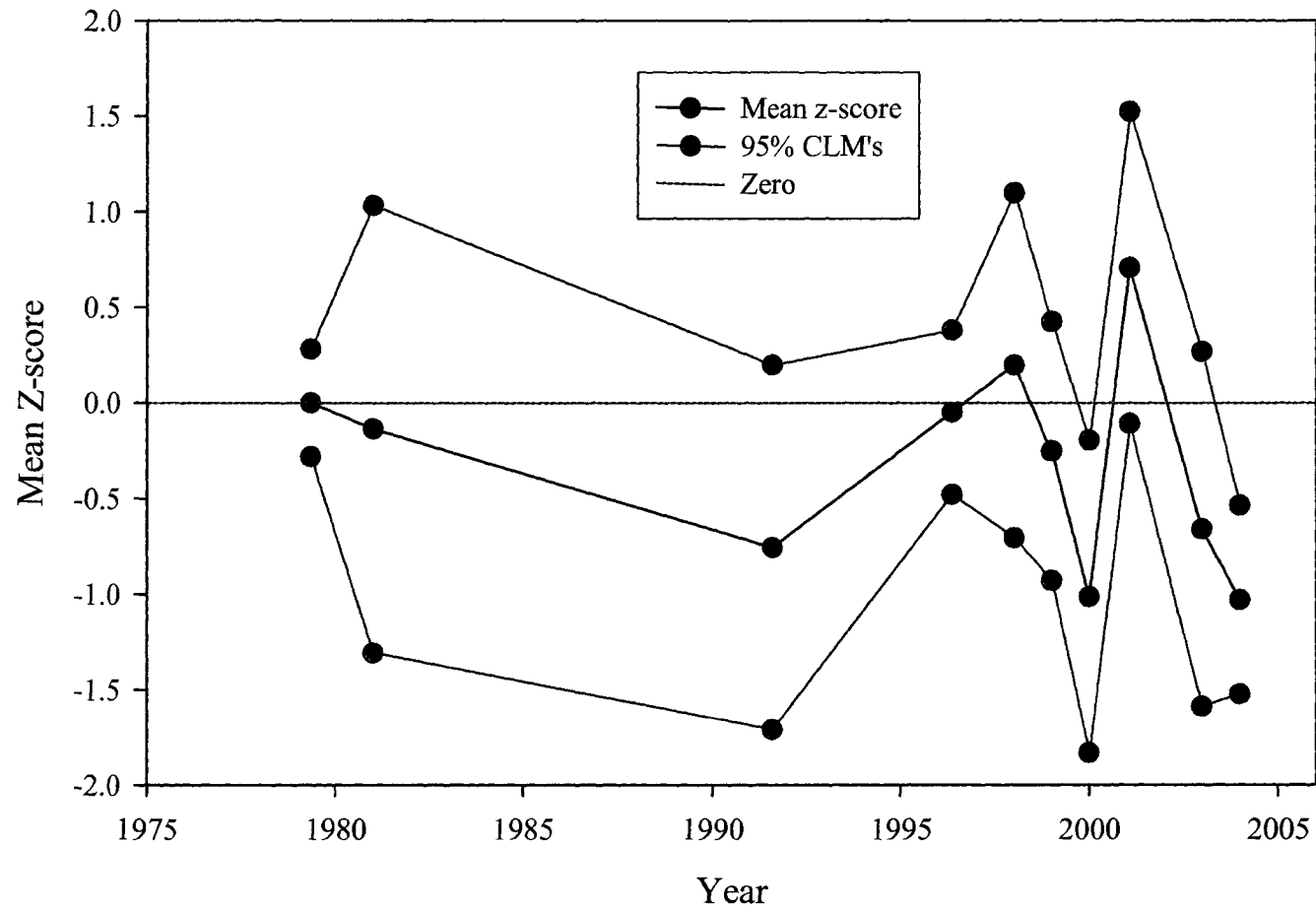


Figure 3.14: Results of z-score transformation analysis of female *M. canis* length data. Black line indicates yearly mean; red lines indicate 95% confidence limits of the means. Blue reference line indicates zero, the level which indicates no change in the shape of the size-frequency distribution.

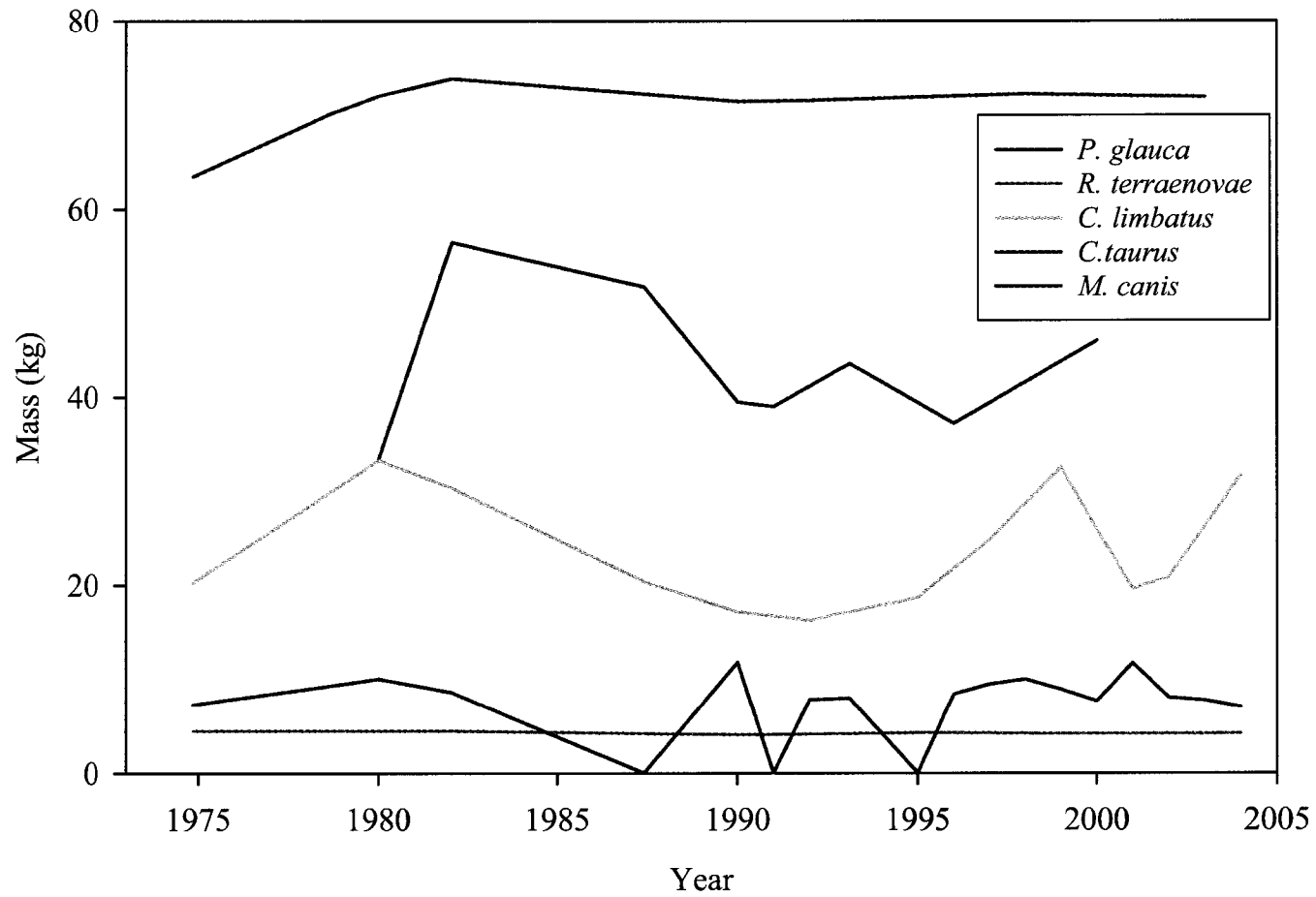


Figure 3.15: Statistically significant trends from a GAM lowess-smoothed model of mass per individual shark over time. This shows the trends in five of the species determined to show no biologically significant trend in mean size per shark.



Figure 3.16: Statistically significant trends from a GAM lowess-smoothed model of mass per individual shark over time. This figure shows the trends in two of the species determined to show biologically significant declining trends in mean size per shark.

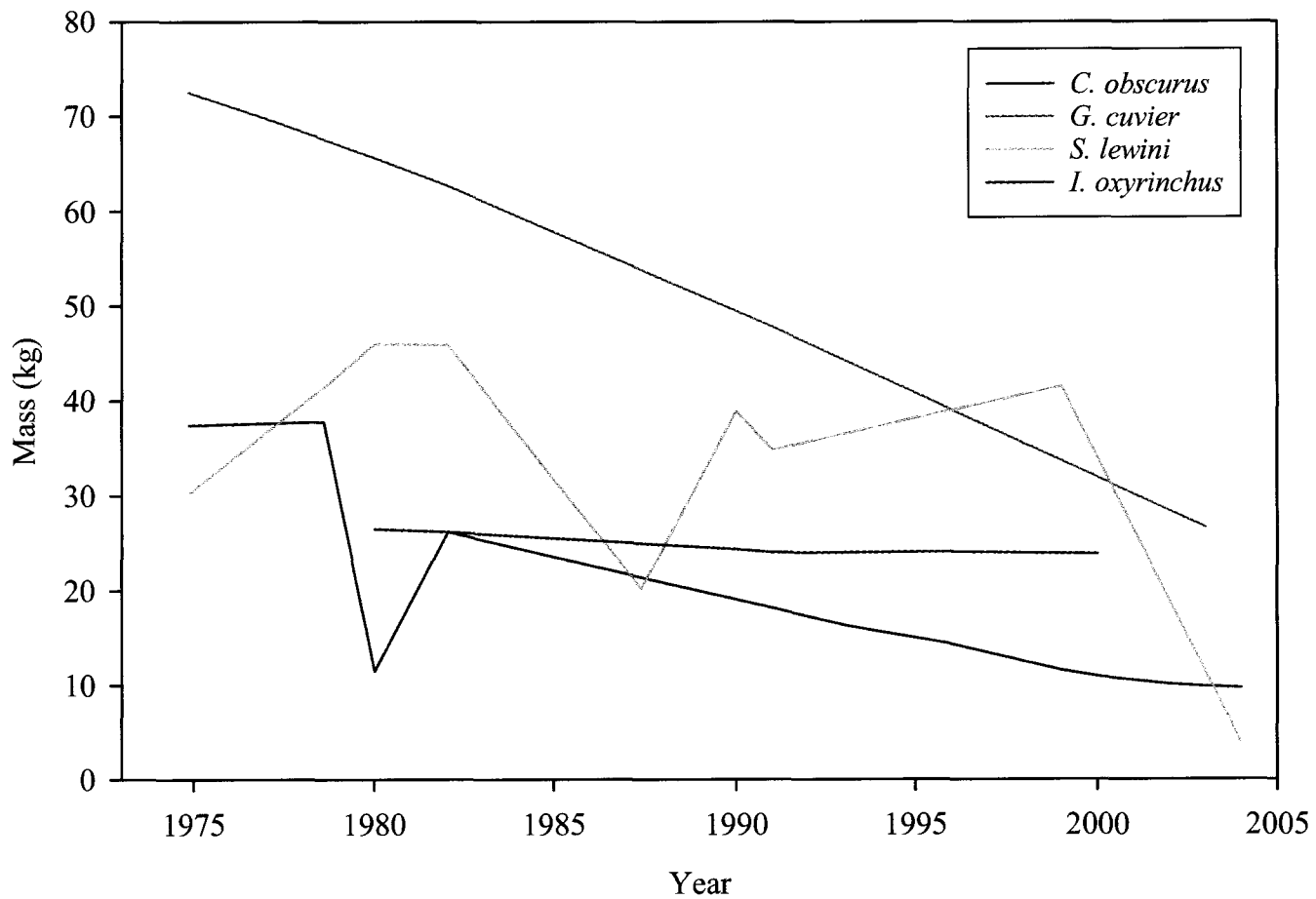


Figure 3.17: Statistically significant trends from a GAM lowess-smoothed model of mass per individual shark over time. This figure shows the trends in three of the species determined to show biologically significant decreasing trends in mean size per shark, and one species showing no significant trend in mean size per shark.

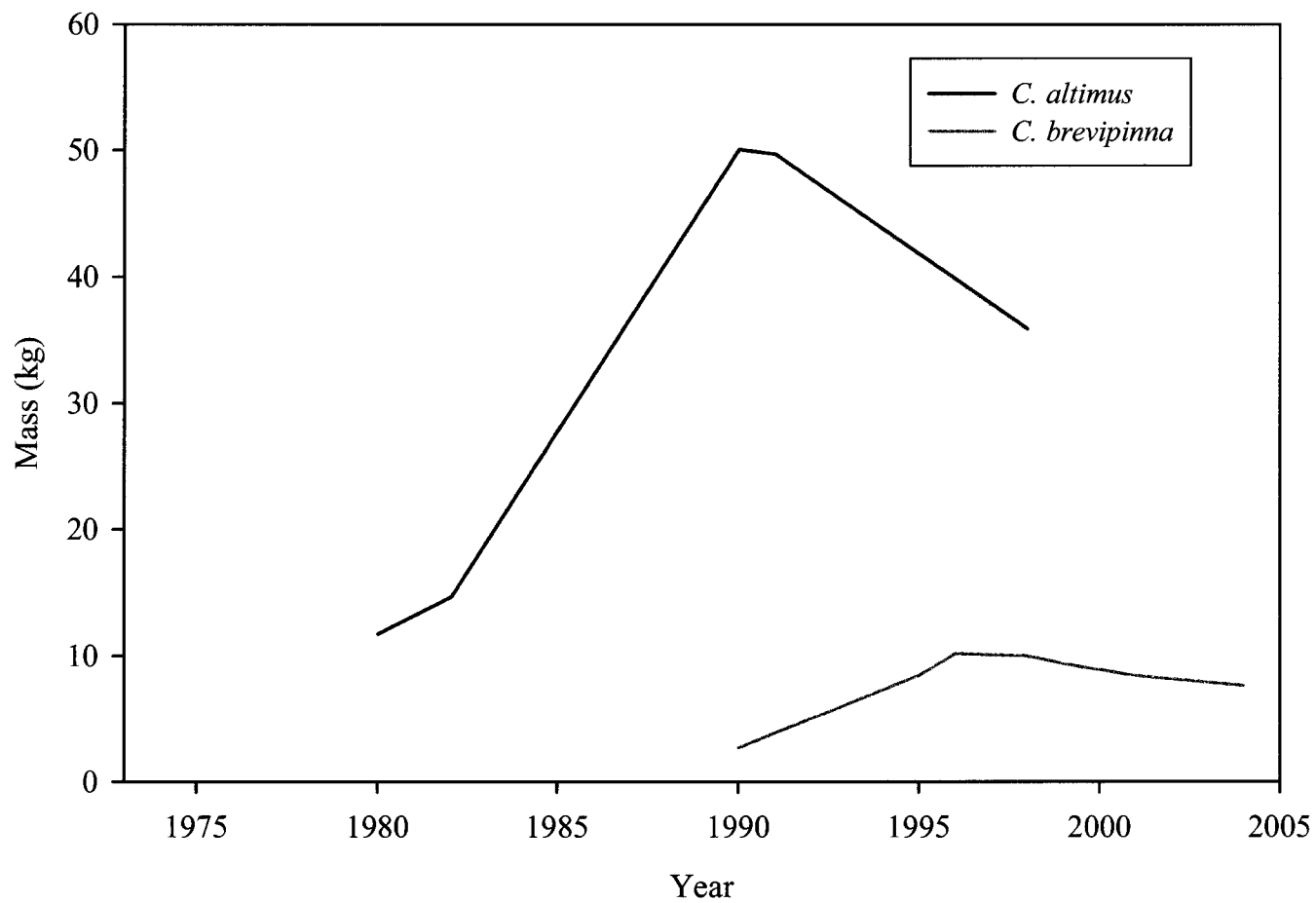


Figure 3.18: Statistically significant trends from a GAM lowess-smoothed model of mass per individual shark over time. This figure shows the trends in the two species determined to show a biologically significant increasing trend in mean size per shark.

Chapter 4: Habitat Utilization

Elasmobranchs in general and sharks in particular have become increasingly a target of fisheries since the Second World War (Musick et al. 1993, Bonfil 1994, Castro et al. 1999, Baum et al. 2003). Elasmobranchs have also become increasingly threatened due to bycatch in other fisheries, which has also increased (Bonfil 1994, Camhi et al. 1998). Hoff and Musick (1990) surveyed western North Atlantic shark fisheries and documented a rapid expansion of these fisheries during the 1980's, as well as increased bycatch as a result of increasing swordfish and tuna fisheries. Baum et al. (2003) analyzed eight shark species/groups taken as bycatch in the oceanic long-line fishery in the northwest Atlantic ocean, and suggested that all species/groups except makos have declined more than 50% in the past 8-15 years.

Musick et al. (1993) examined the VIMS survey dataset to the 1991 season, and, in addition to analyzing the whole dataset, separated it by species, by depth strata, by month, and by size categories for common species. Marked declines in catch per unit effort (CPUE) were found in four of the six most commonly caught shark species, *C. plumbeus*, *C. obscurus*, *C. taurus*, and *G. cuvier*. All species of elasmobranchs in the US fall under the jurisdiction of the NMFS, which was asked by the regional fisheries management councils to develop a shark fishery management plan (FMP), under the authority of the Magnuson Stevens Fishery Conservation and Management Act. The

NMFS conducted a LCS stock assessment published in 1996 that led to rulings to reduce the commercial and recreational catch, and to establish a prohibited species list that included the whale shark, *Rhincodon typus*, the basking shark, *Cetorhinus maximus*, the sand tiger shark, *Carcharias taurus*, the bigeye sand tiger shark, *Odontaspis noronhai*, and the white shark, *Carcharodon carcharias* (NMFS 1996). The 2002 SCS and LCS stock assessments provided more recent information on the status of shark species classed as LCS and SCS, and showed that the LCS complex was in better condition than in 1998, but that it was overfished and that overfishing was occurring.

One of the mandates of the Magnuson-Stevens Act is identification of “Essential Fish Habitat” (EFH) for all species regulated by a fisheries management plan. It defines EFH as “...those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity.” (NMFS 2003). Identification of such habitats is difficult for any fish species, but is even more challenging for highly mobile species like most sharks. For this reason, there is a need for much more work to define EFH for sharks (NMFS 2003). One aspect of this chapter is to examine the long-line data set for patterns that may help contribute to our knowledge of EFH for the shark species caught in Virginia waters.

In addition to trying to define EFH for these species, this chapter also examines effects of climate variation on these species. Many fish species have been found to be affected by year-to-year or decadal scale changes in the earth’s climate, and effects of such oscillations in the Pacific are well studied (Beamish et al., 1999; Mantua et al., 1997). In the Pacific, the El Nino Southern Oscillation is the best known of these, but others include the Pacific Decadal Oscillation. In the Atlantic, the North Atlantic

Oscillation (NAO) is a recurring pressure pattern in the North Atlantic Ocean affecting weather in both Europe and North America (Hurrell, 1995). The NAO is commonly defined by the difference in sea-level pressure between Iceland and the Azores; more specifically, the difference in sea level pressure between Stykkisholmur, Iceland, and Ponta Delgada in the Azore Islands.

Other climate variables analyzed in this study are variations over a larger spatial scale than the environmental data gathered with each set, such as depth and water temperature. These variables include Chesapeake Bay water discharge (cubic feet per second), and the Palmer Drought Severity Index (PDSI) (known operationally as the Palmer Drought Index (PDI)), which attempts to measure the duration and intensity of the long-term drought-inducing circulation patterns. Long-term drought is cumulative, so the intensity of drought during the current month is dependent on the current weather patterns plus the cumulative patterns of previous months. Since weather patterns can change abruptly from a long-term drought pattern to a long-term wet pattern, the PDI can respond fairly rapidly (NCDC, 2006a). For the PDI, negative numbers indicate drought conditions, zero indicates average conditions, and positive indicates wet conditions. Palmer Drought Index values of 0 to -0.5 indicate normal moisture conditions; -0.5 to -1.0 indicate incipient drought conditions; -1.0 to -2.0 indicate mild drought; -2.0 to -3.0 indicate moderate drought; -3.0 to -4.0 indicate severe drought; and greater than -4.0 indicate extreme drought conditions (NOAA, 1994).

Research in the Atlantic has documented the effects of such climate variation on many stocks of fish and shellfish. These include stocks such as Skagerrak cod (a stock of

the Atlantic cod, *Gadus morhua*; Levke et al., 2002), North Sea horse mackerel (*Trachurus trachurus*; Reid et al., 2001), juvenile fishes in the Thames River estuary (Attrill and Power, 2002). A summary paper by Parsons and Lear (2001) discusses the trends in Northeast Atlantic gadoids (*G. morhua*, haddock, *Melanogrammus aeglefinus*, whiting, *Merlangius merlangius* and saithe, *Pollachius virens*) and herring (Atlantic herring, *Clupea harengus* and sardine, *Sardinia pilchardus*), and Northwest Atlantic cod and shellfish (lobster, *Homarus americanus*, snow crab, *Cnionoecetes opilio*, and Northern or pink shrimp, *Pandalus borealis*).

In Virginia and the Chesapeake Bay, data suggest that several marine species have experienced effects of climate changes, including oysters (*Crassostrea virginica*), juvenile finfishes, and blue crabs (*Callinectes sapidus*) (Austin 2002). Austin (2002) showed effects of a combined index (the Chesapeake Bay Index or CBI) that included water temperature, NAO index, and Chesapeake Bay discharge on several species groups. Conditions in the Bay following Tropical Storm Agnes in 1972 led to lowered indices of abundance of bay-spawning species (including bay anchovy, *Anchoa mitchilli*; oysters; weakfish, *Cynoscion regalis*; and blue crabs). A regime shift around 1977 was also found, in which the CBI reversed its pattern of low index values that had begun following Agnes. Following this shift, the indices of abundance of river dependent species (such as striped bass), and Bay mouth and shelf spawning species (such as Atlantic croaker and flounder) also increased. These results show a positive correlation between the CBI and indices of most Chesapeake Bay marine species.

Methods

This chapter uses two different methods to examine the VIMS long-line data for correlations between environmental variables and shark CPUE, as measured by CPUE. Also included in these analyses are several indicators of large-scale environmental factors, such as river discharge (USGS, 2006), drought levels (Center, 2006; NCDC, 2006b), and the magnitude of the North Atlantic Oscillation (NAO) (Hurrell, 2006).

Not all species and species groups analyzed in Chapter 2 were analyzed in this chapter. Low proportions of male *C. plumbeus* led to the removal of the sub-groups of male and female *C. plumbeus* from this analysis. In addition, since environmental correlations are likely species-specific, the NMFS management groups were not included in these analyses.

GLM Modelling

All stations sampled with the standard long-line gear were used, and only catches on standard gangions were included. Statistical transformation of the data was necessary as outlined in Chapter 2. Any species or group that passed the normality criterion were analyzed with PROC GLMSELECT using the SAS statistical package (SAS, 2002). For those that failed the criterion, logistic regression analysis was performed.

In order to find the model best able to account for CPUE and to remove the effects of correlated independent variables, a stepwise statistical model, based on

information rather than significance, was used. The stepwise procedure used the same main model, which included all main effects and those first order interaction effects most likely to occur, for each species/ species group analyzed. While the variables year, latitude and longitude were included in the model, they were not the focus of this chapter as they are not environmental variables. They were included only as covariates, in order to remove any interaction effects they may have had with environmental variables.

The stepwise selection procedure was run using the corrected Akaike's Information Criterion (AICc) as the information criterion best suited to this type of analysis (Burnham and Anderson 2002) for addition and removal from the model, as well as the end criterion. In order to preserve the hierarchical nature of the models, all interaction terms could only be added to the model once both the main effects they included qualified for inclusion in the model (Quinn and Keough 2002). After the initial stepwise procedure for each species, outliers were removed based on the Cook's D statistic, and those observations that exceeded $p=0.05$ were deleted (McCullagh and Nedler 1999). The same selection procedure was re-performed with the outliers removed (if necessary), and the resulting model was used as the final model for each species/species group. The main model for this analysis took the form:

$$\eta_i = \beta_0 + \left(\sum_{j=1}^p \beta_j X_{ij} \right) + \varepsilon_i \quad 4.1$$

With η_i being the value of the response variable for the i^{th} observation, β_0 the intercept, β_j the regression coefficient for the j^{th} predictor variable, X_{ij} the value of the predictor

variable j for the i^{th} observation, and ε_i the error term. There are p total predictor variables, and these are listed in Tables 1 and 2 .

As mentioned in Chapter 1, additional environmental parameters (which include surface and bottom salinity and dissolved oxygen) have been recorded for each long-line set since 1995. The shorter time span of these variables led to their being included in a second stepwise GLM (short-scale), based on the first (long-scale). All species and species sub-groups analyzed in the long-scale GLM (Table 4.1) were analyzed in the short-scale GLM (Table 4.2). The second main model was arrived by adding the new independent variables and selected first-order interactions to the main model used above, with the variables NAO, PDI, and river discharge and their interactions removed. The analyses then proceeded as described above.

The predicted values from both models were lowess-smoothed for each of the significant main effects observed using generalized cross-validation to determine the smoothing parameter (SAS, 2002). Species/variable combinations that were not able to meet the requirements of lowess smoothing were plotted as linear regressions.

Non-normalized species

The CPUE for each of these species with a total sample size over five was transformed by changing all positive catches into ones, and analyzed with a logistic model (SAS, 2002). Since the sample sizes of these species were uniformly low, the model fit included only main effects with no interactions. For each species, the full model was run initially, the least significant effect was removed, and the process was

repeated until all effects remaining were significant at the $p=0.05$ level. For each species with a sample size of five or above since 1995, the short-scale environmental parameters (main effects only) were added to the final model obtained above, and non-significant effects removed as above until all remaining effects were significant.

Tests for environmental selection by sharks

In order to conclusively state that sharks preferred certain environmental conditions, it was necessary to test whether the sharks were found in certain environmental conditions non-randomly. To do this, it was necessary to test whether a species' CPUE across levels of an environmental variable (like depth) was significantly different than the CPUEs one would expect based on the amount of effort expended in each level. One way of showing this is via electivity analysis, commonly used in feeding studies (Diggins et al., 1979; Scarlett and Smith, 1991).

The continuous independent variables had to be categorized in order to perform electivity analysis. Depth was categorized into the same categories used in Musick et al. (1993), which are <10m depth, 10-20 m depth, and >20m depth. All other independent variables were split into even intervals so that there were approximately five categories for each variable. The patterns for each independent variable were tested for statistical significance using a X^2 goodness-of-fit test.

The electivity index, e , was calculated from the formula $e=(r-p)/(r+p)$, where r is the % catch of the shark in a level of an environmental variable, and p is the % of total effort expended in that level. A negative value for e indicates avoidance, and vice-versa,

while a value of zero indicates no preference. A value of 1 indicates total preference, and a value of -1 indicates total avoidance. This was done for 5 environmental variables present in the data set.

A χ^2 goodness of-fit test compared the distribution of the catch amongst the levels of a variable against the distribution of effort amongst the levels of that variable. The formula used was of the form $(O-E)^2/E$, where O is the observed value for a level (number of sharks), and E, the expected value, is the proportion of the total effort expended at that level times the total number of sharks of that species caught. This was summed over all levels of the variable, and the χ^2 value compared to a χ^2 distribution for the number-of-levels-minus-1 degrees of freedom. This was done for all species with a total sample size greater than 30 for month and depth, and all species with a total sample size greater than 130 for surface and bottom temperature, salinity, and dissolved oxygen (Microsoft, 2000).

Results

The GLM model was usable for four species and the three age groups of *C. plumbeus* (Table 4.3). The results of the first (long-scale) GLM models show that latitude and bottom temperature were most common independent variables included in the models and found to have a significant effect, but all other variables except PDI were significant for at least one species or species group (Table 4.4; Figures 4.1-4.9). The results of the second models show that bottom salinity and surface salinity were most often included in the model and significant, while bottom dO was never (Table 4.5;

Figures 4.10-4.12).

Four species were not present in sufficient sample sizes to be included in the logistic analysis (Table 4.6). Of the thirteen analyzed with the first model, six were not present in sufficient sample sizes to be analyzed with the second, more limited, model (Table 4.6). Several variables were not found to have significant effects on species CPUE through the logistic models, however, most species did show correlations with an environmental variable (Table 4.6; Figures 4.13-4.18). The results of the logistic analyses show that depth and surface temperature were most often significant (Table 4.7). Results of X^2 goodness-of-fit tests show significant effects in many cases (Table 4.8). Each variable tested was split into four to six categories (Table 4.9). In the following summary of these results, the depth category of “Bay,” includes all Chesapeake Bay waters, while any depth category mentioned by a number refers to stations outside the Bay only. In reading the following results, it is also important to note that the data are all categorical, and hence less precise than results from either GLM or logistic regression analyses. In most cases, species fell into groups according to their electivity distributions for each independent variable (Figures 4.19-4.27).

C. plumbeus Young-of-year

Young-of-year *C. plumbeus* showed an increase in CPUE with increasing latitude (Figure 4.1), and were most common at stations with higher bottom temperatures (Figure 4.7). The NAO index had a significant effect on young-of-year *C. plumbeus* with CPUEs

higher at stations with lower values of the index (Figure 4.9). In the second analysis, young-of-year *C. plumbeus* were most commonly caught at stations with surface salinities above 25 ppt (Figure 4.10).

Electivity analyses showed young-of-year *C. plumbeus* had higher CPUEs in Chesapeake Bay waters (Figure 4.19), and in late summer months, peaking in August (Figure 4.21). This group was also more abundant in surface and bottom temperatures over 22.5 °C (Figures 4.23 and 4.25). Young-of-year *C. plumbeus* had higher CPUEs in lower surface and bottom salinities, below 27.5 ppt (Figures 4.26 and 4.27).

C. plumbeus Juveniles

Juvenile *C. plumbeus* showed an decreasing trend with depth (Figure 4.3), and had highest CPUEs at stations with higher bottom temperatures (Figure 4.7). In the second analysis, juvenile *C. plumbeus* had highest CPUEs at stations with bottom salinities between 25 and 30 ppt (Figure 4.11).

In electivity analyses, juvenile *C. plumbeus* had higher CPUEs in Chesapeake Bay waters (Figure 4.19), and showed a slight increase in CPUE in summer months, with a slight dip in late summer (August) (Figure 4.22). This group was more abundant in surface temperatures over 22.5 °C, peaking in the 27.5-32.5 °C category (Figure 4.23). Juvenile *C. plumbeus* had higher CPUEs in lower surface salinities, below 27.5 ppt (Figure 4.26), and higher CPUEs in bottom salinities between 22.5 and 32.5 ppt (Figure 4.27).

C. plumbeus Adults

Adult *C. plumbeus* were most commonly caught at mid-latitudes (of those represented in this study; Figure 4.2). They showed a slight increasing trend with depth (Figure 4.3), and a significantly bimodal pattern in month, with highest CPUEs in June and September (Figure 4.5). In addition, this species showed highest CPUEs at bottom temperatures between 17 and 22 °C (Figure 4.7). In the second analysis, adult *C. plumbeus* were most commonly caught at stations with surface salinities above 25 ppt (Figure 4.10).

In electivity analyses, adult *C. plumbeus* had higher CPUEs in waters deeper than 20m (Figure 4.19), and showed two peaks in CPUE, one in June and one in September (Figure 4.22). Adult *C. plumbeus* had higher CPUEs in surface temperatures in the 17.5 °C to 27.5 °C range (Figure 4.23), and higher CPUEs in bottom temperatures between 12.5 °C and 22.5 °C (Figure 4.24). They also had higher CPUEs in high surface and bottom salinities, above 27.5 ppt (Figures 4.26 and 4.27).

C. obscurus

Carcharhinus obscurus CPUE decreased with increasing latitude (Figure 4.1), and showed some increase with higher Chesapeake Bay discharge (Figure 4.8). The NAO index had a significant effect on *C. obscurus*, with CPUEs higher at stations with lower values of the index (Figure 4.9). In the second analysis, *C. obscurus* had highest CPUEs at stations with higher bottom salinities, above 32 ppt (Figure 4.11).

In electivity analyses, *C. obscurus* had higher CPUEs in waters 10-20 meters deep

(Figure 4.20). *Carcharhinus obscurus* showed higher CPUEs in surface and bottom temperatures in the 17.5-22.5 °C range (Figure 4.23 and 4.24). This species also had higher CPUEs in high surface and bottom salinities, above 30 ppt (Figures 4.26 and 4.27).

R. terraenovae

The pattern in *R. terraenovae* CPUE with latitude was difficult to interpret (Figure 4.1). *Rhizoprionodon terraenovae* showed highest CPUEs in the summer months (Figure 4.4), and was most commonly caught at stations with bottom temperatures between 15 and 22 °C (Figure 4.7). In the second analysis, *R. terraenovae* were caught most often at bottom salinities between 30 and 34 ppt (Figure 4.11).

In electivity analyses, *R. terraenovae* had higher CPUEs in waters 10-20 meters deep (Figure 4.20), and had higher CPUEs in late summer months, peaking in August (Figure 4.21). This species also had higher CPUEs in surface temperatures between 22.5 and 27.5 °C (Figure 4.23), and in bottom temperatures between 17.5 °C and 22.5 °C (Figure 4.24). They showed higher CPUEs in higher surface and bottom salinities, above 27.5 ppt (Figures 4.26 and 4.27).

M. canis

M. canis showed higher CPUEs in May than other months (Figure 4.4), and highest CPUEs with low surface temperatures (Figure 4.6). In the second analysis, *M. canis* had highest CPUEs at stations with higher bottom salinities, above 32 ppt (Figure

4.11), and was most commonly caught at stations with surface dO between 9 and 10 mg/L (Figure 4.12).

In electivity analyses *M. canis* had higher CPUEs in waters 10-20 meters deep (Figure 4.20), and higher CPUEs in late spring (May) (Figure 4.22). Further, *M. canis* had higher CPUEs in surface and bottom temperatures below 17.5 °C (Figures 4.23 and 4.25). This species also had higher CPUEs in high surface and bottom salinities, above 27.5 ppt (Figures 4.26 and 4.27).

C. taurus

Carcharias taurus CPUEs decreased with increasing latitude (Figure 4.2), and showed an decreasing trend with depth (Figure 4.3). *C. taurus* was more abundant in waters under 20 m deep outside the Chesapeake Bay (Figure 4.19).

In electivity analyses, *C. taurus* had two peaks in CPUE, one in June and one in September (Figure 4.22). *C. taurus* had higher CPUEs in surface temperatures between 12.5 and 22.5 °C (Figure 4.23), and in bottom temperatures between 12.5 and 17.5 °C (Figure 4.24). *Carcharias taurus* had higher CPUEs in high surface and bottom salinities, above 27.5 ppt (Figures 4.26 and 4.27).

Other species

N. brevirostris was more likely to be caught at stations with maximum depths less than 10 m (Figure 4.13), and at stations with warmer surface temperature waters, above 25 °C (Figure 4.15). *C. leucas* was more likely to be caught at stations with maximum

depths less than 10 m (Figure 4.13). *C. falciformis* was more likely to be caught at stations with maximum depths greater than 180 m (Figure 4.14). *A. vulpinus* were most likely to be caught at stations with cooler bottom temperature waters, below 14 °C (Figure 4.17).

From logistic analyses, *Isurus oxyrinchus* was more likely to be caught at stations with maximum depths greater than 180 m (Figure 4.14). Electivity analyses for this species showed higher CPUEs in waters deeper than 20m (Figure 4.19). From logistic analysis, *P. glauca* was more likely to be caught at stations with maximum depths greater than 180 m (Figure 4.14), and at stations with cooler surface temperature waters, below 17 °C (Figure 4.16). Electivity analysis of this species found they had higher CPUEs in waters deeper than 20m (Figure 4.19), and higher CPUEs in late spring (May) (Figure 4.22).

Logistic analysis showed that *C. limbatus* were more likely to be caught at stations with warmer surface temperature waters, above 25 °C (Figure 4.15), and an equivocal trend in CPUE with bottom salinity (Figure 4.17). Electivity analysis showed that *C. limbatus* were more abundant in waters under 20 m deep outside the Chesapeake Bay (Figure 4.19). Further, *C. limbatus* had higher CPUEs in surface temperatures over 22.5 °C (Figure 4.23), and had higher CPUEs in bottom temperatures between 17.5 and 27.5 °C (Figure 4.24). *Carcharhinus limbatus* had higher CPUEs in surface salinities between 27.5 and 32.5 ppt (Figure 4.26), and had higher CPUEs in higher bottom salinities, above 27.5 ppt (Figure 4.27).

Results of logistic analysis showed that *C. brevipinna* were more likely to be

caught at stations with warmer surface temperature waters, above 25 °C (Figure 4.15), and were most likely to be caught at stations with cooler bottom temperature waters, below 14 °C (Figure 4.17). This species also showed highest probabilities of catch at stations with higher salinities, above 30 ppt (Figure 4.18). Electivity analyses found that *C. brevipinna* had higher CPUEs in waters 10-20 meters deep (Figure 4.20).

Logistic regression results showed that *S. acanthias* were more likely to be caught at stations with cooler surface temperature waters, below 17 °C (Figure 4.16). Electivity analysis showed that this species had higher CPUEs in waters deeper than 20m (Figure 4.19), and higher CPUEs in late spring (May) (Figure 4.22). *S. acanthias* had higher CPUEs in surface temperatures below 17.5 °C (Figure 4.23), and higher CPUEs in bottom temperatures below 12.5 °C (Figure 4.25).

In the results of logistic regression analysis, *G. cuvier* showed a peak catch probability at stations at 25 °C (surface), with a steep drop in catch probability above that (Figure 4.16). They were also most likely to be caught at stations with cooler bottom temperature waters, below 14 °C (Figure 4.17), and showed highest probabilities of catch at stations with higher bottom salinities, above 30 ppt (Figure 4.18). Electivity analysis found that this species had higher CPUEs in waters deeper than 20m (Figure 4.19), and higher CPUEs in bottom temperatures below 17.5 °C (Figure 4.25).

Logistic regression found that *S. zygaena* were most likely to be caught at stations with cooler bottom temperature waters, below 14 °C (Figure 4.17), while electivity analysis showed highest probabilities of catch at stations with higher salinities, above 27.5 ppt (Figure 4.18). Logistic regression found that *S. lewini* had higher CPUEs

in waters deeper than 20m (Figure 4.19), while electivity analysis found two peaks in CPUE for this species, one in June and one in September (Figure 4.22). Logistic regression analysis found that *C. altimus* had higher CPUEs in waters deeper than 20m (Figure 4.19), and electivity analysis found that they had higher CPUEs in late summer months, peaking in August (Figure 4.21).

Discussion

Climatological Effects

The independent variables that most often proved significant were basic physical and chemical properties of the water where the sets were made. These included depth, water temperature, salinity, and dissolved oxygen. Time and location also proved significant in many cases, but these variables were often confounded with the physical and chemical parameters listed above. For example, early months of the survey were most likely to show lower temperatures, while offshore stations were most likely also to be deep, with lower bottom temperature.

Climate variables were most often significant for *C. obscurus*, which showed significant effects of discharge and NAO. This species showed higher CPUEs with higher discharge levels (which indicates more moist conditions). In the second model, *C. obscurus* showed higher CPUEs with higher bottom salinities, yet one would expect this species to prefer lower salinities based on the results for discharge. However, the effect of discharge is nearly an order of magnitude smaller than bottom salinity, indicating that bottom salinity may be the factor of higher ecological import.

Two species showed significant effects of the NAO, *C. obscurus* and young-of-year *C. plumbeus*, which both showed a positive correlation with NAO. This positive correlation means that they are more abundant when the NAO is high, and a high NAO index value leads to warmer drier conditions along the East coast of the U.S. The positive relationship with NAO in young-of-year *C. plumbeus* may indicate that these sharks are more available to the fishing gear when conditions are drier, since they move further into the estuary during the summer (Musick, personal communication). Also, warmer temperatures may keep them from using shallower areas of the Bay, and keep them in the main stem of the Bay, where our sampling sites are, for longer periods. The results of the effects of bottom temperature bear this out, as their CPUE drops sharply above 22 °C bottom temperature.

Several other factors could contribute to both the anomalous patterns and the lack of results for a majority of species in climate variables. First, the data for these effects in many cases was of low resolution, leading to less statistical power to discern patterns. Secondly, such effects have been mainly demonstrated in fish species of a much lower trophic level, and much more r-selected than the sharks in this study. Herring, mackerel, juvenile fish assemblages, and shellfish all fit into this category (Attrill and Power, 2002; Corten, 1999; Parsons and Lear, 2001; Reid et al., 2001, Wood, 2000), as well as juvenile oysters, finfish, and blue crabs in the Chesapeake Bay (Austin, 2002). The effects of large-scale environmental variation may be damped as they move higher in the trophic system. The only example of large-scale environmental effects on behavior and distribution of a shark was in *C. maximus*, a planktivore, and on a much lower trophic

level than the sharks in this study (Sims and Quayle, 1998). Finally, the long life-span and slow reproduction of these shark species may mean that any effects may be delayed for as long as a generation, if the effects are more severe on very young sharks. Thus a much longer time series may be necessary before any effects can be seen. Effects of the NAO have been found in fish at mid-trophic levels, such as cod and other groundfish stocks, but in those cases the data sets were of a much longer duration than that of the present study, back to 1919 in one case (Levke et al., 2002; Parsons and Lear, 2001). Lagged effects of the NAO have been found in a marine bird, the northern fulmar (Thompson and Ollason, 2001), but the authors used a data set ten times longer than the lag duration they found, which may indicate that we need at least another 20 years of data to find effects of the NAO on shark CPUEs.

Summary of EFH of common Virginia shark species

When environmental variables are examined for implications to defining EFH for these species, groups become apparent (Table 4.10). The species show the presence of four distinct groups, one group of “data-deficient” species, and 5 species not readily grouped. The first three species are those with too few parameters to assign it to a group, including *A. vulpinus*, *S. zygaena*, and *C. leucas*. The next five species are those not easily grouped. The first real group consists of species that prefer colder ocean waters, while the next group is coastal species that prefer moderate temperatures and salinities and show a bimodal pattern in month of highest catch. The third group is found primarily in the warmer, lower salinity waters inside the Bay, and the last group is those that prefer

offshore deep waters.

Turning first to those species not clearly a member of a group, all these species except *R. terraenovae* are relatively rare in the VIMS survey. These species commonly were found in warmer waters off shore, and both *C. brevipinna* and *G. cuvier* have been described by other researchers as preferring warmer waters (Allen and Cliff, 2000; Heithaus, 2001). Researchers working in South Africa found that catches of *C. limbatus* dip during the period of lowest water temperatures (August and September; Dudley and Cliff, 1993). *Negaprion brevirostris* was most abundant in warm, shallow coastal waters, which agrees with the established EFH definition for *N. brevirostris* of shallow coastal waters (NMFS 1999). *Carcharhinus brevipinna* was more abundant in coastal waters deeper (10-20 m) than those preferred by *N. brevirostris*, but did not go as deep as suggested by NMFS (1999), which described the adults as coastal to the 100 m isobath. *Galeocerdo cuvier* preferred the deepest waters of these three species, preferring waters deeper than 20 m, which agrees with the established EFH, which describes the depth preferences of adult *G. cuvier* as 25 to 200 meters (NMFS 1999).

The second most often caught shark species in this survey, *R. terraenovae*, was found to be a offshore summer visitor to this area. It was found most often in cooler, high-salinity waters, characteristic of offshore waters. This species most likely migrates northward into this area in the early summer and uses this area as feeding grounds until late summer, when it returns south to its over-wintering and spawning habitat (NMFS 1999).

The first real group, which includes *M. canis* and *S. acanthias*, were the only

winter inhabitants of the survey area. Both were found to be strongly associated with low temperatures, and both showed peaks in May, the earliest (and hence coldest) month of the survey. *Squalus acanthias* are an abundant winter resident in the area (Nammack et al. 1985), whereas *M. canis* migrate through the area to northern summering grounds in May and June (Conrath and Musick 2002).

This next group includes the young-of-year and juvenile *C. plumbeus*, which were found most often in Chesapeake Bay waters during summer months. Juvenile *C. plumbeus* prefer slightly cooler temperatures and higher salinities than young-of-year. No other species examined in this study was found commonly inside the Bay.

Adult *C. plumbeus*, however, show a much different pattern, being associated with deeper, non-Bay waters, cooler temperatures, and higher salinities. These characteristics, along with a pattern with month, are also seen in *C. taurus* and *C. obscurus*. These three show a bimodal pattern with month, peaking in June and September in adult *C. plumbeus* and *C. taurus*, and peaking in June and October in the case of *C. obscurus*. This pattern is most likely the result of seasonal migration patterns, with the animals moving north early in the summer, using habitat to the north of this survey's area during the mid-summer, and returning south at the end of the summer (NMFS, 1999). The only other work to examine environmental preferences of any of these species was a study on *C. obscurus* in South African waters, where they found that adults and juveniles were most abundant in temperatures over 23 °C (Dudley et al., 2005; Smale, 1991).

The final group comprises those species that preferred deepwater offshore areas,

and this group includes *P. glauca*, *C. altimus*, *I. oxyrinchus*, *S. lewini*, and *C. falciformis*. *Prionace glauca* and *I. oxyrinchus* are both classified as pelagics by NMFS (1999), while the same report classifies *C. falciformis*, *C. altimus* and *S. lewini* as found most often in waters at least 50 m deep. In addition, Hazin et al. (1994) found that *P. glauca* preferred deeper waters. Smale (1991) found that *S. lewini* in South Africa are more common further from shore.

The analyses in this chapter provide evidence of an ontogenetic shift in depth zone usage by *C. plumbeus*. Figure 4.22 shows that young-of-year *C. plumbeus* use the Bay areas exclusively, while juveniles are found in some areas outside the Bay. Figure 4.20 shows that adult *C. plumbeus* prefer waters over 20 m in depth. This pattern is similar to that described by Musick et al. (1993).

Conclusions

One of the primary purposes of this work was to establish EFH more precisely for the shark species caught in the VIMS survey, and this chapter has fulfilled that goal. The model selection procedure made highlighted the most important effects for each species or age class, while the logistic analysis, though less powerful, allowed the most important effects for less numerous species to be seen. In most cases depth was a significant factor in determining CPUE, while water temperature and salinity also showed significant effects in many cases. A lack of significant effects of climatological factors like the NAO, Chesapeake Bay discharge, and the PDI was found, as well.

	Latitude	Longitude	Month	Year	Depth	Surface Temp.	Bottom Temp.	NAO Index	PDI	Discharge
Main effect	x	x	x	x	x	x	x	x	x	x
Latitude		x	x	x	x	x	x	x	x	x
Longitude			x	x	x	x	x	x	x	x
Month				x	x	x	x	x	x	x
Year					x	x	x	x	x	x
Depth						x	x	x	x	x
Surface Temp.							x	x	x	x
Bottom Temp.								x	x	x
NAO Index										
PDI										
Discharge										

Table 4.1: Main effects and interactions included in the first (long time series) GLM model.

	Latitude	Longitude	Month	Year	Depth	Surface Temp.	Bottom Temp.	Surface Salinity	Bottom Salinity	Surface dO
Main effect	x	x	x	x	x	x	x	x	x	x
Latitude		x	x	x	x	x	x	x	x	x
Longitude			x	x	x	x	x	x	x	x
Month				x	x	x	x	x	x	x
Year					x	x	x	x	x	x
Depth						x	x	x	x	x
Surface Temp.							x			
Bottom Temp.										
Surface Salinity										
Bottom Salinity										
Surface dO										

Table 4.2: Main effects and interactions included in the second (short time series) model.

Species	Before Transformation		After Transformation	
	Skew	Kurtosis	Skew	Kurtosis
<i>Alopias superciliosus</i>				
<i>Alopias vulpinus</i>	8	67	7	44
<i>Carcharhinus acronotus</i>	7	47	7	43
<i>Carcharhinus altimus</i>	12	135	9	94
<i>Carcharhinus brevipinna</i>	5	26	3	7
<i>Carcharhinus falciformis</i>	8	64	7	47
<i>Carcharhinus leucas</i>	7	49	5	23
<i>Carcharhinus limbatus</i>	7	55	3	13
<i>Carcharhinus obscurus</i>	3	9	1	2
<i>Carcharhinus plumbeus</i>	2	7	1	1
<i>Carcharhinus signatus</i>	8	70	8	67
<i>Carcharias taurus</i>	5	26	2	5
<i>Carcharodon carcharias</i>				
<i>Galeocerdo cuvier</i>	6	44	2	6
<i>Isurus oxyrinchus</i>	7	67	3	14
<i>Mustelus canis</i>	4	15	2	4
<i>Negaprion brevirostris</i>	6	40	5	23
<i>Prionace glauca</i>	5	29	3	11
<i>Rhizoprionodon terraenovae</i>	7	68	1	4
<i>Sphyrna lewini</i>	6	47	3	12
<i>Sphyrna zygaena</i>	5	23	5	20
<i>Squalus acanthias</i>	11	127	8	73
Large Coastal Sharks	2	7	1	1
Small Coastal Sharks	6	53	1	4
Pelagics	5	32	2	5
YOY <i>C. plumbeus</i>	5	40	2	4
Juvenile <i>C. plumbeus</i>	3	13	0	1
Adult <i>C. plumbeus</i>	3	13	2	2
Female <i>C. plumbeus</i>	3	15	1	2
Male <i>C. plumbeus</i>	4	26	0	1

Table 4.3: Results of application of the angular transform to the data for all stations, with species/age groups that met the criterion for GLM analysis after transformation in bold.

Entry Order	<i>R. terraenovae</i>	<i>C. taurus</i>		<i>C. obscurus</i>		<i>M. canis</i>		Young-of-year		<i>C. plumbeus</i> Juveniles		Adults		
1	month	***	Year	***	Month	ns	Month	***	BT	**	BT	***	Year	ns
2	bt	***	Depth	**	BT	ns	ST	***	Lat	*	Depth	***	Depth	***
3	lat	**	Lat	***	BT*month	**	ST*Month	***	Year	**	Year	ns	Month	***
4	lat*bt	***	NAO	ns	Year	*			NAO	**			Year*Month	***
5	PDI	ns	Year*Depth	**	Lat	*			Lat*NAO	**			Year*Depth	***
6					Disch	**			Lat*BT	**			Depth*Month	**
7					BT*Disch	**			PDI	ns			Lat	*
8					Disch*Month	*			BT*PDI	*			BT	*
9					NAO	***			BT*NAO	ns			Lat*BT	*
10					Year*NAO	***							Disch	ns
11													Lat*Disch	ns
12													Year*Disch	ns
Adj. r ²	0.1232	0.0678		0.1365		0.2765		0.1747		0.125		0.3133		

Table 4.4: Comparison of the results of GLM analyses for all species and age groups of *C. plumbeus* from the first model. Model selection runs in order of addition or removal from the model are shown, with the adjusted r² values. Significance levels at the p=0.05 level shown for each model term.

Entry Order	<i>R. terraenovae</i>		<i>C. taurus</i>		<i>C. obscurus</i>		<i>M. canis</i>		<i>C. plumbeus</i>					
									Young-of-year		Juveniles		Adults	
1	Bsal	***	Lat	*	Month	ns	ST	**	Bsal		BT	***	Ssal	*
2	Month	*	Bdo	ns	Bsal	**	Month	***	BT	***	Month	***	Lat	
3	BT	**	Depth	*	Bsal*Month	*	Sdo	*	Ssal	***	Bsal	***	Month	ns
4	BT*Month	***	Lat*Depth	*	ST	ns	Sdo*Month	***	-Bsal		Sdo	ns	Year	**
5	Bsal*Month	*	BT	***			Lat	***					-Lat	
6			Lat*BT	***			Bsal	*					Depth	*
7			Lat*Bdo				Bsal*Month	***					Ssal*Month	*
8			Depth*BT				Lat*ST	**					ST	ns
9			st	*										
10			st*bt	**										
11			-depth*BT											
12			Lat*ST	*										
13			Depth*ST	**										
14			Depth*BT	**										
15			-Lat*Bdo											
Adj. r ²	0.2503		0.2238		0.1537		0.4441		0.1528		0.1889		0.0978	

Table 4.5: Comparison of the results of GLM analyses for all species and age groups of *C. plumbeus* from the second model. Model selection runs in order of addition or removal (shown with a minus symbol) from the model are shown, with the adjusted r² values. Significance levels at the p=0.05 level shown for each model term.

	N, full	N, limited
<i>Alopias superciliosus</i>	1	1
<i>Alopias vulpinus</i>	6	6
<i>Carcharhinus acronotus</i>	3	1
<i>Carcharhinus altimus</i>	11	1
<i>Carcharhinus brevipinna</i>	33	28
<i>Carcharhinus falciformis</i>	12	0
<i>Carcharhinus leucas</i>	7	0
<i>Carcharhinus limbatus</i>	46	24
<i>Carcharhinus signatus</i>	2	1
<i>Carcharodon carcharias</i>	1	1
<i>Galeocerdo cuvier</i>	52	17
<i>Isurus oxyrinchus</i>	20	3
<i>Negaprion brevirostris</i>	10	0
<i>Prionace glauca</i>	19	2
<i>Sphyrna lewini</i>	46	5
<i>Sphyrna zygaena</i>	6	5
<i>Squalus acanthias</i>	10	6

Table 4.6: Species included in full logistic analysis using the first model and those analyzed with the second logistic model. Shaded cells indicate those species not analyzed by model. Fourteen out of eighteen species were analyzed with the first model and seven with the second.

	Depth		Surface Temp.		Bottom Temp.		Bottom Sal.	
<i>Alopias vulpinus</i>					0.0010	**		
<i>Carcharhinus altimus</i>								
<i>Carcharhinus brevipinna</i>			0.0019	**	0.0010	**	<0.0001	***
<i>Carcharhinus falciformis</i>	0.0006	***						
<i>Carcharhinus leucas</i>	0.0121	*						
<i>Carcharhinus limbatus</i>			0.0420	*			0.0006	***
<i>Galeocerdo cuvier</i>			0.0121	*	<0.0001	***	0.0016	**
<i>Isurus oxyrinchus</i>	<0.0001	***						
<i>Negaprion brevirostris</i>	0.0144	*	0.0448	*				
<i>Prionace glauca</i>	<0.0001	***	0.0071	**				
<i>Sphyrna lewini</i>								
<i>Sphyrna zygaena</i>					0.0286	*	0.0471	*
<i>Squalus acanthias</i>			<0.0001	***				

Table 4.7: Statistically significant results of logistic analyses of species that did not meet the criterion for GLM analysis. Results for both the first and second models are shown. *Carcharhinus altimus* and *Sphyrna lewini* showed no significant results.

	Depth		Month		Surface Temp		Bottom Temp		Surface Salinity		Bottom Salinity	
<i>C. altimus</i>	***	deeper than 20 m	***	August								
<i>C. limbatus</i>	***	0-20, no bay	***	June	***	above 25	**	12-22	***	less than 27	***	above 27
<i>C. brevipinna</i>	***	10-20 m	***	June								
<i>C. obscurus</i>	***	10-20 m	***	June	***	17-23	***	12-22	***	above 27	***	above 27
<i>C. taurus</i>	***	0-20, no bay	***	June & September	***	17-23	***	12-22	***	above 27	**	above 27
<i>I. oxyrinchus</i>	***	deeper than 20 m										
<i>P. glauca</i>	***	deeper than 20 m	*	May								
<i>G. cuvier</i>	***	deeper than 20 m					*	less than 15				
<i>M. canis</i>	***	10-20 m	***	May	***	less than 20	***	less than 15	***	above 27	***	above 27
<i>R. terraenovae</i>	***	10-20 m	***	August	***	17-23	***	12-22	***	22-32	***	above 27
<i>S. acanthias</i>	***	deeper than 20 m	***	May		less than 20		less than 15				
<i>S. lewini</i>	***	deeper than 20 m	***	June & September								
Juveniles	***	bay	***	June/July	***	above 25	***	above 22	***	22-32	***	below 27
YOY	***	bay	***	August	***	above 25	***	above 22	***	less than 27	***	below 27
Adult	***	deeper than 20 m	***	June & September	***	17-23	***	12-22	***	above 27	***	above 27

Table 4.8: Statistically significant results of X^2 goodness-of-fit modeling of categorical data. Shaded areas indicate factors and species that were not tested due to low N values (see text).

Temperature, °C		Salinity, ppt		Depth, m	Month
Bottom	Surface	Surface	Bottom		
10	10	20	20	Bay	5
15	15	25	25	0-10	6
20	20	30	30	10-20	7
25	25	35	35	>20	8
30	30				9
					10

Table 4.9: Categories used in analysis of electivity by shark species. Values for temperature and salinity are the midpoints of the category.

	Surf. Temp.	Bot. Temp.	Surf. Salinity	Bot. Salinity	Depth	Month
	°C	°C	ppt	ppt	m	
<i>Alopias vulpinus</i>		<14				
<i>Sphyrna zygaena</i>		<14		>30		
<i>Carcharhinus leucas</i>					0-10	
<i>Megapristis brevirostris</i>	>25				0-10	
<i>Carcharhinus brevipinna</i>	>25	<14		>30	0-20	June
<i>Galeocerdo cuvier</i>	20-26	<18		>30	20-	
<i>Rhizoprionodon terraenovae</i>	13-28	18-23	22-32	30-34	10-20	August
<i>Carcharhinus limbatus</i>	>25	18-28	<27	>27	0-20	June
<i>Mustelus canis</i>	<23	<18	>27	>30	10-20	May
<i>Squalus acanthias</i>	<18	<13			20-	May
Juvenile <i>C. plumbeus</i>	>25	12-22	>27	>27	bay	August
Juvenile <i>C. plumbeus</i>	>25	>22	22-32	>30	bay	June/July
Adult <i>C. plumbeus</i>	17-28	13-23	>27	>27	20-	June & September
<i>Carcharias taurus</i>	13-23	13-18	>27	>27	0-20	June & September
<i>Carcharhinus obscurus</i>	17-23	18-23	>27	>27	10-20	June & October
<i>Prionace glauca</i>	<17				20-	May
<i>Carcharhinus altimus</i>					20-	August
<i>Isurus paucus</i>					20-	
<i>Sphyrna tiburo</i>					20-	June & September
<i>Carcharhinus fideiformis</i>					>180	

Table 4.10: Essential Fish Habitat summarized for all species that showed at least one significant effect for the six variables presented in this table. Shaded groups are groups of species with similar values for most of these variables, and are described in greater detail in the text.

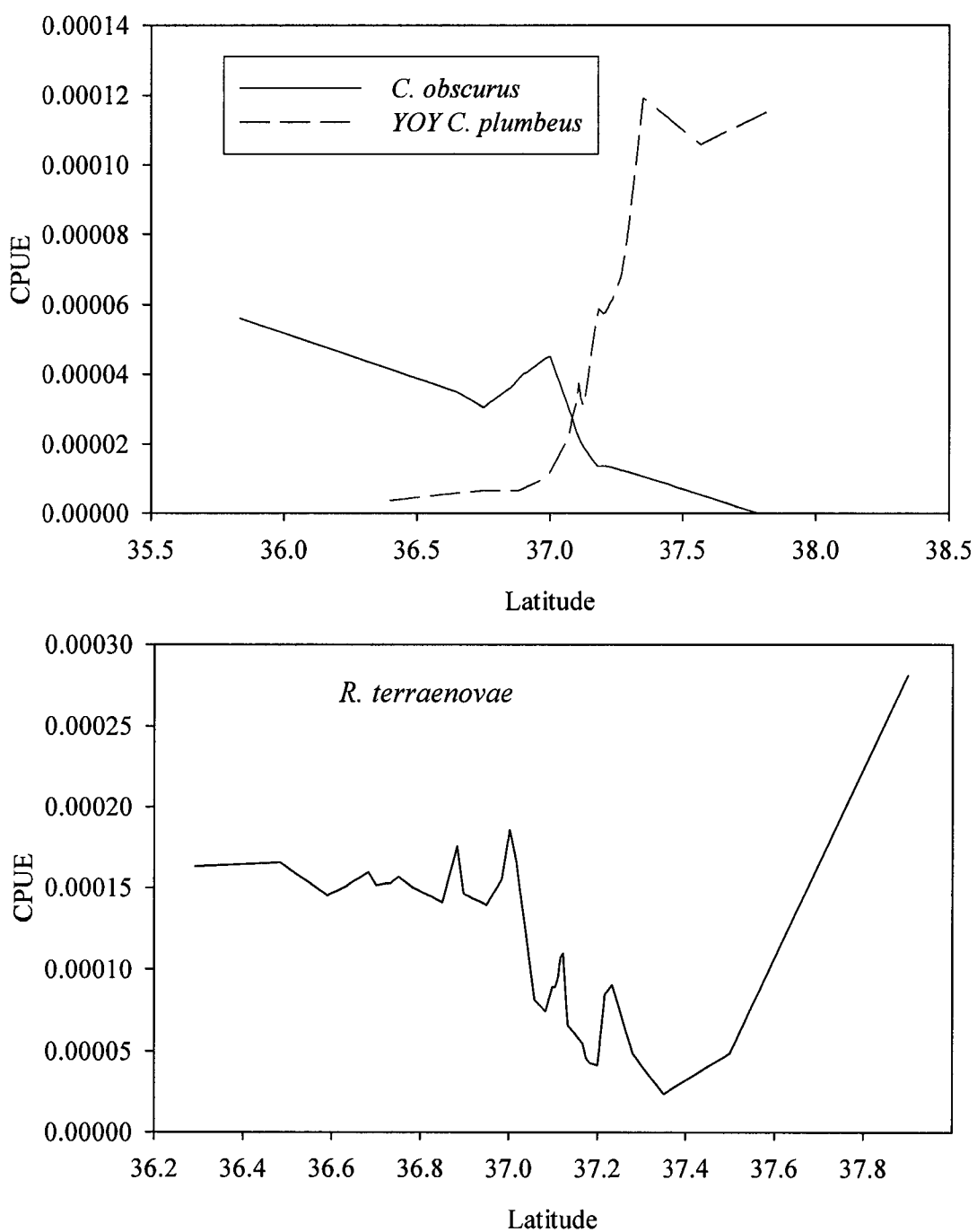


Figure 4.1: Significant results for variable latitude from GLM analyses described in this chapter.

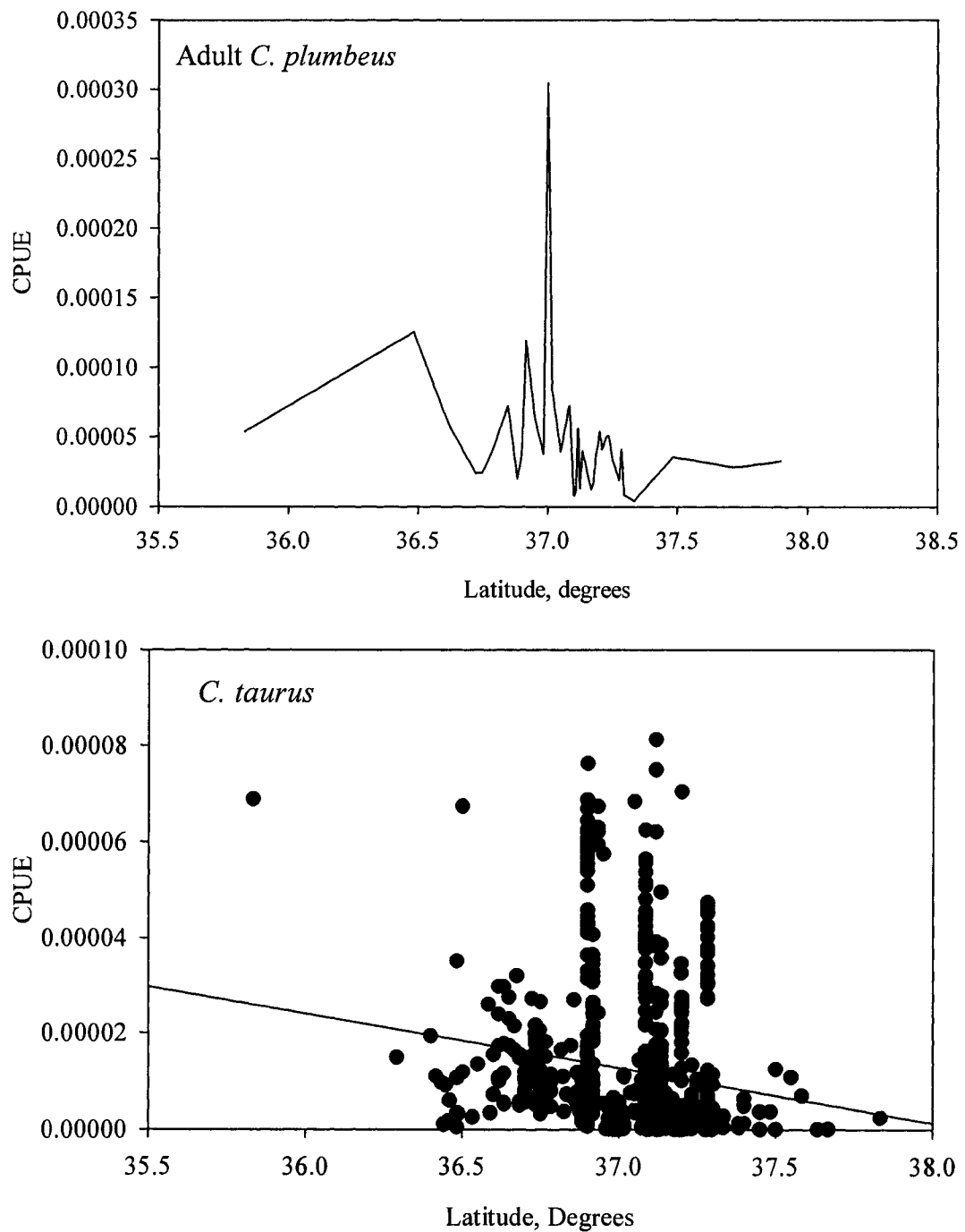


Figure 4.2: Significant results for variable latitude from GLM analyses described in this chapter. Top figure has been less smoothed; lower figure was unable to be less smoothed, so a simple regression is shown.

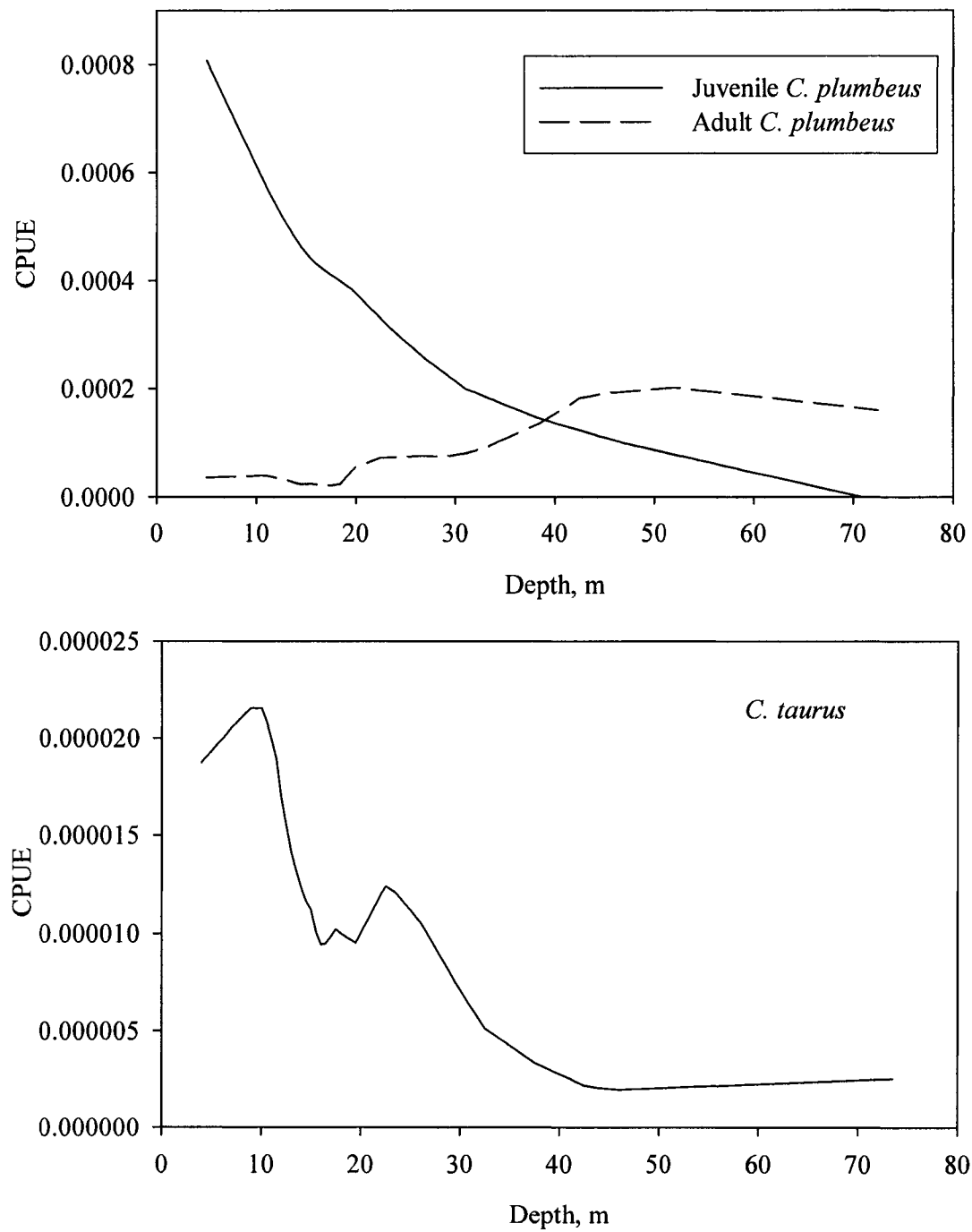


Figure 4.3: Significant results for variable depth from GLM analyses described in this chapter.

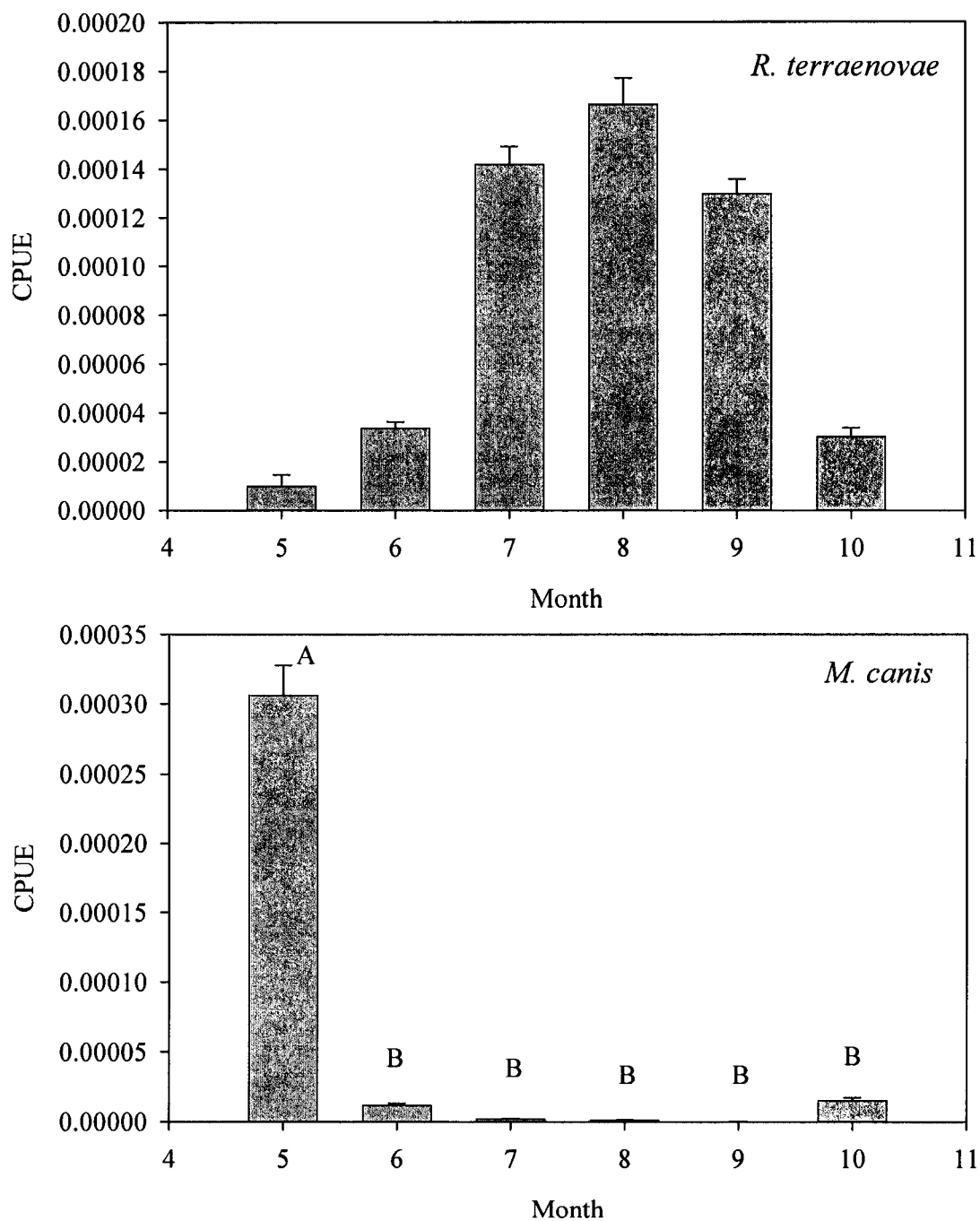


Figure 4.4: Significant results for variable month from GLM analyses described in this chapter. Month groups designated with different letters were found to have significantly different means.

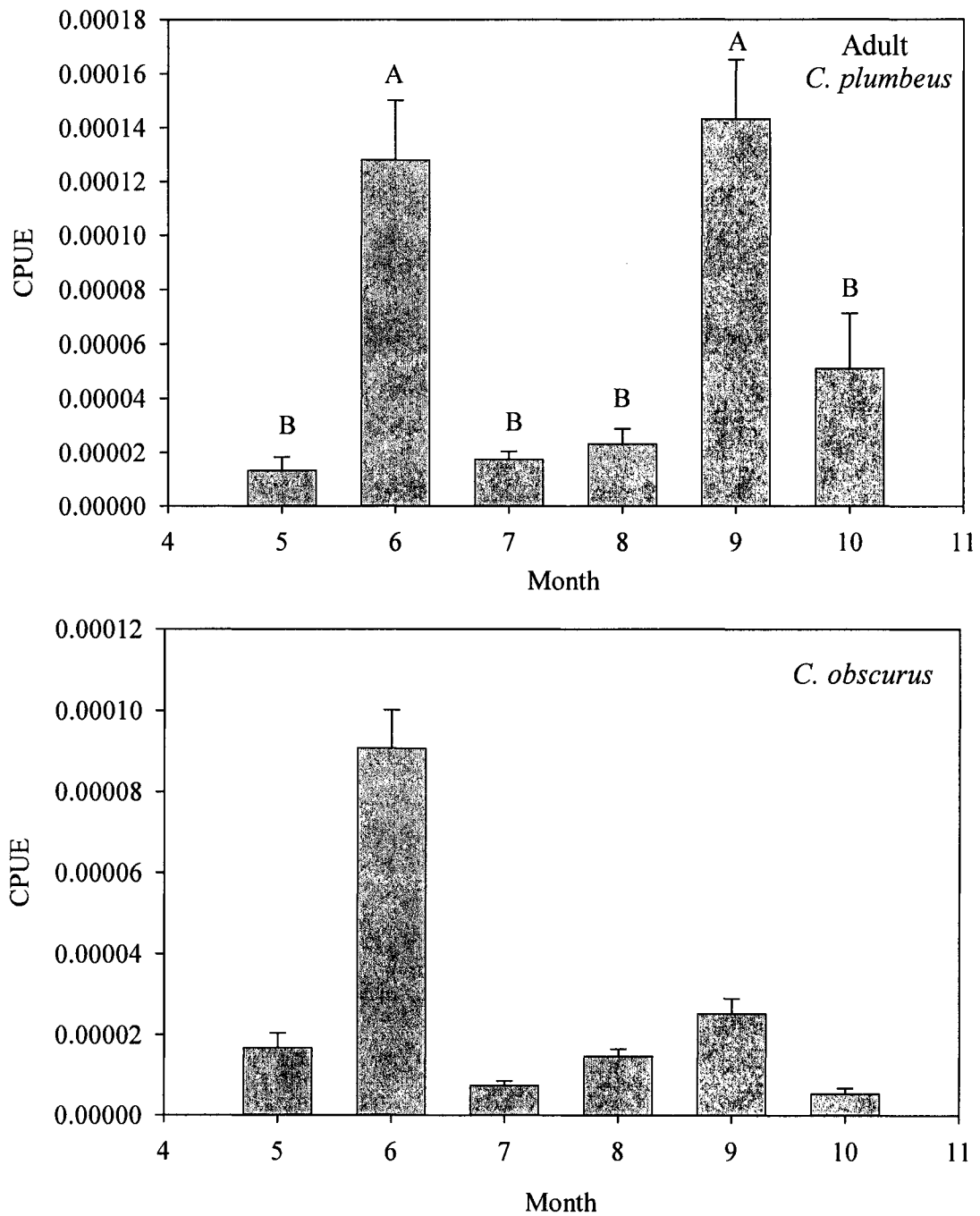


Figure 4.5: Significant results for variable month from GLM analyses described in this chapter. Month groups designated with different letters were found to have significantly different means.

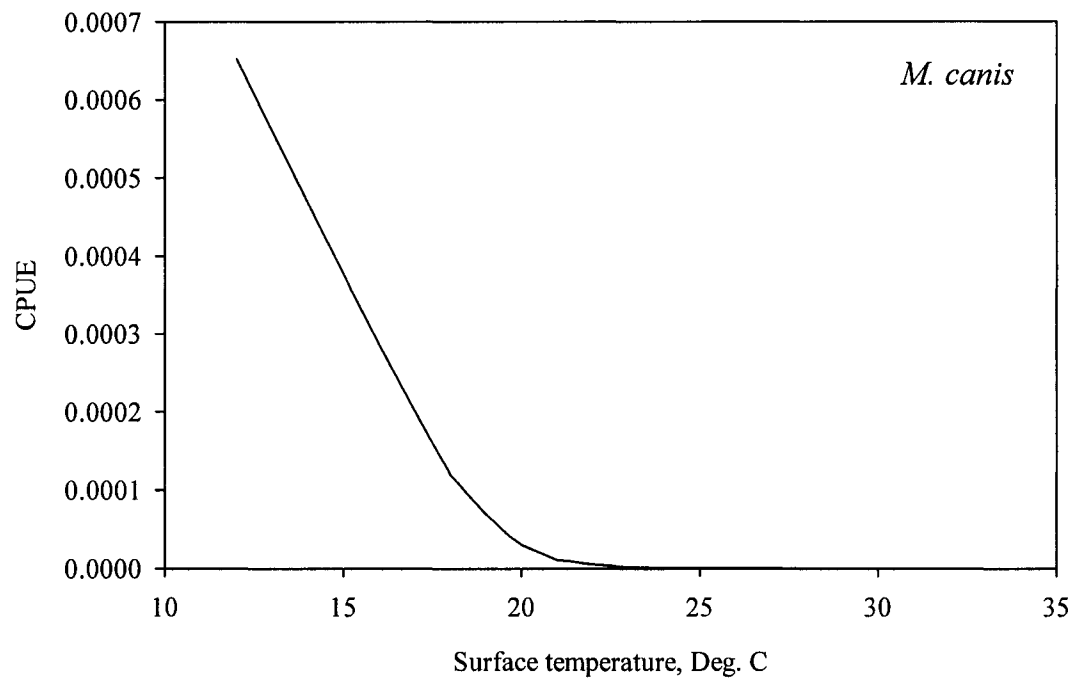


Figure 4.6: Significant results for variable surface temperature from GLM analyses described in this chapter.

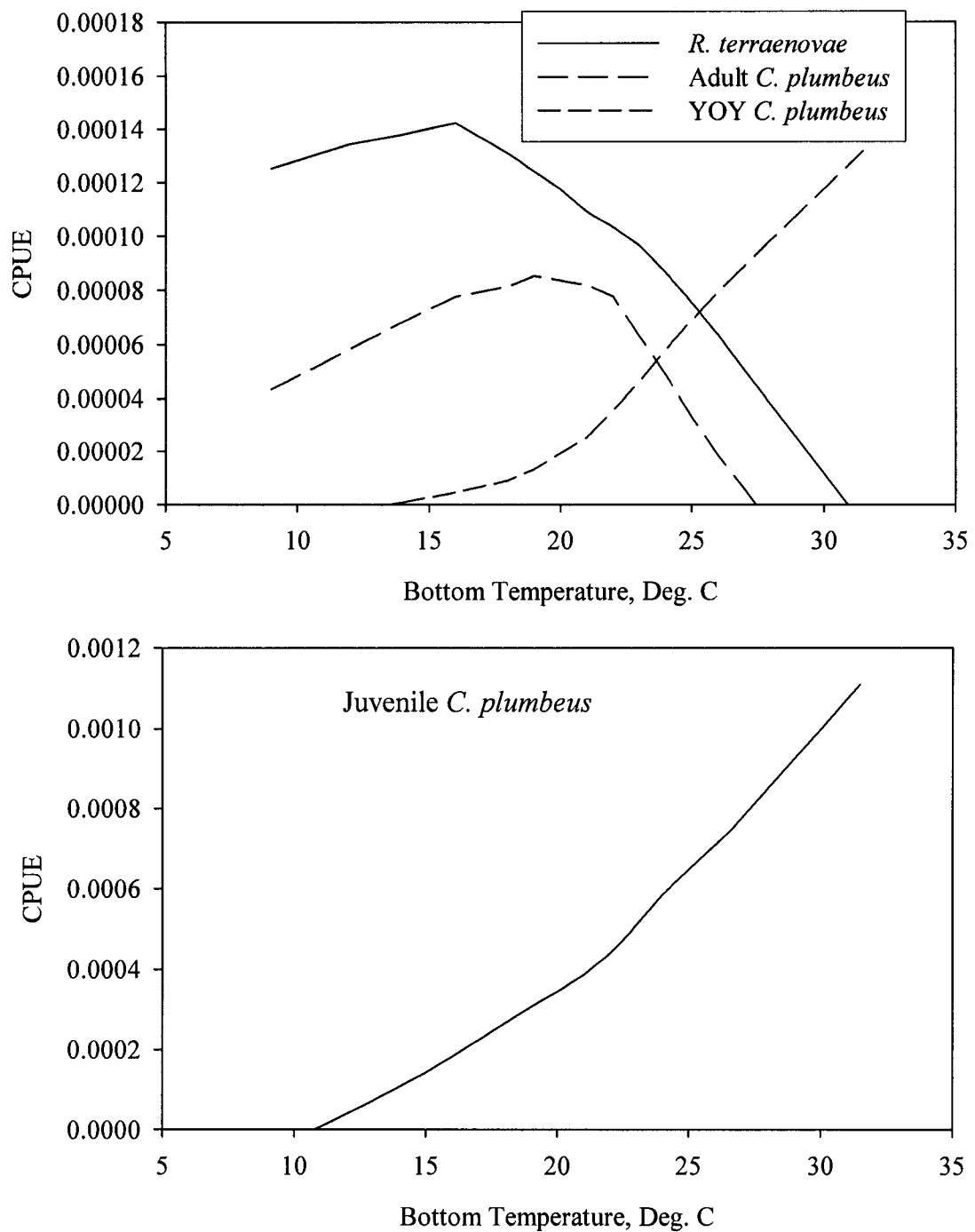


Figure 4.7: Significant results for variable bottom temperature from GLM analyses described in this chapter.

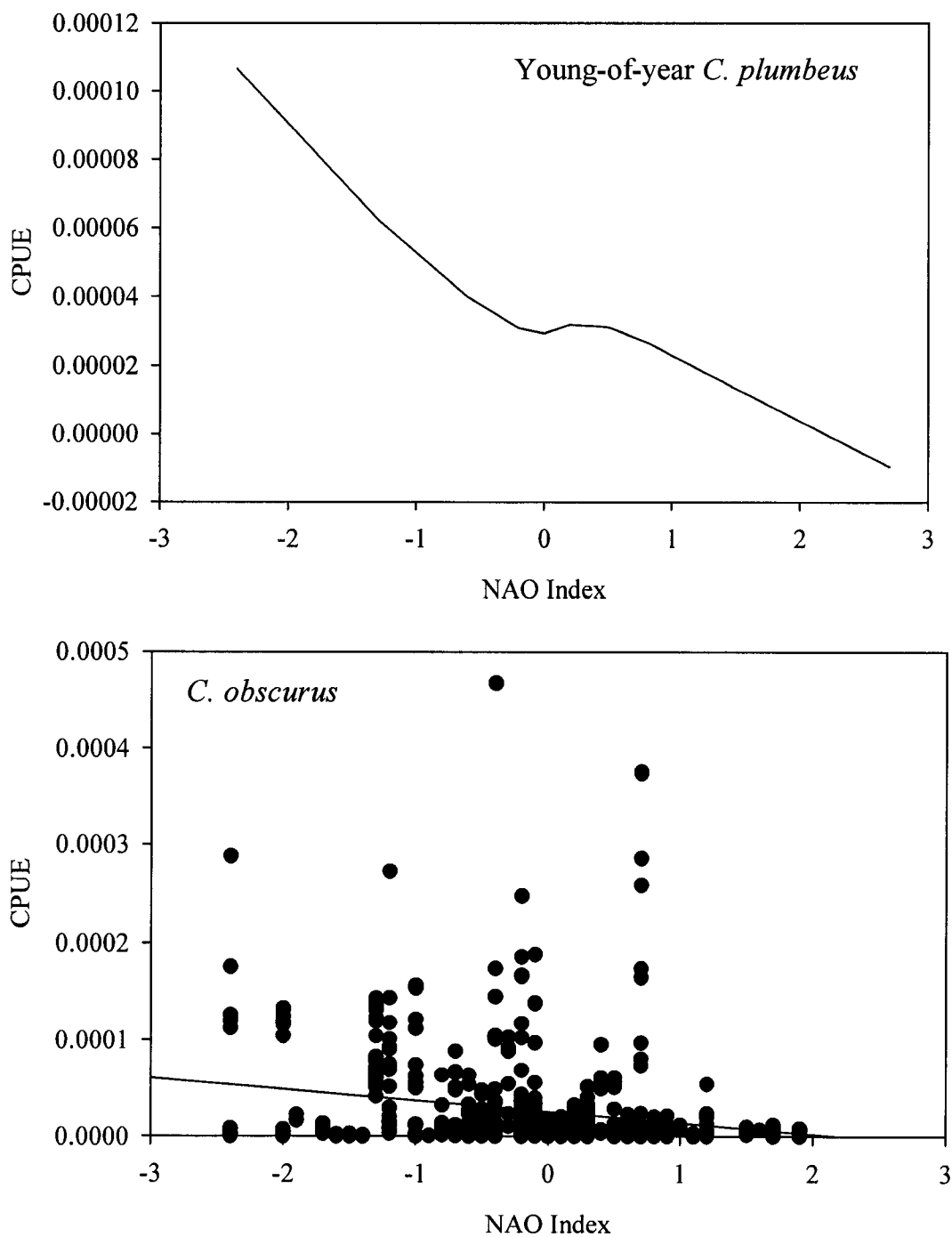


Figure 4.8: Significant results for North Atlantic Oscillation index for young-of-year *C. plumbeus* and *C. obscurus*. Results for *C. obscurus* could not be smoothed via Lowess smoothing, and are instead shown with simple linear regression.

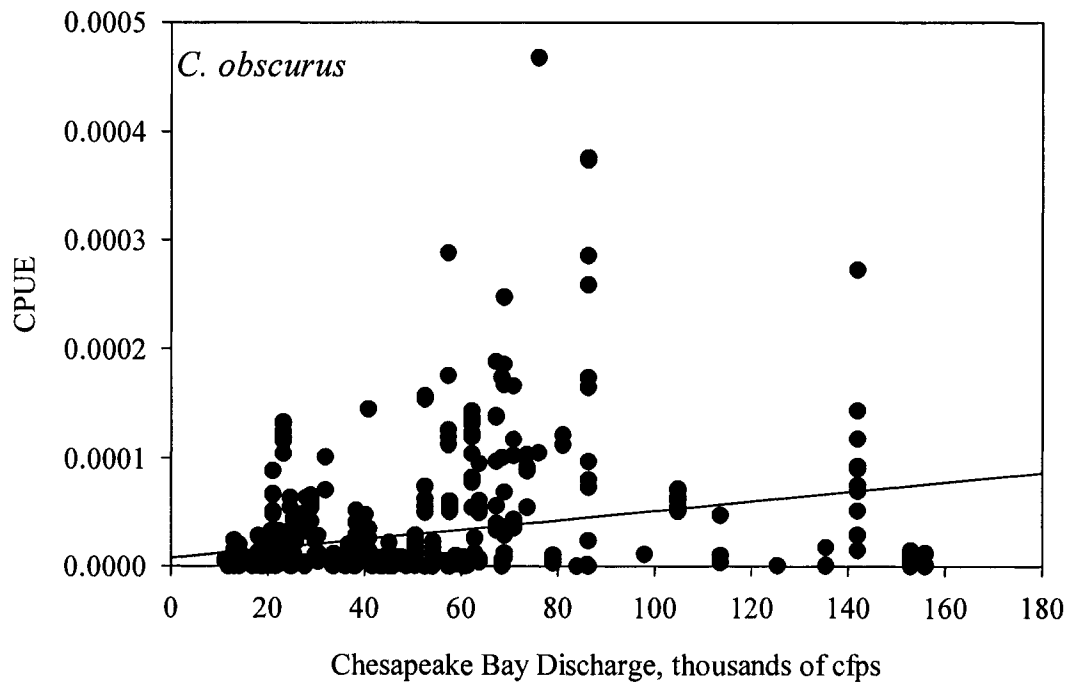


Figure 4.9: Significant results for Chesapeake Bay discharge, in thousands of cubic feet per second, from GLM analyses described in this chapter. Results could not be smoothed via Lowess smoothing, and are instead shown with simple linear regression.

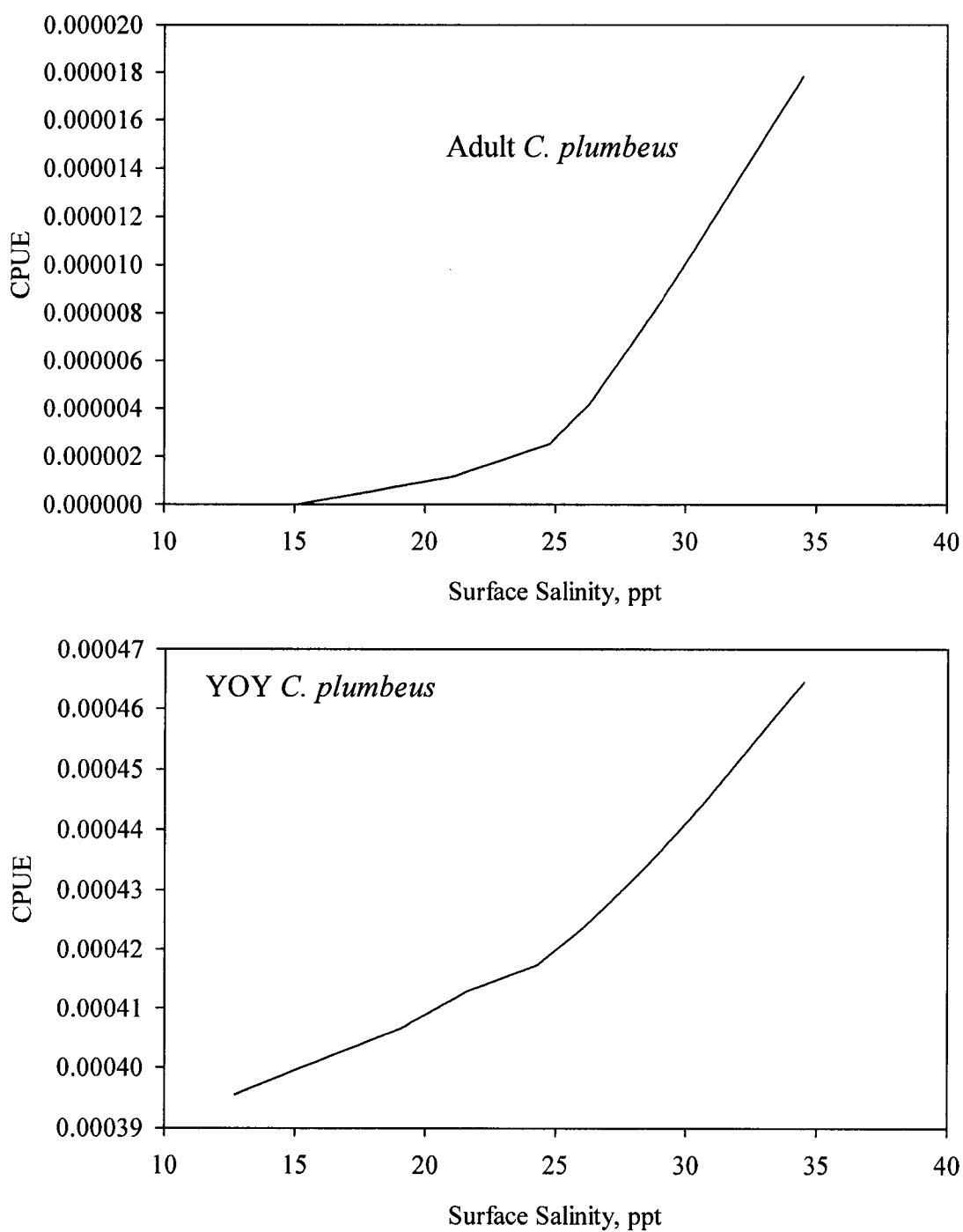


Figure 4.10: Significant results for variable surface salinity from GLM analyses described in this chapter.

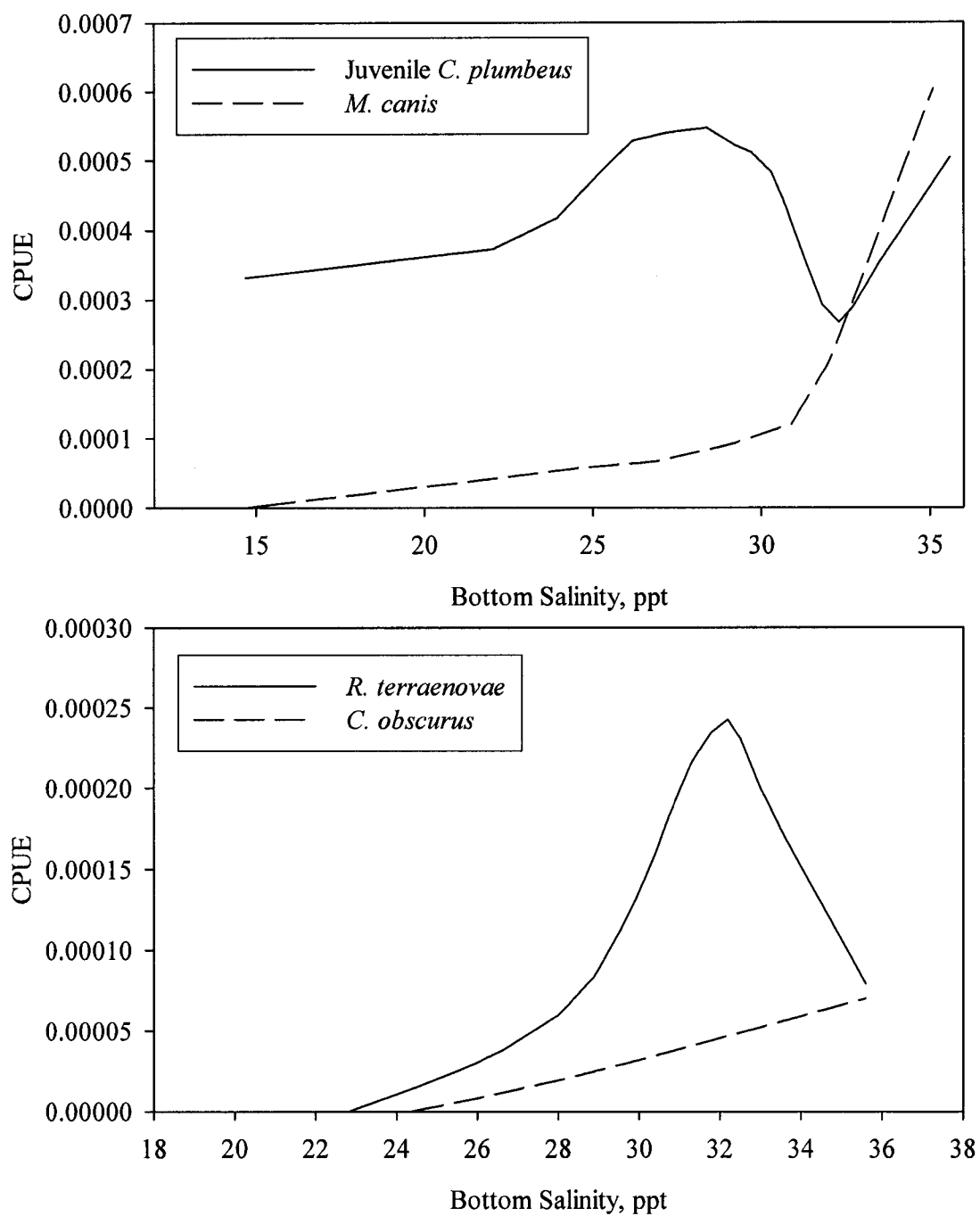


Figure 4.11: Significant results for variable bottom salinity from GLM analyses described in this chapter.

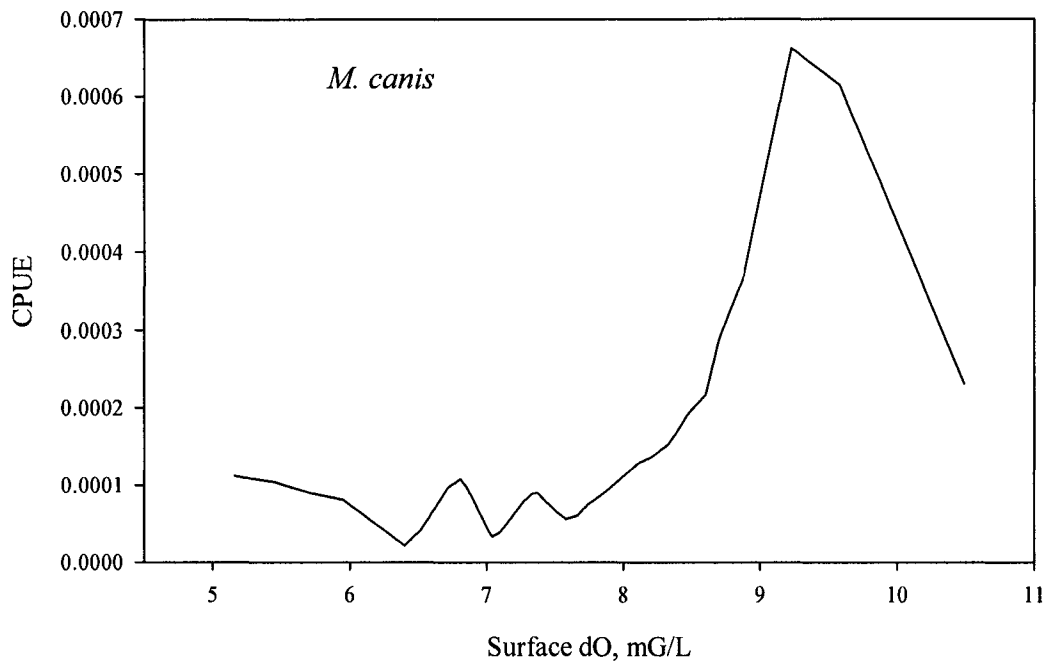


Figure 4.12: Significant results for variable surface dissolved oxygen from GLM analyses described in this chapter.

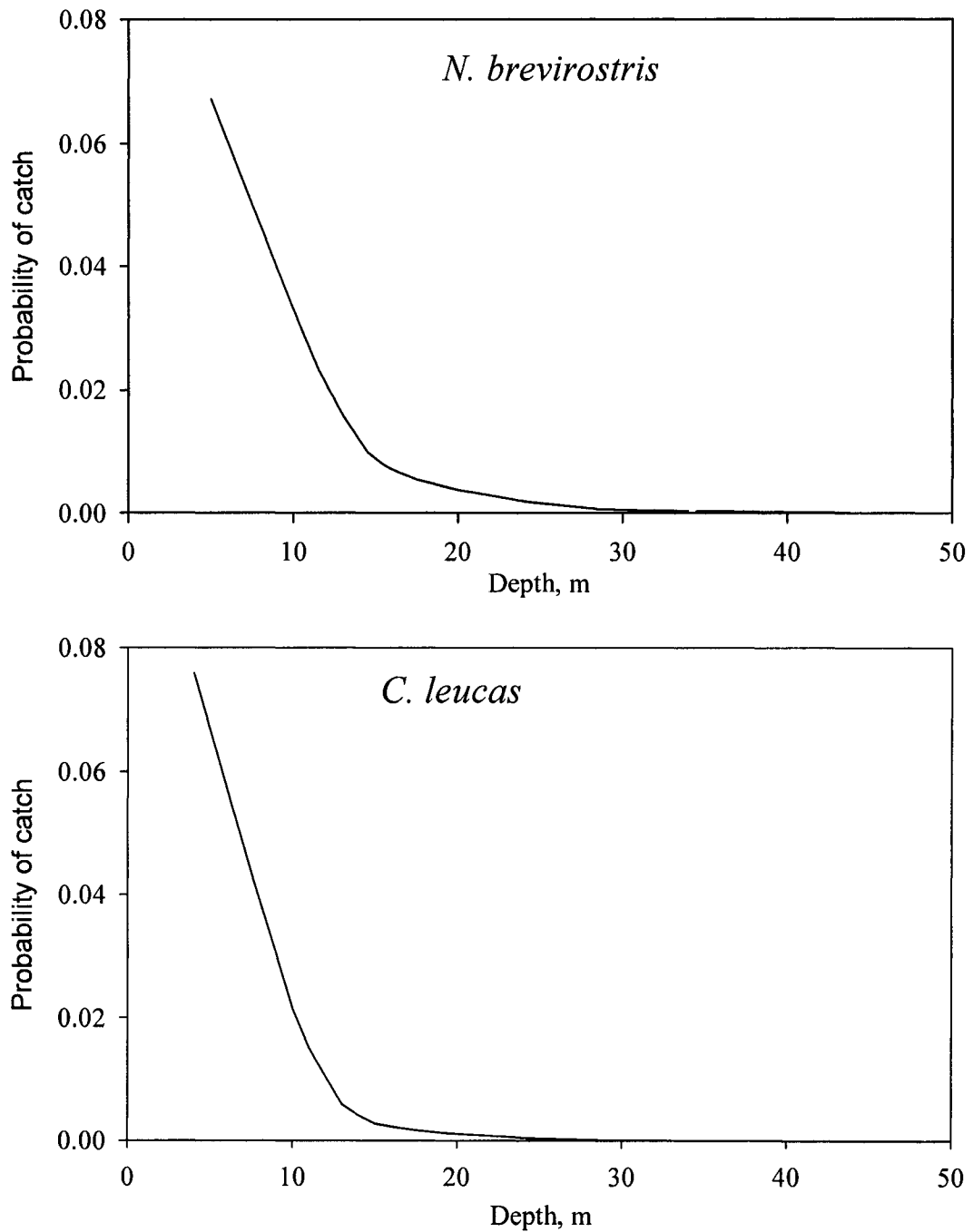


Figure 4.13: Significant results for depth from logistic analyses of species that did not meet the criterion for GLM analysis, as described in this chapter. The Y axis in these graphs is in the probability of capture of the species.

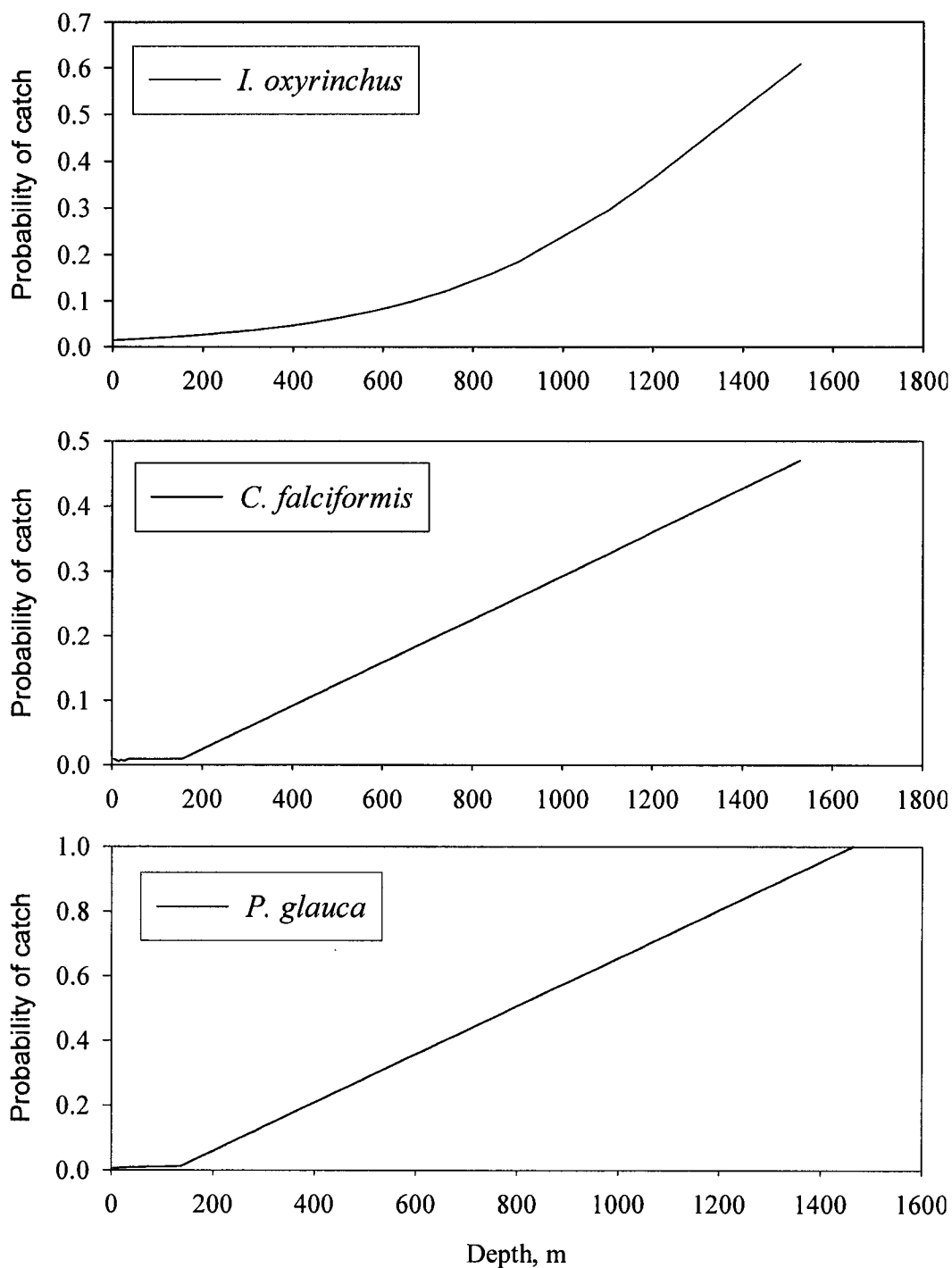


Figure 4.14: Significant results for depth from logistic analyses of species that did not meet the criterion for GLM analysis, as described in this chapter. The Y axis in these graphs is in the probability of capture of the species.

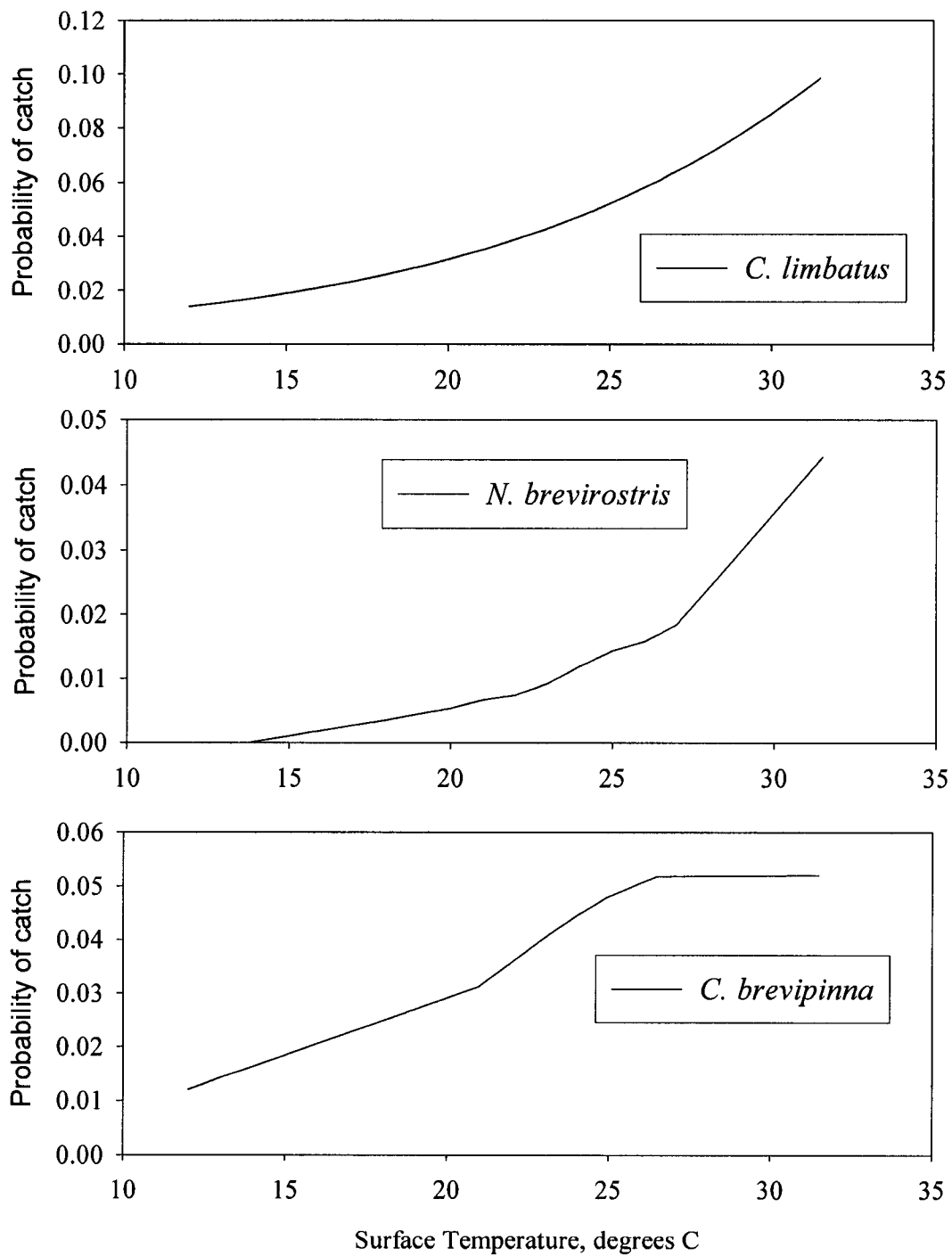


Figure 4.15: Significant results for surface temperature from logistic analyses of species that did not meet the criterion for GLM analysis, as described in this chapter. The Y axis in these graphs is in the probability of capture of the species.

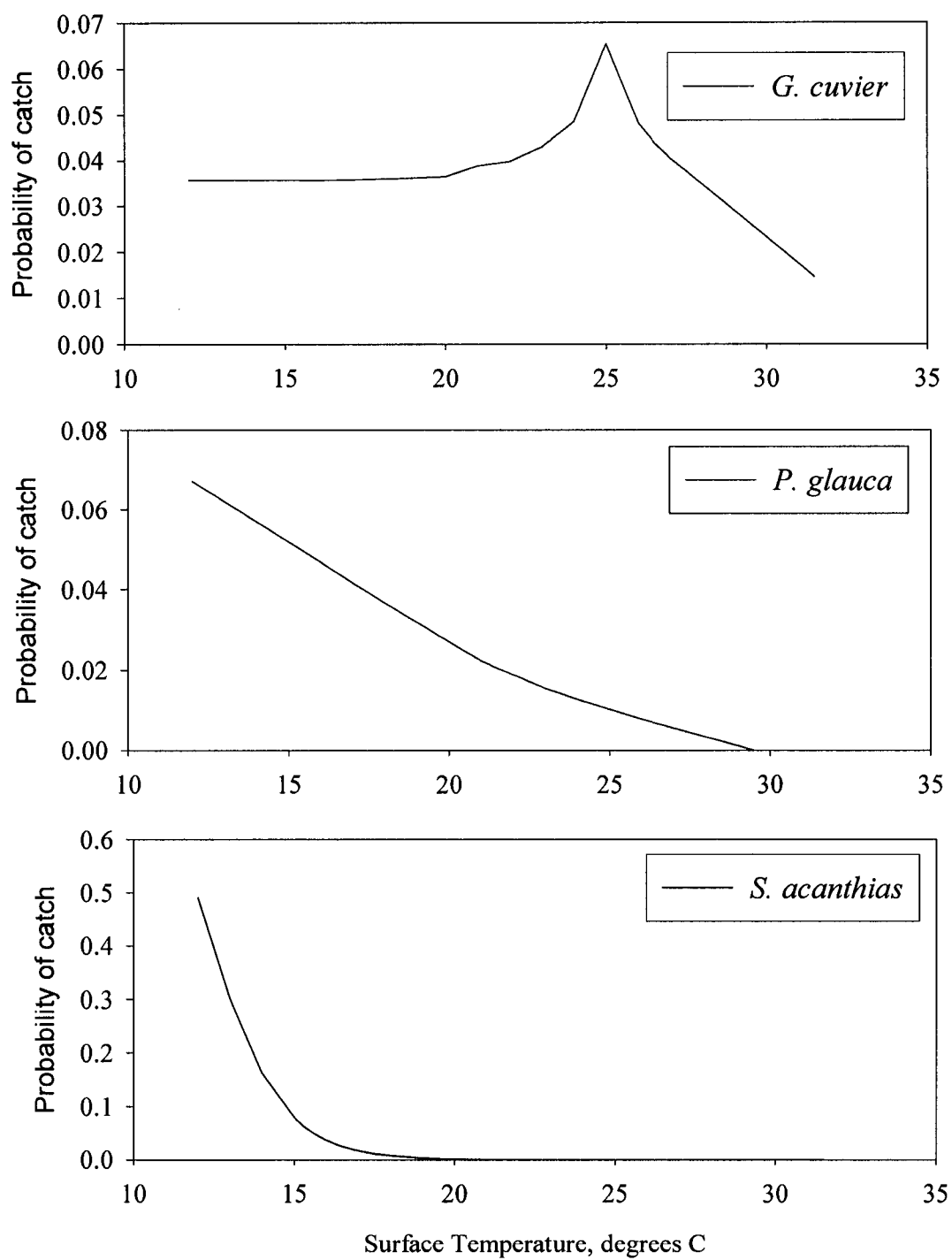


Figure 4.16: Significant results for surface temperature from logistic analyses of species that did not meet the criterion for GLM analysis, as described in this chapter. The Y axis in these graphs is in the probability of capture of the species.

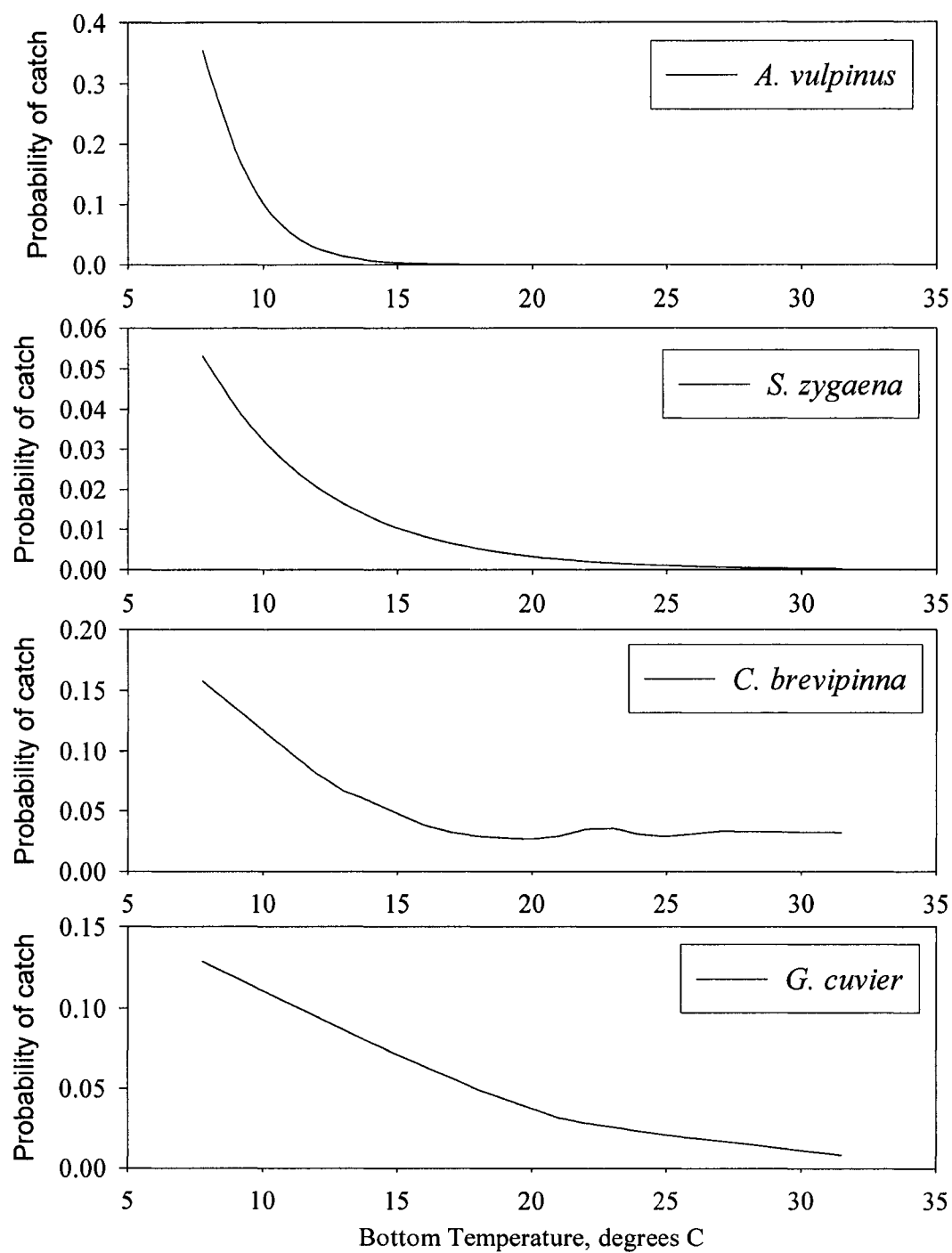


Figure 4.17: Significant results for bottom temperature from logistic analyses of species that did not meet the criterion for GLM analysis, as described in this chapter. The Y axis in these graphs is in the probability of capture of the species.

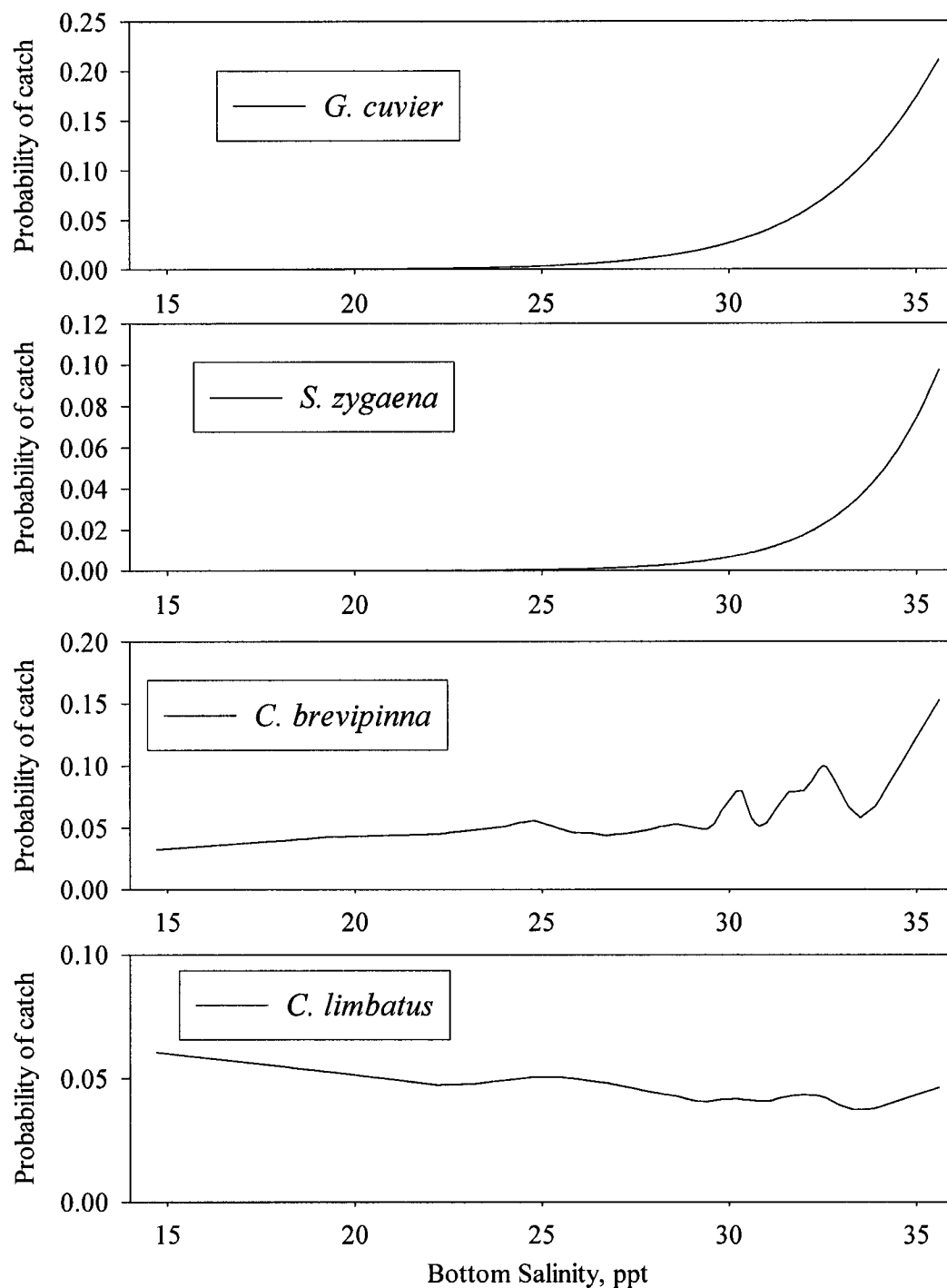


Figure 4.18: Significant results for bottom salinity from logistic analyses of species that did not meet the criterion for GLM analysis, as described in this chapter. The Y axis in these graphs is in the probability of capture of the species.

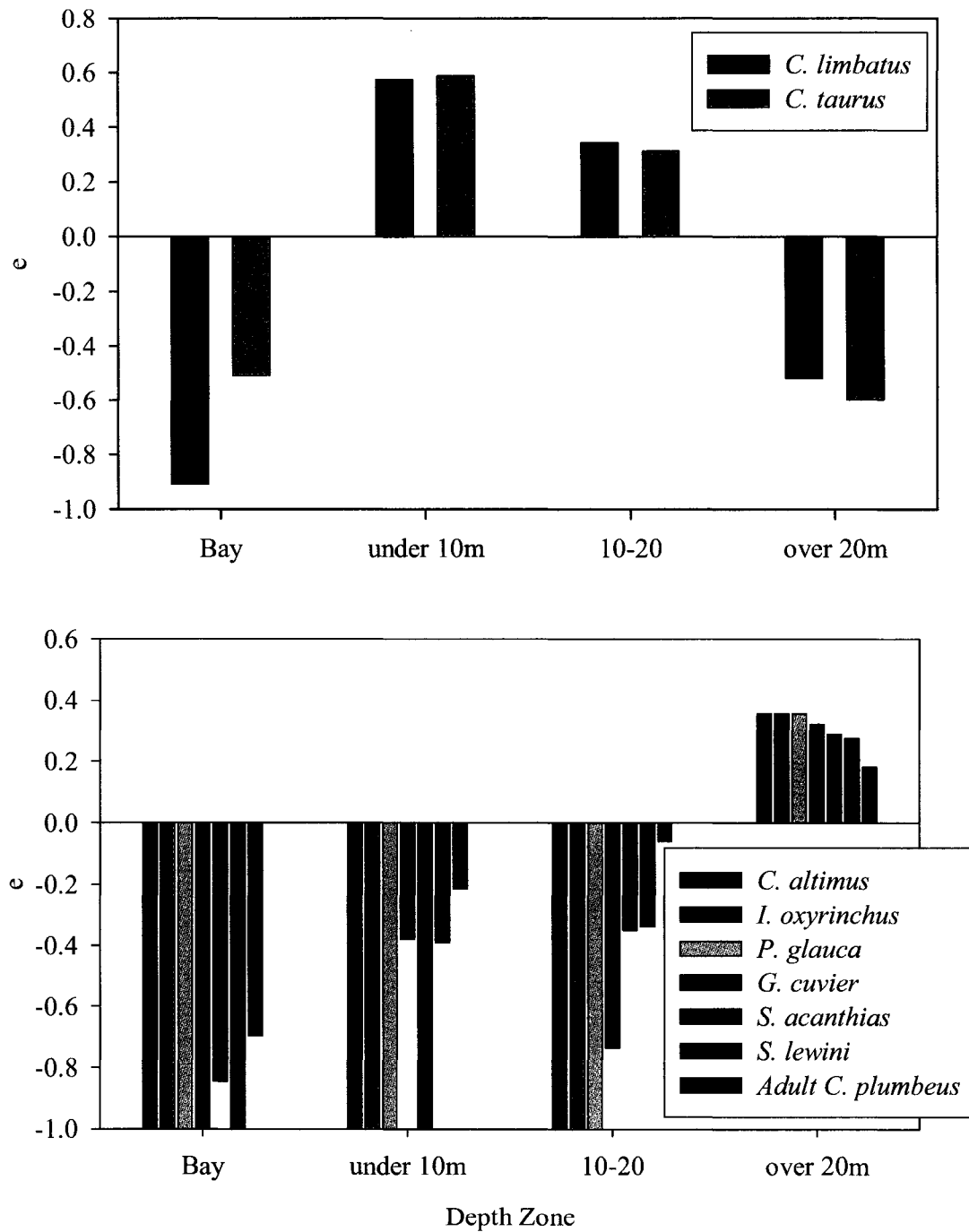


Figure 4.19: Results of electivity analyses by depth zone. The Y axis is in electivity, in which a value of 1 indicates total preference for, -1 indicates total preference against, and 0 indicates no preference.

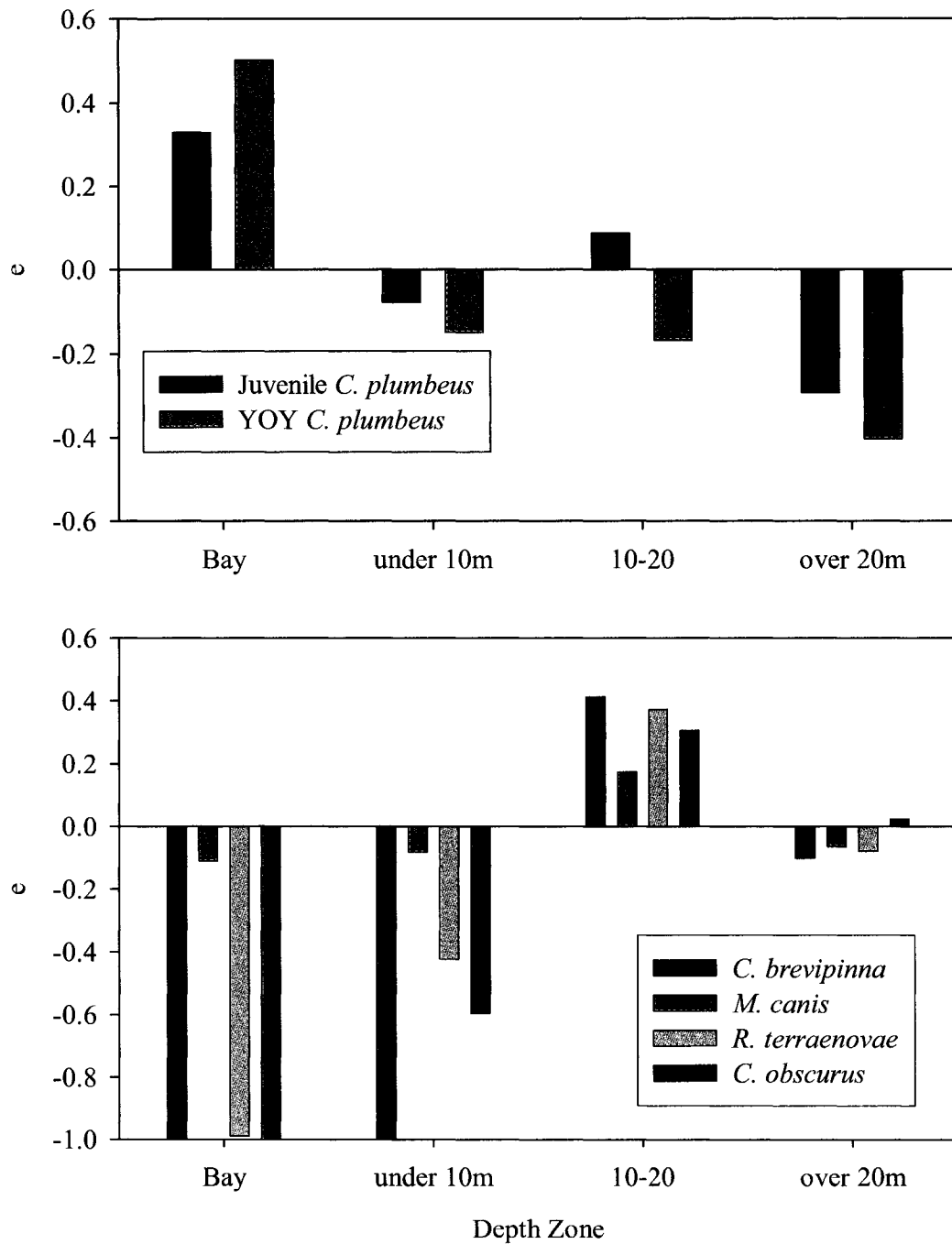


Figure 4.20: Results of electivity analyses by depth zone. The Y axis is in electivity, in which a value of 1 indicates total preference for, -1 indicates total preference against, and 0 indicates no preference.

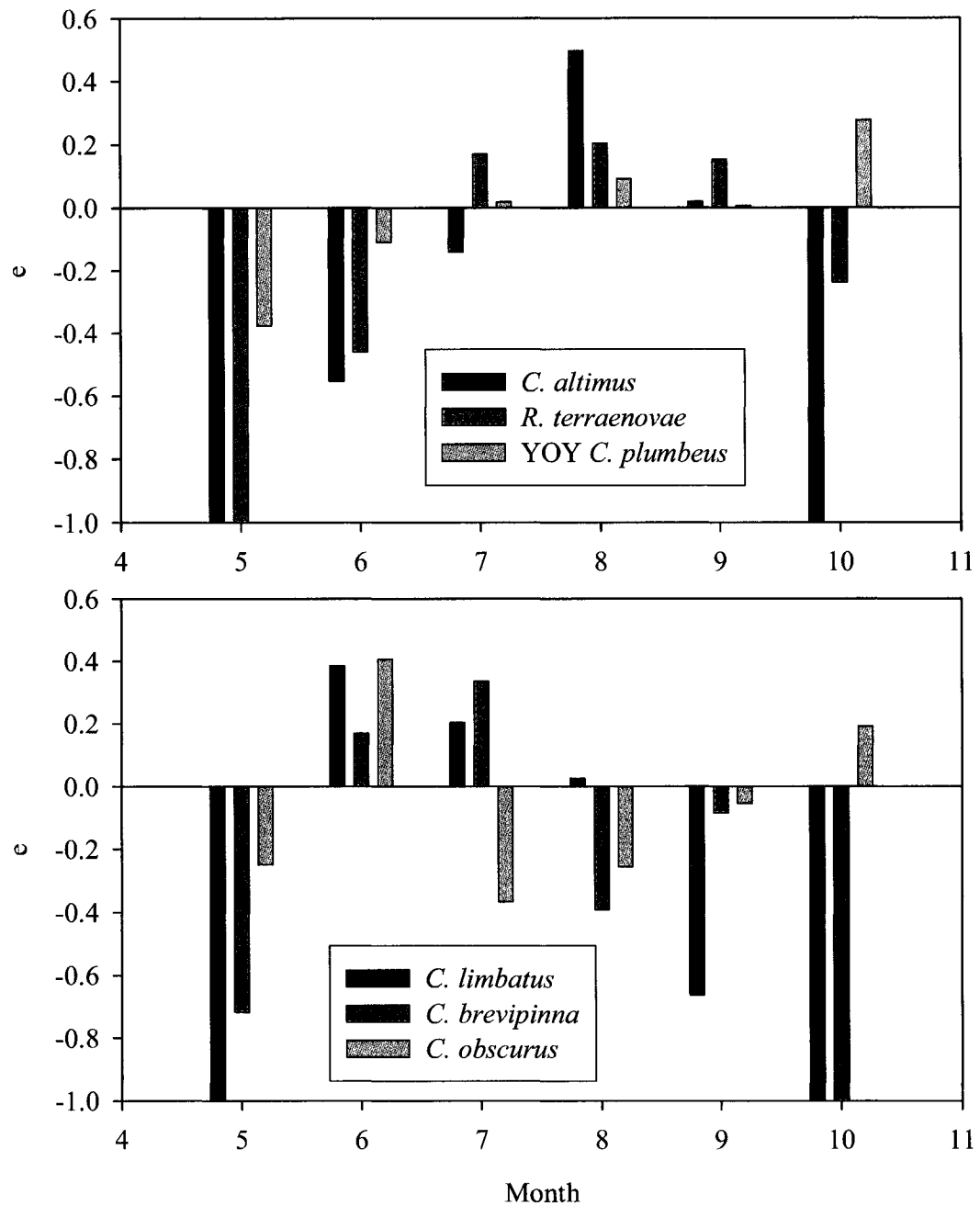


Figure 4.21: Results of electivity analyses by month. The Y axis is in electivity, in which a value of 1 indicates total preference for, -1 indicates total preference against, and 0 indicates no preference.

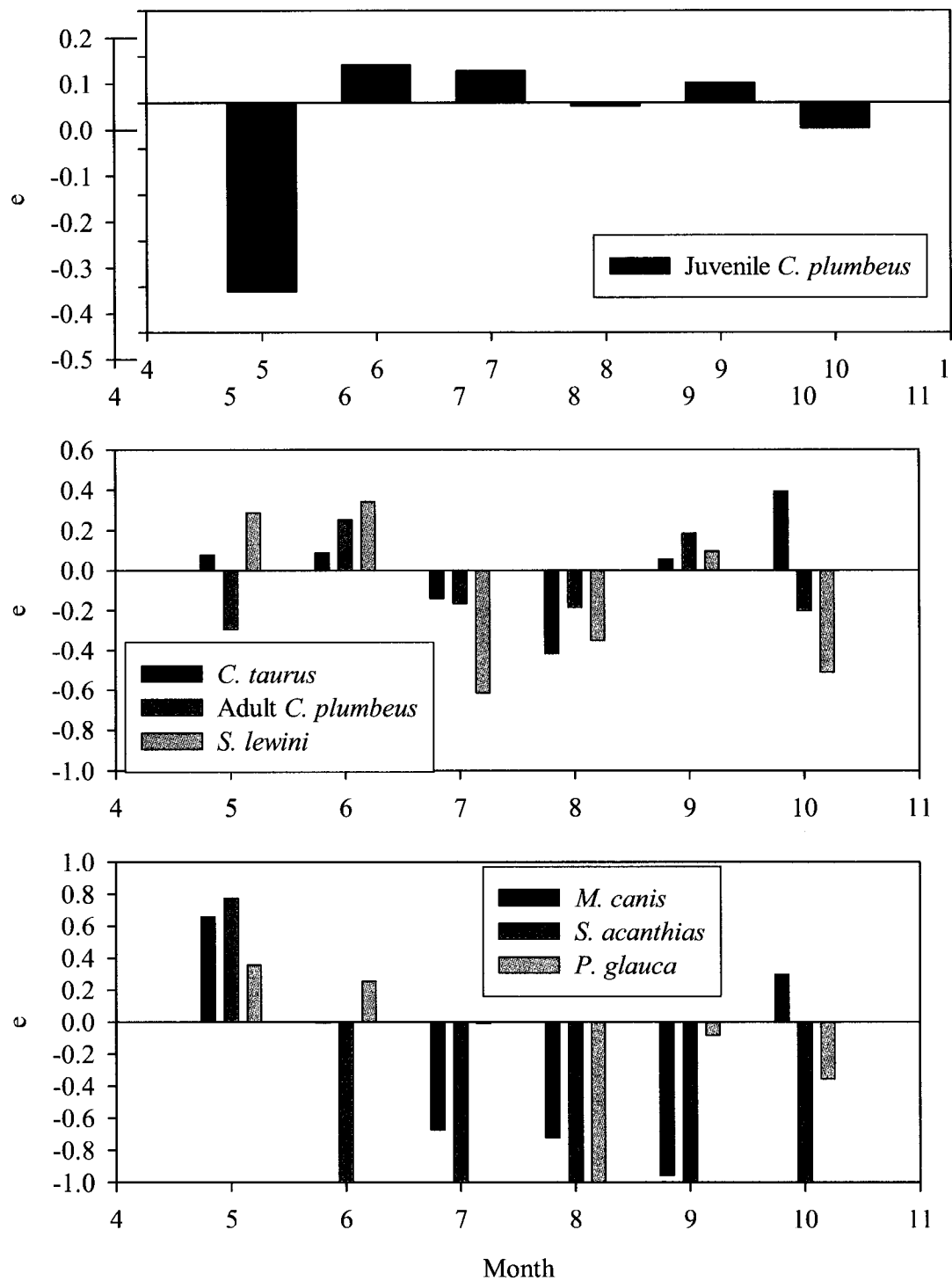


Figure 4.22: Results of electivity analyses by month. The Y axis is in electivity, in which a value of 1 indicates total preference for, -1 indicates total preference against, and 0 indicates no preference.

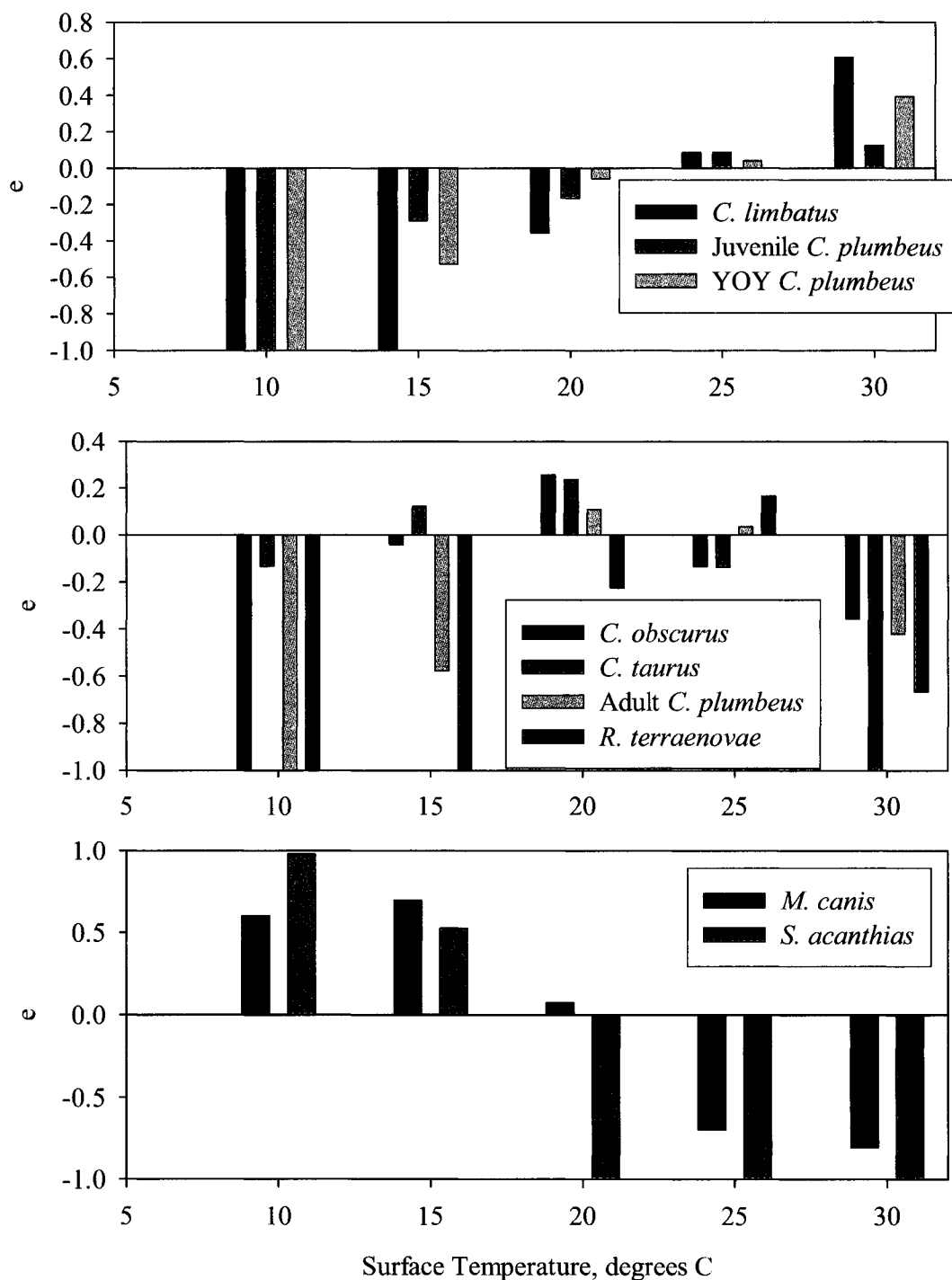


Figure 4.23: Results of electivity analyses by surface temperature. The Y axis is in electivity, in which a value of 1 indicates total preference for, -1 indicates total preference against, and 0 indicates no preference.

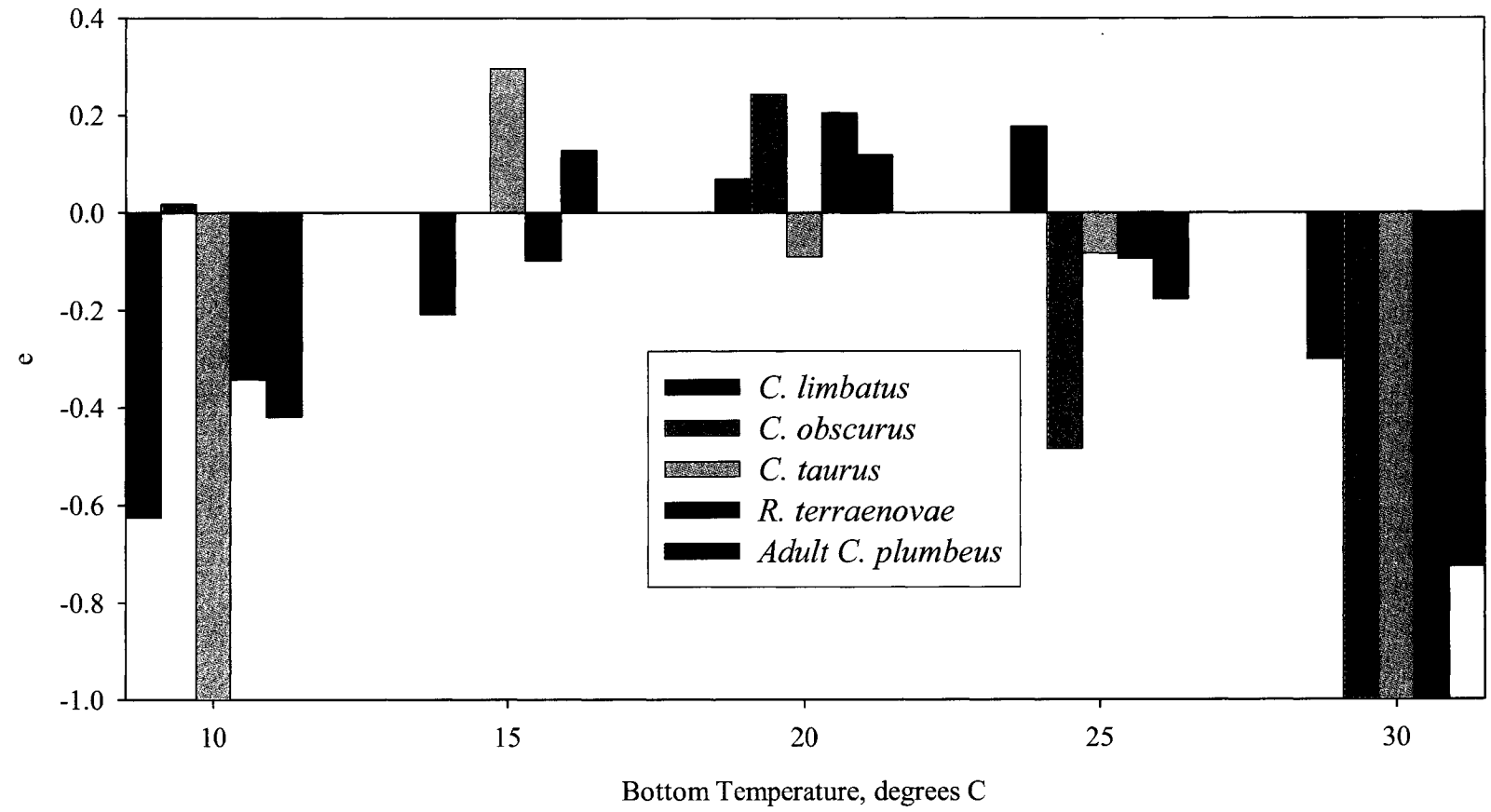


Figure 4.24: Results of electivity analyses by bottom temperature. The Y axis is in electivity, in which a value of 1 indicates total preference for, -1 indicates total preference against, and 0 indicates no preference.

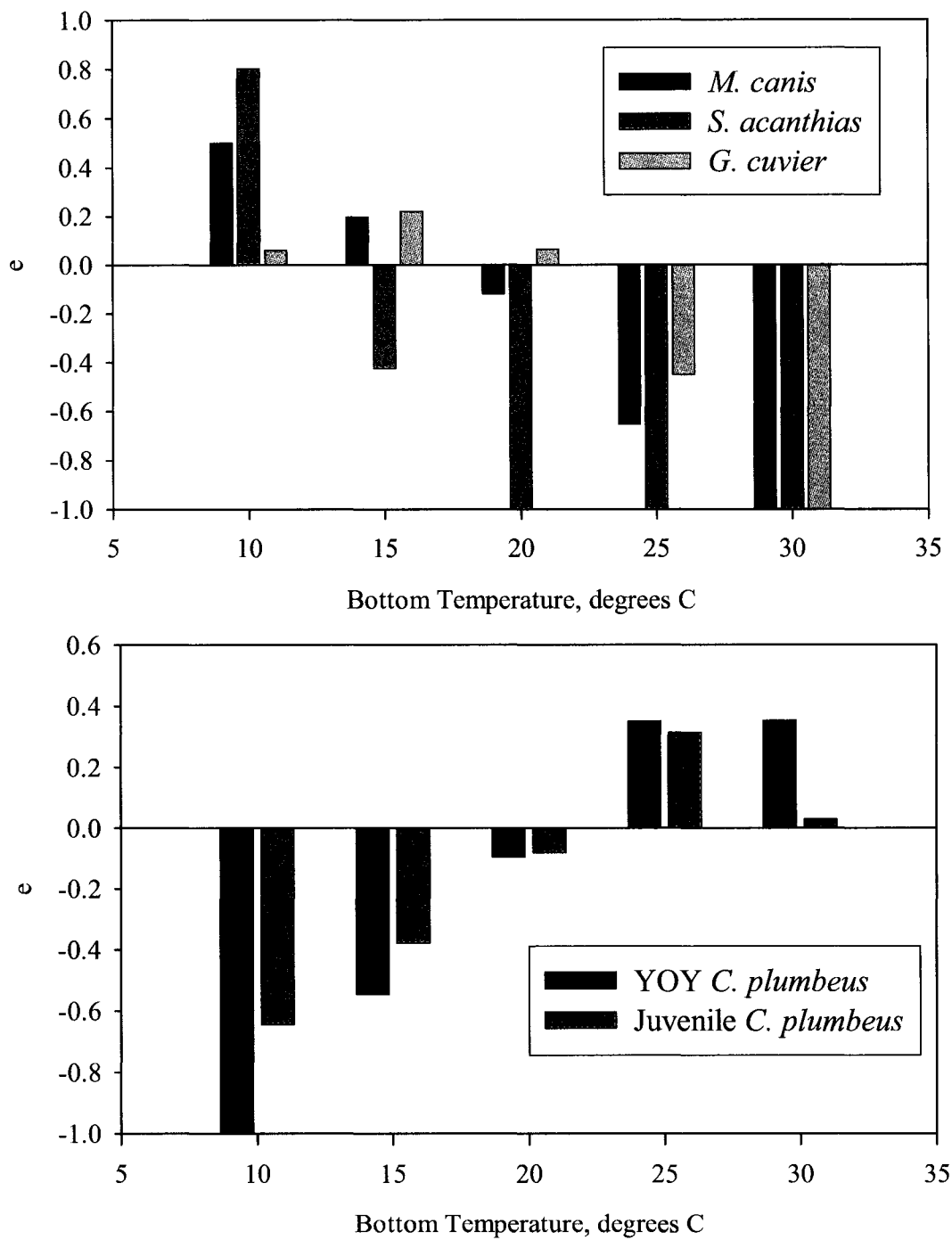


Figure 4.25: Results of electivity analyses by bottom temperature. The Y axis is in electivity, in which a value of 1 indicates total preference for, -1 indicates total preference against, and 0 indicates no preference.

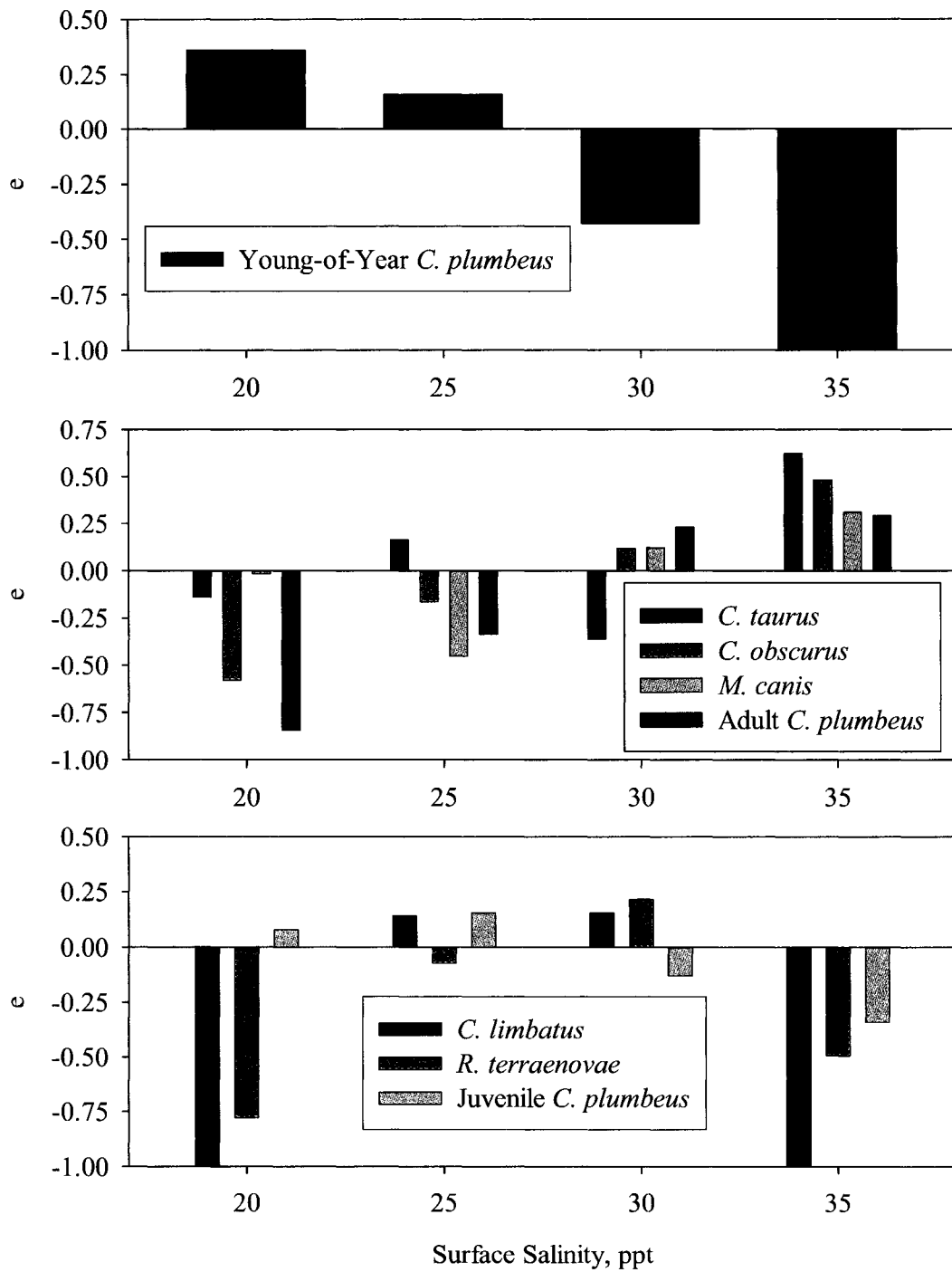


Figure 4.26: Results of electivity analyses by surface salinity. The Y axis is in electivity, in which a value of 1 indicates total preference for, -1 indicates total preference against, and 0 indicates no preference.

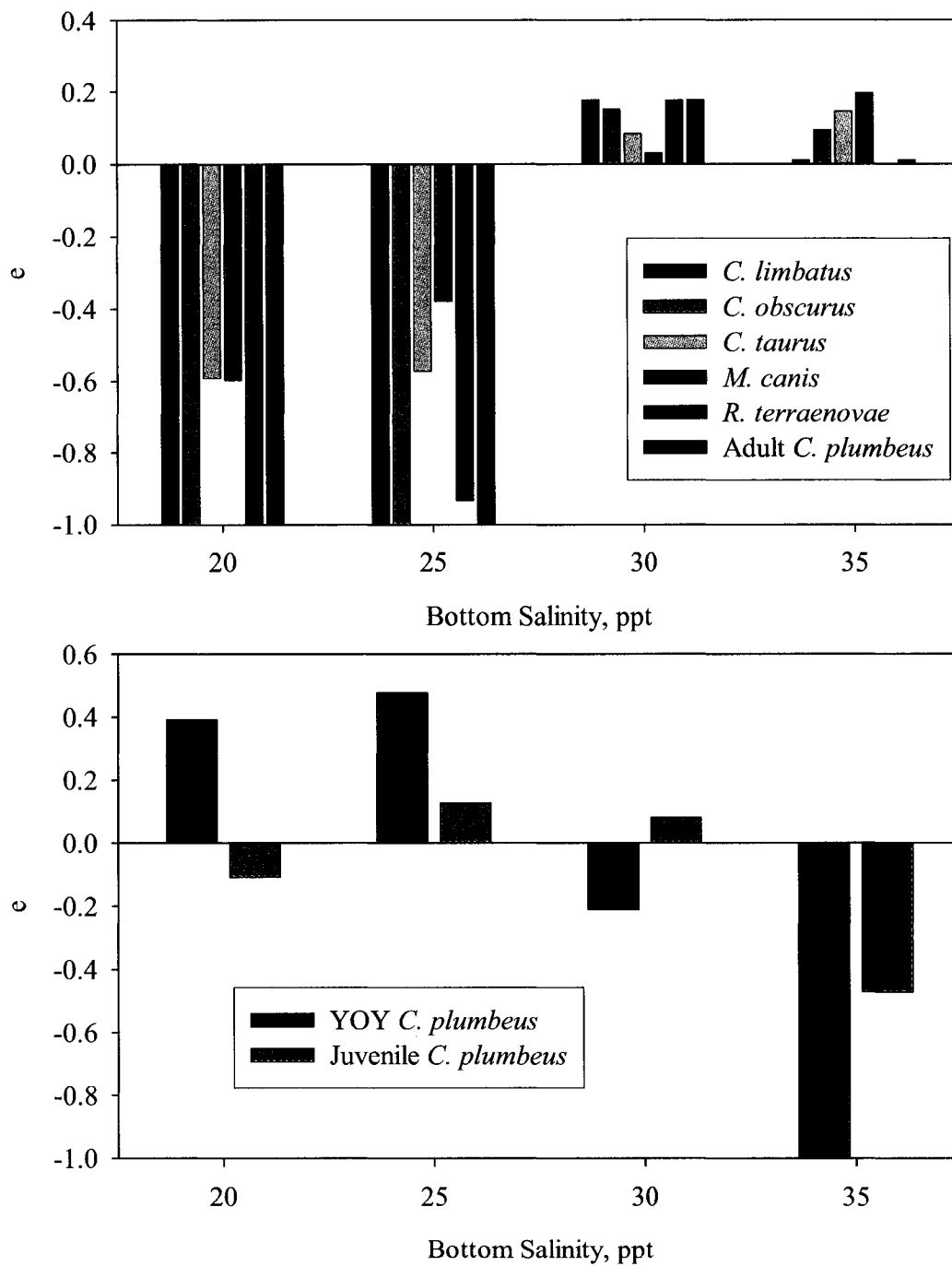


Figure 4.27: Results of electivity analyses by bottom salinity. The Y axis is in electivity, in which a value of 1 indicates total preference for, -1 indicates total preference against, and 0 indicates no preference.

Chapter 5: Historical Comparison of Shark Abundances off New Jersey.

Introduction

In the summer of 1961, J. A. Musick and J. A. Casey conducted a long-line survey off the coast of New Jersey (Figure 5.1). Since there are few studies available to compare with the findings of the VIMS Virginia long-line survey, resampling of some of the sites sampled in 1961 was performed. The results might provide insights into both early abundances, and whether the trends seen in the Virginia long-line survey exist in other areas of the Atlantic coast. In addition, other studies comparing long term trends in shark abundance (Baum et al. 2003) have been criticized because of changes in fishing gear and techniques during the course of the study. The present New Jersey study offers a rare opportunity to compare shark CPUEs for the same locations over a more than forty year time span using the same fishing gear and methods.

Methods

The 1961-62 data were obtained from NMFS, and a sub-sample of the 1961 sites were resampled in July of 2005 (Figure 5.2). Further description of methods can be found in Chapter 1. The 1962 data were used only to increase sample sizes for biomass comparisons. The 1961 surveys were conducted between August and October of 1961, at

water depths ranging from 4 m to 900 m. Sets varied from 76 to 321 hooks, with a mean of 127 ± 10 .

Statistical Methods

Eighteen stations from the 1961 survey were resampled in 2005 (Figure 5.2). Catch data for both 1961 and 2005 data were converted to catch per unit effort in the same manner as used in Chapter 2, by dividing the catch by the number of hooks times the number of soak hours. Thus, CPUE for this chapter is defined as catch (number of sharks) per effort (hook * hours). Weight was also calculated for every fish measured, using the same length conversions (Chapter 3, Table 3) and length/weight equations (Chapter 3, Table 4) as used earlier. Since these data represent only two points in time, t-tests were used to compare the CPUE and mass data for each species that occurred in both sampling years by station. For this reason, the CPUE data did not have to be transformed as in Chapter 2.

The 1961/2005 comparison data were used to estimate shark abundances (LCS, *C. obscurus*, *G. cuvieri* and *C. plumbeus*) in Virginia in 1961 based on the ratio between the two sampling years. The proportion 1961/2005 was multiplied by 2004 (2003 for *G. cuvieri*) Virginia long-line CPUE's for the sharks under study, and the result was used as the estimate for Virginia sharks abundance in 1961. These yearly CPUE data were lowess-smoothed using Proc GAM with the SAS statistical package (SAS Inc., 2002).

For information on the early stock composition, length-frequency distributions for all species with an sample size higher than five were made. In order to increase sample

sizes, sharks collected in the 1962 continuation of the 1961 survey were included in this analysis.

Results

Six species occurred in both sampling years, while 2 were caught only in 1961, and 2 were caught only in 2005 (Table 5.1). The mean biomass per standard set of the long-line in 2005 was 14% of the same in 1961 (Table 5.1). The most common species in both years was *C. plumbeus* (Figure 5.3), while the rarest species in both years was *A. vulpinus* (Table 1). Most species that occurred in both 1961 and 2005 had lower mean sizes and narrower size distributions in 2005 than in 1961 (Figures 3-4). One exception to this was *M. canis*, which showed similar distributions between these two years (Figure 5.3). *Carcharhinus obscurus* might have been another exception, as it showed a similar mean between years, although data were sparse from the 2005 dataset (Figure 5.3).

The CPUE of two species, *C. obscurus* and *G. cuvier*, declined between 1961 and 2005 (Table 5.1). Mean weight per shark declined significantly in three species (*C. plumbeus*, *C. obscurus*, and *I. oxyrinchus*), increased significantly in one (*M. canis*), and the error for *G. cuvier* mass in 2005 is not estimable because only one individual was caught in 2005. The results of including an estimated 1961 CPUE point in the Virginia long-line data showed dramatic 1961-1973 declines in all species except *C. plumbeus* (Figure 5.5). The LCS complex also showed a decline in CPUE with the estimated 1961 point added (Figure 5.6).

Discussion

The decline in abundances of both tiger and dusky sharks was similar to the decline found in those species in the VIMS Virginia long-line survey (see Chapter 2). The qualitative declines in abundance (although not statistically significant) in *C. plumbeus* were also seen in the VIMS Virginia long-line survey. The declines in mean mass per shark in *C. plumbeus*, *I. oxyrinchus*, *C. obscurus* and *G. cuvieri* also mirrored the trends found in the VIMS Virginia long-line survey (Chapter 3). These findings provide separate corroboration of the patterns found in the more detailed Virginia data set, suggesting that any trends in abundance and/or mean body mass are not unique to Virginia or to the sampling period, at least for these species, some of the most common on the Atlantic coast north of Cape Hatteras (NMFS 2003). When the declines in weight are examined jointly with the size-frequency distributions, one has a clearer snapshot of pre-exploitation shark population parameters than has previously been available for this area.

The results of estimation of 1961 Virginia CPUE levels from the New Jersey comparison show that declines in shark populations began before the advent of recorded commercial fishing pressure (Figure 1.1). Unreported fishing mortality, either in directed commercial or recreational fisheries or as bycatch may be a factor in this, although no other studies exist for comparison. The anomalous result in *C. plumbeus* may be caused by the change in size composition of *C. plumbeus* rather than any other factor, since the Virginia long-line sample includes one of the largest nursery grounds for this species.

Species	Total Length, cm				Mass, kg				Mean CPUE			Total Biomass		
	1961-62		2005		1961		2005		1961	2005		1961	2005	
	N	Mean	N	Mean	N	Mean	N	Mean						
<i>Carcharhinus plumbeus</i>	162	195.24	32	157.32	43	63.20	32	27.06	***	0.01	0.005		259	55
<i>Carcharhinus obscurus</i>	91	145.48	10	116.60	25	31.75	10	10.69	*	0.006	0.002	**	72	7
<i>Mustelus canis</i>	70	104.34	26	111.85	38	5.01	26	9.87	***	0.002	0.004		5	15
<i>Galeocerdo cuvier</i>	28	246.31	1	178.00	12	169.01	1	26.66		0.004	2E-04	*	240	2
<i>Isurus oxyrinchus</i>	6	237.91	6	154.30	4	126.00	6	36.82	***	0.001	8E-04		51	12
<i>Sphyrna lewini</i>	11	237.99											0	0
<i>Carcharodon carcharias</i>	7	208.59			3	99.15				4E-04			15	0
<i>Carcharias taurus</i>	6	243.16			1	112.50				3E-04			13	0
<i>Sphyrna zygaena</i>	2	132.08											0	0
<i>Alopias vulpinus</i>	1	388.62			1	247.50	1	101.25		3E-04	1E-04		29	5
<i>Carcharhinus leucas</i>	1	264.00											0	0
<i>Squalus acanthias</i>			3	77.50			2	1.95			2E-04		0	0
<i>Rhizoprionodon terraenovae</i>			1	950.00			1	4.15			4E-04		0	1
													684	98

Table 5.1. Summary of species collected at the sites sampled in both 1961 and 2005 off the New Jersey coast. Length values include 1961 and 1962 data as described in the text to give a better idea of the size structure of shark populations off New Jersey in the early 1960's. Only sharks caught in 1961 sets were used in the t-tests comparing CPUE and biomass. The final two columns are the average biomass of each shark species in each year of this study, with the total of all shark species at the bottom. Significance values from t-tests are also shown.

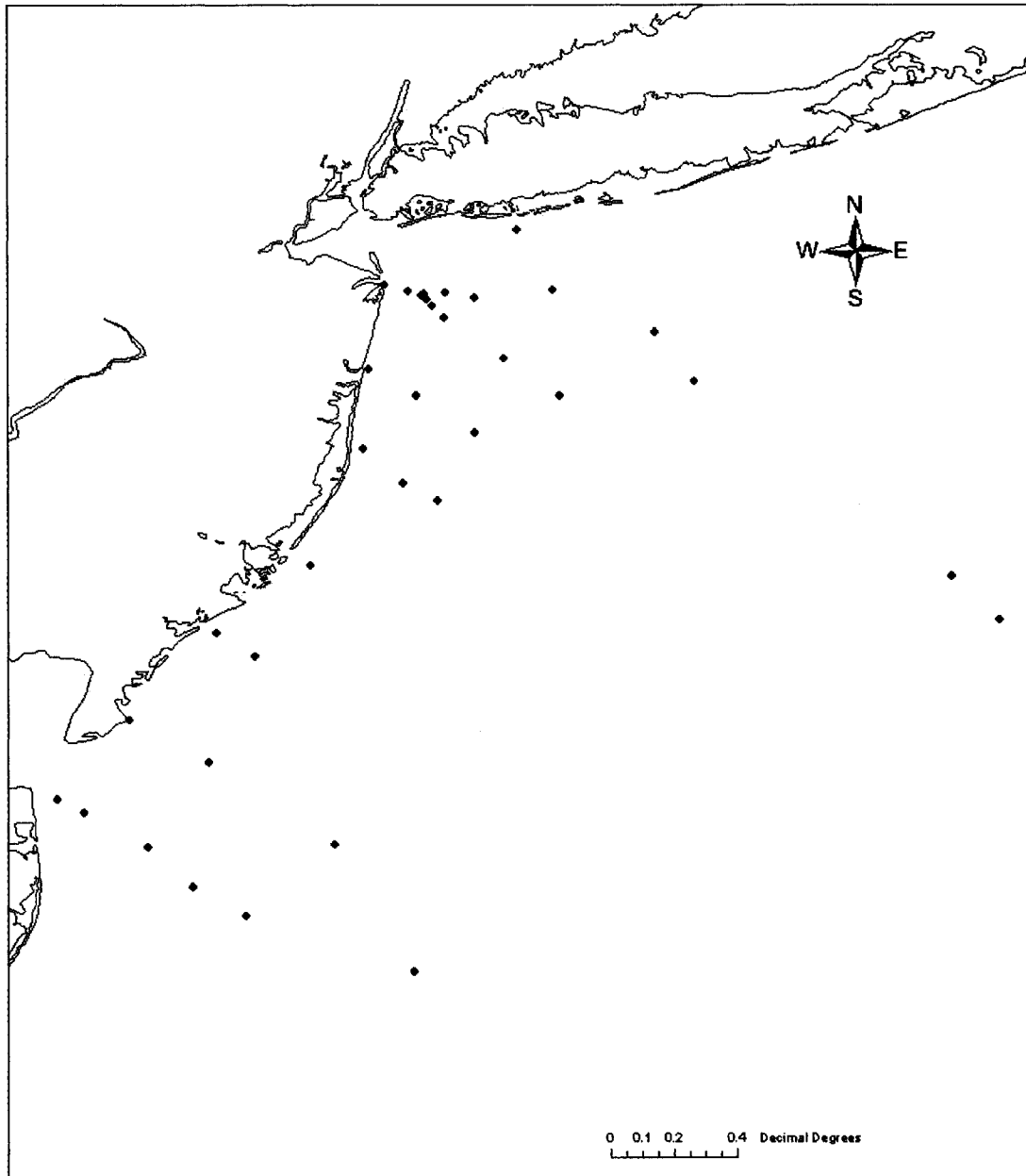


Figure 5.1. Map showing all stations sampled in the 1961 long-line sampling program.

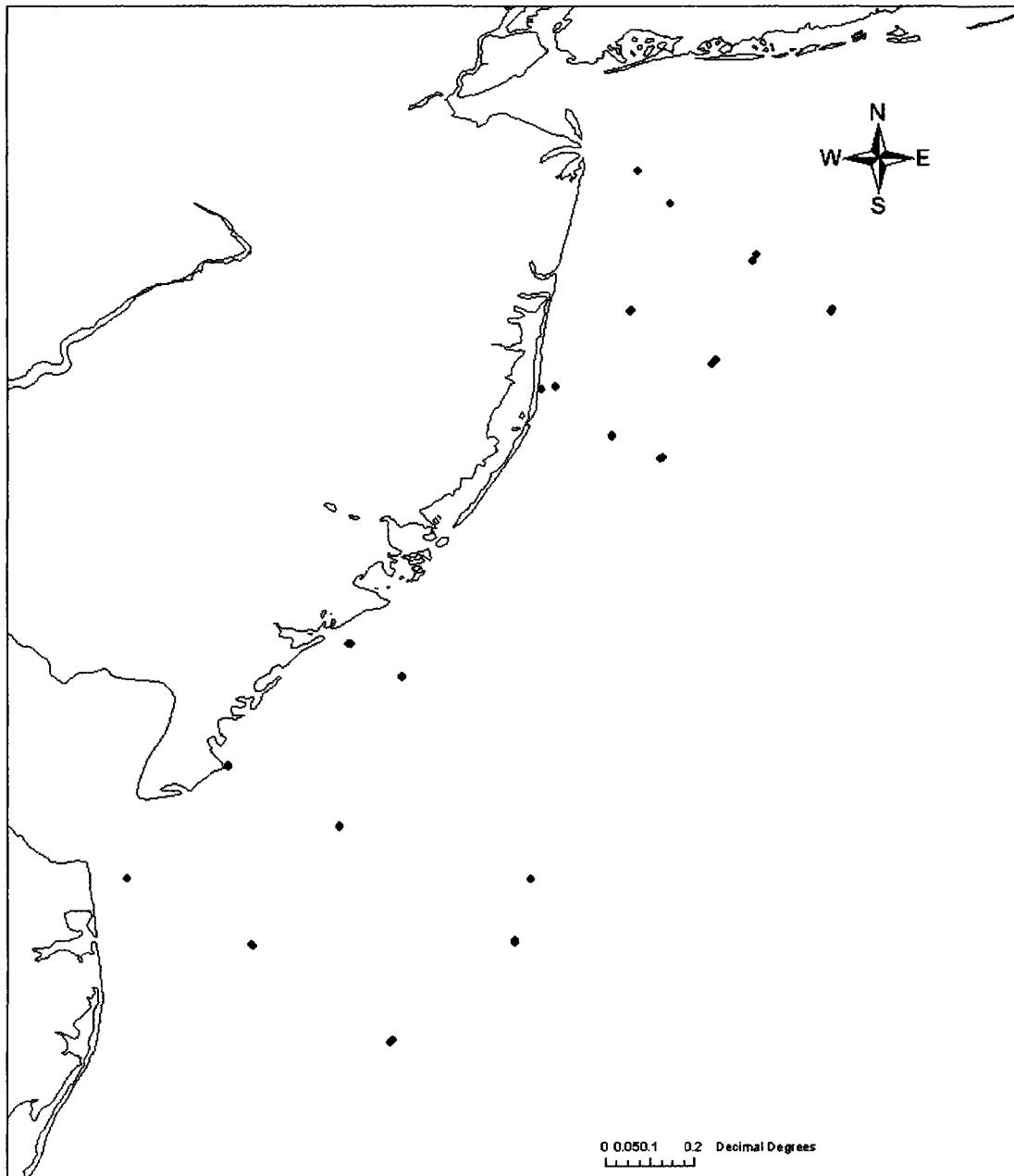


Figure 5.2. Map showing sites sampled in 1961 that were re-sampled in 2005.

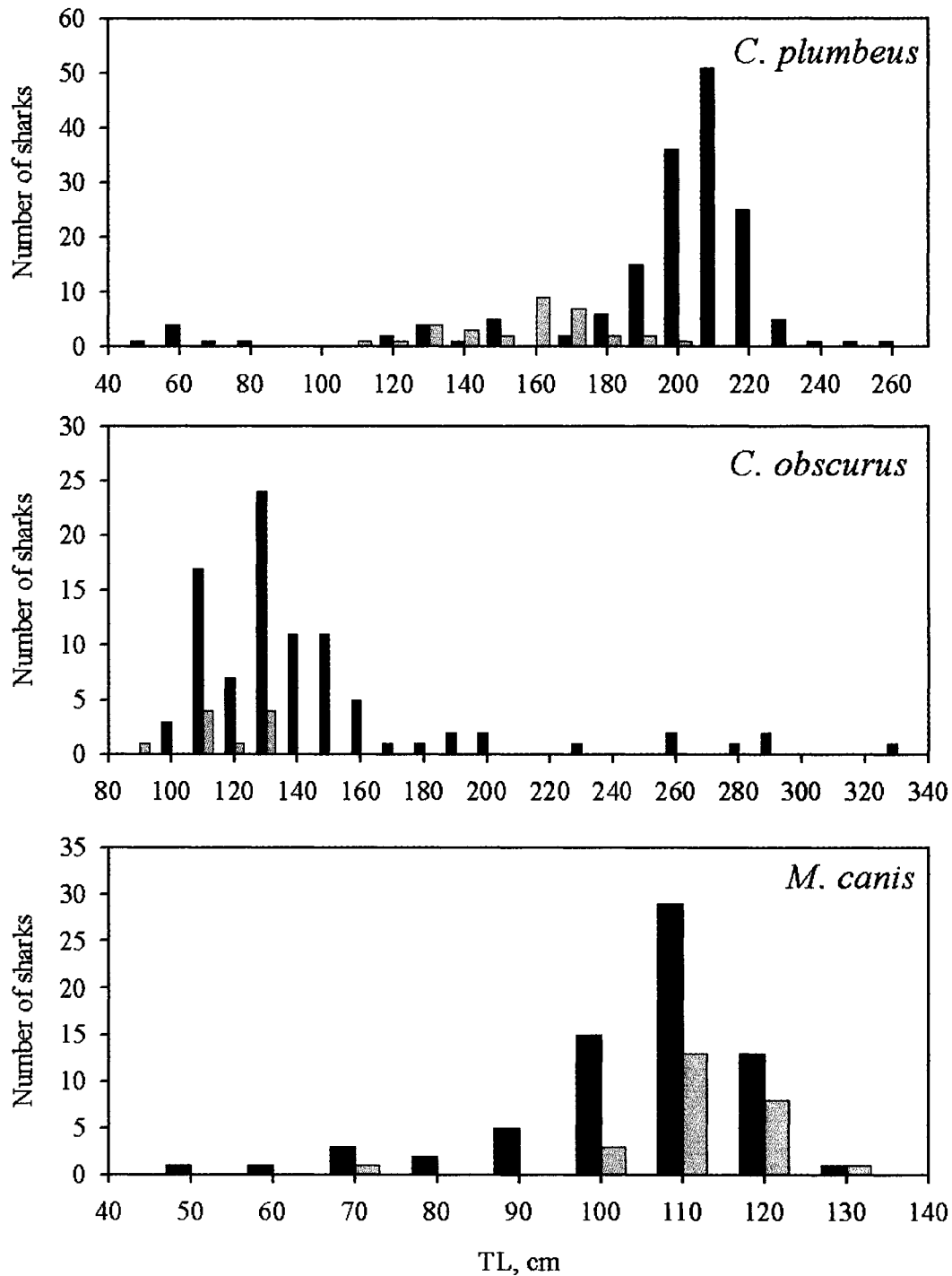


Figure 5.3. Size-frequency histograms of the three most abundant species in 1961 data. Dark bars represent 1961/62 data, while grey bars indicate 2005 data.

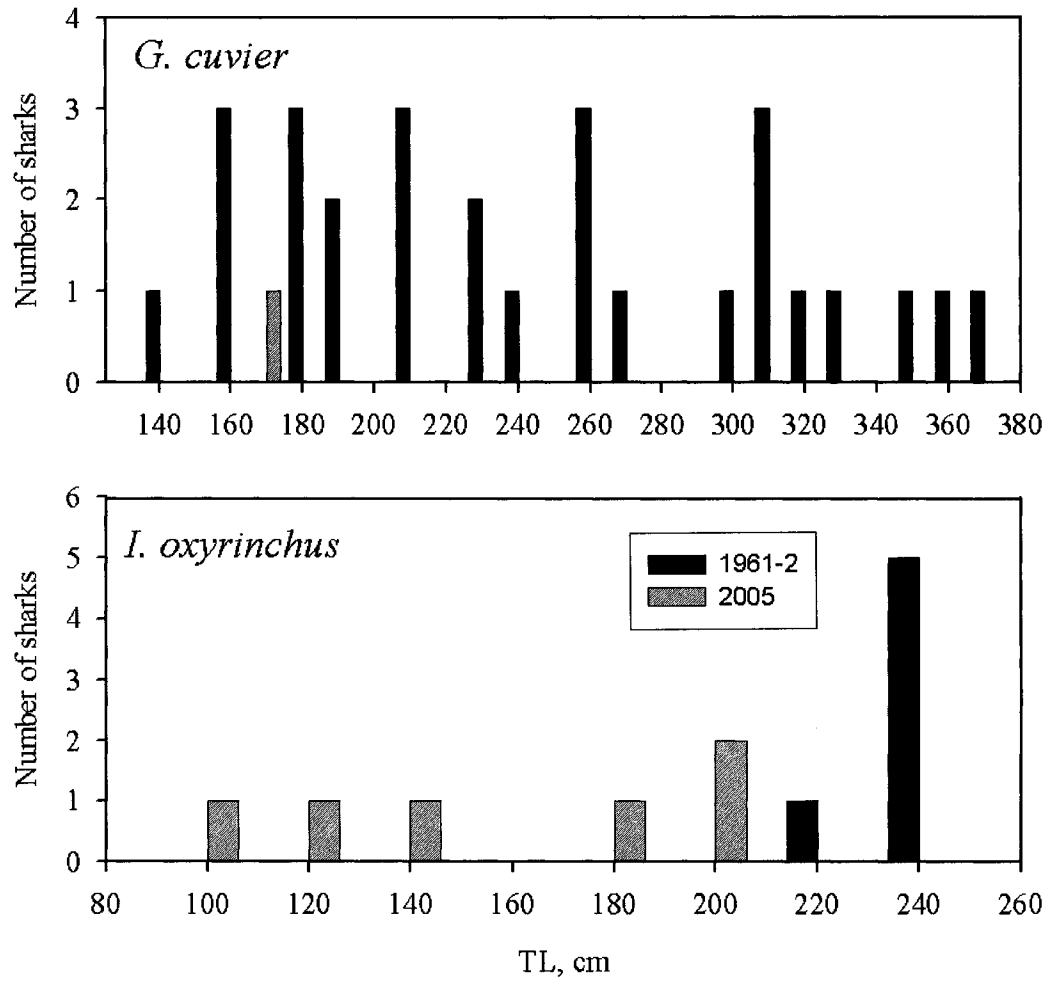


Figure 5.4. Size-frequency histograms of less common species in 1961/2 data.

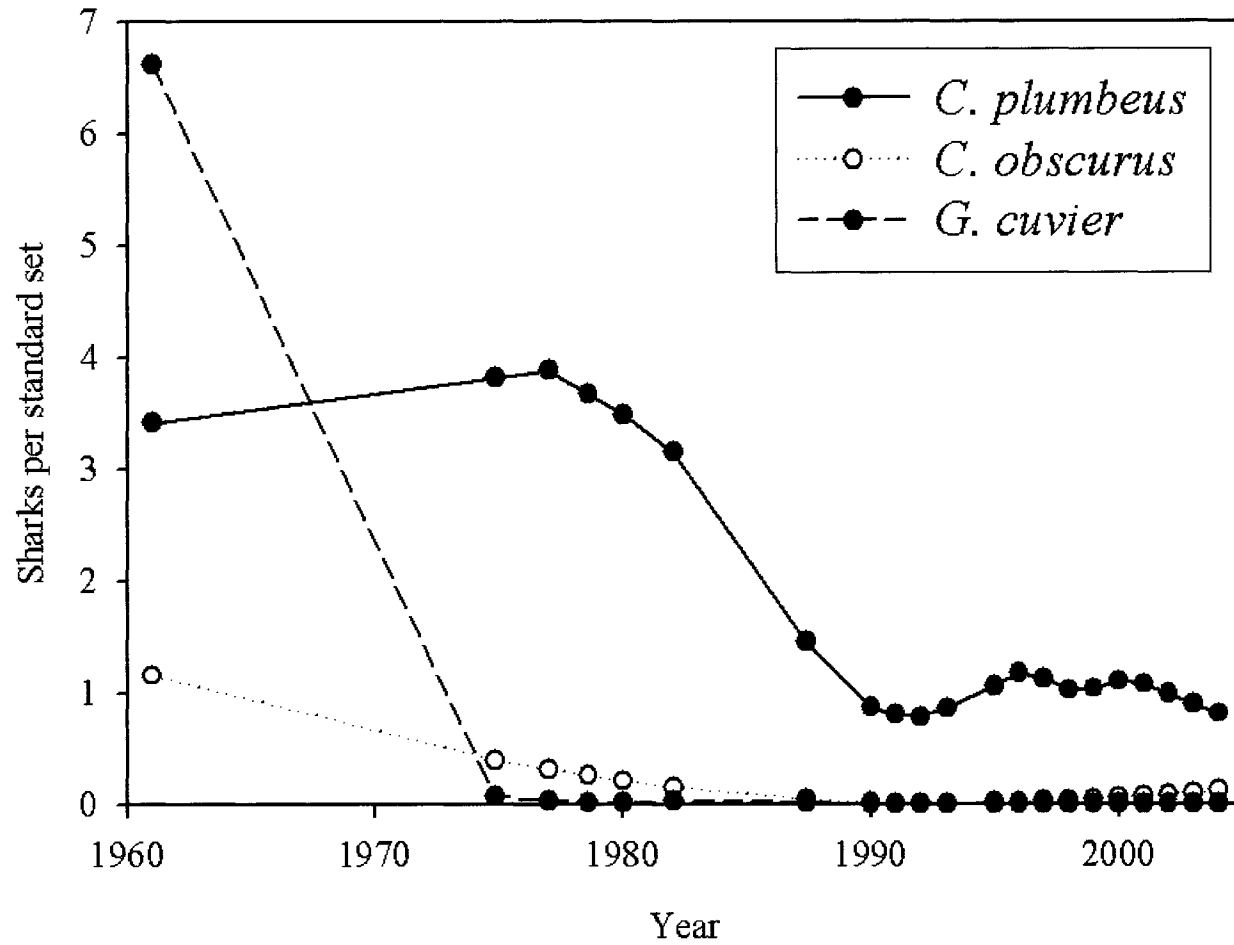


Figure 5.5. Result of inclusion of a 1961 data point estimated from the New Jersey comparison into the Virginia long-line data, for *C. plumbeus*, *C. obscurus*, and *G. cuvier*.

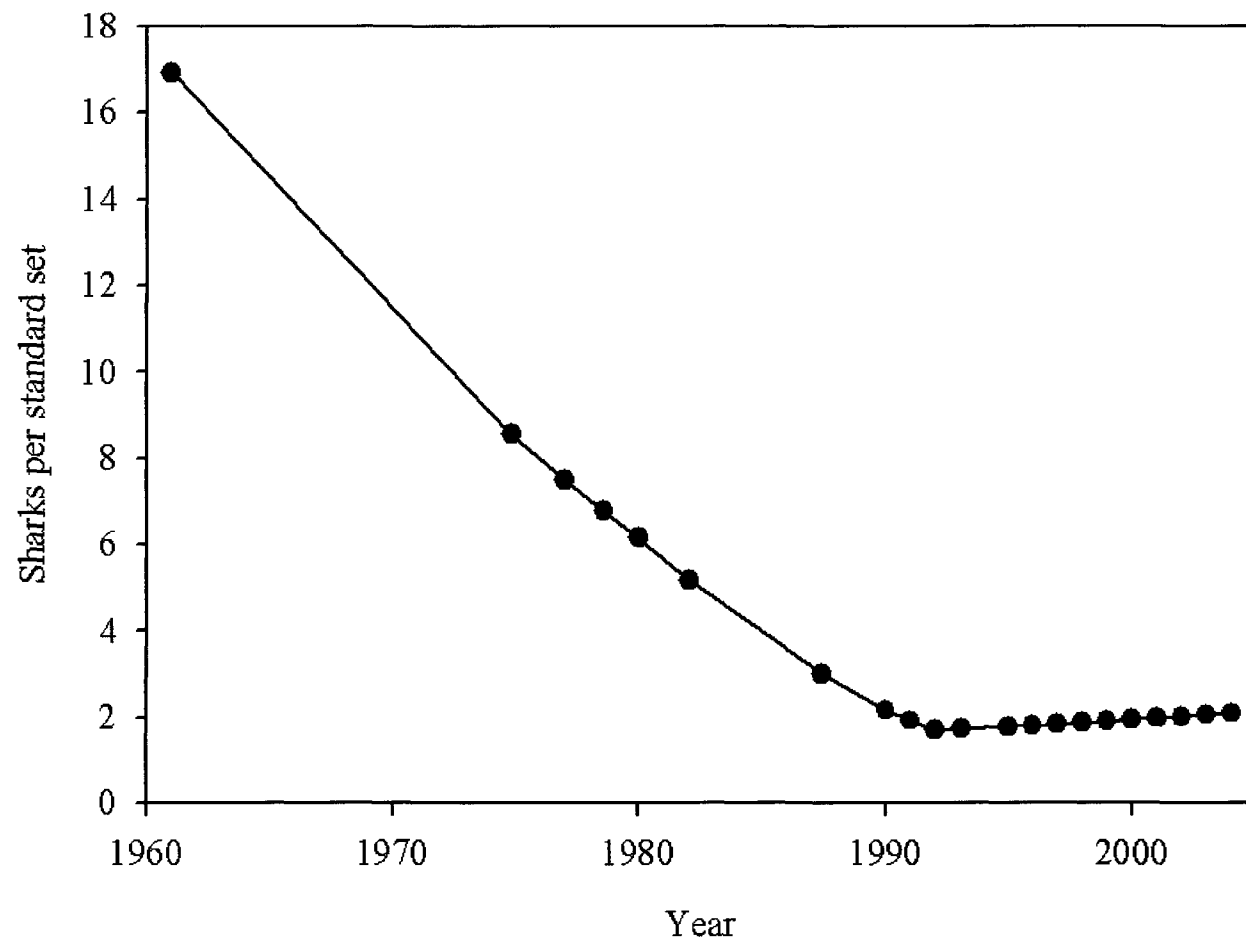


Figure 5.6. Result of inclusion of a 1961 data point estimated from the New Jersey comparison into the Virginia long-line data, for the LCS management group (original definition, 1992).

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VITA

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Daniel Stuart Ha was born in Miami, Florida on January 20, 1970. He graduated from Solanco Hish School in Quarryville, Pennsylvania in June 1988. Daniel received his Bachelor of Sciences degree from Millersville University in Millersville, Pennsylvania in June 1993, with a major in Biology (Marine option) and a minor in Theatre (technical option). He received his Master of Sciences degree from the University of Windsor in Windsor, Ontario, Canada in June 1996, in Biological Sciences. His Master's thesis title was, ““An Investigation of Timed-Tethering: A Method for Study of Coral Reef Piscivory.”

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