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Tagging and Habitat Utilization of Juvenile Summer Flounder, Paralichthys dentatus

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TAGGING AND HABITAT UTILIZATION OF JUVENILE SUMMER FLOUNDER, *Paralichthys dentatus*

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Richard Thomas Kraus

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of

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This thesis is dedicated to Dr. and Mrs. David Charles Kraus, my parents, whose devoted love has inspired and supported my determination to make a career in marine science.

"Fish have tails."
Julian Anthony Penello
1995

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ABSTRACT

Recent management objectives have outlined the needs to continue developing stock identification methods and evaluate the habitat requirements of summer flounder, *Paralichthys dentatus*. As summer flounder is a highly migratory species with a remarkably dynamic life history, it is necessary to treat ontogenetic stages separately when considering habitat and migrations. This study, consisting of two parts, focuses on the inshore juvenile life history stage, for which a comprehensive view is lacking. Over 10,000 juvenile summer flounder were tagged in Chesapeake Bay and the seaside Eastern Shore of Virginia. Short-term recaptures showed that growth rates of juveniles in late summer on the seaside of Virginia's Eastern Shore were similar to growth rates of tagged individuals in New Jersey, 1.3mm/day (Rountree & Able 1992). Long-term recaptures, five in all, were reported from Cape Henlopen to Long Island Sound, demonstrating that while juveniles may reside rather permanently in estuaries during the summer, they are capable of regional scale migrations in less than one year at large. Holding studies do not explain the lack of recaptures. Data from VIMS' juvenile finfish trawl survey, spanning 18 years and over 13,000 observations, were analyzed to develop a model of juvenile summer flounder habitat utilization in the Chesapeake Bay. GIS technology was used to apply additional variables to the data set, and logistic regression techniques were used to model the seasonal presence or absence of a summer flounder in trawl catches. Logistic regression modeling identified significant yearly fluctuations in occurrence, increased catch probability at mid-range salinities (4-20ppt), and demonstrated the importance of proximity to SAV in catching summer flounder. Decreased catch probability was observed in hypoxic conditions and at low temperatures. One habitat variable not considered in previous studies is slope of the bottom, which is shown here to significantly increase the probability of summer flounder occurrence in trawl catches.

TAGGING AND HABITAT UTILIZATION OF JUVENILE SUMMER FLOUNDER, *Paralichthys dentatus*

GENERAL INTRODUCTION

The summer flounder, *Paralichthys dentatus*, is a highly migratory coastal bothid (Pleuronectiformes) of the northwestern Atlantic, and occurs from Nova Scotia, Canada to Florida, USA (Nelson 1994). The summer flounder fishery is one of the largest within the Mid-Atlantic Bight (MAB), and landings have historically been split 60% commercial and 40% recreational (Anonymous 1995). Estimations of stock biomass show a 60% decline over the past two decades with only 12% of the stock biomass in age-3 and older fish (Sisson et al. 1994, Anonymous 1995). For comparison, a rebuilt stock fished at a rate of 0.23, fishing mortality at a theoretic maximum sustainable yield (F_{max}), would be expected to have 77% of the biomass in age-3 and older fish (Anonymous 1995). In response to the compressed age structure and the decline in stock biomass of the summer flounder, the Mid-Atlantic Fisheries Management Council and Atlantic States Marine Fisheries Commission (MAFMC&ASMFC) have enacted a fishery management plan (FMP) for summer flounder in which minimum size and mesh size limits are imposed along with quotas to achieve the F_{max} of 0.23 (Scarlett 1981, Amendment 7 to the FMP for summer flounder 1995).

Despite regulations on the fishery and over a decade of new research, comprehensive ecological and life history knowledge is still lacking, and management agencies have yet to adopt a plan which recognizes a multi-stock scenario for summer flounder. Recently, the ASMFC (1997) reiterated the need to "develop stock identification methods via meristics, morphometrics, biochemical research and tagging; particularly off Virginia and North Carolina". In addition, the Magnuson-Stevens Act (1997), administered by National Marine Fisheries Service (NMFS), has mandated that each FMP delineate essential fish habitat (EFH). Summer flounder was chosen as the model species for which the EFH assessment approach prototype was designed (Schreiber & Gill 1995), but the parameters used in the prototype were only those for which source data maps were immediately available.

This study focuses on the two problems of stock identification and habitat delineation of the juvenile stage of summer flounder, which is thought to be an ontogenetic bottleneck influencing year class strength (Able & Kaiser 1994). External tagging of juveniles was used to determine stock contribution of different nurseries within the southern MAB, while historical survey data from Chesapeake Bay was used to model the spatial and temporal heterogeneity of juvenile summer flounder across environmental gradients. Both studies provide much needed information for effective management of the summer flounder fishery, and together, these components demonstrate the importance of summer flounder nursery habitat within the southern MAB to one of the most productive fisheries in the region.

CHAPTER I. Tagging

INTRODUCTION

The term *stock* encompasses an array of concepts whereby the method of stock identification paradoxically determines its exact definition. Because of such varied usage, the term stock must be defined for individual studies. While the term stock has always generally referred to a biological population, there exists the implicit assumption that a stock is also a manageable unit (Gulland 1983). Gulland (1983) gives a theoretic example of a multiple species stock when those species are sympatric and have similar growth potential and life histories.

However useful a multiple species stock is for management, most biologists are concerned with intraspecific stocks. Smith et al. (1990) made two distinctions in the stock concept: the *fisheries stock* which comprises any group of fish exploited in a specific area by a specific method as a matter of convenience; and the *biological stock* which assumes a group of randomly mating individuals with temporal and spatial integrity. The biological stock concept can be subdivided further by using Carvalho & Hauser's (1994) notion of a *harvest stock* versus a *genetic stock*. A *genetic stock* assumes a high degree of integrity with genetic differences among stocks. The extreme of genetic stocks would result in speciation when, over a long period of time, different selection pressures are present among stocks and the stocks remain reproductively isolated. Since genetic heterogeneity among stocks can be masked by one spawn outside in 50,000 per generation (Gauldie 1991), the opportunity for a harvest stock to exist is much greater. A *harvest stock* assumes no genetic heterogeneity among stocks, yet fishing on one stock will not affect sister stocks. The distinction, then, between a genetic or harvest stock and a fisheries stock is that there is some biological basis for defining the former where delineation of the latter is completely arbitrary.

The identification of biological stocks is paramount to conservation management; however, delineation of a fisheries stock may be suitable for the early stages in the management of a fishery when biological information is sparse (Gulland 1983). A fisheries stock is not useful for conservation management, but used conservatively, it is a surrogate until the proper biological data are gathered. If there are more fisheries stock divisions imposed on a species than naturally occurring biological divisions, then the effort needed to manage the fishery may be unnecessarily high and individual stock dynamics will be insensitive to management. This could be the case when say a new coastal fishery is opening and responsibility for management is on a statewide basis. The consequences of assuming too few stocks are far more dangerous. For instance, suppose there exists a single fisheries stock, which in reality represents a single harvest stock. In theory, half of the biomass could be removed from this stock without hampering recruitment. On the other hand, if two equal harvest stocks were represented by this single fisheries stock, removing half the biomass could decrease recruitment by up to half, if the fraction of the biomass removed was from only one of the harvest stocks. Thus, in statistical terms, the object of stock identification studies should be to minimize Type II error, failing to reject the hypothesis of a single stock when multiple stocks exist.

Stock identification of *Paralichthys dentatus* (Linnaeus), also known as fluke, flounder, plaise, splaice, turbot, chicken halibut, brail, puckermouth, flatfish, and summer flounder (which is the official common name adopted by Ginsburg (1952) and is the official name given by the American Fisheries Society, Robins et al. 1991), has been attempted as early as 1952 when Ginsburg indicated that summer flounder from south of Cape Hatteras, NC might belong to a different population than those from Virginia based on meristics. Since then, much of stock identification work on summer flounder has been to study the effects of Cape Hatteras as a zoogeographic barrier to summer flounder populations in the South Atlantic Bight (SAB) and Middle Atlantic Bight (MAB) (Ginsburg 1952, Wilk et al. 1980, Fogarty et al. 1983, Van Housen 1984, Delaney 1986, Jones & Quattro 1996, Monaghan 1996,). In 1981, the Atlantic States Marine Fisheries Commission (ASMFC) in conjunction with the Mid-Atlantic Fisheries Management Council (MAMAFC) and the National Marine Fisheries Service (NMFS) enacted a summer flounder fishery management plan (FMP) which presupposes one stock from the southern border of Canada along the Atlantic coast to southern border of NC (Scarlett, 1981). As previously defined, the single stock outlined in the FMP is a fisheries stock.

The primary motivation for stock identification research on summer flounder has been highly fluctuating landings with a declining trend over the past twenty years (Anonymous 1995, Anonymous 1996). Despite ever stringent fishing regulations (Amendment 7 to the FMP), the summer flounder stock has also shown a trend towards juvenescence (Anonymous 1996). The poor status of the summer flounder stock and the multitude of biological data on summer flounder requires that prudent management consider multiple stock hypotheses while paying close attention to Type II error.

For a biological stock to exist, there must be biological parameters, such as genetics, life history, growth, fecundity, morphology, etc., that serve to separate and identify the stock. Circumstantial evidence for multiple stocks of summer flounder exists in the general biological data that has been gathered. Summer flounder egg distribution data indicates that spawning occurs along the mid-continental shelf in the fall (Smith 1973) and progresses southward with the season (Able et al. 1990, Able & Kaiser 1994). Smith (1973) noted three nearly independent spawning populations based on egg distribution data: one northeast of Delaware, one from Virginia to Cape Hatteras, and one south of Cape Lookout, NC. Because eggs will hatch within 74-94 hours under normal conditions (Martin & Drewry 1978), there is not likely to be any significant organization of egg distribution by continental shelf currents.

The dominant winter transport regime along the continental shelf will tend to carry eggs and larvae southwest (Beardsley et al. 1985, Mountain 1991). Settlement of larvae occurs in estuaries and immigration to the estuaries is protracted from as early as October to as late as May the following year (Able et al. 1990, Malloy & Targett 1991, Burke et al. 1991, Able & Kaiser 1994, Norcross & Wyanski 1994). There is some evidence, at least in culture, that larval summer flounder settle in waves, and that the earliest settlers are faster growing, hardier individuals (G. Nardi, pers. comm., Great Bay Aquafarms, NH). This would be an advantage to summer flounder larvae that settle early in the fall in northern estuaries when the water temperatures are relatively warm as Malloy & Targett (1991) found that summer flounder would have to reach sizes greater than 50 mm total length (TL) in order to increase survival at extremely low temperatures. Low temperature events (<3C for >8 days) are common during the winter in the estuaries of Delaware and further north and have been shown to cause acute mortality on summer flounder (Malloy & Targett 1991). The effects of acute mortality from low temperature events on summer flounder recruitment is unknown, yet Malloy & Targett (1994) also indicated that DE fish were more tolerant of low temperatures than NC flounder, again suggesting different biological parameters NC and DE flounder populations.

Latitudinal differences in growth during the first year of life have been also proposed as evidence of separate harvest stocks of summer flounder within the MAB. Dery (1981) backcalulated TL at annulus formation of age-1 summer flounder collected from three Atlantic nurseries and found mean TL at annulus formation to be 260 mm in New Jersey fish, 210 mm in Delaware/Maryland fish, and 190 mm in Virginia fish. However, Dery's (1981) assumption that these age-1 fish were captured in their nursery of origin was never tested. In contrast to Dery's (1981) findings, Malloy & Targett (1994) found in laboratory holding studies that post-settlement juveniles from more southern nurseries in North Carolina had higher maximum growth rates and gross growth efficiencies than Delaware juveniles. One hypothesis that resolves this conflict is that fast growing juveniles from more southern nurseries migrated north by the time of their first annulus formation so that Dery's (1981) faster growing New Jersey fish actually originated from southern nurseries. To confound matters, Szedlmayer et al. (1992) compared his length frequency estimate of growth in the first year of NJ summer flounder to that of Powell's (1982) estimate on NC summer flounder and suggested slower growth rates in NC fish. The problem of latitudinal growth differences clearly deserves more attention.

Juveniles can be captured in estuaries in various abundance throughout the year (Bonzek et al. 1992); however, larger juveniles which have completed their first summer of life are more commonly found offshore in shallow coastal waters when compared to inshore estuarine nursery areas (Able et al 1990, Szedlmayer & Able 1993, Able & Kaiser 1994). As summer flounder mature, they adopt a more highly migratory lifestyle where adults spend the winter at the edge of the continental shelf and migrate to inshore estuaries and shallow coastal waters for the summer (Able & Kaiser 1994, Desfosse 1995). Most stock identification work on summer flounder has been directed at adult populations and has looked at morphometrics and meristics, biochemistry or tag-recapture data to infer stock structure.

Morphometric and meristic data indicate two groups of adult summer flounder in the western Atlantic: one north of Cape Hatteras and one south of Cape Hatteras (Wilk et al. 1980, Fogarty et al. 1983, Delaney 1986). However, as Fogarty et al. (1983) remarked about their own study, no attempt was made in any of these studies to ascribe genotypic differences for these morphometric and meristic characters, and size related effects, not completely eliminated, could have contributed to observed differences among areas. In Delaney (1986) and Wilk et al. (1980), the majority of samples were not taken during the autumn spawning period, instead it was assumed that maximum stock separation occurred during the winter-spring season. Thus, samples were taken during a winter-spring survey. Also, in all of these studies, no consideration was given to age distribution within samples and the possible resulting effects of temporal phenotypic plasticity.

Genetic stock based studies also rely on the assumption that samples are taken at the time of maximum stock separation. Maximum stock separation would be during the fall spawn; for if there were to be any genetic differences among stocks, interstock spawning must be minimal. Isozyme analysis, which has the advantage of identifying possible genetic stocks, indicates north-south differences around Cape Hatteras in (VanHousen 1984). Jones & Quattro (1996) found preliminary evidence of genetic stocks of summer flounder in the Western Atlantic by sequencing base pairs of mitochondrial DNA; however, their proposed stock structure broke down when a greater distribution of samples was added (J. Jones, pers. comm., University of South Carolina, Columbia). Contradictory DNA results could result from violation of the maximum stock separation assumption.

Tagging data, which can be divided into offshore and inshore studies based on release location, show trends in the highly migratory movements of summer flounder. Migratory patterns can then be used to judge the likelihood of mixing between groups and subsequently identify potential harvest stocks. Of the offshore tagging studies, summer flounder tagged during the winter off Cape Cod (Hamer & Lux 1962), at Hudson Canyon (Lux & Nichy 1981), near the beaches from Cape Henry, VA to Corolla, NC (Monaghan, 1996), and north of Cape Hatteras (Gilliken in prep. cited in Able & Kaiser 1994) were recaptured in inshore waters to the north and east. Except for a small percentage of returns from tagging areas off NC, none were recaptured south of the release locations.

The inshore (summer) tagging data shows a trend in the autumn migration of summer flounder and provides additional information about the spring migration. Summer flounder tagged in the seaside estuaries of Long Island (Westman & Neville 1946) were recaptured southeast of their release sites during their first winter at large. Recaptures during the first autumn at large from summer flounder tagged at Sandy Hook, NJ, at Cape May, NJ (Murawski 1970), at Wachapreague, VA, in Chesapeake Bay, and coastal VA (Desfosse 1995) were distributed along the continental shelf from NJ to NC. The pattern of autumn migration from these studies showed a general southeast movement to wintering grounds at the edge of the continental shelf, but also indicated that some summer flounder from Virginia would have the opportunity to spawn with some Delaware Bay fish and some Cape May, NJ fish would have the opportunity to spawn with some Sandy Hook fish and visa versa for these various combinations (Murawski 1970, Desfosse 1995). Between the both studies, two groups of adult MAB flounder were observed. Those north of Cape Charles, VA tended to move directly offshore to the edge of the continental shelf, spawning over the mid-shelf during the migration (Murawski 1970, Desfosse 1995); whereas another group moved along the VA/NC coast during spawning and wintered on either side of Cape Hatteras, NC (Desfosse 1995). The most interesting phenomenon that occurred in these studies is shown in the distribution of recaptures in the following summer after release as fish were presumably on their inshore migration. Except for one fish recaptured south of Cape Hatteras in Defosse's (1995) study, all recaptures early in the following summer were from the release areas or further north, which shows some site fidelity to previous summer residences coupled with a northeast movement from wintering grounds. Desfosse (1995) additionally broke down the recapture data to show that the spring-summer migrants to locations north and east of release sites were smaller, and suggested that perhaps these individuals originated from more northern spawning grounds.

Considering that the possibility for two western Atlantic stocks exists based on preliminary evidence from morphometric, meristic, and biochemical data (Wilk et al.

1980, Fogarty et al. 1983, Van Housen 1984, Delaney 1986, Jones & Quattro 1996), and considering that hypothetical spawning aggregations of summer flounder within the MAB are likely to include adults from a wide geographic range of summer inshore residences based on tag-recapture data (Murawski 1970, Desfosse 1995), then the question of recruitment plays a great role in identifying potential stocks. It is well established that a majority of adult summer flounder tend to use the same inshore residences as in previous years (Murawski 1970, Desfosse 1995), but it is not clear if these same estuaries harbored them as juveniles, in which case each major estuarine system of MAB might warrant a separate harvest stock. While detailed migratory patterns of adults have yet to be elucidated for the SAB, the origin of adult summer flounder populations based on recruitment from inshore juveniles would provide the most valuable insight to the life history of the species in light of the apparent northeastern migration of adults in the MAB.

Although substantial effort has identified important nurseries for summer flounder exist from the southern half of New Jersey (in some years) through the sounds of North Carolina (Smith & Daiber 1977, Powell 1982, Able et al. 1990, Burke et al. 1991, Malloy and Targett 1991, Szedlemayer & Able 1992, Able & Kaiser 1994, Norcross & Wyanski 1994), little is known about what happens to these juveniles once they leave the nursery, especially in terms of how they recruit to the adult population. Within the MAB, the sporadic occurrence of inshore juveniles in NJ and lack thereof further north coupled with the tendency for eggs and larvae to be carried southwest along the shelf has led to the hypothesis that southern MAB nurseries, especially those of the Chesapeake Bay and North Carolina, are the important summer flounder nurseries for the

MAB (Rogers & Van Den Avyle 1983 in Able et al. 1990). This would imply that recruits from southern nurseries support adult populations at higher latitudes within the MAB. Further support for this linkage is shown by correlation of VIMS recruitment index with the NMFS age-2 index (D. Hata pers. com.). This explanation is suitable for Virginia nurseries, but as Wilk et al. (1990) noted, there is only one small access to North Carolina sounds for summer flounder of the MAB, and that is Oregon Inlet. Alternatively, Able et al. (1990) proposed that settling summer flounder in the northern MAB might utilize an offshore nursery. While no one has collected fully metamorphosed summer flounder on the continental shelf, there exists no data to confirm or refute Able's hypothesis.

Of the summer flounder tagged by Monoghan (1997) only in the sounds and inlets of NC, recaptures >20 km from the release sites occurred within NC sounds and inlets or further south. Monaghan (1996) released flounder which were modally 200-250 mm in TL (Y-O-Y by length at age predictions); however, a breakdown of the recaptures by size at release was not given. While this study discredits the idea that North Carolina estuaries are important nurseries for MAB summer flounder, it strengthens the hypothesis that Cape Hatteras represents a zoogeographic barrier to MAB and SAB summer flounder stocks.

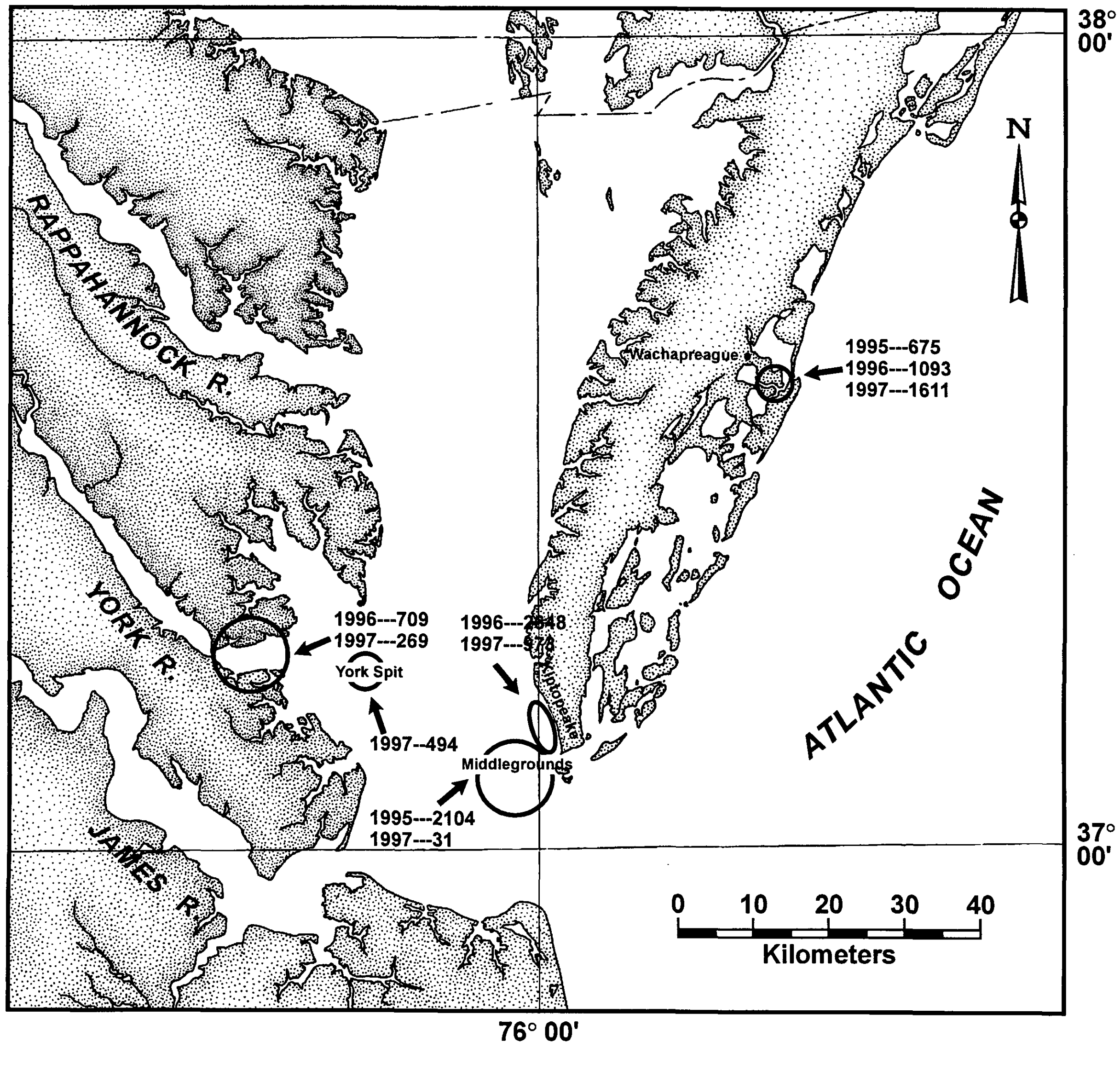
There appears to be strong evidence of separate MAB and SAB populations in the stock identification work on summer flounder. Based on tagging and life history data, there is also evidence of at least two loosely coherent groups of adult summer flounder within the MAB. The limitation of summer flounder nursery habitat to the southern MAB suggests that if there were two MAB populations, they would likely occur together as juveniles. Tagging estuarine juveniles in the MAB, as in Monaghan's (1996) study, would provide valuable information towards understanding the origins of adult summer flounder populations, and is one purpose of this thesis. The focus of this part of the study is to tag juvenile summer flounder inhabiting Virginia estuarine systems of the Chesapeake Bay and seaside tidal creeks and lagoons of the Eastern Shore. Short-term recaptures are used to describe the growth of juvenile summer flounder in Virginia nurseries, while patterns of recruitment to adult populations of summer flounder seen in this study provide information to help resolve the various hypotheses concerning the origin of adult summer flounder stocks in the MAB.

METHODS

Using semi-balloon unlined otter trawls, juvenile summer flounder (<280mm TL) were captured, tagged and released at several localities in Virginia waters (Figure 1): the seaside tidal creeks out of Wachapreague, VA; the lower York River; York Spit light; on the Middlegrounds of lower Chesapeake Bay; and off Kiptopeake beach. A target of ca. 2000 flounder per year were to be tagged, but abundance and availability determined actual numbers. Other limiting factors to tagging were growth and seasonal migration of flounder: it was not until August of each year that substantial numbers of YOY flounder attained a size large enough (>100mm TL) to survive capture and tagging, and by October, because most of these juveniles dispersed (presumably) offshore, availability of flounder declined so that it was not cost effective to conduct tagging operations.

Multiple gears were used depending on the location and vessel availability (Table 1). At Wachapreague the same configuration of fishing gear was used for all three years: a 6.7m runabout used to tow an otter-trawl. During 1995 in Chesapeake Bay, the chartered 30.5m side-trawl configured F/V *Anthony Anne* was used to tow a considerably larger otter trawl. All other trawling was accomplished by the 8.8m R/V *Fish Hawk* out of VIMS, which was rigged for stern trawling. On the R/V *Fish Hawk* and the Privateer, it was necessary to reduce the catch of blue crabs, *Callinectes sapidus*, by periodically removing the tickle chain in order to increase the capture survival of summer flounder. A cooperative venture with a commercial haul-seiner was attempted in the York River;

Figure 1. Map of release locations for juvenile summer flounder tagged in Virginia. Number of summer flounder released at each site is indicated by year.



RAPPAHANNOCK R.
YORK R.
JAMES R.
1996---709
1997---269
York Spit
1997--494
Middlegrounds
1995---2104
1997---31
Wachapreague
1995---675
1996---1093
1997---1611
ATLANTIC OCEAN
N
0 10 20 30 40
Kilometers
38° 00'
37° 00'
76° 00'

Table 1. Gear specifications for trawl nets used to capture juvenile summer flounder for tagging. Measurements are given in centimeters except for door size, bridle length and headrope, which are given in meters. Cable material was stainless steel and diameter is indicated. Tickle chain was galvanized.

		Bridle		Doors			Mesh			
	Tow Line	dia.	length	Type	Size	Headrope	Body	Cod End	Liner	Tickle Chain
Privateer	0.64	0.95	18.28	Wood	61x46	6.7	6.35	3.81	none	0.95
F/V *Anthony Anne*	2.22	1.27	54.86	Wood	488x274	24.4	10.16	6.35	none	none
R/V *Fish Hawk*	0.63	0.95	18.28	Steel-V	61x46	9.4	7.62	5.08	none	0.95

however, no summer flounder <290 mm were captured.

Total length (TL) of each summer flounder was measured to the nearest millimeter and all healthy individuals under 290 mm TL were tagged. Scales were sampled from the left side above the lateral line and just anterior to the caudal peduncle. Once cleared, an intramuscular T-bar anchor tag was inserted into this area. Scales were stored in coin envelopes for subsequent age verification. Individually numbered, orange fine-fabric tags (model FF-94 by Floy Mfg. Co. Inc., Seattle, WA) with the word "REWARD" and the VIMS address were used throughout this study. A larger, yellow, standard-sized fabric tag (model FD-94 also by Floy Mfg. Co. Inc.) which additionally displayed a phone number was used alternatively during the final year of tagging. To avoid immediate recaptures, tagged flounder were kept in holding tanks onboard while the trawl was deployed. This allowed the flounder to be observed for a short period before release. Two dollars and an entry in a spring drawing for $500 was offered for each returned tag. Rewards for tagged flounder were advertised throughout the MAB by way of posters placed at important recreational and commercial landing ports, press releases to newspapers, presentations at recreational fishing events, and televised broadcasts of the spring drawing.

Three holding experiments were conducted to examine tag retention, mortality, and growth effects. Flounder were captured by otter trawl, tagged and transported in holding tanks to recirculating aquarium facilities at VIMS. *Ad libitum* feedings occurred approximately three times weekly with cut squid and menhaden. Measurements (TL) of tagged and untagged fish were taken approximately monthly except for the first experiment where TL was measured only at the beginning and end.

Scale impressions were used to determine age. Impressions of the proximal scale surface were made in 0.5mm acetate sheets using a hydraulic press (18,000 psi) under low heat (70-75 C). The criteria according to Dery (1983) for determining age from summer flounder scale impressions was followed.

RESULTS

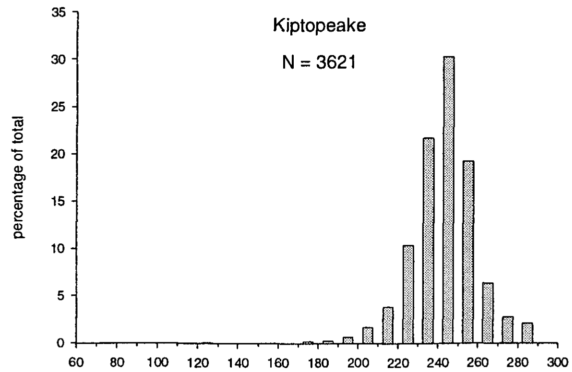
Catch Data

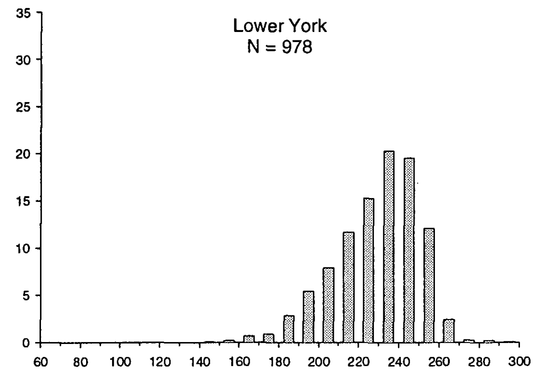
From 1995 to 1997 a total of 10,607 juvenile summer flounder were tagged in Virginia (Figure 1). Catch per unit effort (CPUE), defined as number of fish tagged per minute tow, can be used to compare catch rates by year and gear type (Table 2). The F/V *Anthony Anne* offered the highest CPUE, 1.47, and thus the greatest efficiency, for tagging juvenile summer flounder. Unfortunately, the *Anthony Anne* was destroyed in a fire in 1995, and the R/V *Fish Hawk* was substituted for tagging operations in Chesapeake Bay during 1996-97. Overall CPUE for the *Fish Hawk*, 0.74, was half of that for the *Anthony Anne*, but it was possible to exert a much higher effort with the *Fish Hawk* resulting in greater overall numbers of tagged fish with this vessel (Figure 1). Most of the fish tagged on the *Fish Hawk* in 1996 were captured off Kiptopeake (CPUE = 1.07). In 1997, Kiptopeake did not produce as many fish, and other localities were explored for higher concentrations of summer flounder, but CPUE remained low (0.47). The highest CPUE at Wachapreague, 1.06, was in 1997 and the lowest, 0.56, occurred in 1996. Length distributions of tagged fish were only slightly different between stations near the mouth of Chesapeake Bay (modally 245 mm TL) and stations near the mouth of the York River (modally 235 mm TL), whereas summer flounder tagged at Wachapreague were modally 50 to 60 mm TL smaller (see Figure 2).

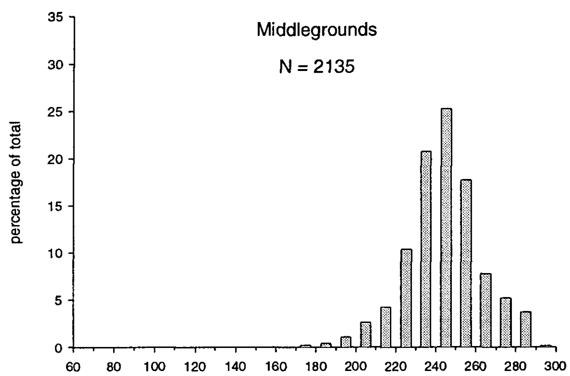
Table 2. Catch per unit effort (CPUE), defined as number of juvenile summer flounder captured by otter trawl per minute of tow time, by gear and year. Gear is designated by vessel.

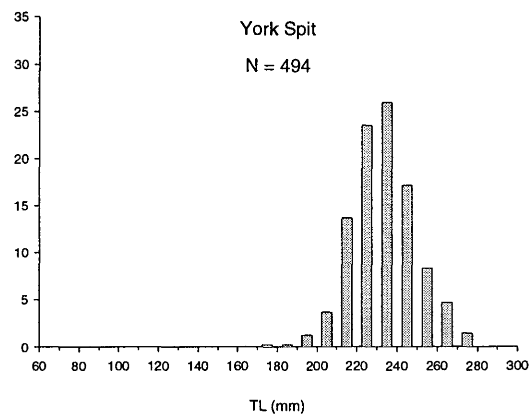
	1995	1996	1997	Overall
Privateer	0.74	0.56	1.06	0.77
Anthony Anne	1.47			1.47
Fish Hawk		1.07	0.47	0.74

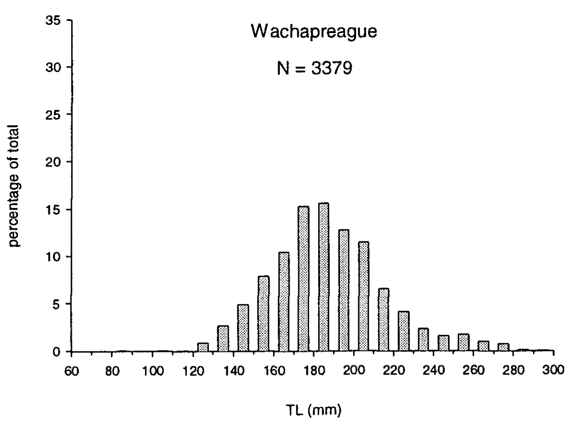
Figure 2. Length frequency distributions of tagged summer flounder by release location. Data are pooled from 1995 – 1997.


Kiptopeake
N = 3621
percentage of total
0 5 10 15 20 25 30 35
60 80 100 120 140 160 180 200 220 240 260 280 300


Lower York
N = 978
0 5 10 15 20 25 30 35
60 80 100 120 140 160 180 200 220 240 260 280 300


Middlegrounds
N = 2135
percentage of total
0 5 10 15 20 25 30 35
60 80 100 120 140 160 180 200 220 240 260 280 300


York Spit
N = 494
0 5 10 15 20 25 30 35
60 80 100 120 140 160 180 200 220 240 260 280 300
TL (mm)


Wachapreague
N = 3379
percentage of total
0 5 10 15 20 25 30 35
60 80 100 120 140 160 180 200 220 240 260 280 300
TL (mm)

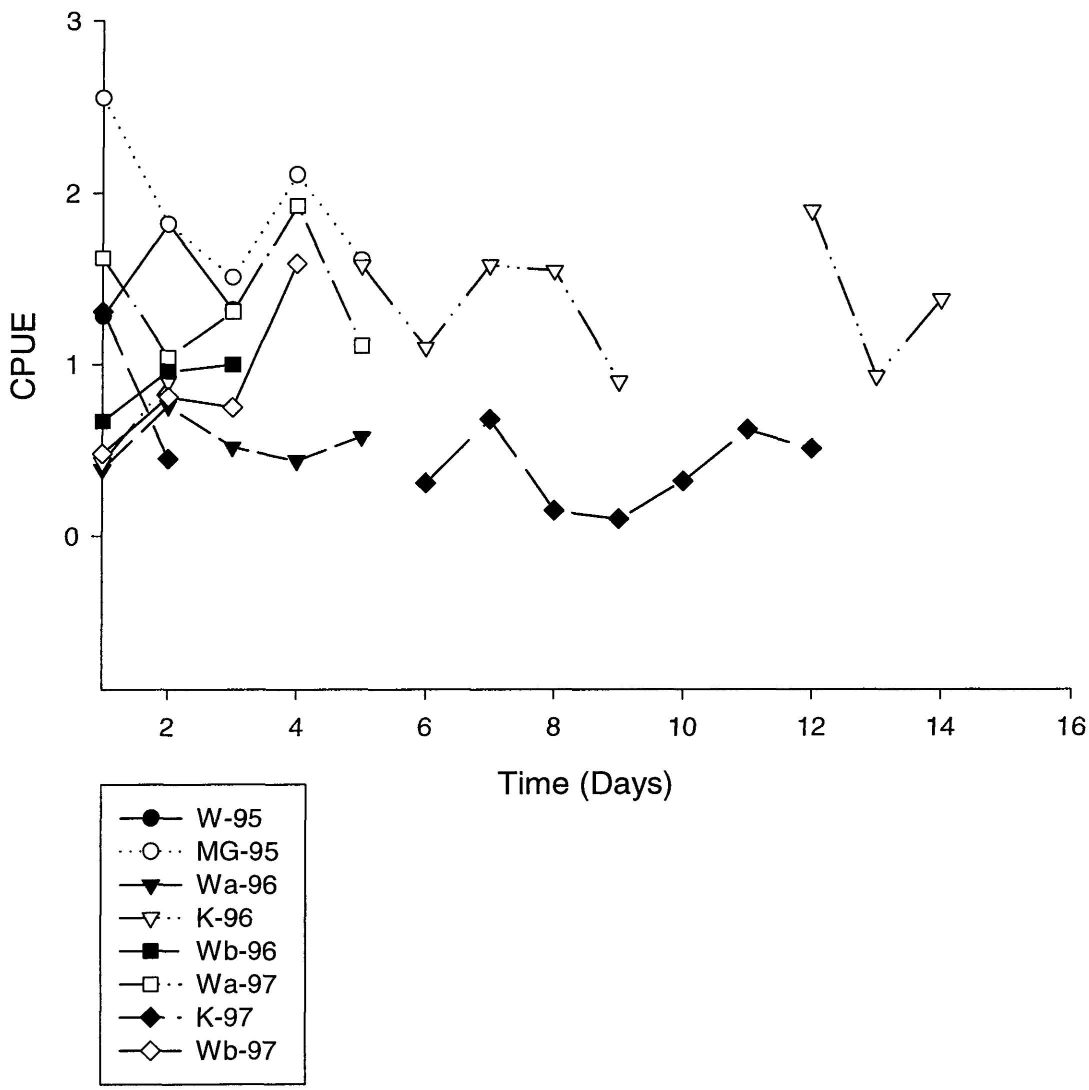
At selected locations, where trawling took place in sequence of three days or more, it was observed that cumulative fishing pressure had little or no effect on catch rates of summer flounder <290 mm TL (Figure 3). In the first four days of trawling, there was a short-term upward trend in CPUE for Kiptopeake in 1996, Wachapreague (second trip) in 1996, and Wachapreague (second trip) in 1997. A short-term downward trend was observed at Middlegrounds in 1995, Wachapreague (first trip) in 1997, and Kiptopeake in 1997. There rest of the data show the highly variable nature of daily catch rates with no apparent trend.

Holding studies

Three holding experiments were conducted to estimate tag retention, mortality, and growth effects. Logistical constraints determined the duration and number held in each experiment. All summer flounder were handled identically regardless of the randomly assigned tag and blocking treatments, and all were in the size range of those released in the field study. No tag-effects on behavior were noted in any of the experiments.

In the first experiment, 111 (52 tagged) summer flounder were held from 51 to 57 days depending on the date of capture. The FF-94 tag was used for this experiment. Three tagged fish (6%) died within 12 hours of capture, and the mortality is attributed to poor initial condition. Ten additional summer flounder corpses (five tagged) were found on the laboratory floor. One tag was shed for a retention rate of 98% during this experiment. Only initial and final length (TL) were measured. Once these measurements were determined to be normally distributed and the variance homogenous,

Figure 3. Daily catch per unit effort (CPUE), defined as number of juvenile summer flounder captured by otter trawl per minute of tow time, for selected locations by year: W = Wachapreague, MG = Middlegrounds, K = Kiptopeake, and *a* or *b* designates the first or second trip respectively. Last two digits of the year are given after each location identifier. Trawling at any one location took place almost every day for up to two weeks. Individual days at a location are ordered consecutively on the x-axis. Breaks in the lines show missing days.



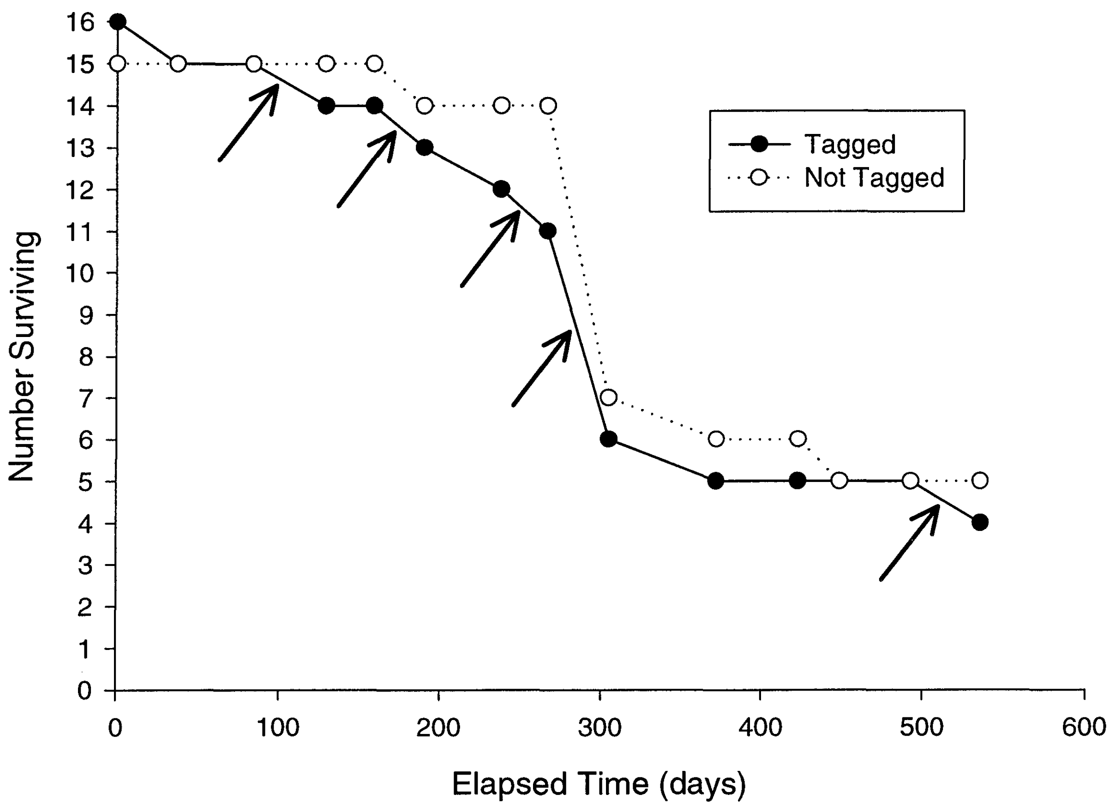
3
2
1
0
CPUE
2
4
6
8
10
12
14
16
Time (Days)
W-95
MG-95
Wa-96
K-96
Wb-96
Wa-97
K-97
Wb-97

ANOVA blocking by tank showed significant growth in TL overall at $\alpha = 0.05$ (F=33.05, d.f.=1, p<0.001), but no difference was found in final size between tagged and untagged fish (F=0.78, d.f.=1, p=0.377). Chance of Type II error in detecting no difference in growth was less than 1%.

The second holding experiment allowed for long-term (536 days) study of the FF-94 tag but with a smaller sample size: 31 fish (16 tagged) were held. A single tank was used. Numbers of fish were recorded, and measurements of total length were made approximately monthly. Numbers of tagged and untagged summer flounder plotted against time (Figure 4), show a striking die off during the interval from 267-305 days. Since tag loss essentially transformed tagged fish into untagged fish, independence was not conserved, and no comparison of mortality between tagged and untagged treatments can be made. Tag loss (31%) was estimated to occur prior to the 84, 159, 238, 267 and 493 day observation times (Figure 4). There were: nine deaths (four tagged) that occurred in-tank; twelve escaped from the holding tanks; and one tagged fish was never found. Average growth trends were the same among tagged and untagged fish (Figure 5). While average TL between tagged and untagged fish was different only in the last two observations, the results are confounded by tag loss and size selective mortality. In addition, the data show a trend of heteroskedasticity, or increasing variance over time.

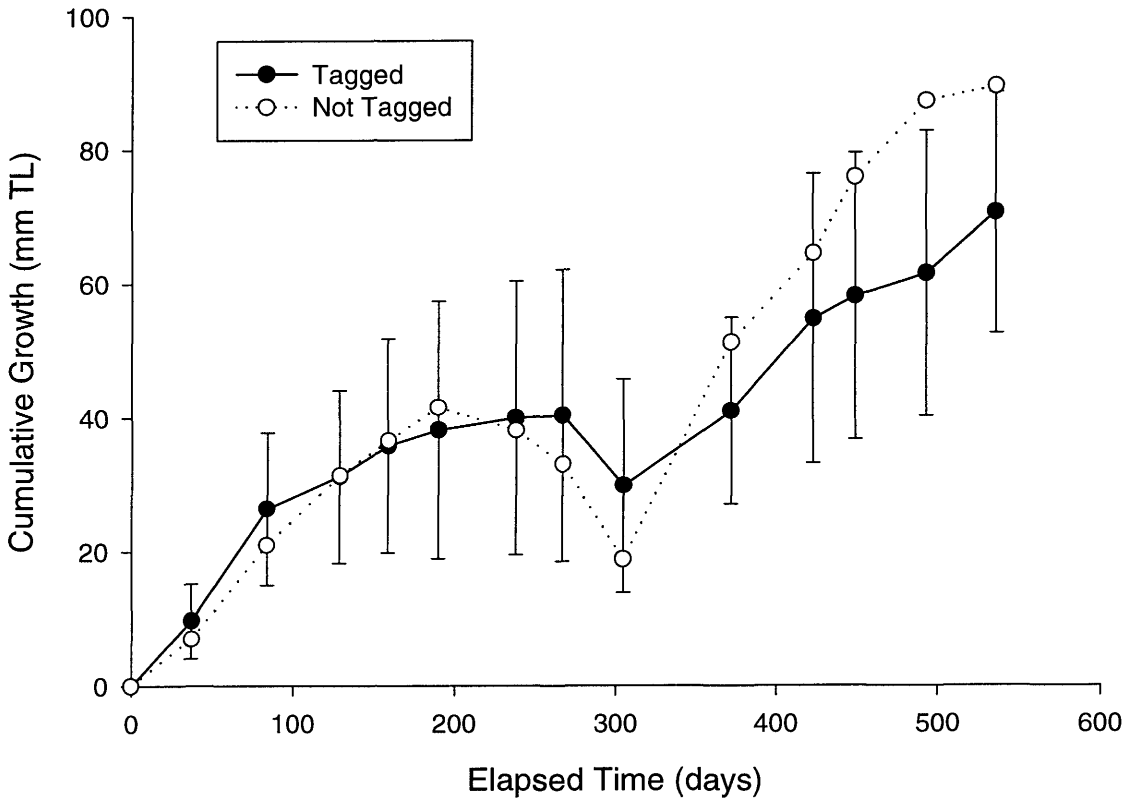
The third experiment was initiated to examine the effects of the FD-94 tag, a larger and presumably more traumatic tag, incorporated into the field study during the final year. In this experiment, 21 summer flounder (16 tagged) were held for 162 days.

Figure 4. Time series of periodic number of surviving tagged and untagged summer flounder in the second holding experiment. Arrows indicate time interval in which a tag was lost.



Number Surviving
Elapsed Time (days)
Tagged
Not Tagged
0
100
200
300
400
500
600
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 5. Average change in length of tagged and untagged summer flounder over time during the second holding experiment. Error bars indicate 95% confidence intervals for tagged fish, and are calculated by averaging growth of individual fish within a time period. Untagged fish were not individually identified; therefore, no error bars are shown.



Tagged
Not Tagged
Cumulative Growth (mm TL)
Elapsed Time (days)
0
20
40
60
80
100
0
100
200
300
400
500
600

While there was no tag loss, no mortality, and no difference in growth during this period (Figure 6), a power outage resulted in the premature termination of the experiment.

Short-Term Recapture Data

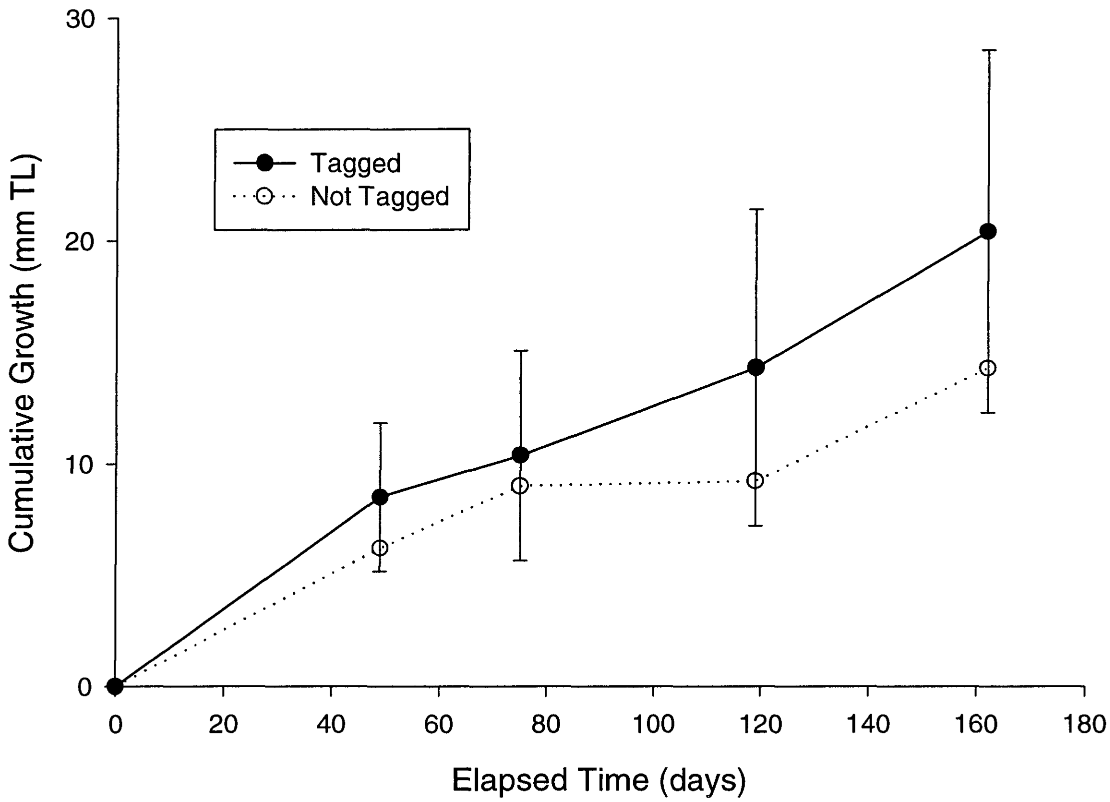
Though efforts were made to reduce immediate recaptures, there were a total of 238 short term recaptures (those recaptured in less than 40 days). One was taken in the recreational fishery after being at large for two days, and the rest were taken in our own research gear. None of the short-term summer flounder recaptures indicated movement from the release areas. Out of the 238 short-term recaptures, 18 were at large for longer than 25 days, and these were considered informative for estimating growth rates. All of these 18 recaptures were from Wachapreague in 1996 and 1997, aside from one at York Spit in 1997. Average growth for these 18 summer flounder was 1.3 mm/day. No difference in growth rate between the FF-94 and the FD-94 tags was detected.

Long-Term Recapture Data

Although an average annual tag reporting rate of 5.6% (total tagged = 15,578) was reported by Monaghan (1996) for similar sized summer flounder in NC, tag reporting rates for this study were much lower. Only five long-term recaptures were reported out of 10,602 tagged. All were recaptured in 1996 by the recreational fishery. Refer to Figure 7 for a geographic representation of recapture locations and their original release sites. Fortunately, all the anglers measured their recaptures to the nearest half inch, and approximate growth was then estimated to the nearest millimeter.

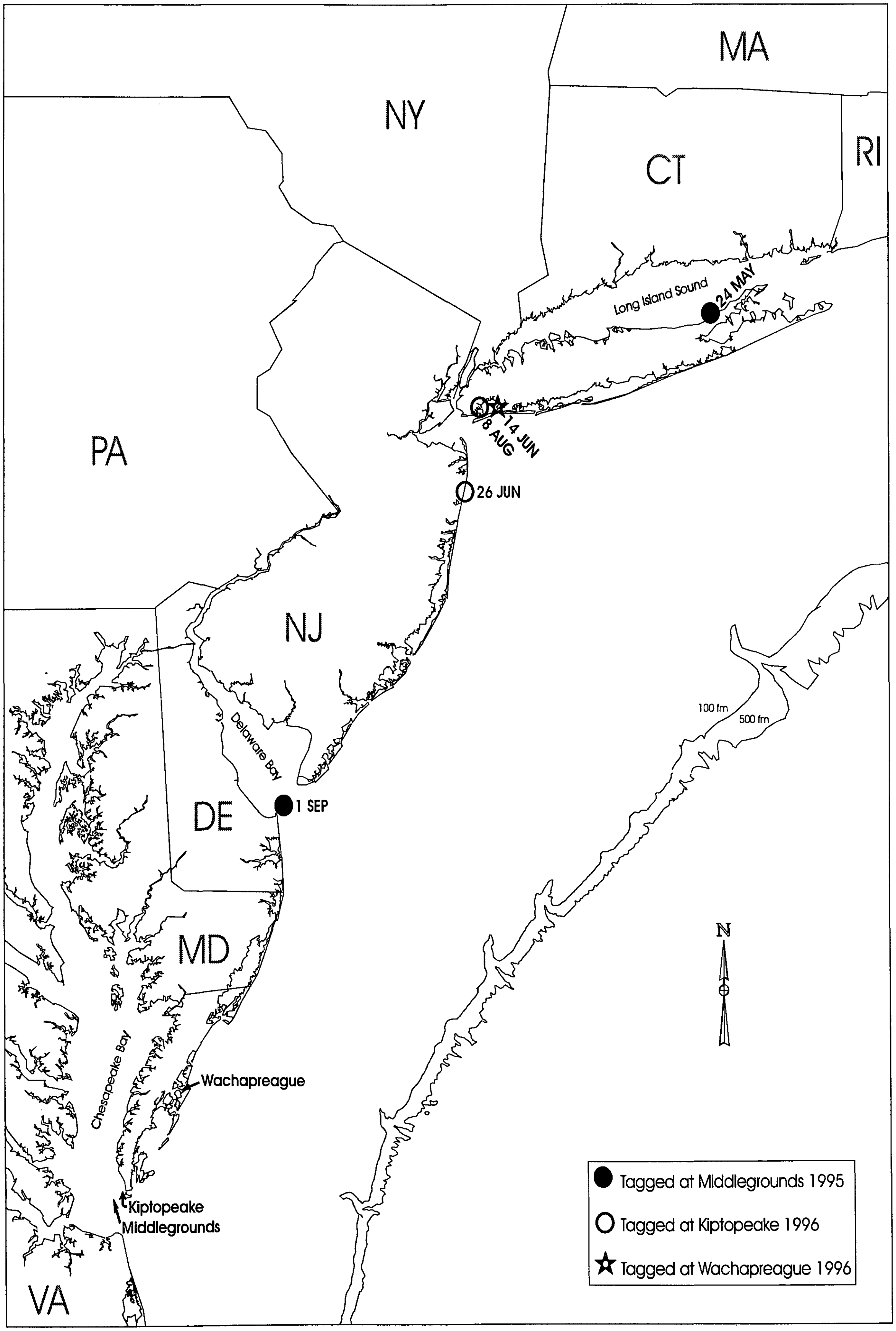
The first, recaptured on the 24th of May from Long Island Sound off Mattituck, NY, was at large for 618 days and grew an estimated 146 mm. The second was

Figure 6. Average change in length of tagged and untagged summer flounder over time during the third holding experiment. Error bars indicate 95% confidence intervals for tagged fish, and are calculated by averaging growth of individual fish within a time period. Untagged fish were not individually identified; therefore, no error bars are shown.



30
20
10
0
Tagged
Not Tagged
Cumulative Growth (mm TL)
0
20
40
60
80
100
120
140
160
180
Elapsed Time (days)

Figure 7. Location of long-term recaptures reported in 1997, and their respective release sites. Date of recapture is also indicated.



MA
NY
CT
RI
Long Island Sound
24 MAY
14 JUN
8 AUG
26 JUN
PA
NJ
Delaware Bay
1 SEP
DE
MD
100 fm
500 fm
N
Chesapeake Bay
Wachapreague
Kiptopeake
Middlegrounds
VA
Tagged at Middlegrounds 1995
Tagged at Kiptopeake 1996
Tagged at Wachapreague 1996

recaptured on the 14th of June in Jamaica Bay, NY, and grew an estimated 123 mm in 310 days. Twelve days later, a recapture was reported from Shark River, NJ. This fish was the largest of the five at the release time, measuring 273mm TL, but only grew an estimated 67 mm over its 311 days at large. The fourth recapture was again reported from Jamaica Bay, NY on the 8th of September after being at large for 347 days and grew an estimated 121 mm TL. The fifth and last reported recapture, at large for 427 days, was reported off Cape Henlopen Point, DE, on the 1st of September and is estimated to have grown 134mm. In four of the fish, no annuli were observed on any of the scales taken before release. Scales from the fish recaptured in Shark River, NJ were either never sampled or misplaced in storage.

DISCUSSION

This three-year tagging study has generated a modest amount of information about the biology of juvenile summer flounder. While some of this new information provides further evidence as to the nature of proposed summer flounder stocks in the MAB, much of it leads to ideas for further research. The results may also be useful in planning future tagging studies on summer flounder.

Some important points can be drawn from the catch data in reference to juvenile summer flounder index surveys at VIMS. Most notable of these, is the decline in *Fish Hawk* CPUE from 1996 to 1997 (Table 1) which could be attributed to yearly fluctuations in abundance or changes in spatial distribution. VIMS juvenile summer flounder recruitment index for the Chesapeake Bay and its tributaries indicates an increase in juvenile abundance from 1996 to 1997 (Geer & Austin 1997). Therefore, local areas of high abundance of juvenile summer flounder may change annually independently of the overall abundance of juveniles within Chesapeake Bay. In addition, Wachapreague CPUE from 1996 to 1997 followed the VIMS index. While shifts in spatial distribution may again be used to explain any differences seen at Wachapreague, correspondence between Wachapreague CPUE and the VIMS index could also indicate that recruitment between Chesapeake Bay and the eastern shore is somehow coupled. Modal differences in size between Chesapeake Bay stations and Wachapreague (Figure 2) are more than likely due to gear selection and location effects because the 22' Privateer allowed for trawling in depths less than 3 meters with smaller mesh.

It was observed in the field that constant trawling in any particular area of high summer flounder concentration did not seem to affect the supply of summer flounder. In general, daily CPUE (Figure 3) was highly variable and did not decline over the course of two weeks. Short-term (less than four day) deleterious impacts were observed at a few locations, but other locations, showed a short-term increase in CPUE, probably reflecting a learning curve as we were able to target small flounder more efficiently over time. The lack of decline in daily CPUE trends is either indicative of an enormous local population of juvenile summer flounder or high exchange rates from surrounding areas through immigration and emigration. Short-term recaptures could not be used to estimate population size in the tagging areas since we attempted to avoid immediate recaptures by our own gear.

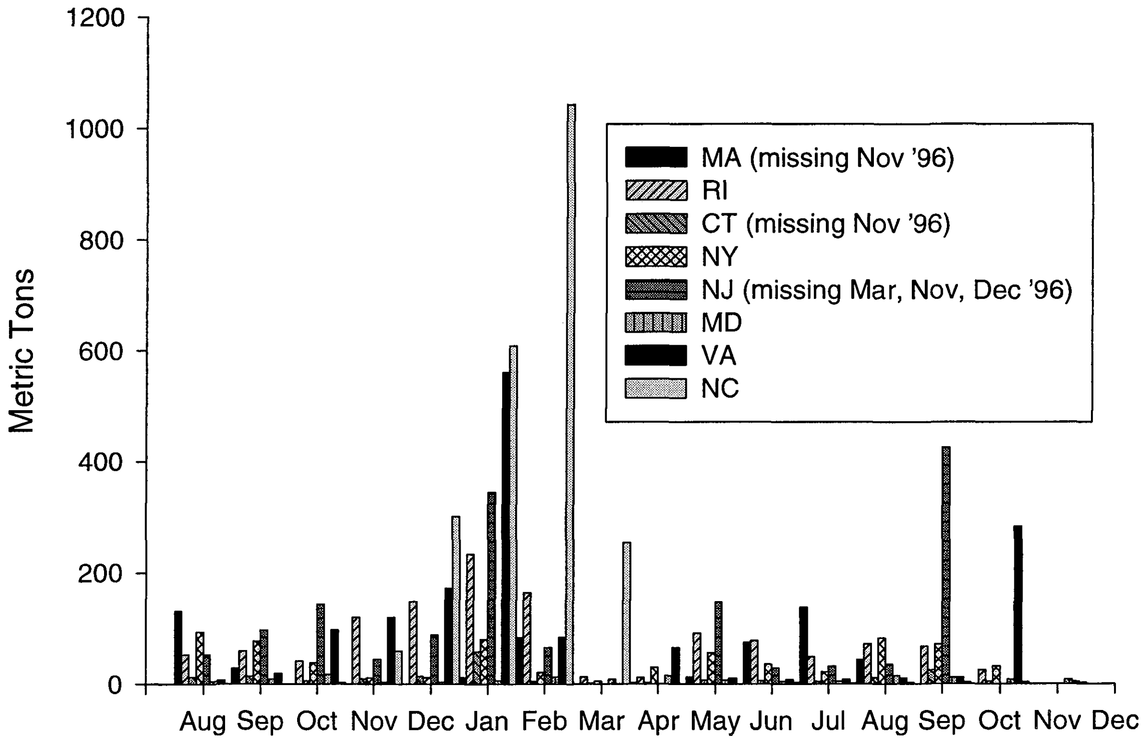
Growth observed in 18 of the short-term recaptures, 1.3 mm/day, is the same as that observed from similar tagging data by Rountree & Able (1992) in NJ marsh creeks, suggesting that growth of tagged YOY summer flounder in VA is comparable to NJ. Other length frequency analysis estimates of short-term growth of YOY summer flounder in NJ are higher: 1.7 mm/day (Rountree & Able 1992) and 1.9 mm/day (Szedlmayer et al. 1992). Differences in growth rates between the length-frequency and recapture methods are potentially due to tagging effects on growth; however, our holding experiments indicated that tags used in this study do not affect short-term growth. Reduction of sample size by escapement and mortality in our holding experiments precludes any definitive statement about long-term growth.

The extremely low recapture rate has been detrimental to the original objectives of this project, and little explanation can be found in the holding studies. There is no clear indication of tagging mortality from the holding studies other than the initial mortality in the first experiment of 6%, which can be attributed to capture stress. Whether the tag makes juvenile flounder more visible to predators is unknown; however, other tagging studies have been successful using larger and more visible tags. Monaghan (1996) achieved an overall recapture rate of 5.6% using internal anchor and cinch-up tags which were larger and more visible than either the FF-94 or FD-94 T-bar tags used in this study. However, this recapture rate may not be comparable because flounder tagged by Monaghan (1996) were up to 550mm TL, and the majority of the recaptures may have been from larger flounder. The third holding study indicated that the larger of the two tags used in this study, FD-94, had better retention, despite increased trauma to the fish. Although there was a higher drag ratio with the larger tag, the "T" anchor section was more rigid than in the smaller tag and probably prevented it from being dislodged from the neural spines. Performance of the larger tag in the field study was contraindicative as none have been returned after one year at large. This leaves two explanations for the lack of returns: high natural mortality and high fishing mortality.

Natural mortality by predation on larger YOY summer flounder is known from the gut contents of many local fishes including sharks, cobia, striped bass, and adult flounder (Medved et al. 1985, Stillwell & Kohler 1993, Walter & Austin in press, Gelsleichter et al. in press, D. Hata pers. comm., the author pers. obs.). Low temperature induced parasite infection by *Tryplanoplasma bullocki* has also been attributed to significant juvenile summer flounder mortality in Virginia (Burreson & Zwerner 1982, Burreson & Zwerner 1984); however, the winters from 1996 to present have been too warm for epidemic infection (H. M. Austin pers. comm.). Natural mortality rate has been inferred for summer flounder at 0.2 for fisheries modeling purposes on fully recruited ages (Anonymous 1996); however, this may be an underestimate of natural mortality for YOY summer flounder. If we assume that the (Anonymous 1996) estimates for total proportion of the stock taken by the summer flounder fishery in 1995 (age-0 = 0.3, age-1 = 0.62, and age-2 = 0.99) do not change through time and 20% of the tagged population is lost per year due to natural mortality in addition to immediate tag loss (~33%, the highest observed in the holding studies), then the predicted number of tagged fish taken by the summer flounder fishery can be estimated at 309 in 1995-96, 1240 in 1996-97, and 1742 in 1997-98. These recapture estimates are clearly erroneous, as they would lead to an overall 45% recapture rate; however, the tagged flounder were not randomly distributed throughout the management area.

Life history and tagging data suggest that many young flounder from VA follow their adult counterparts along the coast of VA/NC and offshore when they leave the estuary, at which time they would encounter the winter trawl fishery gear. Recaptures in the winter trawl fishery from adult fish tagged in VA were mostly reported by fish cutters at seafood processing plants (Desfosse 1995). Young flounder in this study would be undersized and discarded if captured. Few, if any, undersized flounder would be landed, and discard mortality is estimated at 80% (Anonymous 1996). Monthly landings by state in the MAB (Figure 8) show not only that NC landings account for most of the annual commercial catch but also that the timing and location of this intensive exploitation corresponds with the migration of summer flounder from VA. Almost all of the commercial trawl recaptures (88%) in Monaghan's (1996) NC study

Figure 8. Preliminary commercial landings by month from AUG 1995 to DEC 1996 for MAB states.


Metric Tons
1200
1000
800
600
400
200
0
Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
MA (missing Nov '96)
RI
CT (missing Nov '96)
NY
NJ (missing Mar, Nov, Dec '96)
MD
VA
NC

were from shrimp trawlers near the Cape Fear River. The possibility of such a single high mortality source and under-reporting of tags due to discarding should be considered in any future mark-recapture studies on summer flounder or other species available to the NC winter trawl fishery.

The five long-term recaptures reported from far north and east of the release sites in this study may be significant in that they support the hypothesis that Virginia estuaries provide the primary nurseries for Mid-Atlantic fisheries to the north. The northern and southern stocks proposed by Defosse (1995) for the MAB are supported by the egg distribution data (Smith 1973), and there is at least some evidence from this study that the two stocks occur together in Virginia as juveniles. Not all of the YOY summer flounder from southern nurseries can migrate northeast after their first year as evidenced by the adult summer flounder populations present in southern MAB estuaries. Based on Monoghan's tagging study (1996), inshore juveniles from NC estuaries will not be recaptured as adults in VA or further north in subsequent years; therefore, some of the YOY summer flounder that occur in VA estuaries must return as adults.

Northern and southern populations of MAB summer flounder have only been observed through differences in spawning and migration behavior (Smith 1973, Desfosse 1995). Attempts to develop methods to identify northern and southern biological stocks within the MAB have failed (Smith & Daiber 1977, Wilk et al. 1980, Fogarty et al. 1983, Van Housen 1984, Delaney 1986, J. Jones pers comm). The failure is due in part to invalid stock separation assumptions, but may also stem from inadequate technology which more modern techniques such as microsatellite DNA analysis could provide. Alternatively, there may be no basis for northern and southern MAB biological stocks according to the definition which has been presented, as a moderate amount of mixing between the populations has been demonstrated (Murawski 1970, Desfosse 1995).

A relatively new concept for fisheries biology, which has been explored extensively in terrestrial ecology and may have application for MAB summer flounder, is the metapopulation (McQuinn 1997). Local populations within a metapopulation do not necessarily provide a basis for biological stocks because survival of the species in a metapopulation depends on migrants establishing new local populations on an evolutionary time scale. McQuinn (1997) argues that newly recruited immature Atlantic herring in a spawning group can be entrained on a migration; that the route and locations of the migration are imprinted; and that learned highly migratory behavior from adults serves to perpetuate local populations. The metatpopulation theory not only provides a framework for a moderate amount of mixing between northern and southern local MAB flounder populations, but it also explains how recruits to VA nurseries from northern populations may return to their spawning grounds.

In summary, the potential for Type II error in assuming a single summer flounder population in the MAB is apparently high. Further information on the recruitment patterns of YOY summer flounder to adult populations is needed to develop a potential metapopulation model for the MAB, or applied stock identification methods are needed for MAB populations. Discard mortality in the NC winter trawl fishery is likely a major contributing factor to the lack of recaptures in this study; however, the few reported recaptures show the potential for long migration of juveniles upon exiting the estuary.

CHAPTER II. Habitat Utilization

INTRODUCTION

Fishes have physiological tolerances and preferences to environmental parameters, and their response is to adapt to or escape from intolerable conditions and distribute themselves across environmental gradients based on their preferences (Moyle & Cech 1988, Wooton 1990). Add to this a highly migratory behavior and strong temporal fluctuations in abundance and you have the framework for the habitat description of *Paralichthys dentatus*, the summer flounder. When considering the dynamic life cycle of summer flounder, which is punctuated by abrupt changes in life history stages, identifying important habitat parameters presents a challenge because habitat requirements change ontogenetically.

A recent mandate in the Magnuson-Stevens Fisheries Management Act (Anonymous 1997a), requires that all Fishery Management Plans (FMPs), including the summer flounder FMP, identify and delineate Essential Fish Habitat (EFH). At the most preliminary level of EFH identification, anywhere a species occurs is considered EFH, but of special consideration for management are those habitats, which are the least available and most susceptible to perturbation (Anonymous 1997a). For summer flounder, the inshore juvenile stage is highly limited by habitat because it prefers shallow estuarine nurseries (Able & Kaiser 1994, Norcross & Wyanski 1994). Offshore continental shelf habitats, which support pelagic eggs and larvae and can sustain benthic adult summer flounder populations, are magnitudes more expansive and not nearly as susceptible to environmental or anthropogenic perturbations as estuaries. Thus, this study focuses on inshore juvenile summer flounder habitat because it represents an ontogentic bottleneck to the species' life history. In particular, we focus on the Virginia portion of the Chesapeake Bay and its system of sub-estuaries because this is arguably the single most important nursery area for Mid-Atlantic Bight summer flounder populations (Poole 1966, Powell and Schwartz 1977, Wyanski 1990, Desfosse 1995, Rogers & Van Den Avyle 1983, Monaghan 1996).

Some important habitat parameters for summer flounder have been outlined in Able & Kaiser (1994) as a synthesis of current knowledge. For the most part these parameters have been analyzed independently; therefore, little can be said about the relative effects of these parameters. The inshore juvenile stage begins in the estuaries at settlement after metamorphosis (Able & Kaiser 1994), which occurs anytime from October to May in the following year (Keefe & Able 1994, Wyanski 1990, Norcross & Wyanski 1994, G. Cicchetti pers. com. VIMS). Young settled juveniles < 50mm TL have been encountered in a range of salinities from nearly fresh water to 36ppt (Powell & Schwartz 1977, Hoffman 1991) but are more abundant at salinities > 10ppt (Burke et al. 1991, Wyanski 1990). These young inshore juveniles have also been collected at temperatures as low as 3.8°C in Virginia (Wyanski 1990); however, laboratory studies indicate growth inhibition below 10°C and acute mortality below 3°C, temperatures which are common during the winter in the northern part of summer flounder range (Malloy & Targett 1991). Whereas laboratory holding studies have indicated a preference for sandy substrate (Keefe & Able 1994), juveniles (< 50mm TL) are found primarily on shallow flats or in small marsh creeks (Wyanski 1990, Burke 1995, Burke et al. 1991, G. Cicchetti pers. comm.) with fine substrate in VA (Wyanski 1990), or mixed substrate in NC (Burke et al. 1991). This pattern appears to change with age, as larger juveniles are found more often over deeper sandy substrates or shallow habitats with eelgrass in Virginia (Wyanski 1990). One confounding problem with the NC study is that substrate is correlated with salinity (Burke et al. 1991). Larger juveniles (>50 mm) are more frequently captured as the season progresses and growth and migration to deeper habitats allows them to be recruited to different gears such as otter trawls (Wyanski 1990, Bonzek et al. 1992). Larger juveniles remain in the higher salinity regions of the estuaries until the fall or winter when they move offshore with declining estuarine temperatures (Able & Kaiser 1994). Tidally correlated movements of larger juveniles in a New Jersey marsh creek have been observed as a result of hypoxia avoidance (Szedlmayer & Able 1993), and annual variation in abundance and occurrence is also documented (Anonymous 1996). Other factors such as predation (Keefe & Able 1994) prey availability (Burke 1995), and interspecific behavior in a community response (Wagner & Austin in press) have been shown to influence the distribution of juvenile summer flounder in estuaries, but it is not within the scope of this study to quantify and compare such biotic variables.

This study is limited to the temporal, spatial, and environmental variables that are thought to influence the occurrence of summer flounder, and the object is to use an exploratory multivariate approach to model summer flounder occurrence. Because small juveniles that inhabit depths <2m have been the primary focus of previous habitat work (Wyanski 1990, Burke et al. 1991, Malloy & Targett 1991, Roundtree & Able 1992, Keefe & Able 1994, Burke 1995) and less is known about larger inshore juveniles that also inhabit greater depths, the concentration of this study will be on the larger inshore juvenile stage. Also, there is extensive long-term unpublished data on larger juveniles in the lower Chesapeake Bay through VIMS juvenile finfish trawl survey. The EFH identification prototype, for which summer flounder is the model species, considers only regional scale seasonal usage, estuarine salinity and substrate (Schrieber & Gill 1997). All of the hypothesized habitat parameters of summer flounder (year, season, spatial distribution, temperature, salinity, dissolved oxygen, depth, substrate, and tidal stage) as well as two other habitat parameters not previously considered (slope of bottom and distance to Submerged Aquatic Vegetation or SAV) will be analyzed on a much finer scale than in the EFH prototype. It has been a long standing anecdote that the best places to capture summer flounder are on the steepest edges of channels (A. D. Estes pers. comm, VIMS), and in Chapter I, it was found that the steepest channel edges consistently produced more juvenile flounder to tag. In addition, Lascara (1991) that SAV might be important to juvenile summer flounder occurrence, as SAV may provide significant forage (Lascara 1991). The advantage to using multivariate techniques is the ability to compare the significance and relative contribution of the variables. This approach will model the probability of catching summer flounder along environmental gradients through the analysis of presence/absence data.

METHODS

Trawl Survey Data Collection

The VIMS juvenile fish trawl survey database has been conducting monthly surveys since 1955, but only since 1979 has the gear been standardized with a tickler chain to catch small flatfishes (Geer et al. 1995). This study analyzes the period from 1979 to 1997 in the database (> 13,000 observations), during which time some minor sampling and gear modifications were made. The statistical design of the survey has remained constant for fixed stations in the rivers, while the exact location of a tow for a fixed station has varied as much as one nautical mile depending on navigation conditions (P. J. Geer pers. comm.). In Chesapeake Bay, sampling has been conducted since 1988 under a depth stratified random design with no fixed stations, and since 1996 depth stratified random stations in all three river systems have been sampled in addition to the fixed stations (Geer et al. 1995). The R/V Captain John Smith was used until 1990 when the R/V Fish Hawk, which was specifically designed for the trawl survey, was purchased. The R/V Fish Hawk is considerably smaller and safety concerns necessitated a change from larger wooden doors (61cm x 137cm) to smaller steel, china-V doors (49cm x 71 cm). Due to draft limitations on the vessels, the survey is limited to depths greater than 1.5 meters. The bridle length also changed in 1980 from 12m to 18m, and the net, which has a 9m headrope, has remained constant with 3.8cm mesh in the body and wings, 3.2cm cod end mesh, and 1.3cm cod end liner mesh.

Because the absolute efficiency of this gear is unknown, the estimates of occurrence or abundance on any one species represent a relative index. It is important, then, to realize that the observed response of a species to any environmental parameters is a property of the gear. For instance, the survey gear used in this study may catch flounder more efficiently over fine substrate. Only when there is equal gear efficiency across an environmental gradient can the response of a species validly represent a property of that species. To test the assumptions of equal gear efficiency, we must consider how variables were recorded.

Bottom salinity, temperature, and dissolved oxygen were recorded whenever possible and by several methods. Salinity was always measured by conductivity in Standard Salinity Units, or SSUs (essentially parts per thousand, ppt). Before 1985, salinity samples were collected and brought back to the laboratory for processing, but from 1985 to 1989, salinity was measured directly in the field with a YSI meter. Before 1985, temperature was recorded from a stem thermometer, and from 1985 to 1989 it was measured either with a YSI meter or a stem thermometer. Dissolved oxygen was almost always measured from bottled samples by the Winkler titration method until 1989. Since 1989, a Hydrolab has been used to measure salinity, temperature, and dissolved oxygen directly in the field.

Depth was recorded directly from the research platform with an ultrasonic depth sounder. Recorded depth is actually the distance from the transducer to solid bottom, and not the actual water depth. The bias in depth measurement is estimated to be less than 0.75m with either vessel. Response of summer flounder occurrence to depth was scaled to nearest whole meter; thus, no adjustment to actual water depth was made in this study.

Due to the depth stratified sampling design of the survey, the captain of the vessel would try to maintain a constant depth with the aid of the depth sounder.

Tide stage was estimated based on current to one of four categories: flood or ebb; and slack before flood or ebb. The estimate was made in the field with the aid of tide and current predictions published annually for mariners by the National Oceanic and Atmospheric Administration (NOAA).

Beginning and ending location of each tow was determined in latitude and longitude coordinates by several methods. In the rivers the location was determined roughly by landmarks and navigation aids, and the coordinates determined from a chart (North American Datum 1927 or NAD27). Loran C conversions to latitude and longitude were also recorded in the rivers, but due to the inaccuracy of Loran C converted latitude and longitude in the river systems, they were later verified or adjusted visually on a chart (D. Hata pers. com.). In Chesapeake Bay coordinates were converted to latitude & longitude (NAD27) onboard by the Loran C navigation computer. In October 1993, the survey switched to a handheld GPS from which latitude and longitude were recorded directly for both the river systems and the Bay (North American Datum 1983 or NAD83). The handheld unit was used until August of 1996 when a new Differential-GPS chart plotter was installed. The Differential-GPS decreased measurement error of latitude and longitude (NAD27) to within 50m of the actual location. Tow distance was determined since 1988 by calculating the straight-line distance between the beginning and ending coordinates. Straight-line tow distance estimates are generally adequate; however, occasionally tows were more arc-shaped than straight (P. J. Geer pers. comm.). Beginning latitude and longitude coordinates were arbitrarily chosen to identify individual trawls in geographic space because conditions recorded at the beginning of the tow, such as depth, were a target for starting the tow and held constant as much as possible.

Data Additions and Manipulations Using GIS

The addition of the variables, distance to Bay mouth, proximity to SAV, sediment and slope was accomplished with the aid of Geographic Information Systems (GISs): ARC/INFO version 7.0.4 and ArcView GIS version 3.0a by Environmental Research Systems Institute, Inc (ESRI, 1982-1996 and 1992-1997 respectively). Values were interpolated from the intersection of trawl survey data points with source data maps. Digital data maps of shoreline and bathymetry were obtained from the Chesapeake Bay Program (EPA, Annapolis, MD 1997). Other source data maps were constructed from VIMS seagrass mapping data (Orth et al. 1997) or were created specifically for this project.

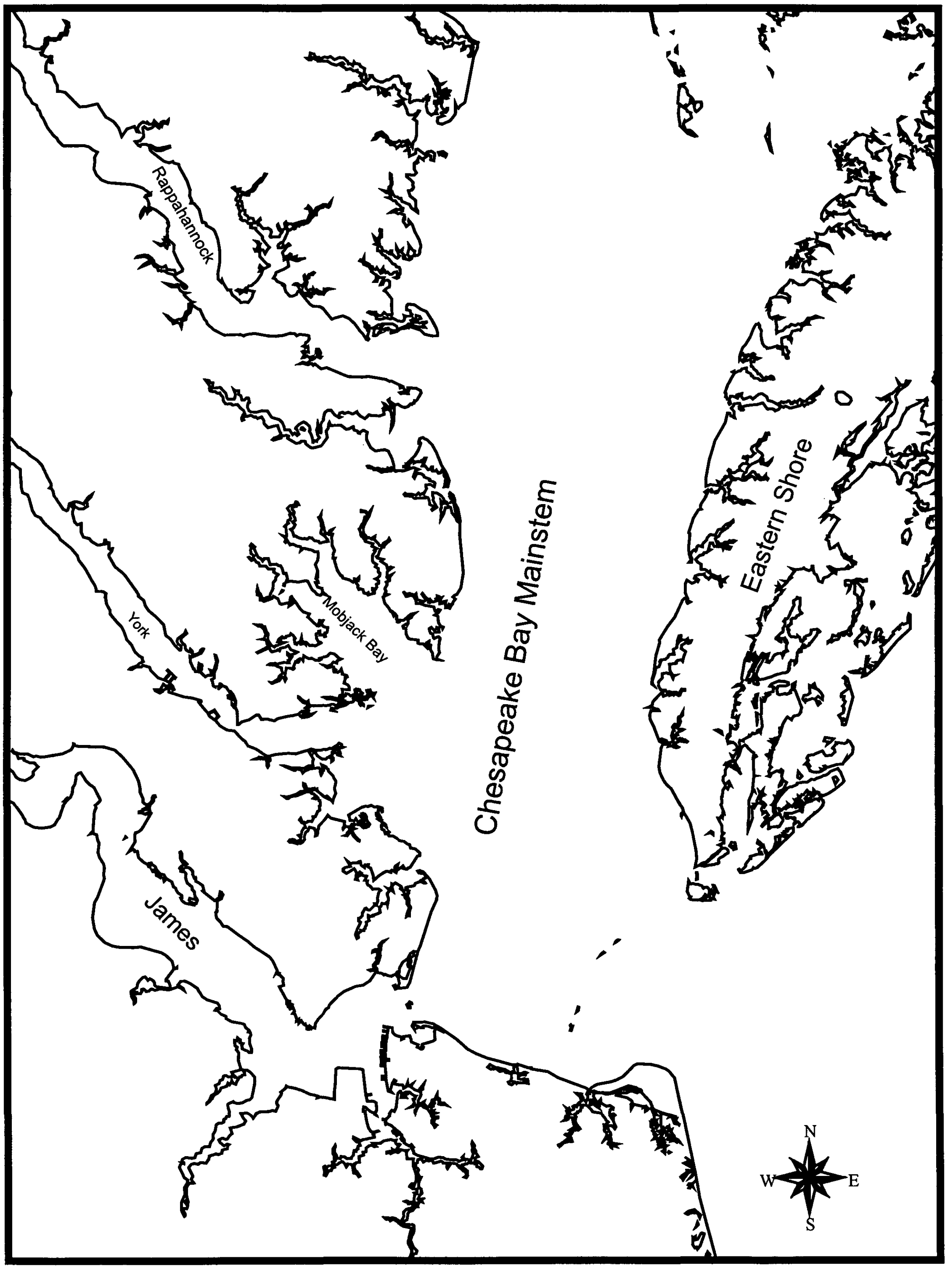
Trawl survey point coordinates (beginning latitude & longitude) were converted to UTM (Universal Transverse Mercator), zone 18, coordinates through an ArcView Avenue algorithm produced at VIMS. UTM coordinates simplify mathematical calculations in geographic space and produce meaningful distance measurements (in meters). The points were converted to an ArcView shapefile and then imported to ARC/INFO with the *shapearc* command.

In the Chesapeake Bay region, the difference between a point referenced to North American Map Datum 1927, NAD27, and the same point referenced to NAD83 both plotted on the same coordinate plane is about 200m in the north-south direction. A majority of the source data from which additional variables were to be extracted were referenced to NAD83; therefore, it was decided to reproject the portions of the trawl survey point data that were recorded in NAD27 to NAD83. This was accomplished in ARC/INFO with the *reselect*, *projectdefine*, and *project* commands. The reprojected NAD83 data were rejoined with the data originally recorded in NAD83 using the *append* command.

To facilitate interpolation and spatial analysis, some of the source data was recoded into 100m square grid cells. Considering the average tow distance of ~400m, this provided sufficient resolution without significantly increasing processing time. NOAA's medium resolution shoreline polygon coverage (NAD83) of the Chesapeake Bay, which was digitized from 1:10,000 and 1:80,000 scale maps, was obtained from the EPA, Chesapeake Bay Program, Annapolis, Maryland. The *polygrid* command was used to raterize this shoreline coverage and generate a geographic grid where cells over water would have a different value than cells over land. An ARC/INFO line coverage was created demarcating the mouth of the Chesapeake Bay from Cape Henry to Cape Charles, and this was also rasterized using the *polygrid* command. Polygon coverages for SAV (mostly *Zostera marina* and *Ruppia maritima*) are also available through ongoing mapping and monitoring efforts at VIMS (Orth et al. 1997). A time series of SAV maps has been produced since 1971 (D.J.Wilcox pers. comm.). Although most SAV is currently at a fraction its historical distribution a century ago, it has increased since 1979 in Virginia (Batiuk et al. 1992, D.J. Wilcox pers. comm.); therefore, to simplify this study and maximize any observed responses, only the 1996 map of SAV (one of the most current and accurate) was used. The polygon coverage of SAV in 1996 was rasterized as well, also with the *polygrid* command. Grid coverages representing distance to the mouth of the Bay and distance to nearest SAV bed were calculated using the *costdistance* function in ARC/INFO's Grid package. The shoreline grid was used to specify areas of nodata (land) and an even cost surface (water). In concept, this operation gives a zero value to any cell directly on SAV or the Bay mouth line, and all other cells not specified as 'nodata' are given an integer value for their distance to either SAV or the Bay mouth. Data for distance to SAV and the Bay mouth were then linearly interpolated from these two grid coverages for each trawl survey data point by the *latticespot* command in ARC/INFO.

The VIMS juvenile fish trawl survey does not characterize sediment at any stations; therefore, an interpolated sediment value was calculated for each trawl survey data point from the VIMS winter blue crab dredge survey. Since its inception in 1990, the crab dredge survey has used a fully randomized sampling design with 7131 stations in the Virginia portion of the Chesapeake Bay mainstem and the three major Virginia sub-estuaries: Rappahannock, York, and James. Sediment samples on this survey are taken at each station, which is located by a GPS in latitude and longitude (NAD83). Sediment classification methods used by the crab dredge survey are those outlined in Folk (1980). Only the wet sieving procedures of Folk (1980) were used to classify %fine sediment (<0.0625mm), %sand sediment (<0.0625mm and <2.0mm), and % gravel (>2.0mm). For analysis of trawl survey data, the sediment samples were reclassified based on grain sizes less than 2.0mm. Thus, each sample was characterized by % of fines (clay, silt, and very fine sand) which is equated to % sand by: %fine + %sand = 100. The crab dredge survey points were converted to UTM, zone 18, coordinates in ArcView with the VIMS Avenue script algorithm, converted to a shapefile, and imported

Figure 9. Medium resolution shoreline map of the sampling area, excluding the upper reaches of the river systems. Major sub-estuaries are identified. Data are from EPA, Chesapeake Bay Program.


Rappahannock
York
Mobjack Bay
Chesapeake Bay Mainstem
Eastern Shore
James
N
W
E
S

to ARC/INFO with the *shapearc* command. The points were rasterized with the *pointgrid* command. The *costallocation* function in ARC/INFO's Grid package was used to assign %fine values to unknown grid cells with the shoreline grid specified as the cost surface. This created two new grids: the *costallocation* grid contained the cell values of %fine based on the nearest samplel, and the *costdistance* grid contained the distance in meters of a cell to the nearest sample. The *latticespot* command was used to linearly interpolate %fine sediment and distance values for trawl survey points as they intersected each grid; therefore, trawl survey locations could be classified by the sediment at the nearest dredge survey location, and selected based on their distance from a dredge survey station.

Bathymetry data, obtained from the EPA, Chesapeake Bay Program, Annapolis, Maryland, were used to interpolate a value for slope of the bottom at each trawl survey location. These bathymetry data, over 3.5 million observations, for the Chesapeake Bay were sectioned into arbitrary regions defined by the Chesapeake Bay Program (Anonymous 1997b) and stored in a triangular irregular network (TIN). In TIN modeling, data points are connected to their two nearest neighbors to form a network of triangles. Each point has geographic coordinates and a Z value (depth), and each triangle has a unique slope, aspect and area. A value for slope in degrees was linearly interpolated from the intersection of the trawl survey points with each TIN. First each TIN was converted to a polygon coverage with the *tinarc* command, and then slope values were assigned to the trawl survey points with the *identity* command.

Each TIN had overlapping regions with other bordering TINs and the bounding polygon of each TIN was coded as shoreline regardless of the true geographic depth value. This created two problems: (1) Some trawl survey data points could potentially have three values from the intersection with different TINs. (2) TIN edges that fell over water would produce erroneously high slope values and shallow depths due to the sharply ascending triangles created between the real data points and the shoreline-coded bounding polygon. Because each TIN used the same data points in the overlap regions, interpolated values would be the same from either TIN; therefore, values from overlap regions were arbitrarily chosen from a single TIN. Trawl survey points that fell directly on the highly influential TIN edges were highly problematic to remove from the analysis, but since they accounted for <1% of the trawl survey data, they were considered a tolerable amount of stochastic variation in the model and left in the data set.

The *tinarc* command failed to work on the region CB8 TIN; therefore, a program was written in ARC/INFO Macro Language to circumvent the problem (see Appendix VI). This program resulted in the same triangular slope-coded polygon coverage that the *tinarc* command normally creates. The CB8 tin is bounded by the shoreline from Cape Henry to shortly beyond Little Creek and reaches roughly three-quarters of the way across the mouth of the Bay. Again, the *identity* command was used to apply slope values to trawl survey points in the CB8 region.

Statistical Analyses

Further manipulation of the data included deletion of erroneous and non-informative data points. A portion of the trawl survey data consisted of double tows (immediately consecutive tows at the same station), stations outside of the Virginia portion of the Chesapeake Bay, and stations which fell on land due to the resolution of the shoreline and the accuracy of the coordinates. These stations were removed from the data set for the analysis.

When modeling a dichotomous response variable such as presence/absence, where a binomial distribution is expected, logistic regression using the Logit link is the most appropriate method (Agresti 1990). The response of catching or not catching a flounder, an event which is an assumed random binomial variable, in logistic regression, is linked to a linear combination of the variables by the logit:

$$\mathrm{Logit}(\pi(\mathrm{x})) = \log\{\pi(x) / (1 - \pi(x))\} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_i X_i$$

This is called the logistic function, where α is a constant, and β_i is the parameter coefficient of X_i, which is a linear predictor of the Logit. The variance of the expected logit was calculated as with any linear combination of variables as "the sum of the variance of each term in the expression plus two times the covariance of each possible pair of terms" (Hosmer & Lemeshow 1989). The model assumes no interaction between variables, no correlation between variables, and represents a monotonic, 'S'-shaped relationship between each variable and the response. The equation can also be expressed more specifically in terms of the probability of catching a flounder:

$$\pi(x) = \exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_i X_i) \;/\; \{1 + \exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_i X_i)\}$$

$\exp\beta_i$ is the odds of an event occurring due to X_i when all other factors remain constant. In logistic regression, maximum likelihood estimates, from a binomial probability distribution in this case, for the parameters are calculated iteratively by minimizing sums of squares. Minitab version 12.0 (Minitab, Inc. State College, PA) and SAS/STAT version 6.12 (SAS, Inc., Cary NC 1996), which use the Newton-Ralphson algorithm for iterative calculations, were used for logistic regression analyses in this study.

One goal of model building in this study was to reduce the number of covariate patterns. The term covariate pattern refers to a unique set of values for the covariates in the model (Hosmer & Lemeshow 1989). As the covariate patterns in the data were reduced by grouping independent variables into coded or dummy variables, the continuous nature, and thus resolution, of some of the data was lost. However, reducing the number of covariate patterns was necessary because of small sample size. As the number of covariate patterns was reduced, the sample size within a covariate pattern increased; the parameter estimates became more stable, and the goodness of fit measures became more reliable (Hosmer & Lemeshow 1989).

Univariate regressions on each variable were performed for each season. Univariate regression on each variable was preferred over forward, backward and stepwise model selection techniques to maximize the use of the data. This is because variables such as tow distance, %fines, tide, hypoxia, would severely limit the number of observations that could be used due to missing data values. Significant variables from the univariate regressions were included in multivariate models for each season. Appropriate scaling of significant explanatory variables in the reduced model was accomplished through systematic grouping of values and nominal scale analysis. This procedure not only simplified interpretation of the model but also decreased the number of possible covariate patterns, J, thus avoiding bias in the Deviance and Pearson chi-square goodness of fit measures as J approaches n (Hosmer & Lemeshow 1989). Non-signifcant variables in the multivariate models were then removed. The object of selecting a reduced model which eliminates non-significant variables is to develop the most parsimonious interpretation of the data.

Some preliminary scaling took place to ensure an adequate sample size at each level of the explanatory variables for initial univariate analyses. Depth was divided to 1m divisions and grouped stations <2m and >20m. Initially, temperature was divided into 3 degree intervals and salinity into 2ppt intervals. The ends of the temperature and salinity ranges were truncated to categories of <3°C, >27°C, <2ppt and >28ppt. A dummy variable for slope was created which partitioned the data into three categories: flat bottom (0-1°), moderate slope (1-2°), and high slope (>2°). Only those values for percent of fine sediment which fell within 300 meters of a crab survey observation were analyzed, and the data were categorized into 10% intervals. Dissolved oxygen data proved problematic when a considerable portion of the data equated to >120% saturation. Due to this apparent bias, the oxygen values were categorized into hypoxic (<3.0 ml/L) and normoxic (≥ 3.0 ml/L) levels. This seemed reasonable as the only response to dissolved oxygen known in the literature is hypoxia (≤ 2 ml/L) avoidance (Szedlmayer & Able 1993). It was assumed that the influence of SAV would be negligible beyond a certain distance; therefore, a dichotomous dummy variable based on stations within 2km of SAV and other stations was established. The 2km cut point allowed enough trawl survey locations to be categorized as proximal to SAV for statistical comparison to those samples outside of the region. Tow distance was categorized into 100m intervals, and distance to the Bay mouth was categorized into 10km intervals. Year, Tide, Slope and Oxygen were all modeled as nominal predictors whereas all other variables were modeled as ordinal. For the multivariate analyses, salinity and distance to the Bay mouth were further categorized into 4ppt and 20km intervals respectively to help reduce the number of possible covariate patterns. Examining % fines and salinity as nominal scale variables in the multivariate regressions tested for evidence of curvilinearity observed by Burke et al. (1991). Quadratic terms were added to the models where appropriate.

Several statistics were used to evaluate the models at different stages. In the univariate stage, the log likelihood of the model was tested against a model with only a constant by the G statistic. The likelihood is simply the product of the probability of the event with the probability of no event. Estimates of the parameters are given which maximize the likelihood. The quantity of –2 times the natural log of the ratio of the likelihood from a model with only a coefficient to a model with a variable is the G statistic. The G statistic is expected to have a chi-square distribution, and when it is greater than its degrees of freedom, the model with the variable explains a significant amount of variation in the data over a model with only a constant. The same chi-square test of the likelihood ratio was used in the multivariate models to test the overall significance of nominal scale variables having more than one degree of freedom (more than one category). The Deviance statistic, D, which is a measure of how well the data fit a binomial distribution, is -2 times the natural log of the likelihood ratio of the current model over a saturated model. The saturated model is one in which there are as many parameters as data points, and it has a perfect fit. Another measure of how well the data exhibit binomial variability, is the Pearson's statistic. The Pearson's statistic is the sum of all the Pearson residuals, which are the average residual from each covariate pattern. Both the Deviance and the Pearson's statistic have degrees of freedom equal to the number of covariate patterns minus the number of terms in the model and are expected to have a chi-square distribtion. The Hosmer & Lemeshow goodness of fit test was also used to assess the model, especially when the Pearson and Deviance statistics could not be used due to scaling of the covariance matrix. The Hosmer & Lemeshow statistic is a measure of the difference between observed and expected frequencies based on no less than six divisions of the data and usually ten. The data are grouped by similar expected probabilities into *g*-groups and the statistic is expected to have a chi-square distribution with *g*-2 degrees of freedom. A non-significant Hosmer & Lemeshow test statistic indicates that the observed frequencies do not differ significantly from the expected.

Model Evaluation With GIS

In evaluating regression models, it helps to visualize the response surface. When there are only a few variables, it is possible to plot a response surface; however, if there are many variables, there may be too many dimensions to display satisfactorily in an X,Y,Z plot. Some of the parameters, such as distance to the Bay mouth, depth, slope, and system are relatively fixed in geographic space. Other parameters, such as temperature, salinity, and oxygen are more dynamic, but have regular regimes that are relatively localized in geographic space at a particular time. To simplify the models for evaluation, a response surface was created for each season in geographic space using several source data. While year was significant in all models, source data from all years was not available; therefore, year was held constant for response surface evaluation. Geographical generalization of dynamic variables, such as salinity, for mapping limits exploration of rare covariate patterns (e.g. 4-8ppt salinity near the mouth of the Bay in 1996), but the additional information conveyed by a geographically dependent response surface is more ecologically meaningful. ARC/INFO allows source grids of the variables to be used in an equation to calculate a resultant output grid. The actual operation is performed on individual cells of the source grids to calculate each new cell in the output grid. Thus, the probability response surface as well as the variance of the expected logit from reduced logistic models was calculated using variable source grids in each season.

Grids of depth and slope with 100m cells were created with the *tinlattice* and *polygrid* commands. Grids of depth were created directly from the TINs and joined. Grids of slope values were created from polygon coverages, which were created with the *tinarc* command from the TIN data (the problem previously described for section CB8 was handled by the same program). In the output grids of depth and slope, the cells on the edge of the TINs were assigned the value of the section onto which they overlapped. This assignment smoothed out barriers between sections of the Bay and provided a more realistic continuous surface. The depth grid was used to crop the response surface grids to depths within the sampling frame of the trawl survey, depths ≥ 3m. Grids of distance to the Bay mouth and distance to SAV were already created for the regression analysis.

Grids of the dynamic variables of temperature and salinity were taken from Rennie & Neilson (1994). Rennie & Neilson (1994) is an interactive CD-ROM atlas created for the Chesapeake Bay Program, and has interpolated images of water quality data for a series of years including 1990 (the most recent, complete set of images available which were used in this analysis). The images are grids with a cell size (resolution) of one kilometer; however, they are not in a GIS format. The middle months from each season for each variable of salinity, temperature, and oxygen image were downloaded, bitmap edited to remove unwanted text, rectified in geographic space as images using ARC/INFO, and converted to ARC/INFO grids with the *imagegrid* command.

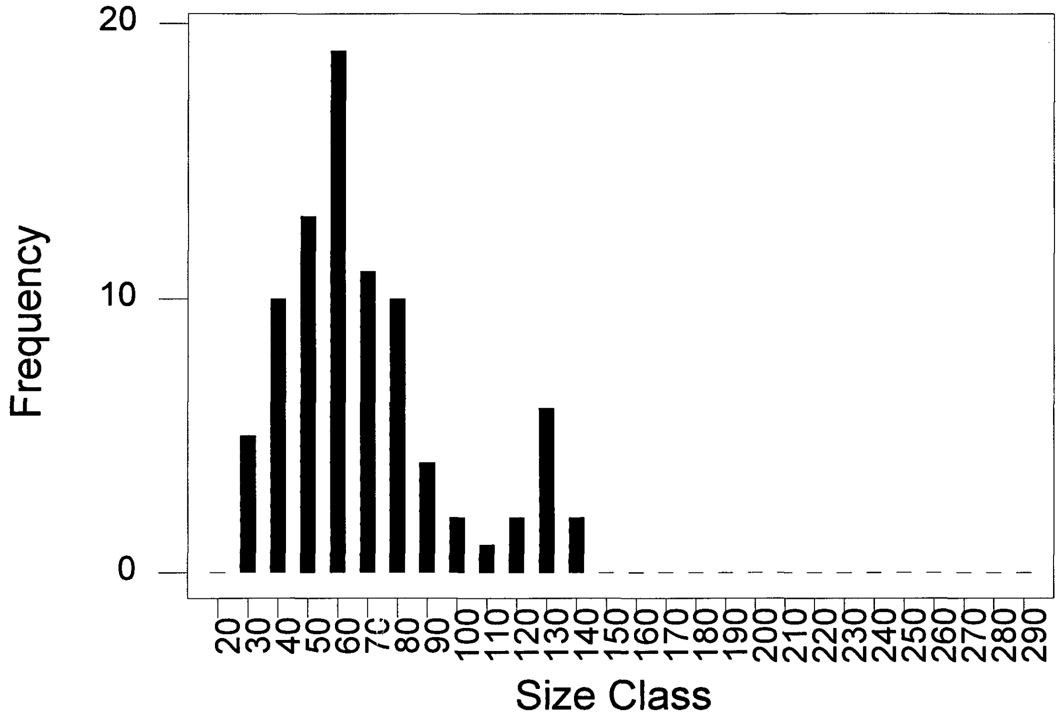
RESULTS

Length cut-points by month are used by the VIMS trawl survey to identify summer flounder in the young-of-year (YOY) size range (Geer & Austin 1996). Cut-points (TL) for the spring months are 60mm in March, 100mm in April, and 140mm in May (Geer & Austin 1996). In the portion of the trawl survey data used for this study, few Y-O-Y flounder were captured in the spring compared to other seasons (Figures 10-13). Cut-points for the summer months continue to increase through the year and are 170mm in June, 200mm in July, and 225mm in August (Geer & Austin 1996). The summer modal size class of Y-O-Y flounder used in this study was 130-140mm (Figure 11). The greatest number of Y-O-Y captured on the survey is in the fall with a modal size class of 170-180mm (Figure 12). Cut-points for the fall months are 250mm in September, 275mm in October, and 290mm in November (Geer & Austin 1996). The winter cut-points are 290mm for all months (Geer & Austin 1996). During the winter fewer flounder are captured than during the summer months, and while the cut-points are the highest, the mode is 150-160mm (Figure 13).

Winter

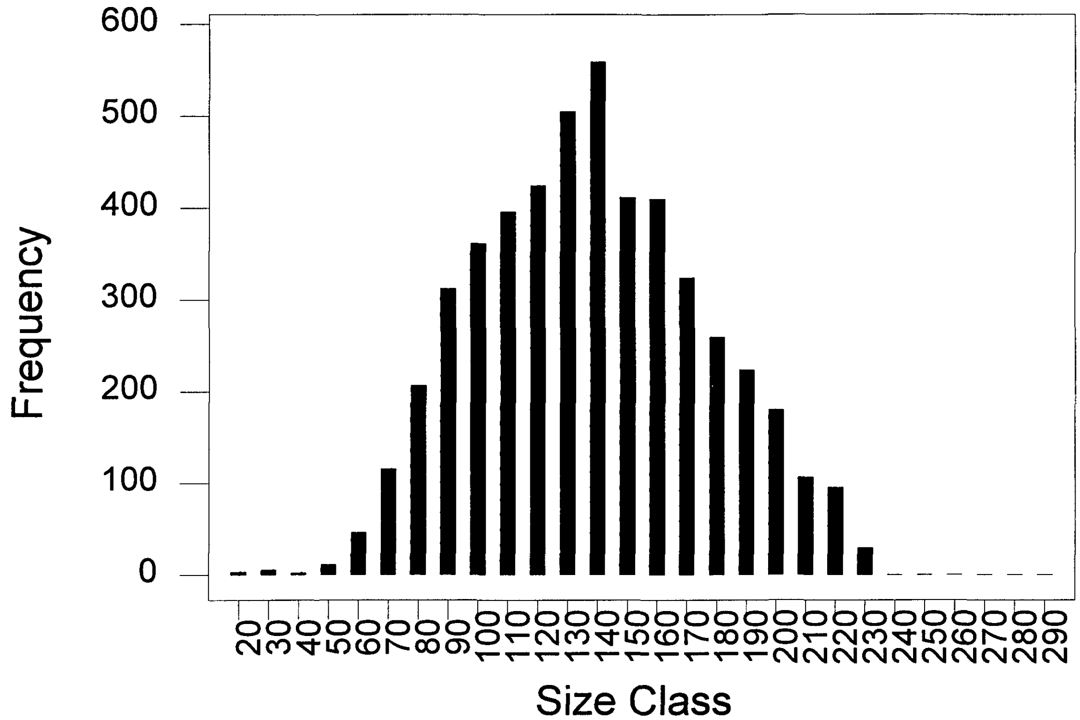
Univariate regressions identified year, tide, depth, temperature, salinity, SAV, slope, and %fines as variables which accounted for a significant amount of variation (at $\alpha = 0.10$) in the winter trawl data. This is shown by the significant probability values of the G-statistics (Table 3). The wide range of LLs, which depend on sample size, can be

Figure 10. Length frequency chart of Y-O-Y summer flounder caught by the VIMS trawl survey since 1979 in the spring. Bin widths are 10mm of total length and are labeled as the highest value in the bin. Y-O-Y are defined by lengths cut-off values by month, which are 60mm in March, 100mm in April and 140mm in May.



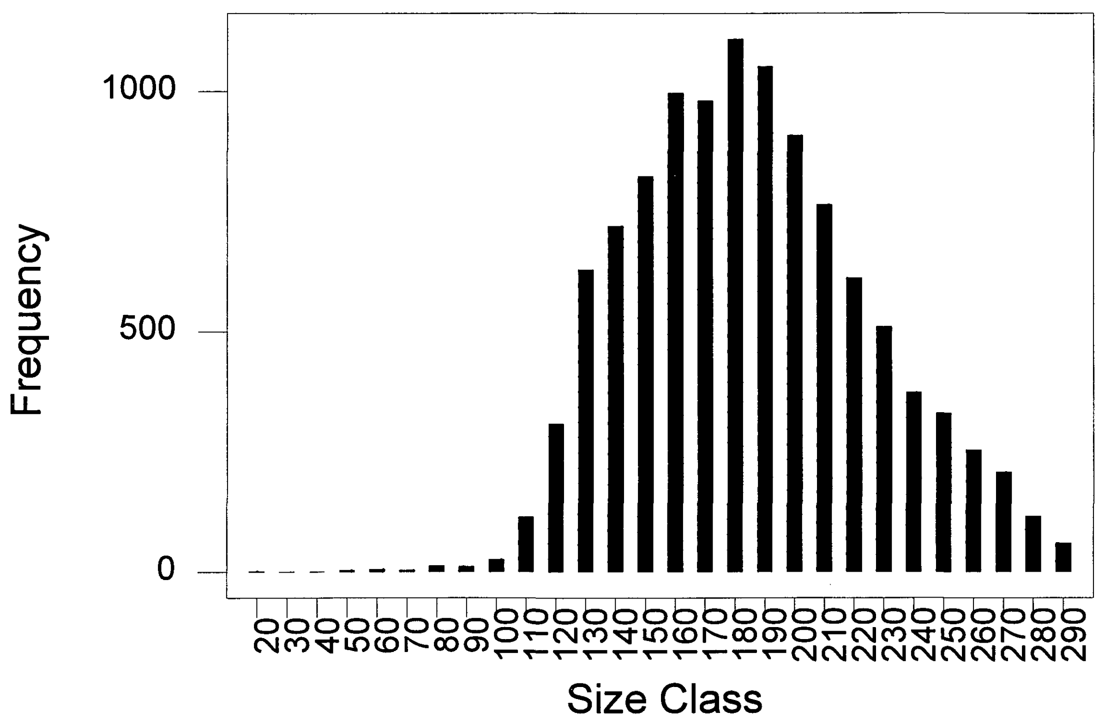
20
10
0
Frequency
20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290
Size Class

Figure 11. Length frequency chart of Y-O-Y summer flounder caught by the VIMS trawl survey since 1979 in the summer. Bin widths are 10mm of total length and are labeled as the highest value in the bin. Y-O-Y are defined by lengths cut-off values by month, which are 170mm in June, 200mm in July and 225mm in August.



Frequency
600
500
400
300
200
100
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290
Size Class

Figure 12. Length frequency chart of Y-O-Y summer flounder caught by the VIMS trawl survey since 1979 in the fall. Bin widths are 10mm of total length and are labeled as the highest value in the bin. Y-O-Y are defined by lengths cut-off values by month, which are 250mm in September, 275mm in October and 290mm in November.



Frequency
1000
500
0
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
Size Class

Figure 13. Length frequency chart of Y-O-Y summer flounder caught by the VIMS trawl survey since 1979 in the winter. Bin widths are 10mm of total length and are labeled as the highest value in the bin. Y-O-Y are defined by a length cut-off value, which is 290mm for winter months.

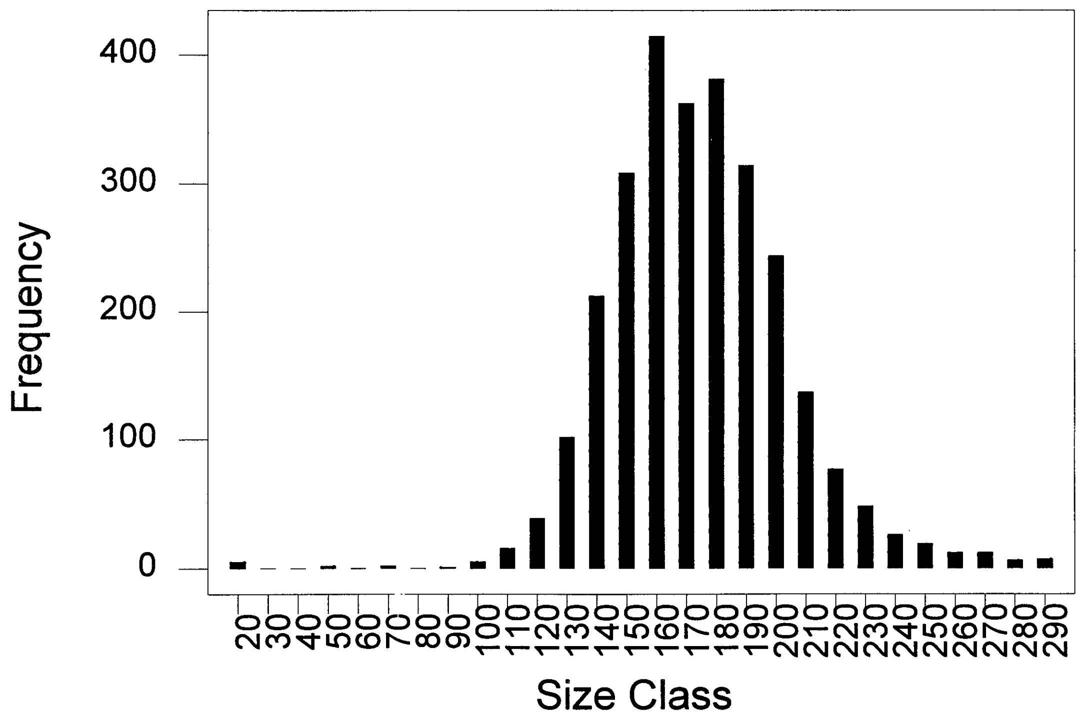

Frequency
400
300
200
100
0
20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290
Size Class

Table 3. Univariate logistic regressions for winter. Coefficients (β) and standard deviations (s.d.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. Log likelihood (LL) values for each univariate model and the G statistic for the log likelihood is given. A probability-value (p-value) is also shown for the G statistic. For regressions on nominal variables with more than one degree of only the LL statistics are shown.

				95% C.I.				
	β	s.d.	Ψ	lower	upper	LL	G	P-value
Year						-844.1	329.7	<0.001
Tide						-967.6	9.9	0.019
Mouth	<0.001	0.002	1.00	1.00	1.00	-1008.9	0.02	0.887
Depth	0.09	0.01	1.09	1.07	1.12	-984.2	49.3	<0.001
Temperature	0.14	0.02	1.16	1.11	1.20	-982.6	52.6	<0.001
Salinity	0.05	0.008	1.05	1.03	1.07	-987.6	42.6	<0.001
SAV	0.35	0.16	1.42	1.04	1.93	-1006.5	4.8	0.029
Slope						-996.7	24.4	<0.001
Tow Distance	-0.001	<0.001	1.00	1.00	1.00	-419.8	1.6	0.208
Hypoxia	1.76	1.42	5.84	0.36	93.55	-903.3	1.4	0.239
%Fines	0.004	0.002	1.00	1.00	1.01	-454.1	3.0	0.085

explained by missing data in some of the variables. Multivariate regression on significant variables from the univariate models showed significant coefficients for variables year, temperature, salinity, and slope at $\alpha = 0.05$ (Table 4). Variables with non-significant coefficients or odds ratios equal to 1.00 were removed from the model where appropriate after individual examination within the multivariate model. The sequence of models used in examining non-significant for removal or evidence of curvilinearity is shown in Appendix I. Evidence of curvelinearity in salinity and %fines was not observed in through nominal scale analysis of categories. All non-significant variables from the winter multivariate model were removed. Categories of the dummy variable for moderate and high slope were within the confidence intervals of each other's odds ratios; therefore, these two categories were collapsed to form a statistically significant dichotomous dummy variable. When compared to the total number of observations used in the final reduced model, n=2387, the degrees of freedom, d.f. = 553, for Pearson's chi-square and Deviance goodness of fit measures were n-asymptotic (Table 5); however, the Pearson's and Deviance statistics are still considered reliable when the proper model is specified (Hosmer & Lemeshow 1989). Pearson's chi-square (909.5) and the Deviance statistic (725.9) were both significantly ($p <0.001$) greater than their degrees of freedom (d.f. = 553) indicating that the actual variability of the response was almost to 1.5 to 2 times greater than the variability expected in a binomial distribution, a phenomenon known as overdispersion. Agresti (1996) noted that "overdispersion is common in the modeling of Poisson and binomial counts," and results in underestimation of variance. Since the Hosmer & Lemeshow goodness of fit statistic

Table 4. Multivariate logistic regression on significant variables from winter univariate regressions. Coefficients (β) and standard deviations (s.d.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. A chi-square (χ^2) test was used to test the significance of nominal variables with more than one degree of freedom. Probability-values (p-values) are shown for the χ^2 statistic or the significance of H_o: β=0. Only 890 of 2387 observations were used due to missing values. 170 of those observations had at least one flounder.

				95% C. I.				
	β	s.d.	Ψ	lower	upper	χ^2	d.f.	P-value
Year						121.3	18	<0.001
Tide						1.0	3	0.796
Depth	~0.00	0.026	1.00	0.95	1.05			0.972
Temperature	0.204	0.040	1.23	1.13	1.33			<0.001
Salinity	0.086	0.019	1.09	1.05	1.13			<0.001
SAV	-0.423	0.298	0.65	0.37	1.17			0.156
Slope						13.1	2	0.001
%Fine	0.003	0.003	1.00	1.00	1.01			0.356
Constant	-4.012	0.647						<0.001

Table 5. Reduced multivariate logistic regression model for winter. Coefficients (β) and standard errors (s.e.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. A chi-square (χ^2) test was used to test the significance of nominal variables with more than one degree of freedom. Probability-values (p-values) are shown for the χ^2 statistic or the significance of H_o: β=0. Of 2387 observations, 358 had at least one flounder.

				95% C. I.				
	β	s.e.	Ψ	lower	upper	χ^2	d.f.	P-value
Year						276.8	18	<0.001
1980	0.437	0.392	1.55	0.72	3.34			0.265
1981	0.873	0.407	2.39	1.08	5.31			0.032
1982	-0.395	0.493	0.67	0.26	1.77			0.422
1983	0.595	0.423	1.81	0.79	4.16			0.160
1984	-0.398	0.612	0.67	0.20	2.23			0.516
1985	-1.132	0.583	0.32	0.10	1.01			0.052
1986	-1.013	0.576	0.36	0.11	1.12			0.079
1987	-0.459	0.645	0.63	0.18	2.24			0.477
1988	-2.971	0.663	0.05	0.01	0.19			<0.001
1989	-1.746	0.478	0.18	0.07	0.45			<0.001
1990	-1.776	0.427	0.17	0.07	0.39			<0.001
1991	-1.549	0.435	0.21	0.09	0.50			<0.001
1992	-1.306	0.424	0.27	0.12	0.62			0.002
1993	-3.156	0.626	0.04	0.01	0.15			<0.001
1994	-2.296	0.524	0.10	0.04	0.28			<0.001
1995	-2.135	0.513	0.12	0.04	0.32			<0.001
1996	-3.159	0.655	0.04	0.01	0.15			<0.001
1997	-2.036	0.451	0.13	0.05	0.32			<0.001
Temperature	0.209	0.034	1.23	1.15	1.32			<0.001
Salinity	0.078	0.013	1.08	1.05	1.11			<0.001
Slope =>1°	0.495	0.190	1.64	1.13	2.38			0.009
Constant	-3.689	0.423						<0.001

showed that the model fit the data well ($\chi^2 = 5.1$, d.f. = 8, p = 0.748), a transformation, or scaling, of the covariance matrix by Pearson's dispersion factor (Pearson's χ^2/d.f. = 1.6446) was used to correct variance estimates for overdispersion (SAS Institute, Inc. 1996). The reduced, scaled multivariate model for summer flounder occurrence in winter is shown in Table 5, and while scaling will not change the estimates of the coefficients, marginally significant variables will tend to become non-significant because the variance estimates are increased.

Direct interpretation of the regression coefficients is only meaningful on the Logit scale. Since it is difficult to think on a Logit scale, transformation of the coefficients, by e_β, to the odds-ratio provides a way to compare the direction and magnitude of the effects of each variable. When all other variables are constant, the reduced multivariate model shows that flounder occur 1.08 times more frequently in winter trawls with each 4ppt increase of salinity (Table 5). With each three-degree increase in temperature flounder occur 1.23 times more frequently in winter trawls (Table 5). Flounder also occur 1.64 times more frequently in winter trawls over moderately to highly sloped areas ($\geq 1°$) than in catches over flat bottom (Table 5). The occurrence of flounder in winter trawls in most years before 1988, is not significantly different from 1979 (Table 5). Two exceptions are 1981 when flounder were 2.39 times more frequent, and 1985 when flounder occurrence was 60% that in 1979 (Table 5). Since 1988, the model shows that the frequency of flounder in winter catches has been only a fraction, <30%, of what it was in 1979 (Table 5).

Source data grids which generalized the location of different variables were combined using the logistic model to create a surface of the event probability (response surface); however, the term for year was not used in the calculation. Areas of sloped bottom, ≥1°, constitute only a small fraction of the total sampling area and generally correspond to the edges of channels (Figure 14). The average January salinity in 1990 shows a decreasing gradient from the Bay mouth, which is most pronounced in the James river (Figure 15). Average bottom temperature in January 1990 shows that the northern part of the Bay frame is generally 3 degrees colder than the southern half or the rivers. The York river is 3 to 6 degrees warmer than anywhere else in the sampling frame (Figure 16). Areas greater than 60% probability of catching a flounder were limited to the high salinity (>24ppt, Figure 15) region at the Bay mouth (Figure 17). Other areas of greater than 60% probability (Figure 17) corresponded to those areas of sloped bottom in the mid to high ranges of salinity (>16 ppt, Figures 14 and 15), and temperatures greater than 3°C (Figure 16). Areas of highest probability, >70%, are located in the sloped bottom areas in the high salinity water surrounding the Chesapeake Bay Bridge Tunnel (Figures 14, 15, and 17). A relatively homogeneous variance surface over the gradients of temperature and salinity is punctuated by areas of higher variability which correspond to areas of moderate to high slope (Figure 18). Relatively higher variability in sloped bottom areas demonstrates effects of dummy variable coding of slope values. Catches over flat bottom were coded as zero and do not contribute to the variance of the expected Logit, whereas sloped bottom areas nearly double the variance.

Figure 14. Map of sloped bottom regions ≥1°. Resolution is 100m, and the surface is derived from ARC/INFO TINs of depth by the *tinarc* and *tinlattice* commands.


≥ 1°

Figure 15. Map of typical winter salinity regime based on average January salinities in 1990 (Rennie & Nelson 1994). Resolution is approximately one kilometer, and salinity is given in parts per thousand.

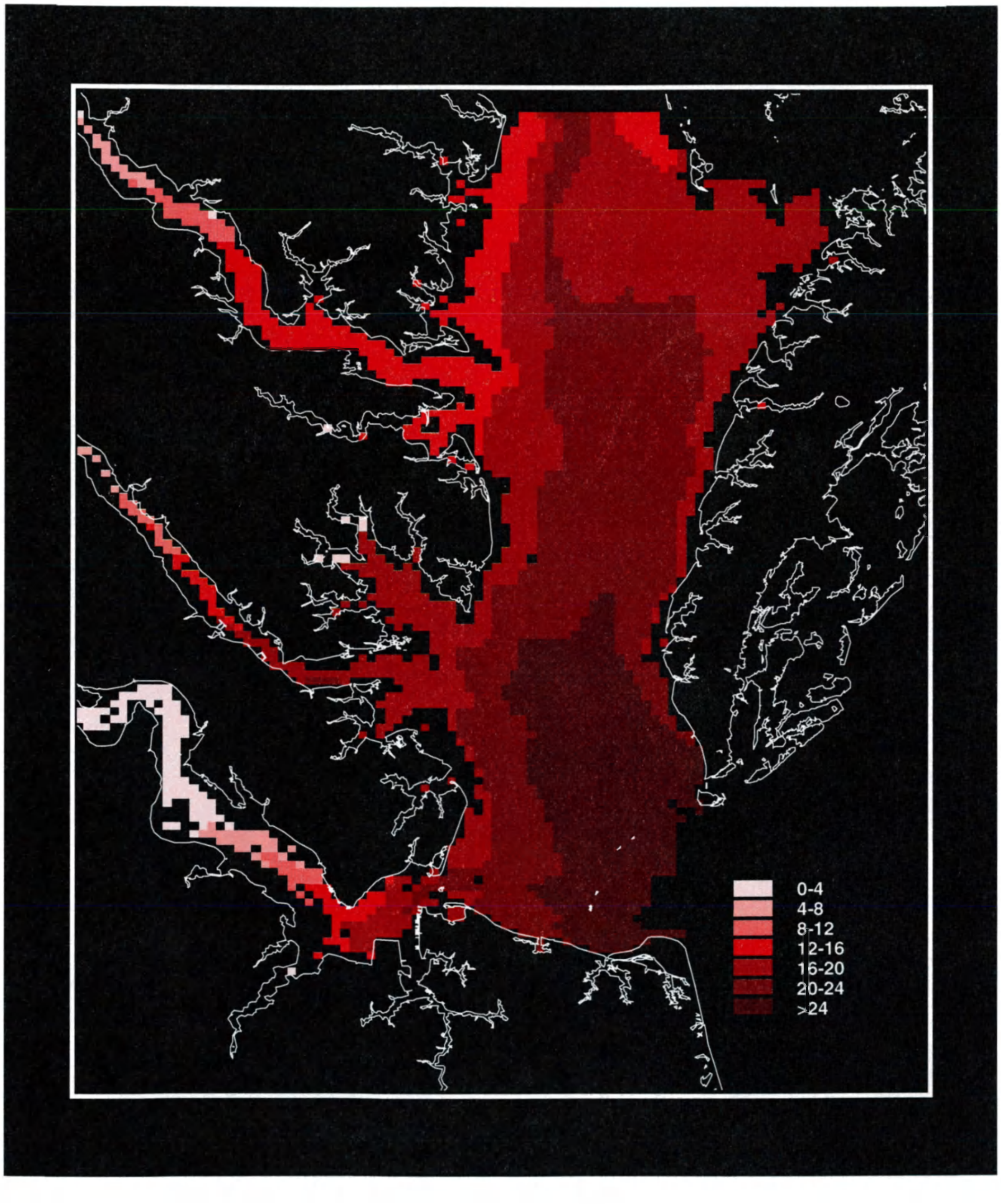

0-4
4-8
8-12
12-16
16-20
20-24
>24

Figure 16. Map of typical winter temperature regime based on average temperatures in January 1990 (Rennie & Nelson 1994). Resolution is approximately one kilometer, and temperature units are in Celsius.

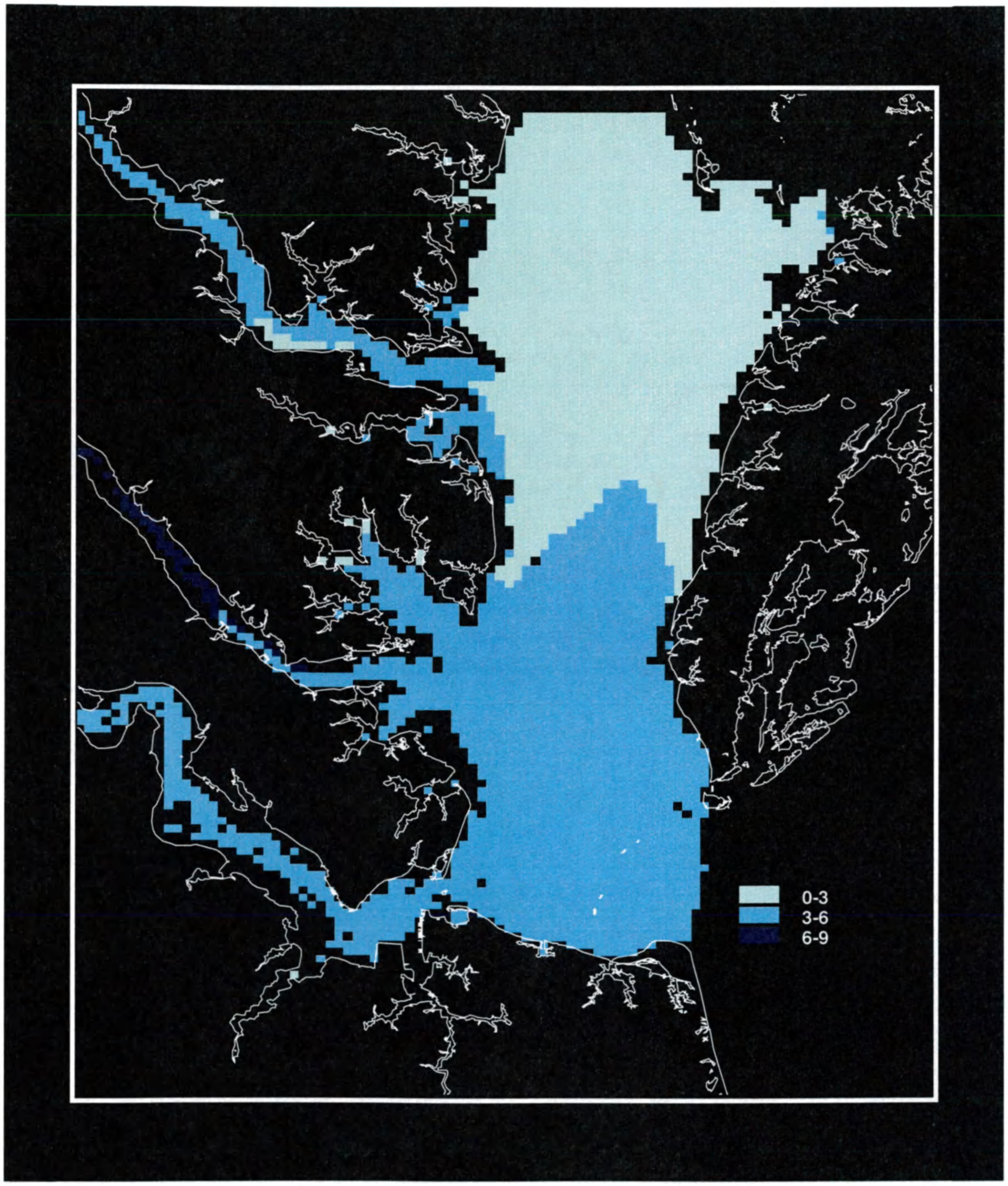

0-3
3-6
6-9

Figure 17. Map of expected winter catch probability based on the reduced multivariate logistic model. Source data grids shown in Figures 14-16 were combined using the logistic model with the parameter estimates from Table 5. Resolution is 100m, and the term for year was not included.

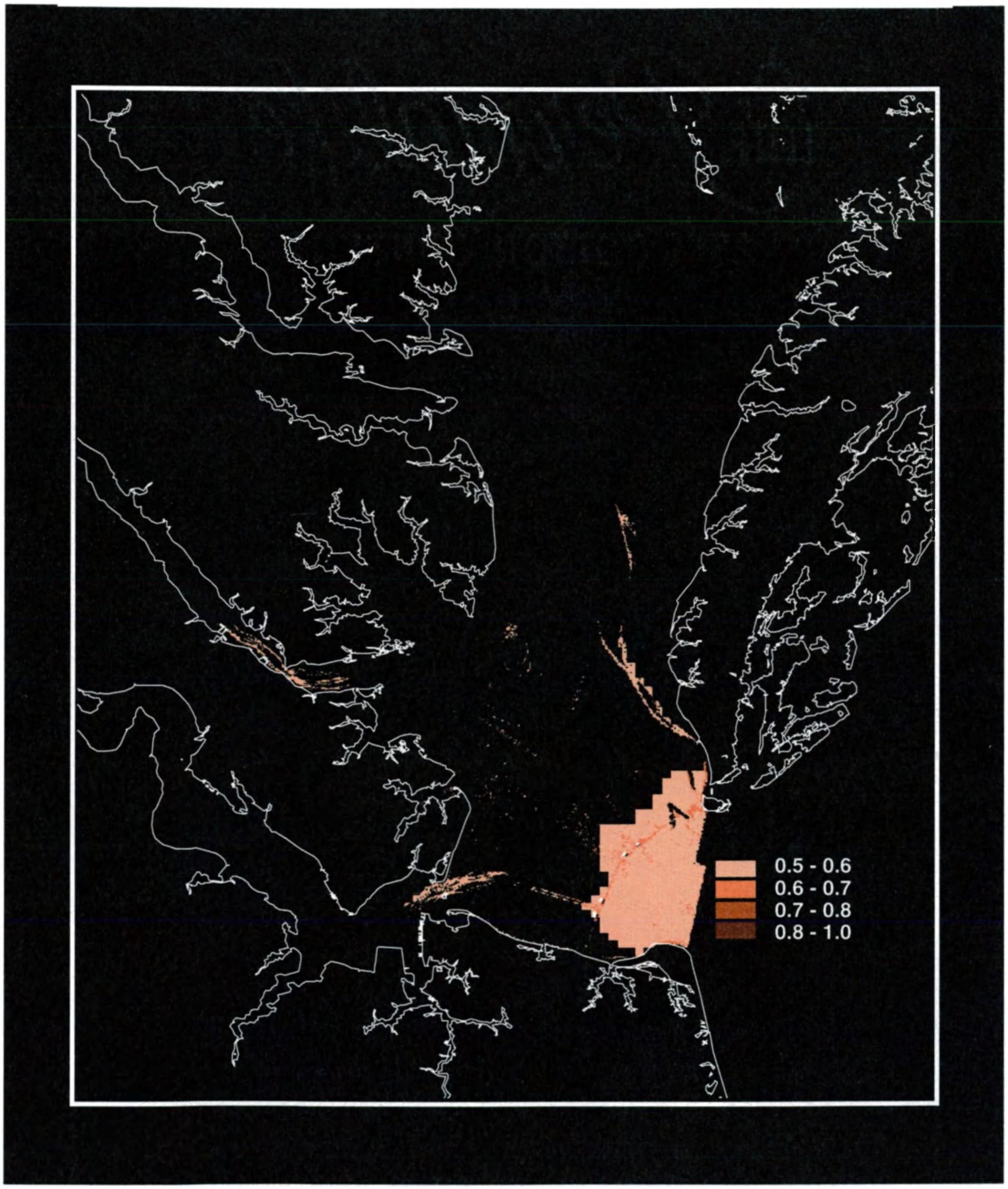
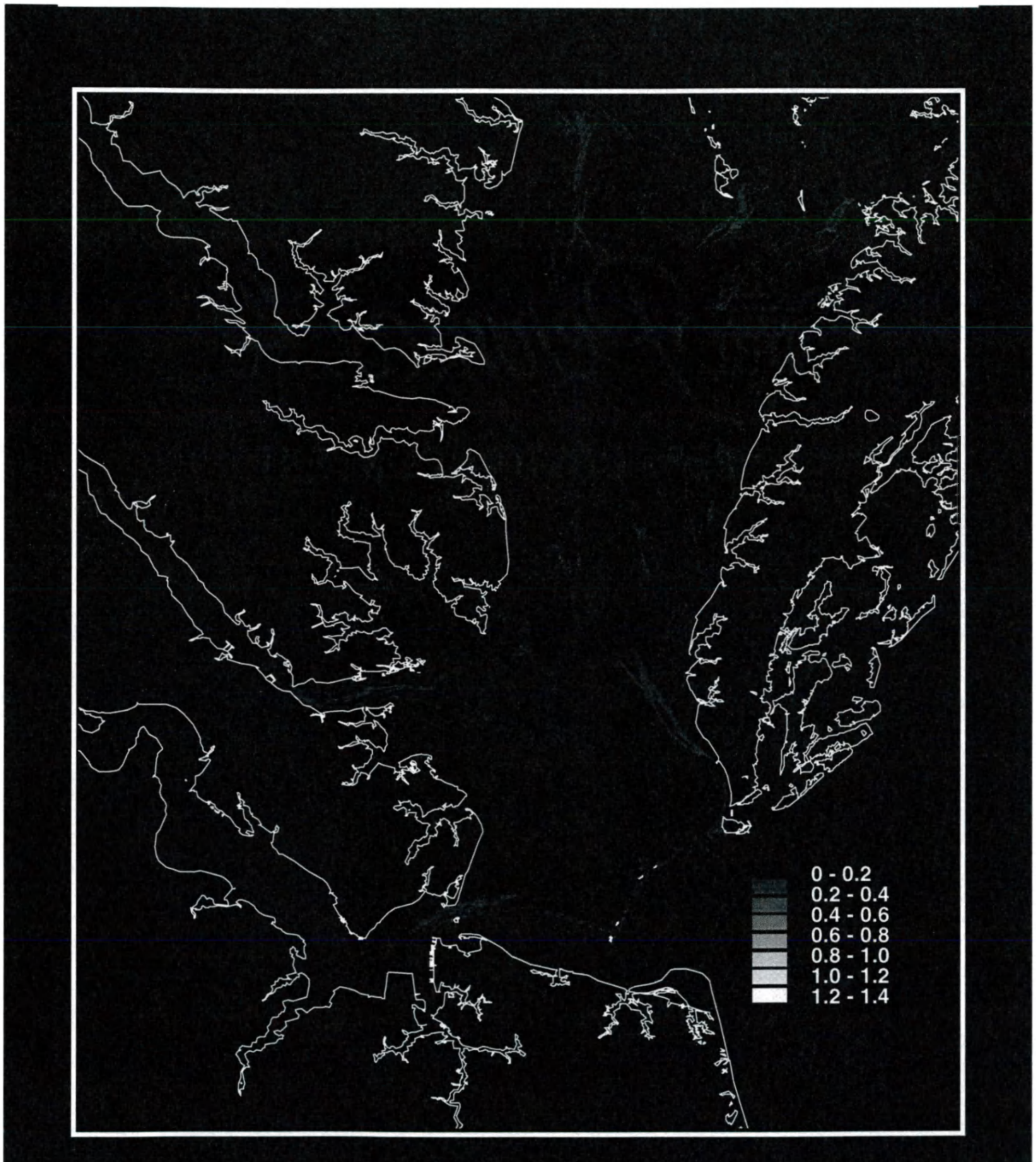

0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 1.0

Figure 18. Map of the variance of the expected Logit in winter for the reduced multivariate logistic model. Source data grids shown in Figures 14-16 were combined using variance and covariance estimates from the model in Table 5. Resloution is 100m, and the term for year was not included.


0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
1.0 - 1.2
1.2 - 1.4

Spring

Univariate regression identified year, distance to the Bay mouth, salinity, SAV, and slope as variables with accounted for a significant (at $\alpha = 0.10$) amount of variation in the spring trawl data. This is shown by the significant probability values of the G-statistics (Table 6). The wide range of LLs, which depend on sample size, can be explained by missing data in some of the variables. Multivariate regression on significant variables from the univariate models showed significant coefficients for all variables except salinity (Table 7). The sequence of regression models used to refine the multivariate model by scaling the variables is shown in Appendix II. Nominal scale analysis of salinity in the multivariate model revealed a non-symmetrical curvilinear relationship which was modeled by grouping ranges of salinity into a significant trichotomous dummy variable where: 0 = <4 and >20ppt, 1 = 16 -20ppt, and 2 = 4-16ppt. To further reduce the high number of covariate patterns, distance to the Bay mouth was also grouped into a trichotomous dummy variable where: 0 = >80km, 1 = <20km and 40-80km and 2 = 20-40km. Only the high slope category was significantly different from the flat bottom category; therefore, the moderate slope category was collapsed into the flat bottom category to form a dummy variable for low and highly sloped bottom (Table 7). Fit of the model was poor (Hosmer & Lemeshow $\chi^2 = 65.41$, d.f. = 8, p = 0.090) due to collinearity between salinity and distance to the Bay mouth; therefore, distance to the Bay mouth was removed from the model because it is a surrogate variable for salinity. Removal of distance to the Bay mouth variable produced a model with a good fit (Hosmer & Lemeshow $\chi^2 = 8.01$, d.f. = 8, p = 0.433), and only slightly changed the coefficient values for salinity indicating that distance to the Bay mouth contributed very

Table 6. Univariate logistic regressions for spring. Coefficients (β) and standard deviations (s.d.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. Log likelihood (LL) values for each univariate model and the G statistic for the log likelihood is given. A probability-value (p-value) is also shown for the G statistic. For regression on nominal variables with more than one degree of only the LL statistics are shown.

				95% C. I.				
	β	s.d.	Ψ	lower	upper	LL	G	P-value
Year						-811.9	139.4	<0.001
Tide						-854.1	0.9	0.833
Mouth	-0.006	0.002	0.99	0.99	1.00	-878.2	6.8	0.009
Depth	0.020	0.015	1.02	0.99	1.05	-880.7	1.8	0.179
Temperature	0.020	0.014	1.02	0.99	1.05	-880.7	1.9	0.171
Salinity	0.016	0.008	1.02	1.00	1.03	-879.6	4.1	0.044
SAV	1.039	0.153	2.83	2.09	3.81	-861.1	40.9	<0.001
Slope						-869.8	23.7	<0.001
Tow Distance	<0.001	<0.001	1.00	1.00	1.00	-486.5	0.8	0.363
Hypoxia	-0.532	0.066	0.59	0.08	4.51	-817.7	0.3	0.581
%Fines	0.002	0.002	1.00	1.00	1.01	-402.9	0.7	0.405

Table 7. Multivariate logistic regression on significant variables from spring univariate regressions. Coefficients (β) and standard deviations (s.d.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. A chi-square (χ^2) test was used to test the significance of nominal variables with more than one degree of freedom. Probability-values (p-values) are shown for the χ^2 statistic or the significance of H_o: β=0. 2456 observations were used of which 285 had at least one flounder.

				95% C. I.				
	β	s.d.	Ψ	lower	upper	χ^2	d.f.	P-value
Year						126.5	18	<0.001
Mouth	-0.016	0.004	0.98	0.98	0.99			<0.001
Salinity	-0.018	0.014	0.98	0.96	1.01			0.194
SAV	0.775	0.173	2.17	1.55	3.05			<0.001
Slope						20.5	2	<0.001
Constant	-1.696	0.836						0.042

little to the model and could be removed. Non-significantly different odds ratios allowed grouping of two salinity categories resulted in a model with a better fit (Hosmer & Lemeshow χ^2 = 4.39, d.f. = 8, p = 0.734), and marginally significant Pearson's (χ^2 = 131.6, d.f = 102, p = 0.026) and Deviance (χ^2 = 131.5, d.f. = 102, p 0.026) measures, indicating slight overdispersion. Scaling of the covariance matrix by the Pearson's dispersion factor (1.2897) was used to correct variance estimates for overdispersion, and fit of the final reduced multivariate model (Table 8) showed further improvement by the Hosmer & Lemeshow test (χ^2= 4.41, d.f. = 8, p = 0.819).

When all other variables are held constant, the reduced multivariate model shows that in spring flounder are 2.30 times more frequent in trawls over highly sloped areas; that flounder are 2.63 times more frequent in trawls near SAV, and that flounder are 2.90 times more frequent in trawls where salinity is between 4 and 20 ppt. (Table 8). In only one year, 1983, was frequency of flounder in spring trawls significantly different from 1979 (Table 8). Source data grids which generalized the location of different variables were combined using the logistic model to create a surface of the event probability (response surface); however, the term for year was not used in the calculation. Based on average spring salinity regimes (Appendix V), proximal SAV regions (Figure 20), and highly sloped bottom areas (Figure 22), the expected catch probability surface for spring was spatially homogenous, <30%. The Logit variance was also spatially homogenous, but relatively higher than in other seasons.

Table 8. Reduced multivariate logistic regression model for spring. Coefficients (β) and standard errors (s.e.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. A chi-square (χ^2) test was used to test the significance of nominal variables with more than one degree of freedom. Probability-values (p-values) are shown for the χ^2 statistic or the significance of H_o: β=0. Of 2456 observations, 285 had at least one flounder.

	β	s.e.	Ψ	95% C. I. lower	95% C. I. upper	χ^2	d.f.	P-value
Year						119.4	18	<0.001
1980	1.251	0.885	3.49	0.62	19.78			0.158
1981	1.394	0.885	4.03	0.71	22.84			0.115
1982	1.622	0.889	5.06	0.89	28.89			0.068
1983	2.296	0.887	9.93	1.75	56.56			0.010
1984	1.235	0.885	3.44	0.61	19.48			0.163
1985	0.485	0.925	1.62	0.27	9.95			0.600
1986	0.384	1.030	1.47	0.20	11.04			0.710
1987	0.971	0.901	2.64	0.45	15.42			0.281
1988	-0.775	0.978	0.46	0.07	3.13			0.428
1989	-1.044	1.009	0.35	0.05	2.54			0.301
1990	0.220	0.902	1.25	0.21	7.29			0.807
1991	0.321	0.885	1.38	0.24	7.82			0.717
1992	1.442	0.861	4.23	0.78	22.86			0.094
1993	0.395	0.894	1.48	0.26	8.55			0.659
1994	-0.515	0.958	0.60	0.09	3.91			0.591
1995	1.448	0.863	4.26	0.78	23.11			0.094
1996	0.239	0.864	1.27	0.23	6.90			0.782
1997	0.335	0.864	1.40	0.26	7.60			0.698
Salinity								
4-20ppt	1.064	0.184	2.90	2.02	4.16			<0.001
SAV <=2km	0.968	0.186	2.63	1.83	3.79			<0.001
Slope =>2°	0.833	0.221	2.30	1.49	3.54			<0.001
Constant	-3.689	0.834						<0.001

Summer

Univariate regressions identified year, tide, temperature, salinity, SAV, slope, hypoxia, and %fines as variables which accounted for a significant (at $\alpha = 0.10$) amount of variation in the summer trawl data (Table 9). This is shown by the significant probability values of the G-statistics (Table 9). The wide range of LLs, which depend on sample size, can be explained by missing data in some of the variables. Multivariate regression on significant variables from the univariate models showed significant (at $\alpha = 0.05$) coefficients for all variables except temperature (Table 10); therefore, temperature was removed. The sequence of regressions used to refine the reduced multivariate model by scaling of the variables is shown in Appendix III. The only tide category significantly different from the reference was slack before ebb in which there were only 35 trawls out of 1027. Based on the marginal overall significance of tide apparently due to the small sample size in the slack before ebb category, tide was removed from the model. The variable slope was simplified to a dichotomous dummy variable for high slope ($\geq 2°$) and low slope. Evidence of strong curvilinearity was observed in the odds ratios for nominal scale analysis of salinity within the multivariate model; therefore, a significant quadratic term for salinity was added. Nominal scale analysis identified a strong trend towards significantly greater occurrence of summer flounder over >70%fine substrate with one outlying category at 10 -20% fines. This outlying category was examined in detail in the raw data, and it was discovered that out of 90 observations where a flounder was caught in 10-20%fines, 78 were from fixed stations in the lower James River. Due to the questionable accuracy of the coordinates for these stations before 1988 (D. Hata pers. comm.) and the reliance of sediment characterization on geographical accuracy, the

Table 9. Univariate logistic regressions for summer. Coefficients (β) and standard deviations (s.d.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. Log likelihood (LL) values for each univariate model and the G statistic for the log likelihood is given. A probability-value (p-value) is also shown for the G statistic. For regressions on nominal variables with more than one degree of only the LL statistics are shown.

				95% C. I.				
	β	s.d.	Ψ	lower	upper	LL	G	P-value
Year						-1380.3	316.0	<0.001
Tide						-1519.6	10.8	0.013
Mouth	-0.002	0.002	1.00	1.00	1.00	-1537.7	1.3	0.256
Depth	-0.002	0.011	1.00	0.98	1.02	-1538.3	0.02	0.879
Temperature	0.062	0.014	1.06	1.03	1.09	-1528.8	19.1	<0.001
Salinity	0.019	0.006	1.02	1.01	1.03	-1533.8	9.1	0.003
SAV	1.522	0.120	4.58	3.62	5.80	-1461.0	154.8	<0.001
Slope						-1525.8	25.2	<0.001
Tow Distance	-0.001	<0.001	1.00	1.00	1.00	-791.4	2.5	0.117
Hypoxia	-0.920	0.205	0.40	0.27	0.60	-1384.3	24.8	<0.001
%Fines	0.006	0.002	1.01	1.00	1.01	-656.8	10.1	0.001

Table 10. Multivariate logistic regression on significant variables from summer univariate regressions. Coefficients (β) and standard deviations (s.d.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. A chi-square (χ^2) test was used to test the significance of nominal variables with more than one degree of freedom. Probability-values (p-values) are shown for the χ^2 statistic or the significance of H_o: β=0. Only 1027 of 2911 observations were used due to missing values. 272 of those observations had at least one flounder.

	β	s.d.	Ψ	95% C. I. lower	95% C. I. upper	χ^2	d.f.	P-value
Year						151.5	17	<0.001
Tide						7.9	3	0.047
Temperature	0.051	0.031	1.05	0.99	1.12			0.100
Salinity	0.079	0.017	1.08	1.05	1.12			<0.001
SAV	1.737	0.226	5.68	3.65	8.84			<0.001
Slope(=>1°)	1.072	0.288	2.92	1.66	5.14			<0.001
Hypoxia	-0.721	0.332	0.49	0.25	0.93			0.030
%Fines	0.010	0.003	1.01	1.01	1.02			<0.001
Constant	-2.607	0.957						0.006

outlying situation at 10-20%fines proved to be problematic. Regardless, %fines was grouped into a significant dichotomous dummy variable for ≥70%fines. Despite reduction of covariate patterns through scaling of the variables, the model showed overdispersion by the Pearson's ($\chi^2 = 422.5$, d.f. = 332, p = 0.001) and Deviance ($\chi^2 = 391.4$, d.f. = 322, p 0.014) measures of fit. Therefore, the covariance matrix was scaled by the Pearson's dispersion factor (1.2727) to account for overdispersion (Table 11).

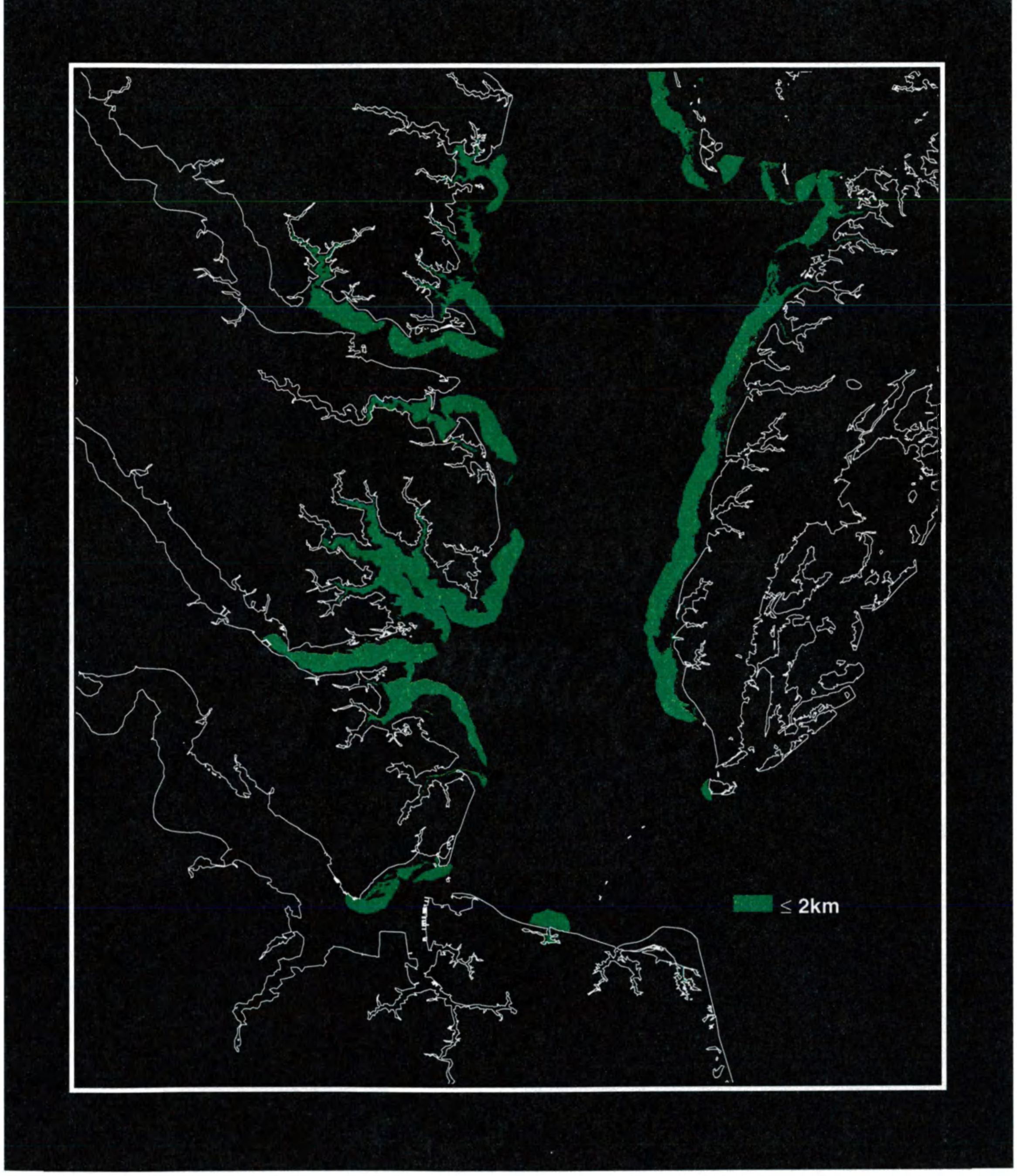
In the final multivariate model for summer when all other variables are held constant, the odds ratio for salinity indicates that flounder occur 1.85 times more frequently with each 4ppt increase, but as the square of salinity increases, flounder occurrence in trawl catches decreases by 0.984 (Table 11). Thus, according to the model, the combination of salinity with its quadratic term indicates that in the summer flounder are most often captured in mid-range salinities. Also, while holding all else constant, flounder are 4.53 times more frequent in trawls within 2km of SAV; they are 2.65 times more frequent in trawls over highly sloped areas, and they are 1.58 times more frequent in trawls over sediment that is ≥70% fines (Table 11). Flounder are 0.36 times less frequent in trawls where oxygen levels are hypoxic (Table 11). Only years 1980-1983, and 1985 were not significantly different from 1979 in flounder occurrence. In all other years, flounder occurrence was <20% of what it was in 1979 (Table 11).

Source data grids, which generalized the location of different variables, were combined using the logistic model to create a surface of the event probability (response surface); however, the term for year was not used in the calculation. Regions of the Chesapeake Bay within 2km of SAV beds in the source data are located at the mouths of the river systems and along the eastern shore (Figure 19). Areas of sloped bottom, ≥2°,

Table 11. Reduced multivariate logistic regression model for summer. Coefficients (β) and standard errors (s.e.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. A chi-square (χ^2) test was used to test the significance of nominal variables with more than one degree of freedom. Probability-values (p-values) are shown for the χ^2 statistic or the significance of H_o: β=0. Of 1030 observations, 273 had at least one flounder. * No data is available for 1986 in the summer.

				95% C. I.				
	β	s.e.	Ψ	lower	upper	χ^2	d.f.	P-value
Year						151.9	17	<0.001
1980	-0.573	0.662	0.56	0.15	2.06			0.386
1981	-0.269	0.676	0.76	0.20	2.87			0.691
1982	-0.503	0.625	0.61	0.18	2.06			0.421
1983	-0.740	0.578	0.48	0.15	1.48			0.200
1984	-1.647	0.646	0.19	0.05	0.68			0.011
1985	-0.721	0.632	0.49	0.14	1.68			0.254
1986*								
1987	-2.346	0.763	0.10	0.02	0.43			0.002
1988	-3.329	0.708	0.04	0.01	0.14			<0.001
1989	-3.691	0.733	0.03	0.01	0.11			<0.001
1990	-2.194	0.607	0.11	0.01	0.11			<0.001
1991	-1.892	0.603	0.15	0.05	0.49			0.002
1992	-2.363	0.610	0.09	0.03	0.31			<0.001
1993	-4.088	0.840	0.02	0.003	0.09			<0.001
1994	-3.206	0.663	0.04	0.01	0.15			<0.001
1995	-3.982	0.781	0.02	0.004	0.09			<0.001
1996	-2.738	0.561	0.07	0.02	0.19			<0.001
1997	-2.704	0.567	0.07	0.02	0.20			<0.001
Salinity	0.615	0.111	1.85	1.48	2.30			<0.001
Salinity^2	-0.017	0.003	0.98	0.98	0.99			<0.001
SAV <=2km	1.511	0.255	4.53	2.75	7.47			<0.001
Slope	0.973	0.331	2.65	1.38	5.06			0.003
Hypoxia	-1.010	0.372	0.36	0.18	0.75			0.007
>70%Fines	0.459	0.218	1.58	1.03	2.43			0.035
Constant	-4.540	0.984						<0.001

Figure 19. Map of regions within 2km of SAV beds based on VIMS remote sensing data from 1996. Resolution is 100m.


≤ 2km

are basically in the same locations as areas of sloped bottom which are important in the model for winter but are less extensive (Figure 20). The generalized salinity regime for summer shows a decreasing gradient from the mouth of the Bay, which is most pronounced in the James river (Figure 21). Areas of large scale hypoxia are shown as a fist-shaped intrusion extending from Maryland to slightly past the mouth of the Rappahannock in the mainstem of the Bay (Figure 22). Areas of ≥70% fine substrate identified in the crab dredge survey are shown as gray circles with a 300m radius in Figure 23, and correspond to the river channels, the majority of Mobjack Bay, and in localized areas in the northwestern region of the Virginia portion of the Bay mainstem. The response surface is limited to those areas within 300m of a crab dredge survey location because the rest of the surface is beyond the extent of the data (Figure 24). To aid in the visualization of the response surface, the *costallocation* function in ARC/INFO was used to assign values for areas of no data based on the nearest known sample (Figure 25). Areas with the highest probability of catching flounder correspond to those regions within 2km of SAV, or those areas with sloped bottom and/or ≥70% fine substrate (Figures 24, 25). Probability of catching a flounder is greater than 50% in most of the Bay mainstem, the Rappahannock, and York rivers (Figures 24, 25). Markedly reduced probabilities, <50%, occur in regions corresponding to hypoxia, low salinity in the upper James, and the high salinity regions at the Bay mouth (Figures 24, 25); however, hypoxia and low/high salinity effects are counteracted by high slope and muddy sediment. These low probability regions are also the most variable (Figure 26). Other highly variable catch probabilities correspond to areas of sloped bottom; although, most of the sampling

Figure 20. Map of sloped bottom regions ≥2°. Resolution is 100m, and the surface is derived from ARC/INFO TINs of depth by the *tinarc* and *tinlattice* commands.


≥ 2°

Figure 21. Map of typical summer salinity regime based on average July salinities in 1990 (Rennie & Nelson 1994). Resolution is approximately one kilometer, and salinity units are parts per thousand.

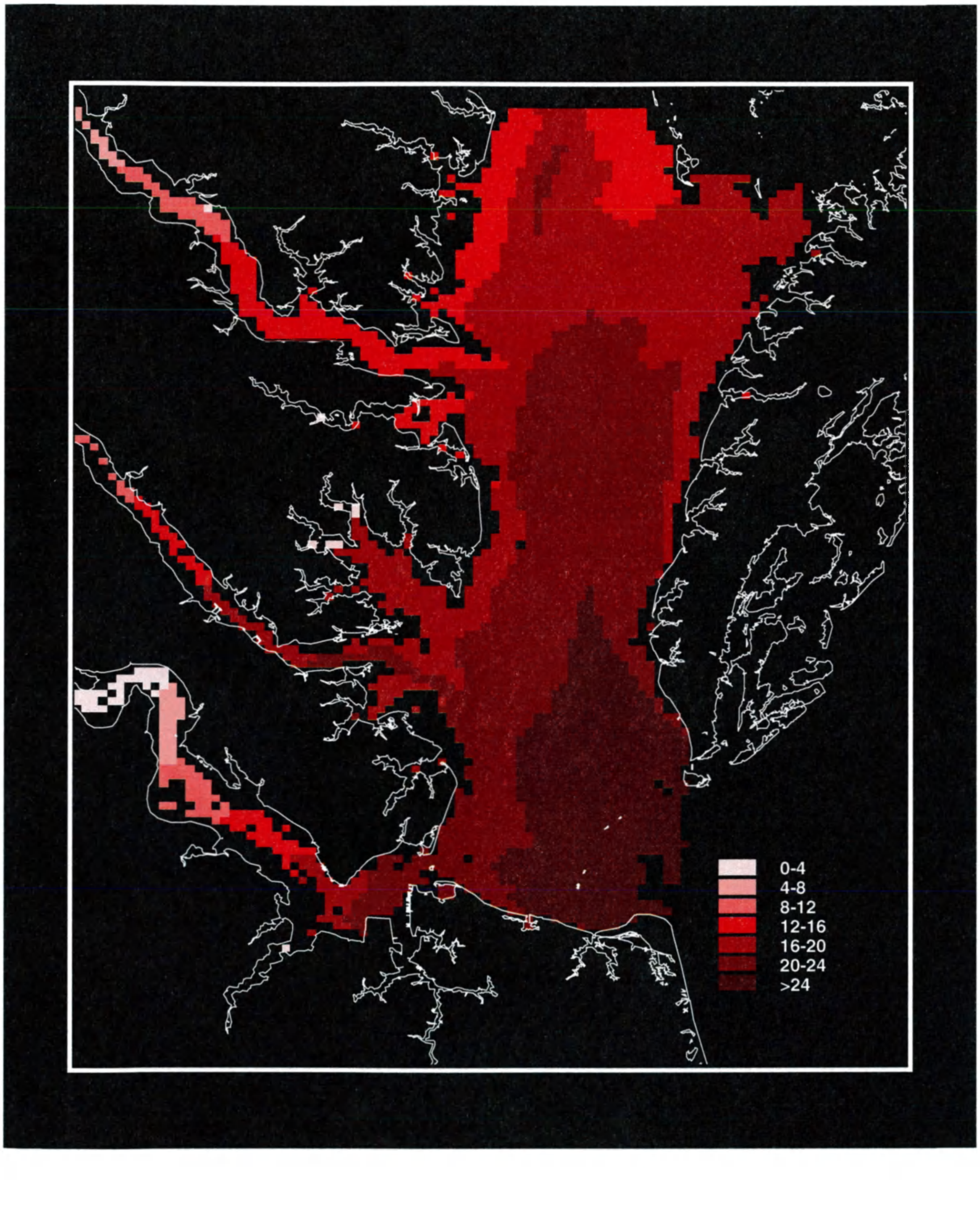

0-4
4-8
8-12
12-16
16-20
20-24
>24

Figure 22. Map of large scale hypoxia (dissolved oxygen ≤ 2ppm) in July 1990 (Rennie & Nelson 1994). Resolution is approximately one kilometer.

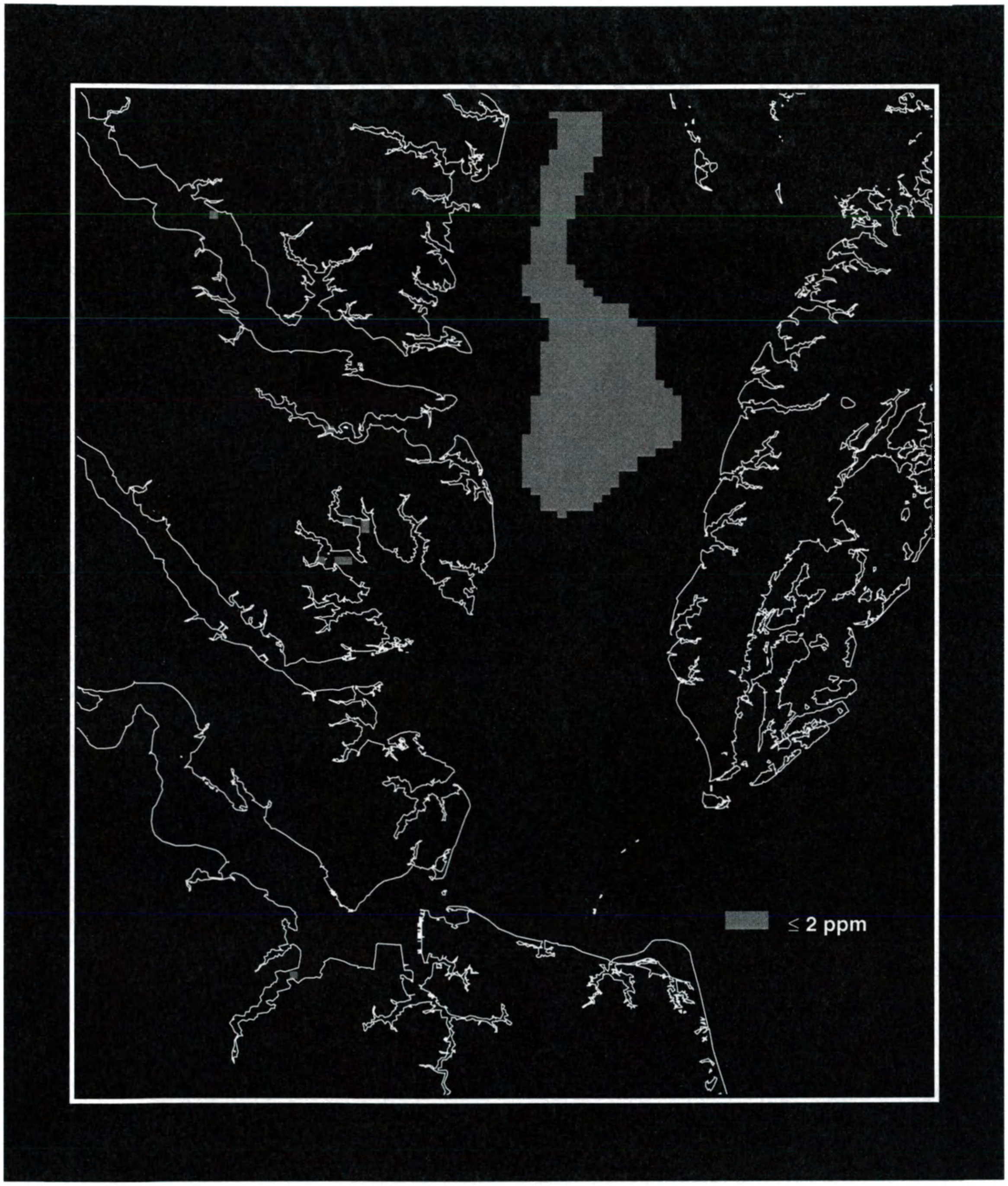

≤ 2 ppm

Figure 23. Map of VIMS crab dredge survey stations, including 300m radius, where substrate was characterized as ≥70% fine sediment. Resolution is 100m.

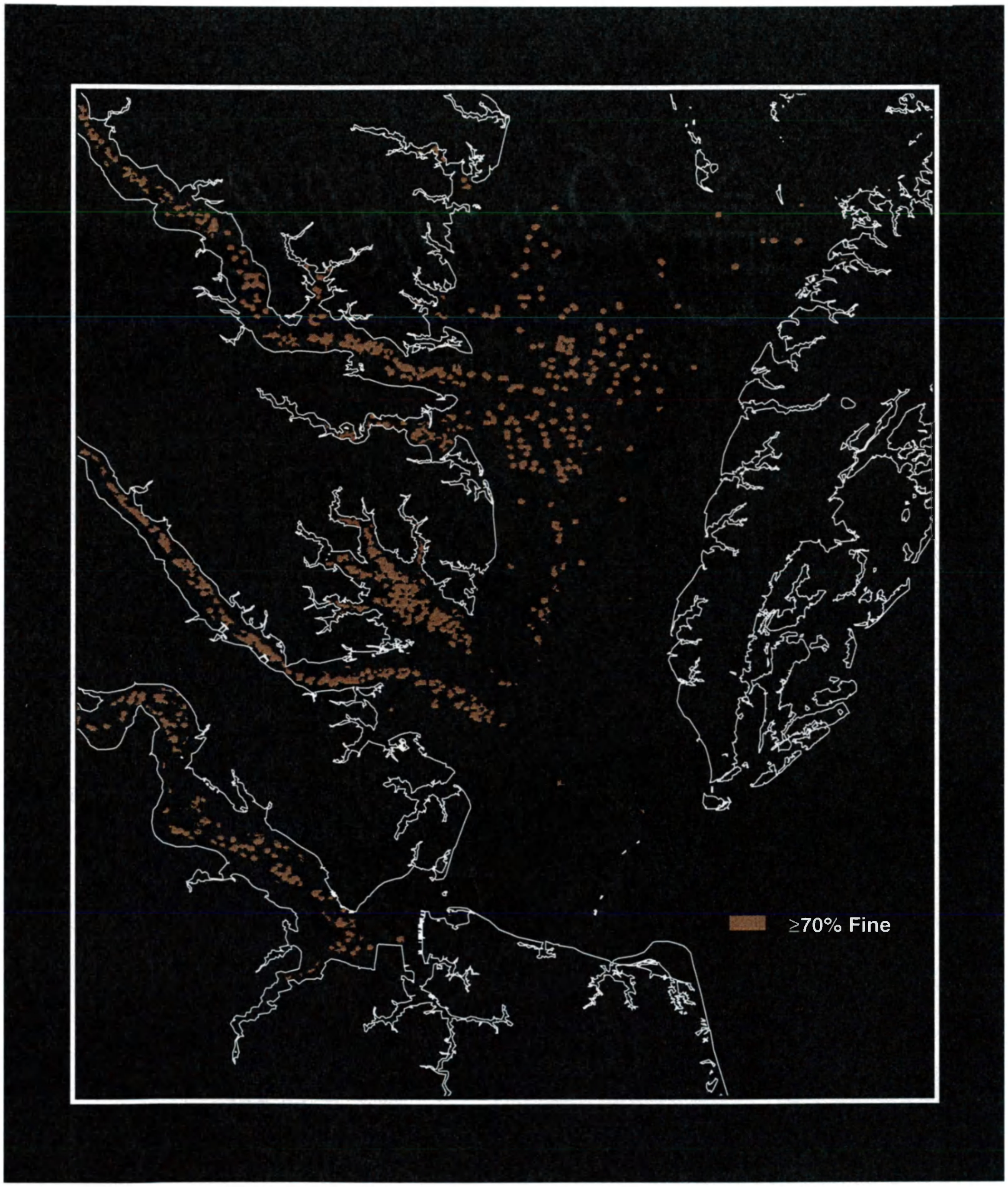

≥70% Fine

Figure 24. Map of expected summer catch probability based on the reduced multivariate logistic model. Source data grids shown in Figures 19-23 were combined using the logistic model with the parameter estimates from Table 11. Resolution is 100m, and the term for year was not included. Surface appears as circles, 300m in radius, outside of which there is no data available.

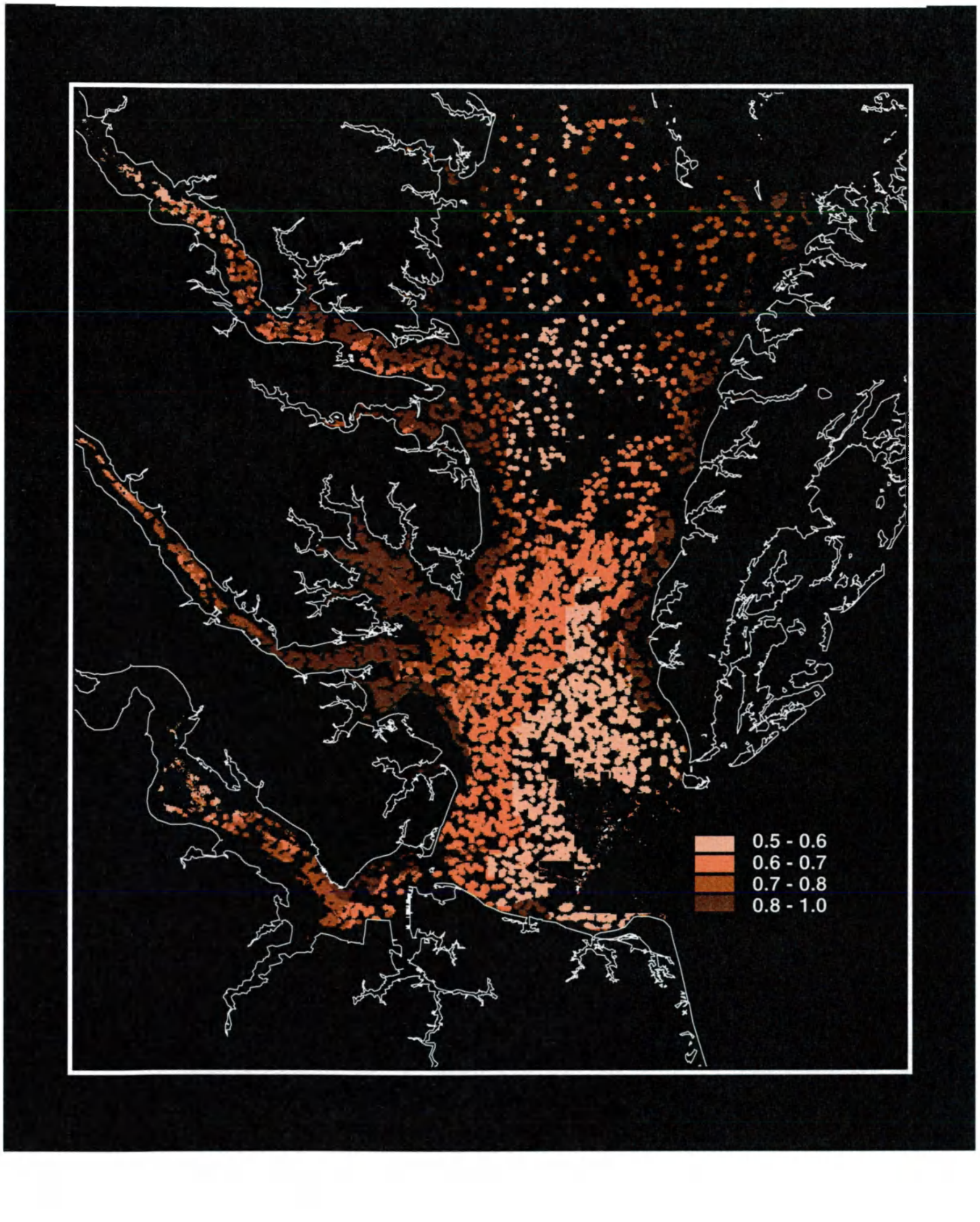

0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 1.0

Figure 25. Data from Figure 24 in which areas of no data have been assigned a probability value based nearest known cell value. Resolution is 100m.

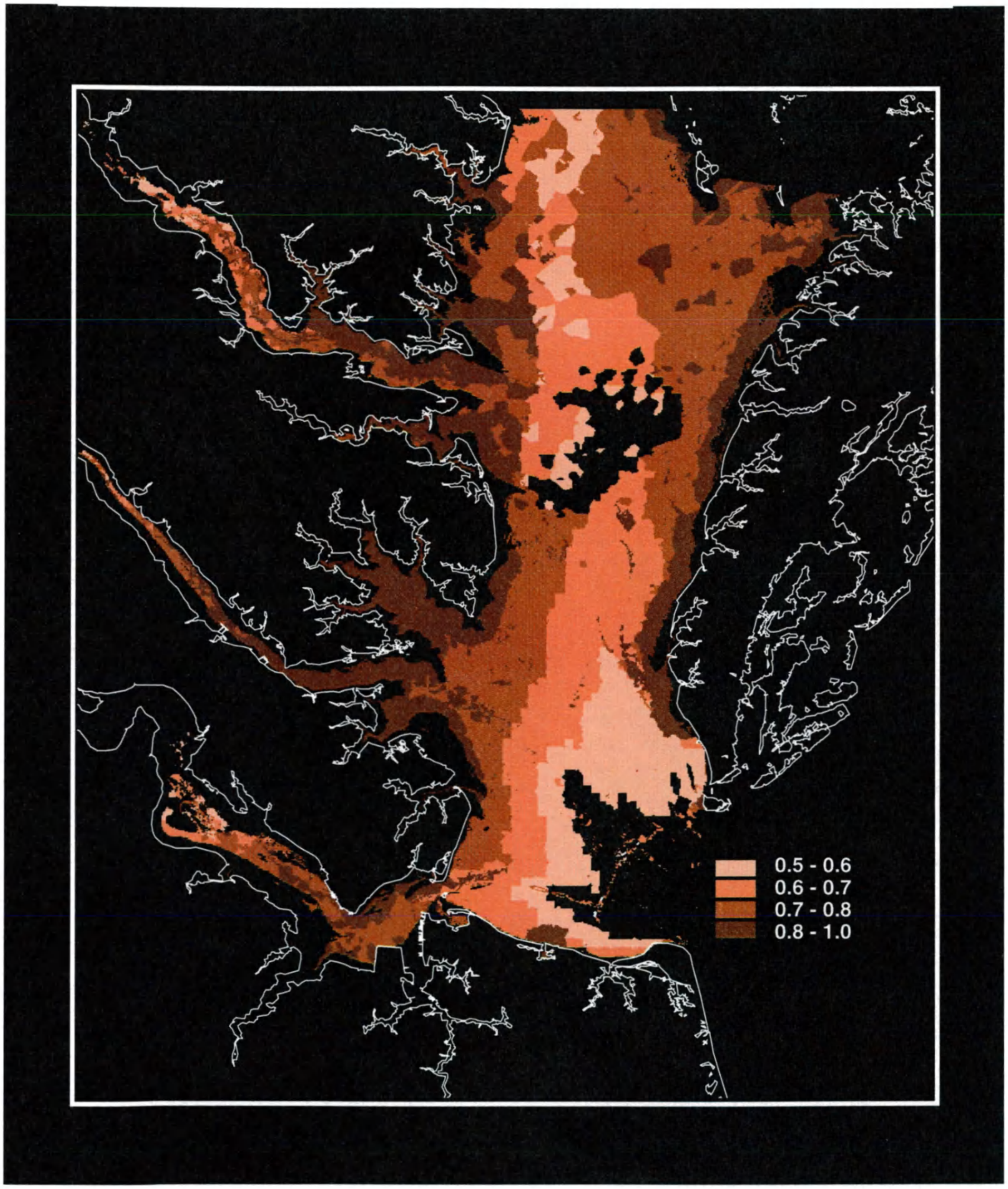
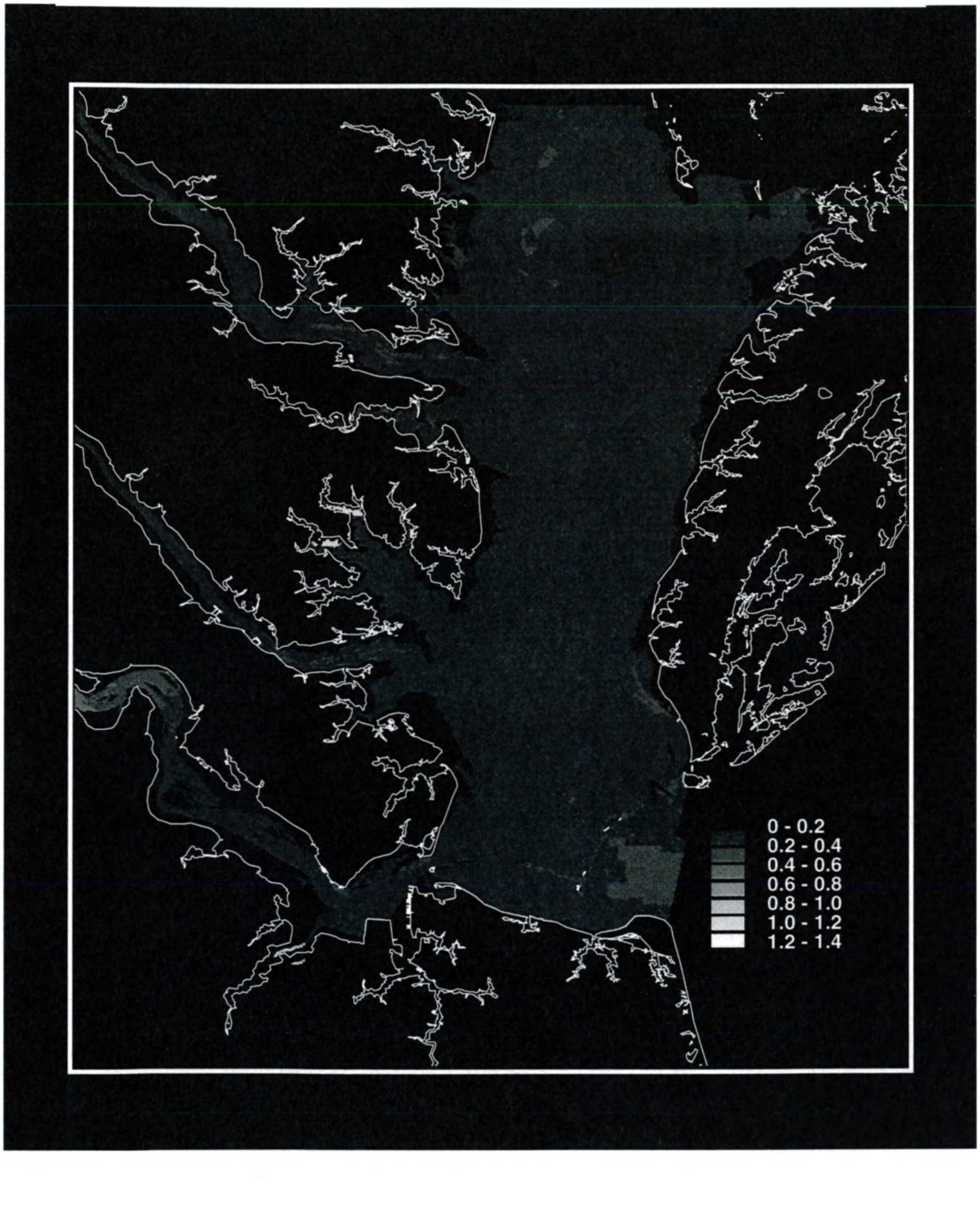

0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 1.0

Figure 26. Map of the variance of the expected Logit in summer for the reduced multivariate logistic model. Source data grids shown in Figures 19-23 were combined using variance and covariance estimates from the model. Resolution is 100m, and the term for year was not included. Values in areas of nodata were assigned the nearest known cell value.


0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
1.0 - 1.2
1.2 - 1.4

frame has a moderate, homogeneous variance, regardless of the catch probability (Figures 24, 25).

Fall

Univariate regressions identified year, tide, distance to the Bay mouth, depth, temperature, salinity, proximity to SAV, slope and %fines as variables which accounted for a significant amount of variation (at $\alpha = 0.10$) in the fall trawl data (Table 12). This is shown by the significant probability values of the G-statistics (Table 13). The wide range of LLs, which depend on sample size, can be explained by missing data in some of the variables. Multivariate regression on significant variables from the univariate models showed significant coefficients for variables year, distance to the Bay mouth, depth, temperature, salinity, proximity to SAV, and slope. Tide was not significant and removed from the model. The sequence of regression models used to refine the multivariate model by scaling the variables is shown in Appendix IV. No patterns in the categories of %fines were observed through nominal scale analysis and its coefficient was not significant; thus, it was justifiably removed from the model. Evidence of strong curvilinearity was observed in through nominal scale analysis of the odds ratios for categories of salinity; therefore, a significant quadratic term was added to the model. Odds ratios for the moderate and high slope categories were within each other's confidence limits; therefore, a dichotomous dummy variable for high, ≥1°, and low slopes was created. Nominal scale analysis of temperature categories showed that at temperatures greater than 21°C there was a significant decrease in the occurrence of flounder in trawl catches; therefore, a dichotomous temperature dummy variable was modeled for high, >21°C, and low temperatures. With the removal of %fines sample

Table 12. Univariate logistic regressions for fall. Coefficients (β) and standard deviations (s.d.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. Log likelihood (LL) values for each univariate model and the G statistic for the log likelihood is given. A probability-value (p-value) is also shown for the G statistic. For regressions on nominal variables with more than one degree of only the LL statistics are shown.

				95% C. I.				
	β	s.d.	Ψ	lower	upper	LL	G	P-value
Year						-1659.5	417.7	<0.001
Tide						-1854.2	10.0	0.018
Mouth	0.006	0.001	1.01	1.00	1.01	-1858.4	20.0	<0.001
Depth	0.049	0.010	1.05	1.03	1.07	-1855.8	24.0	<0.001
Temperature	-0.033	0.008	0.97	0.95	0.98	-1859.9	16.9	<0.001
Salinity	0.014	0.006	1.01	1.00	1.03	-1865.8	5.15	0.023
SAV	1.16	0.119	3.19	2.53	4.04	-1819.9	96.8	<0.001
Slope						-1840.8	55.1	<0.001
Tow Distance	<0.001	<0.001	1.00	1.00	1.00	-1127.0	0.1	0.711
Hypoxia	-0.434	0.290	0.65	0.37	1.14	-1704.4	2.4	0.122
%Fines	0.006	0.002	1.01	1.00	1.01	-752.4	11.9	0.001

Table 13. Multivariate logistic regression on significant variables from fall univariate regressions. Coefficients (β) and standard deviations (s.d.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. A chi-square (χ^2) test was used to test the significance of nominal variables with more than one degree of freedom. Probability-values (p-values) are shown for the χ^2 statistic or the significance of H_o: β=0. Only 1109 of 2889 observations were used due to missing values. 462 of those observations had at least one flounder.

	β	s.d.	Ψ	95% C. I. lower	95% C. I. upper	χ^2	d.f.	P-value
Year						136.8	18	<0.001
Tide						1.4	3	0.708
Mouth	0.013	0.004	1.01	1.00	1.02			0.002
Depth	0.052	0.020	1.05	1.01	1.10			0.008
Temperature	-0.051	0.015	0.95	0.92	0.98			0.001
Salinity	0.075	0.020	1.08	1.04	1.12			<0.001
SAV	1.023	0.211	2.78	1.84	4.21			<0.001
Slope						10.5	2	0.005
%Fines	0.003	0.002	1.00	1.00	1.01			0.187
Constant	-2.177	0.676						0.001

size increased and depth became non-significant was removed from the model. Distance to the Bay mouth, which contributed very little to the model based on an odds ratio of not more than 1.05 at any step, became non-significant when with addition of a quadratic salinity term; therefore, distance to the Bay mouth was removed from the model. In light of the adequate fit of the model as determined by Hosmer & Lemeshow test χ^2 = 11.3, d.f. = 8, p = 0.183), Pearson's (χ^2 = 661.4, d.f. = 500, p <0.001) and Deviance (χ^2 = 730.3, d.f. = 500, p <0.001) measures indicated overdispersion in the model. The Pearson's dispersion factor (1.3228) was used to scale the covariance matrix for the final reduced model (Table 14).

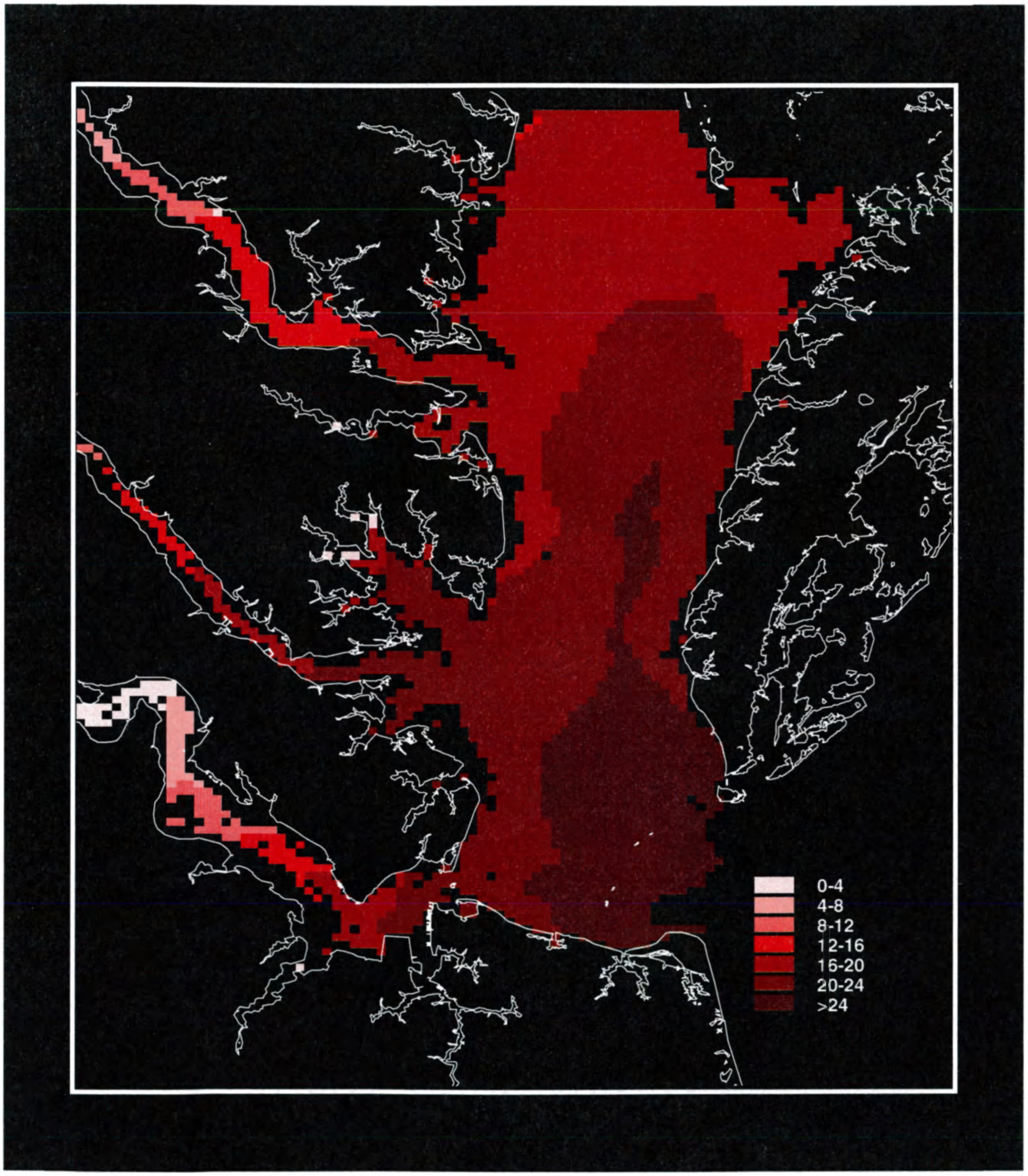
As seen in the model for summer, the final reduced model for fall shows the same peak probability of catching flounder at mid-range salinities. This is evident in the positive coefficient (odds ratio >1) for salinity and the negative coefficient (odds ratio <1) for the square of salinity (Table 14). When all else is constant, flounder occur almost half as frequently in fall trawl catches at high temperatures (ψ = 0.60); they occur nearly three times more frequently in trawl catches within 2km of SAV beds than in other areas, and flounder occur 1.54 times more frequently in trawl over moderately to highly sloped bottom, ≥1° (Table 14). In years 1980, 1981 and 1983 flounder occurrence in fall trawl catches was significantly higher than in 1979 (Table 14). In years 1988, 1989, 1992, 1994-1997, and marginally so in 1987, flounder occurrence in fall trawl catches was reduced by more than half (Table 14). All other years were not significantly different from 1979 in flounder occurrence (Table 14).

Source data maps of regions ≤2km of SAV beds and sloped bottom, ≥1°, used for the fall model are the same as for summer (Figure 19) and winter (Figure 14)

Table 14. Reduced multivariate logistic regression model for fall. Coefficients (β) and standard errors (s.e.) of the coefficients are shown. Odds ratios (Ψ) are given with 95% confidence intervals. A chi-square (χ^2) test was used to test the significance of nominal variables with more than one degree of freedom. Probability-values (p-values) are shown for the χ^2 statistic or the significance of H_o: β=0. Of 2899 observations, 1001 had at least one flounder.

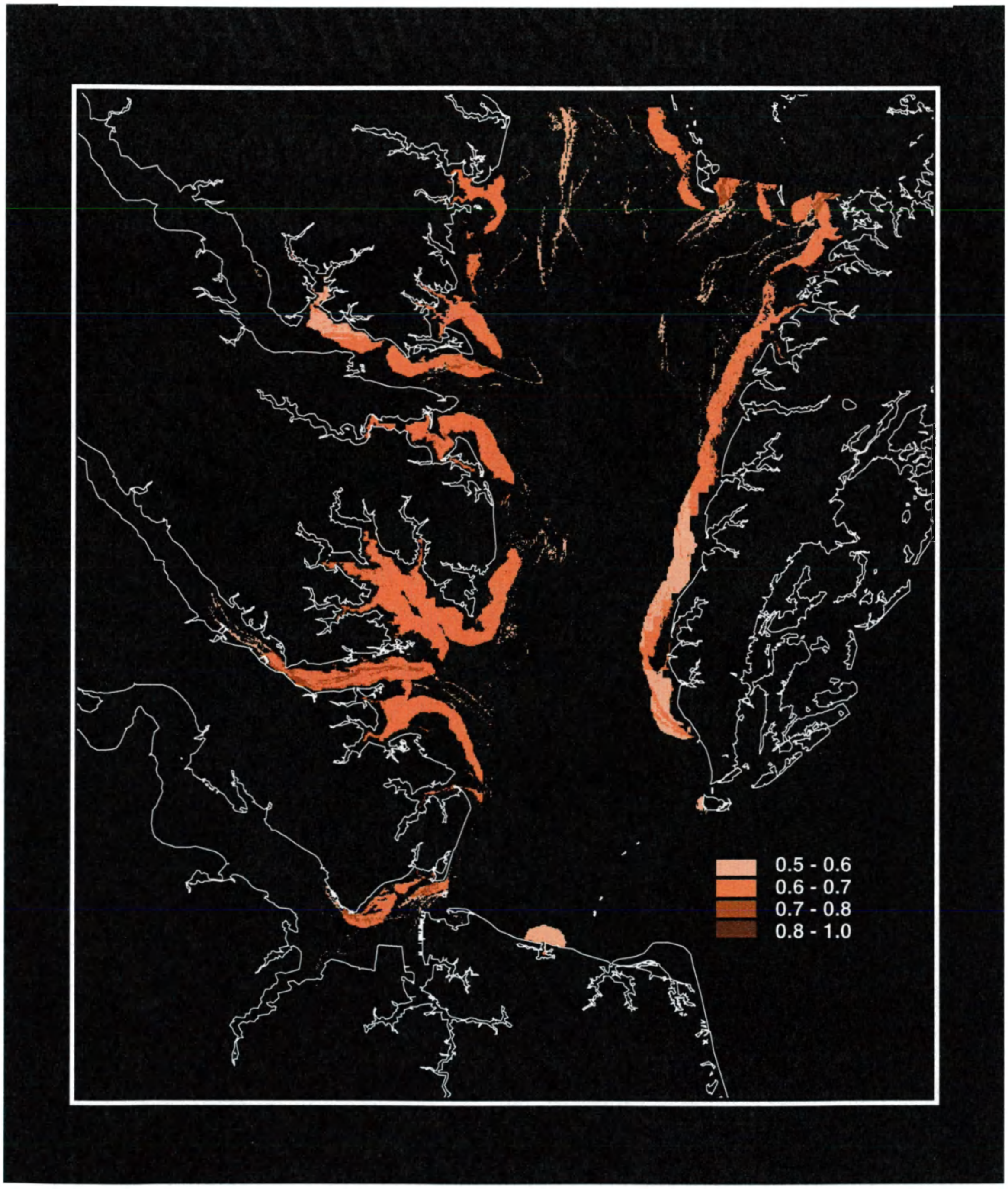
	β	s.e.	Ψ	95% C. I. lower	95% C. I. upper	χ^2	d.f.	P-value
Year						322.0	18	<0.001
1980	1.739	0.426	5.69	2.47	13.11			<0.001
1981	0.964	0.398	2.62	1.20	5.72			0.016
1982	0.459	0.378	1.58	0.76	3.32			0.224
1983	1.581	0.406	4.86	2.19	10.76			<0.001
1984	0.420	0.387	1.52	0.71	3.25			0.277
1985	-0.335	0.460	0.72	0.29	1.76			0.466
1986	0.255	0.394	1.29	0.60	2.80			0.518
1987	-0.750	0.388	0.47	0.22	1.01			0.053
1988	-2.005	0.391	0.14	0.06	0.29			<0.001
1989	-0.955	0.352	0.39	0.19	0.77			0.007
1990	-0.407	0.345	0.67	0.34	1.31			0.238
1991	-0.482	0.355	0.62	0.31	1.24			0.174
1992	-0.867	0.356	0.42	0.21	0.85			0.015
1993	-0.541	0.355	0.58	0.29	1.17			0.128
1994	-1.166	0.360	0.31	0.15	0.63			0.001
1995	-1.265	0.381	0.28	0.13	0.60			<0.001
1996	-1.039	0.328	0.35	0.19	0.67			0.002
1997	-0.735	0.335	0.48	0.25	0.92			0.028
Temperature	-0.512	0.108	0.60	0.49	0.74			<0.001
Salinity	0.353	0.048	1.42	1.29	1.56			<0.001
Salinity^2	-0.009	0.001	0.99	0.989	0.99			<0.001
SAV <=2km	1.087	0.154	2.96	2.19	4.01			<0.001
Slope <=1°	0.433	0.121	1.54	1.22	1.96			<0.001
Constant	-3.356	0.475						<0.001

Figure 27. Map of typical fall salinity regime based on average October salinities in 1990 (Rennie & Nelson 1994). Resolution is approximately one kilometer, and salinity units are parts per thousand.


0-4
4-8
8-12
12-16
16-20
20-24
>24

respectively. The fall salinity regime is similar to summer (Figure 27), and the average October temperature anywhere in the sampling frame is ≤21°C. Areas with >50% catch probability correspond to moderatly to highly sloped areas in mid range salinities (roughly between 4 and 20ppt) and all areas within 2km of SAV (Figure 28). Despite the environmental gradients on which the probability surface depends, the variance of the expected Logit surface was homogenous and relatively low compared to other seasons.

Figure 28. Map of expected fall catch probability based on the reduced multivariate logistic model. Source data grids shown in Figures 14, 19, and 29 were combined using the logistic model with the parameter estimates from Table 14. Cell size is 100m, and the term for year was not included in the model.


0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.8 - 1.0

DISCUSSION

The advantage of multivariate analysis including all possible variables is a parsimonious interpretation of the data based on the most important variables and their relative effects. This analysis demonstrates that annual and seasonal variation along with regional scale effects of salinity and temperature are important in combination with meso-scale spatial effects of slope of the bottom and proximity to SAV beds to determine the occurrence of juvenile summer flounder in trawl catches. Hypoxia events and sediment were also found to be significant in one season (summer); however, sediment effects may be an artifact of other variables. Univariate regressions on tide, depth, and distance to the Bay mouth were significant in specific seasons, and previous work has shown that tide and depth influence the distribution of summer flounder (Szedlemayer & Able 1993, Able et al. 1990). However, variation accounted for by these variables in the multivariate regressions was either non-significant or confounding as in the case of distance to the Bay mouth in spring.

Temporal variation on an annual scale accounts for fluctuating year-class strength, and variation in the different seasonal models reflects growth and recruitment of individual cohorts. Annual variation in abundance is documented well for juveniles in Virginia (Norcross & Wyanski 1994, Geer & Austin 1997), and by other recruitment indices in the MAB (Anonymous 1996). The annual trend in odds ratios for the fall model corresponds roughly with the VIMS abundance-based index (Geer & Austin

1997). The lack of annual variation in spring model reflects the low occurrence of flounder in spring trawls. This is due to the inaccessibility of small flounder to the gear because they inhabit shallow marsh flats outside of the sampling frame during this time (Powell & Schwartz 1977, Wyanski 1990, Burke et al. 1991, Able & Kaiser 1994). One year, 1983, accounted for the majority of the spring-caught flounder as shown by the significantly high odds ratio ($\psi = 9.93$). Comparison of annual trends among the four models shows that relative cohort occurrence in trawls may exhibit dramatic change as the seasons progress. For instance, in 1981, catch probability during summer was significantly lower than in 1979, whereas catch probability during fall of 1981 was significantly higher than in 1979. The winter model dampens cohort effects by combining the December catches of one cohort with the January and February catches of the previous cohort. However, the months of January and February are not consistently sampled in all years, and most of the annual variation in the winter model can be attributed to December catches.

Regional scale salinity effects were observed for all seasons. Salinity was significant in all seasons, and except for winter, mid-range salinities between 4 and 20ppt show the highest catch probabilities. The 4-20ppt salinity range of increased catch probability can be seen not only in the nominal scale analysis of salinity in the spring (Table 8), but also in the simulation response maps of the summer and fall models where catch probability exceeds 50% (Figures 24 and 28). Burke et al. (1991) found a similar curvilinear relationship with salinity and catch probability; however, the effects of the highly correlated sediment variable resulted in the non-significance of salinity in a multivariate model. Possible curvilinearity modeled by Burke et al. (1991) may be substantiated by the present study as salinity and sediment are not significantly correlated in these data. Explanation for this apparent preference for mid-range salinities in light of earlier work which found a preference of flounder for higher salinities (Powell & Schwartz 1977, Wyanski 1990, Hoffman 1991), could simply be that evidence of mid-range salinity preference was not considered. In contrast to the spring, summer and fall models, the winter model shows a simple increase in summer flounder occurrence with salinity (Table 5). This winter phenomenon likely reflects a shift in the distribution of flounder as they emigrate from the estuary to become offshore residents for the winter (Szedlmayer & Able 1993, Able et al. 1990).

The meso-scale effects of bottom slope punctuated the regional scale effects of the salinity gradient, and showed that flounder occurred 1.5 to 2.6 times more frequently in trawls over moderately to highly sloped bottom (Tables 5, 8,11 and 14). The values of slope in the data ranged from 0 to 14° with most of the data values less than 3°. It is not likely that the efficiency of the trawl gear is sensitive to such small changes in slope; therefore, the response of summer flounder occurrence to sloped bottom is either a property or indicator of a property of the species' behavior. Investigation of slope as a habitat variable has received limited attention in the literature. Jones et al. (1990) showed that channel edge (sloped) habitat supports a benthic infauna standing stock that is an order of magnitude less than surrounding ocean plume and tidal flat habitat in the Columbia River, OR. In littoral areas of the Great Lakes it was observed that while fish numbers decreased, size of fishes increased with increasing slope (Randall et al. 1996). As slope was significant in all seasons, there is no indication of size dependent slope effects in this study. The sloped bottom areas, which flank the channels of the estuary, are areas of hydrodynamic convergence (Mann & Lazier 1991). Fronts are created along these high slope areas during tidal movements and concentrate zooplankton which attract small predators. In turn, larger predators sometimes congregate along these fronts to feed on the small predators, and summer flounder may be no exception in preferring channel edges as optimal foraging grounds.

Meso-scale effects of SAV beds, with odds ratios ranging from 2.63 in the spring to 4.53 in the summer, were more influential than the effects of bottom slope. While most of the SAV beds are of substantial geographic extent, the variable for proximity to SAV beds used in this study weighs large and small SAV beds equally. This should serve to obscure the observed differences; however, regional change in the areas of >50% catch probabilities shifted from all areas of mid-range salinities in the summer (Figure 24), to only those regions within 2km of SAV beds or sloped bottom in the fall (Figure 28). This shift is remarkable because fall is the season with the highest catch rates but the most geographically limited >50% expected probability. SAV does not grow to depths within the sampling frame (~>3m) of the survey (Batiuk et al. 1996); therefore, the proximity affect of SAV on flounder occurrence may be a surrogate for other variables. Depth is an obvious possibility; however, depths with in 2km of SAV range from 1.2 to 25m with an average depth of 10.6m, and it is not likely that the SAV dummy variable is a surrogate for shallow habitats. Another possible surrogate is salinity, as much of the general distribution of SAV is centered in the mid-range salinities between 4 and 20 ppt (Figures 15, 19, 21, 27, and Appendix V). However, the majority of the sampling area in mid-range salinities is not within 2km of SAV. SAV plays an important role in structuring fish communties (Adams 1976, Orth & Heck 1980, Middleton et al. 1984, Pollard 1984, Olney & Boehlert 1988, Ruiz et al. 1993, Connolly 1994b), providing protection from predation (Lascara 1981, Pollard 1984, Laprise & Blaber 1992, Gotceitas et al. 1997), and providing forage (Burchmore et al. 1984, Robertson 1984, Shaw & Jenkins 1992, Connolly 1994a). SAV affords little protection from predation for summer flounder as their morphology makes them more conspicuous lying in grass beds than on bare sediment (Lascara 1981). Secondary production in fish communities with heavily vegetated habitat has been estimated at twice that of sparsely-vegetated habitat (Robertson 1984), and food has been identified as one of the most important habitat variables for flatfish (Gibson 1994). Comparison of the feeding and abundance of a juvenile flatfish, *Rhombosolea tapirina,* in vegetated and non-vegetated bays showed that fish in the non-vegetated bay were food-limited whereas fish in the vegetated bay were more abundant and had higher feeding rates (Shaw & Jenkins 1992). It is highly probably that the increased catch probability close to SAV beds in this study represents a foraging association of summer flounder with seagrass habitat. Furthermore, Lascara (1981) identified summer flounder as a crepuscular predator around seagrass habitat, and Sogard and Able (1994) suggested that diel immigration of fish and decapod crustaceans to seagrass beds was driven by predation risk. In contrast to the theory of active selection of sloped habitat based on hydrodynamic concentration of prey proposed previously, the significance of sloped bottom areas in this study could represent a daytime refuge that allows easy access to more productive shallow seagrass habitat when predation risk is lower. Trawling was only conducted during daytime hours; therefore, no diel variation of flounder occurrence in trawls can be examined. That the SAV proximity variable simply represented a near-shore phenomenon was discounted as it was not significant in the winter model. SAV dies-back during the winter (Orth & Heck 1980), and thus provides no cover or forage for nearby flounder.

Temperature effects were observed on a regional scale in the models for fall and winter and with opposite patterns (Tables 5 and 14). While temperature has highly important survival and growth effects at certain ontogenetic stages of summer flounder (Malloy & Targett 1991, Szedlmayer 1992, Gibson 1994, Malloy & Targett 1994), temperature is only marginally important in determining flounder occurrence in trawls. Catch probability increased with temperature during the winter; however, fall occurrence of flounder in trawls was greater at temperatures ≤21°C. The winter scenario is physiologically compatible with observations of summer flounder in the laboratory (Malloy & Targett 1991). Fall temperatures ranged from 8 to 30°C with a mean of 19°C whereas winter temperatures ranged from 0 to 22°C with a mean of 5°C, and together, the models of fall and winter flounder occurrence suggest a preference of summer flounder for mid-range temperatures. Partitioning of the data into seasons, and thus smaller than annual temperature ranges, limits the ability of this modeling approach to fully explore temperature effects. During the fall months flounder abundance in the trawl catches increases to a maximum in November, while fall temperatures decrease to a minimum in November (Geer & Austin 1997). It is likely that the model for winter indicates active selection of warmer temperatures whereas the effects of temperature in fall simply represent a dramatic fall temperature change typical of the Chesapeake Bay coupled with increasing recruitment to the trawl gear.

Hypoxia avoidance described by Szedlmayer & Able (1993) is evident in the model for summer. Hypoxia was not a significant variable in any other season because dissolved oxygen values never dropped to 2ml/L or below. The large scale hypoxia distribution map used in the response surface simulation of the summer model (Figure 22) did not include hypoxic regions in the lower Rappahannock, although hypoxic levels there are frequent in the data for deep water in late summer.

Significance of the sediment variable in only the summer model may represent an ontogenetic artifact of substrate preference of smaller individuals, which could have been masked in the spring model by low occurrence combined with limited sample size. Fine to mixed substrate preference has been observed for small juveniles (Wyanski 1990, Burke et al. 1991). However, the effects of sediment in this study appear to be highly influenced by other associated variables. The model for summer shows that flounder are nearly 1.6 more frequent in trawls over substrate with ≥70% fines when all other variables are held constant. The trawl survey gear opens wider on average over sandy substrate than over muddy (D. Hata pers. comm.). This demonstrates that the gear should be more efficient over sandy substrate; however, the model shows greater catch rates over muddy substrate. Therefore, the variability in flounder occurrence due to substrate is greater than variability in trawl gear efficiency over different substrates. One particular covariate pattern for which this model does not fit well is stations of the lower James, which are in mid-range salinities within 2km of SAV and have 10-20% fine substrate. These stations account for almost all flounder occurrence in the 10-20% fine sediment category. This is a weakness of the model, which may or may not be enhanced by small sample size, but the geographic extent of areas proximal to SAV beds and mid-range salinities in the lower James is limited to a small stretch of the river. Also, in this study a majority of stations with ≥70% fine sediment occur in the highly influential mid-range salinities regions within 2km of SAV. In contrast to the modeling of sediment in this study, Wyanski (1990) observed similar sized flounder more frequently occur over deeper sandy substrates. If one accepts Wyanski's hypothesis, then it could be said that this study's model poorly fits the covariate pattern ≥70% fines, within 2km of SAV in mid-range salinities. While the discrepancies in substrate preference for summer flounder appear to change ontogenetically, it is more probable that the high catch probabilities seen at 10-20% and ≥70% fine substrate are merely an artifact of the highly influential mid-range salinities within 2km of SAV.

As the accuracy of variables such as slope and %fines depend greatly on the accuracy of the station coordinates and the accuracy of the source data, extrabinomial variability, seen in all of the models by the significance of the Pearson's and Deviance tests, could be an artifact of interpolation of additional variables with GIS. Using the reduced winter model as an example (Table 5), it can be shown that removal of the only geographically dependent variable, slope, will not improve the Pearson's ($\chi^2 = 727.0$, d.f. = 329, p <0.001) and Deviance ($\chi^2 = 591.4$, d.f. = 329, p <0.001) tests, yet the model retains an adequate fit by the Hosmer & Lemeshow test ($\chi^2 = 6.72$, d.f. = 8, p = 0.568). Thus, the extrabinomial variability is most likely not due to geographical inaccuracy of the data.

In summary, the models developed in this study stress the importance of a few variables in the probability of catching large juvenile summer flounder. In general, moderately to highly sloped bottom within 2km of SAV are identified as key areas with high catch probabilities when the salinity is between 4 and 20ppt. The ability of the different models for spring, summer, and fall to identify the same 4-20ppt salinity range as important habitat by nominal and ordinal scale analysis lends strength to a mid-range salinity preference hypothesis. High catch probability in areas of high slope may represent a meso-scale feeding aggregation of summer flounder in a more productive hydrodynamic convergence zone or it may also represent daytime refugia that allow access to shallow vegetated habitat on crepuscular feeding migrations. Proximity to SAV beds was often the most influential variable in a particular model, which shows an association of summer flounder with SAV possibly based on food availability. Substrate is of questionable importance to large juvenile summer flounder due to association with other significant variables such as salinity and proximity to SAV beds and conflicting information in the literature. Exclusion of substrate from the EFH identification prototype warrants consideration, but requires further research in reference to large juvenile summer flounder. Two significant variables in this study, not considered by the EFH prototype, are proximity to SAV and slope of the bottom. Identification of these new variables by this study should be influential not only in the identification of EFH parameters, but also in inspiring new research on the habitat utilization of summer flounder as well as other flatfish species.

APPENDIX I

Winter: Intermediate Multivariate Logistic Regressions

Ia.

Response Information

Variable	Value	Count	
Presence	1	178	(Event)
Absence	0	759	
	Total	937	

937 cases were used
1450 cases contained missing values

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-4.0638	0.6581	0.000			
YEAR						
1980	0.1651	0.4883	0.735	1.18	0.45	3.07
1981	1.2738	0.5135	0.013	3.57	1.31	9.78
1982	-0.1372	0.6153	0.824	0.87	0.26	2.91
1983	1.1680	0.5357	0.029	3.22	1.13	9.19
1984	-0.0203	0.6455	0.975	0.98	0.28	3.47
1985	-0.6135	0.6347	0.334	0.54	0.16	1.88
1986	-1.9654	0.8434	0.020	0.14	0.03	0.73
1987	-0.5996	0.7486	0.423	0.55	0.13	2.38
1988	-2.8119	0.8223	0.001	0.06	0.01	0.30
1989	-1.4556	0.5860	0.013	0.23	0.07	0.74
1990	-1.5383	0.5307	0.004	0.21	0.08	0.61
1991	-1.2384	0.5339	0.020	0.29	0.10	0.83
1992	-0.8742	0.5133	0.089	0.42	0.15	1.14
1993	-2.6482	0.7213	0.000	0.07	0.02	0.29
1994	-2.3734	0.6778	0.000	0.09	0.02	0.35
1995	-1.3887	0.5649	0.014	0.25	0.08	0.75
1996	-2.7512	0.7052	0.000	0.06	0.02	0.25
1997	-2.1500	0.5767	0.000	0.12	0.04	0.36
Depth	-0.01889	0.02525	0.455	0.98	0.93	1.03
Temperature	0.20959	0.03997	0.000	1.23	1.14	1.33
Salinity	0.09379	0.01903	0.000	1.10	1.06	1.14
Slope						
1-2°	0.6723	0.2647	0.011	1.96	1.17	3.29
≥2°	1.1274	0.3336	0.001	3.09	1.61	5.94
%Fines						
20	-0.0054	0.3751	0.989	0.99	0.48	2.07
30	0.1646	0.4886	0.736	1.18	0.45	3.07
40	0.4530	0.4233	0.284	1.57	0.69	3.61
50	0.4492	0.5560	0.419	1.57	0.53	4.66
60	0.4458	0.4665	0.339	1.56	0.63	3.90
70	0.5239	0.6552	0.424	1.69	0.47	6.10
80	-0.1736	0.5936	0.770	0.84	0.26	2.69
90	0.0178	0.3865	0.963	1.02	0.48	2.17
100	0.2895	0.3163	0.360	1.34	0.72	2.48

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	121.393	18	0.000
Slope	14.719	2	0.001
%Fines	3.456	9	0.943

Log-Likelihood = -333.234
Test that all slopes are zero: G = 244.626, DF = 32, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	883.441	855	0.243
Deviance	647.061	855	1.000
Hosmer-Lemeshow	7.145	8	0.521

Ib.

Response Information

Variable	Value	Count	
Presence	1	358	(Event)
Absence	0	2029	
	Total	2387	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	Upper
Constant	-3.8178	0.3502	0.000			
YEAR						
1980	0.4009	0.3079	0.193	1.49	0.82	2.73
1981	0.8713	0.3180	0.006	2.39	1.28	4.46
1982	-0.4120	0.3851	0.285	0.66	0.31	1.41
1983	0.5786	0.3308	0.080	1.78	0.93	3.41
1984	-0.3875	0.4785	0.418	0.68	0.27	1.73
1985	-1.1503	0.4565	0.012	0.32	0.13	0.77
1986	-1.0046	0.4499	0.026	0.37	0.15	0.88
1987	-0.4774	0.5036	0.343	0.62	0.23	1.66
1988	-2.9711	0.5174	0.000	0.05	0.02	0.14
1989	-1.7657	0.3739	0.000	0.17	0.08	0.36
1990	-1.7849	0.3338	0.000	0.17	0.09	0.32
1991	-1.5437	0.3396	0.000	0.21	0.11	0.42
1992	-1.2982	0.3321	0.000	0.27	0.14	0.52
1993	-3.1623	0.4885	0.000	0.04	0.02	0.11
1994	-2.2916	0.4096	0.000	0.10	0.05	0.23
1995	-2.1345	0.4013	0.000	0.12	0.05	0.26
1996	-3.1455	0.5114	0.000	0.04	0.02	0.12
1997	-2.0331	0.3525	0.000	0.13	0.07	0.26
Depth	0.01857	0.01661	0.264	1.02	0.99	1.05
Temperature	0.20937	0.02627	0.000	1.23	1.17	1.30
Salinity	0.07382	0.01103	0.000	1.08	1.05	1.10
Slope						
1-2°	0.4623	0.1722	0.007	1.59	1.13	2.23
=>2°	0.4937	0.2252	0.028	1.64	1.05	2.55

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	273.044	18	0.000
Slope	10.029	2	0.007

Log-Likelihood = -768.519
Test that all slopes are zero: G = 480.802, DF = 23, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	1954.281	1514	0.000
Deviance	1274.685	1514	1.000
Hosmer-Lemeshow	4.684	8	0.791

Ic.

Response Information

Variable	Value	Count	
Presence	1	358	(Event)
Absence	0	2029	
	Total	2387	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-3.6891	0.3300	0.000			
YEAR						
1980	0.4371	0.3057	0.153	1.55	0.85	2.82
1981	0.8730	0.3172	0.006	2.39	1.29	4.46
1982	-0.3954	0.3841	0.303	0.67	0.32	1.43
1983	0.5946	0.3301	0.072	1.81	0.95	3.46
1984	-0.3975	0.4772	0.405	0.67	0.26	1.71
1985	-1.1320	0.4548	0.013	0.32	0.13	0.79
1986	-1.0127	0.4488	0.024	0.36	0.15	0.88
1987	-0.4592	0.5029	0.361	0.63	0.24	1.69
1988	-2.9711	0.5169	0.000	0.05	0.02	0.14
1989	-1.7455	0.3729	0.000	0.17	0.08	0.36
1990	-1.7761	0.3328	0.000	0.17	0.09	0.33
1991	-1.5492	0.3391	0.000	0.21	0.11	0.41
1992	-1.3063	0.3308	0.000	0.27	0.14	0.52
1993	-3.1557	0.4877	0.000	0.04	0.02	0.11
1994	-2.2958	0.4086	0.000	0.10	0.05	0.22
1995	-2.1350	0.4003	0.000	0.12	0.05	0.26
1996	-3.1589	0.5106	0.000	0.04	0.02	0.12
1997	-2.0356	0.3519	0.000	0.13	0.07	0.26
Temperature	0.20878	0.02625	0.000	1.23	1.17	1.30
Salinity	0.07791	0.01033	0.000	1.08	1.06	1.10
Slope						
=>1°	0.4952	0.1480	0.001	1.64	1.23	2.19

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	276.809	18	0.000

Log-Likelihood = -769.149
Test that all slopes are zero: G = 479.542, DF = 21, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	909.484	553	0.000
Deviance	725.884	553	0.000
Hosmer-Lemeshow	5.087	8	0.748

Id.

Response Information

Variable	Value	Count	
Presence	1	358	(Event)
Absence	0	2029	
	Total	2387	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	Upper
Constant	-4.6514	0.4748	0.000			
YEAR						
1980	0.2772	0.3250	0.394	1.32	0.70	2.49
1981	0.8689	0.3400	0.011	2.38	1.22	4.64
1982	-0.4655	0.4032	0.248	0.63	0.28	1.38
1983	0.4381	0.3503	0.211	1.55	0.78	3.08
1984	-0.5876	0.5022	0.242	0.56	0.21	1.49
1985	-1.3078	0.4857	0.007	0.27	0.10	0.70
1986	-1.2317	0.4653	0.008	0.29	0.12	0.73
1987	-0.7141	0.5255	0.174	0.49	0.17	1.37
1988	-3.1287	0.5231	0.000	0.04	0.02	0.12
1989	-1.9180	0.3845	0.000	0.15	0.07	0.31
1990	-1.7533	0.3455	0.000	0.17	0.09	0.34
1991	-1.6766	0.3506	0.000	0.19	0.09	0.37
1992	-1.3486	0.3457	0.000	0.26	0.13	0.51
1993	-3.2097	0.4960	0.000	0.04	0.02	0.11
1994	-2.3310	0.4193	0.000	0.10	0.04	0.22
1995	-2.1409	0.4115	0.000	0.12	0.05	0.26
1996	-3.3676	0.5198	0.000	0.03	0.01	0.10
1997	-2.3576	0.3692	0.000	0.09	0.05	0.20
Temperature	0.21465	0.02685	0.000	1.24	1.18	1.31
Salinity						
8	1.3839	0.5022	0.006	3.99	1.49	10.68
12	2.4231	0.4356	0.000	11.28	4.80	26.49
16	2.8922	0.4270	0.000	18.03	7.81	41.64
20	2.6855	0.4251	0.000	14.67	6.37	33.74
24	2.6011	0.4304	0.000	13.48	5.80	31.33
28	3.0071	0.4431	0.000	20.23	8.49	48.21
Slope						
=>1°	0.4787	0.1499	0.001	1.61	1.20	2.17

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	284.355	18	0.000
Salinity	66.084	6	0.000

Log-Likelihood = -747.086
Test that all slopes are zero: G = 523.668, DF = 26, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	874.999	548	0.000
Deviance	681.758	548	0.000
Hosmer-Lemeshow	12.217	8	0.142

APPENDIX II

Spring: Intermediate Multivariate Logistic Regressions

IIa.

Response Information

Variable	Value	Count	
Presence	1	285	(Event)
Absence	0	2171	
	Total	2456	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-1.4379	0.8459	0.089			
YEAR						
1980	1.2180	0.7963	0.126	3.38	0.71	16.10
1981	1.6657	0.8031	0.038	5.29	1.10	25.53
1982	1.5733	0.8024	0.050	4.82	1.00	23.24
1983	2.3030	0.8007	0.004	10.00	2.08	48.06
1984	1.0456	0.7989	0.191	2.85	0.59	13.62
1985	0.4719	0.8324	0.571	1.60	0.31	8.19
1986	0.3896	0.9296	0.675	1.48	0.24	9.13
1987	0.9936	0.8110	0.221	2.70	0.55	13.24
1988	-1.2207	0.8817	0.166	0.30	0.05	1.66
1989	-1.5888	0.9076	0.080	0.20	0.03	1.21
1990	-0.1804	0.8155	0.825	0.83	0.17	4.13
1991	-0.0909	0.8001	0.910	0.91	0.19	4.38
1992	1.3635	0.7848	0.082	3.91	0.84	18.20
1993	-0.2776	0.8076	0.731	0.76	0.16	3.69
1994	-1.2760	0.8673	0.141	0.28	0.05	1.53
1995	1.4065	0.7839	0.073	4.08	0.88	18.97
1996	-0.1033	0.7779	0.894	0.90	0.20	4.14
1997	0.0583	0.7790	0.940	1.06	0.23	4.88
Mouth	-0.029544	0.004114	0.000	0.97	0.96	0.98
Salinity						
4-8	1.0511	0.3933	0.008	2.86	1.32	6.18
8-12	1.4061	0.3385	0.000	4.08	2.10	7.92
12-16	1.5696	0.3266	0.000	4.80	2.53	9.11
16-20	0.9438	0.3454	0.006	2.57	1.31	5.06
20-24	-0.4774	0.4092	0.243	0.62	0.28	1.38
>24	-0.8889	0.4648	0.056	0.41	0.17	1.02
SAV						
<=2km	0.7302	0.1802	0.000	2.08	1.46	2.95
Slope						
1-2°	0.2694	0.1878	0.152	1.31	0.91	1.89
=>2°	1.0287	0.2129	0.000	2.80	1.84	4.25

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	148.350	18	0.000
Salinity	88.765	6	0.000
Slope	23.565	2	0.000

Log-Likelihood = -724.862
Test that all slopes are zero: G = 313.511, DF = 28, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	967.862	717	0.000
Deviance	749.774	717	0.192
Hosmer-Lemeshow	5.333	8	0.721

IIb.

Response Information

Variable	Value	Count	
Presence	1	285	(Event)
Absence	0	2171	
	Total	2456	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-2.0682	0.7794	0.008			
YEAR						
1980	1.1342	0.7907	0.151	3.11	0.66	14.64
1981	1.4666	0.7922	0.064	4.33	0.92	20.48
1982	1.6047	0.7988	0.045	4.98	1.04	23.82
1983	2.3343	0.7955	0.003	10.32	2.17	49.08
1984	1.0531	0.7966	0.186	2.87	0.60	13.66
1985	0.3969	0.8262	0.631	1.49	0.29	7.51
1986	0.3225	0.9205	0.726	1.38	0.23	8.39
1987	0.9257	0.8056	0.250	2.52	0.52	12.24
1988	-1.1789	0.8765	0.179	0.31	0.06	1.71
1989	-1.4771	0.9029	0.102	0.23	0.04	1.34
1990	-0.2526	0.8100	0.755	0.78	0.16	3.80
1991	-0.1336	0.7953	0.867	0.87	0.18	4.16
1992	1.1665	0.7736	0.132	3.21	0.70	14.62
1993	-0.2339	0.8052	0.771	0.79	0.16	3.84
1994	-1.1799	0.8640	0.172	0.31	0.06	1.67
1995	1.1974	0.7736	0.122	3.31	0.73	15.08
1996	-0.1299	0.7745	0.867	0.88	0.19	4.01
1997	-0.0001	0.7739	1.000	1.00	0.22	4.56
Mouth	-0.025154	0.003389	0.000	0.98	0.97	0.98
Salinity						
4-8	1.1163	0.2048	0.000	3.05	2.04	4.56
8-20	1.7677	0.2100	0.000	5.86	3.88	8.84
SAV						
<=2km	0.7015	0.1750	0.000	2.02	1.43	2.84
Slope						
1-2°	0.2677	0.1866	0.151	1.31	0.91	1.88
=>2°	1.0290	0.2071	0.000	2.80	1.86	4.20

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	145.293	18	0.000
Salinity	71.136	2	0.000
Slope	24.899	2	0.000

Log-Likelihood = -732.700

Test that all slopes are zero: G = 297.835, DF = 24, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	662.958	555	0.001
Deviance	584.512	555	0.187
Hosmer-Lemeshow	11.305	8	0.185

IIc.

Response Information

Variable	Value	Count	
Presence	1	285	(Event)
Absence	0	2171	
	Total	2456	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-3.6594	0.8155	0.000			
YEAR						
1980	1.1495	0.7939	0.148	3.16	0.67	14.96
1981	1.4835	0.7960	0.062	4.41	0.93	20.98
1982	1.6322	0.8043	0.042	5.11	1.06	24.74
1983	2.3930	0.7996	0.003	10.95	2.28	52.47
1984	1.0477	0.8017	0.191	2.85	0.59	13.72
1985	0.4552	0.8306	0.584	1.58	0.31	8.03
1986	0.3769	0.9249	0.684	1.46	0.24	8.93
1987	0.9790	0.8100	0.227	2.66	0.54	13.02
1988	-1.1772	0.8807	0.181	0.31	0.05	1.73
1989	-1.4313	0.9062	0.114	0.24	0.04	1.41
1990	-0.1890	0.8132	0.816	0.83	0.17	4.08
1991	-0.1284	0.7998	0.872	0.88	0.18	4.22
1992	1.2238	0.7772	0.115	3.40	0.74	15.60
1993	-0.2699	0.8109	0.739	0.76	0.16	3.74
1994	-1.1823	0.8680	0.173	0.31	0.06	1.68
1995	1.3047	0.7783	0.094	3.69	0.80	16.95
1996	-0.0573	0.7779	0.941	0.94	0.21	4.34
1997	-0.0019	0.7778	0.998	1.00	0.22	4.58
Mouth						
20-40km	1.1939	0.3533	0.001	3.30	1.65	6.60
40-60km	0.3899	0.3703	0.292	1.48	0.71	3.05
60-80km	-0.1497	0.3751	0.690	0.86	0.41	1.80
>80km	-1.0079	0.3909	0.010	0.36	0.17	0.79
Salinity						
4-8	0.8432	0.2089	0.000	2.32	1.54	3.50
8-20	1.5937	0.2066	0.000	4.92	3.28	7.38
SAV						
<=2km	0.4959	0.1831	0.007	1.64	1.15	2.35
Slope						
1-2°	0.2653	0.1887	0.160	1.30	0.90	1.89
>2°	0.9902	0.2091	0.000	2.69	1.79	4.06

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	145.202	18	0.000
Mouth	86.707	4	0.000
Salinity	59.866	2	0.000
Slope	22.682	2	0.000

Log-Likelihood = -716.038
Test that all slopes are zero: G = 331.159, DF = 27, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	662.101	552	0.001
Deviance	551.189	552	0.502
Hosmer-Lemeshow	17.700	8	0.024

IId.

Response Information

Variable	Value	Count	
Presence	1	285	(Event)
Absence	0	2171	
	Total	2456	

Logistic Regression Table

				Odds	95% CI	
Predictor	Coef	StDev	P	Ratio	Lower	Upper
Constant	-4.5839	0.7648	0.000			
YEAR						
1980	1.1121	0.7901	0.159	3.04	0.65	14.31
1981	1.4336	0.7927	0.071	4.19	0.89	19.83
1982	1.5845	0.7997	0.048	4.88	1.02	23.38
1983	2.3254	0.7950	0.003	10.23	2.15	48.60
1984	1.0153	0.7971	0.203	2.76	0.58	13.17
1985	0.3908	0.8275	0.637	1.48	0.29	7.48
1986	0.3022	0.9218	0.743	1.35	0.22	8.24
1987	0.9356	0.8061	0.246	2.55	0.52	12.37
1988	-1.2066	0.8766	0.169	0.30	0.05	1.67
1989	-1.4715	0.9023	0.103	0.23	0.04	1.35
1990	-0.1881	0.8086	0.816	0.83	0.17	4.04
1991	-0.1649	0.7955	0.836	0.85	0.18	4.03
1992	1.1793	0.7727	0.127	3.25	0.72	14.79
1993	-0.2637	0.8057	0.743	0.77	0.16	3.73
1994	-1.1739	0.8631	0.174	0.31	0.06	1.68
1995	1.2237	0.7733	0.114	3.40	0.75	15.48
1996	-0.0948	0.7735	0.902	0.91	0.20	4.14
1997	-0.0275	0.7737	0.972	0.97	0.21	4.43
Mouth						
40-80km	1.0401	0.1898	0.000	2.83	1.95	4.10
20-40km	2.1237	0.2373	0.000	8.36	5.25	13.31
Salinity						
4-8	0.8681	0.2027	0.000	2.38	1.60	3.54
8-20	1.5498	0.1927	0.000	4.71	3.23	6.87
SAV						
<=2km	0.6096	0.1772	0.001	1.84	1.30	2.60
Slope						
1-2°	0.2724	0.1872	0.146	1.31	0.91	1.90
=>2°	0.9472	0.2073	0.000	2.58	1.72	3.87

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	146.173	18	0.000
Mouth	80.826	2	0.000
Salinity	64.788	2	0.000
Slope	21.217	2	0.000

Log-Likelihood = -719.354
Test that all slopes are zero: G = 324.527, DF = 25, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	525.099	433	0.002
Deviance	467.962	433	0.119
Hosmer-Lemeshow	12.293	8	0.139

IIe.

Response Information

Variable	Value	Count	
Presence	1	285	(Event)
Absence	0	2171	
	Total	2456	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-4.4962	0.7612	0.000			
YEAR						
1980	1.0818	0.7893	0.170	2.95	0.63	13.86
1981	1.4287	0.7921	0.071	4.17	0.88	19.71
1982	1.5573	0.7988	0.051	4.75	0.99	22.72
1983	2.2820	0.7936	0.004	9.80	2.07	46.41
1984	0.9948	0.7964	0.212	2.70	0.57	12.88
1985	0.3878	0.8264	0.639	1.47	0.29	7.45
1986	0.2899	0.9208	0.753	1.34	0.22	8.12
1987	0.9099	0.8054	0.259	2.48	0.51	12.04
1988	-1.2690	0.8749	0.147	0.28	0.05	1.56
1989	-1.5166	0.9010	0.092	0.22	0.04	1.28
1990	-0.2423	0.8072	0.764	0.78	0.16	3.82
1991	-0.2212	0.7939	0.781	0.80	0.17	3.80
1992	1.1235	0.7712	0.145	3.08	0.68	13.94
1993	-0.3088	0.8046	0.701	0.73	0.15	3.55
1994	-1.2347	0.8614	0.152	0.29	0.05	1.57
1995	1.1751	0.7720	0.128	3.24	0.71	14.70
1996	-0.1411	0.7723	0.855	0.87	0.19	3.95
1997	-0.0791	0.7723	0.918	0.92	0.20	4.20
Mouth						
40-80km	1.0445	0.1903	0.000	2.84	1.96	4.13
20-40km	2.1077	0.2372	0.000	8.23	5.17	13.10
Salinity						
4-8	0.8658	0.2026	0.000	2.38	1.60	3.54
8-20	1.5573	0.1927	0.000	4.75	3.25	6.92
SAV						
<=2km	0.6310	0.1763	0.000	1.88	1.33	2.66
Slope						
=>2°	0.8926	0.2036	0.000	2.44	1.64	3.64

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	148.634	18	0.000
Mouth	79.628	2	0.000
Salinity	65.408	2	0.000

Log-Likelihood = -720.384
Test that all slopes are zero: G = 322.467, DF = 24, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	402.788	307	0.000
Deviance	375.651	307	0.004
Hosmer-Lemeshow	13.701	8	0.090

IIf.

Response Information

Variable	Value	Count	
Presence	1	285	(Event)
Absence	0	2171	
	Total	2456	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-3.7217	0.7355	0.000			
YEAR						
1980	1.2559	0.7791	0.107	3.51	0.76	16.17
1981	1.4285	0.7804	0.067	4.17	0.90	19.26
1982	1.6432	0.7829	0.036	5.17	1.11	23.99
1983	2.3285	0.7820	0.003	10.26	2.22	47.52
1984	1.2109	0.7800	0.121	3.36	0.73	15.48
1985	0.4943	0.8146	0.544	1.64	0.33	8.09
1986	0.3977	0.9068	0.661	1.49	0.25	8.80
1987	0.9792	0.7931	0.217	2.66	0.56	12.60
1988	-0.7395	0.8617	0.391	0.48	0.09	2.58
1989	-0.9965	0.8897	0.263	0.37	0.06	2.11
1990	0.2619	0.7949	0.742	1.30	0.27	6.17
1991	0.3519	0.7804	0.652	1.42	0.31	6.56
1992	1.4781	0.7593	0.052	4.38	0.99	19.42
1993	0.3985	0.7874	0.613	1.49	0.32	6.97
1994	-0.5178	0.8445	0.540	0.60	0.11	3.12
1995	1.4826	0.7612	0.051	4.40	0.99	19.58
1996	0.2560	0.7609	0.737	1.29	0.29	5.74
1997	0.3382	0.7608	0.657	1.40	0.32	6.23
Salinity						
4-8	0.9374	0.1955	0.000	2.55	1.74	3.75
8-20	1.1411	0.1742	0.000	3.13	2.22	4.40
SAV						
<=2km	1.0136	0.1679	0.000	2.76	1.98	3.83
Slope						
=>2°	0.8235	0.1945	0.000	2.28	1.56	3.34

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	120.015	18	0.000
Salinity	44.501	2	0.000

Log-Likelihood = -762.282
Test that all slopes are zero: G = 238.670, DF = 22, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	228.435	146	0.000
Deviance	215.636	146	0.000
Hosmer-Lemeshow	8.005	8	0.433

IIg.

Response Information

Variable	Value	Count	
Presence	1	285	(Event)
Absence	0	2171	
	Total	2456	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-3.6891	0.7344	0.000			
YEAR						
1980	1.2506	0.7790	0.108	3.49	0.76	16.08
1981	1.3935	0.7794	0.074	4.03	0.87	18.56
1982	1.6218	0.7824	0.038	5.06	1.09	23.46
1983	2.2959	0.7814	0.003	9.93	2.15	45.95
1984	1.2353	0.7791	0.113	3.44	0.75	15.84
1985	0.4847	0.8143	0.552	1.62	0.33	8.01
1986	0.3836	0.9065	0.672	1.47	0.25	8.67
1987	0.9709	0.7930	0.221	2.64	0.56	12.49
1988	-0.7753	0.8607	0.368	0.46	0.09	2.49
1989	-1.0444	0.8886	0.240	0.35	0.06	2.01
1990	0.2197	0.7938	0.782	1.25	0.26	5.90
1991	0.3206	0.7796	0.681	1.38	0.30	6.35
1992	1.4416	0.7583	0.057	4.23	0.96	18.69
1993	0.3946	0.7868	0.616	1.48	0.32	6.94
1994	-0.5145	0.8439	0.542	0.60	0.11	3.12
1995	1.4481	0.7603	0.057	4.26	0.96	18.88
1996	0.2392	0.7605	0.753	1.27	0.29	5.64
1997	0.3353	0.7605	0.659	1.40	0.31	6.21
Salinity						
4-20	1.0644	0.1620	0.000	2.90	2.11	3.98
SAV						
<=2km	0.9679	0.1638	0.000	2.63	1.91	3.63
Slope						
=>2°	0.8328	0.1942	0.000	2.30	1.57	3.37

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	119.372	18	0.000

Log-Likelihood = -762.994

Test that all slopes are zero: G = 237.247, DF = 21, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	131.554	102	0.026
Deviance	131.511	102	0.026
Hosmer-Lemeshow	4.391	7	0.734

APPENDIX III

Summer: Intermediate Multivariate Logistic Regressions

IIIa.

Response Information

Variable	Value	Count	
Presence	1	272	(Event)
Absence	0	755	
	Total	1027	

1027 cases were used
1884 cases contained missing values

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	Upper
Constant	-1.6161	0.5409	0.003			
YEAR						
1980	-0.0286	0.5780	0.961	0.97	0.31	3.02
1981	-0.0244	0.5694	0.966	0.98	0.32	2.98
1982	-0.1788	0.5237	0.733	0.84	0.30	2.33
1983	-0.5156	0.4887	0.291	0.60	0.23	1.56
1984	-1.3534	0.5537	0.015	0.26	0.09	0.76
1985	-0.4418	0.5441	0.417	0.64	0.22	1.87
1987	-2.1828	0.6829	0.001	0.11	0.03	0.43
1988	-3.2674	0.6251	0.000	0.04	0.01	0.13
1989	-3.5930	0.6370	0.000	0.03	0.01	0.10
1990	-1.9925	0.5189	0.000	0.14	0.05	0.38
1991	-1.6120	0.5181	0.002	0.20	0.07	0.55
1992	-2.3857	0.5246	0.000	0.09	0.03	0.26
1993	-4.0853	0.7394	0.000	0.02	0.00	0.07
1994	-2.8365	0.5715	0.000	0.06	0.02	0.18
1995	-3.9394	0.6820	0.000	0.02	0.01	0.07
1996	-2.3568	0.4757	0.000	0.09	0.04	0.24
1997	-2.4447	0.4887	0.000	0.09	0.03	0.23
Tide						
Low slack	-0.2299	0.7191	0.749	0.79	0.19	3.25
Flood	0.1447	0.1837	0.431	1.16	0.81	1.66
High slack	1.3249	0.4905	0.007	3.76	1.44	9.84
Salinity	0.07569	0.01715	0.000	1.08	1.04	1.12
SAV						
<=2km	1.7048	0.2254	0.000	5.50	3.54	8.56
slope						
1-2°	0.3962	0.2333	0.089	1.49	0.94	2.35
=>2°	1.1440	0.2896	0.000	3.14	1.78	5.54
OXYGEN						
hypoxia	-0.6973	0.3336	0.037	0.50	0.26	0.96
%Fines	0.010502	0.002564	0.000	1.01	1.01	1.02

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	154.281	17	0.000
Tide	7.514	3	0.057
Slope	16.906	2	0.000

Log-Likelihood = -431.868
Test that all slopes are zero: G = 323.615, DF = 26, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	882.211	689	0.000
Deviance	720.067	689	0.200
Hosmer-Lemeshow	14.149	8	0.078

IIIb.

Response Information

Variable	Value	Count	
Presence	1	273	(Event)
Absence	0	757	
	Total	1030	

1030 cases were used
1881 cases contained missing values

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-0.9912	0.4766	0.038			
YEAR						
1980	-0.3509	0.5494	0.523	0.70	0.24	2.07
1981	-0.1538	0.5599	0.784	0.86	0.29	2.57
1982	-0.2804	0.5112	0.583	0.76	0.28	2.06
1983	-0.7433	0.4745	0.117	0.48	0.19	1.21
1984	-1.5500	0.5318	0.004	0.21	0.07	0.60
1985	-0.6007	0.5347	0.261	0.55	0.19	1.56
1987	-2.4369	0.6640	0.000	0.09	0.02	0.32
1988	-3.4699	0.6176	0.000	0.03	0.01	0.10
1989	-3.8052	0.6272	0.000	0.02	0.01	0.08
1990	-2.2299	0.5087	0.000	0.11	0.04	0.29
1991	-1.8230	0.5085	0.000	0.16	0.06	0.44
1992	-2.5683	0.5140	0.000	0.08	0.03	0.21
1993	-4.0844	0.7317	0.000	0.02	0.00	0.07
1994	-3.1057	0.5577	0.000	0.04	0.02	0.13
1995	-4.1178	0.6747	0.000	0.02	0.00	0.06
1996	-2.5828	0.4650	0.000	0.08	0.03	0.19
1997	-2.6526	0.4750	0.000	0.07	0.03	0.18
Salinity	0.06558	0.01632	0.000	1.07	1.03	1.10
SAV						
<=2km	1.6655	0.2244	0.000	5.29	3.41	8.21
Slope						
=>2°	1.0424	0.2836	0.000	2.84	1.63	4.94
OXYGEN						
Hypoxia	-0.7559	0.3310	0.022	0.47	0.25	0.90
%Fines	0.009984	0.002521	0.000	1.01	1.01	1.02

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	163.617	17	0.000

Log-Likelihood = -439.410
Test that all slopes are zero: G = 312.420, DF = 22, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	690.289	550	0.000
Deviance	600.200	550	0.068
Hosmer-Lemeshow	15.347	8	0.053

IIIc.

Response Information

Variable	Value	Count	
Presence	1	273	(Event)
Absence	0	757	
	Total	1030	

1030 cases were used
1881 cases contained missing values

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	Upper
Constant	-2.3663	0.8296	0.004			
YEAR						
1980	-0.5783	0.5873	0.325	0.56	0.18	1.77
1981	-0.3001	0.5986	0.616	0.74	0.23	2.39
1982	-0.4881	0.5533	0.378	0.61	0.21	1.82
1983	-0.6949	0.5083	0.172	0.50	0.18	1.35
1984	-1.5710	0.5726	0.006	0.21	0.07	0.64
1985	-0.8133	0.5620	0.148	0.44	0.15	1.33
1987	-2.6393	0.6839	0.000	0.07	0.02	0.27
1988	-3.5203	0.6339	0.000	0.03	0.01	0.10
1989	-3.8289	0.6564	0.000	0.02	0.01	0.08
1990	-2.2114	0.5417	0.000	0.11	0.04	0.32
1991	-1.8500	0.5379	0.001	0.16	0.05	0.45
1992	-2.4284	0.5463	0.000	0.09	0.03	0.26
1993	-4.0498	0.7402	0.000	0.02	0.00	0.07
1994	-3.3022	0.5926	0.000	0.04	0.01	0.12
1995	-4.0898	0.7038	0.000	0.02	0.00	0.07
1996	-2.7740	0.4979	0.000	0.06	0.02	0.17
1997	-2.6892	0.5025	0.000	0.07	0.03	0.18
Salinity						
4-8	1.7619	0.8178	0.031	5.82	1.17	28.93
8-12	2.4462	0.7762	0.002	11.54	2.52	52.86
12-16	3.0943	0.7593	0.000	22.07	4.98	97.76
16-20	3.7918	0.7685	0.000	44.34	9.83	199.93
20-24	2.7083	0.7803	0.001	15.00	3.25	69.24
>24	1.9281	0.8896	0.030	6.88	1.20	39.32
SAV						
<=2km	1.5310	0.2307	0.000	4.62	2.94	7.27
Slope						
=>2°	0.8371	0.2976	0.005	2.31	1.29	4.14
OXYGEN						
hypoxia	-1.0532	0.3349	0.002	0.35	0.18	0.67
%Fines	0.006568	0.002607	0.012	1.01	1.00	1.01

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	153.929	17	0.000
Salinity	58.465	6	0.000

Log-Likelihood = -408.842
Test that all slopes are zero: G = 373.556, DF = 27, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	593.454	545	0.074
Deviance	539.064	545	0.564
Hosmer-Lemeshow	6.338	8	0.609

IIId.

Response Information

Variable	Value	Count	
Presence	1	273	(Event)
Absence	0	757	
	Total	1030	

1030 cases were used
1881 cases contained missing values

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-4.8798	0.8734	0.000			
YEAR						
1980	-0.5884	0.5878	0.317	0.56	0.18	1.76
1981	-0.2916	0.5988	0.626	0.75	0.23	2.42
1982	-0.5140	0.5542	0.354	0.60	0.20	1.77
1983	-0.7822	0.5116	0.126	0.46	0.17	1.25
1984	-1.6866	0.5743	0.003	0.19	0.06	0.57
1985	-0.7656	0.5607	0.172	0.47	0.15	1.40
1987	-2.4298	0.6785	0.000	0.09	0.02	0.33
1988	-3.4099	0.6309	0.000	0.03	0.01	0.11
1989	-3.7554	0.6506	0.000	0.02	0.01	0.08
1990	-2.2499	0.5395	0.000	0.11	0.04	0.30
1991	-1.9292	0.5347	0.000	0.15	0.05	0.41
1992	-2.4075	0.5426	0.000	0.09	0.03	0.26
1993	-4.1371	0.7446	0.000	0.02	0.00	0.07
1994	-3.2486	0.5878	0.000	0.04	0.01	0.12
1995	-4.0210	0.6938	0.000	0.02	0.00	0.07
1996	-2.7793	0.4978	0.000	0.06	0.02	0.16
1997	-2.7310	0.5033	0.000	0.07	0.02	0.17
Salinity	0.63922	0.09726	0.000	1.90	1.57	2.29
Salinity^2	-0.017171	0.002762	0.000	0.98	0.98	0.99
SAV						
<=2km	1.5234	0.2261	0.000	4.59	2.95	7.15
Slope						
=>2°	0.9294	0.2914	0.001	2.53	1.43	4.48
OXYGEN						
hypoxia	-1.0002	0.3285	0.002	0.37	0.19	0.70
%Fines	0.006222	0.002573	0.016	1.01	1.00	1.01

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	153.490	17	0.000

Log-Likelihood = -413.648
Test that all slopes are zero: G = 363.944, DF = 23, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	649.342	549	0.002
Deviance	548.675	549	0.496
Hosmer-Lemeshow	6.540	8	0.587

IIIe.

Response Information

Variable	Value	Count	
Presence	1	273	(Event)
Absence	0	757	
	Total	1030	

1030 cases were used
1881 cases contained missing values

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	Upper
Constant	-5.2120	0.9500	0.000			
YEAR						
1980	-0.5460	0.6231	0.381	0.58	0.17	1.96
1981	-0.2642	0.6284	0.674	0.77	0.22	2.63
1982	-0.4808	0.5852	0.411	0.62	0.20	1.95
1983	-0.5917	0.5520	0.284	0.55	0.19	1.63
1984	-1.5918	0.5980	0.008	0.20	0.06	0.66
1985	-0.7948	0.5842	0.174	0.45	0.14	1.42
1987	-2.1125	0.7126	0.003	0.12	0.03	0.49
1988	-3.1414	0.6550	0.000	0.04	0.01	0.16
1989	-3.3951	0.6768	0.000	0.03	0.01	0.13
1990	-2.0026	0.5704	0.000	0.13	0.04	0.41
1991	-1.6945	0.5687	0.003	0.18	0.06	0.56
1992	-2.2617	0.5727	0.000	0.10	0.03	0.32
1993	-3.8273	0.7776	0.000	0.02	0.00	0.10
1994	-3.1878	0.6166	0.000	0.04	0.01	0.14
1995	-3.6817	0.7187	0.000	0.03	0.01	0.10
1996	-2.5450	0.5288	0.000	0.08	0.03	0.22
1997	-2.5211	0.5309	0.000	0.08	0.03	0.23
Salinity	0.6117	0.1041	0.000	1.84	1.50	2.26
Salinity^2	-0.016845	0.002977	0.000	0.98	0.98	0.99
SAV						
<=2km	1.5504	0.2419	0.000	4.71	2.93	7.57
Slope						
=>2°	0.7824	0.3037	0.010	2.19	1.21	3.97
OXYGEN						
Hypoxia	-0.9377	0.3312	0.005	0.39	0.20	0.75
%Fines						
10-20	1.4857	0.2922	0.000	4.42	2.49	7.83
20-30	0.5451	0.4646	0.241	1.72	0.69	4.29
30-40	0.6063	0.5586	0.278	1.83	0.61	5.48
40-50	0.7593	0.4390	0.084	2.14	0.90	5.05
50-60	0.8411	0.5002	0.093	2.32	0.87	6.18
60-70	-0.005	1.118	0.996	0.99	0.11	8.90
70-80	1.5650	0.3970	0.000	4.78	2.20	10.41
80-90	1.2469	0.3853	0.001	3.48	1.64	7.40
>90	0.9743	0.2909	0.001	2.65	1.50	4.69

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	119.374	17	0.000
%Fines	33.610	9	0.000

Log-Likelihood = -398.642
Test that all slopes are zero: G = 393.955, DF = 31, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	653.301	541	0.001
Deviance	518.665	541	0.748
Hosmer-Lemeshow	6.507	8	0.591

IIIf.

Response Information

Variable	Value	Count	
Presence	1	273	(Event)
Absence	0	757	
	Total	1030	

1030 cases were used
1881 cases contained missing values

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	Upper
Constant	-4.5398	0.8718	0.000			
YEAR						
1980	-0.5734	0.5866	0.328	0.56	0.18	1.78
1981	-0.2690	0.5990	0.653	0.76	0.24	2.47
1982	-0.5029	0.5537	0.364	0.60	0.20	1.79
1983	-0.7404	0.5121	0.148	0.48	0.17	1.30
1984	-1.6470	0.5728	0.004	0.19	0.06	0.59
1985	-0.7209	0.5598	0.198	0.49	0.16	1.46
1987	-2.3460	0.6759	0.001	0.10	0.03	0.36
1988	-3.3290	0.6272	0.000	0.04	0.01	0.12
1989	-3.6911	0.6496	0.000	0.02	0.01	0.09
1990	-2.1944	0.5378	0.000	0.11	0.04	0.32
1991	-1.8917	0.5341	0.000	0.15	0.05	0.43
1992	-2.3625	0.5403	0.000	0.09	0.03	0.27
1993	-4.0881	0.7445	0.000	0.02	0.00	0.07
1994	-3.2060	0.5875	0.000	0.04	0.01	0.13
1995	-3.9817	0.6926	0.000	0.02	0.00	0.07
1996	-2.7378	0.4972	0.000	0.06	0.02	0.17
1997	-2.7043	0.5024	0.000	0.07	0.02	0.18
Salinity	0.61534	0.09871	0.000	1.85	1.52	2.25
Salinity^2	-0.016616	0.002806	0.000	0.98	0.98	0.99
SAV						
<=2km	1.5114	0.2261	0.000	4.53	2.91	7.06
Slope						
=>2°	0.9727	0.2936	0.001	2.65	1.49	4.70
OXYGEN						
hypoxia	-1.0104	0.3294	0.002	0.36	0.19	0.69
%Fines						
>70%	0.4588	0.1934	0.018	1.58	1.08	2.31

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	151.921	17	0.000

Log-Likelihood = -413.777
Test that all slopes are zero: G = 363.685, DF = 23, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	422.545	332	0.001
Deviance	391.422	332	0.014
Hosmer-Lemeshow	3.974	8	0.859

APPENDIX IV

Fall: Intermediate Multivariate Logistic Regressions

IVa.

Response Information

Variable	Value	Count	
Presence	1	462	(Event)
Absence	0	647	
	Total	1109	

1109 cases were used
1790 cases contained missing values

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-2.1777	0.6757	0.001			
YEAR						
1980	2.3667	0.8304	0.004	10.66	2.09	54.28
1981	2.3043	0.8452	0.006	10.02	1.91	52.50
1982	0.9879	0.5320	0.063	2.69	0.95	7.62
1983	1.4032	0.5187	0.007	4.07	1.47	11.24
1984	0.8488	0.5193	0.102	2.34	0.84	6.47
1985	-0.8922	0.5904	0.131	0.41	0.13	1.30
1986	-0.6570	0.5112	0.199	0.52	0.19	1.41
1987	-1.2820	0.5068	0.011	0.28	0.10	0.75
1988	-2.0669	0.5060	0.000	0.13	0.05	0.34
1989	-1.2712	0.4575	0.005	0.28	0.11	0.69
1990	-0.6296	0.4429	0.155	0.53	0.22	1.27
1991	-0.6290	0.4605	0.172	0.53	0.22	1.31
1992	-1.0704	0.4540	0.018	0.34	0.14	0.83
1993	-0.6916	0.4607	0.133	0.50	0.20	1.24
1994	-0.9158	0.4525	0.043	0.40	0.16	0.97
1995	-1.7194	0.4997	0.001	0.18	0.07	0.48
1996	-0.7515	0.4132	0.069	0.47	0.21	1.06
1997	-1.4308	0.4509	0.002	0.24	0.10	0.58
Tide						
Low slack	-0.2593	0.4906	0.597	0.77	0.29	2.02
Flood	0.1336	0.1498	0.372	1.14	0.85	1.53
High slack	-0.1694	0.5359	0.752	0.84	0.30	2.41
Mouth	0.013673	0.004372	0.002	1.01	1.01	1.02
Depth	0.05244	0.01984	0.008	1.05	1.01	1.10
Temperature	-0.05090	0.01536	0.001	0.95	0.92	0.98
Salinity	0.07514	0.02005	0.000	1.08	1.04	1.12
SAV						
<=2km	1.0234	0.2118	0.000	2.78	1.84	4.21
Slope						
1-2°	0.5177	0.2076	0.013	1.68	1.12	2.52
=>2°	0.6052	0.2460	0.014	1.83	1.13	2.97
%Fines	0.003080	0.002334	0.187	1.00	1.00	1.01

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	136.838	18	0.000
Tide	1.387	3	0.708
Slope	10.485	2	0.005

Log-Likelihood = -589.165
Test that all slopes are zero: G = 328.065, DF = 29, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	944.048	934	0.402
Deviance	1068.473	934	0.001
Hosmer-Lemeshow	5.134	8	0.743

IVb.

Response Information

Variable	Value	Count	
Presence	1	466	(Event)
Absence	0	650	
	Total	1116	

1116 cases were used
1783 cases contained missing values

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	Upper
Constant	-2.3921	0.7419	0.001			
YEAR						
1980	2.4070	0.8380	0.004	11.10	2.15	57.37
1981	2.2500	0.8376	0.007	9.49	1.84	48.99
1982	1.0383	0.5440	0.056	2.82	0.97	8.20
1983	1.3929	0.5399	0.010	4.03	1.40	11.60
1984	0.6948	0.5285	0.189	2.00	0.71	5.64
1985	-0.8865	0.6083	0.145	0.41	0.13	1.36
1986	-0.6462	0.5211	0.215	0.52	0.19	1.46
1987	-1.3587	0.5199	0.009	0.26	0.09	0.71
1988	-2.0523	0.5131	0.000	0.13	0.05	0.35
1989	-1.2965	0.4752	0.006	0.27	0.11	0.69
1990	-0.6330	0.4597	0.169	0.53	0.22	1.31
1991	-0.7144	0.4749	0.133	0.49	0.19	1.24
1992	-1.1747	0.4731	0.013	0.31	0.12	0.78
1993	-0.7303	0.4808	0.129	0.48	0.19	1.24
1994	-1.0115	0.4682	0.031	0.36	0.15	0.91
1995	-1.8026	0.5160	0.000	0.16	0.06	0.45
1996	-0.7058	0.4329	0.103	0.49	0.21	1.15
1997	-1.5053	0.4668	0.001	0.22	0.09	0.55
Mouth	0.013379	0.004564	0.003	1.01	1.00	1.02
Depth	0.05187	0.02024	0.010	1.05	1.01	1.10
Temperature	-0.05069	0.01541	0.001	0.95	0.92	0.98
Salinity	0.08490	0.02120	0.000	1.09	1.04	1.13
SAV						
<=2km	0.9032	0.2171	0.000	2.47	1.61	3.78
Slope						
1-2°	0.6196	0.2115	0.003	1.86	1.23	2.81
=>2°	0.5837	0.2535	0.021	1.79	1.09	2.95
%Fines						
10-20	0.7317	0.2466	0.003	2.08	1.28	3.37
20-30	-0.1263	0.3197	0.693	0.88	0.47	1.65
30-40	0.2946	0.3346	0.379	1.34	0.70	2.59
40-50	-0.1877	0.3458	0.587	0.83	0.42	1.63
50-60	0.5499	0.3637	0.131	1.73	0.85	3.54
60-70	0.4984	0.4593	0.278	1.65	0.67	4.05
70-80	-0.0865	0.3911	0.825	0.92	0.43	1.97
80-90	0.4877	0.3122	0.118	1.63	0.88	3.00
>90	0.5090	0.2456	0.038	1.66	1.03	2.69

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	133.807	18	0.000
Slope	11.971	2	0.003
%Fines	17.429	9	0.042

Log-Likelihood = -584.658
Test that all slopes are zero: G = 347.313, DF = 34, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	950.038	930	0.317
Deviance	1056.686	930	0.002
Hosmer-Lemeshow	7.916	8	0.442

IVc.

Response Information

Variable	Value	Count	
Presence	1	1001	(Event)
Absence	0	1898	
	Total	2899	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-1.8200	0.4230	0.000			
YEAR						
1980	1.6431	0.3600	0.000	5.17	2.55	10.47
1981	1.0063	0.3410	0.003	2.74	1.40	5.34
1982	0.5037	0.3202	0.116	1.65	0.88	3.10
1983	1.5304	0.3405	0.000	4.62	2.37	9.01
1984	0.3885	0.3245	0.231	1.47	0.78	2.79
1985	-0.4640	0.3880	0.232	0.63	0.29	1.35
1986	0.1305	0.3419	0.703	1.14	0.58	2.23
1987	-0.7725	0.3365	0.022	0.46	0.24	0.89
1988	-2.0793	0.3359	0.000	0.13	0.06	0.24
1989	-0.9144	0.2959	0.002	0.40	0.22	0.72
1990	-0.4225	0.2911	0.147	0.66	0.37	1.16
1991	-0.6518	0.3036	0.032	0.52	0.29	0.94
1992	-0.7592	0.3027	0.012	0.47	0.26	0.85
1993	-0.5806	0.3026	0.055	0.56	0.31	1.01
1994	-0.9914	0.3038	0.001	0.37	0.20	0.67
1995	-1.3753	0.3239	0.000	0.25	0.13	0.48
1996	-0.7409	0.2722	0.006	0.48	0.28	0.81
1997	-0.7858	0.2839	0.006	0.46	0.26	0.80
Mouth	0.011527	0.002448	0.000	1.01	1.01	1.02
Depth	0.01553	0.01193	0.193	1.02	0.99	1.04
Temperature	-0.047834	0.009340	0.000	0.95	0.94	0.97
Salinity	0.06993	0.01231	0.000	1.07	1.05	1.10
SAV						
<=2km	1.2370	0.1339	0.000	3.45	2.65	4.48
Slope						
1-2°	0.3722	0.1227	0.002	1.45	1.14	1.85
=>2°	0.5616	0.1586	0.000	1.75	1.29	2.39

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	287.024	18	0.000
Slope	18.448	2	0.000

Log-Likelihood = -1565.312
Test that all slopes are zero: G = 606.089, DF = 25, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	2307.346	2066	0.000
Deviance	2552.945	2066	0.000
Hosmer-Lemeshow	9.769	8	0.282

IVd.

Response Information

Variable	Value	Count	
Presence	1	1001	(Event)
Absence	0	1898	
	Total	2899	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-1.8066	0.4230	0.000			
YEAR						
1980	1.6308	0.3595	0.000	5.11	2.52	10.33
1981	0.9738	0.3399	0.004	2.65	1.36	5.15
1982	0.4814	0.3196	0.132	1.62	0.87	3.03
1983	1.5200	0.3399	0.000	4.57	2.35	8.90
1984	0.4168	0.3202	0.193	1.52	0.81	2.84
1985	-0.4694	0.3857	0.224	0.63	0.29	1.33
1986	0.1169	0.3391	0.730	1.12	0.58	2.18
1987	-0.7837	0.3339	0.019	0.46	0.24	0.88
1988	-2.0991	0.3342	0.000	0.12	0.06	0.24
1989	-0.9218	0.2953	0.002	0.40	0.22	0.71
1990	-0.4252	0.2895	0.142	0.65	0.37	1.15
1991	-0.6702	0.3013	0.026	0.51	0.28	0.92
1992	-0.7689	0.3011	0.011	0.46	0.26	0.84
1993	-0.5978	0.3011	0.047	0.55	0.30	0.99
1994	-0.9904	0.3025	0.001	0.37	0.21	0.67
1995	-1.3910	0.3225	0.000	0.25	0.13	0.47
1996	-0.7425	0.2715	0.006	0.48	0.28	0.81
1997	-0.8212	0.2805	0.003	0.44	0.25	0.76
Mouth	0.012049	0.002397	0.000	1.01	1.01	1.02
Temperature	-0.047775	0.009332	0.000	0.95	0.94	0.97
Salinity	0.07558	0.01148	0.000	1.08	1.05	1.10
SAV						
<=2km	1.2294	0.1337	0.000	3.42	2.63	4.44
Slope						
=>1°	0.4579	0.1039	0.000	1.58	1.29	1.94

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	288.495	18	0.000

Log-Likelihood = -1566.690

Test that all slopes are zero: G = 603.332, DF = 23, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	1634.563	1273	0.000
Deviance	1846.838	1273	0.000
Hosmer-Lemeshow	8.565	8	0.380

IVe.

Response Information

Variable	Value	Count	
Presence	1	1001	(Event)
Absence	0	1898	
	Total	2899	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	Upper
Constant	-1.6967	0.4866	0.000			
YEAR						
1980	1.6232	0.3748	0.000	5.07	2.43	10.57
1981	0.8445	0.3500	0.016	2.33	1.17	4.62
1982	0.2987	0.3298	0.365	1.35	0.71	2.57
1983	1.4002	0.3543	0.000	4.06	2.03	8.12
1984	0.3184	0.3379	0.346	1.37	0.71	2.67
1985	-0.5894	0.3984	0.139	0.55	0.25	1.21
1986	0.1092	0.3494	0.755	1.12	0.56	2.21
1987	-0.8973	0.3428	0.009	0.41	0.21	0.80
1988	-2.1582	0.3434	0.000	0.12	0.06	0.23
1989	-1.0369	0.3065	0.001	0.35	0.19	0.65
1990	-0.5232	0.3000	0.081	0.59	0.33	1.07
1991	-0.6507	0.3113	0.037	0.52	0.28	0.96
1992	-0.8817	0.3116	0.005	0.41	0.22	0.76
1993	-0.6521	0.3114	0.036	0.52	0.28	0.96
1994	-1.1920	0.3139	0.000	0.30	0.16	0.56
1995	-1.4318	0.3322	0.000	0.24	0.12	0.46
1996	-1.0368	0.2881	0.000	0.35	0.20	0.62
1997	-0.9134	0.2925	0.002	0.40	0.23	0.71
Mouth	0.003383	0.002687	0.208	1.00	1.00	1.01
Temperature	-0.050375	0.009421	0.000	0.95	0.93	0.97
Salinity						
4-8	1.2659	0.4030	0.002	3.55	1.61	7.81
8-12	1.6619	0.3655	0.000	5.27	2.57	10.79
12-16	2.3483	0.3579	0.000	10.47	5.19	21.11
16-20	2.4593	0.3591	0.000	11.70	5.79	23.64
20-24	2.2699	0.3799	0.000	9.68	4.60	20.38
>24	2.0585	0.4100	0.000	7.83	3.51	17.50
SAV						
<=2km	1.1222	0.1362	0.000	3.07	2.35	4.01
Slope						
=>2°	0.4311	0.1056	0.000	1.54	1.25	1.89

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	283.872	18	0.000
Salinity	79.731	6	0.000

Log-Likelihood = -1540.041
Test that all slopes are zero: G = 656.631, DF = 28, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	1613.315	1268	0.000
Deviance	1793.539	1268	0.000
Hosmer-Lemeshow	9.467	8	0.304

IVf.

Response Information

Variable	Value	Count	
Presence	1	1001	(Event)
Absence	0	1898	
	Total	2899	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	Upper
Constant	-2.9052	0.4831	0.000			
YEAR						
1980	1.6150	0.3722	0.000	5.03	2.42	10.43
1981	0.8358	0.3483	0.016	2.31	1.17	4.57
1982	0.3135	0.3288	0.340	1.37	0.72	2.61
1983	1.3943	0.3525	0.000	4.03	2.02	8.05
1984	0.3624	0.3355	0.280	1.44	0.74	2.77
1985	-0.5612	0.3969	0.157	0.57	0.26	1.24
1986	0.1206	0.3475	0.729	1.13	0.57	2.23
1987	-0.8822	0.3414	0.010	0.41	0.21	0.81
1988	-2.1442	0.3420	0.000	0.12	0.06	0.23
1989	-1.0161	0.3053	0.001	0.36	0.20	0.66
1990	-0.4925	0.2985	0.099	0.61	0.34	1.10
1991	-0.6360	0.3101	0.040	0.53	0.29	0.97
1992	-0.8714	0.3102	0.005	0.42	0.23	0.77
1993	-0.6316	0.3100	0.042	0.53	0.29	0.98
1994	-1.1690	0.3124	0.000	0.31	0.17	0.57
1995	-1.4206	0.3308	0.000	0.24	0.13	0.46
1996	-1.0049	0.2862	0.000	0.37	0.21	0.64
1997	-0.8951	0.2907	0.002	0.41	0.23	0.72
Mouth	0.003717	0.002662	0.163	1.00	1.00	1.01
Temperature	-0.050231	0.009400	0.000	0.95	0.93	0.97
Salinity	0.34804	0.04310	0.000	1.42	1.30	1.54
Salinity^2	-0.008385	0.001242	0.000	0.99	0.99	0.99
SAV						
<=2km	1.1021	0.1346	0.000	3.01	2.31	3.92
Slope						
=>2°	0.4320	0.1052	0.000	1.54	1.25	1.89

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	283.325	18	0.000

Log-Likelihood = -1541.875

Test that all slopes are zero: G = 652.962, DF = 24, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	1609.259	1272	0.000
Deviance	1797.208	1272	0.000
Hosmer-Lemeshow	21.384	8	0.006

IVg.

Response Information

Variable	Value	Count	
Presence	1	1001	(Event)
Absence	0	1898	
	Total	2899	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	Upper
Constant	-2.6397	0.4448	0.000			
YEAR						
1980	1.6748	0.3703	0.000	5.34	2.58	11.03
1981	0.8939	0.3465	0.010	2.44	1.24	4.82
1982	0.3532	0.3282	0.282	1.42	0.75	2.71
1983	1.4280	0.3515	0.000	4.17	2.09	8.31
1984	0.3784	0.3359	0.260	1.46	0.76	2.82
1985	-0.5335	0.3963	0.178	0.59	0.27	1.28
1986	0.2018	0.3430	0.556	1.22	0.62	2.40
1987	-0.8212	0.3386	0.015	0.44	0.23	0.85
1988	-2.1023	0.3412	0.000	0.12	0.06	0.24
1989	-1.0139	0.3060	0.001	0.36	0.20	0.66
1990	-0.4850	0.2990	0.105	0.62	0.34	1.11
1991	-0.5904	0.3088	0.056	0.55	0.30	1.02
1992	-0.8576	0.3105	0.006	0.42	0.23	0.78
1993	-0.5963	0.3096	0.054	0.55	0.30	1.01
1994	-1.1737	0.3131	0.000	0.31	0.17	0.57
1995	-1.3971	0.3308	0.000	0.25	0.13	0.47
1996	-1.0429	0.2859	0.000	0.35	0.20	0.62
1997	-0.8556	0.2898	0.003	0.43	0.24	0.75
Temperature	-0.050231	0.009400	0.000	0.95	0.93	0.97
Salinity	0.36191	0.04205	0.000	1.44	1.32	1.56
Salinity^2	-0.009109	0.001132	0.000	0.99	0.99	0.99
SAV						
<=2km	1.0792	0.1336	0.000	2.94	2.26	3.82
Slope						
=>2°	0.4289	0.1052	0.000	1.54	1.25	1.89

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	298.902	18	0.000

Log-Likelihood = -1542.852

Test that all slopes are zero: G = 651.008, DF = 23, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	1102.834	868	0.000
Deviance	1229.706	868	0.000
Hosmer-Lemeshow	14.788	8	0.063

IVh.

Response Information

Variable	Value	Count	
Presence	1	1001	(Event)
Absence	0	1898	
	Total	2899	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-3.4840	0.4303	0.000			
YEAR						
1980	1.7306	0.3732	0.000	5.64	2.72	11.73
1981	0.9674	0.3489	0.006	2.63	1.33	5.21
1982	0.4904	0.3341	0.142	1.63	0.85	3.14
1983	1.6128	0.3588	0.000	5.02	2.48	10.13
1984	0.4956	0.3385	0.143	1.64	0.85	3.19
1985	-0.3694	0.4067	0.364	0.69	0.31	1.53
1986	0.4061	0.3494	0.245	1.50	0.76	2.98
1987	-0.6678	0.3431	0.052	0.51	0.26	1.00
1988	-2.0146	0.3450	0.000	0.13	0.07	0.26
1989	-0.9431	0.3072	0.002	0.39	0.21	0.71
1990	-0.3862	0.3028	0.202	0.68	0.38	1.23
1991	-0.4159	0.3150	0.187	0.66	0.36	1.22
1992	-0.8378	0.3110	0.007	0.43	0.24	0.80
1993	-0.5324	0.3111	0.087	0.59	0.32	1.08
1994	-1.1132	0.3146	0.000	0.33	0.18	0.61
1995	-1.2541	0.3372	0.000	0.29	0.15	0.55
1996	-1.0216	0.2866	0.000	0.36	0.21	0.63
1997	-0.7466	0.2952	0.011	0.47	0.27	0.85
Temperature						
12-15	0.2643	0.1651	0.109	1.30	0.94	1.80
15-18	-0.1015	0.1754	0.563	0.90	0.64	1.27
18-21	-0.2902	0.1695	0.087	0.75	0.54	1.04
21-24	-0.5735	0.1621	0.000	0.56	0.41	0.77
>24	-0.3776	0.1819	0.038	0.69	0.48	0.98
Salinity	0.35359	0.04212	0.000	1.42	1.31	1.55
Salinity^2	-0.008842	0.001138	0.000	0.99	0.99	0.99
SAV						
<=2km	1.0903	0.1340	0.000	2.98	2.29	3.87
Slope						
=>2°	0.4230	0.1057	0.000	1.53	1.24	1.88

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	302.945	18	0.000
Temperature	39.375	5	0.000

Log-Likelihood = -1537.328
Test that all slopes are zero: G = 662.057, DF = 27, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	1097.912	864	0.000
Deviance	1218.657	864	0.000
Hosmer-Lemeshow	14.902	8	0.061

IVi.

Response Information

Variable	Value	Count	
Presence	1	1001	(Event)
Absence	0	1898	
	Total	2899	

Logistic Regression Table

Predictor	Coef	StDev	P	Odds Ratio	95% CI Lower	95% CI Upper
Constant	-3.3560	0.4130	0.000			
YEAR						
1980	1.7390	0.3701	0.000	5.69	2.76	11.76
1981	0.9638	0.3464	0.005	2.62	1.33	5.17
1982	0.4589	0.3282	0.162	1.58	0.83	3.01
1983	1.5808	0.3528	0.000	4.86	2.43	9.70
1984	0.4199	0.3361	0.212	1.52	0.79	2.94
1985	-0.3351	0.3998	0.402	0.72	0.33	1.57
1986	0.2550	0.3428	0.457	1.29	0.66	2.53
1987	-0.7500	0.3372	0.026	0.47	0.24	0.91
1988	-2.0046	0.3401	0.000	0.13	0.07	0.26
1989	-0.9551	0.3056	0.002	0.38	0.21	0.70
1990	-0.4070	0.2996	0.174	0.67	0.37	1.20
1991	-0.4821	0.3085	0.118	0.62	0.34	1.13
1992	-0.8666	0.3098	0.005	0.42	0.23	0.77
1993	-0.5408	0.3090	0.080	0.58	0.32	1.07
1994	-1.1655	0.3126	0.000	0.31	0.17	0.58
1995	-1.2645	0.3310	0.000	0.28	0.15	0.54
1996	-1.0386	0.2853	0.000	0.35	0.20	0.62
1997	-0.7352	0.2911	0.012	0.48	0.27	0.85
Temperature						
>21	-0.51180	0.09417	0.000	0.60	0.50	0.72
Salinity	0.35245	0.04194	0.000	1.42	1.31	1.54
Salinity^2	-0.008844	0.001130	0.000	0.99	0.99	0.99
SAV						
<=2km	1.0866	0.1338	0.000	2.96	2.28	3.85
Slope						
=>2°	0.4331	0.1053	0.000	1.54	1.25	1.90

Tests for terms with more than 1 degree of freedom

Term	Chi-Square	DF	P
YEAR	303.730	18	0.000

Log-Likelihood = -1542.355

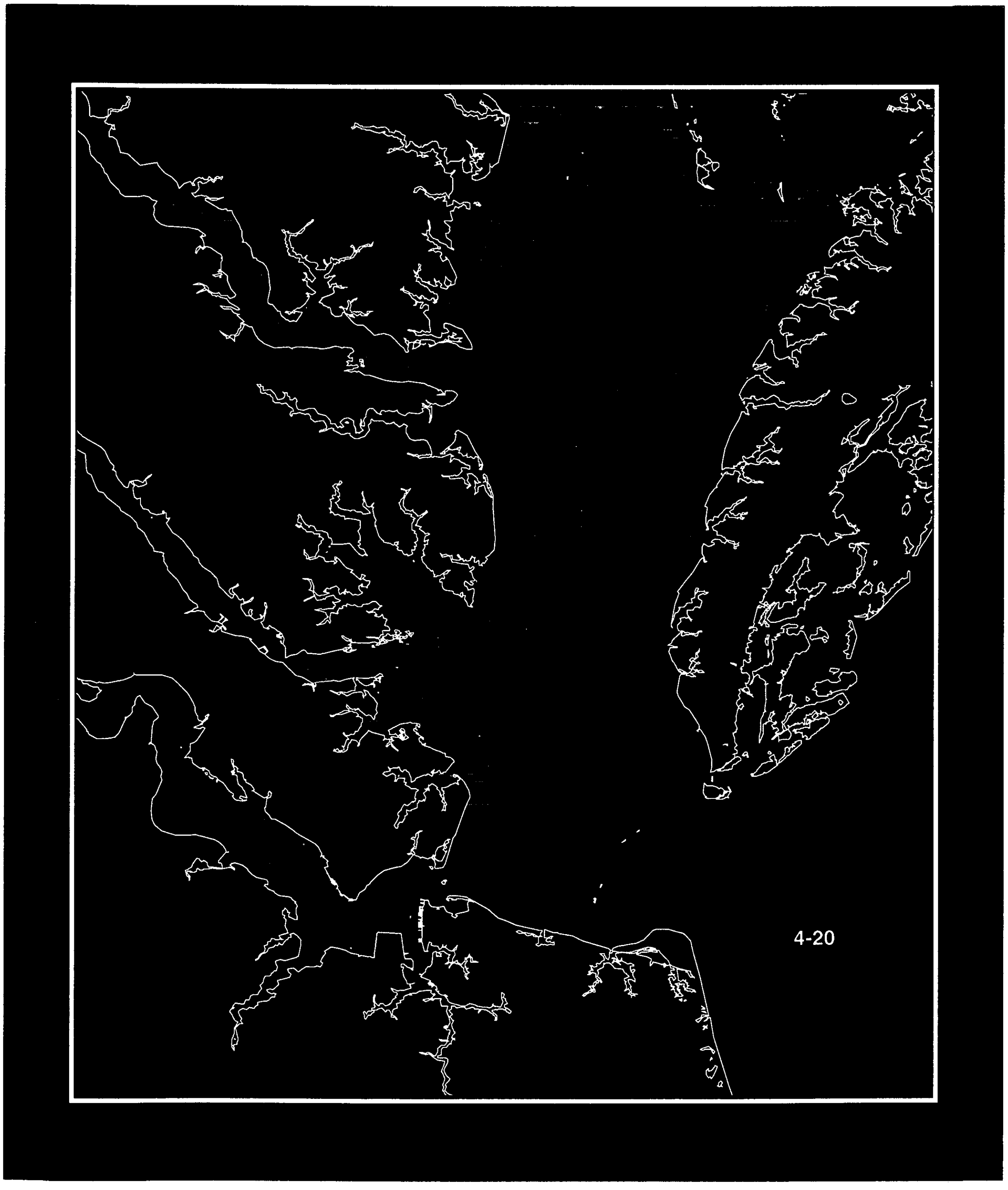
Test that all slopes are zero: G = 652.003, DF = 23, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	661.415	500	0.000
Deviance	730.326	500	0.000
Hosmer-Lemeshow	11.340	8	0.183

APPENDIX V

Source data map of typical spring salinity regime based on average April salinities in 1990 (Rennie & Nelson 1994). Resolution is one kilometer, and the shaded region represents salinity values, which were coded as 1 in a dichotomous dummy variable for regression analysis.



APPENDIX VI

ARC/INFO Macro Language Program: used to create an ARC/INFO polygon coverage with slope values of TIN, CB8. The program uses begins with a line coverage of TIN, CB8, created by the *tinarc* command.

```
&args tin cov
&s pi = 3.141592654
&s deg_conv = 180 / %pi%
/*&if [exists %cov% -cover] &then
/*    kill %cov% all
/*tinarc %tin% %cov% line degree
/*build %cov% poly
&messages &off &all
relate add
lpoly
%cov%.aat
info
%cov%#
lpoly#
linear
ro
rpoly
%cov%.aat
info
%cov%#
rpoly#
linear
ro
~
&goto here
additem %cov%.pat %cov%.pat slope 8 18 f 5
additem %cov%.aat %cov%.aat x1 8 18 f 5
additem %cov%.aat %cov%.aat y1 8 18 f 5
additem %cov%.aat %cov%.aat z1 8 18 f 5
additem %cov%.aat %cov%.aat x2 8 18 f 5
additem %cov%.aat %cov%.aat y2 8 18 f 5
additem %cov%.aat %cov%.aat z2 8 18 f 5
ARCPLOT
cursor tincur declare %cov% line rw
cursor tincur open
&do &while %:tincur.aml$next%
    &s :tincur.x1 = [extract 1 [show select %cov% line 1 xy 1]]
    &s :tincur.y1 = [extract 2 [show select %cov% line 1 xy 1]]
    &s :tincur.z1 = %:tincur.zfrom%
    &s :tincur.x2 = [extract 1 [show select %cov% line 1 xy 2]]
    &s :tincur.y2 = [extract 2 [show select %cov% line 1 xy 2]]
    &s :tincur.z2 = %:tincur.zto%
   cursor tincur next
&end
cursor tincur close
cursor tincur remove
&label here
ap
&s done = .False.
&do &while ^ %done%
    aselect %cov%.pat info
    reselect %cov%.pat info slope = -9999
    cursor tincur declare %cov%.pat info rw
    cursor tincur open
    &if %:tincur.aml$nsel% <> 1 &then &do
        /* skip outside polygon
        cursor tincur next
        &s cnt = 1
        &do &while %:tincur.aml$next% and %cnt% < 1000
            &s cnt = %cnt% + 1
            &s sides = 0
            cursor tincur relate lpoly first
            &do &while %:tincur.lpoly//aml$next% and %sides% < 2
                &s sides = %sides% + 1
                &s side%sides% = [value :tincur.lpoly//%cov%#]
                &s s%sides%x1 = %:tincur.lpoly//x1%
```

```
            &s s%sides%y1 = %:tincur.lpoly//y1%
            &s s%sides%z1 = %:tincur.lpoly//zfrom%
            &s s%sides%x2 = %:tincur.lpoly//x2%
            &s s%sides%y2 = %:tincur.lpoly//y2%
            &s s%sides%z2 = %:tincur.lpoly//zto%
            cursor tincur relate lpoly next
        &end
        cursor tincur relate rpoly first
        &do &while %:tincur.rpoly//aml$next% and %sides% < 2
            &s sides = %sides% + 1
            &s side%sides% = [value :tincur.rpoly//%cov%#]
            &s s%sides%x1 = %:tincur.rpoly//x1%
            &s s%sides%y1 = %:tincur.rpoly//y1%
            &s s%sides%z1 = %:tincur.rpoly//zfrom%
            &s s%sides%x2 = %:tincur.rpoly//x2%
            &s s%sides%y2 = %:tincur.rpoly//y2%
            &s s%sides%z2 = %:tincur.rpoly//zto%
            cursor tincur relate rpoly next
        &end
        &s s1dx = %s1x2% - %s1x1%
        &s s1dy = %s1y2% - %s1y1%
        &s s1dz = %s1z2% - %s1z1%
        &s s2dx = %s2x2% - %s2x1%
        &s s2dy = %s2y2% - %s2y1%
        &s s2dz = %s2z2% - %s2z1%
        &s nx = %s1dy% * %s2dz% - %s1dz% * %s2dy%
        &s ny = %s1dz% * %s2dx% - %s1dx% * %s2dz%
        &s nz = %s1dx% * %s2dy% - %s1dy% * %s2dx%
        &s :tincur.slope = [abs [calc [atan [calc [sqrt [calc %nx% * %nx% + %ny% *
%ny%]] / %nz%]] * %deg_conv%]]
/*    &type Side 1: %side1% x1: %s1x1% y1: %s1y1% z1: %s1z1% x2: %s1x2% y2: %s1y2% z2:
%s1z2%
/*    &type                 dx: %s1dx% dy: %s1dy% dz: %s1dz%
/*    &type Side 2: %side2% x1: %s2x1% y1: %s2y1% z1: %s2z1% x2: %s2x2% y2: %s2y2% z2:
%s2z2%
/*    &type                 dx: %s2dx% dy: %s2dy% dz: %s2dz%
/*    &type                 nx: %nx% ny: %ny% nz: %nz% slope: %:tincur.slope%
    &type              [value :tincur.%cov%#]   slope: %:tincur.slope%
            cursor tincur next
        &end
    &end
    &else
        &s done = .True.
    cursor tincur close
    cursor tincur remove
&end
&messages &on
quit
relate drop
lpoly
rpoly
~
&return
```

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