Reference No. 4

DRAFT

REVIEW AND EVALUATION OF FOUNDATIONAL LITERATURE AND DATA RELATED TO THE PROPOSED EPA SALINITY STANDARD

Prepared for

The California Urban Water Agencies
Sacramento, California

By

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NOTICE

This draft report was prepared as a technical document for reference use by California Urban Water Agencies and others in preparing their comments to the US Environmental Protection agency on "Water Quality Standards for Surface Waters of the Sacramento River, San Joaquin River, and San Francisco Bay and Delta of the State of California, January 6, 1994." This draft technical report is not part of the CUWA formal comment to EPA.

EXECUTIVE SUMMARY

The foundational literature used by the Environmental Protection Agency (EPA) to support the proposed X2 Standard was reviewed to identify potential advantages and disadvantages of the salinity standard, to assess possible relationships between aquatic organisms and salinity conditions in the Bay-Delta, and to identify pertinent ecological issues related to implementation of the standard. Technical comments and concerns regarding the X2 Standard were developed during this literature review, and are provided in this report. In addition, a detailed technical review of the biological data used by Jassby (1993) and the EPA (1993) to develop salinity criteria for the Bay-Delta was conducted to determine whether these data realistically portrayed yearly spatial, seasonal, and annual patterns in the abundance for those key aquatic species used to support the X2 standard.

Those species most likely to benefit from the X2 standard or alternative salinity criteria are a limited number of species which either prefer low salinity conditions, or which benefit from the greater food production found in conjunction with low salinity conditions. These species include Delta smelt, longfin smelt, opossum shrimp, Sacramento splittail, bay (grass) shrimp, striped bass, and the starry flounder. Other species which may benefit from certain salinity conditions in the Bay-Delta include chinook salmon, American shad, threadfin shad, and white croaker. Review of the California Department of Fish and Game's midwater trawl data suggests that of these species, only Delta smelt increase in abundance in the vicinity of the 2 ppt salinity isohaline value. Correcting Delta smelt salinity utilization data for sampling effort indicates that a wide range of salinity conditions are used by this fish, with a salinity value of 3 ppt having the highest suitability. The other species reviewed were all found within a wide range of salinity conditions, and were found to be widely distributed in the Bay-Delta on a seasonal and yearly basis. With the exception of Delta smelt, none of these species appear to "prefer" the 2 ppt isohaline. Support for the EPA's proposed salinity consequently falls upon the asserted benefits derived from nursery conditions occurring when the 2 ppt isohaline position is in the vicinity of Suisun Bay. These benefits, which includes increased survival, growth, and food availability for larval and juvenile fish, have not been substantiated since such data of this type is scarce or have not been collected. Support for a salinity standard thus fall upon observed correlations between the yearly mean position of X2 and annual abundance indices for a few "key" aquatic organisms. The mechanisms underlying these correlations have not been established through any "cause-and-effect" relationships, although maintenance of nursery conditions is strongly implied as being the most important of the possible "driving" factors responsible.

Considerable spatial and temporal variability was observed in the catch data used to derive the annual abundance indices for those species used by Jassby and the EPA to support a salinity standard for the Bay-Delta. Abundance values can vary considerably from month to month, and within and among different subareas which were sampled. Consequently, there is a considerable level of uncertainty (from both statistical and biological viewpoints) around the abundance indices which form the basis for the "key" correlations used to support a salinity standard. In addition, several sources of biases or error have been found in the catch data used to calculate the annual abundance indices. Sources of error or bias identified in this review include the time of day in which a sample is obtained, the time of year (i.e., month) sampled, variable sampling intensity and fish population dispersion among different subareas sampled, turbidity, volume of water sampled, and depth. After giving consideration to these sources of bias, the yearly trends in abundance suggested by these data still appear to be valid, and we have concluded that observed changes in these annual abundance indices most likely reflect actual changes in population levels. However, relationships developed from these data should be regarded with considerable caution due to the high intrinsic variability or uncertainty surrounding individual annual abundance values.

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

On December 15, 1993, the Environmental Protection Agency (EPA) released a proposed water quality rule applicable to the San Francisco/Sacramento-San Joaquin Estuary. The proposed rule, entitled "Water Quality Standards of Surface Waters of the Sacramento River, San Joaquin River, and San Francisco Bay and Delta of the State of California" would establish three sets of water quality criteria for the Delta, including: 1) salinity criteria of two part per thousand (2 ppt) in Suisun Bay; 2) survival targets for migrating young Chinook salmon; and 3) salinity criteria to protect striped bass spawning areas in the San Joaquin Delta. A detailed description of the standards is provided in a separate report. The U.S.Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) likewise announced several proposals on December 15. The USFWS proposals included: 1) listing of California splittail as threatened under the Endangered Species Act (ESA); 2) identification of critical habitat for the Delta smelt, a threatened species; and 3) allocation of 800,000 acre-feet (AF) of Central Valley Water (CVP) for fish and wildlife resources. The NMFS action proposed the reclassification of the winter-run chinook salmon from threatened to "endangered."

Each of the above actions and proposals was based on extensive field studies and monitoring programs conducted by agencies and research institutions. Much of the foundational material used for the EPA standards was collected as part of the San Francisco Estuary Program (SFEP) which evaluated trends of abundance for a variety of resources including: aquatic resources, wildlife and wetlands, pollution, and land use. The evaluation of aquatic and fisheries resources completed under this program relied on data collected by the California Department of Fish and Game (CDFG), the Bay Institute, and the University of California at Davis.

The EPA will accept comments on the proposed standards until March 11, 1994 and has specifically requested comments on 17 issues related to the refinement and implementation of the standards. Because each of the proposed standards/actions has implications relative to the operations of the CVP and the State Water Project (SWP), it is important for the California Urban Water Agencies (CUWA) to understand the technical basis for each of the actions. This understanding is critical for:

1) *Evaluating the technical validity of the standards;*

2) *Assessing the biological benefits of standards implementation (i.e., will they achieve the desired effect?);*

3) *Identifying potential biological impacts from standards implementation (i.e. effects on "other" species); and*

4) *Formulating and evaluating alternatives to, or modifications of the standards which would, on balance, achieve the desired level of resource protection without unnecessarily regulating the CVP and SWP operations.*

Although all three proposed actions (EPA, FWS, and NMFS) warrant this type of evaluation, CUWA has contracted with R2 Resource Consultants, Inc. (R2) to specifically review and evaluate the EPA salinity standards. R2's contract with CUWA specifies an evaluation of the biological basis of the 2 ppt EPA standard (hereinafter defined as X2), and an assessment of its effects on "other species of special concern" in the Bay and Delta. Prerequisite to this is the compilation and review of the major foundational materials used for the standards derivation.

Although the literature and data which describe the aquatic ecosystems of the Bay and Delta are extensive, our review has focused on the following reports:

- Herbold, B., A. Jassby, and P.B. Moyle. 1992. Status and trends report on aquatic resources in the San Francisco Estuary; San Francisco Estuary Project. Prepared under Cooperative Agreement #CE00951-01-1with the Environmental Protection Agency.

- Schubel, J.R. (ed). 1992. Managing freshwater discharge to the San Francisco Bay/Sacramento San Joaquin Delta Estuary. The Scientific Basis for an Estuarine Standard. Conclusions and recommendations of members of the Scientific, Policy, and Management Communities of the Bay/Delta Estuary. San Francisco Estuary Project.

- California Department of Water Resources (DWR). 1993. Biological Assessment - Effects of the Central Valley Project and State Water Project on Delta smelt. Prepared for the U.S. Bureau of Reclamation, Mid-Pacific Region.

- Kimmerer, W. 1992. An evaluation of existing data in the entrapment zone of the San Francisco Bay Estuary. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. FS/BIO-IATR/92-33.

Our review was completed with the intent of identifying supporting data and technical issues under one or more of the following general categories:

- SUMMARY OF X2 STANDARD

- **CHARACTERISTICS OF THE BAY-DELTA SYSTEM**
- **POTENTIAL RELATIONSHIPS OF FISH TO THE X2 STANDARD**
- **ECOLOGICAL ISSUES PERTAINING TO X2 STANDARD**
- **OTHER FACTORS POTENTIALLY LIMITING SPECIES ABUNDANCE AND DISTRIBUTION**
- **TECHNICAL COMMENTS AND CONCERNS REGARDING THE X2 STANDARD**
- **TECHNICAL REVIEW OF DATA USED TO SUPPORT THE X2 STANDARD**
- **FURTHER INFORMATION NEEDS**

As other reports and data are analyzed, additional questions and technical issues will be identified which can be added to each of the categories. The intent of this analysis is to provide a comprehensive review of all technical information used in formulating the EPA salinity standard. For convenience, the report is organized in accordance with each of the categories noted above.

2.0 SUMMARY OF X2 SALINITY STANDARD

This section is limited to a brief discussion of both advantages and disadvantages of the standard, as we presently understand it.

2.1 ADVANTAGES OF X2 STANDARD

Based on our review of the Schubel (1992) and EPA (1993) standards, the following are stated or apparent advantages of the X2 standard:

- The X2 standard is simple by definition and relatively easy to measure.
- The X2 standard pertains directly to salinity, which has a major effect on the distribution of fish, forage items, and vegetation in the Bay-Delta estuary. Salinity may be the single most important physical variable affecting the estuarine ecosystem.
- Salinity is correlated with water withdrawals during periods of reduced discharge, which have many secondary impacts on the Bay-Delta ecosystem (e.g. loss of ichthyoplankton and young-of-year fish). Consequently, salinity may be a good surrogate for the overall impacts of water withdrawals on the Bay-Delta ecosystem.
- Salinity is correlated with a number of factors which have important impacts on the Bay-Delta estuary, including inflow and outflows to the Bay-Delta, many water quality parameters (e.g., temperature), organic carbon transport, primary production, current patterns, and entrainment of fish by water uptake facilities.
- The X2 standard could become a reasonable and appropriate surrogate for a larger number of water quality standards which would be more difficult to implement, monitor, and enforce.
- The X2 standard would result in higher Delta outflows which would minimize the entrainment of young-of-year fish and ichthyoplankton into water uptake facilities.
- The position of X2 has been shown to be correlated with a number of important biological resources in the Bay-Delta system. A number of the biological indices reviewed improve according to reductions in the location of X2 (i.e., the low salinity zone is closer to the Golden Gate).
- The X2 standard has been asserted to provide protection on an ecosystem approach rather than on a species basis by it's proponents. Benefits to primary

and secondary production, as well as to representative species of many trophic levels, have been correlated to reductions in the location of X2.

2.2 DISADVANTAGES OF THE X2 STANDARD

The most obvious disadvantages or shortcomings of the X2 standard as presented include:

- The X2 standard is not based on direct "cause and effect" biological relationships between the 2 ppt isohaline and species specific population dynamics. The standard is a surrogate standard (habitat indicator), and therefore uncertainty exists relative to whether it will accomplish its' purpose. Until such time that: 1) cause and effect relationships are established between biological communities and X2, or 2) the degree of uncertainty is reduced associated with X2 as a surrogate indicator of ecosystem health, the standard should probably, at most be adopted on an interim basis.

- The EPA Standard calls for the maintenance of "variability" in the location of X2 within the estuary. Although the rationale for this is presented, what constitutes "variability" and more importantly, how such variability would be integrated into the standard is not described, nor its impact evaluated in the context of water inflows, outflows, and exports.

- Salinity is only one of a large number of complex and often correlated physical and biological factors affecting biological production and species abundance patterns in the Bay Delta. This is acknowledged by Jassby (1992) by stating that "X2 is not the only variable affecting estuarine resources." Assuming that X2 is an appropriate "habitat indicator," what other parameters should be integrated into the standard? The use of diversions (DIVER) alone seemed to improve the predictive capability of some of the survival indices, which for the example cited in Jassby, had the effect of reducing the conservative placement of X2.

- Spatial and temporal heterogeneity in salinity is very important to the Bay-Delta ecosystem. However, a single standard may tend to promote stable conditions rather then heterogeneity.

- The environmental effects of implementing the X2 standard has only been evaluated for a few species. Those benefits which have been identified have only been implied from empirical relationships established between the position of X2 and the abundance of a few euryhaline species (e.g., starry flounder, striped bass). Effects to other species should be evaluated prior to applying the standard, not afterwards as suggested by the Schubel report. Expected habitat benefits of applying the X2 standard (e.g., increased tidal flat areas and marshlands occurring within low salinity zone) should be quantified.

- The X2 standard is ambiguous because it is expressed as "specific" upstream limits or locations of 2 ppt salinity which would vary according to season and prevailing water conditions. The locations where the 2 ppt salinity standard would be measured would vary depending upon the time of year and the "appropriate level of ecosystem protection" selected; consequently the choice of these locations could become highly subjective. Deciding upon appropriate locations for monitoring X2 could become both complicated and controversial. Consequently, the standard may be hard to implement even though it is "easy" to measure, since the standard may not be applied in a consistent manner.

- It is difficult to determine how the X2 standard would be maintained or enforced. The standard is affected by inflows through the Sacramento-San Joaquin Delta provided by runoff from Central Valley rivers and streams, and by storage from reservoirs. The standard is also affected by a large number of water uses in the Central Valley, including municipal water systems, a large number of agricultural users, and by diversion of water in southern Delta by the Central Valley Project and State Water Project.

- The predictive model developed to evaluate X2 location illustrates the uncertainty associated with its location; the residual errors are high and the actual location of X2 could range as high as ± 5-6 Km from its predicted location. This error compounds the problem associated with setting its location, as well as renders the possibility of secondary impacts to other species and life stages of fish and other organisms which are integral members within the Bay-Delta ecosystem.

3.0 CHARACTERISTICS OF THE BAY - DELTA SYSTEM

In order to identify and evaluate potential beneficial and adverse effects the X2 standard on the Bay-Delta ecosystem, a basic understanding of physical and biological characteristics of this system is necessary. This is briefly provided for the three major areas of the Bay-Delta system which are most likely to be impacted by the proposed standard. These areas include the San Pablo Bay, Suisun Bay, and the Sacramento - San Joaquin River Delta. The proposed X2 standard would most directly impact freshwater inflow values and salinity regimes in Suisun Bay and the Delta. The greatest variability of salinity is in Suisun Bay, which has a strongly varying salinity regime due to tidal influx of ocean waters twice per day.

Wind plays an important role in the mixing of fresh and salt water in the Bay and Delta, and in resuspending bottom accumulations of nutrients, organic matter, and organisms such as phytoplankton. The effectiveness of wind in disrupting salinity stratification and in resuspending bottom materials is very important in Suisun Bay and San Pablo Bay, where water can often become thoroughly mixed. The extent to which salt water can move upstream during tidal influx periods is greatly influenced by wind direction and magnitude.

In addition to wind, water temperature has an important influence to the growth, survival, and food available to many Bay and Delta fish species. However, there is presently very little information on the effects and relationships of temperature to species abundance in the Delta and the San Francisco Bay Estuary.

3.1 SAN PABLO BAY

This upper region of the San Francisco Bay has extensive shallow areas, and often possesses a salinity stratified water column during peak river inflow periods. The biotic community of this region is restricted mainly to marine fishes during summer months when salinities are highest and least variable. Regular occurrences of several euryhaline species, including striped bass, starry flounder, longfin smelt, and yellowfin goby, occur during periods of higher flow. According to Herbold et al. (1992), most characteristic species in the San Pablo Bay have undergone a severe decline in abundance during recent years. Higher salinities during drought years have allowed an increased abundance of adult white croaker, a characteristically marine species. The reduced suitability of upstream nursery areas and spawning sites, as well as toxic effects of pollutants, may be responsible for declines in abundance of many species in the San Pablo Bay. Secondary freshwater zones in San Pablo Bay result from inflow of the Napa and Petaluma rivers.

3.2 SUISUN BAY

Suisun Bay is of great importance to several fish species, principally as nursery ground for young-of-year fish. This region has been strongly affected by the introduction of exotic species, increased water development, and drought. This importance is presumably due to accumulations of food material by interaction of ocean-flowing surface currents and landward bottom currents. This area of freshwater and saltwater mixing has been referred to as the "entrapment zone" (Kimmerer 1992). Resulting high densities of food have supported high densities of zooplankton, juvenile fish, and small fish.

Clams are among the most important benthic organisms in Suisun Bay. Most clams in the estuary are not capable of surviving the highly variable salinities to which the bottom is subjected. Extremely high populations and densities of introduced clams have resulted in greatly reduced densities of phytoplankton and zooplankton. Populations of many fish species that use the nursery areas of Suisun Bay declined prior to the spread of the Asian clam. Rapid development of the clam *Mya arenaria* occurred during the drought in 1976-1977, but rapidly disappeared when the rivers returned to normal flows. The recent invasion of the clam *Potamocorbula amurensis* may have occurred due to similar drought effects occurring in the late 1980s. Changing salinity is thought to be a major factor preventing development of a large benthic fauna in Suisun Bay.

Drought conditions have resulted in migration of the entrapment zone to deeper channels near the upstream end of the Bay. In recent times, the Lower San Joaquin River was subjected to reverse flow conditions only during the summer. However, most recently this condition has prevailed during all seasons, due in part to increased water exports and conditions of long term drought (1987-1992). Reverse flows have been suggested to move larvae away from the entrapment zone in recent years. Delta smelt, longfin smelt, striped bass, and yellowfin goby have declined in this region over the last decade. Opossum shrimp *(Mysis mercedis)* are very important to the diet of most fish species in the Bay and Delta, and have declined in abundance in both areas over the last twenty years. Suisun marsh is very important habitat for native species, including the Sacramento splittail and tule perch which are not abundant elsewhere.

3.3 SACRAMENTO-SAN JOAQUIN DELTA

The Sacramento-San Joaquin Delta has a long history of extensive modification and habitat destruction. More than 95 percent of original tidal wetlands have been eliminated. Dredging of channels has put large portions of the water column beyond the reach of sunlight. Water flow rates have been intentionally increased throughout delta channels for purposes of navigation. Over 1,500 agricultural diversions are unscreened. Increasing diversion of fresh water from the south Delta alters direction of flow in several main channels. Agriculture and urban runoff are the principle sources of pollution.

The Delta is unique because it drains through a narrow notch in the Coast Range near the Carquinez Strait rather than through a wide floodplain as do most rivers. Delta areas above the Sacramento-San Joaquin River confluence have been heavily diked; and 95% of historic flood plain area has been reclaimed for agriculture (Herbold et al., 1992). Dredging of shipping canals and levees along rivers and sloughs have reduced available shallow water habitat to a fraction of pre-development levels. Combined or cumulative impacts of land reclamation for agriculture, ship channel dredging, pollution by toxic contaminants, exotic species introductions, and water withdrawals for agricultural and municipal use have created conditions where fish populations were extremely vulnerable to drought impacts. These impacts were noted during the drought of 1976-1977 and the recent drought period extending from 1987-1992.

Populations of invertebrates and most fishes in the Delta have declined in the past 25-30 years. Invertebrates that have shown declines are mostly planktonic species, including rotifers, cladocerans, and native copepods. The Delta smelt, longfin smelt, and splittail have declined to very low numbers which qualified them for threatened or endangered status under the Federal Endangered Species Act (ESA). Striped bass and chinook salmon have declined from the large numbers observed 20-30 years ago. Entrainment or displacement due to effects of the Central Valley Project and State Water Project are the most frequently cited cause for declines of most species, although a number of "other factors" have contributed to these declines. For example, the decline in striped bass corresponded with increased use of herbicides associated with the rice industry which may have created toxic conditions.

4.0 POTENTIAL RELATIONSHIPS OF FISH TO THE X2 STANDARD

Relationships of the biological community to the proposed X2 standard can be considered to be either direct or indirect. *Direct* relationships involve changes in salinity regime and habitat conditions which affect species requiring low salinity conditions for survival or reproduction, or which depend upon food organisms which require low salinity conditions. *Indirect* effects involve changes in flow regimes and flow patterns in the Delta which result from the imposition of the proposed salinity standard. While the direct intent of the standard is to maintain habitat conditions in the vicinity of Suisun Bay, to accomplish this will require potentially major changes in Delta inflow, outflow, and export rates, which will affect reverse flow conditions (QWEST).

The consumptive water uses most impacted by the proposed standard are the operations of the SWP and CVP. During recent dry years these diversions together with smaller agricultural diversion within the Delta have taken more than half of the potential inflow to the estuary. Negative effects of water diversions include amplification of drought impacts, change in direction of net flow in several main channels of the Delta (delay outmigrations of fish, temperature effects), increased entrainment of larval fish and eggs into diversions, increased susceptibility of larval fish and eggs to predation, and changes in food web.

Since the X2 standard is most applicable to the region between Suisun Bay and the confluence of the Sacramento and San Joaquin River, it has the greatest influence on Delta smelt, longfin smelt, Sacramento splittail, spring and winter run chinook salmon; and striped bass. Thus, although the standard is presented on an "ecosystem protection" basis, its foundation rests on the biological needs of the five "indicator species."

In general, the species which the X2 standard may most directly affect are Delta smelt, longfin smelt, Sacramento splittail, and Bay and opossum shrimp, species which are most dependent upon the low salinity and the shallow habitat conditions provided within this region.

Review of annual abundance data indicate that Delta smelt is the species most likely to benefit from salinity conditions imposed under the EPA standard. Delta smelt annual abundance values are highest when the mean position of X2 from February through June is located in the vicinity of Suisun Bay. Lower mean abundance values are observed during years when X2 is located upstream or downstream of this location (see technical review, Section 8 of this report). In addition, Delta smelt are often found in highest abundance in the vicinity of the 2 ppt isohaline, probably in response to the higher abundance of invertebrate food items associated with the entrapment zone (Moyle et al., 1992).

The X2 standard will indirectly affect chinook salmon, American shad, and striped bass by increasing passage survival of these anadromous fish via greater outflows of freshwater. It has been suggested that striped bass would benefit further by the reduction of reverse flows which subsequently lead to the entrainment of eggs and larval forms of these fish into water uptake facilities and agricultural diversions (Herbold et al., 1992).

In general, the fish species which show most promise in benefiting from X2 are those which require combined shallow water habitat types found in the Suisun Bay estuary and low salinity conditions (e.g., Delta smelt), and those which are subject to entrainment into water export facilities or are affected by reverse flows which occur during low flow periods (e.g., striped bass; benefit due to increased outflows).

4.1 DELTA SMELT - *Hypomesus transpacificus*

Populations of Delta smelt have undergone a major decline over the past ten years, though the overall reasons for this decline are uncertain at this time. The abundance of this species dropped to critically low levels during the 1985-1992 drought, and were thought by many to be threatened by extinction if severe conditions persisted. Review of more recent data suggests that Delta smelt populations have rebounded in 1993 from the low abundance values observed during the previous severe drought period. This is likely the result of improved inflow conditions in the Delta and Estuary in 1993. Delta smelt are listed as "threatened" under the ESA and the USFWS has recently proposed to designate "critical habitats" for the species. These fish are endemic to the upper estuary and have a one-year life cycle. Due to the planktonic nature of young Delta smelt, these fish are thought to be especially vulnerable to increased diversions from the Delta during drought periods. Delta smelt adults are usually found in Suisun Bay and the Delta, and migrate into the Delta to spawn. The distribution of the Delta smelt extends from a downstream limit at Suisun Bay to an upstream limit in the Sacramento River around Isleton, and in the San Joaquin River around Mossdale. Prior to the "reclamation" of most Delta marshlands for agriculture, the range of the Delta smelt probably extended considerably further upstream.

Delta smelt are thought to concentrate into areas near the entrapment zone or in river channels above it, but move upstream into river channels during spawning. These fish reportedly move into deeper channels of the San Joaquin and Sacramento Rivers during low flow periods in correspondence to upstream migration of the entrapment zone. Delta smelt have been suggested to be highly associated with the entrapment zone because of high concentrations of planktonic food which occur in this zone. The planktonic food required by Delta smelt was probably abundant throughout the Delta prior to the extensive reclamation of marshland to farmland. Because of the destruction of 97% of total marshland in the Delta, the highest abundance of a predictable planktonic food supply currently occurs in the low salinity or entrapment zone, which typically is located in the Suisun Bay region of the bay.

4.2 LONGFIN SMELT -*Spirinchus thaleichthys*

The longfin smelt is one of most widely distributed species in the Estuary; they spawn in fresh water in the Delta. Successful spawning by longfin smelt has been attributed to higher Delta outflows. Numbers of these fish in the past decade have declined steadily to the lowest levels ever recorded. Adult longfin smelt live throughout the Bay, and are seldom found outside the Bay except when they migrate into the Delta to spawn. The species is euryhaline and can apparently move within a wide range of salinities; longfin smelt populations in Lake Washington, Washington reside entirely within freshwater. The distribution of adult longfin smelt are not strongly associated with the location of the entrapment zone as are Delta smelt. Longfin smelt generally complete their life cycle in two years, and there is reportedly a distinct difference in habitat use between juvenile and adult fish. The former (juveniles) tend to locate in shallower waters.

4.3 OPOSSUM SHRIMP - *Neomysis mercedis*

The opossum shrimp *Neomysis mercedis* is an important food item to many fish species (e.g., striped bass) in Suisun Bay and nearby areas of the Delta. The abundance of this invertebrate is closely tied to that of *Eurytemora affinis*, an estuarine copepod upon which it feeds, and which has recently undergone a marked reduction in abundance. The opossum shrimp is typically found in brackish waters in the low salinity zone typically located in the vicinity of Suisun Bay. Consequently, this important invertebrate forage species for fish may be strongly affected by the position of X2, as is suggested by the increase in opossum shrimp abundance with reductions in the position of X2 (Jassby, 1992).

4.4 SACRAMENTO SPLITTAIL - *Pogonichthys macrolepidotus*

The Sacramento splittail is an endemic minnow to the Delta which is declining rapidly in abundance. The USFWS has recently proposed the classification of the splittail to "threatened" status under the ESA. Once found throughout the Central Valley, these fish are now confined to the San Francisco Bay Estuary. The severe reduction in the range and abundance of this fish has likely resulted from extensive habitat losses which occurred primarily because of reclamation of Delta and Central Valley floodplains and marshlands for agriculture. This species prefers shallow marshlands for foraging and spawning. Potential benefits of the X2 standard to this species would possibly result from increased marshland habitat provided by higher flows through the Delta and Bay during drought periods.

4.5 CHINOOK SALMON - *Oncorhynchus tshawytscha*

Four major runs of chinook salmon pass through the estuary during juvenile and adult migrations. Conditions during the downstream passage of smolts are thought to be a major source of mortality, especially when outflows are low and pumping rates are high (possible causes: entrainment, lack of current clues, increased predation, lack of growth by young due to decreased invertebrate food abundance). The overall benefits of the X2 standard on this species is uncertain. Higher passage survival of juveniles and adults may occur as a result of higher Delta inflows resulting from implementation of the standard. However, these higher Delta inflows may come at the expense of instream spawning and rearing habitat conditions for fish in Sacramento River drainage. This is because reservoir storage used to maintain habitat and temperatures in Central Valley rivers and streams may be needed to maintain higher Delta inflow values during periods when the X2 standard is imposed. Thus, carryover storage may be reduced and may result in conditions of complete reservoir drawdown. The extent to which the X2 standard alters current reservoir operations is uncertain at this time, but has the potential for impacting both lacustrine and riverine habitats and fisheries (and associated recreational activities).

4.6 STRIPED BASS - *Morone saxatilis*

This introduced species (introduced in 1879) has undergone a long, continuous decline in abundance in the Bay and Delta, and Sacramento and San Joaquin Rivers. Because of its value to recreational fishing, this is the best studied fish species in the Delta. Reductions in abundance of striped bass are likely caused by a number of factors, including low Delta outflows, toxic contamination, inadequate food supply, reduced egg production, disease and parasites, and overfishing (Herbold et al., 1992). Entrainment of larval fish and eggs by water diversions has been suggested to be the most likely cause for the reduced abundance of striped bass in the Delta. However, the direct cause for the decline in abundance of this fish has not been determined, but probably involves a number of environmental factors.

4.7 AMERICAN SHAD - *Alosa spadissima*

The American shad is an abundant, introduced (1871) anadromous species which spawns least successfully during dry years. Reduced spawning success during drought periods may partially be due to entrainment of eggs and larval fish by Delta water diversions. American shad spawn in river channels and their eggs are semi-buoyant; spawning migrations to freshwater occur in March, with peak spawning in May and June. Young fish outmigrate rapidly, although some may spend up to a year in freshwater. According to Herbold et al. (1992), the relationship of American shad survival and abundance may be linked to water temperatures; temperatures >20°C produce high mortality. Thus, to the extent the X2 standard results in greater outflows of cooler water during the spawning season, American shad may benefit.

4.8 THREADFIN SHAD - *Dorosoma petenense*

The threadfin shad, introduced in 1953, serves as a minor component of the diet of striped bass. The abundance of threadfin shad in freshwater habitats has become reduced during the last decade, (Herbold et al., 1992). This fish is found primarily in the Delta and upstream areas, but may be forced into the Bay as a result of high flow conditions. Greatest concentrations are found in the San Joaquin Delta. The effects of the X2 standard on American shad are uncertain, and should be evaluated in the context of the timing and magnitude of flows occurring throughout the Delta.

4.9 WHITE CROAKER - *Genyonemus lineatus*

The white croaker is mainly a marine fish which is often found to be abundant in the northern San Francisco Bay. These fish have expanded their range into the Estuary as the salt water zone has migrated upstream during drought years. Imposition of the X2 standard would likely result in the movement of these fish into more downstream portions of the Estuary during drought periods than would otherwise occur.

4.10 STARRY FLOUNDER - *Platichthys stellatus*

The starry flounder is more euryhaline than other flatfish, and has historically been found to be abundant in the Suisun and San Pablo Bays. Numbers of these fish have been declining in recent years. Although the abundance of these fish has been suggested to be dependent on hydrologic conditions in the Estuary, these fish have been very susceptible to pollution impacts occurring in the Bay.

4.11 BAY SHRIMP - *Crangon franciscorum*

Of the four species of "Bay" or "grass" shrimp frequently found in the estuary, only *Crangon franciscorum* has shown a long-term decline in abundance. The decline in abundance of this shrimp is thought to be linked to freshwater inflows from the Delta. Due to the importance of this species as a forage item to many fish, *Crangon franciscorum* can be considered as the "indicator" invertebrate species linked to the X2 standard (Jassby, 1992). However, the shrimp *Crangon nigricauda* has increased in abundance during the same time period in which a number of *Crangon franciscorum* have been observed to decline (1980-1991; CFG 1992). Increases in the number of *Crangon nigricauda*, as well the *Heptacarpus* shrimp, have offset the declines in the abundance of observed in *Crangon franciscorum*. The food benefits derived through a 2 ppt salinity standard to fish species, as suggested by the EPA (1994), would only occur if certain fish species were solely dependent on *Crangon franciscorum* as a forage item. The abundance of other Bay shrimp species is thought to be tied to marine events, and would likely not be affected by the imposition of the standard.

5.0 ECOLOGICAL ISSUES REGARDING THE X2 STANDARD

The X2 standard has been justified by proponents based mainly on potential impacts to a few key "indicator" species (i.e., Delta smelt, longfin smelt, striped bass, and chinook salmon). However, the impacts of the standard at the ecosystem level, including primary productivity, secondary productivity, trophic dynamics, and community interactions, are largely unknown. A synopsis of information relevant to evaluating potential biological benefits and impacts is provided below for each of the major food web components.

5.1 PHYTOPLANKTON PRODUCTION

5.1.1 San Pablo Bay

According to a study conducted in 1980, primary production in San Pablo Bay is dominated by phytoplankton production, which accounts for 60 percent of total production in this region (Herbold et al. 1992). Benthic microalgal productivity and marsh exports of organic carbon also account for significant secondary sources of production. No long-term data presently exists for shoal phytoplankton, which accounts for almost 80% of total phytoplankton productivity in the San Pablo Bay (Herbold et al, 1992).

5.1.2 Suisun Bay

Organic carbon from riverine sources and the Delta accounts for 60% of the total organic carbon inputs to Suisun Bay, based upon a 1980 study. Marsh export and phytoplankton productivity account for 20% and 10% of organic carbon source. Much of the organic matter contributed to Delta discharge seems to be derived from phytoplankton breakdown. The drought period lasting from 1987-1992 depressed Delta outflows and, presumably, riverine loading of organic matter as well.

Low productivity of phytoplankton has occurred in the Suisun Bay since 1987, a likely result of drought related impacts. Low phytoplankton productivity has been attributed to the reduction in the size of the entrapment zone during high and low Delta outflows, and by suspension-feeding estuarine invertebrates (Asian clam) which became established during periods of prolonged drought. These clams are responsible for increased grazing losses of phytoplankton and other types of particulate organic matter (POC) important to primary and secondary production in the Bay and Delta.

Reductions in sewage inputs may have contributed to declines in organic matter concentrations and primary productivity during recent years. Tidal marsh export could actually be the major nonriverine organic carbon source present. Invasion of the corbulid clam *Potamocorbula amurensis* in 1987 may have led to the persistence of high grazing losses even after the drought ended due to the clam's tolerance to low salinity water. Local productivity could remain low so that riverine loading and tidal marsh export would be increasingly important under these conditions.

5.1.3 Delta

Phytoplankton is the dominant source of primary productivity in the Delta (Herbold et al, 1992). Reclamation of marshland for agriculture, the development of an extensive system of dikes, and dredging of the remaining channels has resulted in the removal of most of the shallow habitat necessary for the growth of benthic algae and emergent vegetation in the Delta. Production of phytoplankton can be substantial in the Delta, and phytoplankton abundance generally increases with distance in a downstream direction.

Long term trends in phytoplankton populations in the Estuary and Delta are poorly understood at this time. However, major changes in species composition and abundance have been taking place in many primary producers in recent years (Herbold et al, 1992; Hergesell, 1994). These changes include intermittent blooms of the diatom *Melosira ganulata* in the Delta, a species thought to be hard for some zooplankton grazers to feed upon. Recent reductions in abundance of phytoplankton in the Suisun Bay and Delta have been thought to be largely a result of introduced filter feeding clams, which filter tremendous volumes of water in this region.

5.2 INVERTEBRATE PRODUCTION

5.2.1 Zooplankton

Zooplankton, an integral component of the aquatic food web, have been sampled on a regular basis only in the Delta and Suisun Bay. Consequently, it is not possible to say much about trends in other parts of the Estuary. Potential affects of the X2 standard on zooplankton are unknown, but could result in either increases or decreases in abundance, which would directly impact higher invertebrate and fish production. Reductions of zooplankton over the past 15 years strongly suggest that large scale environmental factors may be impacting the Delta on an ecosystem level.

- *Rotifers*: rotifers, which are among the smallest of zooplankton, have declined sharply in abundance within the Delta since 1979.

- *Cladocerans*: cladocerans have also shown long-term decline in abundance. This decline is more sudden than that of rotifers and occurred mainly in the late 1970s after rotifer populations had declined.

- *Copepods:* freshwater species of copepods have declined in a manner similar to cladocerans. Marine species (mainly *Arcartia tonsa*) have not shown trends except for a crash in response to the clam invasion. The estuarine copepod *Eurytemora affinis,* an important source of food for shrimp and larval fish, has shown a long-term decline, but has been replaced by other copepod species.

- *Opossum shrimp:* the abundance of opossum shrimp is closely timed with the copepod *E. Affinis* and to freshwater flow into the Bay. Long-term trends in population levels of opossum shrimp, an important forage species for many fish species including striped bass, have been obscured by year-to-year large fluctuations in abundance.

5.3 BENTHIC PRODUCTION

Most benthic organisms in the Estuary are introduced species, and little information is available on population trends for most of these species. The dominant benthic species are thought to depend in large part, on the recent history of freshwater outflow from the Delta and saltwater intrusion. These dimersal organisms are very susceptible to extreme changes in salinity, since most have only a narrow or moderate tolerance to salinity. The wider range of salinities tolerated by the recently introduced Asian clam could be largely responsible for its explosive population growth since 1987. Oysters and marine clams inhabiting the San Francisco Bay Estuary have fluctuated largely in response to harvest, pollution, and invasions of new species. No real long-term trends apparent in these benthic organisms.

5.4 FOOD WEB

Current evidence suggest that most of the organic carbon (e.g., phytoplankton, POC) which is available for uptake enters the food web of the Bay and Delta (Herbold et al., 1992). This is strongly indicative of an ecosystem in which productivity is limited by energy inputs in the form of organic carbon.

Decline in fish production in the upper estuary could be related to the decline in organic carbon sources since the early 1980s as suggested by the relationship between POC and flow in the Suisun Bay (Jassby, 1992). During drought conditions, more organic carbon supply probably shunted through benthic rather than planktonic organisms, favoring an increase in dimersal organisms (e.g., clams).

6.0 OTHER FACTORS POTENTIALLY LIMITING SPECIES ABUNDANCE AND DISTRIBUTION

A large number of factors potentially influence or even limit the abundance and distribution of aquatic organisms in the Delta. It is important to realize that the X2 standard only applies to salinity and the outflows needed to influence its location. Studies suggest that the position of the low salinity isohaline may have its greatest influence on one or two fish species (e.g., Delta smelt, longfin smelt). This is because of the apparent affinity of the species to the entrapment zone and its elevated primary and secondary production levels. Nevertheless, factors other than salinity also influence or limit the abundance and distribution of species. Potential benefits of the X2 standard will only be realized for those species which directly depend upon the location and area provided by the entrapment zone, the higher primary and secondary production associated with this region, or those positively affected by the increased inflows of water and decreased exports of water required to maintain this standard. The following provides a list of potential factors which may also limit species abundance and distribution in the Delta.

6.1 YEARLY VARIABILITY IN FLOW

Yearly variability in flow to the Delta, especially when flow levels are extreme from one year to the next (as occurred during the 1980s), can lead to depressed species populations for a number of reasons. Combinations of extremely wet and extremely dry years during the 1980s are likely a factor causing reductions in fish populations in the Delta. If unsuitable habitat conditions persist from year to year, it will be expected that poor survival will occur from one year to the next. Poor survival can lead to poor recruitment during years when habitat conditions are favorable, a condition which may partially explain the high variability in fish populations (e.g., Delta smelt and striped bass) observed for any given yearly flow conditions (i.e., wet, normal, dry, critically dry). The inability of dimersal species to establish themselves in any given area may largely be due to the extreme spatial variability in salinity within the Delta and Bay among successive years.

6.2 PEAK FLOWS

Variation in flow to the Bay and Delta is the most commonly cited control on abundance, distribution, and reproductive success of many species of fish in the Sacramento-San Joaquin Estuary and Delta. However, it is not evident after reviewing temporal trends for several "key" fish species (e.g., Delta smelt) whether rapid declines were caused by peak flow or flood conditions, or by drought conditions. It is possible that low population levels of many species observed in the late 1980s resulted from a record high flow event which occurred in February 1986, which was followed by extreme drought conditions which prevented species from recovering from this flood.

Volumes of water flowing into the Delta are extremely variable from year to year. The past 15 years have encompassed the wettest year on record (1983), as well as two of the longest and driest droughts on record (1976-1977 and 1987-1992). In addition to year-to-year variations in flow, extreme fluctuations in Delta inflows have been observed on a seasonal basis. For example, during the drought year of 1990 the Central Valley experienced the wettest May on record. High flows may be partially or even largely responsible for a sudden drop in longfin smelt populations in 1983, as high flows presumably flushed a high percentage of mature adults out of the estuary. The same could be true for other fish populations inhabiting the Delta. In particular, populations of Delta smelt (townet index) reached extremely low levels following 1965 and 1986, both years having record high flows.

White sturgeon abundance is tied to spawning success in years of very high outflow. Some species such as the Sacramento splittail spawn more successfully within flooded vegetation, which is more available in years of high outflow.

Contrary to high flow events, moderate Delta outflows are thought to support higher populations of American shad, longfin smelt, and chinook salmon. These species, which migrate through or into the Delta to spawn, may benefit from increased passage survival provided by moderate flows (decreased downstream travel time for young fish, decreased predation risk). Increased discharge has also been thought to increase the total load to phytoplankton as it approaches and passes through the Delta. The importance of this is relatively unknown, but could be great due to the importance of phytoplankton in the Delta food chain.

6.3 DROUGHT IMPACTS

The drought of 1987-1992 resulted in a severe decline of many fish species in the Delta. The impacts to fish occurring during the drought, including flow reversals in the central and southern regions of the Delta and subsequent entrainment into water diversions, may be reduced by the greater total Delta inflows required to maintain the proposed X2 salinity standard. However, population impacts resulting from drought periods would probably occur regardless of the X2 standard. Consequently, benefits derived from implementation of X2 may be offset or reduced during periods of extended drought. The EPA apparently recognizes this, and has proposed different X2 criteria depending on the type of water year. Nevertheless, the effects of extended drought have not been evaluated independent of flow exports. This is important for determining the degree to which natural versus man-induced effects may be influencing the Bay and Delta fish populations. Drought factors both related and unrelated to the salinity standard include:

- Increased susceptibility to entrainment by water uptake facilities. Flows may not be high enough during drought periods to transport eggs, larvae, and young-of-year fish into Suisun Bay, increasing their susceptibility to entrainment into pumps of the SWP, CVP, and numerous irrigation diversions located in the Delta.

- Increased concentration of toxics. Reduced streamflow during drought periods would likely result in increased concentrations of pesticides and other toxins in the Delta and upstream areas. Increased concentrations of toxins could significantly impact invertebrate and fish populations in the Delta.

- Increased abundance of filter feeding invertebrates (including clams) which have lower tolerance for changing salinity conditions. Successive years of stable salinity regimes caused by extended drought periods could result in the temporary establishment of benthic species, especially clams, which are intolerant to extreme changes in salinity. Increased production of clams during drought periods could have extremely negative impacts on the abundance of phytoplankton and zooplankton in the Delta and Estuary. Explosive population growth of exotic clam species and subsequent reductions in phytoplankton and zooplankton availability would impact planktivorous invertebrates (e.g., opossum shrimp) and fish (e.g., Delta smelt).

- Decreased influx of organic carbon (phytoplankton and associated breakdown products resulting from decomposition) due to reduced Delta inflow and reverse currents in southern Delta (organic carbon entrained into agricultural, SWP, and CVPdiversions).

- Increased parasite infections and resulting mortality and lowered fecundity may affect the abundance of fish such as striped bass during drought periods. These increased infections result from the reduction in suitable habitat area during drought periods and the subsequent concentration of fish into these areas, which promotes spreading of parasites. Increased vulnerability due to other forms of stress, including changes in water temperature, food availability, and increased toxic contaminant concentrations may influence parasite loads.

- Reduced habitat, reduced access to upstream spawning grounds, and higher water temperatures in Central Valley river systems for anadromous fish which pass through Delta. Severe reductions in chinook salmon populations during the drought may be largely due to extreme reductions in flows in Central Valley rivers and streams. There is also an increased stranding potential for the redds of spawning fish in upper rivers during drought periods.

- Increased water temperatures resulting from reduced volumes and increased retention time of water in Delta.
- Increased vulnerability to predation. For example, rapid increases in silverside abundance occurred concurrently with reductions in striped bass and Delta smelt in 1980s. Concentration of larvae and eggs in Delta areas increases susceptibility to predation by fish such as silverside.

6.4 LAND RECLAMATION

There should be little doubt that land reclamation has historically had the most severe impact on the Delta and upstream areas. Historically, there has been a vast transformation of freshwater marsh habitat to agricultural lands. Less than 3% of the Delta is similar to the dominant marshland habitat type which occurred 150 years ago. Reclamation of marshland habitat to farmland resulted in the destruction of most of the potential spawning habitat of many native fish species, including Sacramento splittail, Sacramento blackfish, and perhaps longfin smelt and Delta smelt. Tule perch and Sacramento splittail, which originally occurred in abundance throughout the Delta, lost much of their original foraging habitat to resulting losses of marshland. The pace of land alteration has slowed in recent years, although relatively little remaining native Delta marshland is available.

Dredging and diking to create farmland remains the main impact to the Delta ecosystem in recent years. Channelization of rivers has removed littoral zones important to aquatic primary and secondary production, as well as habitat to fish. Over 70% of the Delta is presently characterized as deep, open water habitat.

6.5 NON-NATIVE SPECIES INTRODUCTIONS

6.5.1 Clams

Recent reductions in abundance of phytoplankton in the Delta and Bay have been linked to exotic clams, which were introduced to the Bay Area from the ballast water of ships. The explosive increase in abundance of the Asian clam following its introduction in the mid 1980s have caused declines in other benthic organisms. This clam has also been identified as a potential threat to fish eggs and larvae. The clam was supposedly introduced circa 1985, becoming fully established by 1987. Assuming that this clam succeeds or replaces other benthic species in the Delta and Bay, it is likely that it will filter out large amounts of plankton like previous clams. It is possible, however, that this euryhaline species may persist better under intermediate salinities when compared to its fresh- and salt-water predecessors.

6.5.2 Inland Silverside

The silverside is an introduced fish which increased dramatically in the early 1980s concurrent with declines in Delta smelt abundance. The silverside occurs in high abundance when small eggs and larval fish are present in the Delta. Silversides may prey heavily on striped bass larvae and eggs. Silversides may also prey upon Delta smelt larvae, particularly during low flow periods. An assessment of their abundance and ecological relationship to other Delta and Bay species is warranted.

6.6 EXPLOITATION

Fishing pressure has been thought to substantially reduce numbers of some species in the Bay and Delta, including oysters and marine clams, as well as striped bass.

6.7 POLLUTION

Reductions in sewage disposal have eliminated some species, and allowed recovery of other species in some areas. Industrial pollution is mainly a concern in Suisun Bay and San Pablo Bay whereas agricultural chemicals and non-urban runoff is of most concern in the Delta areas.

6.8 UPSTREAM IMPACTS

The declines in chinook salmon and other anadromous species have largely resulted from dams and diversions upstream of the Delta and Estuary. Upstream or offsite impacts to fish will not be reduced by the X2 salinity standard. If upstream or offsite impacts are those which primarily limit the abundance of a given species, then the proposed standard may have negligible impacts to the population of that species. Other measures (e.g., screening of diversions, flow regulation) must be implemented to protect such species.

7.0 TECHNICAL COMMENTS AND CONCERNS REGARDING THE X2 STANDARD

We have compiled a number of technical comments and concerns regarding the Standards base studies, study results, and arguments. These are provided according to general categories of concern.

7.1 ECOSYSTEM LEVEL VERSUS SPECIES LEVEL OF ANALYSIS

- Based on the life history requirements of the species discussed in the report, it would appear that the X2 standard was designed with Delta smelt specifically in mind. Based upon the midwater trawl and summer townet data, the distribution of adult Delta smelt is often highest in abundance (particularly during the late summer and early fall) in proximity to the 2 ppt isohaline. Benefits to Delta smelt are also suggested to be derived from the increased quality of nursery habitat achieved by placement of the 2 ppt isohaline in the vicinity of Suisun Bay (Moyle et al., 1992), although the effects of food limitations to the growth of larval fish in this region have not been substantiated by available data. However, the relationships between X2 and other species are less certain, and existing relationships are only based upon empirical relationships between species abundances and the location of X2. Mechanistic or causal relationships between X2 and other species need to be investigated. The salinity standard needs to be evaluated in the context of its ability to achieve protection of the ecosystem.

- Temporal changes in populations are measured in terms of numbers. It would be instructive to evaluate changes in total biomass for individual habitat guilds (e.g., by family). This might help differentiate relative importance of distinct physical impacts.

- Examination of temporal changes in numbers and biomass within habitat guilds; e.g., look at relative abundance of Delta and longfin smelt, splittail, etc.; Pacific sardine, herring, and northern anchovy; other groups. This consideration was suggested by the fact that there have been long term cyclic changes in sardine and anchovy populations in the Pacific Ocean. Specific population declines or increases may be indicative of longer-term, cyclic trends that are dependent on climatic or other large time scale processes.

7.2 NATURE OF CAUSE AND EFFECT RELATIONSHIPS

- How are the measures of estuarine ecosystem "structure" provided by Jassby either directly or indirectly related to salinity? What is the nature of covariation between X2 and other environmental factors (e.g., water temperature, seasonal discharge, biological periodicity) that may effect variation in the ecosystem values reported by Jassby? Summer and fall Delta outflows have been noted to be higher, and late fall through spring outflows lower, than historically because of water development activities. Time series studies of changes in annual hydrology should be related to changes in fish population assemblages, and sport and commercial fishery catches, to identify trends. The ongoing timeline analysis may be useful for this.

- Relationships between X2 and the large number of organisms in the Bay-Delta are uncertain. Complex relationships are ultimately responsible for shifts in species and life stage abundance.

- Is the variation in ecosystem values reported by Jassby (1992) a total (i.e., global) population response to physiologically limiting conditions imposed by the existing salinity regime, or is it rather a result of spatial and seasonal variation in local population abundance according to the spatial and temporal variation in salinity and other correlated environmental factors (e.g., water temperature, discharge)?

- The review of data generally indicate that changes in marine fish populations have been negligible in the Bay-Delta system, while freshwater populations may have declined somewhat over the last fifteen years or so (circa late 19'70s-1980). If the changes in population numbers and biomass are indeed local to the Bay-Delta region, then freshwater sources and factors other than salinity differences may be important, for example toxicity to irrigation return water. These other factors could still be linked to reduced freshwater input to the system. In other words, X2 could be a weaker, indirect indicator for many species that are more stenohaline. Comparisons to other estuarine systems would be useful for removing more widespread climatic effects from local effects to the populations.

- Trends in white croaker abundance are at present unexplainable in terms of changes to the Bay-Delta ecosystem. Is the increased number of adults associated with an increased amount of high-salinity habitat in recent years? Existing data need to be evaluated to make this determination. Declines in American shad abundance during drought periods may be more directly tied to freshwater spawning and incubation conditions than to entrainment as postulated.

7.3 SAMPLING DESIGN AND EFFICIENCY

One of the reasons given in the Status and Trends Report for using September trawl data to evaluate annual fish population trends was that "data from other months showed effects of the onset of the next rainy season..." What were those effects and how were they suggested by the data? Why were they not reported? Other concerns relate to the extrapolation of trawl data to population data. These will be addressed in Section 8.0 of this report.

7.4 STATISTICAL SIGNIFICANCE OF SPECIES ABUNDANCE VALUES

- Based upon the limitations of existing data, there is a large uncertainty as to the level to which fish and invertebrate abundance can be increased solely by changing the position of X2. Confidence limits should be used to determine the range of uncertainty in derived population benefits.

- There is considerable variability in the abundance indices calculated for aquatic organisms among months within a given year during which samples are acquired, and among years having similar flow conditions. For example, statistical analysis by the Department of Water Resources (1993) indicates that differences in Delta smelt abundance index values for both midwater trawl and tow net surveys are not significant among water year types (wet versus dry), a result of high variation in index values among the years analyzed. The causes and consequences of this variation need to be accounted for.

- Why are Delta smelt abundance levels so high in 1980 for midwater trawl and beach seine surveys, while they are moderate for summer tow-net surveys? The reasons for inconsistencies among different surveys and studies need to be explained before the empirical relationships used to support the X2 standard can be accepted.

7.5 SPATIAL VARIATION OF THE LOW SALINITY ZONE

Total variation from season to season or year to year may be more important than the location of the low salinity zone. This may be particularly true for sessile species (e.g., benthic invertebrates), or organisms which have difficulty "tracking" upstream and downstream migration of low salinity zone (e.g., immature fish).

7.6 DIVERGENT HABITAT PREFERENCES FOR DIFFERENT LIFE STAGES

The complete life cycle of a species must be considered in assessing potential benefits of the X2 standard. Differences in habitat and salinity requirements among different life stages of some species (e.g., longfin smelt) have not been considered in the development of empirical relationships between abundance and location of X2. Because of potentially large differences in salinity tolerances, temperature tolerances, and preferred flows and habitat among different life stages, it will be important to define relationships between X2 and abundance for individual life stages. This is of particular importance for fish which have larval life stages, or those which migrate for reproduction.

8.0 TECHNICAL REVIEW OF FOUNDATIONAL DATA

The California Department of Fish and Game's (CFG) Bay-Delta Project fisheries databases were reviewed in order to assess the validity of predicted benefits of the X2 standard to the biological community of the Sacramento-San Joaquin Delta and upper San Francisco Bay Estuary. The two databases evaluated are the fall midwater trawl database, which includes fish abundance data collected from 1967 to the present, and the summer townet database, which included fish abundance data collected from 1959 to the present. A third fisheries database - the San Francisco Bay Study - has been just recently obtained from CFG and is currently under review. The objective of this data review and analysis is to test a number of hypothesis regarding fundamental statistical and biological relationships between salinity (i.e. the X2 standard) and fish abundance in the Bay-Delta system. Many of the relationships tested are being used by the EPA as a basis or rationale for the X2 standard. In addition to testing some to the relationships which have been used to justify the X2 standard, we reviewed the data to identify potential biases in collection of fish abundance data or in calculating the fish abundance indices which are derived from this data. Review of the CFG databases involved the following steps:

- Determine how fish data were collected
- Identify how abundance indices were calculated
- Identify sampling biases in the fisheries data sets
- Determine if abundance indices used to support the X2 standard realistically portray patterns of spatial and temporal abundance in the San Francisco Bay Estuary and Sacramento-San Joaquin Delta
- Evaluate spatial and temporal patterns of species abundance with respect to outflow and the position of X2.

8.1 SPECIES REVIEWED

Of the eight response variables used by Jassby (1993) to support the EPA's proposed X2 standard, five were based upon data collected in the Estuary and Delta by the California Department of Fish and Game. These five response variables are:

- *Crangon franciscorum* (Bay shrimp), annual abundance index. This index of the Bay shrimp was obtained from Bay Study data collected from 1980 to 1990.

- Striped bass egg survival, 38 mm index (Peterson egg production). This index was calculated from the number of striped bass attaining 38 mm in summer townet samples. This index was calculated for data collected from 1969 to 1991.

- Striped bass, fall midwater trawl index. This annual abundance index was calculated from data collected from 1968 to 1991.

- Starry flounder, annual abundance index. The starry flounder index employed by Jassby (1993) was calculated from Bay Study data collected from 1980-1991.

- Longfin smelt, annual abundance index. The longfin smelt index was calculated from midwater trawl data collected between 1968 and 1991.

Three additional indices were used by Jassby to substantiate the X2 Standard. These include:

- POC supply in Suisun Bay. Particulate organic carbon (POC), expressed as Gg per year, is a measure of annual primary production plus river load of algal-derived organic matter.

- *Neomysis mercedis*, March through November abundance index. The data for this small shrimp, an important food item to many fish including young striped bass, was collected by the Department of Water Resources (DWR) from 1972 to 1988.

- Molluscs in Grizzly Bay, annual abundance (number per sq-m). This mollusc data was collected by DWR between 1981 and 1990.

In reviewing the midwater trawl data, we have determined how the data were obtained, analyzed spatial and temporal patterns in abundance provided by these data for selected fish and crustacean species, and identified the methods used to transform these spatial and temporal patterns of abundance into annual species abundance indices used by Jassby (1993) and the EPA to substantiate the X2 Standard. We examined data for longfin smelt and striped bass, as the abundance indices for both of these species were cited in the Jassby report (1993) as responding positively to the position of X2 in the San Francisco Bay Estuary and Sacramento-San Joaquin Delta. In addition to these two species, we reviewed and analyzed midwater trawl data for Delta smelt, starry flounder, Sacramento splittail, and *Crangon franciscorum* (Bay shrimp). Annual abundance indices for starry flounder and Bay shrimp were also used by Jassby (1993) and the EPA to support the X2 Standard, although the indices for these species were derived from the Bay Study rather than from the midwater trawl. The remaining two species, Delta smelt and Sacramento splittail, were not included in Jassby's analysis but are cited by the EPA (1993) as threatened species which are dependent upon the position of X2 in the Estuary and Delta.

Spatial and temporal abundance data for all six of these species from the midwater trawl data are summarized in monthly abundance maps provided in Appendices A-1 through A-6 of this report (1977-1990). This period of time was selected because of it included two drought periods (1977; 1987-1992), years of having moderate flows (1979; 1980-1981; 1984-1986), and years having high flows (1982-1983). A wide range of fish abundance indices in the Bay and Delta were observed during this time period. These maps provide a concise and effective method for describing the seasonal and year-to-year changes in species abundance and distribution contained in the midwater trawl data.

8.2 SELECTION OF RESPONSE VARIABLES

The seven species employed by Jassby (1993) as "response variables" to support the X2 standard were selected so that "populations at a number of trophic levels would be represented." The resource variables include a measure of primary production (POC), an index of zooplankton production (*Neomysis mercedis*), abundance indices for benthic organisms (*Crangon franciscorum*, Molluscs in Grizzly Bay), and indices for planktivorous (longfin smelt) and predatory fish (striped bass, starry flounder). Consideration for all trophic levels is important for determining the potential benefits of X2 on an ecosystem level, and this seems to be the motivating reason for selection of the response variables in Jassby's study.

One very important set or organisms, phytoplankton feeding zooplankton (including rotifers and copepods) seems to be missing from this analysis. These organisms are important because they represent the critical link between primary production (phytoplankton, POC) and secondary production (invertebrates) in the Estuary and Delta. Enhancement of secondary production is fundamental to the EPA's argument of maintaining the position of X2 at Roe Island from February to June, and is implicit to understanding the reason why higher trophic levels respond positively to X2 during this time period. Filling in this missing gap may provide an important "cause" in the cause-and-effect which seem to be missing in the EPA's rationale for supporting the X2 standard. Consequently, positive and negative relationships between X2 and secondary production in the Bay and Delta system need to be examined before the impacts of X2 on higher trophic levels can be understood.

Also missing from this analysis is a species which has been suggested to have the greatest dependence upon low salinity conditions in Suisun Bay and would consequently benefit most from the X2 Standard: Delta smelt. Analysis of Delta smelt abundance data from the midwater trawl database indicates that the highest abundance of this species often occurs near the location of the 2 ppt salinity zone in the Estuary. This relationship is apparent after examining the spatial pattern of abundance of Delta smelt during September 1980 (Figure 1), a year of peak abundance for this species. The relationship between the X2 position (February through June) and the Delta smelt annual abundance index is not exactly clear (Figure 2), although peak abundance values are observed for X2 values between 60 and 77 km. The spatial distribution of other species (e.g., longfin smelt, *Crangon* shrimp) thought to be related to the position of X2 is much broader than that observed for Delta smelt for the same September 1980 time period (Figure 3). Though the relationship between the annual abundance indices of these latter two species and the February-June X2 position are used by the EPA to support the X2 Standard, relationships in spatial abundance according to salinity are only evident in Delta smelt.

8.3 DATA SOURCES ANALYZED

Three main sources of data are used to calculate describe spatial and temporal trends of fish and crustacean (e.g., *Crangon* shrimp) populations in the Bay and Delta regions. These include:

- *Fall Midwater Trawl.* This survey, conducted by the California Department of Fish and Game, was initiated in 1967. The fall midwater trawl covers the widest area of the three surveys, extending from San Pablo Bay through Suisun Bay, and into the Sacramento-San Joaquin Delta. In the Sacramento River, the midwater trawl survey extends to just downriver of Hood, while on the San Joaquin River the survey extends to just downriver of Stockton. The number of stations included in the midwater trawl survey varies by year, and more stations have been added since 1990 to better sample delta smelt. However, these newer stations are not used to calculate the annual abundance index in order to maintain continuity with indices calculated in previous years. An average of 78 sampling stations have been used throughout this study, with a maximum of 111 stations sampled in any one year. The fall midwater trawl is conducted on a monthly basis from September to December, although sampling during additional months occurred in the early 1970s. Each sample collected in the midwater trawl consists of a depth integrated tow which is conducted for a duration of 12 minutes at a standard engine RPM. The net is first towed along the bottom, and then hoisted to a number of new depths (each for the same period of time) until the entire water column is sampled. This sampling technique is best applied to midwater areas of San Pablo Bay, Suisun Bay, and the Delta, hence the name midwater trawl.

- *Summer Townet Survey.* The summer townet survey was primarily designed to assess striped bass abundance in the Estuary and Delta. This survey incorporates approximately 30 sites which extend from San Pablo Bay (one site only) to the upper Delta. The most upriver site in the Sacramento River is located just above Rio Vista, while the most upriver site in the San Joaquin River is located near Stockton. The

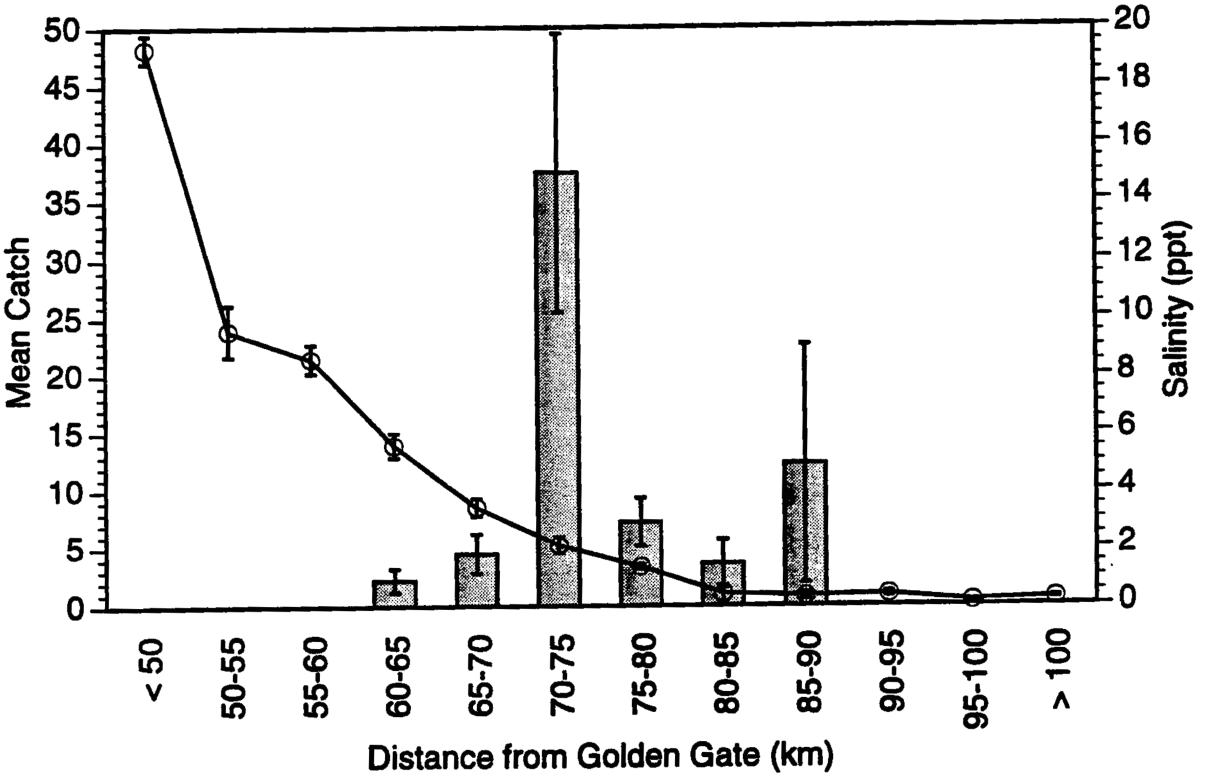


Figure 1. Delta smelt catch values (bars ± SEM) and salinity values (line ± SEM) by river kilometer for September 1980 (source: CFG fall midwater trawl study).

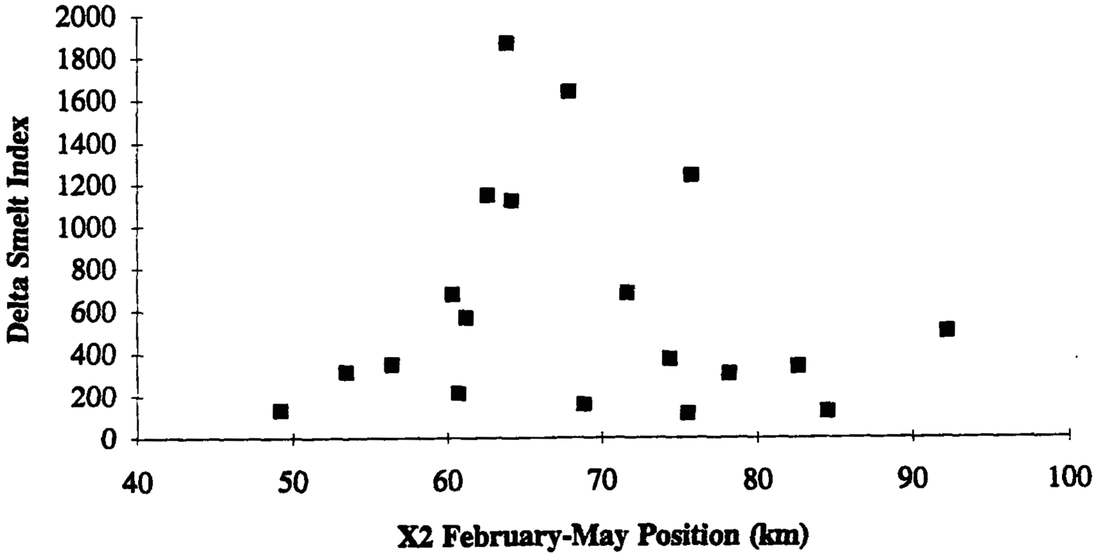


Figure 2. Relationship between Delta smelt annual abundance index (midwater trawl) and position of X2, February through May, 1980.

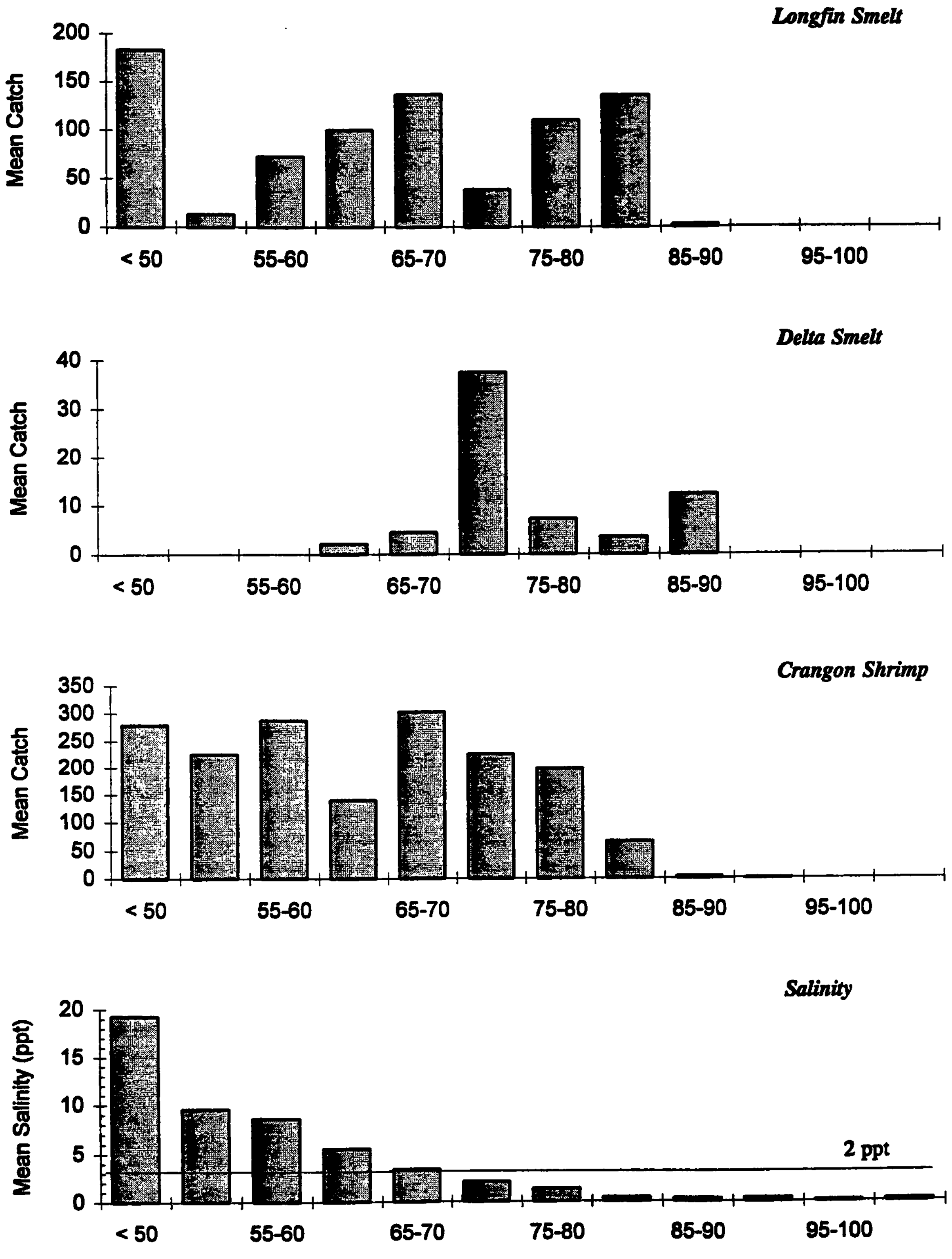


Figure 3. Mean catch of longfin smelt, Delta smelt, and Crangon franciscorum according to river kilometer (from Golden Gate) for September 1980 (source: CFG midwater trawl data).

summer townet survey extends to Clifton Forebay in the southern Delta. Sampling begins in June for a five-day period, and is repeated at two-week intervals until young striped bass attain a length of 38 mm. The survey usually ends anywhere from mid-July to mid-August. The summer tow-net consists of a net mounted on a sled which is held near the bottom during a tow of a set length. Three replicate tows are obtained at each site. The summer townet survey is the longest running of the three fish surveys, as this survey was initiated in 1959.

- *San Francisco Bay Study.* The San Francisco Bay Study is the most recent of the three surveys, and is the most complicated in its sampling protocol. It is also the most comprehensive of the three studies in terms of seasonal sampling, as sampling is conducted every month of the year. This study was designed to determine the effects of freshwater outflows on the distribution of fish, shrimp, and crabs of the San Francisco Estuary, and has been conducted on a monthly basis since 1980. The Bay Study employs a complimentary set of sampling devices, including an otter trawl, midwater trawl, and plankton net, to sample benthic and midwater fish and invertebrate species. This survey includes south, central, and northern sections of San Francisco Bay, extends through Suisun Bay, and terminates near the confluence of the Sacramento and San Joaquin Rivers. A total of 35 sites were originally used to quantify species abundance in open water areas. A total of 13 sites have been added to the original number since 1988. In addition, 27 shoreline sites are sampled with a beach seine, although this sampling program was discontinued in 1987. Also, a total of 12 sites are currently sampled using ringnets to capture crabs. The otter trawl and midwater trawl are towed for a set distance, and the area swept by each net calculated as the net mouth width multiplied by the total distance towed. The otter trawl is towed along the bottom, while the midwater trawl is towed to sample all depths in the water column. Both the otter trawl and midwater trawl are conducted for a 12-minute period at a standard engine RPM. The plankton net is towed for 5 minutes at each site and then retrieved at an oblique angle.

8.4 CALCULATION OF ANNUAL ABUNDANCE INDICES

With the exception of the Suisun Bay POC and Grizzly Bay mollusc density data, all of the response variables used to substantiate the X2 standard are numerical indices based upon abundance data. These index values are useful for comparing spatial, monthly, and year-to-year trends in relative abundance. The basic procedure for calculating these indices is provided below.

1). *Fall Midwater Trawl.* The species abundance indices for the midwater trawl are essentially a weighted mean of the number of fish captured in each sample. The annual index for each species is calculated as follows:

   - Mean catch is calculated for each of 17 subareas located in the Estuary and Delta from the total number of fish captured at each sampling site. Mean catch values for each subarea are calculated separately for each month of sampling. The number of sampling sites per subarea varies, ranging from 1 to 19 sites per subarea. The greatest number and highest density of sampling sites (19) occurs in the Subarea 13, which includes Honker Bay and the upper estuary adjacent to and immediately upstream of Chipps Island. The Suisun Bay area, which is represented by Subareas 12 and 14, has a total of 18 sites. The lower Sacramento River includes 11 sites (Subarea 15), while the lower San Joaquin River includes 12 sites (Subarea 16).

- The mean monthly catch value for each subarea is then multiplied by a weighting factor which represents the volume of water provided by that subarea. This weighting factor is expressed in units of 1000 acre-ft, and varies in value between 2.8 and 20.0. Review of the abundance indices revealed that these weighting factors are assumed to be the same from year to year, although the volume of water occurring in each subarea would be expected to vary according to outflow. Abundance indices have also been developed using the surface area provided by each subarea rather than volume. However, the patterns in yearly abundance resulting from the surface area based index were very similar to those developed from the volumetric weighting factor (DWR 1993).

- For each month (September through December), the volume-weighted mean catch values for each subarea are added to obtain a total monthly index value.

- Lastly, the four monthly index values are then summed to obtain the annual abundance index.

2). *Summer Townet.* The species abundance indices for the summer townet index are calculated in essentially the same manner as the midwater trawl annual abundance indices: mean catch values are calculated on a subarea basis, multiplied by a volumetric weighting factor specific to each subarea, and these are then added to obtain a mean value for each sampling period. In the case of the summer townet data, however, sampling is conducted at two-week intervals instead of on a monthly basis. Moreover, the total number sampling events conducted within a given year is dependent upon the growth of young striped bass, since the summer townet survey is discontinued when these fish attain a length of 38 mm. To maintain consistency from year to year, annual fish abundance indices derived from summer townet data are typically calculated for only the first two sampling periods of the summer.

3). *San Francisco Bay Study.* The methods used to calculate annual abundance indices of species sampled in the Bay Study data are more complicated than those employed for the fall midwater trawl and summer townet data. Unlike the previous two surveys, catch values obtained in the Bay Study are adjusted for the volume of water sampled and net size, as well as the area swept by the net (i.e., mouth width of net multiplied by the distance towed as determined by LORAN-C). The resulting data values are expresses in terms of fish per unit volume (i.e., density) after adjusting for net efficiency, volume of water filtered, and area swept rather than the catch per unit effort as in the fall midwater trawl and summer townet studies. These density values obtained at each sampling site are then averaged and then multiplied by a weighting factor determined by the volume of water provided by the subarea. Resulting subarea index values are then added to obtain a monthly abundance index for each month of the year (Bay Study data is collected during all months of the year). Finally, the annual abundance index for each species sampled in the Bay Study is calculated by averaging monthly index values. Only months where a given species is known to be present within the area covered by the Bay Study are included in calculating the annual abundance index.

8.5 POTENTIAL BIASES IN DATA AND INDEX CALCULATION

At this time, only the midwater trawl database has been reviewed for potential biases in sampling and in calculation of species abundance indices. These data were used by Jassby (1993) to support the X2 standard.

A number of factors potentially resulting in systematic biases to the yearly abundance indices were reviewed in order to determine whether or not the data values used by Jassby (1993) were both valid and realistically portrayed actual spatial and temporal patterns in population distributions in the Estuary and Delta. We recognize that sampling bias and error is an unavoidable part of field sampling programs. Fortunately, the spatial and temporal patterns or trends observed in the field are often pervasive to the point where the effect of sampling biases and error are extremely small or insignificant. Though the fall midwater trawl and summer townet studies were designed primarily to evaluate striped bass populations in the Estuary and Delta, they provide important information regarding spatial and temporal patterns in abundance for many other species as well. The objective of our review was not to question or criticize the intent or validity of these important data collection programs. Instead, our objective was to identify potential biases in the data (or in the calculation of abundance indices) which might substantially lower the level of confidence in these annual abundance values used by Jassby (1993) and the EPA in validating the X2 Standard.

Review and analysis of species abundance patterns contained in the midwater trawl data identified two important characteristics which have an extremely important influence on the value of annual abundance indices. These are: 1) the frequency distribution of the catch data; and 2) the spatial arrangement of the catch data.

The frequency distribution of catch data for most species can best be described by a Poisson distribution, with the greatest number of samples having relatively low catch values, and relatively low number of samples having high catch values. For example, Delta smelt are generally found to be in low abundance (<10 fish) at most sites sampled. However, a limited number of samples will contain higher numbers of fish (>20), and a few will contain very high numbers of fish (>60) relative to other samples. The annual abundance indices for fish species are often driven by a only a few high abundance observations. For some species included in Jassby's (1993) analysis (e.g., longfin smelt, annual abundance indices in some years are substantially elevated in only one or two extremely high data points. Consequently, the abundance indices must be used with caution, as these indices may better reflect the presence of high concentrations of fish in a limited number of areas rather than overall trends in fish abundance for a given time period. Samples containing high numbers of fish are probably a result of the trawl net being towed through a large school of fish, so the actual value for many of the annual abundance indices may reflect the success in "hitting" the large schools or localized concentrations of fish.

The spatial arrangement of catch data for many species can be best described as a "contagious" distribution using statistical terminology. This means that fish are often found to be highly concentrated in only a few areas, or are found to be clustered in a number of different areas, rather than being evenly or randomly distributed over the entire region sampled. This abundance pattern could arise in two ways: 1) fish prefer certain habitats and water quality conditions and are consequently found in these locations; and 2) fish are more susceptible to capture in certain areas. Abundance patterns resulting from preferences for habitat and water quality conditions are apparent for species such as the Delta smelt (see Appendix A-3), which are often found to be highly congregated near low salinity regions in Suisun Bay in wet years, and in the lower Sacramento River channel during dry years. Abundance patterns resulting from susceptibility to capture is probably best illustrated by large changes in population abundance observed from one month to the next within a given year for some fish species (e.g., longfin smelt, Appendix A-1). Their abundance index was relatively low during some months, but high during other months. This suggests that susceptibility to capture changes from month-to-month, assuming that the population is not actually changing during this time period.

Review of the midwater trawl catch data identified a number of biases which could potentially distort or confound the abundance indices used to support the X2 standard. These are described below.

1) *Area Sampled*

Some of the abundance indices used by Jassby (1993) will substantially underestimate actual abundance if part or all of the population moves outside of the area surveyed.

Three species used by Jassby, notably *Crangon franciscorum*, longfin smelt, and starry flounder, will move outside of the area used to calculate abundance indices on a seasonal basis or during certain flow conditions. When this occurs, the abundance indices will underestimate actual abundance levels. The CFG Bay Study, used to derive the annual indices for *Crangon franciscorum* and starry flounder, only extends to the confluence of the Sacramento and San Joaquin Rivers. Examination of midwater trawl data indicate that these species will move into the Sacramento and San Joaquin river channels during dry years (see Appendix A-4 and A-5). When this occurs, a portion of the population essentially moves outside of the boundaries of the Bay Study, which is used to derive the abundance indices used by Jassby for these species. Subsequently, this will result in the underestimation of actual abundance values for these species during dry years. Another example is provided by longfin smelt, which will move from San Pablo Bay and Suisun Bay into central and southern San Francisco Bay during certain times of the year or under high flow conditions. Abundance indices derived from midwater trawl data will underestimate actual populations given this type of migration, as the midwater trawl survey area only extends as far as upper San Pablo Bay.

This source of bias may help explain the large changes in species abundance which often occur from one month to the next within a given year. This source of bias could be better identified by comparing patterns of abundance and distribution between the midwater trawl and Bay Study data sets on a year by year basis.

2) *Sampling Intensity and Population Dispersion*

The accuracy of the annual abundance indices calculated from the midwater trawl and summer townet data is dependent upon the number of replicate samples obtained from each subarea. Because the number of replicate values sampled in each subarea varies, the accuracy of the mean value calculated from each subarea also varies. The number of replicate samples employed in calculation of midwater trawl abundance indices varies from 1 to 19 per subarea. Since the subareas also vary greatly in volume of water represented, comparison of the absolute number of replicate samples may not be as important in terms of accuracy as the density (i.e., samples per unit area) of replicate samples used. In this regard, the most accurate abundance estimates are probably those obtained in the region of the Estuary and Delta between the Carquinez Straits and the confluence of the Sacramento and San Joaquin rivers (including Suisun Bay, Honker Bay, and Chips Island). This region has the highest density of sampling sites. The least accurate abundance estimates may be obtained in the northern, central, and southern portions of the Delta, as sampling locations in this region are the most widely dispersed.

In addition to sampling intensity, the spatial pattern of species abundance may greatly influence the value of annual abundance indices. This is because high concentrations of sampling locations may be more effective in capturing schools of fish, or fish which have a "contagious" or "patchy" distribution, than sampling locations which are widely dispersed. This may have an important influence on the value of annual abundance indices, since annual abundance values for some key species are influenced by a few high abundance samples, which tend to raise mean values for a much larger number of low abundance samples.

The annual abundance index values are also expected to better reflect actual population values when samples are collected at locations where fish are present. In many cases, certain species may move to areas or habitats which are not well sampled by a particular method (e.g., midwater trawl). For example, if fish move into shoal areas or other edge habitats which are not effectively sampled by the midwater trawl, then abundance indices derived from this method will substantially underestimate actual population trends. A good example of a species abundance index value which may be influenced by this type of capture efficiency bias is provided by the Sacramento splittail. Reviewing of spatial abundance data (see Appendix A-6) suggests that high abundance values may be correlated to characteristics of the sampling location, as higher values are typically observed along confined area (Carquinez Straits, within shoals and inlets) when compared to samples obtained in more open areas.

The concentration of sampling sites in different subareas may also have another important influence on potential relationships between species abundance and salinity in the Estuary and Delta. The highest concentration of sampling sites in the midwater trawl and summer townet surveys occurs in the vicinity of Suisun Bay. This is the region of the Estuary and Delta which is most likely to experience low salinity conditions favored by estuarine fish and invertebrates. More fish are potentially sampled in this region compared to other regions because more sampling effort is expended in this area. Without correcting for sampling effort, it would appear that fish favor the salinity values provided by this area of the Delta when in fact this could be an artifact of more intense sampling in this region.

To test this idea, we evaluated the utilization of Delta smelt according to salinity before and after correcting for sampling effort. We first calculated a frequency distribution of Delta smelt abundance according to salinity, with each individual fish counting as an observation of use for a given salinity value (Figure 4). The resulting frequency distribution best resembles a Poisson distribution, with the greatest number of fish observed at near freshwater conditions, with a gradually declining number of fish observed at higher salinity values. The mean value for electroconductivity obtained from this frequency distribution is 3750 microSiemens/cm, value corresponding to 2 ppt salinity. This essentially replicates the method used to identify the 2 ppt mean salinity value used by Delta smelt which has been cited in previous studies. We then corrected this frequency distribution for sampling effort by dividing each frequency observation (bin) by the total number of samples used to obtain that observation. This resulted in a frequency distribution which was considerably different from the first (Figure 5), which suggested a much wider tolerance for electroconductivity (i.e., salinity) than that provided by the uncorrected frequency distribution.

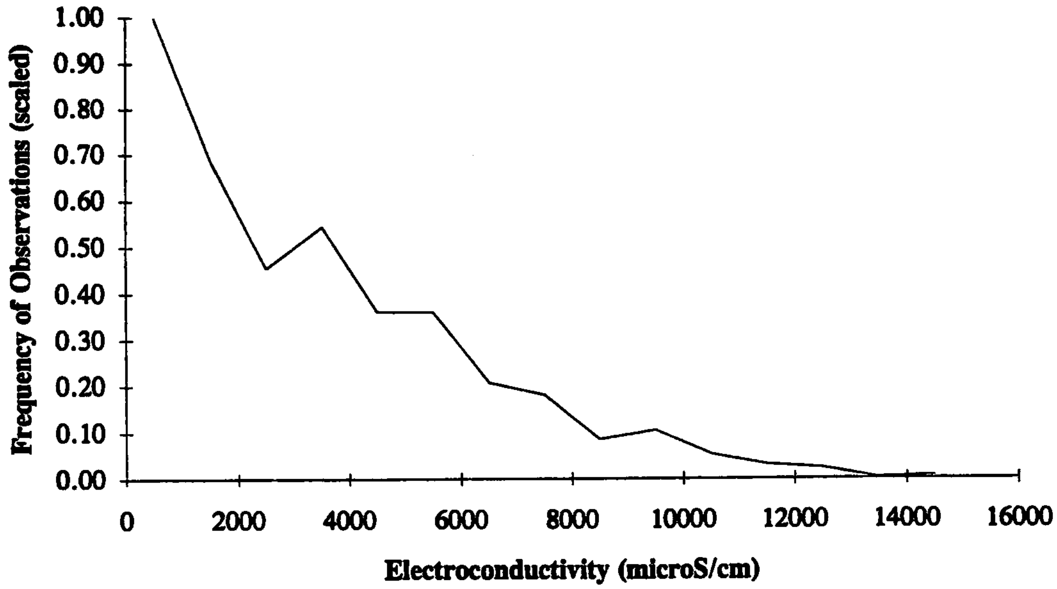


Figure 4. Delta smelt abundance frequency curve for electroconductivity prior to adjusting for sampling effort, September 1967-1992 (source: CFG fall midwater trawl).

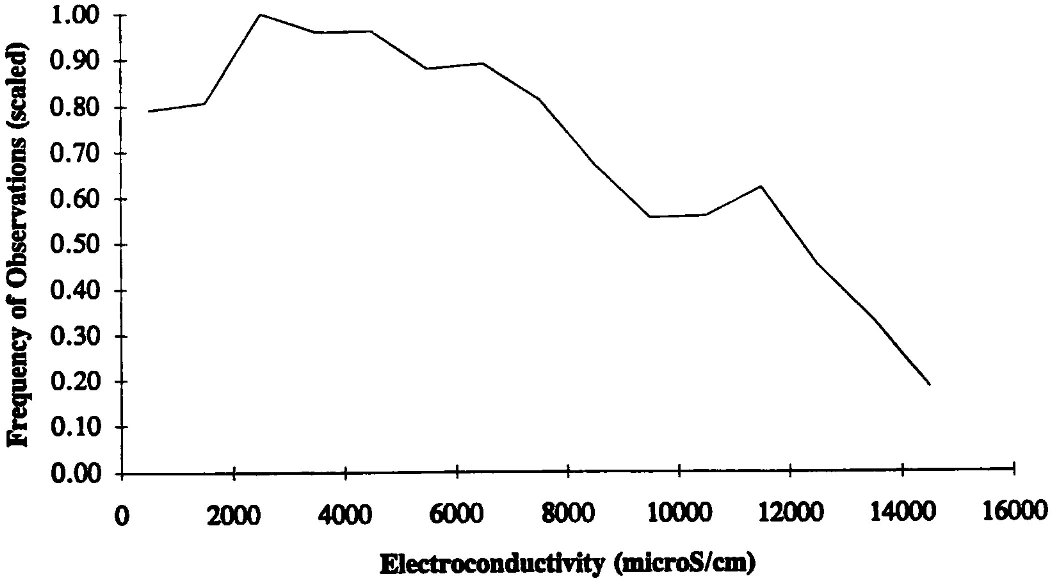


Figure 5. Delta smelt abundance frequency curve for electroconductivity after adjusting for sampling effort, September 1967-1992 (source: CFG fall midwater trawl).

3) *Time of Year*

Considerable variation was observed in monthly abundance values within any given year for most species reviewed (see Appendix A-1 through A-6). As mentioned previously, this monthly variation could be due to: 1) movement of fish outside the boundaries of the survey, 2) changes in sampling efficiency from one month to the next, or 3) actual fluctuations in population. Movement of fish outside the boundaries of the survey area would partially explain trends observed species such as longfin smelt and starry flounder which have been known to move into central and southern San Pablo Bay. This would, however, not explain monthly changes observed in midwater trawl data for fish which remain within the survey areas (e.g., Delta smelt). Changes in actual population levels is not a very plausible explanation, as mortality among the fall months included in the midwater trawl survey is not expected to be high. Moreover, population levels which dramatically increase from one month to the next cannot be easily explained by this hypothesis, unless recruitment to a size class of fish which was more easily captured occurred during this time period. The most likely explanation for month-to-month fluctuations in populations levels is changes in sampling efficiency. Such changes might be caused by seasonal shifts in fish behavior, location, or environmental factors such as turbidity or temperature that vary on a monthly basis and would influence capture efficiency.

4) *Time of Day*

Analysis of a number of environmental variables obtained in the midwater trawl survey (i.e., time, turbidity, sampling depth, tidal current, and boat speed) are summarized in Appendix B-1 through B-8. Of the possible environmental factors that would bias abundance data, time of day was found to be the most significant. Fish species for which the time of day was found to influence abundance values include the longfin smelt, striped bass, delta smelt, and starry flounder. The influence of time of day on delta smelt abundance was found to be the most important, and occurred primarily during dry years. Two examples are provided by Delta smelt catch data for 1989 (Figure 6) and 1990 (Figure 7), two drought years. Peak abundance values during both years were highest during the early morning hours (6-8 a.m.), but gradually declined as the day progressed. Similar patterns were observed in striped bass for 1989 (Figure 8) and 1990 (Figure 9), although these were not as clear as those observed for Delta smelt.

To test the effect this bias might have on abundance index values, we calculated mean catch abundance as related to time of day and by river distance (Figure 10). Two mean abundance values were calculated, one for the entire day, and the other using catch data collected only before 10:00 a.m. The results of this analysis indicate that the source of bias is greatest upstream of the confluence of the Sacramento and San Joaquin Rivers. The effect that time of day has on Delta smelt abundance values is most apparent during low flow years, and progressively becomes less important during years of increasing flow (Figure 11). One possible explanation for this effect is a decreasing catch efficiency for Delta smelt by the midwater trawl as water

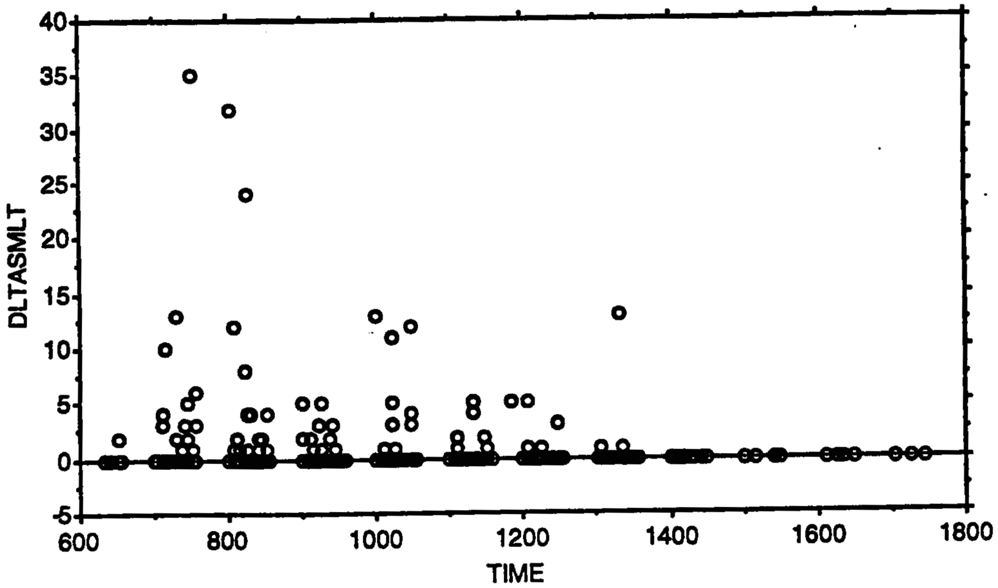


Figure 6. Catch of Delta smelt in midwater trawl by time of day, September-December 1989.

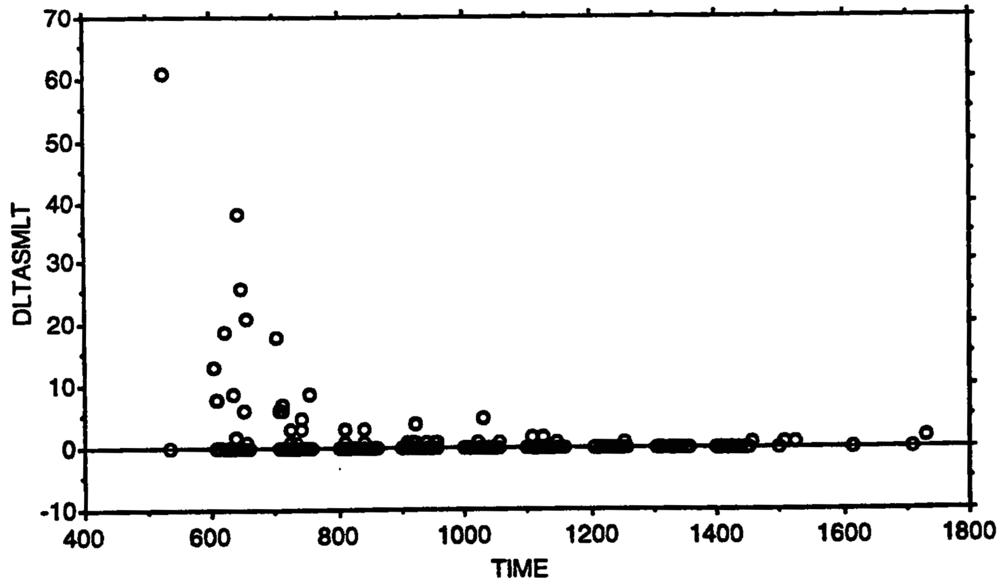


Figure 7. Catch of Delta smelt in midwater trawl by time of day, September-December 1990.

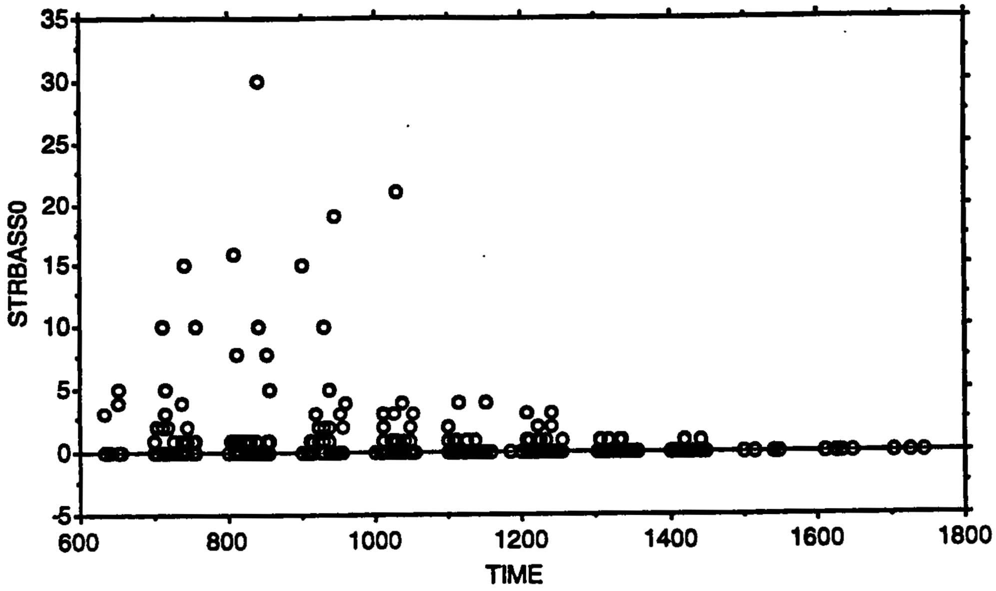


Figure 8. Catch of striped bass (age 0+) in midwater trawl by time of day, September-December 1989.

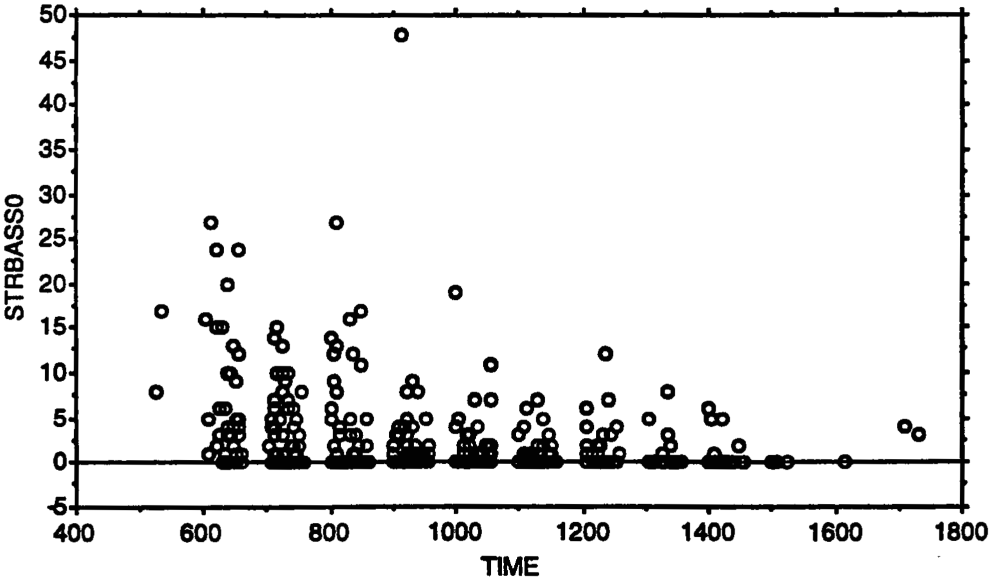


Figure 9. Catch of striped bass (age 0+) in midwater trawl by time of day, September-December 1990.

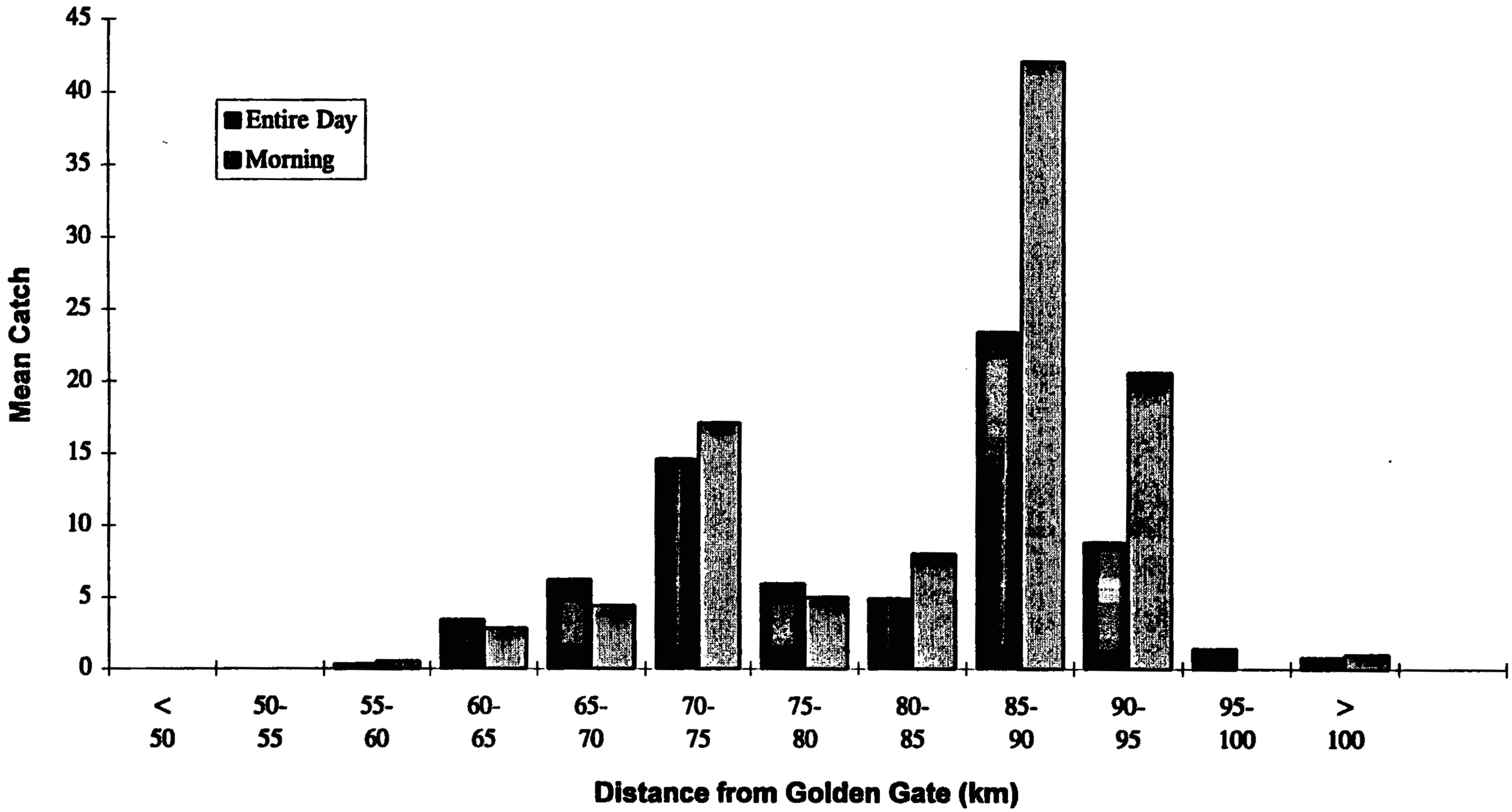


Figure 10. Delta smelt mean catch values by distance calculated from all samples obtained during day, compared with those calculated from early morning samples only (before 10:00 am); (source: CFG midwater trawl data).

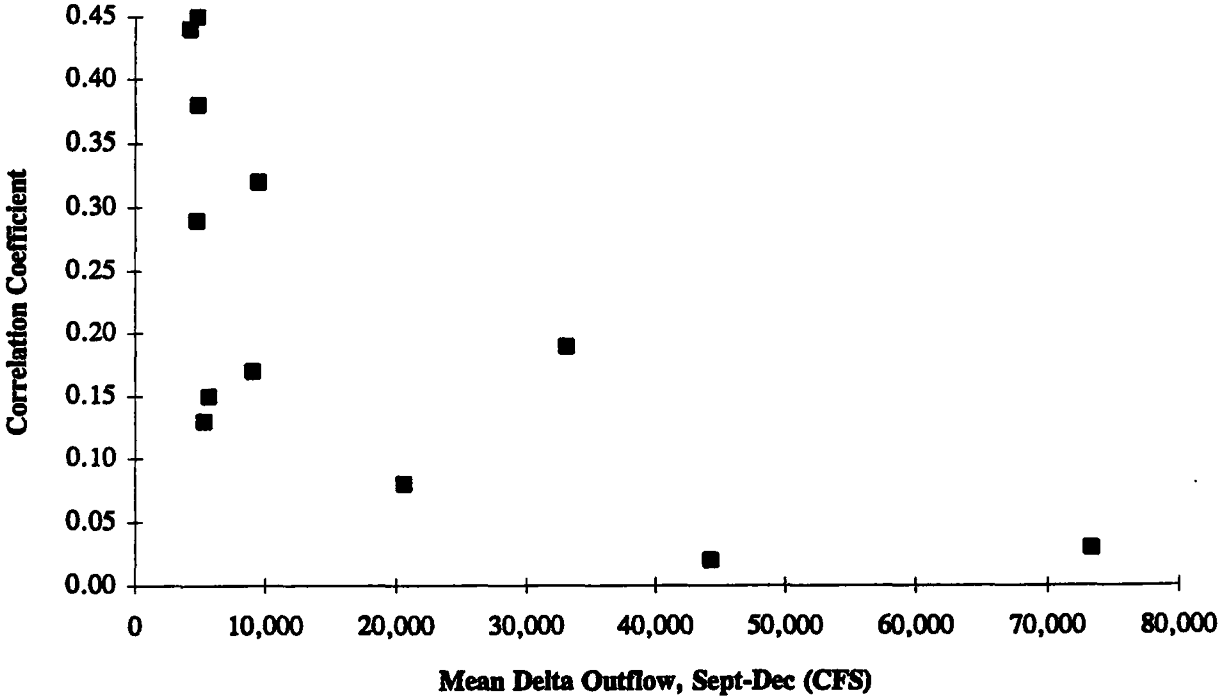


Figure 11. Correlation coefficient values for Delta smelt catch and sampling time as a function of mean Delta outflow (based on 1980-1991 midwater trawl samples). Higher correlation coefficient values indicate that the association between Delta smelt catch values and time of day is becoming greater.

becomes more clear. Water typically becomes more clear in an upriver direction. Water clarity in the Delta also increased during the drought of the late 1980s, possibly as a result of lowered phytoplankton productivity. We further hypothesize that Delta smelt may avoid clear water with increasing daylight in order to minimize vulnerability to predation.

The influence of time of day is not consistent among all the species examined. For example, catch abundance appears to peak during at 11:00 a.m. for longfin smelt (Appendix B-1), and at 10:00 a.m. for Sacramento Splittail (Appendix B-5).

5) *Turbidity*

Turbidity may be another factor influencing catch abundance values in the midwater trawl data. Delta smelt, for example, were generally found in higher abundance at higher turbidity levels in 1989 (Figure 12) and 1990 (Figure 13). Increasing abundance with increasing turbidity (expressed as declining secchi disk depths) was also observed in longfin smelt (Appendix B-1), striped bass (Appendix B-2), starry flounder (Appendix B-4), splittail (Appendix B-5), and Crangon shrimp (Appendix B-6). Observed relationships between turbidity and catch abundance may be explained by increasing vulnerability to capture in more turbid water. However, this relationship for many species (i.e., starry flounder, Delta smelt) may be explained as a preference for low salinity conditions in the Suisun Bay where turbidity tends to be higher than in other areas. Turbidity values also appear to be correlated to the time of day, as turbidity gradually decreases (secchi depth measurements become higher) as the day progresses (Figure 14). The cause for this relationship is unknown, but could be attributed to periodicity of phytoplankton in the Delta and Estuary, or because the surveys are conducted in an upstream direction during the day.

6) *Sampling Depth*

Abundance values for several species appeared to be higher at certain sampling depths employed in the midwater trawl (Appendix B-1 through B-8). For example, Delta smelt abundance values appeared to be higher when the bottom depth is approximately 30 ft. We concluded that, although depth may bias data collected within any given subareas, it probably does not influence the comparison of abundance values among different subareas. This is because the range of depths sampled in most subareas is similar, precluding a systematic bias in abundance estimates among these areas.

7) *Tidal Current*

Midwater trawl samples were obtained at high slack tide, ebb tide, low slack tide, and flood tide. Analysis of the midwater trawl data revealed that most samples were obtained at either ebb tide (39 percent) or at flood tide (58 percent). Further evaluation of data using Analysis of Variance (ANOVA) indicates that abundance values were not significantly related to tide levels for any of the species examined.

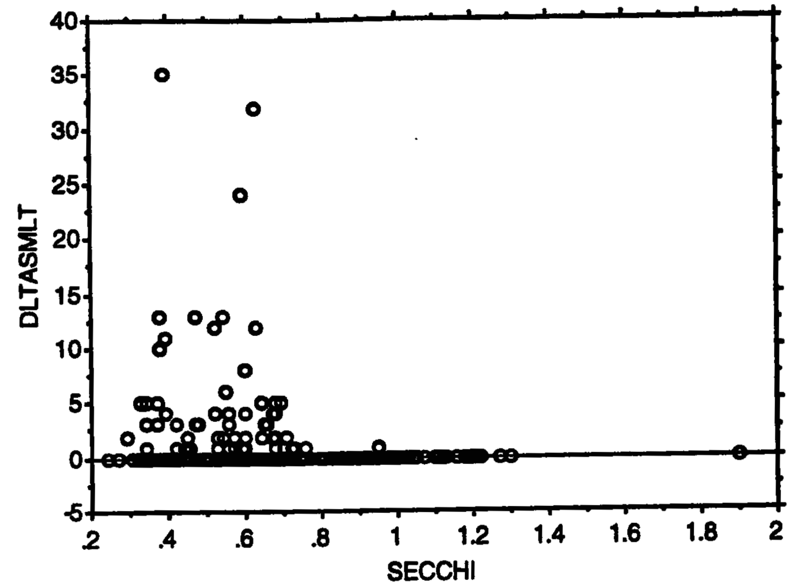


Figure 12. Catch abundance of Delta smelt in midwater trawl by secchi disk depth (meters), September-December, 1989.

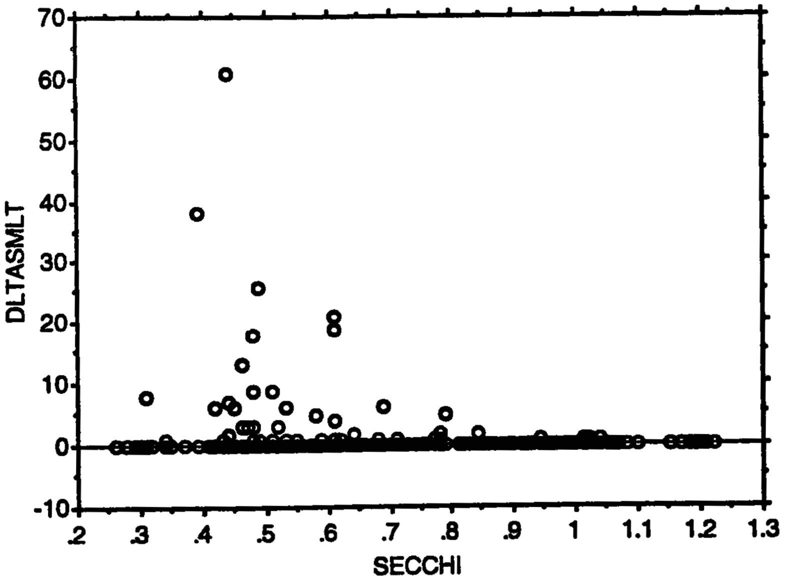


Figure 13. Catch abundance of Delta smelt in midwater trawl by secchi disk depth (meters), September-December, 1990.

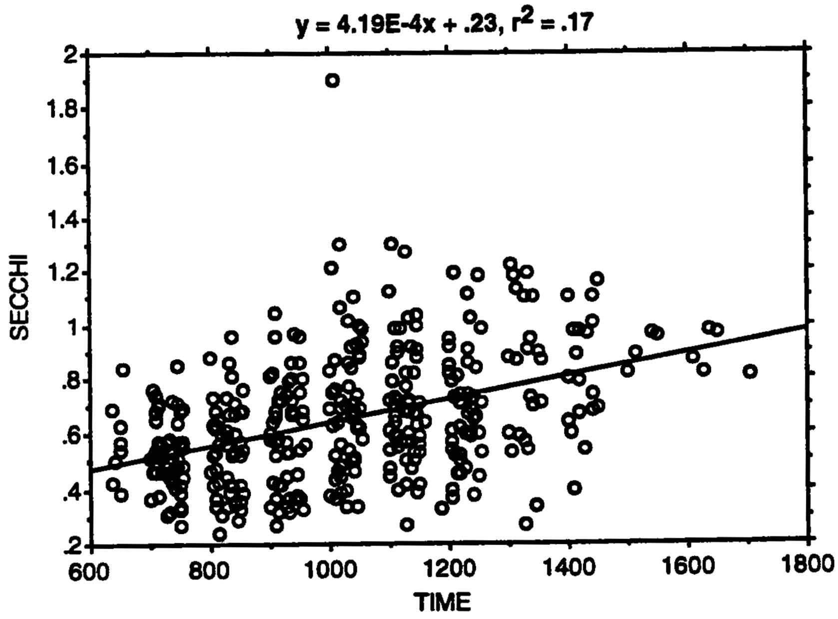


Figure 14. Correlation between secchi disk depth (meters) and time of day for 1989 midwater trawl survey data (source: CFG midwater trawl study).

8) *Volume Sampled*

The total volume of water flowing through the trawl net was collected during the latter years of the midwater trawl survey. As mentioned previously, catch data in the midwater trawl survey is not corrected for the volume of watered filtered through the net. Correcting data for this prior to 1982 would not be possible, since flow data was only collected after this year. Examination of the relationship between catch abundance and volume of water filtered through the net (Appendix B-1 through B-6) did not indicate that this systematically biased abundance data for those species reviewed. The effect of the volume of water passing through the net on abundance is illustrated using Delta smelt. Delta smelt abundance was found to be highest at intermediate volumes of water filtered through the net (as indicated by flow meter reading; Figure 15). This type of bias would tend to reduce the accuracy of the abundance indices.

9) *Sample Size*

One factor which may have a very important effect on mean abundance values is the total number of sites where each species is captured. The total number of sites where a given species is present (i.e., the sample size) varies on a seasonal and yearly basis. Although the abundance index values are generally assumed to reflect populations in the Bay and Delta, it is important to consider that the actual populations of fish sampled in the midwater trawl, summer townet, and Bay studies is unknown. Consequently, there is considerable uncertainty as to the extent to which these abundance indices actually reflect temporal and spatial patterns in actual population numbers.

From a statistical viewpoint, this uncertainty increases as the number of observations obtained within any given sampling period decreases. Those species which are present more frequently in samples, and for which abundance index values have a higher degree of certainty, include the longfin smelt, striped bass, and Crangon shrimp. These species can typically be found at 30 or more sampling sites in the midwater trawl database per monthly sampling period. Delta smelt are found less frequently in the midwater trawl and summer townet samples, and typically are found at 20 or more sites per month, per sampling period. Consequently, there is greater uncertainty as to how well Delta smelt abundance values portray actual population values. Starry flounder and splittail are relatively rare in midwater trawl samples, as these fish are typically found at less than 10 sampling sites, and are sometimes totally absent from monthly midwater trawl samples. There is a high degree of uncertainty as to whether the abundance values for these fish portray actual populations.

10) *Subarea Weighting Factors*

The effect of the subarea weighting factors on annual abundance values was reviewed by calculating annual abundance index values both with and without this weighting factor. In addition, two alternative annual index values were calculated using the

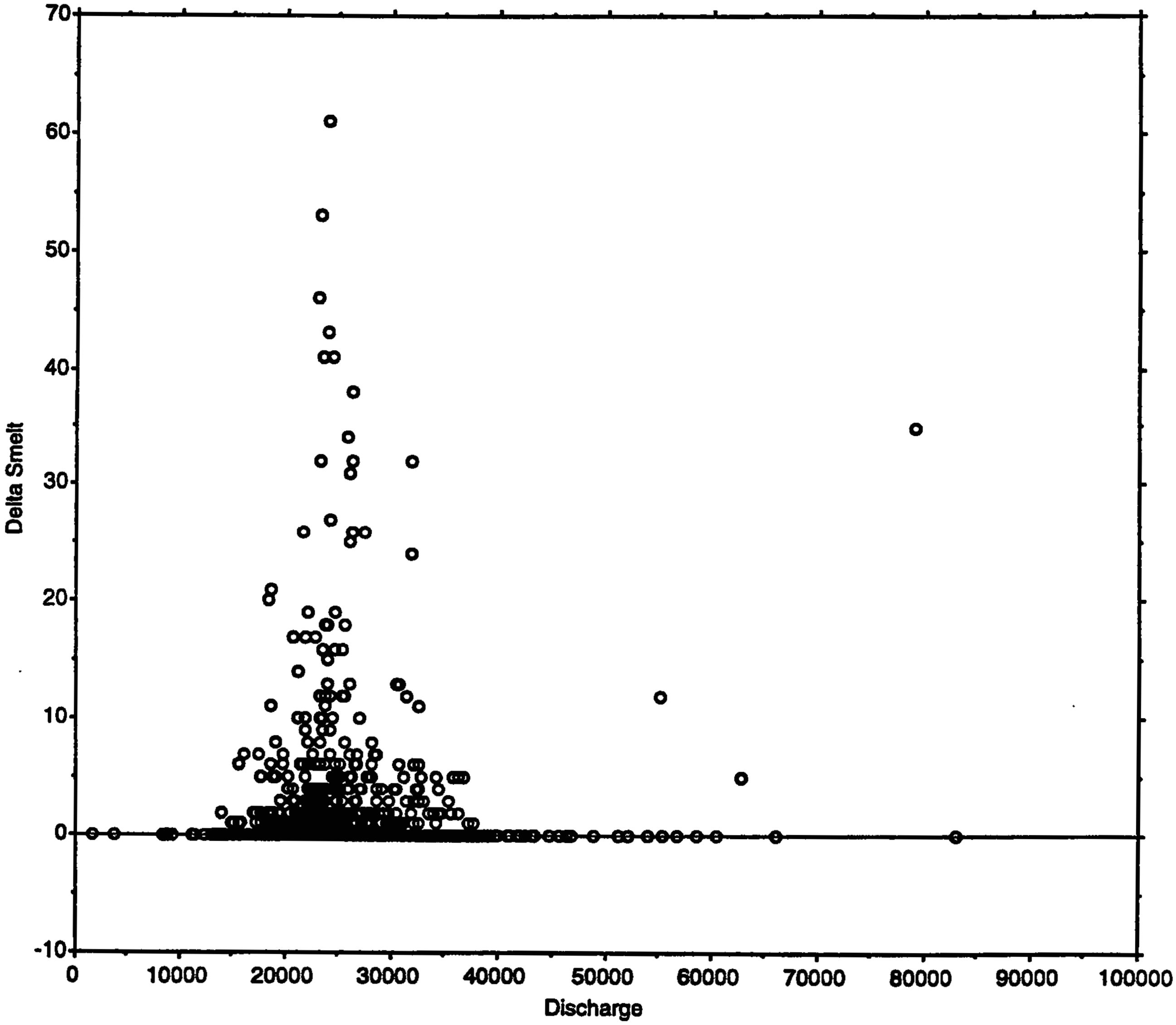


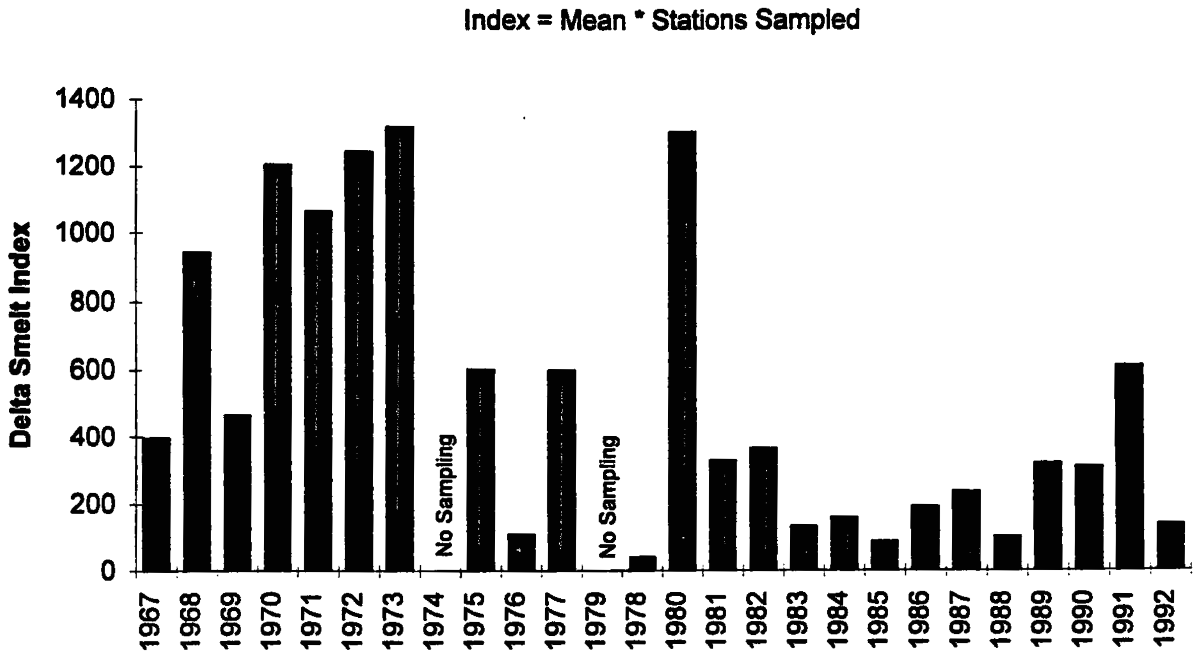
Figure 15. Catch of Delta smelt by volume of water (meter reading) sampled in midwater trawl (source: CFG midwater trawl study).

mean and median values for Delta smelt abundance based upon only those sites where these fish were found (Figure 16). A comparison of the different index values showed nearly the same yearly trends as indicated by the original annual abundance index. After completing this analysis, we concluded that the weighting factor did not distort yearly trends in abundance observed in the midwater trawl data.

8.6 CONCLUSIONS OF DATA REVIEW

We have completed a preliminary review of the California Department of Fish and Game's fish data and the data and methodologies used for the annual abundance indices by Jassby (1993) and the EPA (1993) in the development of the X2 standard. Our effort concentrated on analyzing the midwater trawl database. Only two of eight indices used by Jassby (1993) are derived from this database: longfin smelt and striped bass. However, the midwater trawl survey data represent the most comprehensive source of fisheries data available for the brackish water and freshwater habitat areas in the San Francisco Bay and Sacramento-San Joaquin Delta which are likely to be affected and potentially impacted by water quality conditions imposed by the X2 standard. Review of spatial and temporal patterns of species abundance from the midwater trawl data provides important information on the extent to which various fish species will benefit, be adversely impacted, or not be affected at all by the X2 standard. Conclusions from our current review of the data are as follows:

- Considerable spatial and temporal variability is present in the data used to derive annual abundance indices for species used to support the X2 standard. Most species can be described as having a "contagious" or "patchy" distribution, which is responsible for much of the spatial variability observed in these data. As a result of the spatial and temporal variability intrinsic to fish abundance data, some degree of uncertainty exists as to how well the abundance indices reflect actual species populations in the Bay and Delta. This level of uncertainty increases for species with moderate but widely dispersed populations, including the Delta smelt, starry flounder, and especially the splittail. Consequently, considerable caution should be exercised in assigning validity to the annual abundance values used to support the X2 standard.
- Several sources of bias have been identified after examination of the data, including those attributed to time of sampling during the day, time of sampling during the year, depth, turbidity, and population dispersion. Several of these sources of bias may lead to a significant underestimation of fish populations under certain conditions, and overestimation of fish populations under other conditions. For example, Delta smelt populations appear to be underestimated during drought conditions present in 1988-1991 due to decreasing catch efficiency related to the time of day. Abundance indices for many species, including Crangon shrimp, Delta smelt, longfin smelt, and starry flounder often decrease when populations attain a wider spatial distribution. Changes in these indices may be a result of fish leaving the midwater trawl study area (e.g., longfin smelt migrating into the central bay), or moving into habitat areas where catch



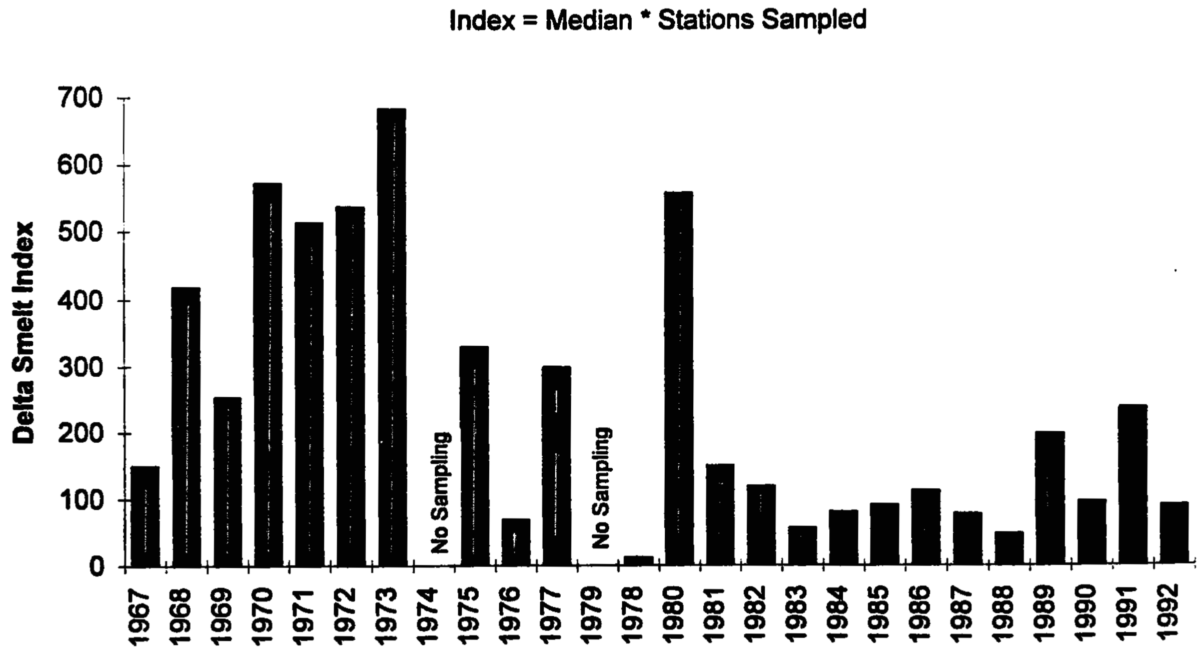


Figure 16. Comparison of alternative annual abundance indices for Delta smelt, 1967-1992 (source: CFG midwater trawl study).

efficiency is lowered. Overall year-to-year trends in population suggest indices appear to be real, even after giving consideration to these sampling biases.

- Certain species of fish are so rare in the surveys that few conclusions can be reached regarding their relationship to salinity or the position of X2. Splittail are probably the best example of a species implied as "X2" dependent but for which very little data supporting this assertion exists.

- The spatial distribution of fish reviewed in the midwater trawl data do not appear to be associated or dependent upon the location of X2, as their distribution is either widely distributed over a broad range of salinity conditions, or is concentrated within salinity conditions which are above or below X2. An exception to this is the Delta smelt, which appears to concentrate in the vicinity of X2 during certain times of the year (especially late summer and early spring).

- Although several sources of bias have been identified in the review of the midwater trawl data, these likely do not seriously distort the overall annual trends in species abundance suggested by these data. The differences in the magnitude of the annual abundance index values observed from 1967-1993, as well as the number of samples for which species are present, are sufficient to strongly indicate that major changes in species populations have occurred during this period. Hence, we conclude that the trends observed in the annual abundance index values are real. However, provided the statistical uncertainty surrounding the annual abundance index values, as well as the sources of bias identified as affecting these values, empirical relationships developed from the data must be regarded with considerable caution.

9.0 FURTHER INFORMATION NEEDS

There are numerous gaps in the understanding of how the proposed X2 standard will benefit or impact the abundance of species in the Delta. Some of the information needs we have identified after reviewing selected studies and reports are identified below.

- Reductions in abundance along all trophic levels of major taxonomic groups at different locations suggest that widespread environmental problems are present at the ecosystem level, rather than occurring to just a few euryhaline species.

- Is the health of the estuarine ecosystem related to the total flow and spatial extent of low salinity habitat, or is it more related to the exact timing of specific salinity conditions for specific locations in the Bay-Delta region? If the latter is true, then the X2 standard may not address the range and timing of salinity conditions required to maintain "health" of specific locations or estuarine ecotypes.

- What are cause and effect relationships between salinity and estuarine ecosystem structure and function?

- What are cause and effect relationships between X2 and fish populations? Are "abundance" and "survival" estimates presented in the Schubel report measured for the total population in the Bay-Delta system or for numbers at (a) reference location(s)? Is the variation in biological resource values reported by Jassby a total (i.e., global) population response to physiologically limiting conditions imposed by the existing salinity regime, or is it rather a result of spatial and seasonal variation in local population abundance according to the spatial and temporal variations in salinity and other correlated environmental factors?

- It is assumed that to be a meaningful standard the salinity conditions maintained by X2 will have a beneficial impact to the total population of target species of fish, forage items, and estuarine vegetation of the Bay-Delta ecosystem. In many cases, the observed variation in ecosystem values may be a result of spatial variation in the population according to shifting environmental conditions, rather than to a numerical response in the total population to X2 and environmental factors directly or indirectly related to this standard. Consequently, it will be important to differentiate correlation and causality with respect to observed relationships between X2 and the biological resources reviewed by Jassby in order to determine if X2 will become a biologically meaningful standard. Is there any evidence that changes in water withdrawals used to maintain X2 standards will positively affect the Bay-Delta estuarine ecosystem? (Note: this is the most important and fundamental question of all). As stated by Schubel, "what are the associated biological benefits" of employing the X2 standard?

- How are the measures of estuarine ecosystem "structure" provided by Jassby (1992) either directly or indirectly related to salinity? What is the nature of covariation between X2 and other important environmental factors (e.g., water temperature, seasonal discharge, biological periodicity) that may affect the biological resource values reported by Jassby? Could other factors (e.g., water temperature) indirectly related to salinity be responsible for variation in values provided by Jassby?

- What is the annual variation in surface/near-bottom salinity ratios? Why is near-bottom salinity "more stable"? Is there non-negligible vertical stratification, and if so, do the species of interest live near the bottom or near the surface?

- What are the effects of drought and peak flows on species abundance? There is an important need to differentiate the effects of drought from those of diversion and export. To what extent would a species (e.g., Delta smelt) be reduced in abundance, given the impacts of drought alone?

- How much of an increase in Delta smelt populations and other species will be realized from X2 standard under drought conditions of the 1980s? It is evident that the implementation of a standard such as the X2 standard was exacerbated by the severe drought which occurred in California in the 1980s. It is difficult to determine what impact water withdrawals alone have on species abundance, since impacts of drought were widespread. Drought conditions alone could have caused reductions in abundance for many of the Delta species. There is little doubt that water withdrawals elevated the impacts of the drought, however, it is difficult to distinguish the impacts of diversions themselves without a causal or mechanistic understanding.

- What are the most important factors limiting abundance? Actual causes for declines in biotic abundance by any one factor have not been proven, though a number of causes are suspected. Food availability, salinity tolerances, and competition from introduced species may be chief limiting factors for some species. Sources of mortality throughout the Bay and Delta Region need to be identified. Predictions of X2 cannot be made unless causal relationships are determined between flow, salinity, and species abundance.

- What are the relationships between X2, flow reversals, and entrainment potential?. Relationships between different X2 locations and impacts of reverse flows into the Delta need to be determined. X2 is assumed to be a surrogate for entrainment and flow reversal impacts to Delta fish, but relationships between X2 and pumping are not well defined except at upper limits of X2 (above Chipps Island). Striped bass egg and larval index declines are attributed to entrainment and predation losses at the CVP and SWP pumps and in Clifton Court Forebay. It is possible that losses were also due to salinity changes during the critical period (i.e., insufficient habitat available with the correct salinity). The eggs are deposited in fresh water and drift downstream during development. It is the larvae that enter the brackish estuarine water. This form of mortality would be related directly to the X2 standard. Methods of estimating losses should be evaluated for bias and precision. Moyle et al. (1992) noted substantial increase in days per year in which reverse flows occurred from 1985 to 1989 and suggested that this was an important factor affecting Delta smelt populations. The highest frequency of reverse flows occurs within the spawning grounds during spawning season. Interference of spawning, entrainment of eggs and planktonic larvae, and increased susceptibility of planktonic larvae to predation (e.g., silversides) are the most probable mechanisms by which reverse flows reduce Delta smelt populations.

- Total entrainment estimates of Delta smelt larvae by the State Water Project and Central Valley project ranged from 579 thousand fish in 1989 to 1.2 million fish in 1992. The total proportion of total larval fish in the Delta needs to be defined to determine if this is significant in terms of the total larval production in the Delta. Flow simulation studies indicate that larvae in the interior Delta will be entrained by pumping and agricultural diversions despite higher positive net flows in the lower San Joaquin River. Consequently, the value of X2 in reducing entrainment of larvae may be tenuous. Further, DWR examined relationships between number of days of reverse flows and Delta smelt midwater trawl and townet indices. However, they did not find a statistically significant relationship between reverse flow frequency and Delta smelt abundance indices.

- What factor or combination of factors was responsible for the initial crash following peak Delta smelt abundances observed in 1978 (summer townet data) and 1980 (fall trawlnet data)? The largest declines in the Delta smelt population occurred in 1982 and 1983. 1982 was a wet year, while 1983 was a year of record high flows. However, proponents of X2 standard suggest that drought conditions combined with increased diversions from State Water Project and Central Valley Project in 1985-1991 was primary cause for decline. Further, several documents claim that a "downward trend" in Delta smelt abundance is evident during 1981 to 1990. However, after reaching a low abundance in 1985 (a year of extreme hydrological variability, drought in summer and record flooding in winter), most reliable Delta smelt abundance indices (summer townet survey and fall midwater trawl survey) progressively increased in value through 1991.

- Is there a relationship between abundance and the magnitude, timing and duration of peak flows? If there is, this could lead to alternative theories regarding abundance declines and viable flow prescriptions.

- What are the reasons for inconsistencies in Delta smelt abundance indices? Midwater trawl surveys indicate much greater recovery than summer tow net surveys. Does this indicate that Delta smelt moved into deeper water during drought periods, which would favor midwater trawl capture efficiency while substantially reducing townet capture efficiency? Variation in Delta smelt spawning would likely change year to year sampling efficiency of summer townet surveys. Summer townet surveys may underestimate Delta smelt during higher flow periods because fish move into Suisun Bay.

- Greatest changes in Delta Smelt Abundance Indices occur for studies which sampled a limited area (e.g., Chipps Island Trawl Survey, UC Davis Suisun Marsh Survey). Changes in abundance observed from these surveys may reflect movement of fish into different areas (as strongly indicated by midwater trawl surveys). Midwater trawl data strongly suggest that Delta smelt moved in lower Sacramento River during

1976-1977 and 1985-19 92 drought periods. Finally, the causes for changes in abundance for many important species is unknown.

- It is presently difficult to determine relationships among causal factors due to the limited data currently available. Impacts of drought conditions are not certain, since the impacts of only the recent drought have been studied. Most available information is for a relatively small number of species obtained from a limited number of areas. An additional problem has been that there is relatively little coordination among studies. Finally, many studies have yielded conflicting results (e.g., Delta smelt abundance analysis). Additional studies and further analysis will be required to determine reasons for this.

- The majority of the species abundance data are for a period of about 10 years. Nevertheless, widesweeping conclusions are drawn from these data. Of particular concern is the fact that the 10-year period contained periods of extended drought, as well as several flood and high flow events. The effects of these natural events are difficult to account for and render any direct conclusions regarding the reasons for declining populations as suspect.

- Ecosystem Goals: conditions circa late 1960s to mid-1970s: The Bay-Delta ecosystem is not a static system and has been changing and adjusting its character, morphology, species composition, etc., for literally thousands of years. The changes that are man-induced over the relatively recent time span have created an ever changing set of conditions that alternately (depending on complex interactions of physical, chemical and hydrologic parameters) favor or dis-favor certain assemblages of fish. To re-establish the same relative abundances of certain "target" fish species as existed in 1965-1976 would require a "reset" of the major factors that shaped the populations to levels at that time, and the elimination or control of factors responsible for reducing the populations to present day levels. Although an admirable, and biologically and politically correct objective, such goals can only be achieved through direct action in the Delta and Bay focused not only on the control of water quality and quantity issues, but also on the creation/restoration of lost physical habitats, elimination of known and controllable sources of mortality such as intake and diversion screening, powerplant entrainment, thermal pollution, and contaminant toxicity, excessive predation, and overexploitation. The setting of an X2 standard would be promulgated under the assumption that it is the location of the 2 ppt isohaline in the Bay and Delta that influences the *overall* ecosystem health. The Status and Trends Reports have noted repeatedly that there are other factors (many of them unquantifiable) which are influencing certain fish populations, and for which the X2 standard will have no effect. A review of biological requirements suggests that the greatest influence of the X2 standard would be on the Delta smelt. This species has an affinity for the 2 ppt isohaline, which occurs in close association with the ET zone. Although Jassby's analysis indicates there are other species which likewise have a relationship to X2, the disaggregation of data demonstrates that X2 explains just a part of the variability in relative abundance for these species below a certain location in the Delta (i.e., below Chipps Island). Thus there is a real potential that the setting and implementation of the X2 standard as presently defined will not achieve the overall desired effect of maintaining total ecosystem health, but would rather have the most applicability to a limited number of species including Delta smelt and longfin smelt. This begs the question: should the EPA develop and mandate standards which have a high degree of biological uncertainty and are most applicable to a few euryhaline species which have high resource use costs associated with their implementation? Given the uncertainty of the biological relationships to X2 and the increased variability in the relationships with distance below Chipps Island, at best the X2 standard should perhaps be implemented on an interim basis, and then only after it is modified so it can be efficiently and realistically administered.

- Benefit:Cost Analysis. What are the biological benefits resulting from X2? What are incremental benefits to the ecosystem resulting from shifts in X2 location relative to water costs. Present analysis suggests that the incremental water costs in moving and maintaining X2 downstream to Roe Island are excessive and unjustified relative to the gains in ecosystem/fisheries health that would be achieved. There is a high degree of uncertainty as to what the contribution of X2 is to the maintenance of fish populations below Chipps Island. Other factors unrelated to X2 (e.g., wind, temperature, pollution, water turbidity, introduced species, etc.) may have a greater influence on populations once X2 is below this location. However, the EPA may prevail on this inasmuch as the data do support the "opportunity for occurrence" of higher populations when X2 is between Roe Island and Chipps Island.

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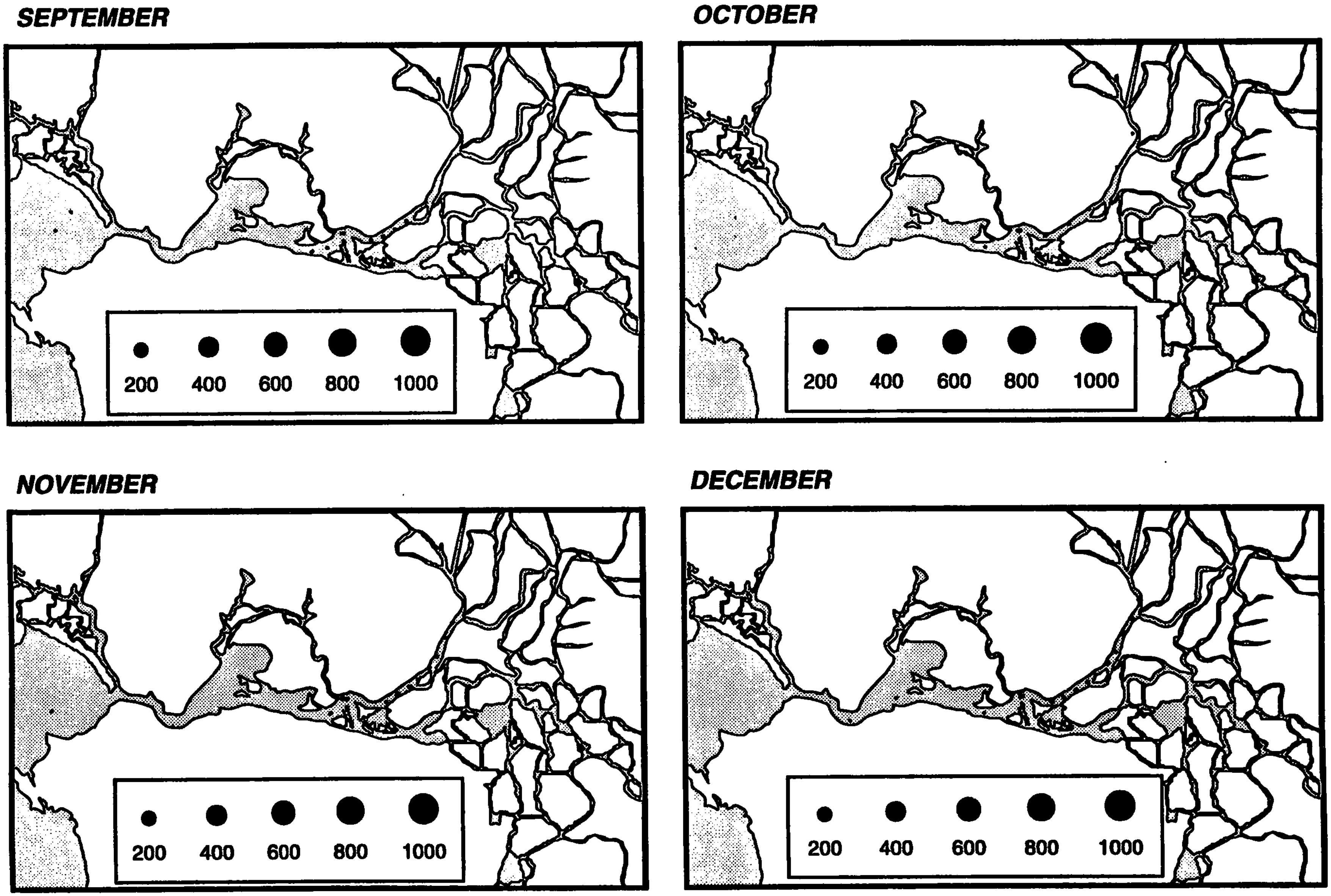
Appendix A

Spatial Abundance Maps for Selected Species Sampled in Midwater Trawl Survey, 1977 - 1990

Appendix A-1

Spatial Abundance Maps for Selected Species Sampled in Midwater Trawl Survey, 1977 - 1990

Longfin Smelt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Longfin Smelt - 1977

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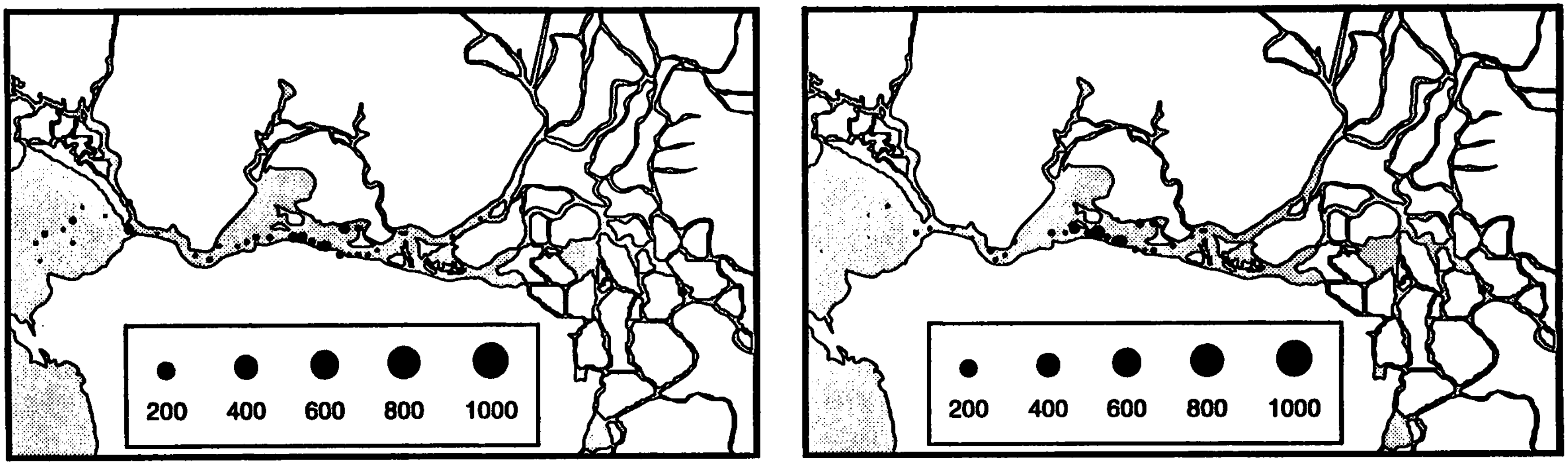

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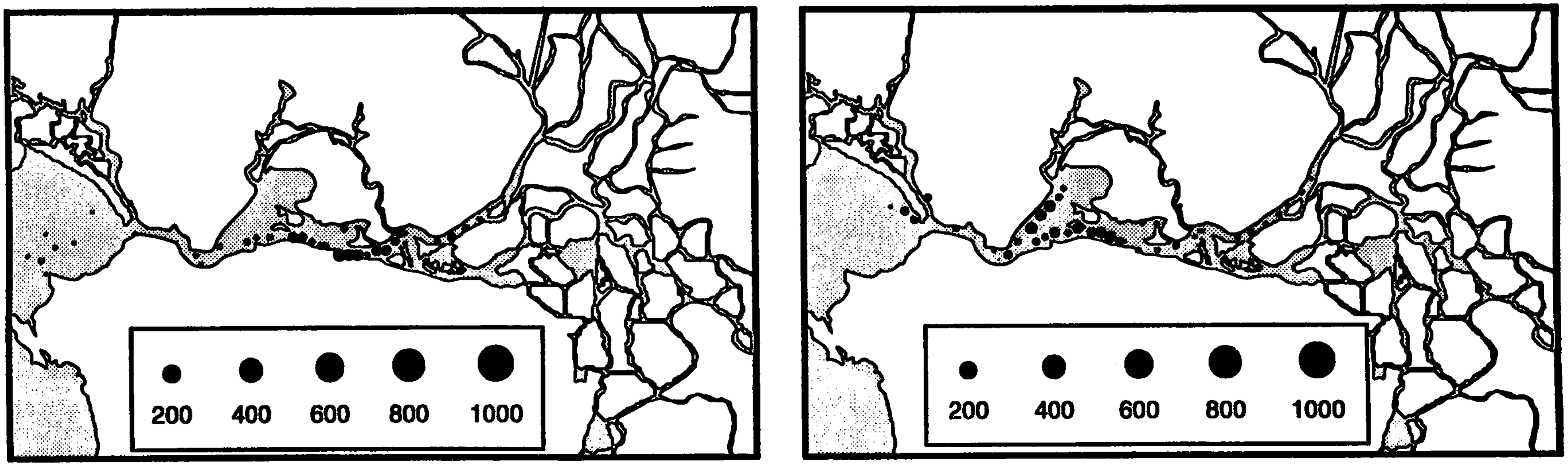

Longfin Smelt - 1978

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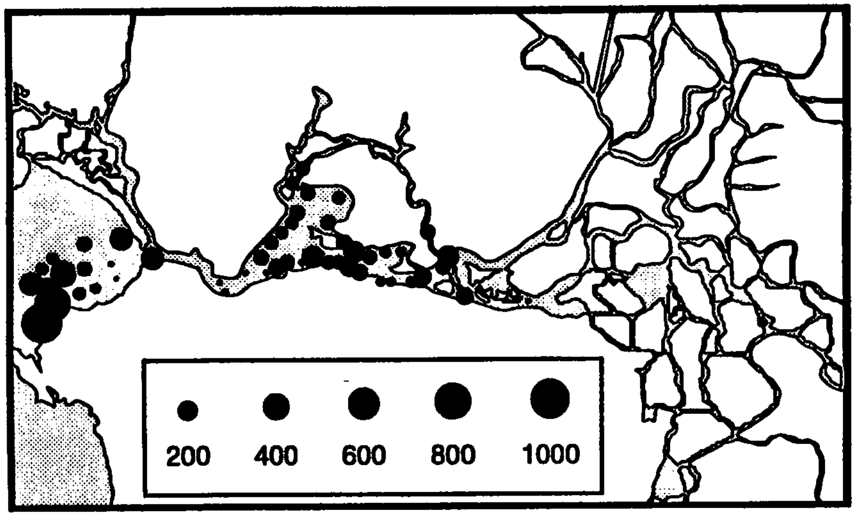

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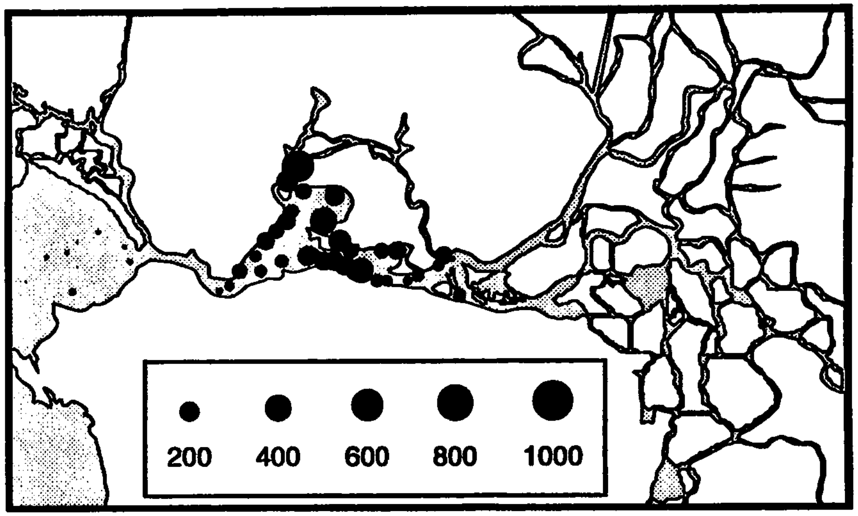

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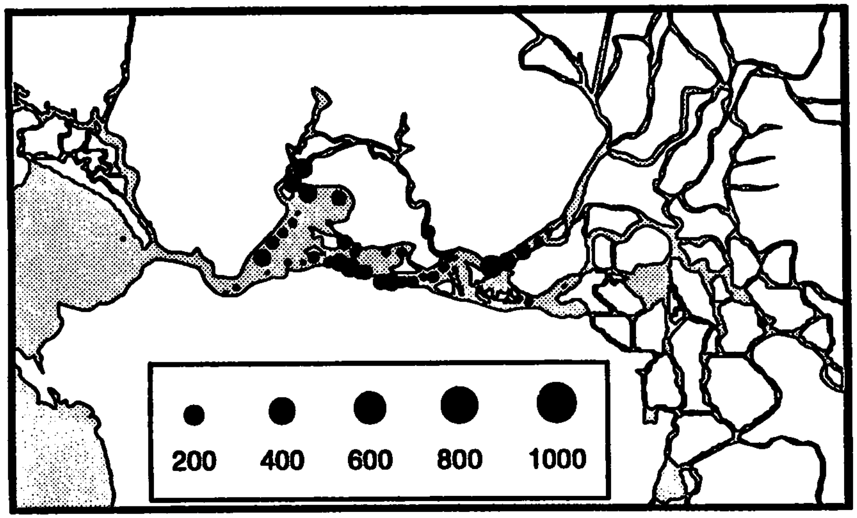

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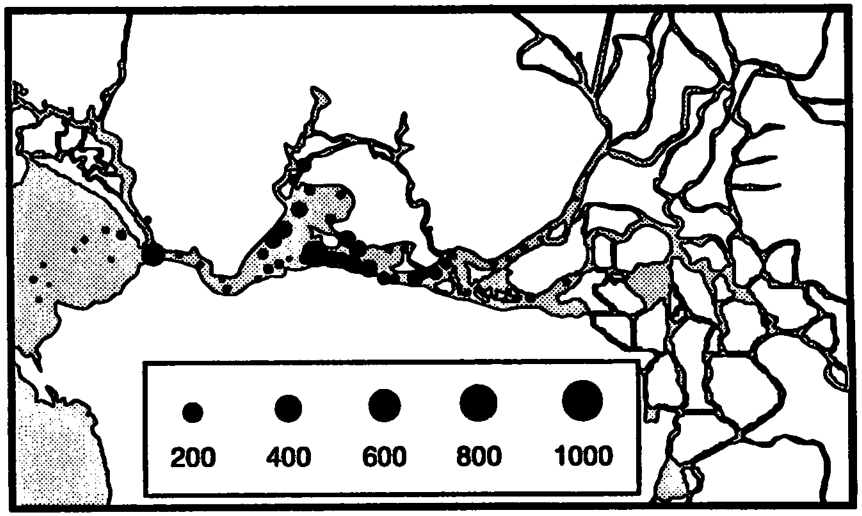
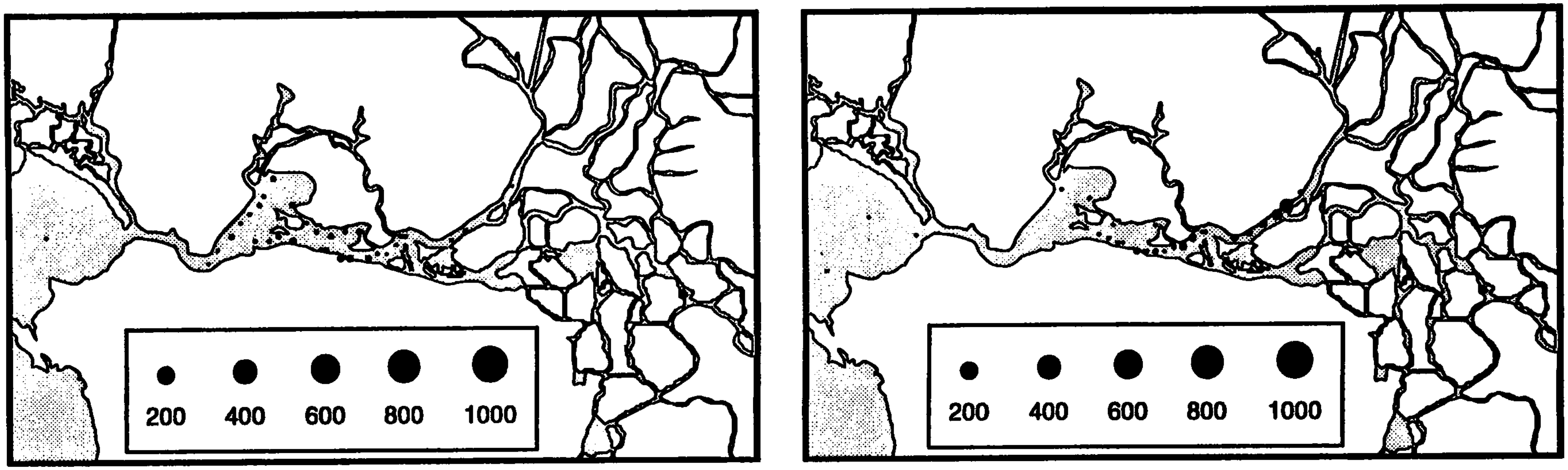


Longfin Smelt - 1980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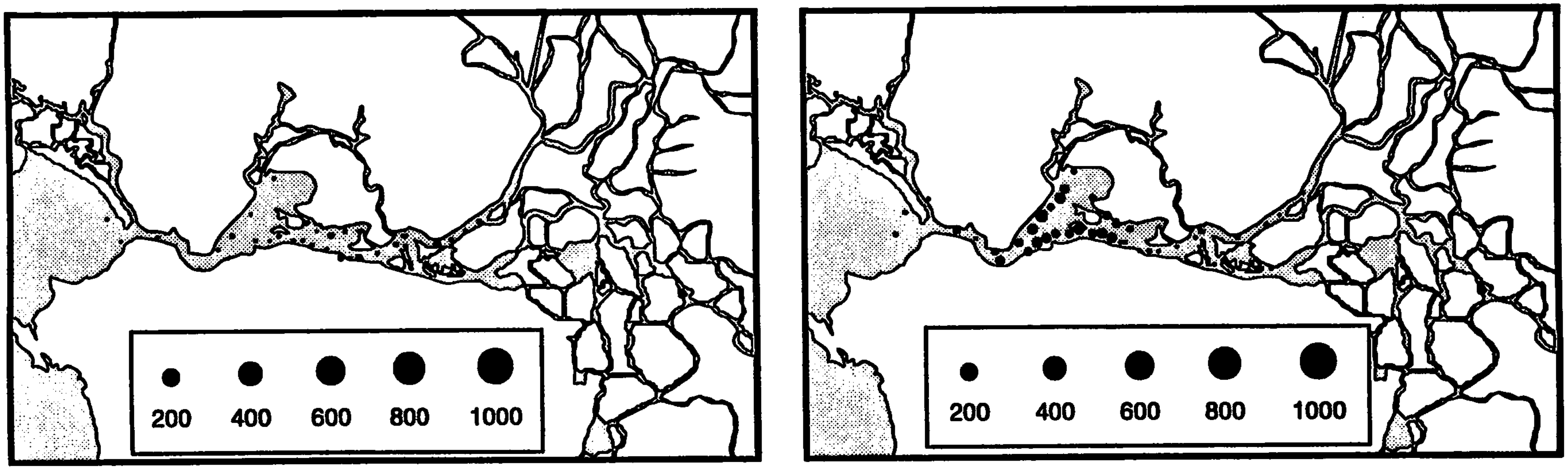
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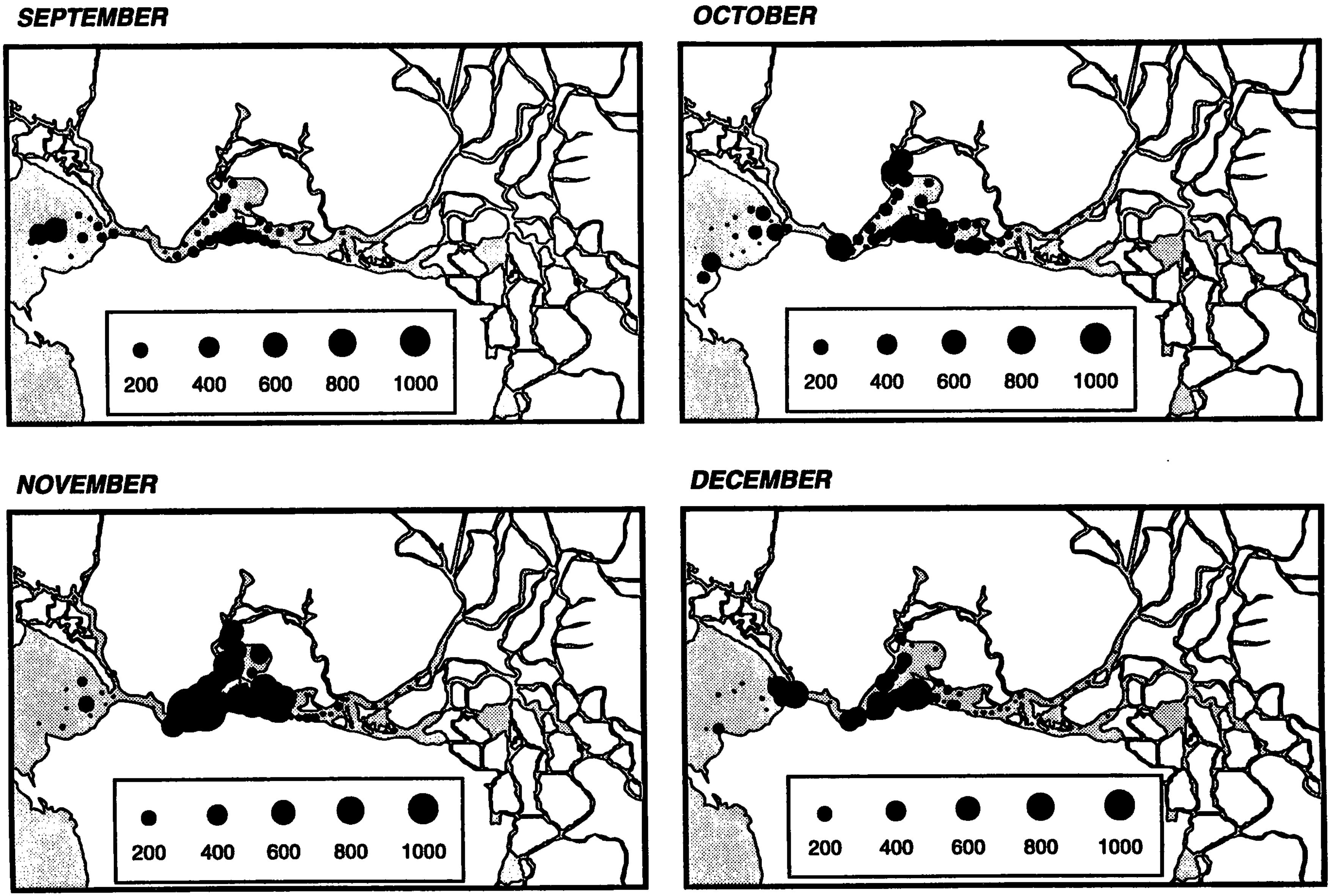
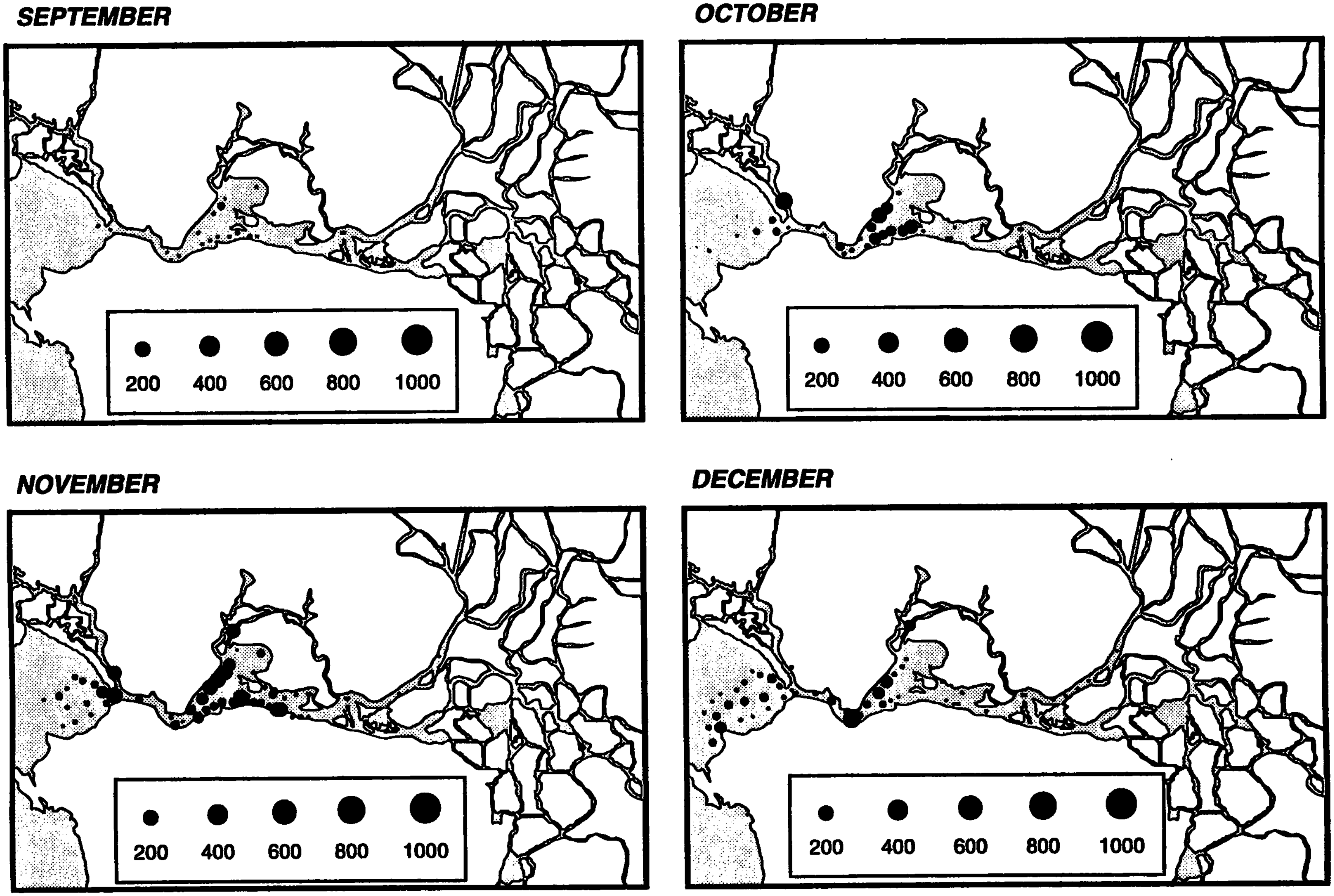
Longfin Smelt - 1981



Longfin Smelt - 1982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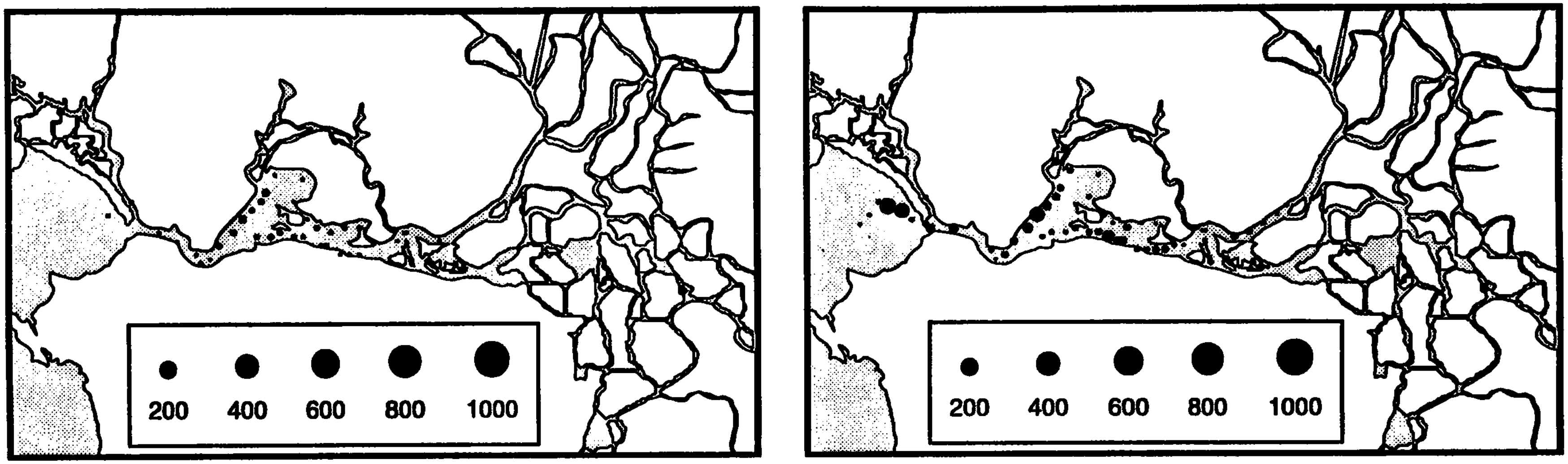

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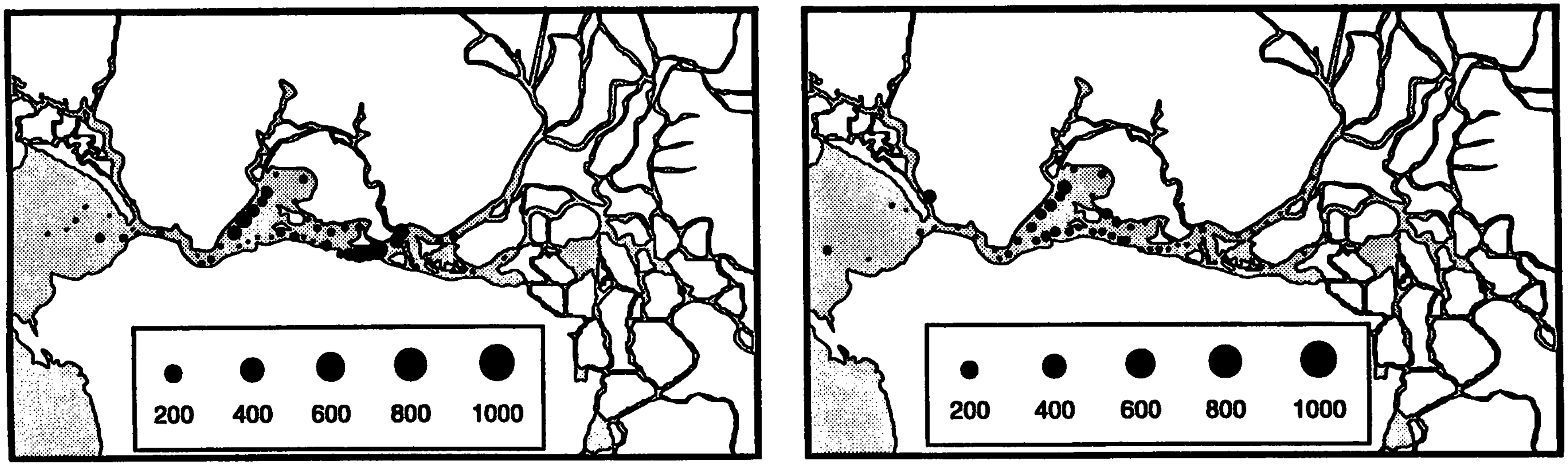

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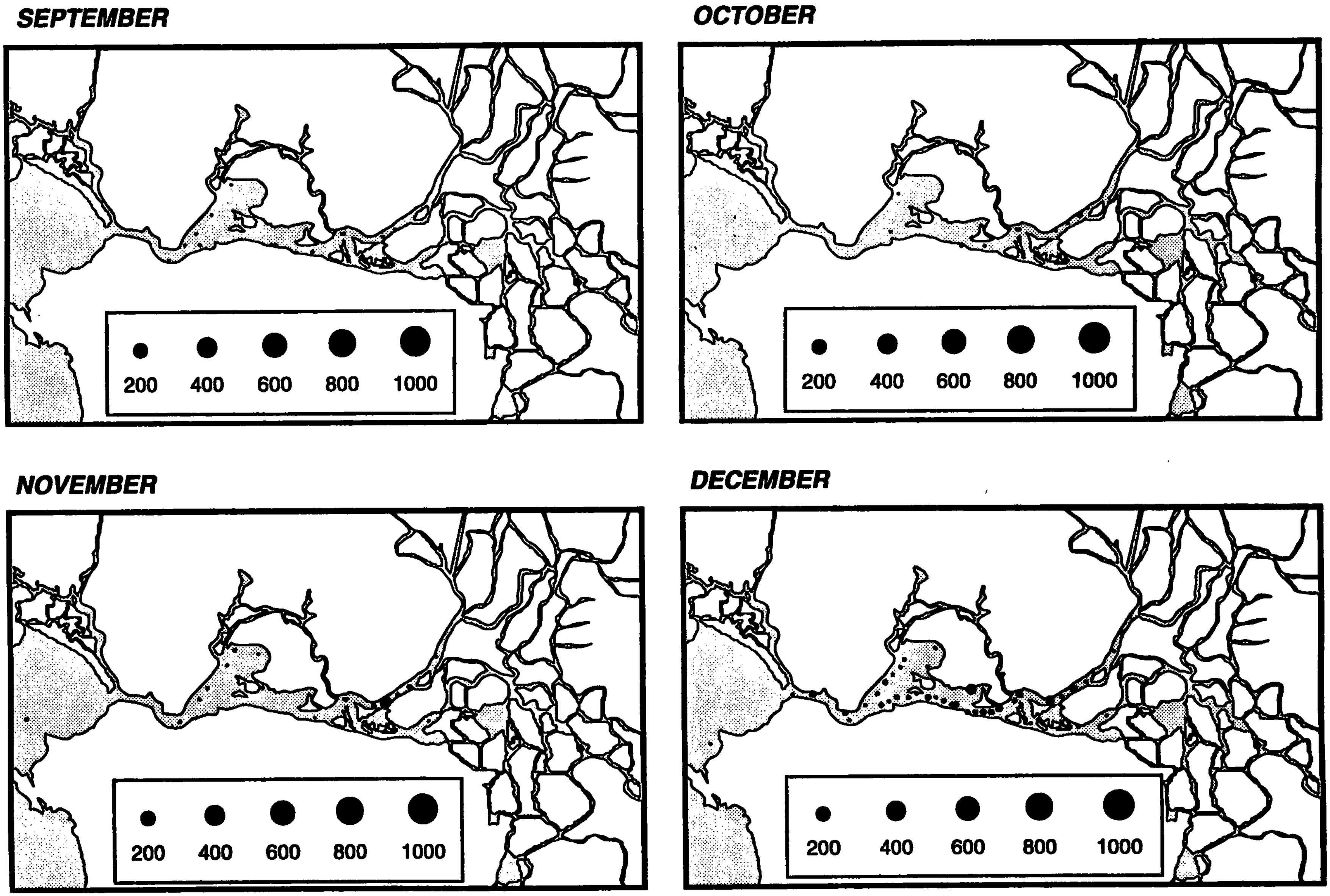
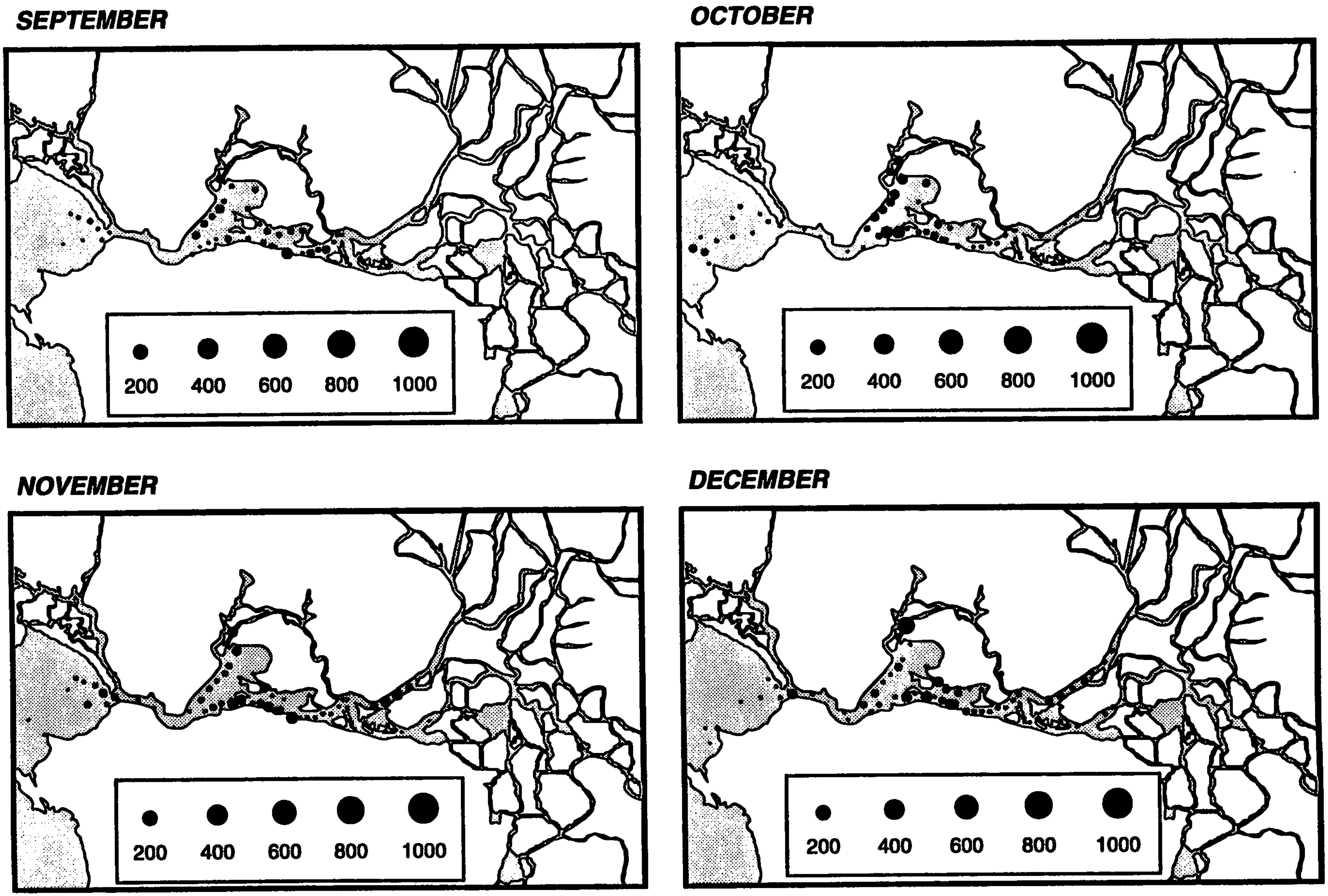
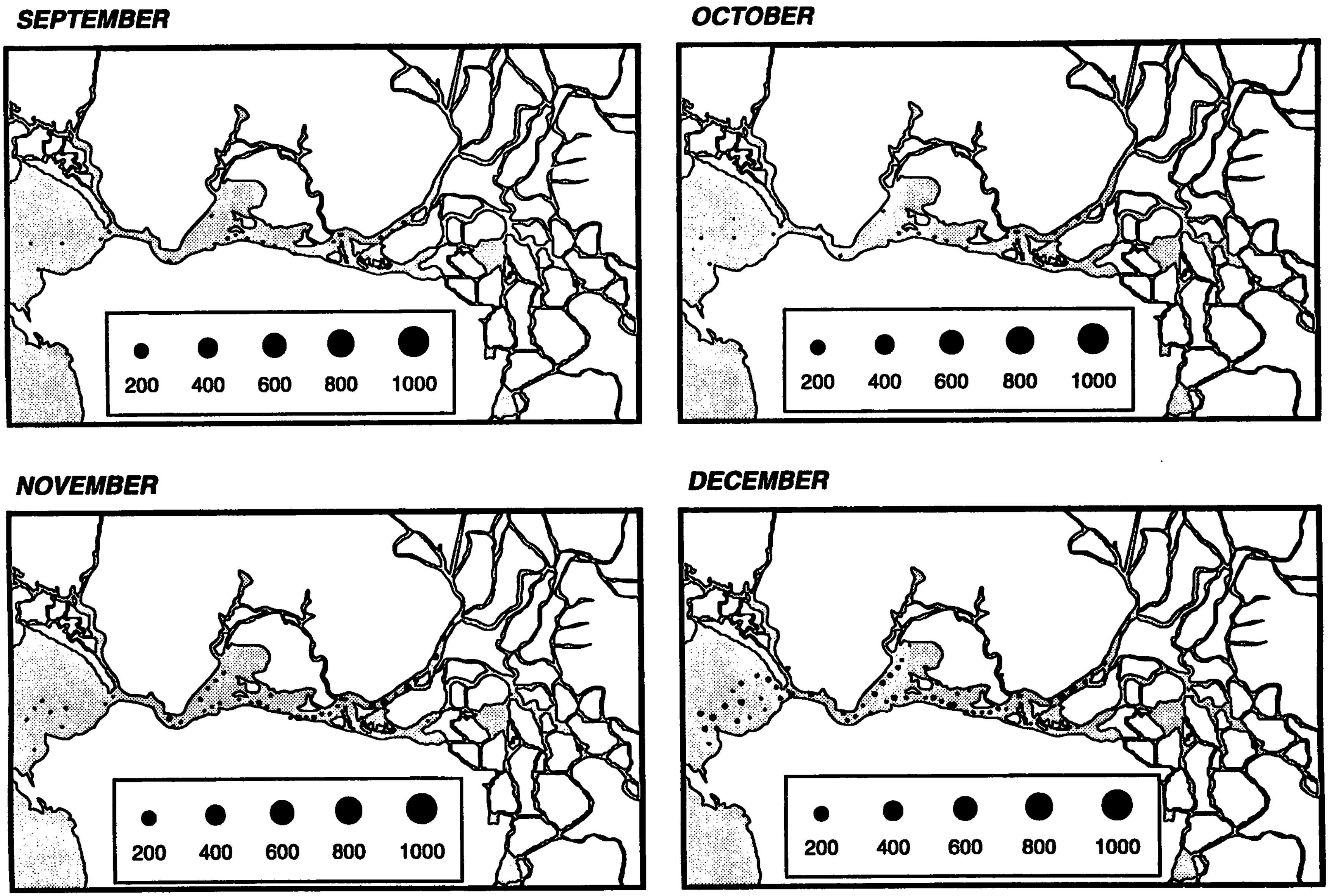
Longfin Smelt - 1984



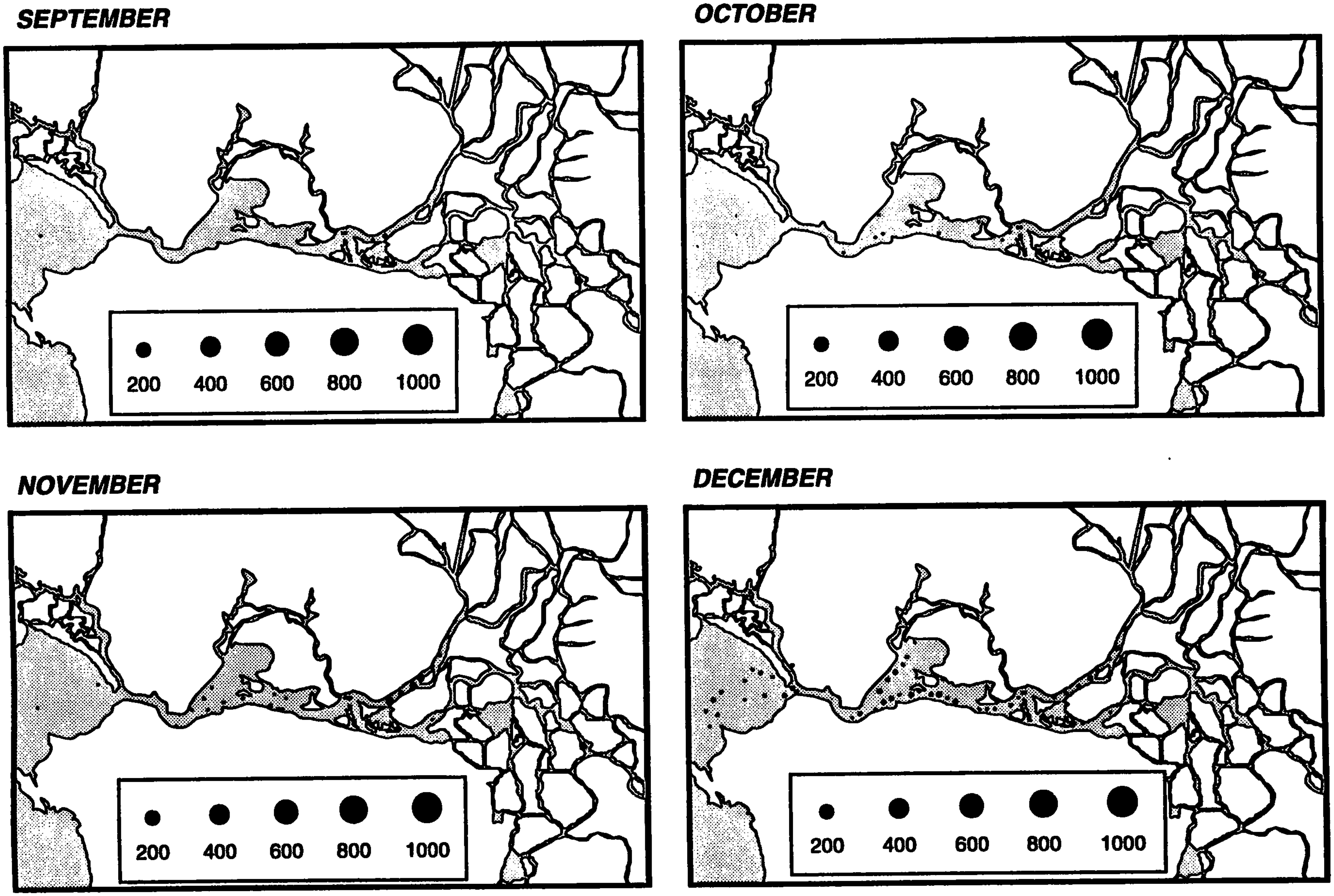
Longfin Smelt - 1985



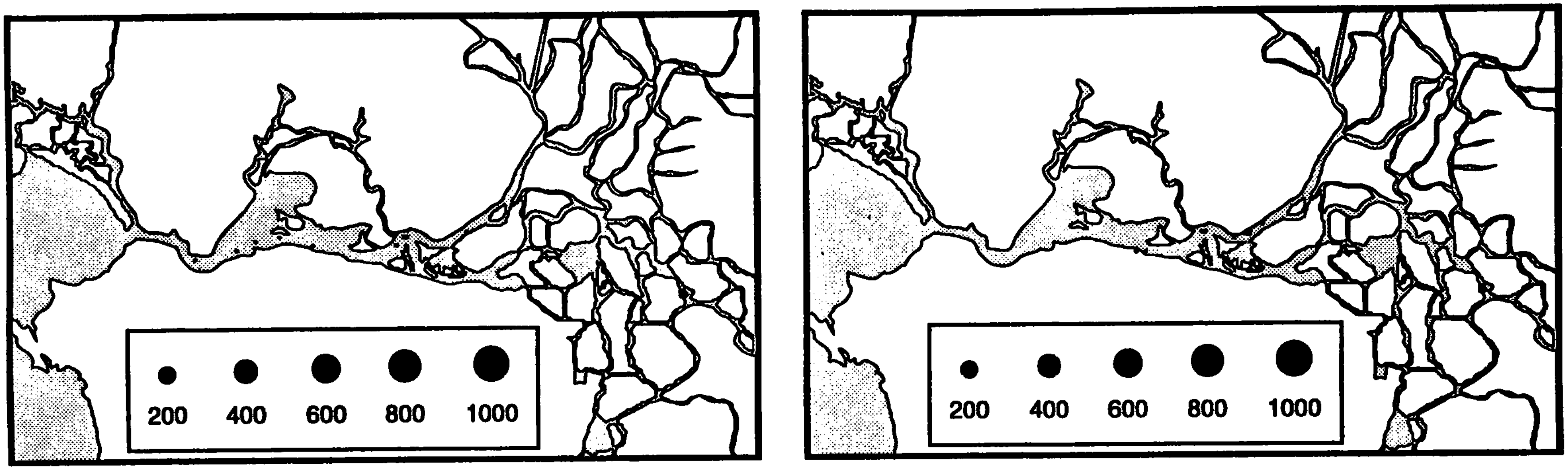
Longfin Smelt - 1986



Longfin Smelt - 1987



Longfin Smelt - 1988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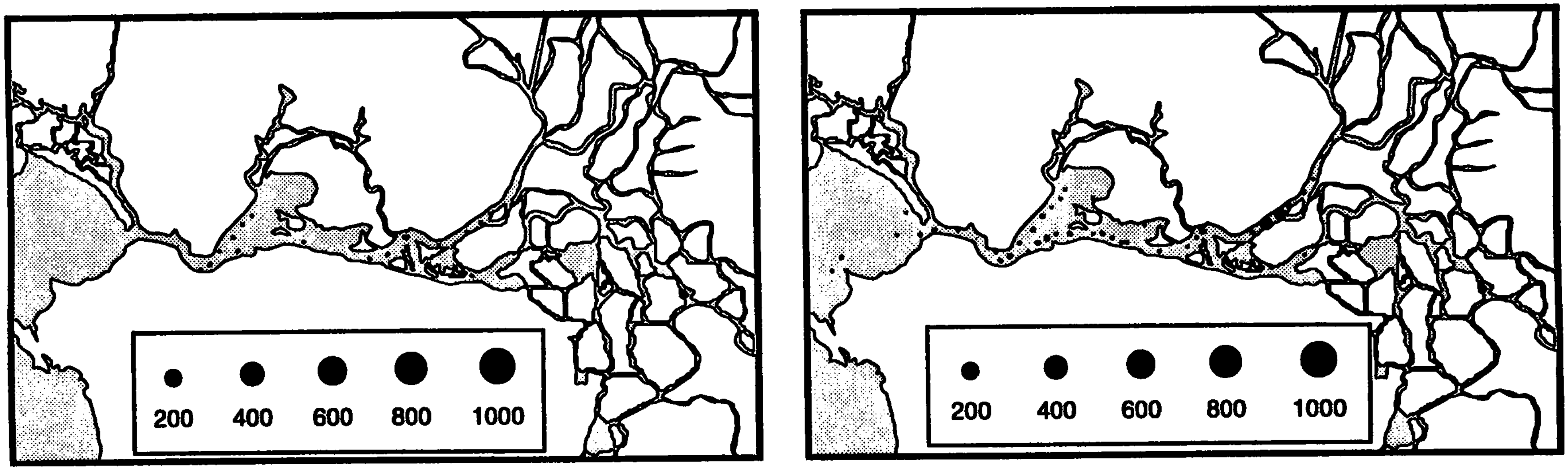
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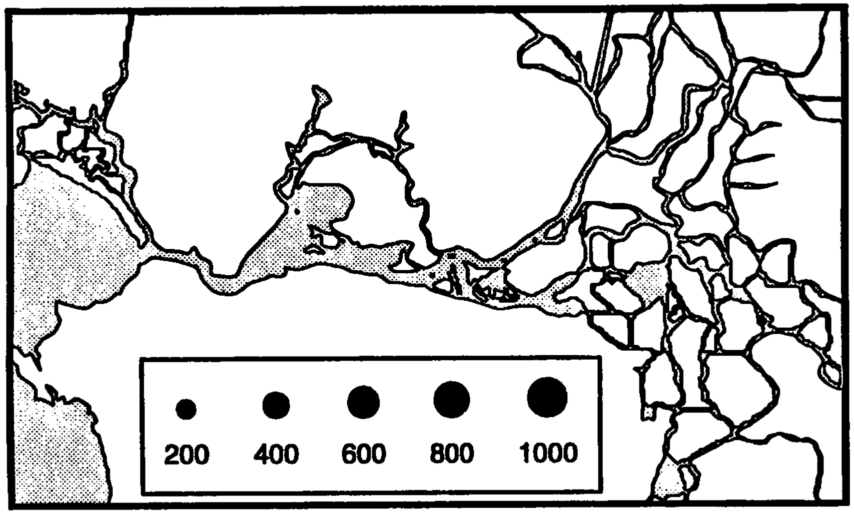

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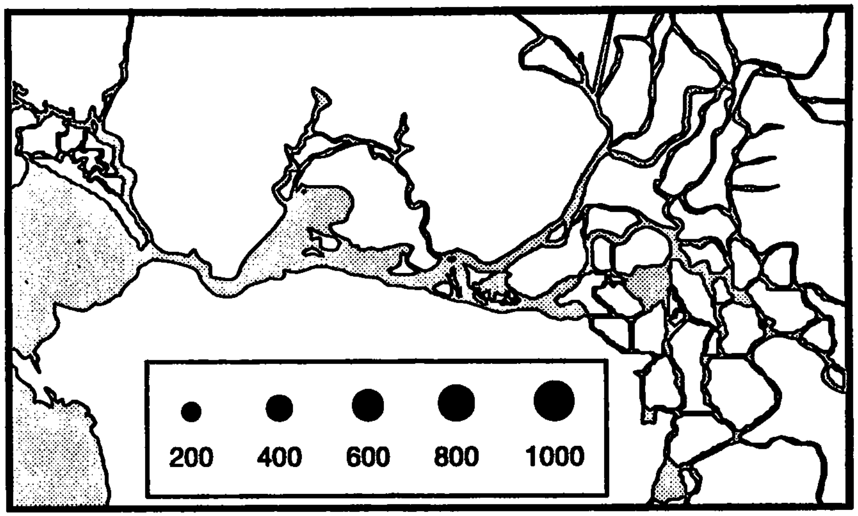

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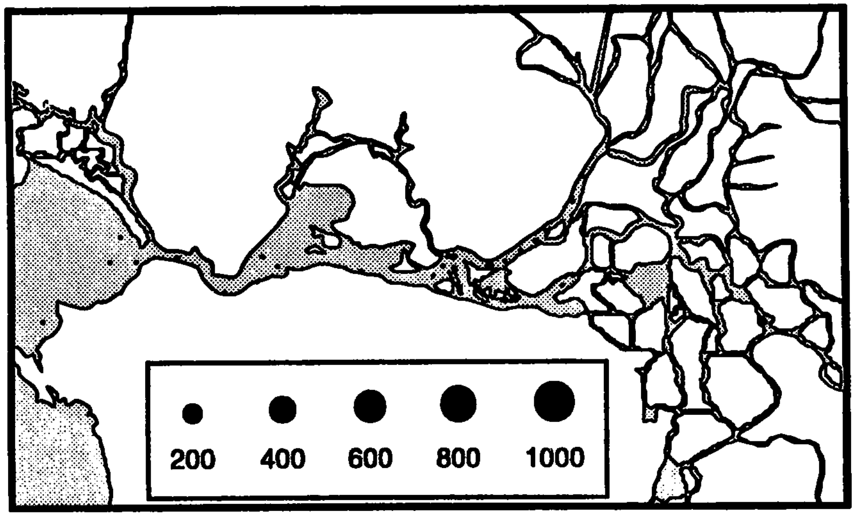

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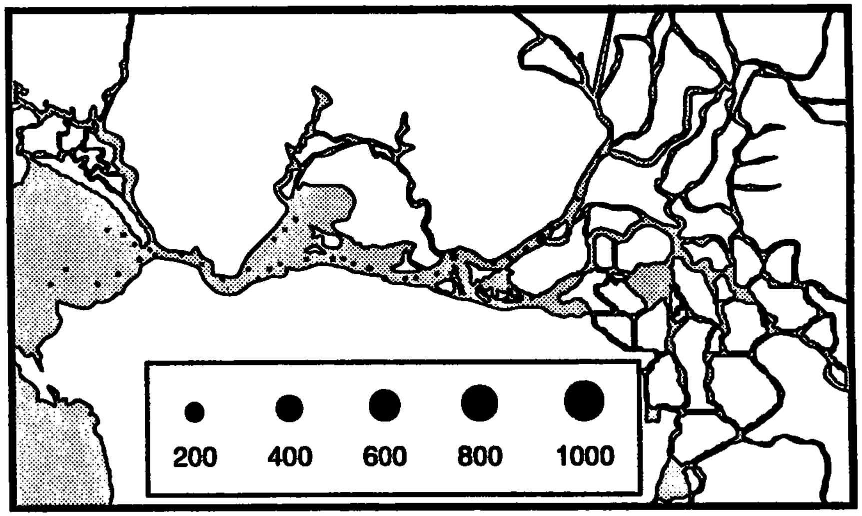
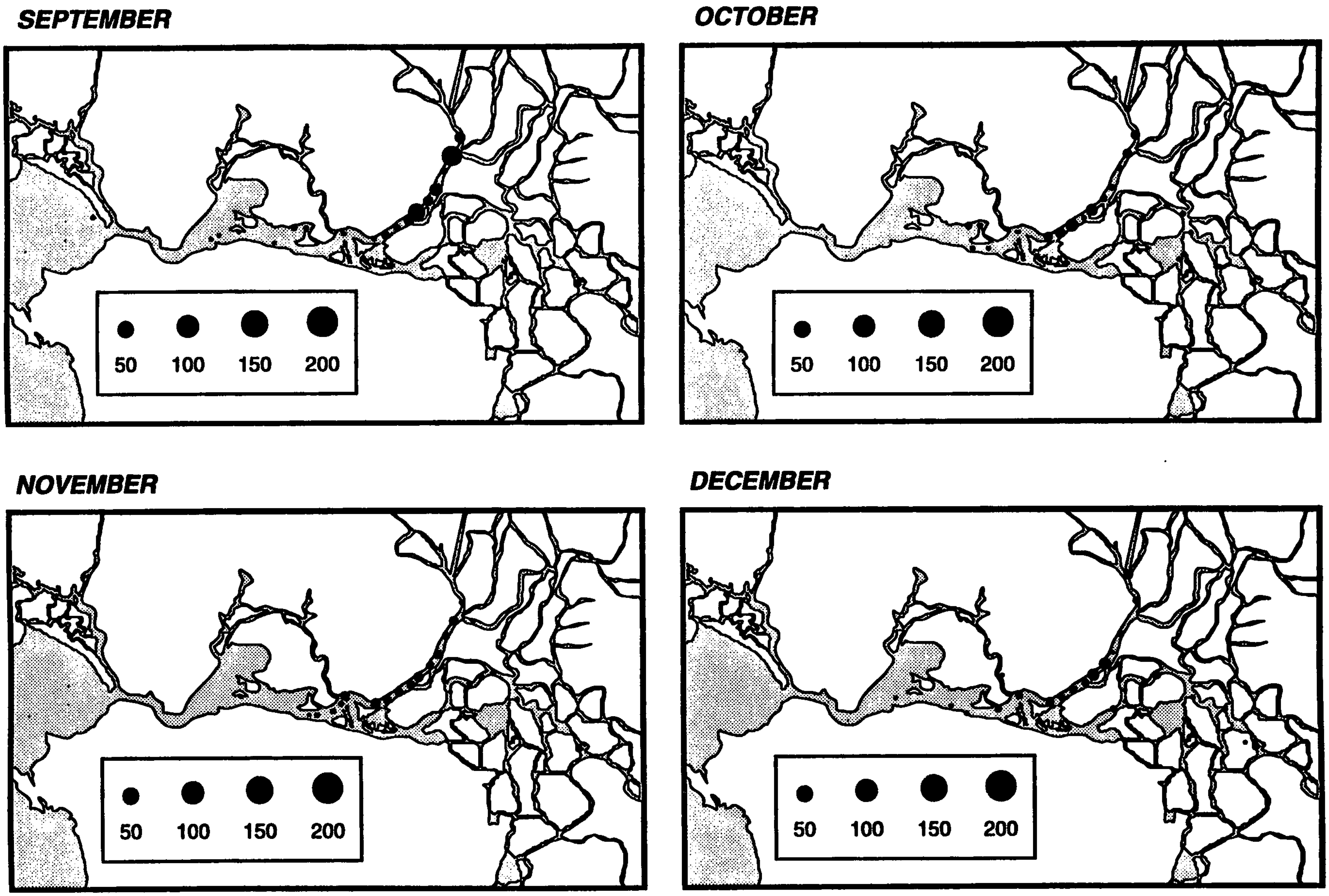


Longfin Smelt - 1990

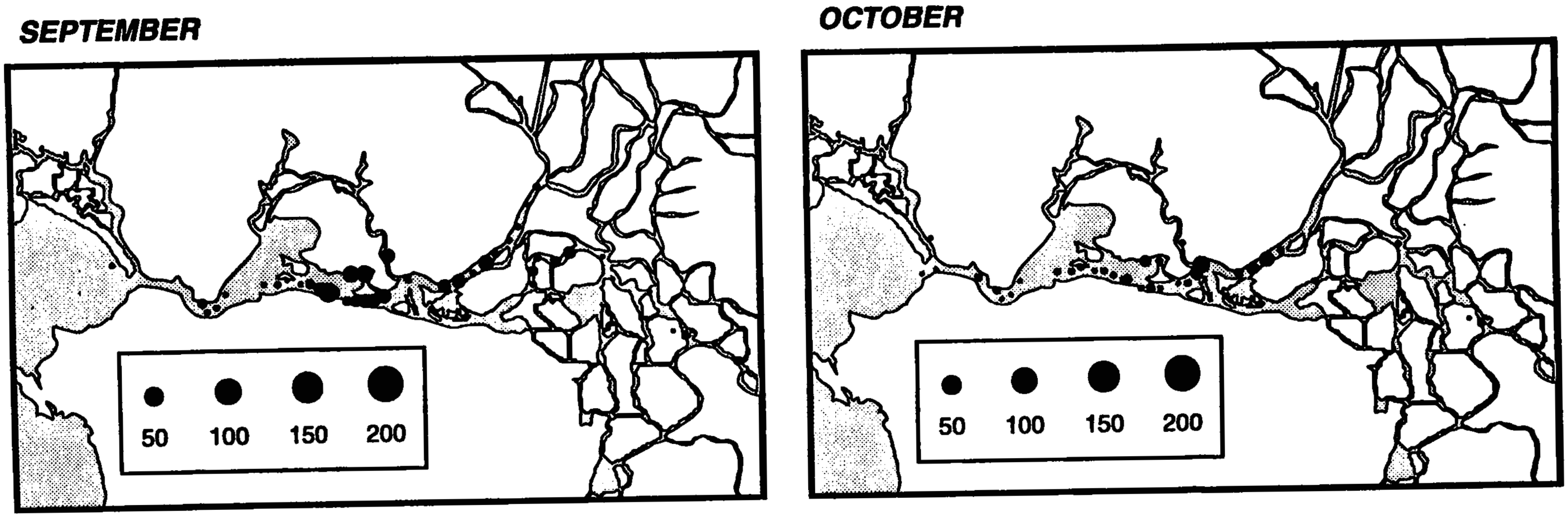
Appendix A-2

Spatial Abundance Maps for Selected Species Sampled in Midwater Trawl Survey, 1977 - 1990

Striped Bass (age 0+)



Striped Bass (Age 0+) - 1977



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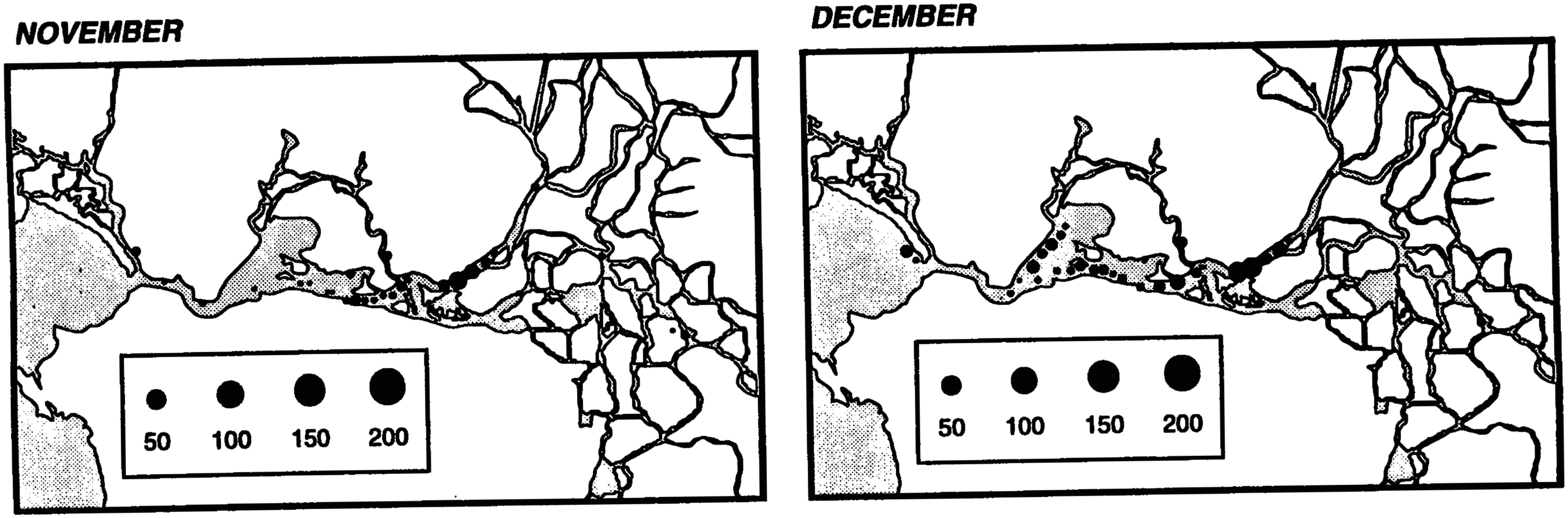

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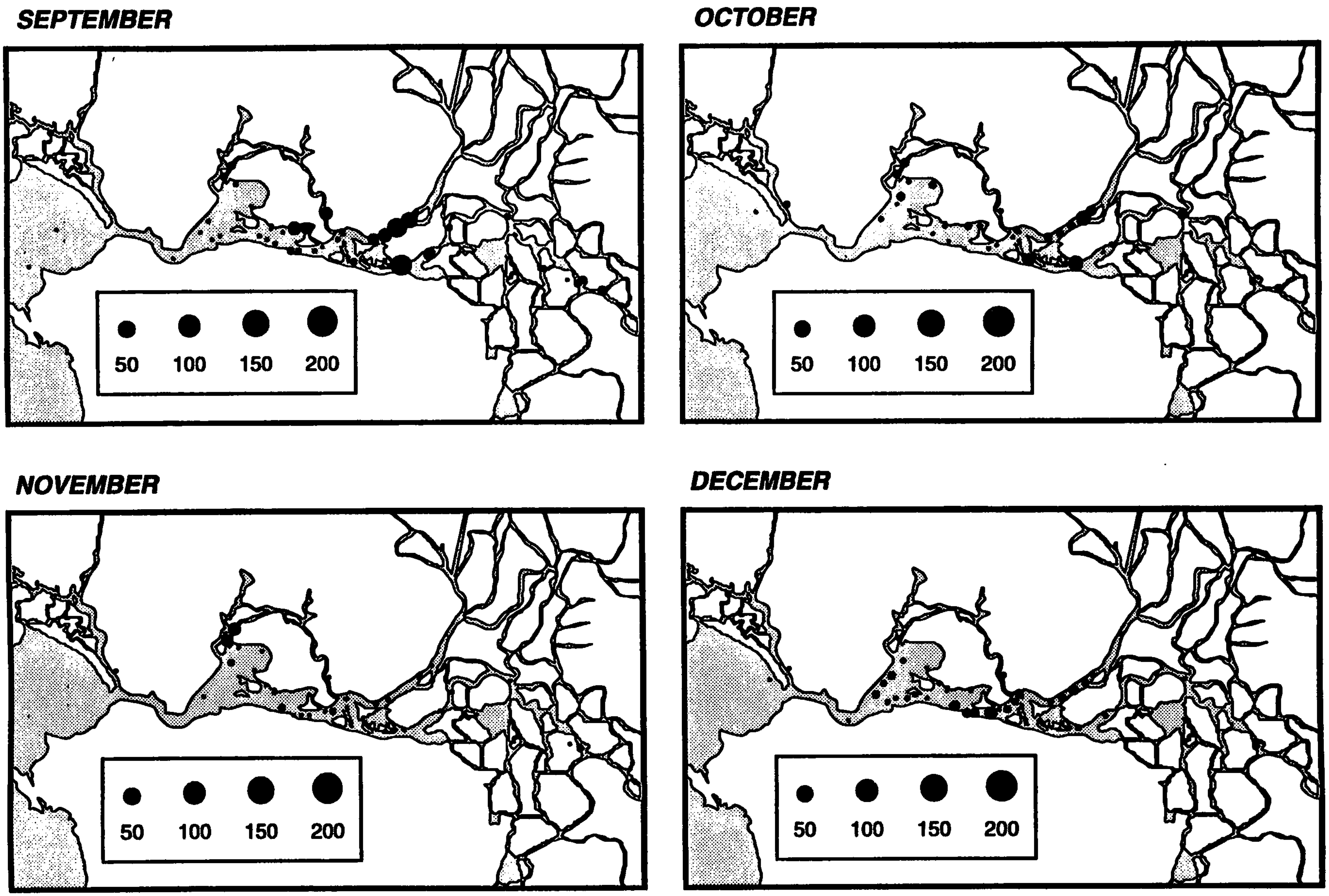
Striped Bass (Age 0+) - 1978



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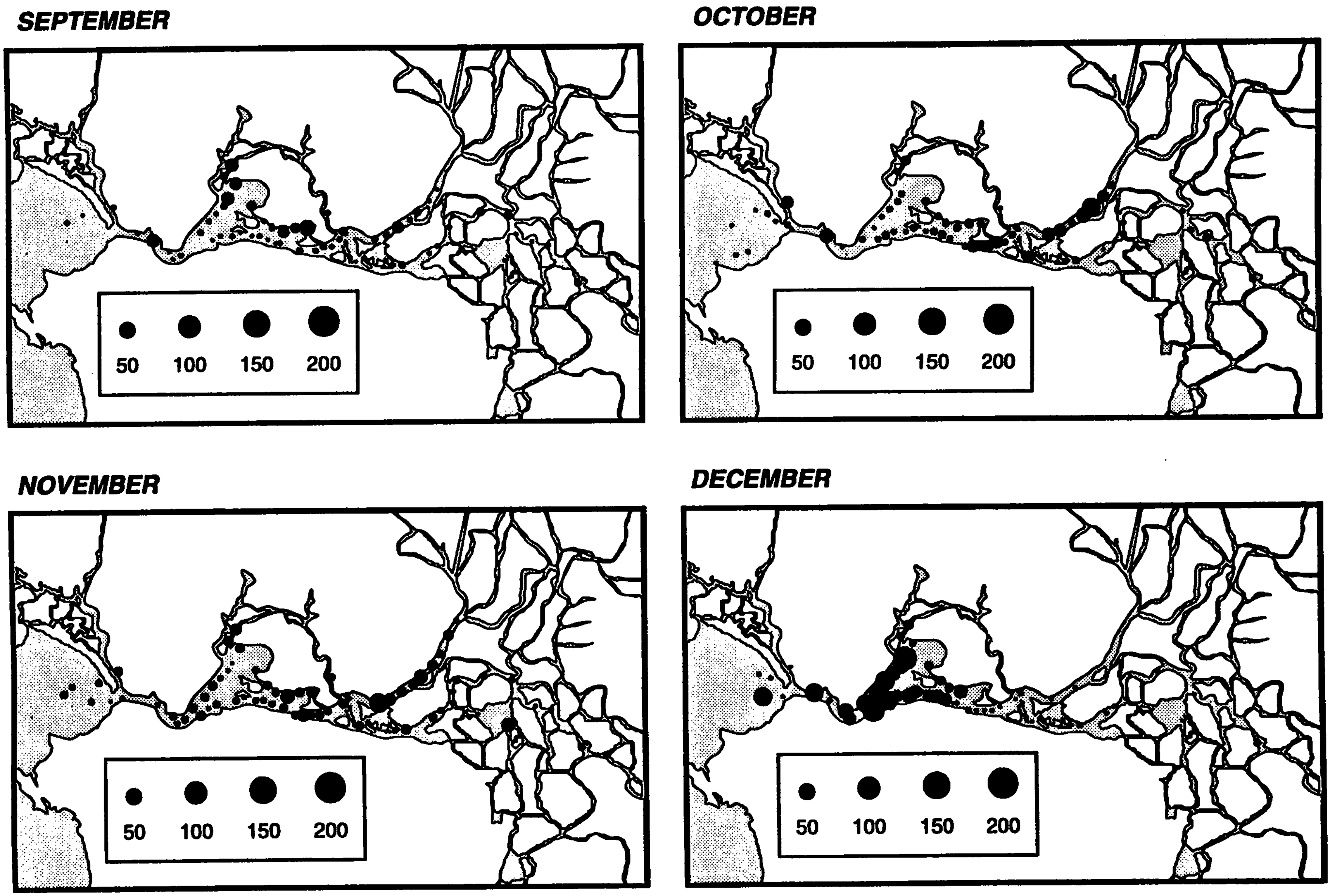
Striped Bass (Age 0+) - 1980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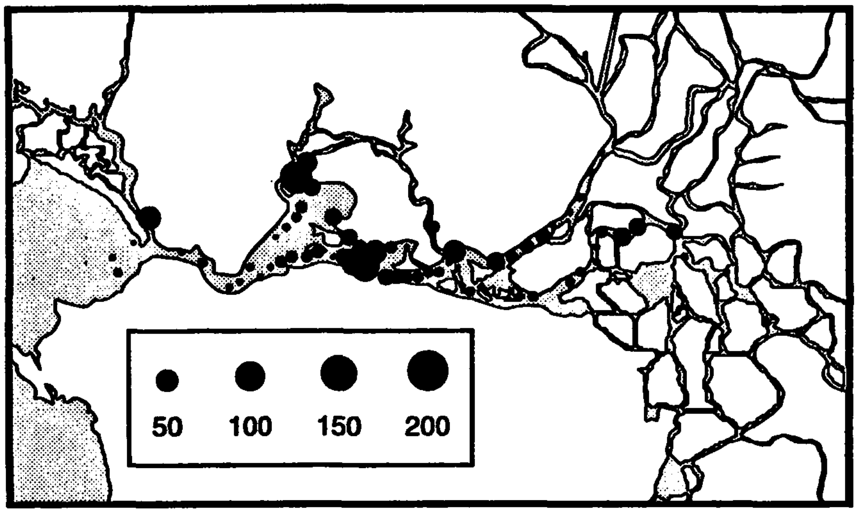
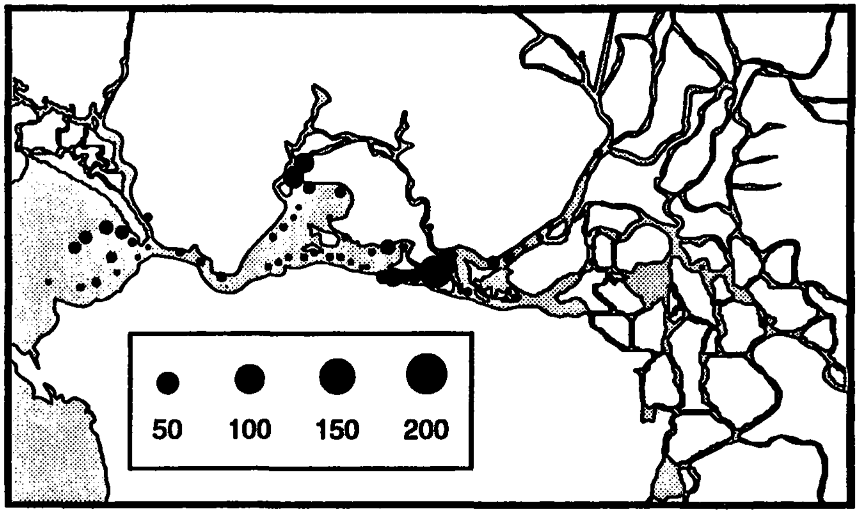
Striped Bass (Age 0+) - 1981

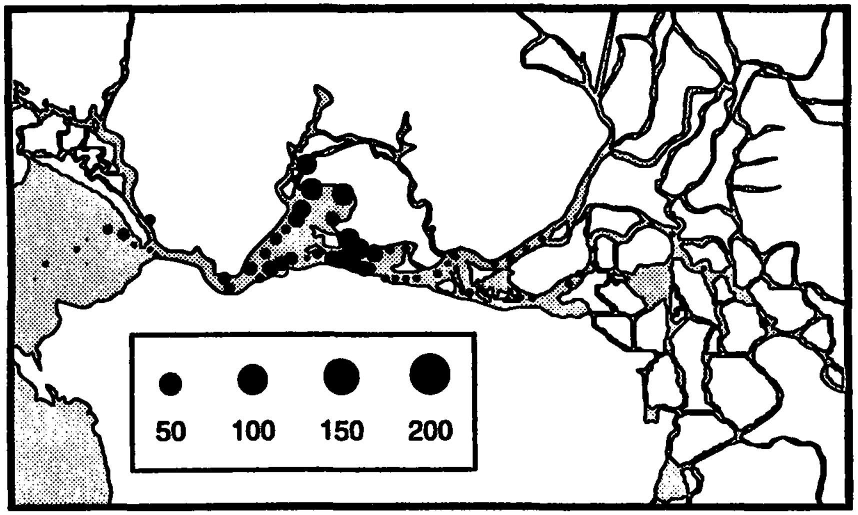
SEPTEMBER



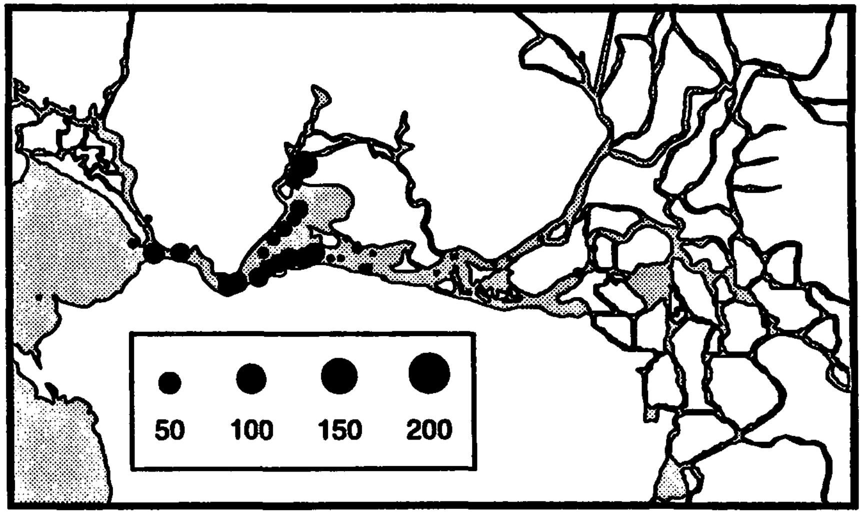
OCTOBER



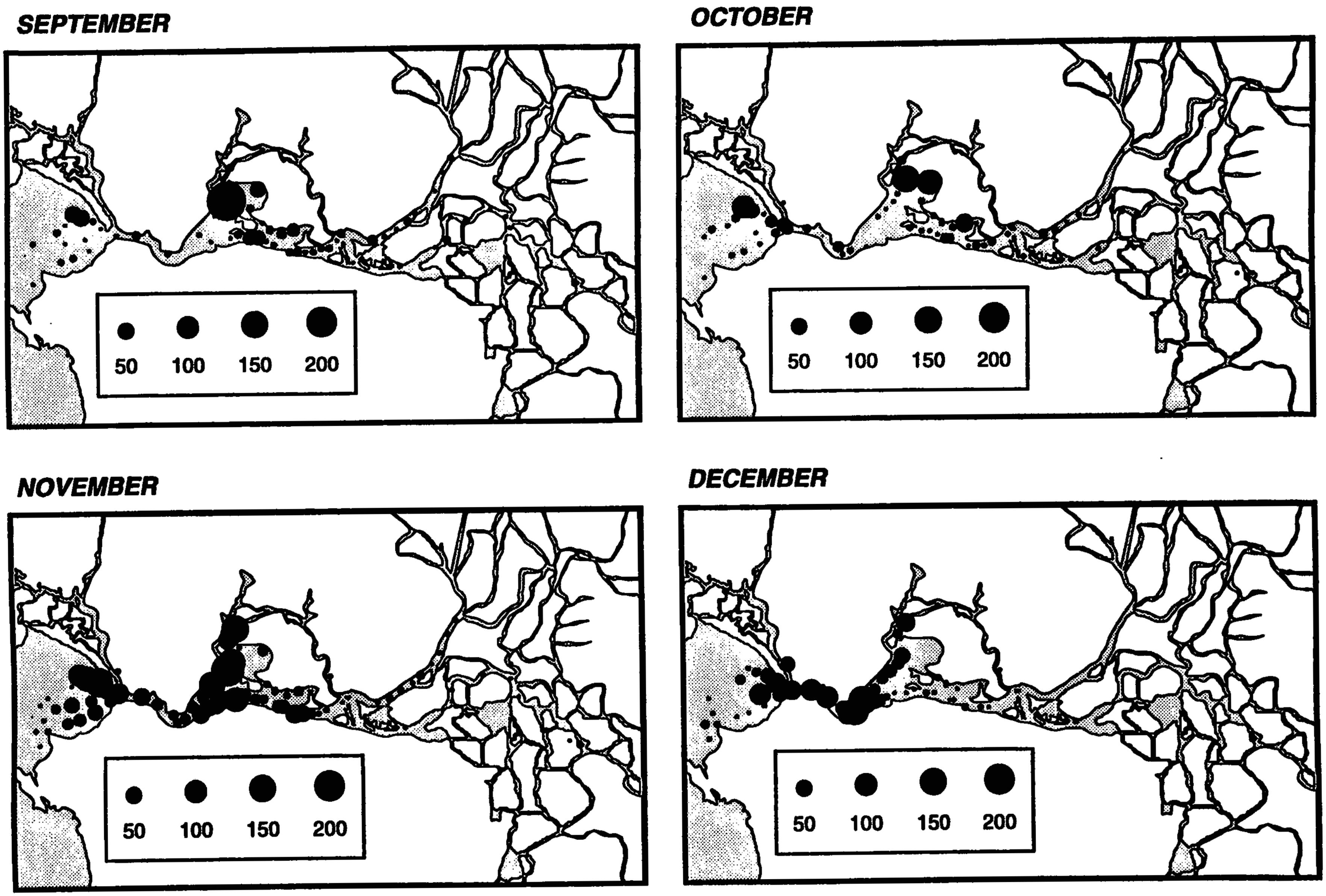
NOVEMBER



DECEMBER

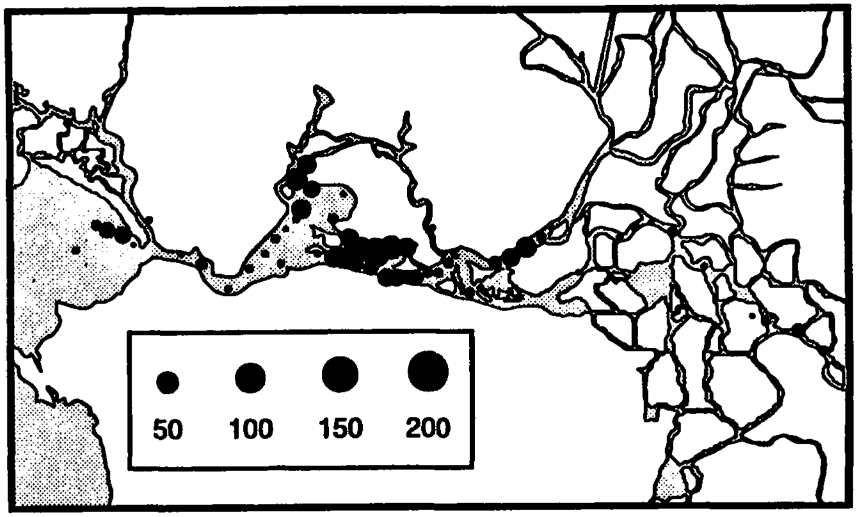


Striped Bass (Age 0+) - 1982

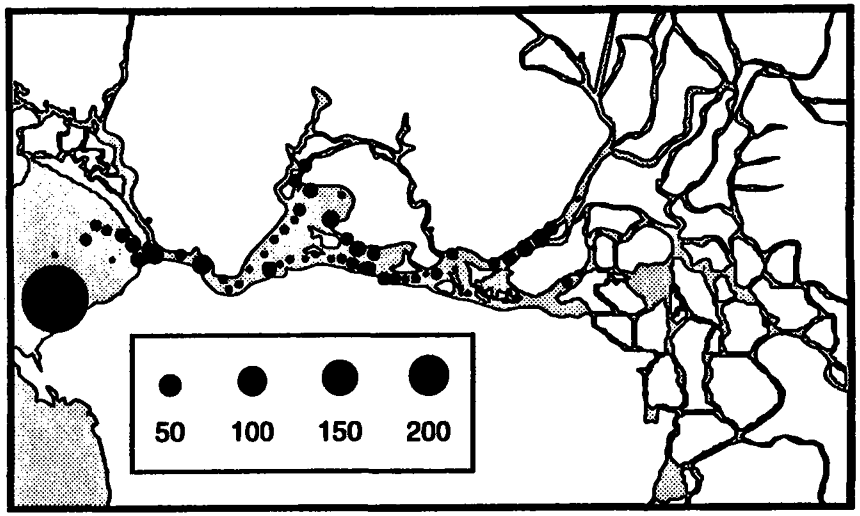


Striped Bass (Age 0+) - 1983

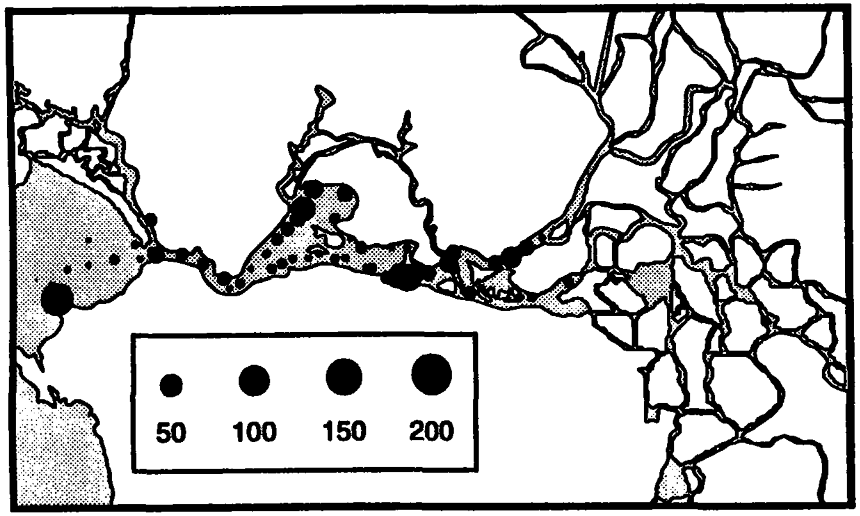
SEPTEMBER



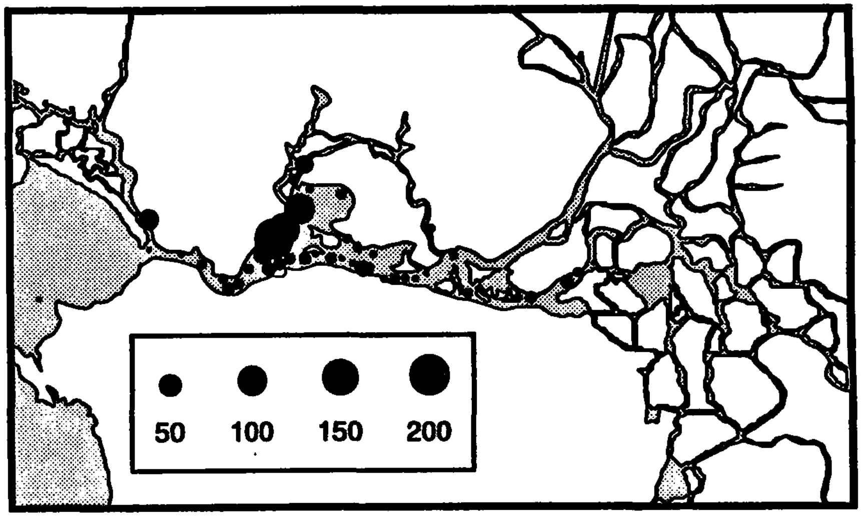
OCTOBER



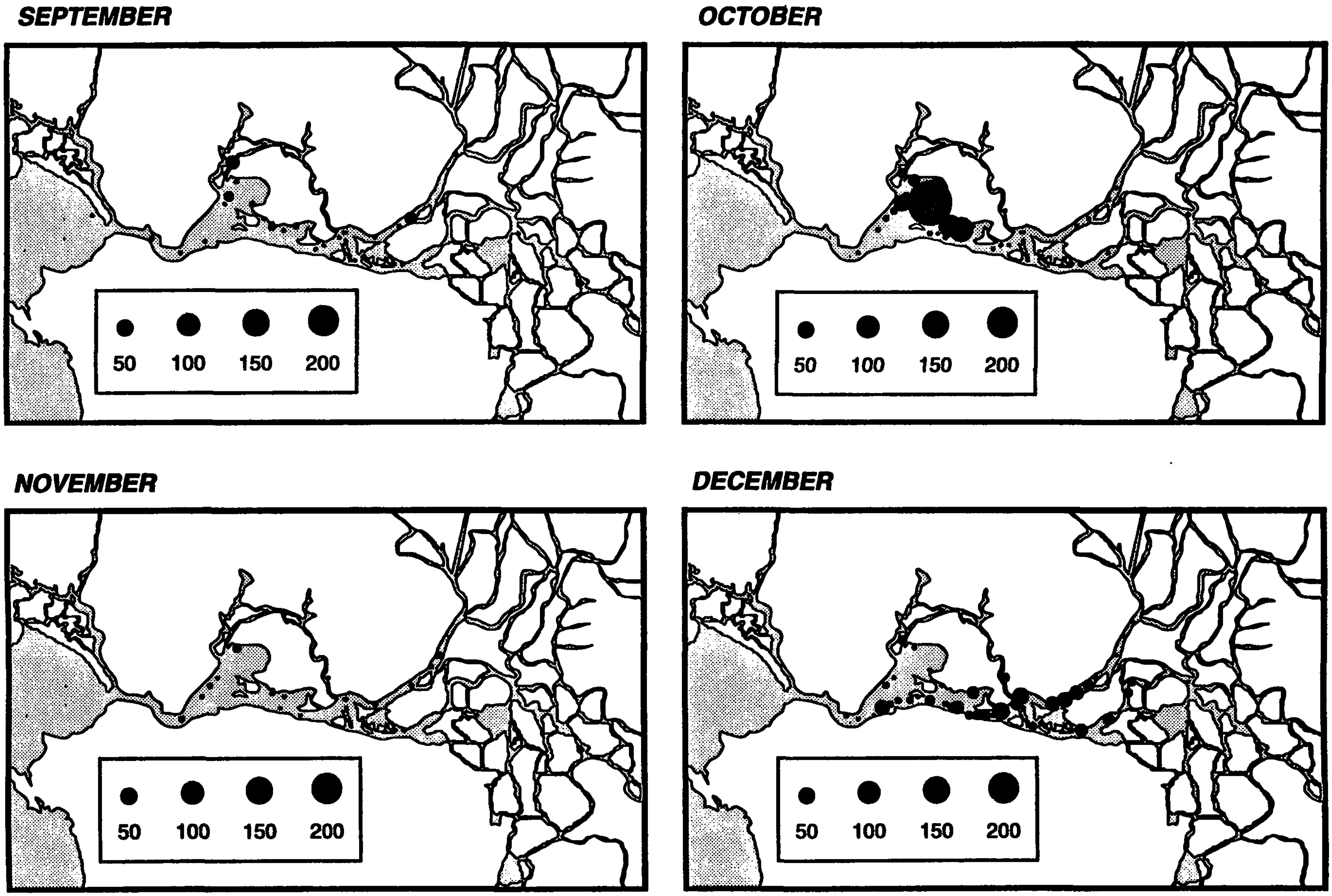
NOVEMBER



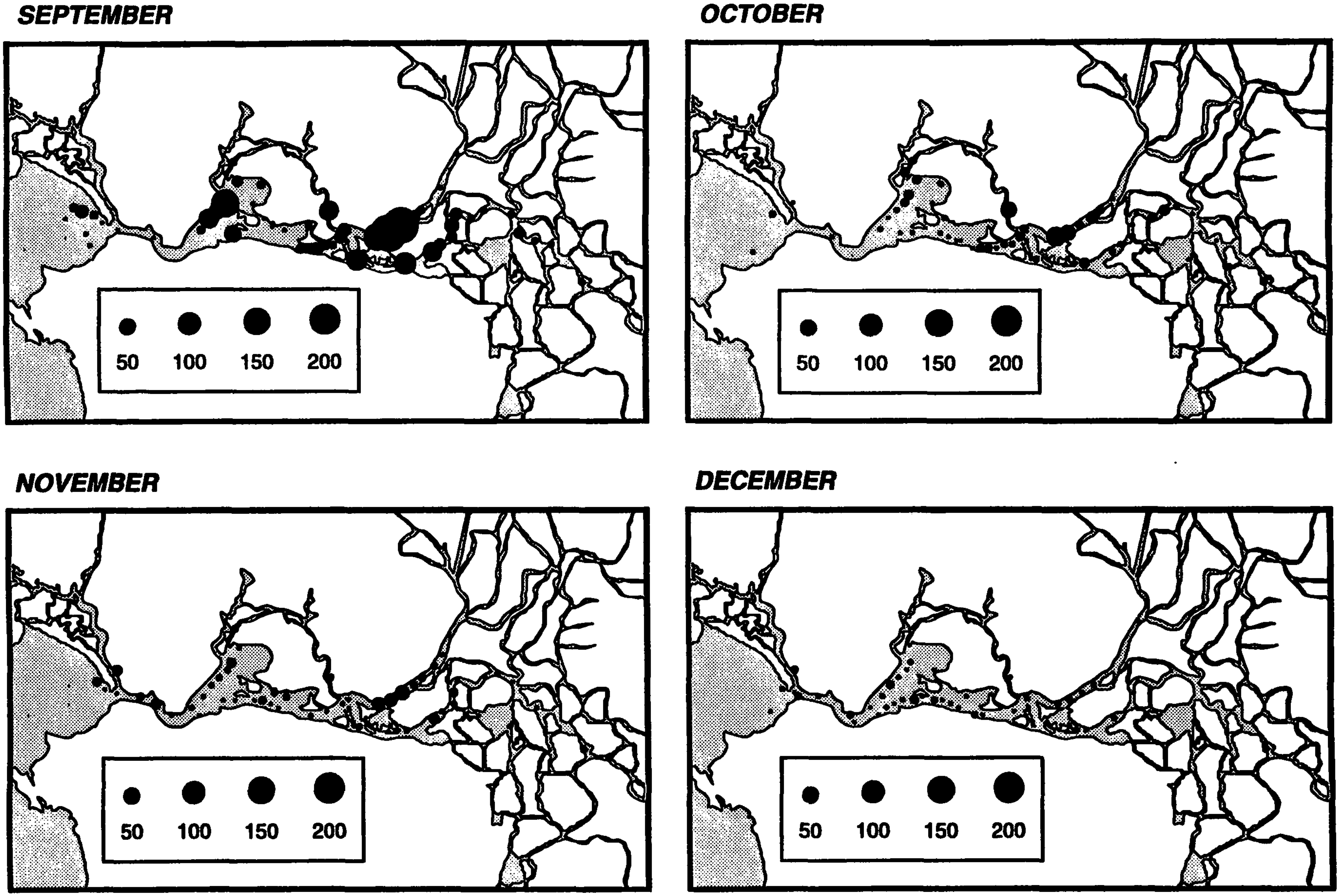
DECEMBER



Striped Bass (Age 0+) - 1984



Striped Bass (Age 0+) - 1985



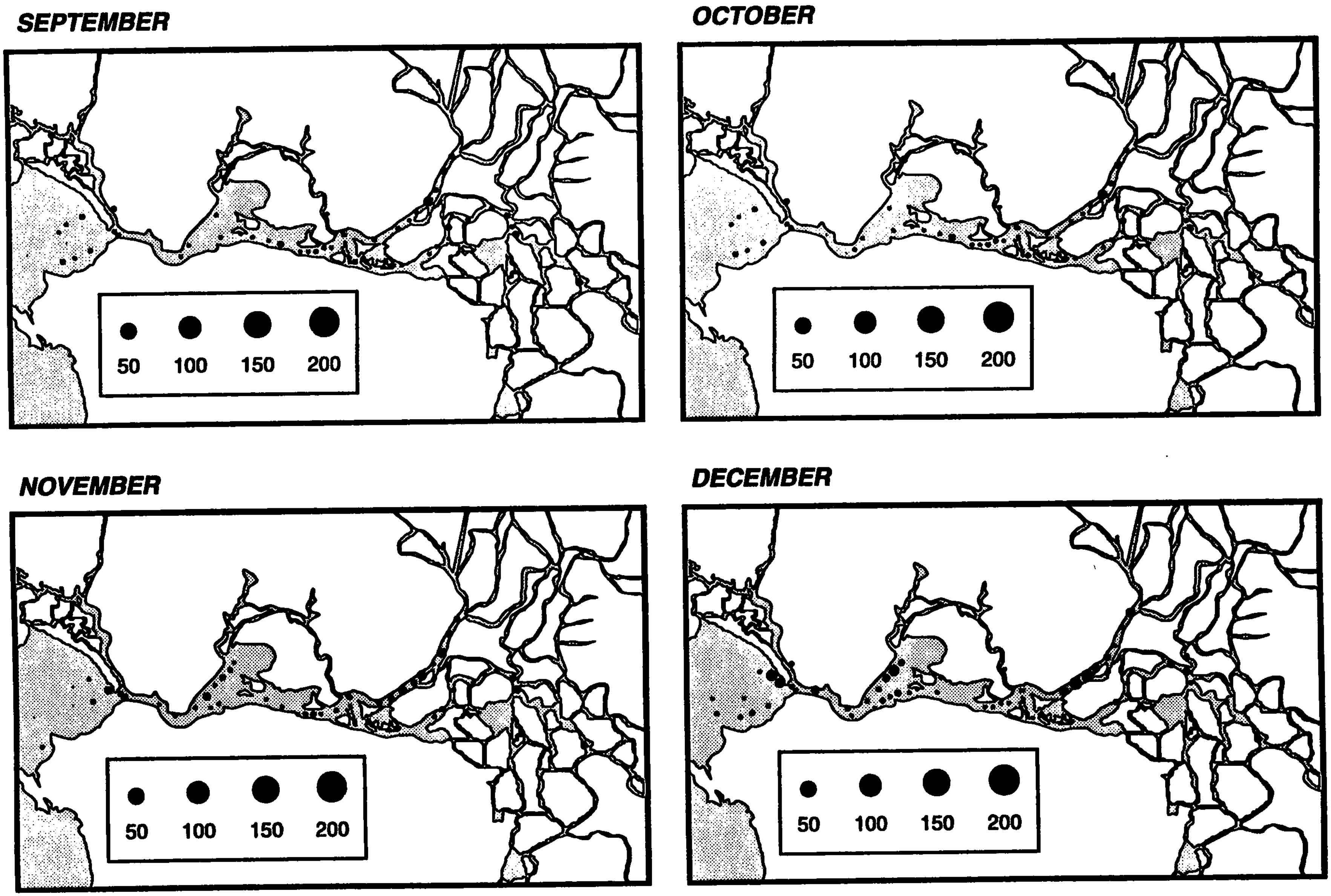
SEPTEMBER

OCTOBER

NOVEMBER

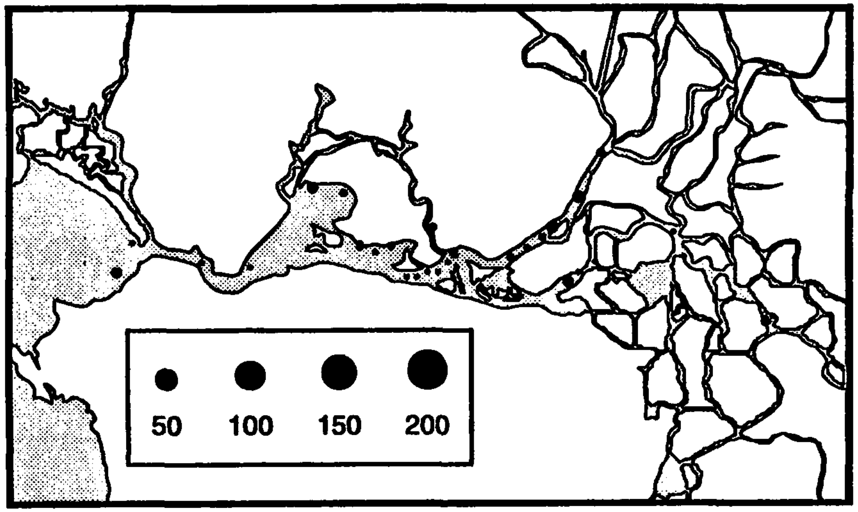
DECEMBER

Striped Bass (Age 0+) - 1986

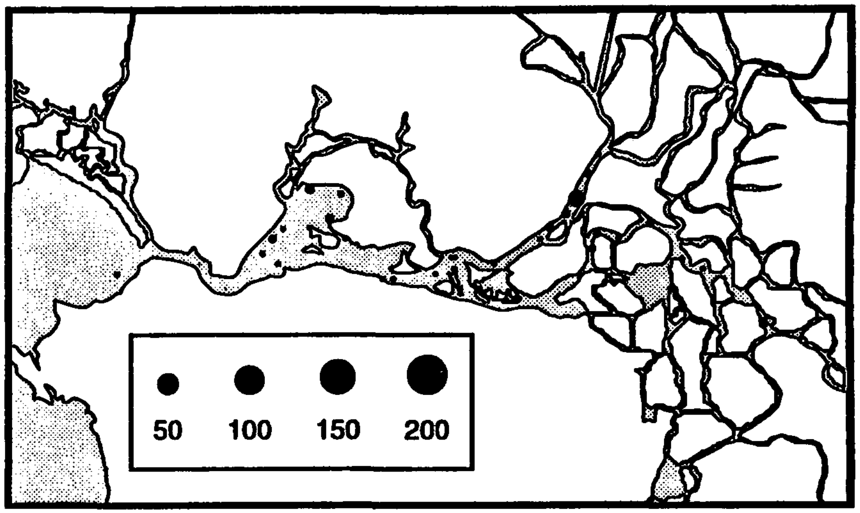


Striped Bass (Age 0+) - 1987

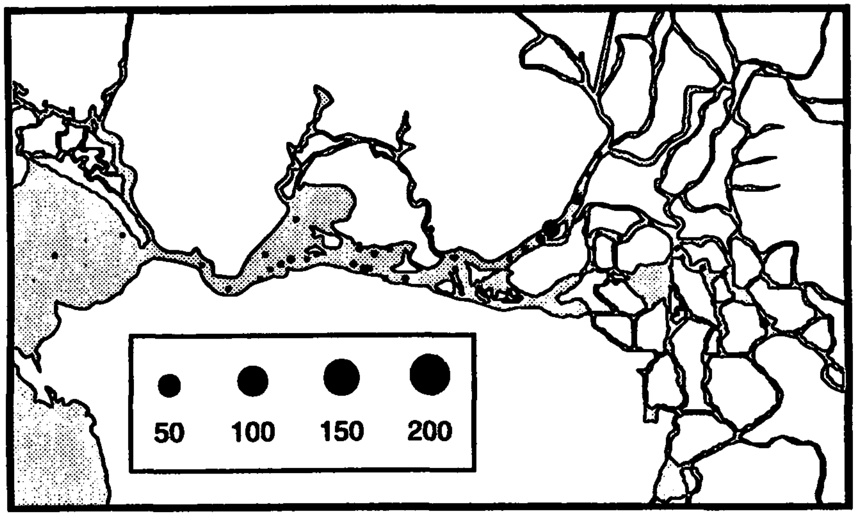
SEPTEMBER



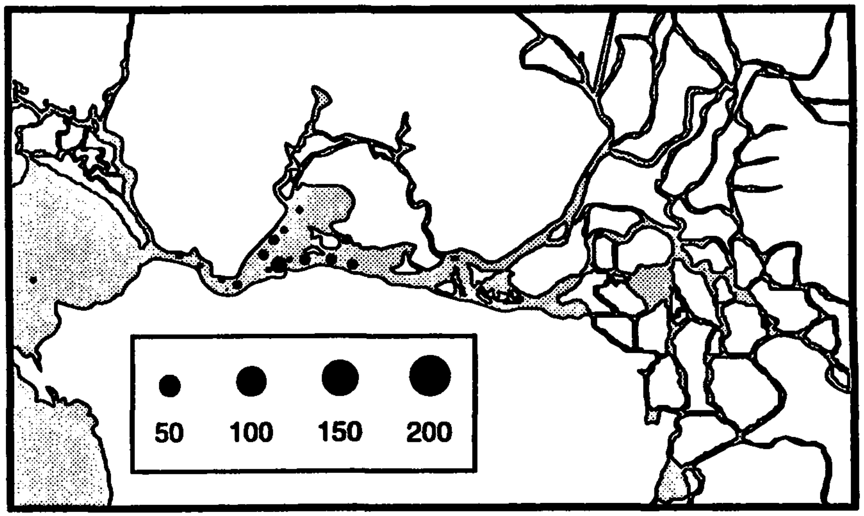
OCTOBER



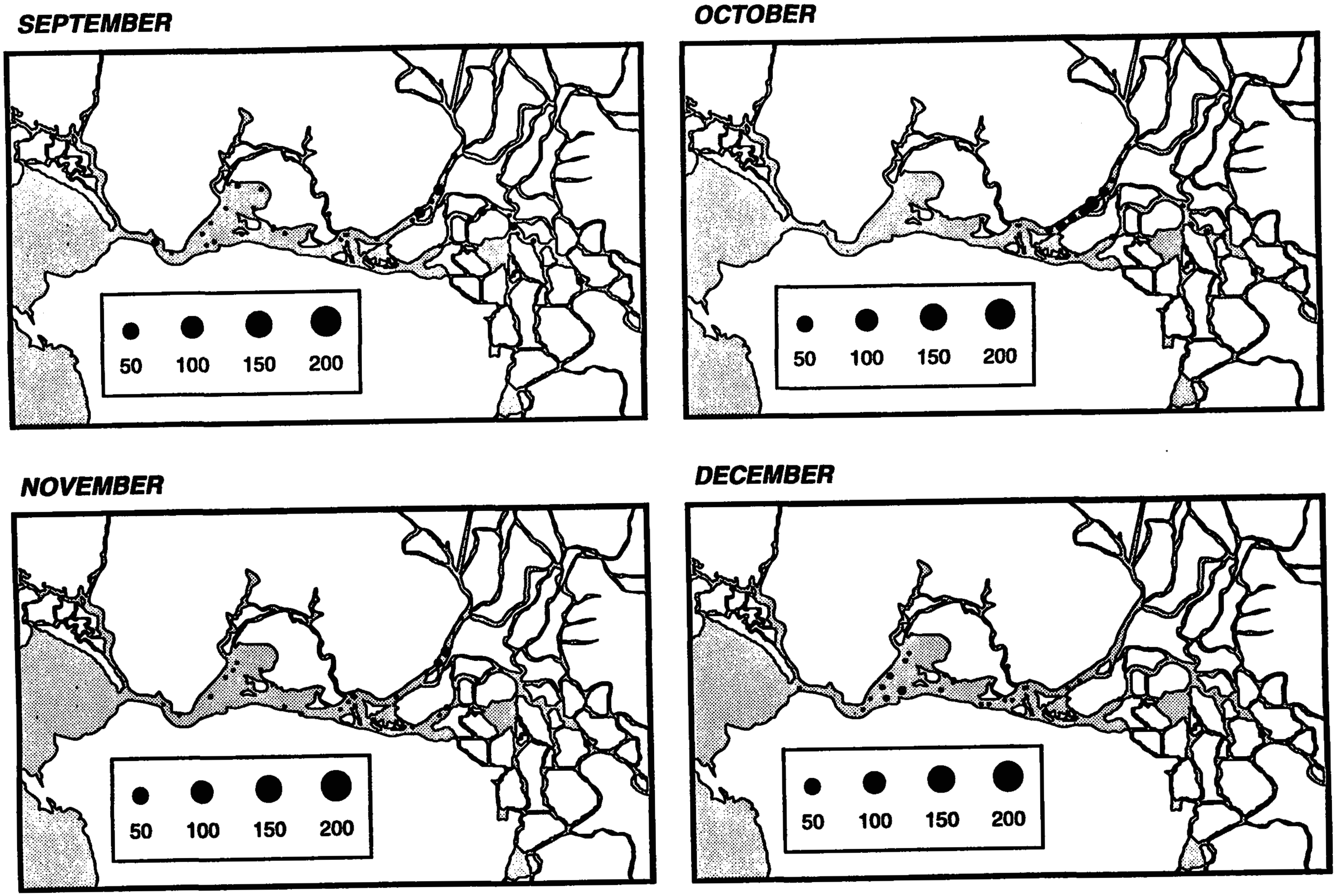
NOVEMBER



DECEMBER

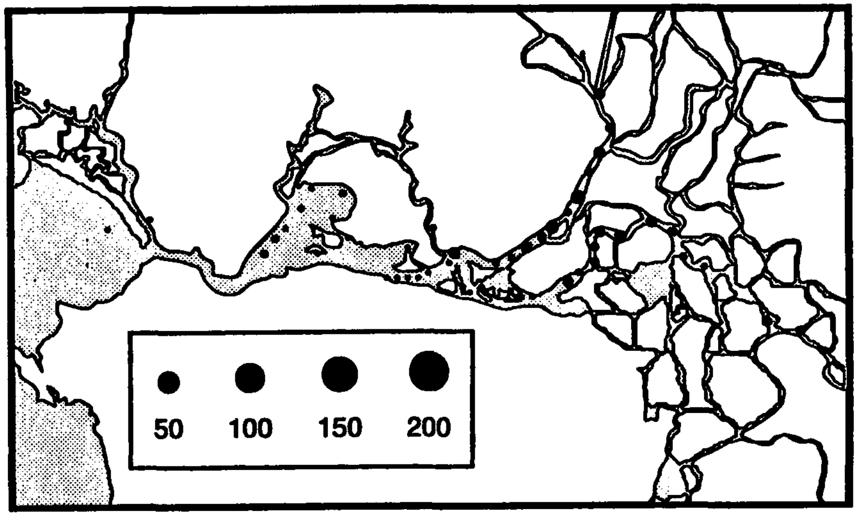


Striped Bass (Age 0+) - 1988

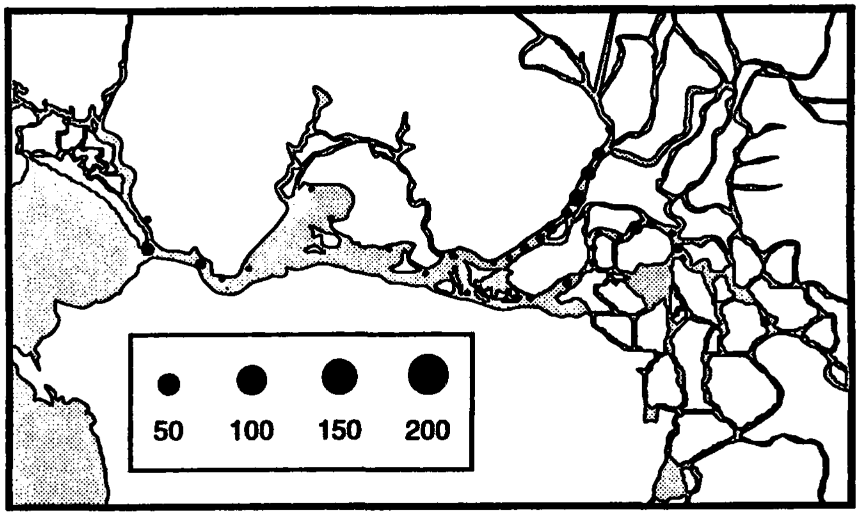


Striped Bass (Age 0+) - 1989

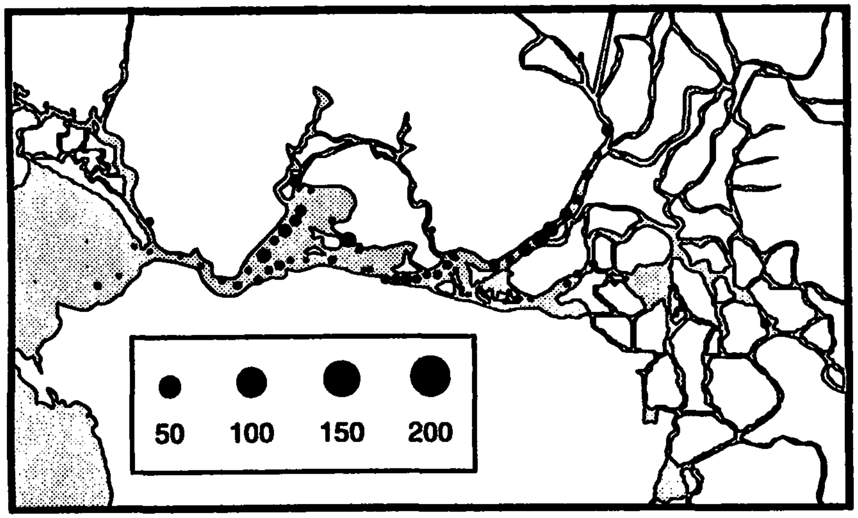
SEPTEMBER



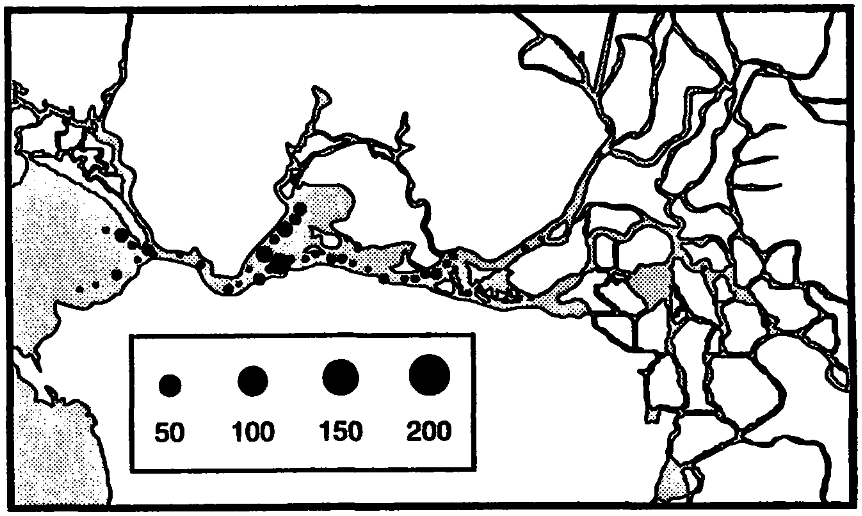
OCTOBER



NOVEMBER



DECEMBER

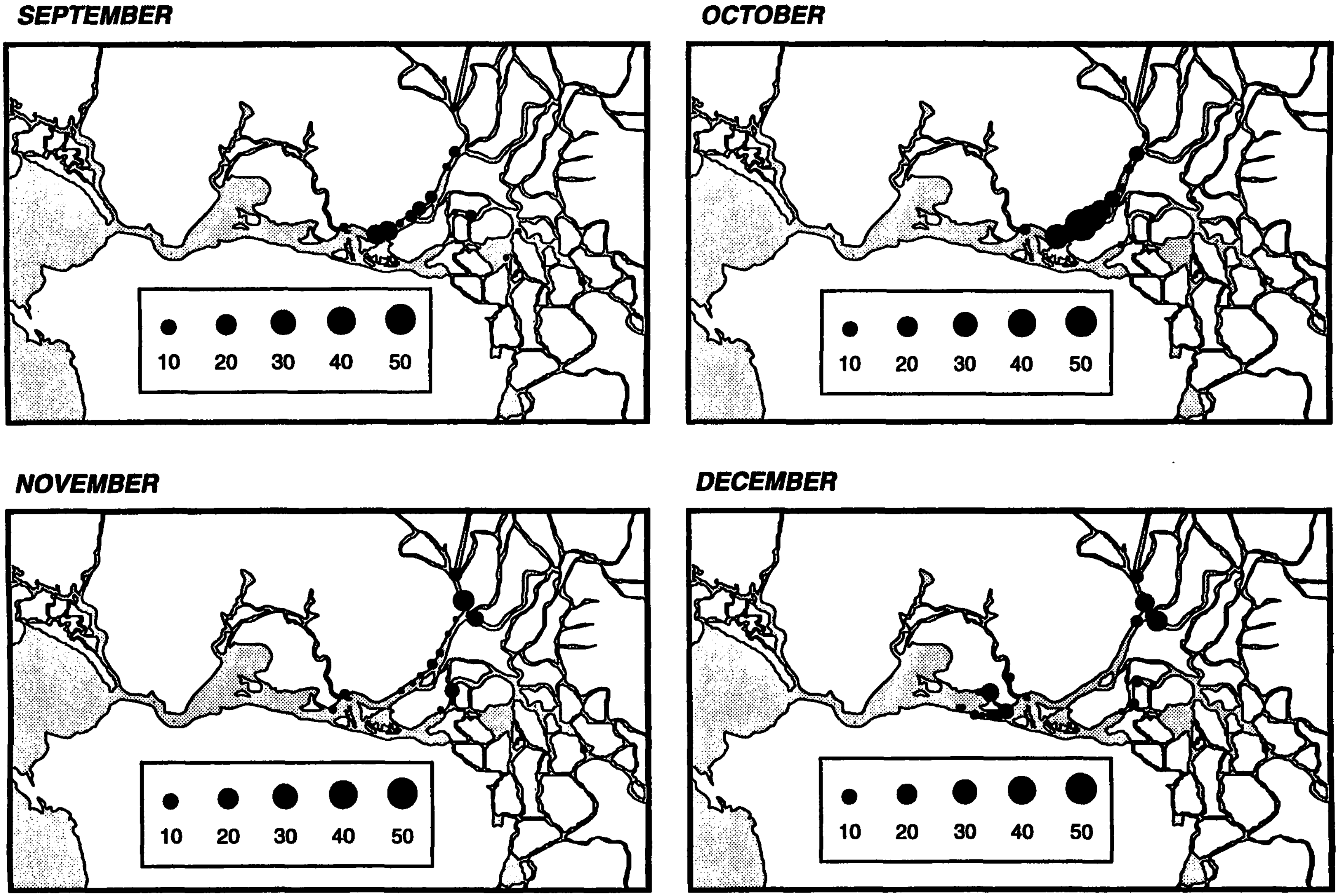


Striped Bass (Age 0+) - 1990

Appendix A-3

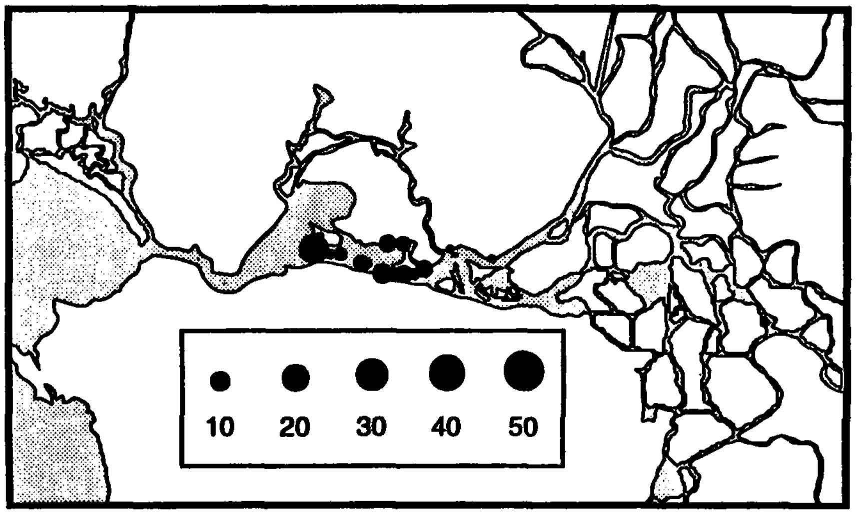
Spatial Abundance Maps for Selected Species Sampled in Midwater Trawl Survey, 1977 - 1990

Delta Smelt

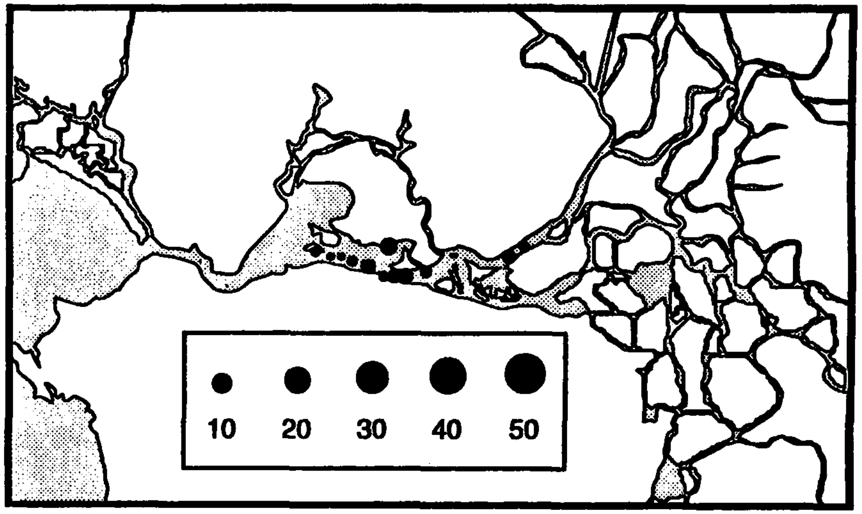


Delta Smelt - 1977

SEPTEMBER



OCTOBER



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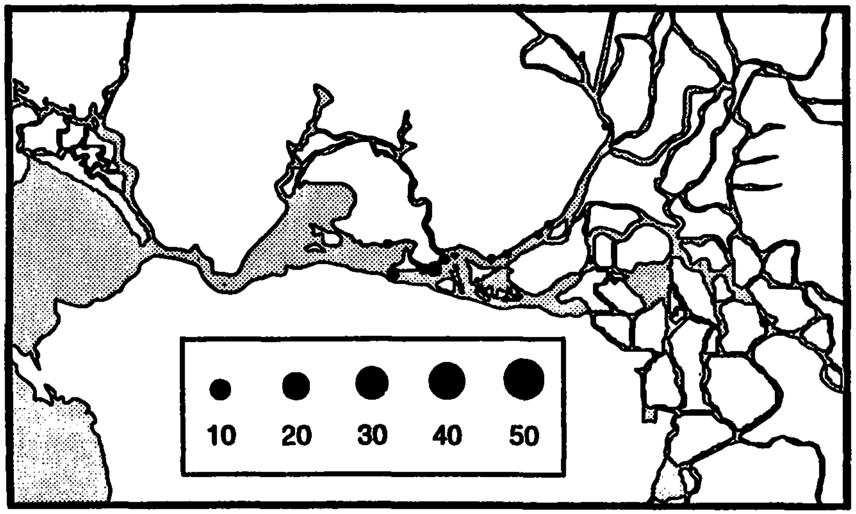
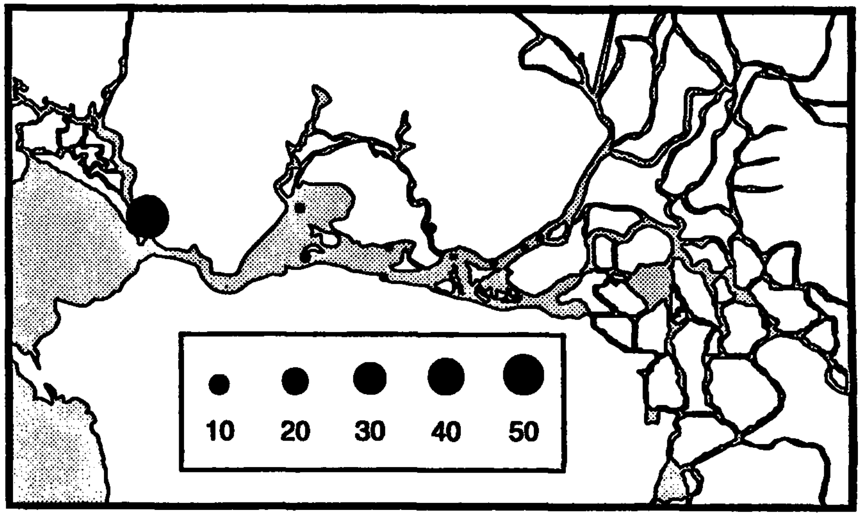
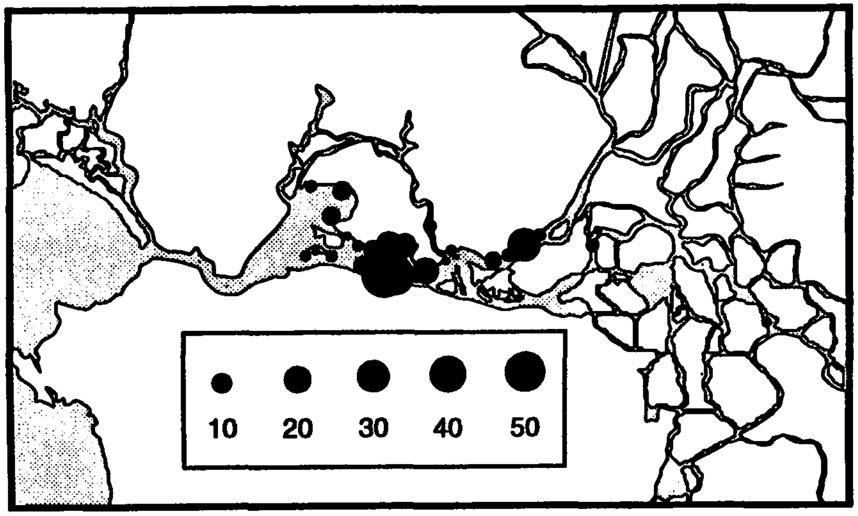


DECEMBER

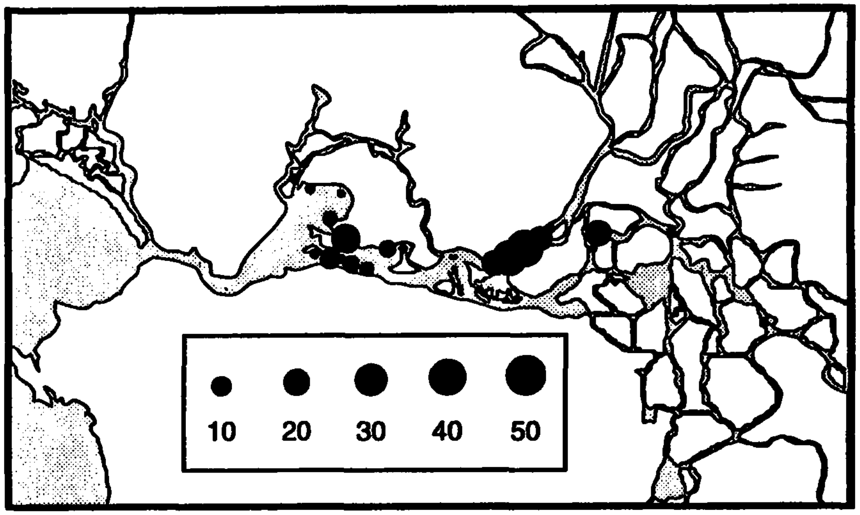


Delta Smelt - 1978

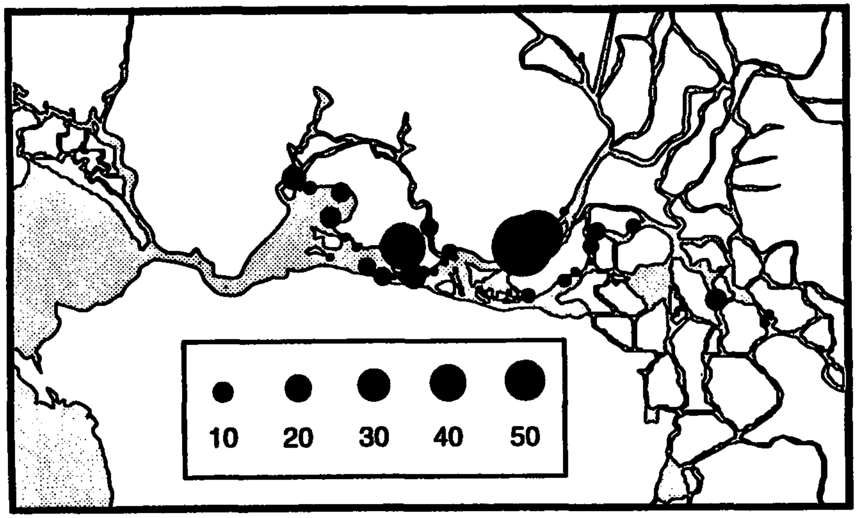
SEPTEMBER



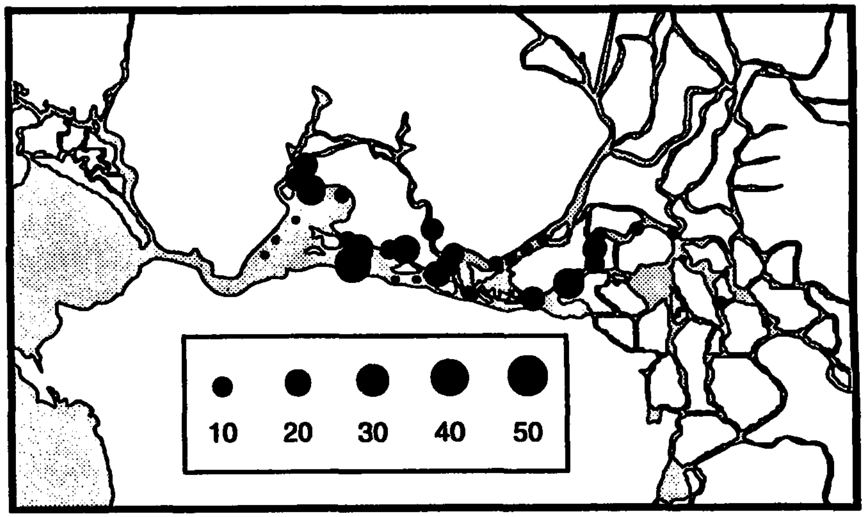
OCTOBER



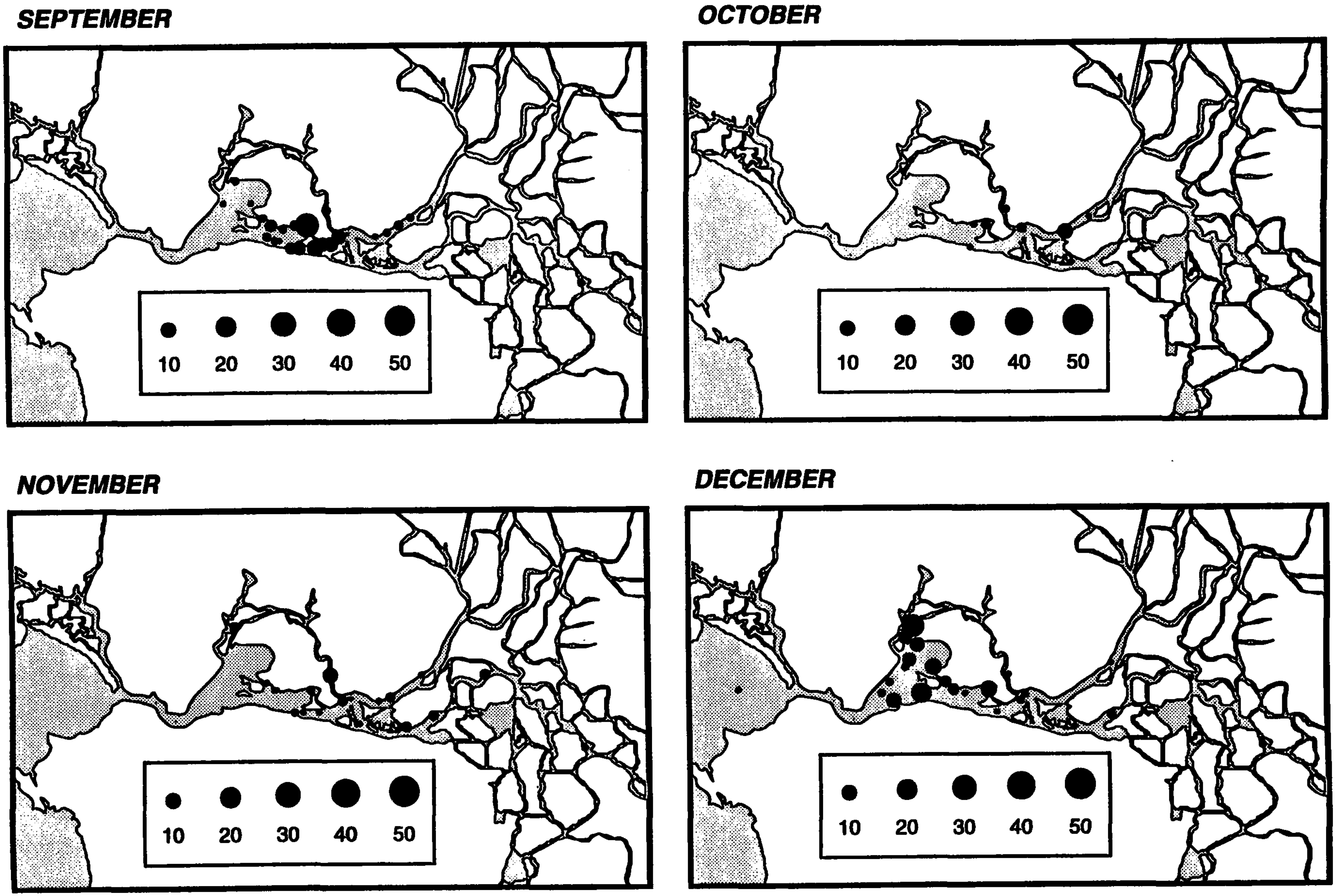
NOVEMBER



DECEMBER



Delta Smelt - 1980

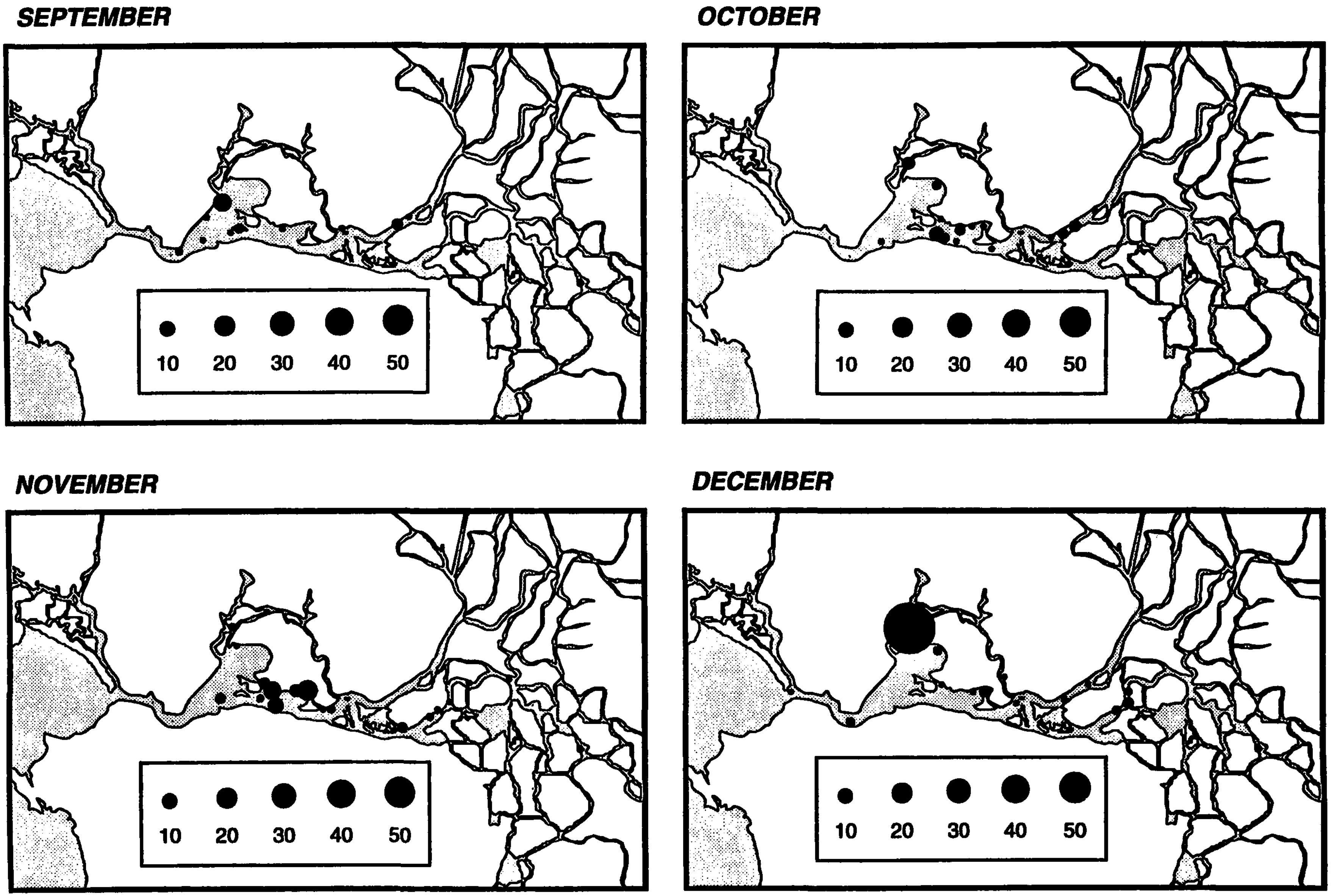

SEPTEMBER

OCTOBER

NOVEMBER

DECEMBER

Delta Smelt - 1981

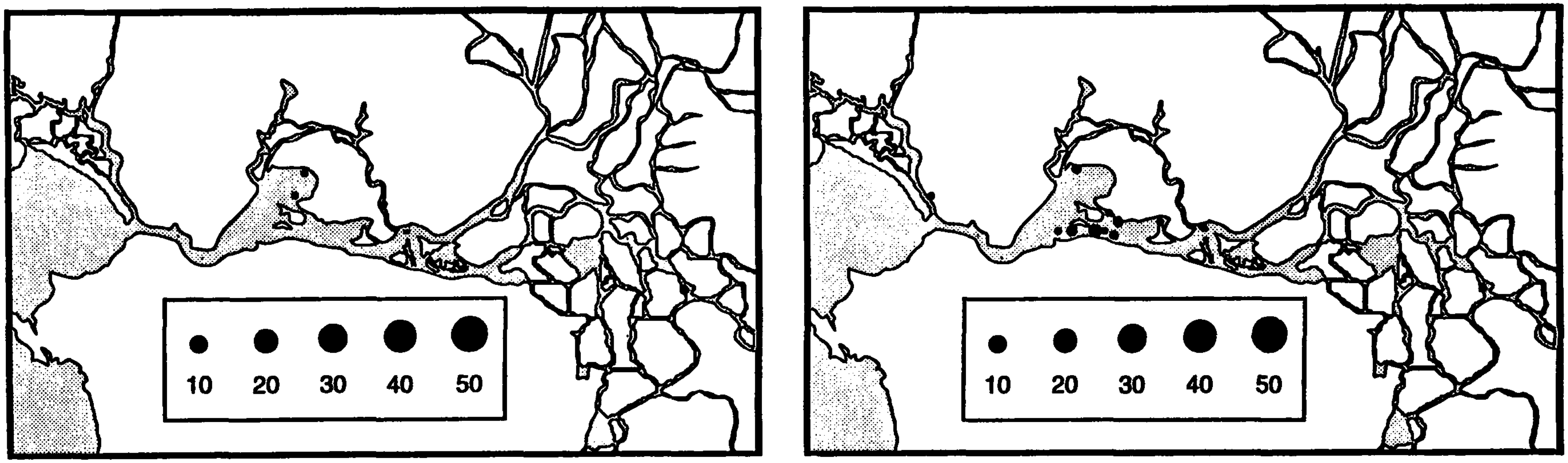

SEPTEMBER

OCTOBER

NOVEMBER

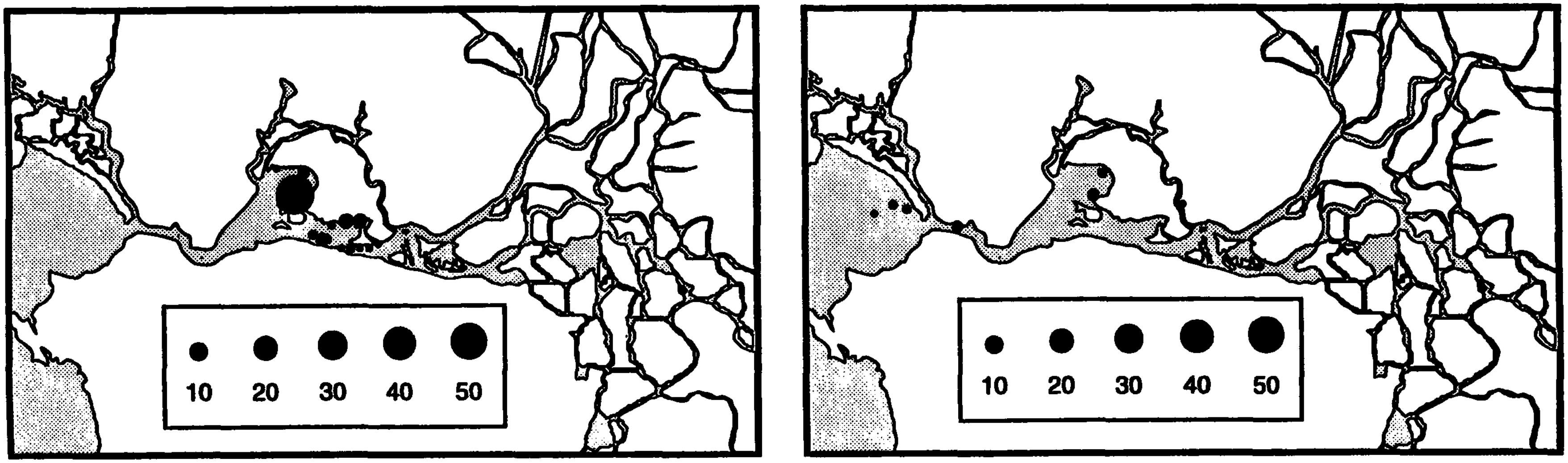
DECEMBER

Delta Smelt - 1982



SEPTEMBER

OCTOBER

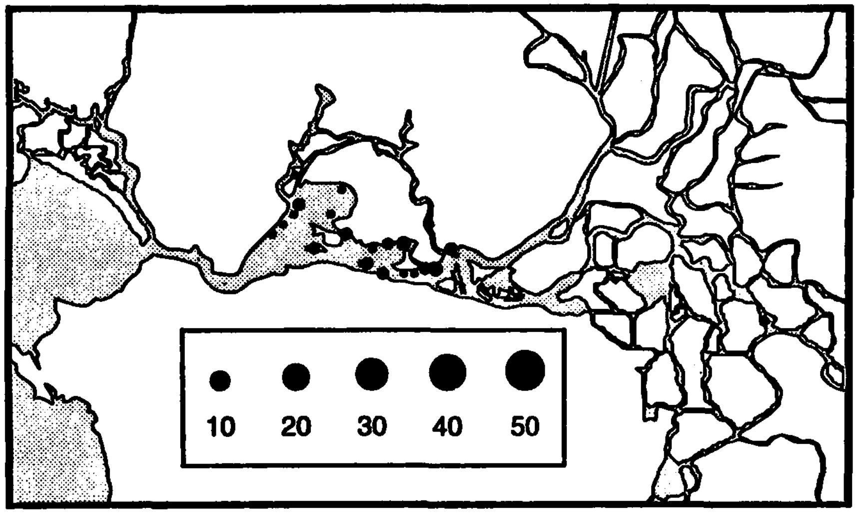


NOVEMBER

DECEMBER

Delta Smelt - 1983

SEPTEMBER



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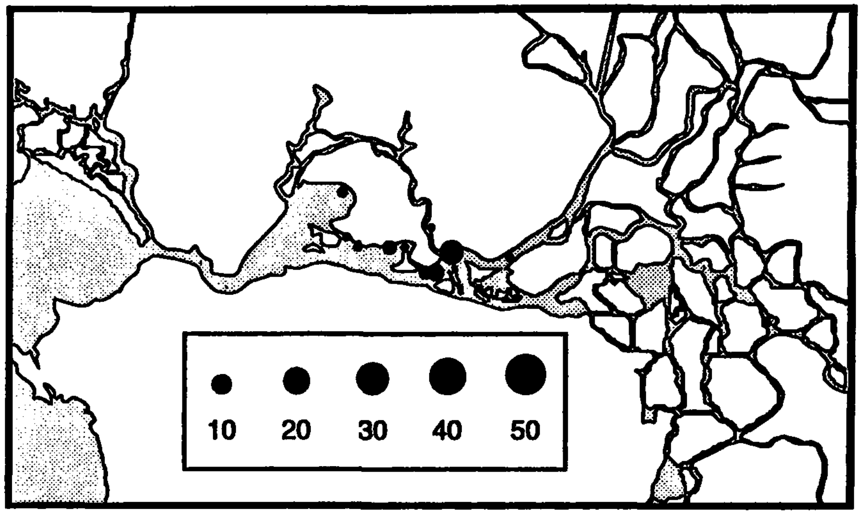

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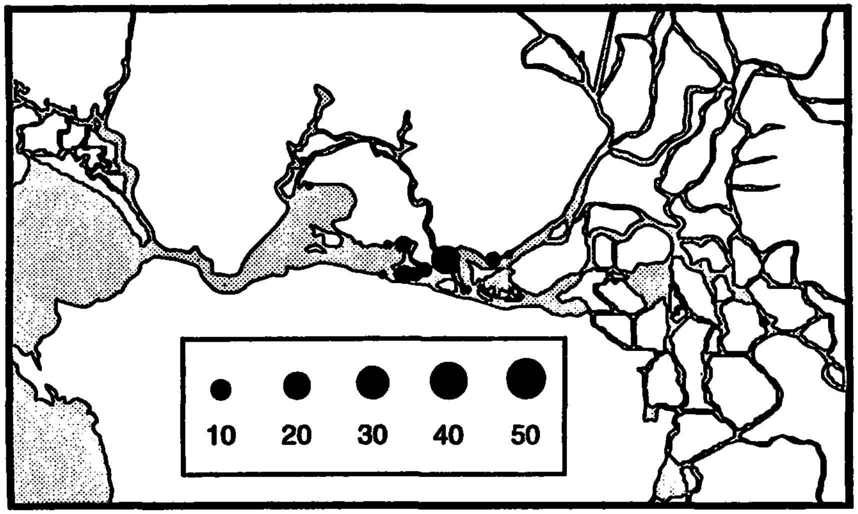
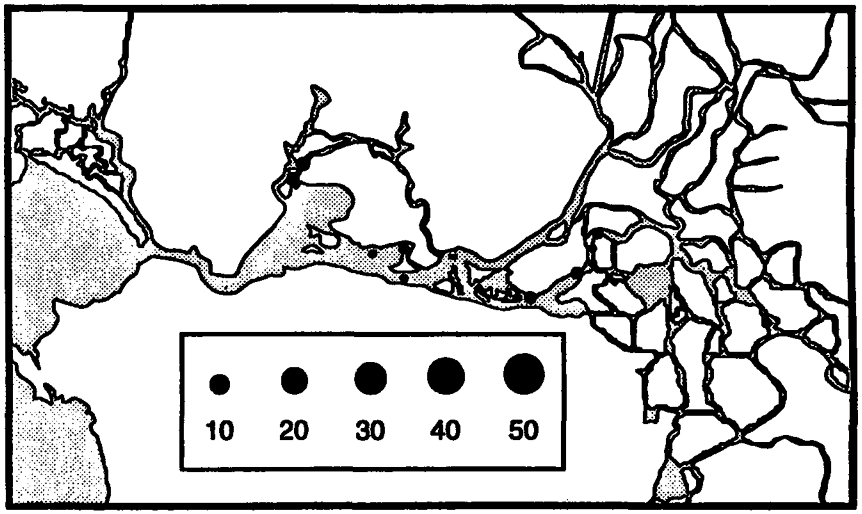
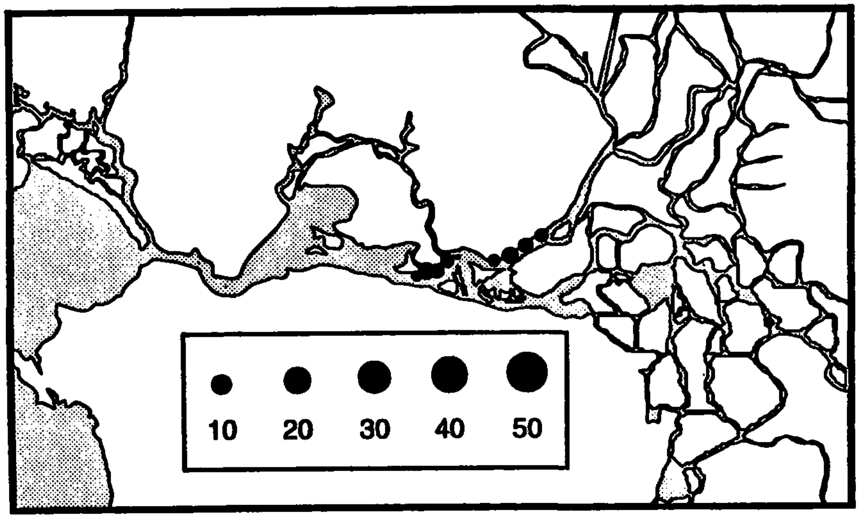


DECEMBER

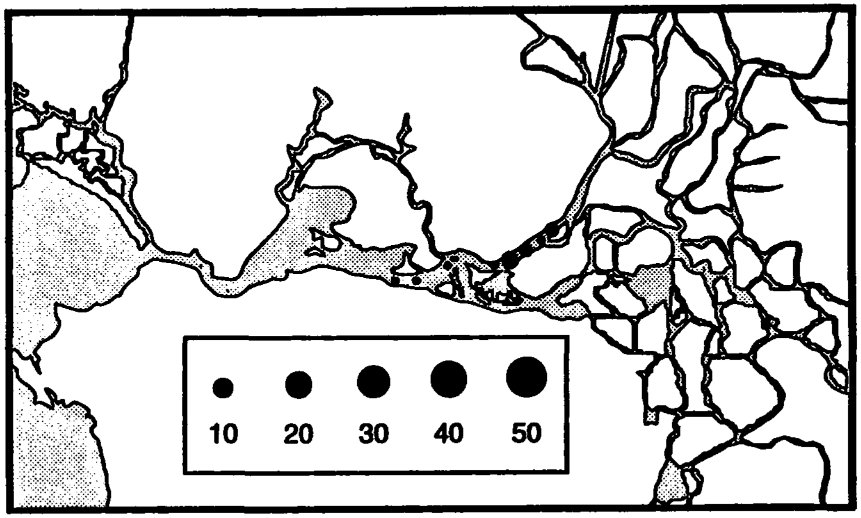


Delta Smelt - 1984

SEPTEMBER



OCTOBER



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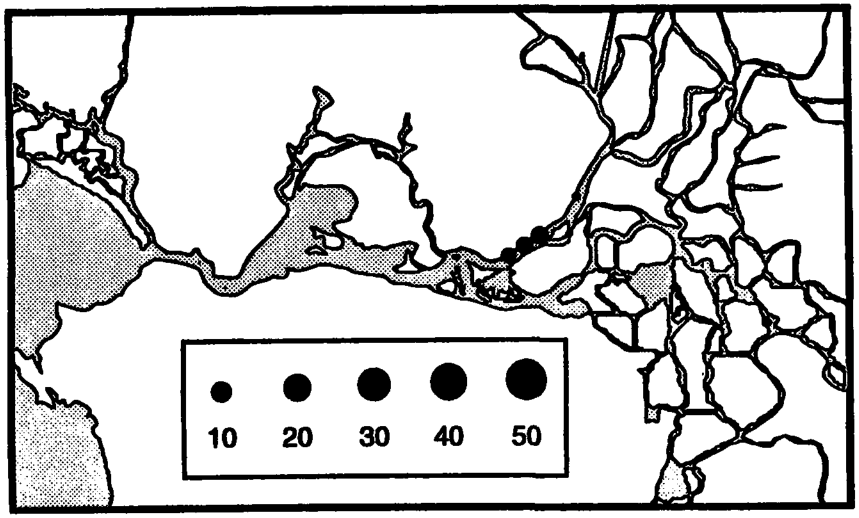
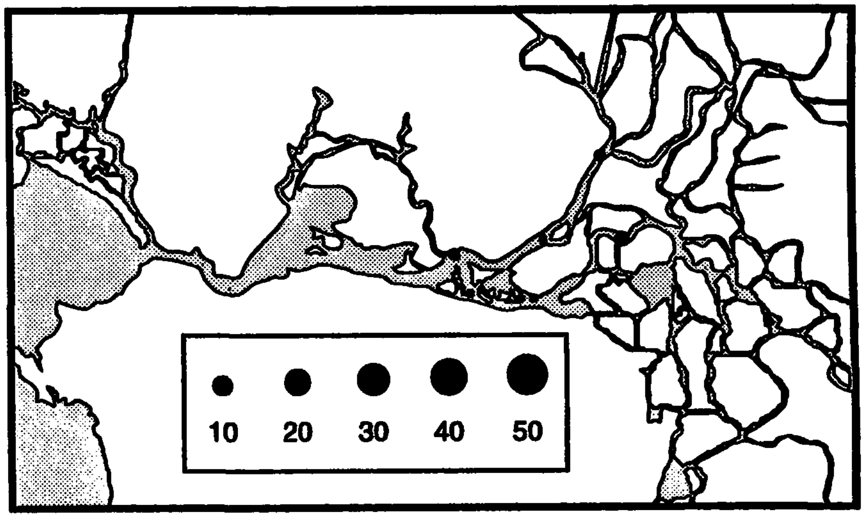
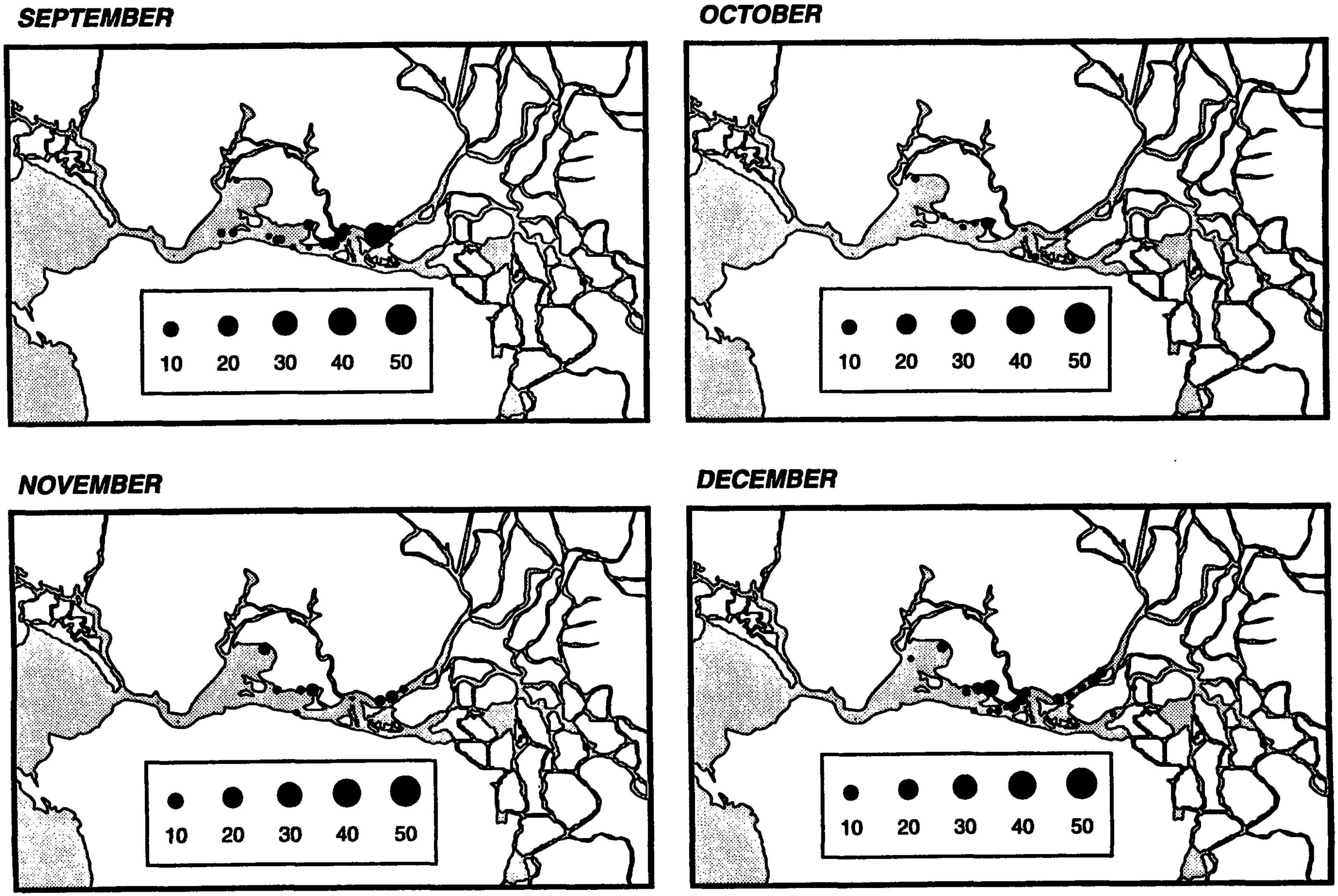


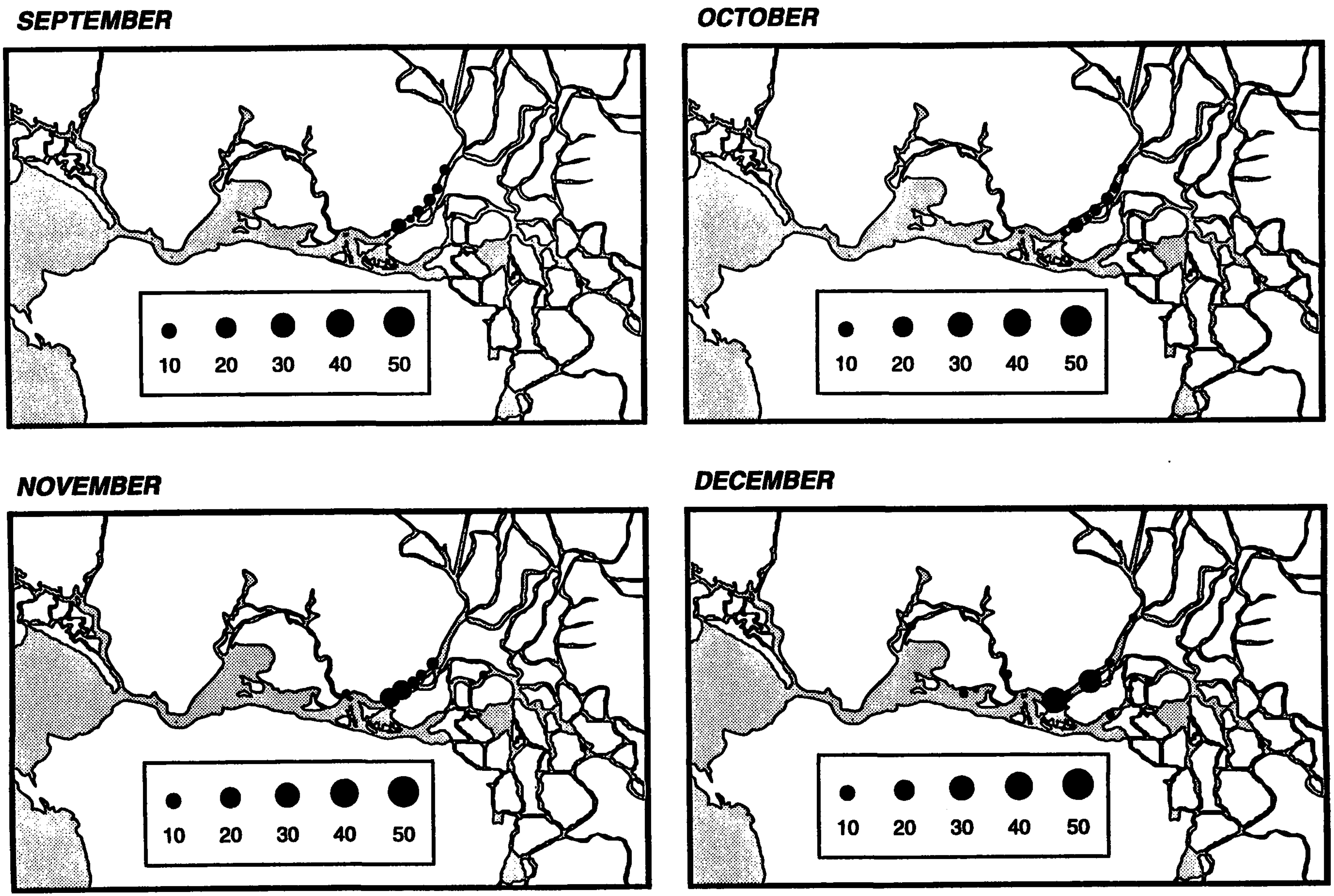
DECEMBER



Delta Smelt - 1985

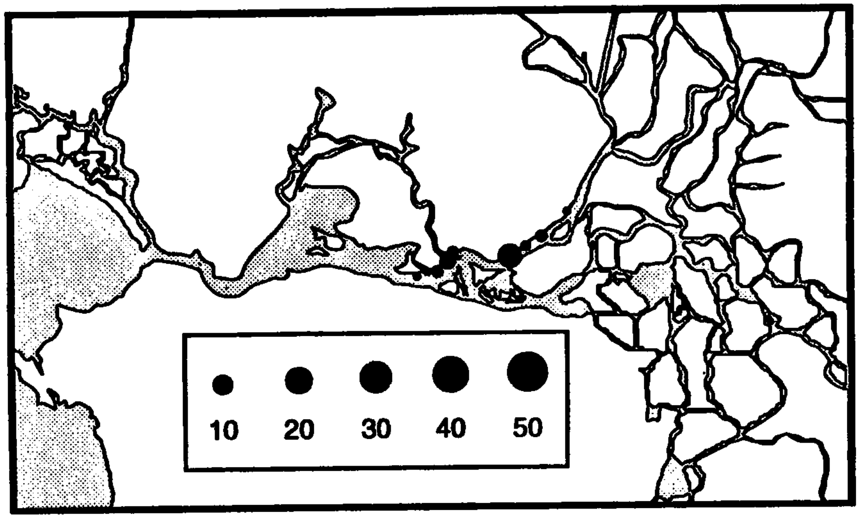


Delta Smelt - 1986

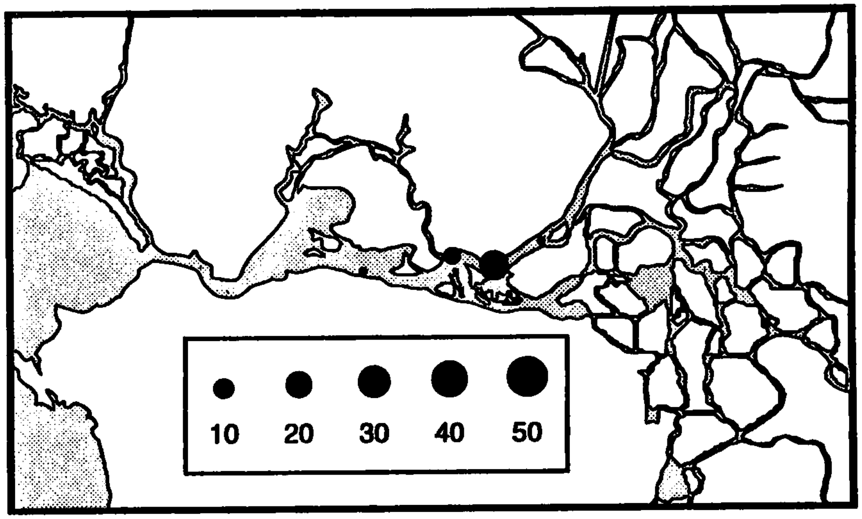


Delta Smelt - 1987

SEPTEMBER



OCTOBER



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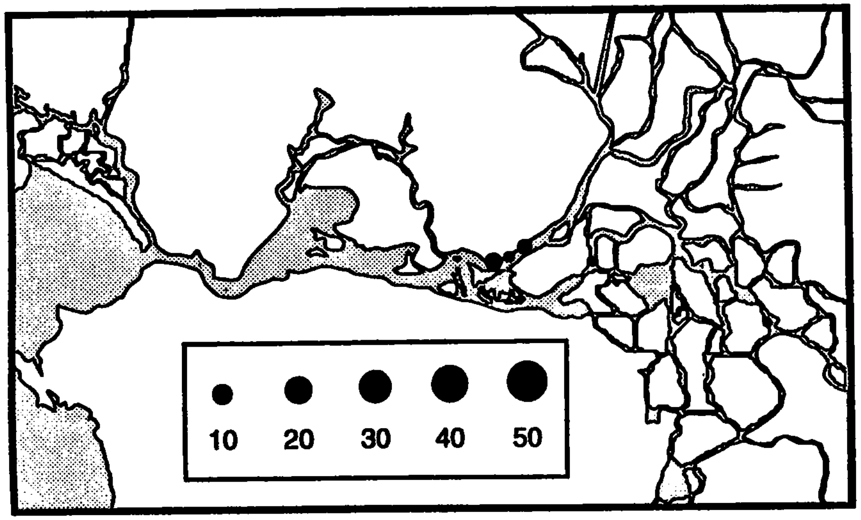

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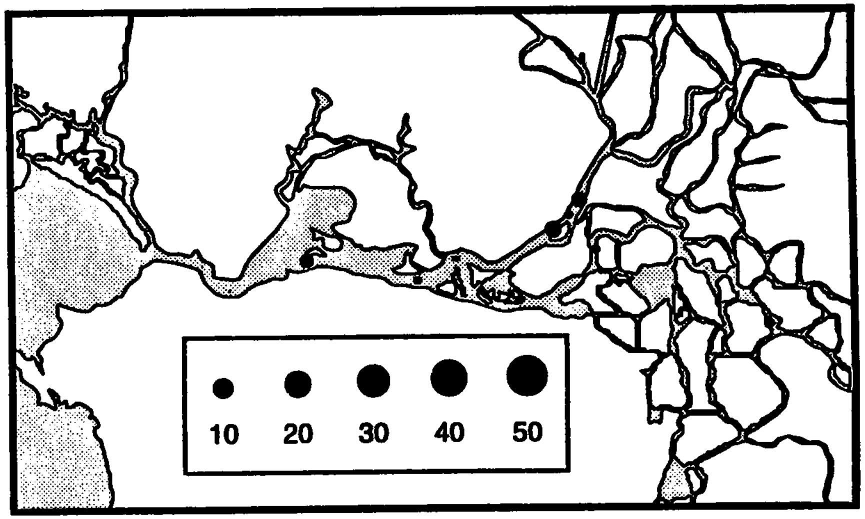
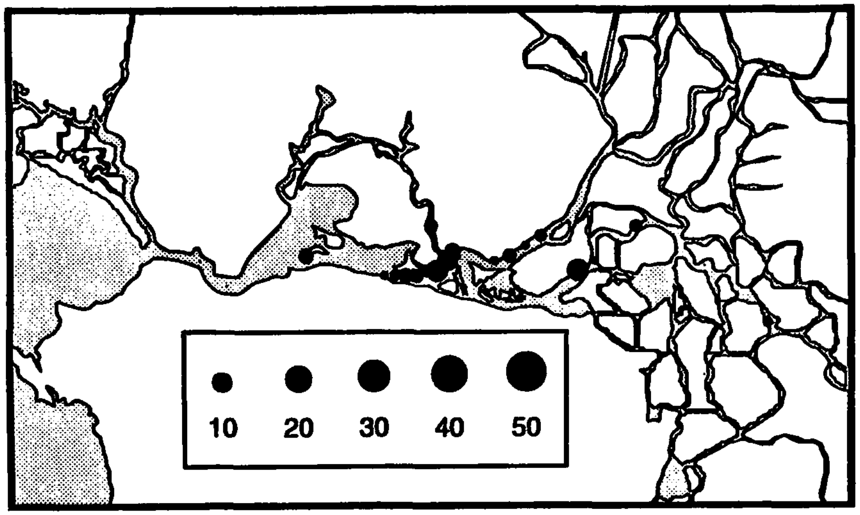
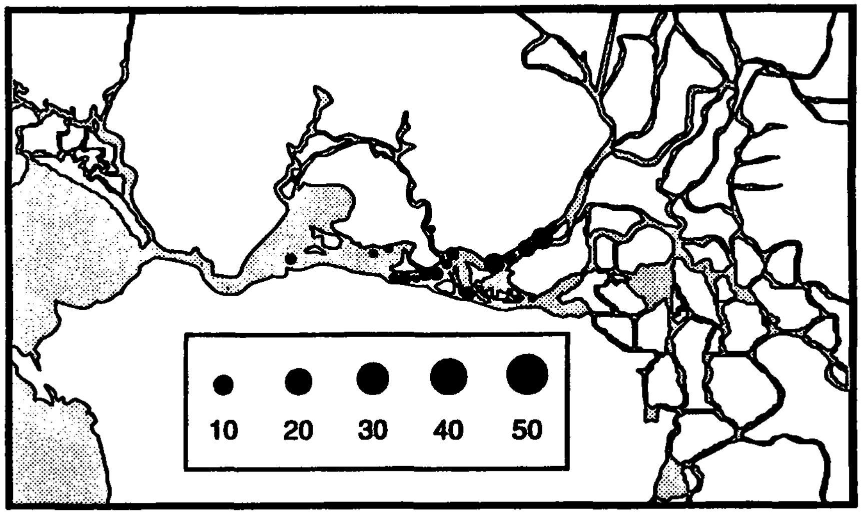


Delta Smelt - 1988

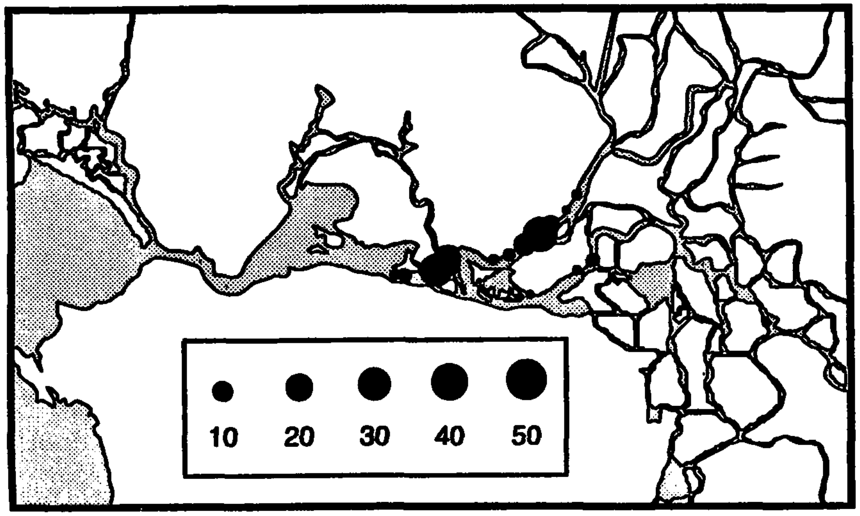
SEPTEMBER



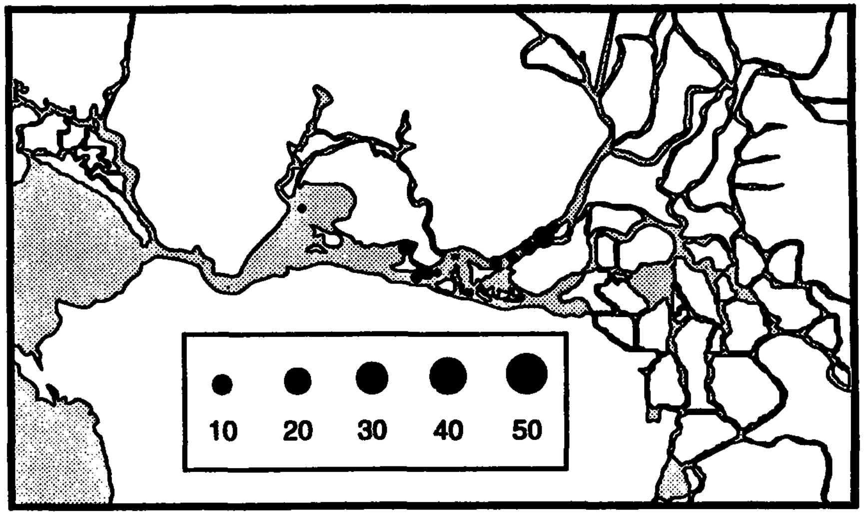
OCTOBER



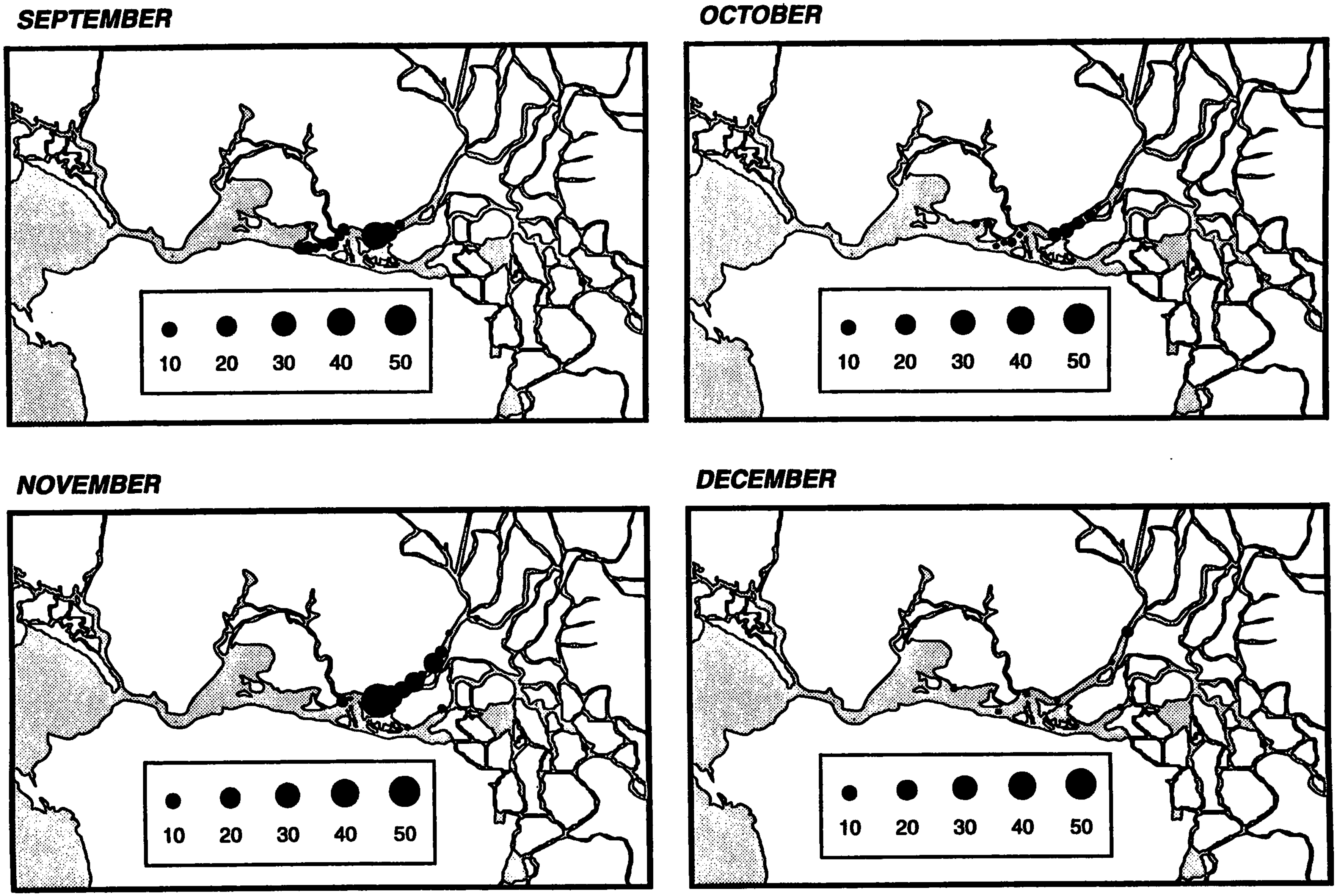
NOVEMBER



DECEMBER



Delta Smelt - 1989



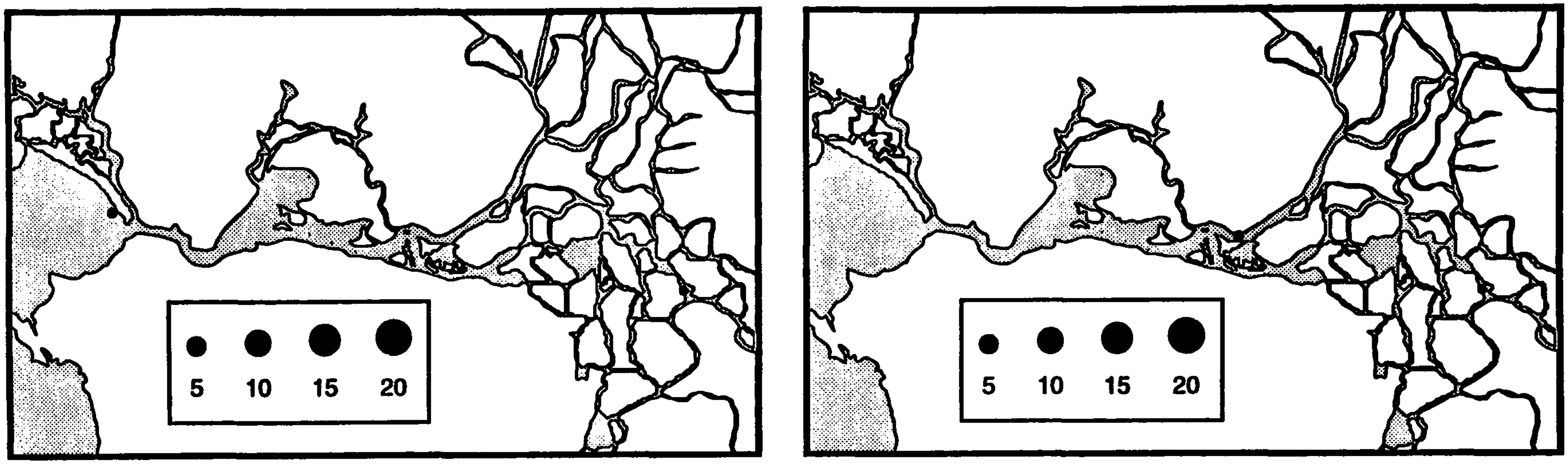
Delta Smelt - 1990

Appendix A-4

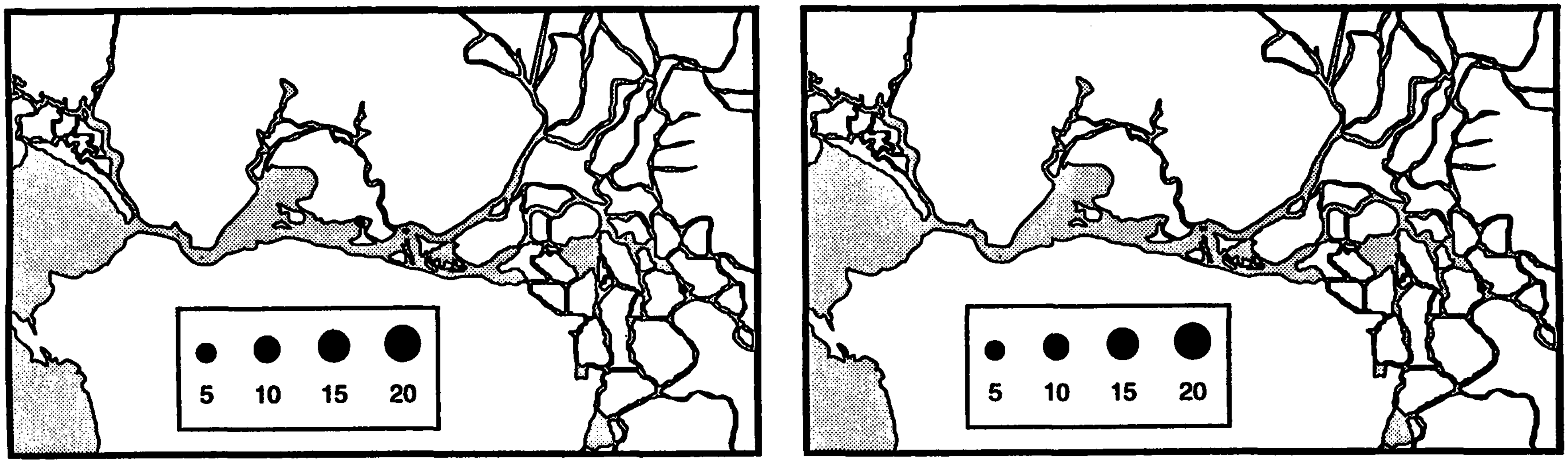
Spatial Abundance Maps for Selected Species Sampled in Midwater Trawl Survey, 1977 - 1990

Starry Flounder

SEPTEMBER OCTOBER

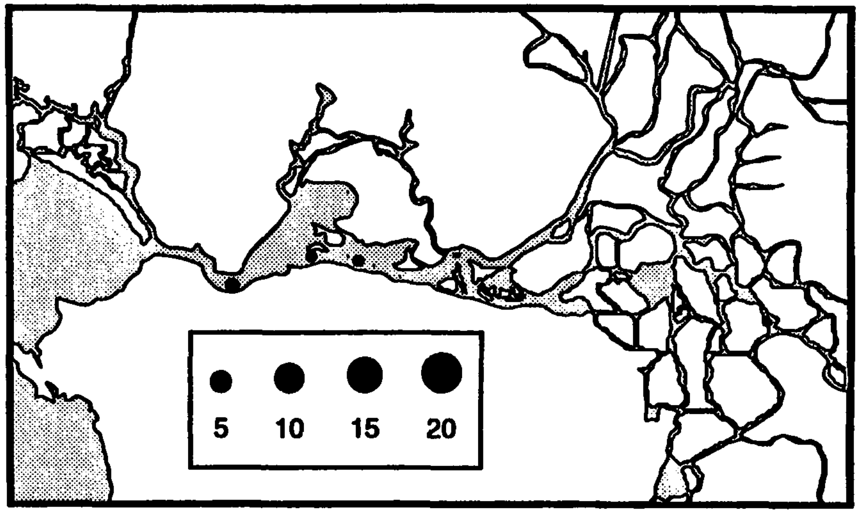


NOVEMBER DECEMBER

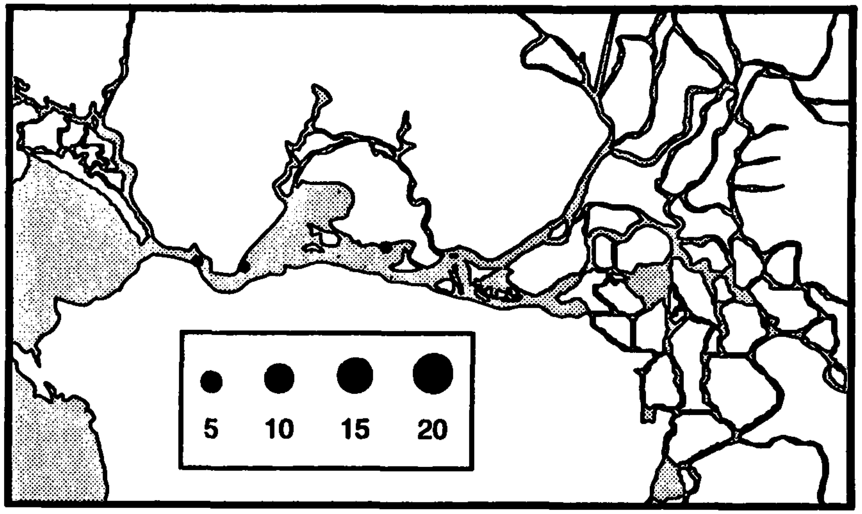


Starry Flounder - 1977

SEPTEMBER



OCTOBER



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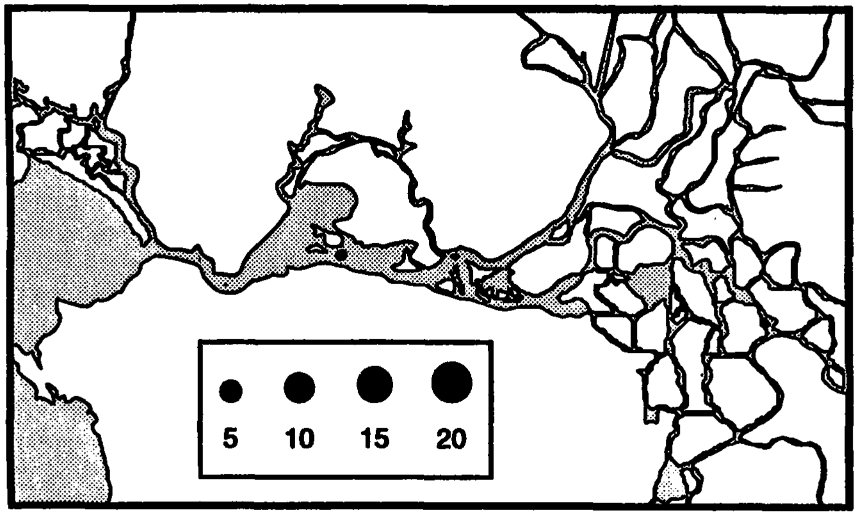
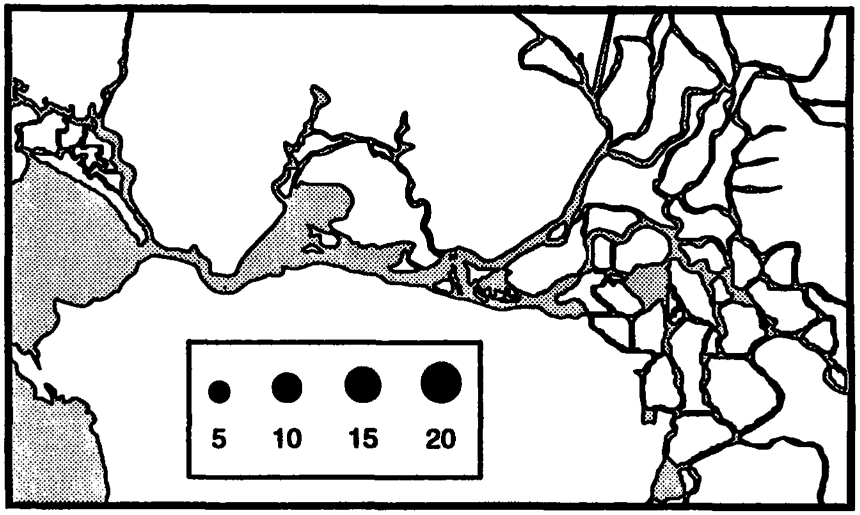
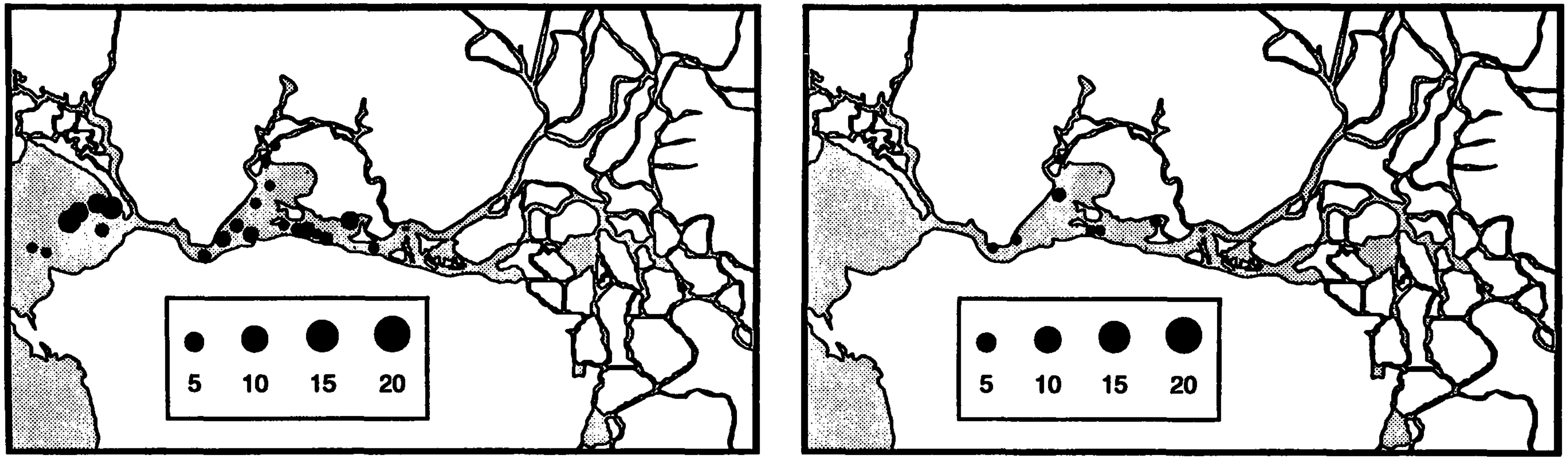


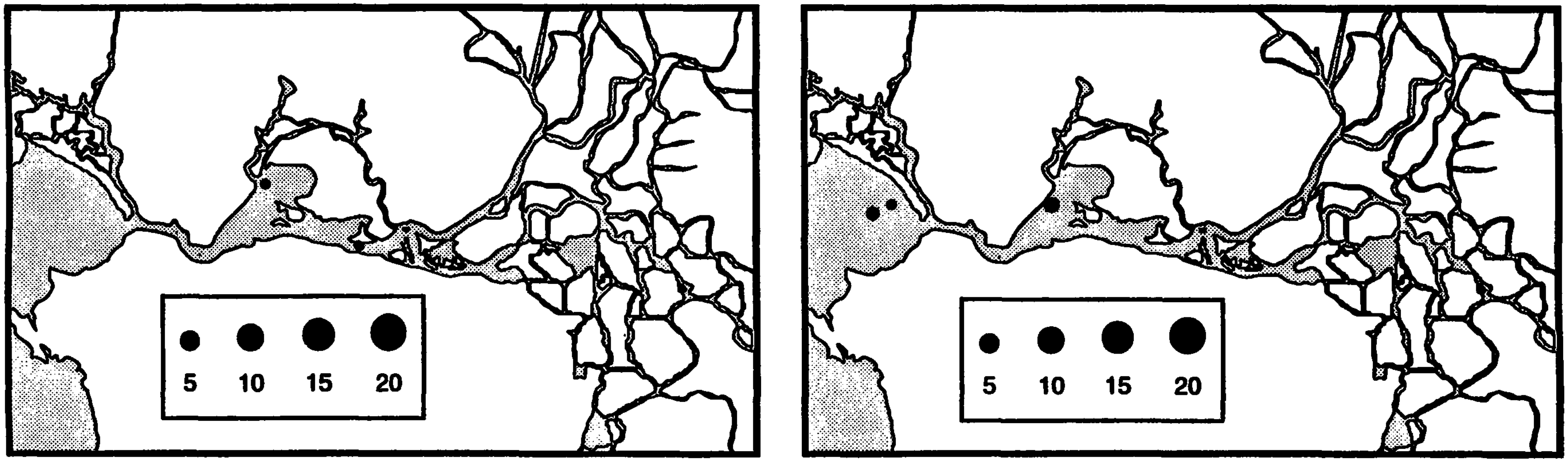
DECEMBER



Starry Flounder - 1978


SEPTEMBER

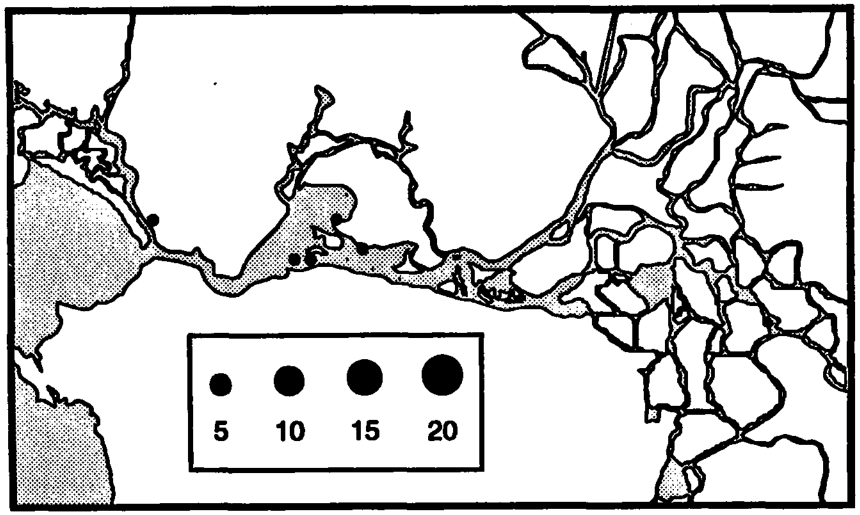
OCTOBER


NOVEMBER

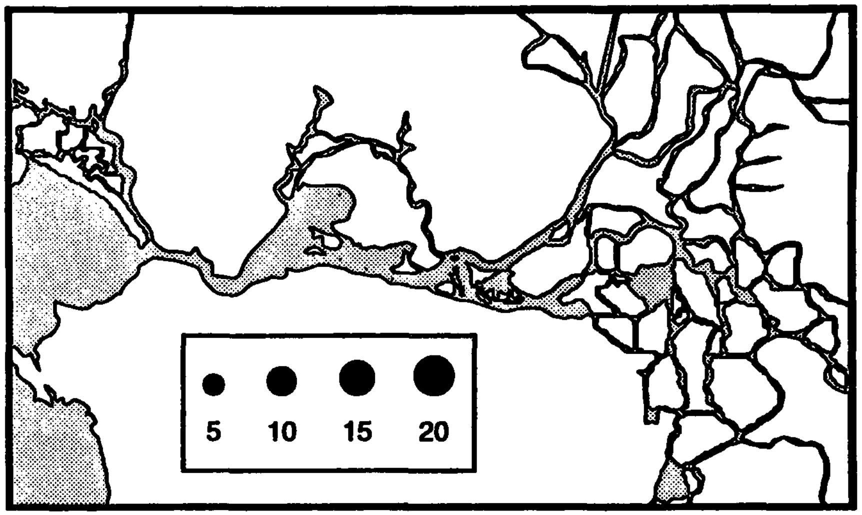
DECEMBER

Starry Flounder - 1980

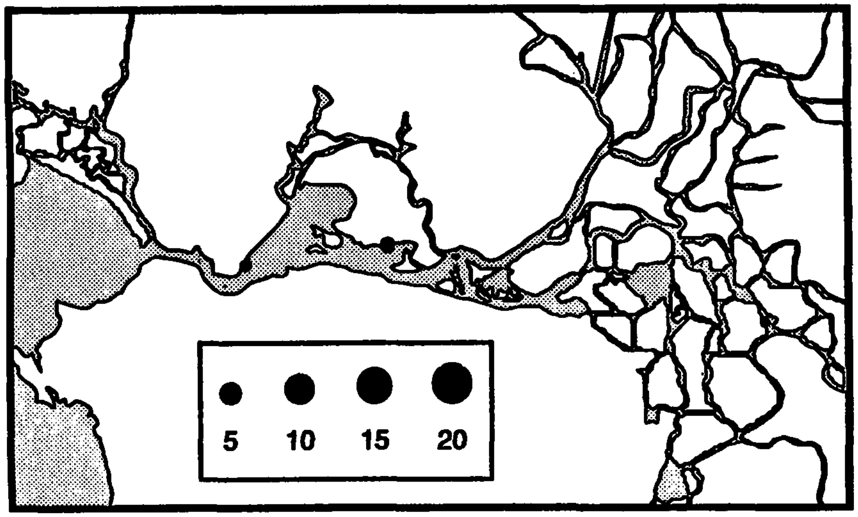
SEPTEMBER



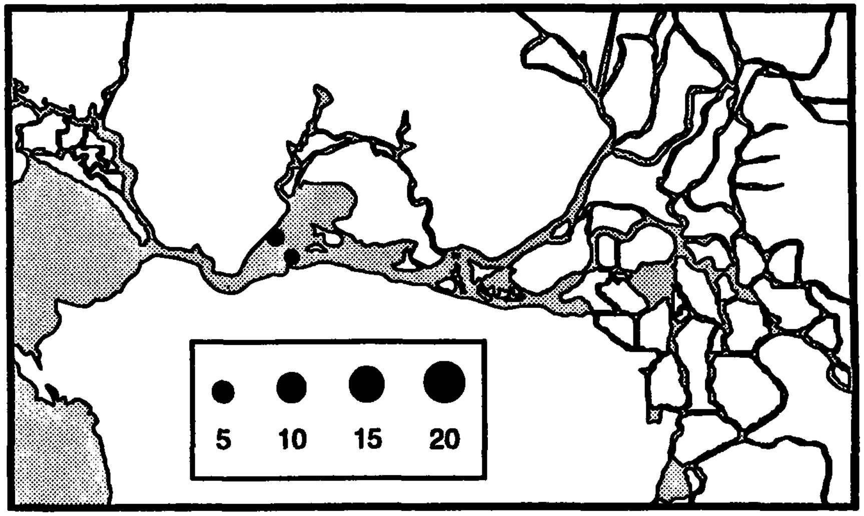
OCTOBER



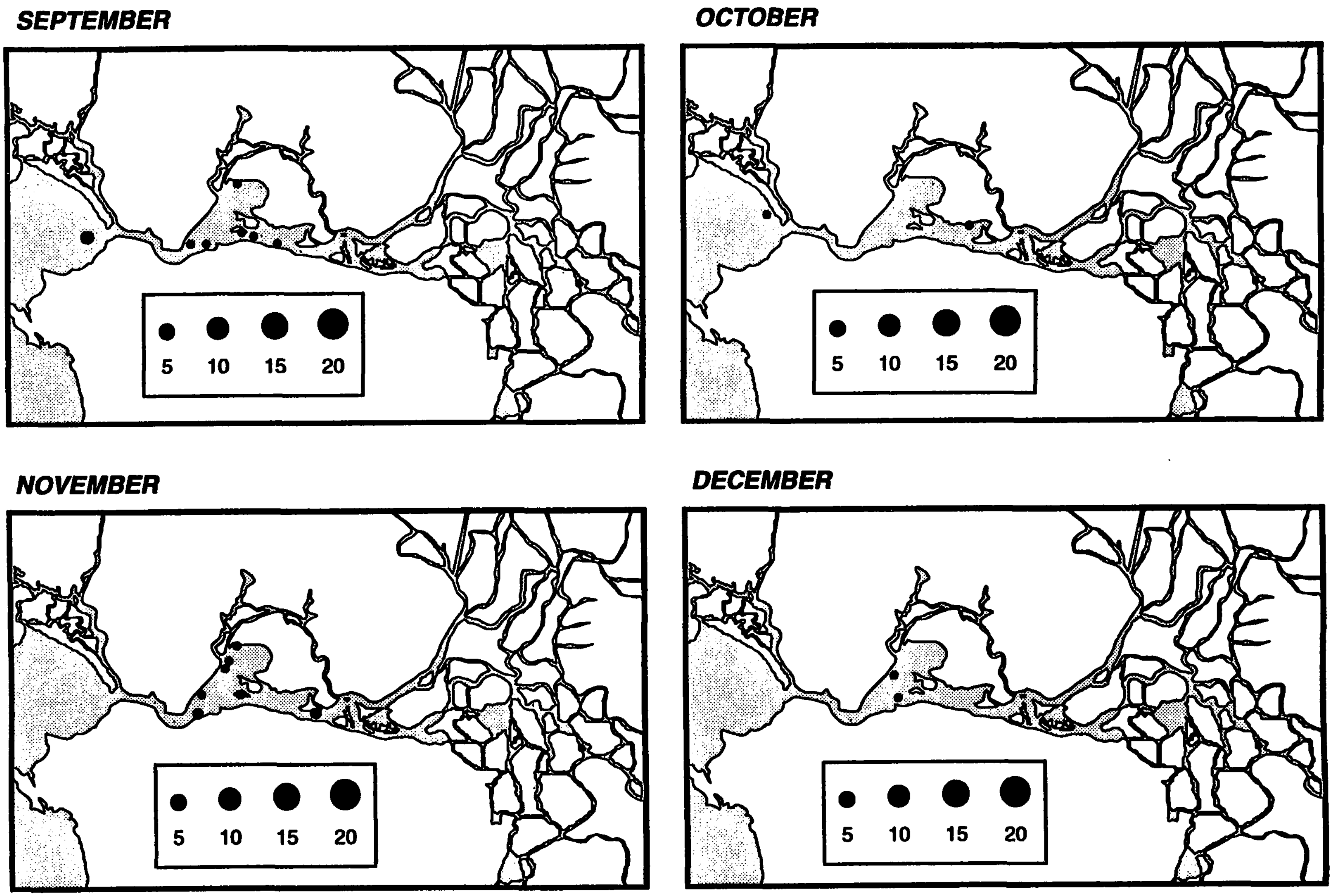
NOVEMBER



DECEMBER



Starry Flounder - 1981



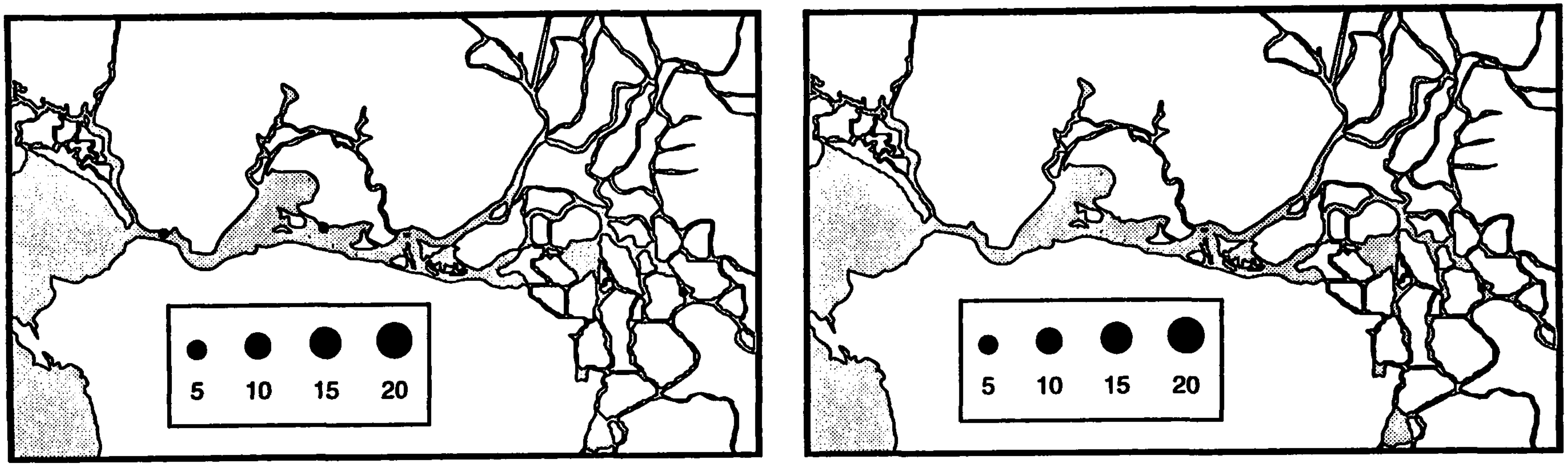
SEPTEMBER

OCTOBER

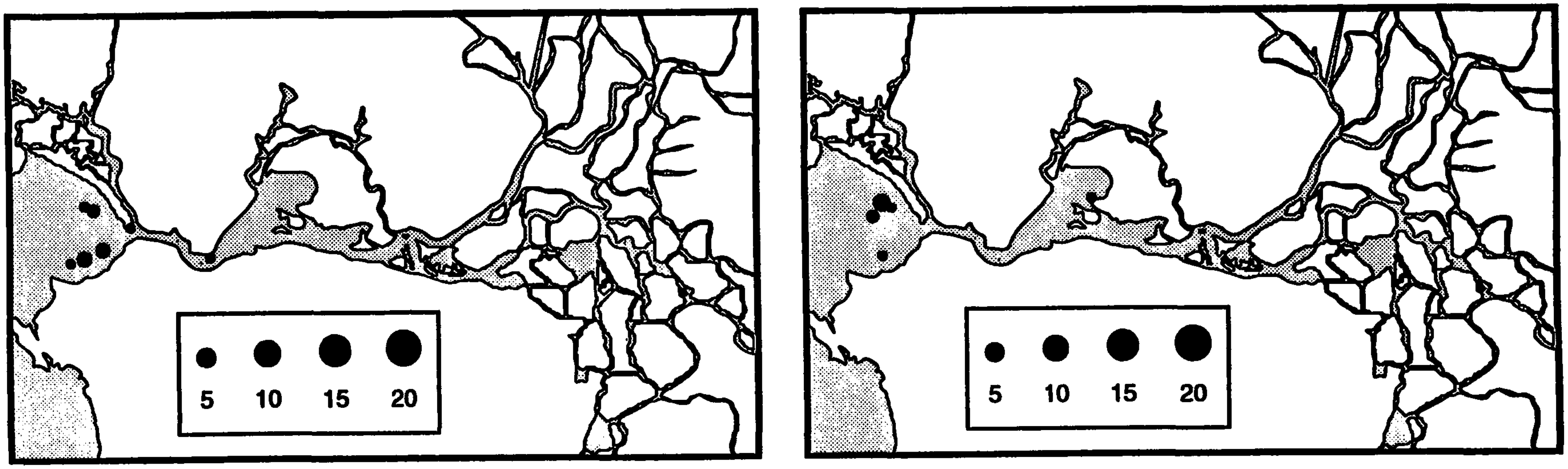
NOVEMBER

DECEMBER

Starry Flounder - 1982

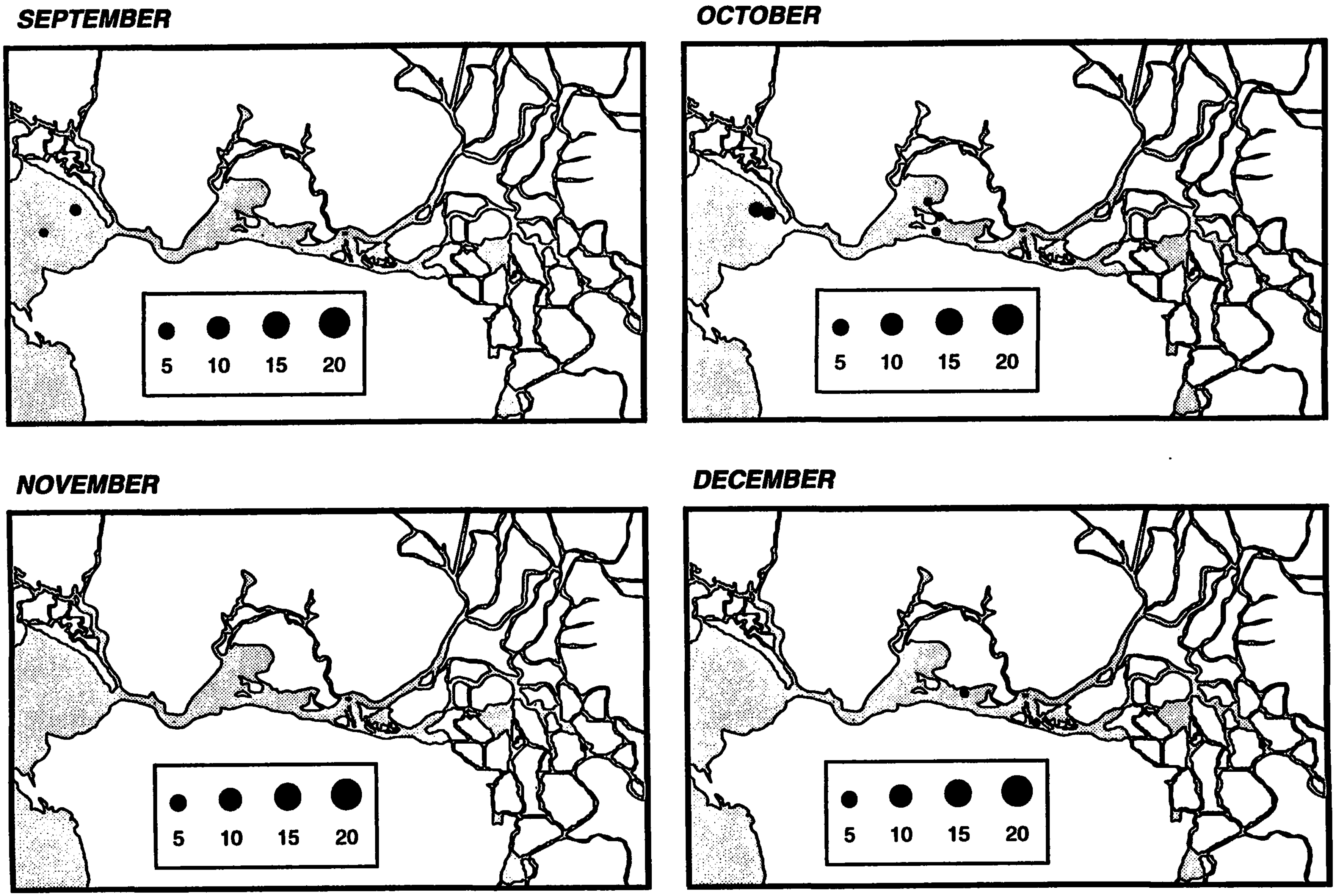

SEPTEMBER

OCTOBER


NOVEMBER

DECEMBER

Starry Flounder - 1983



SEPTEMBER

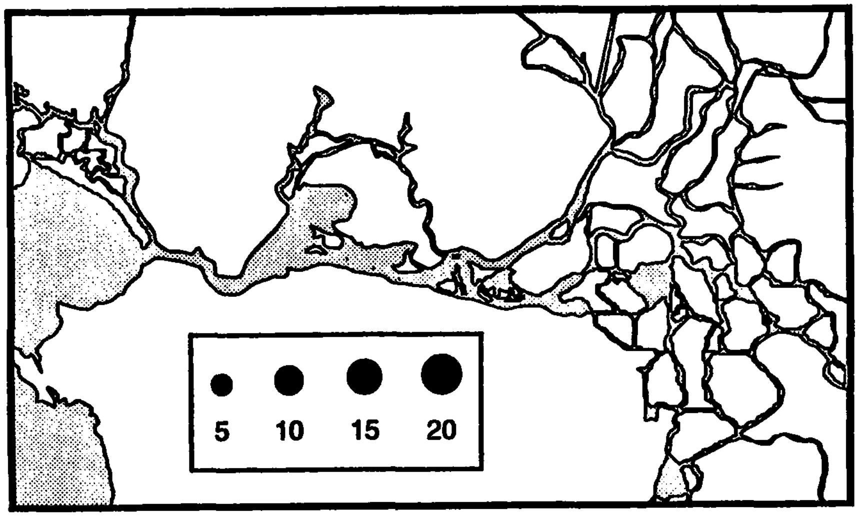
OCTOBER

NOVEMBER

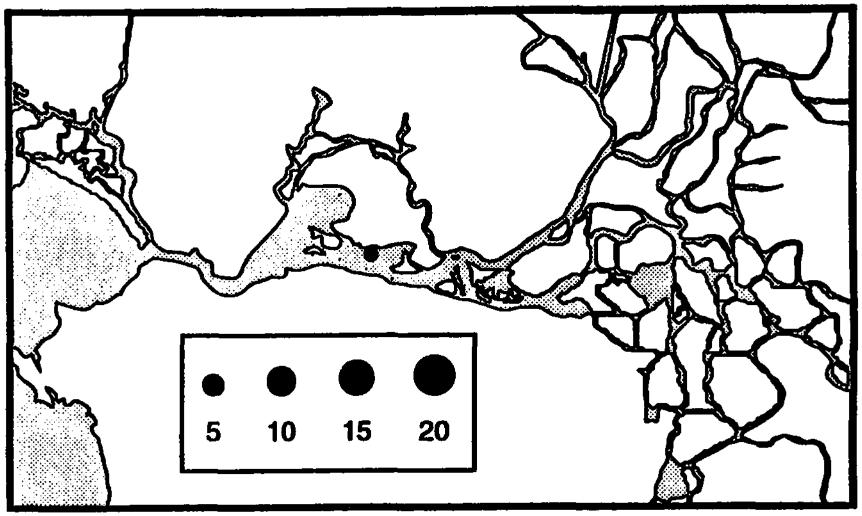
DECEMBER

Starry Flounder - 1984

SEPTEMBER



OCTOBER



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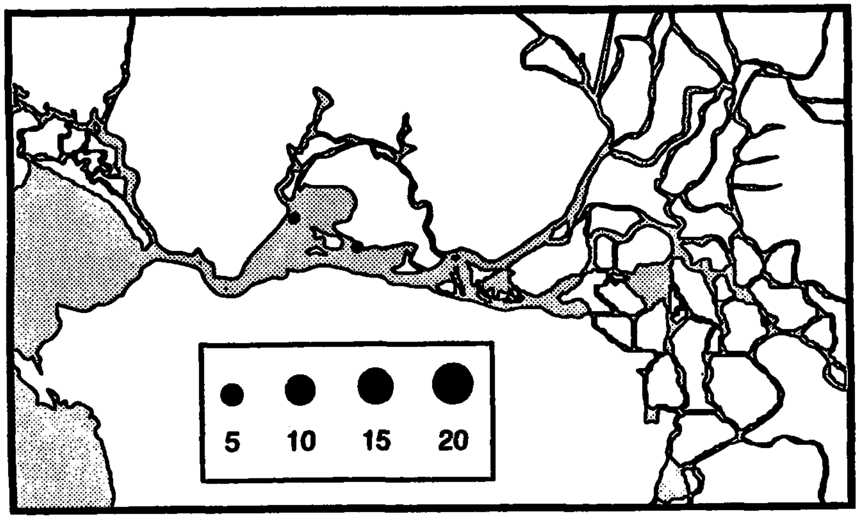
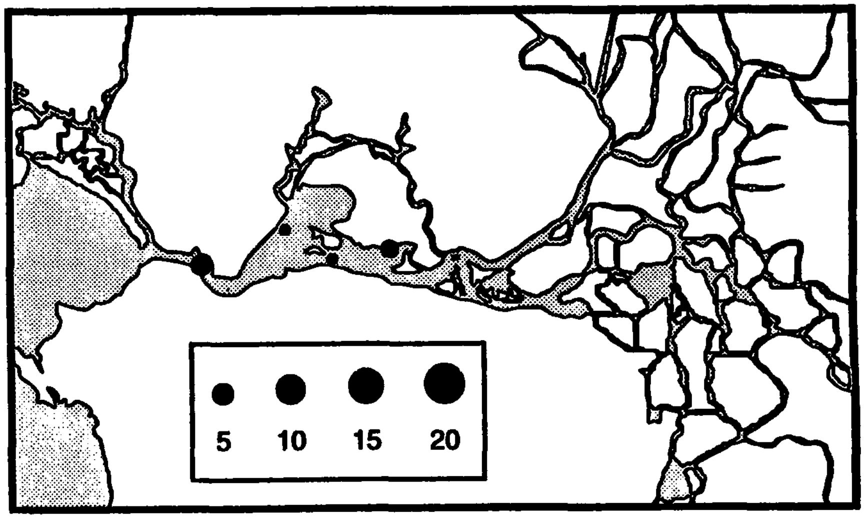
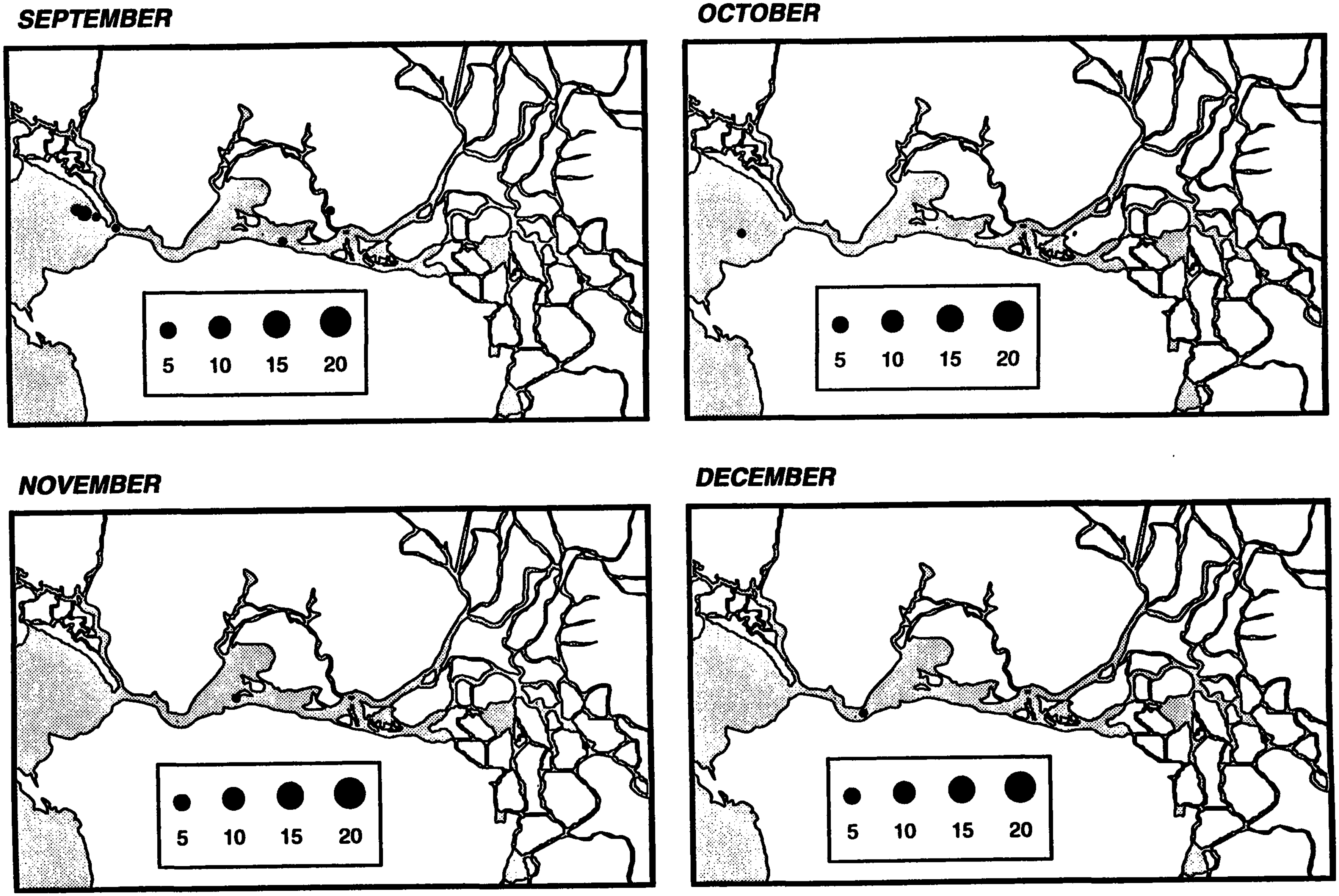


DECEMBER

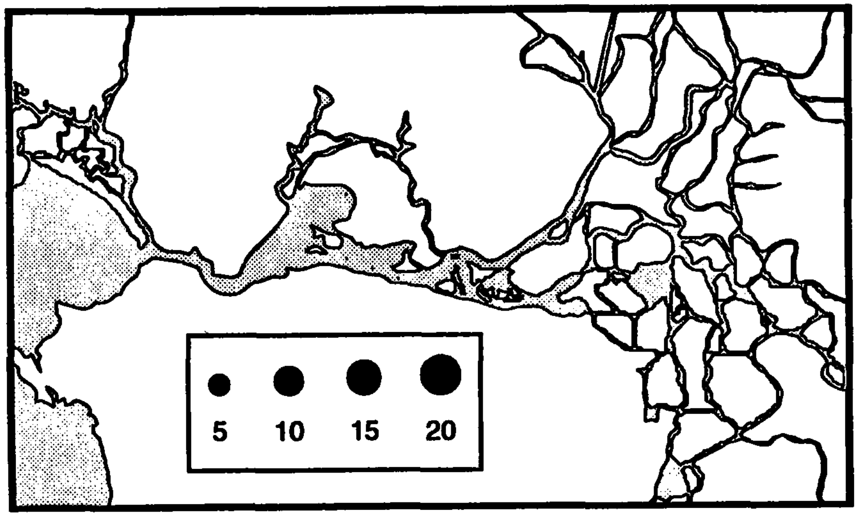


Starry Flounder - 1985



Starry Flounder - 1986

SEPTEMBER



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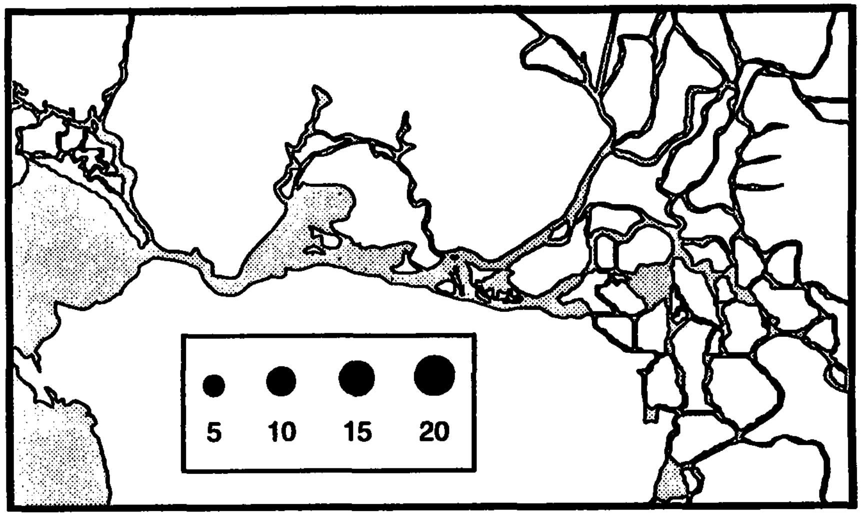

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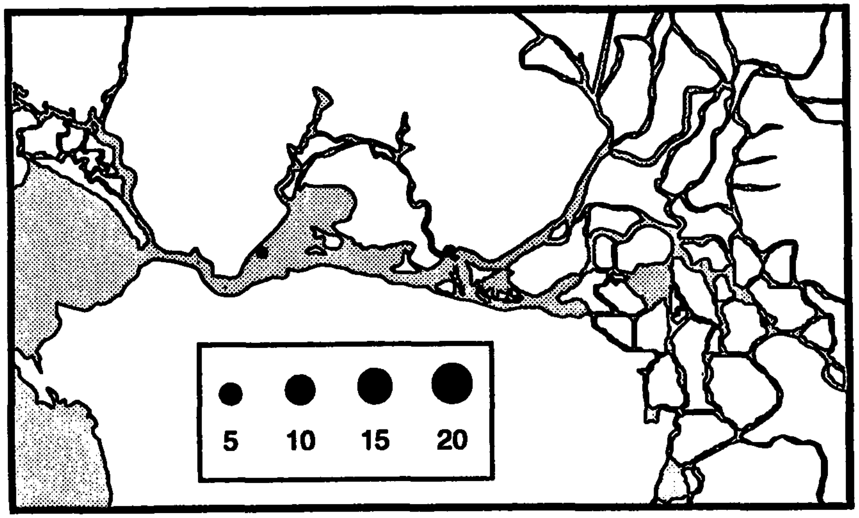

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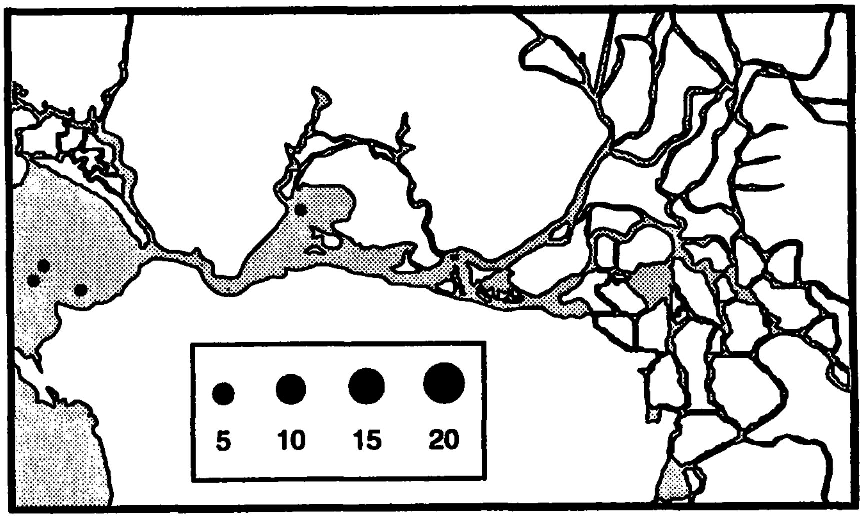
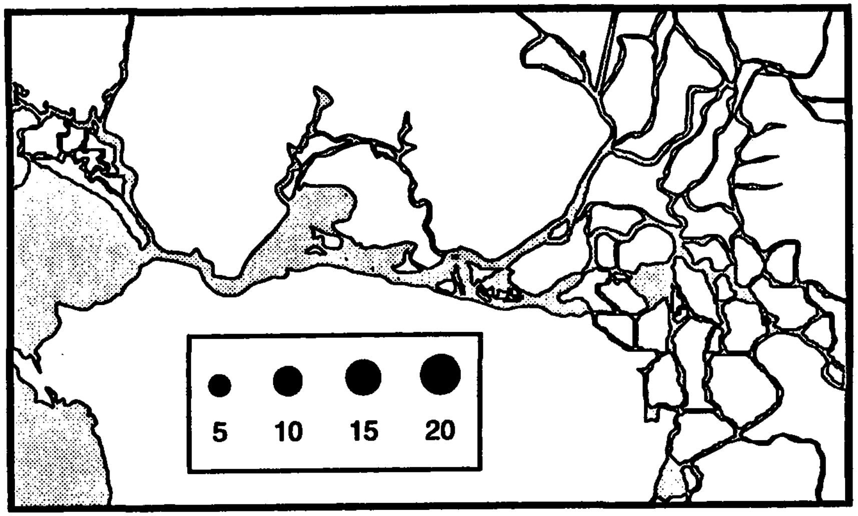


Starry Flounder - 1987

SEPTEMBER



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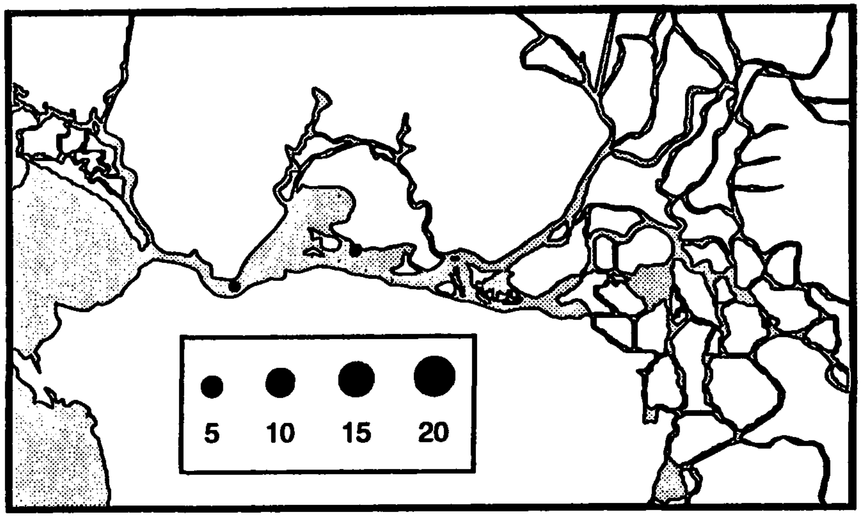

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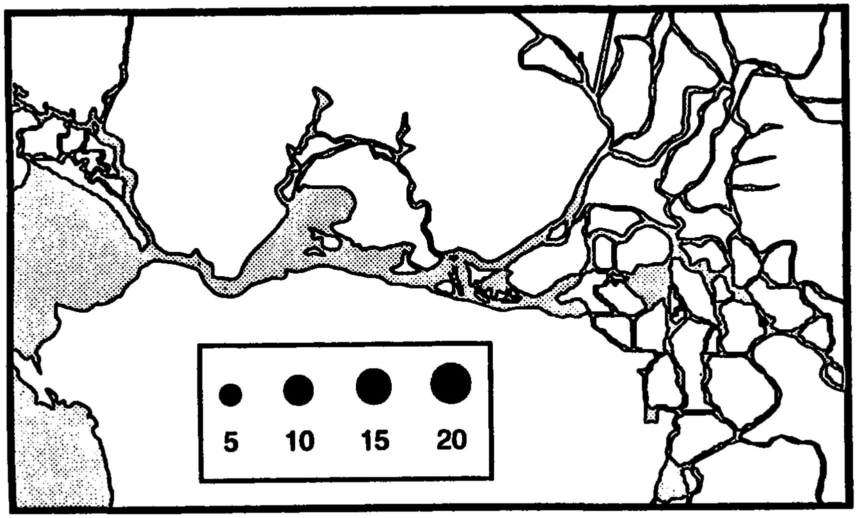

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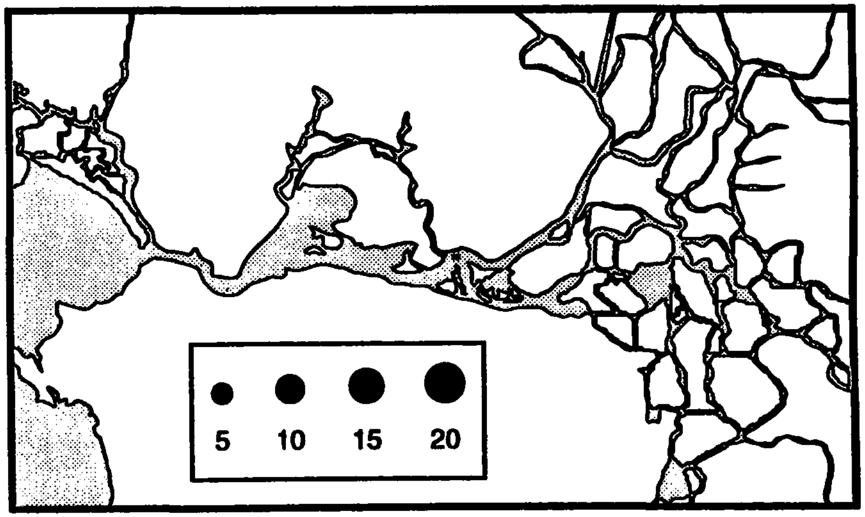
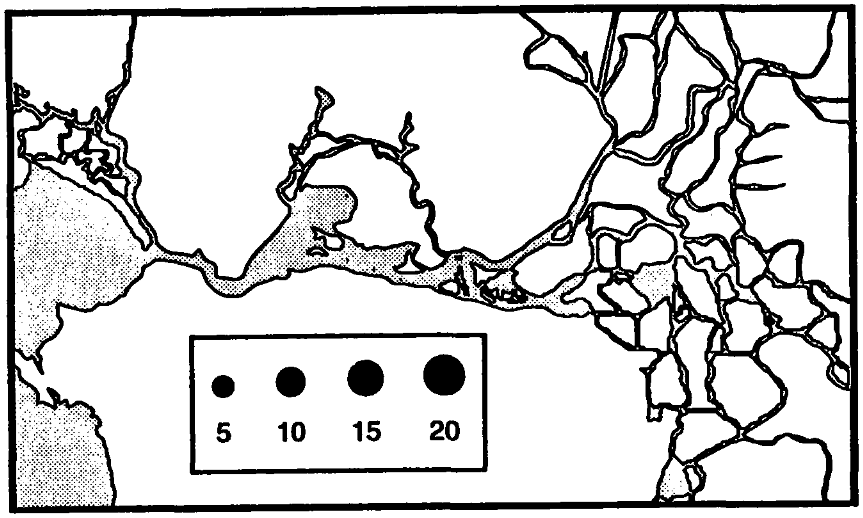


Starry Flounder - 1988

SEPTEMBER



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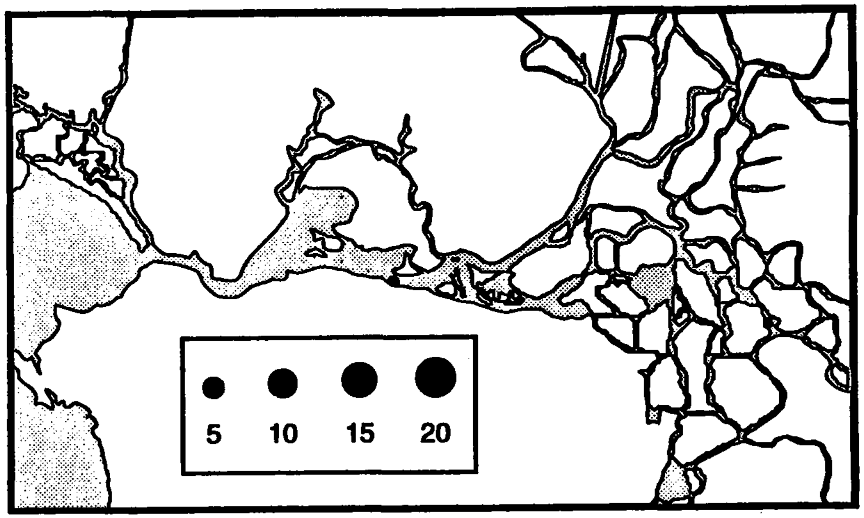

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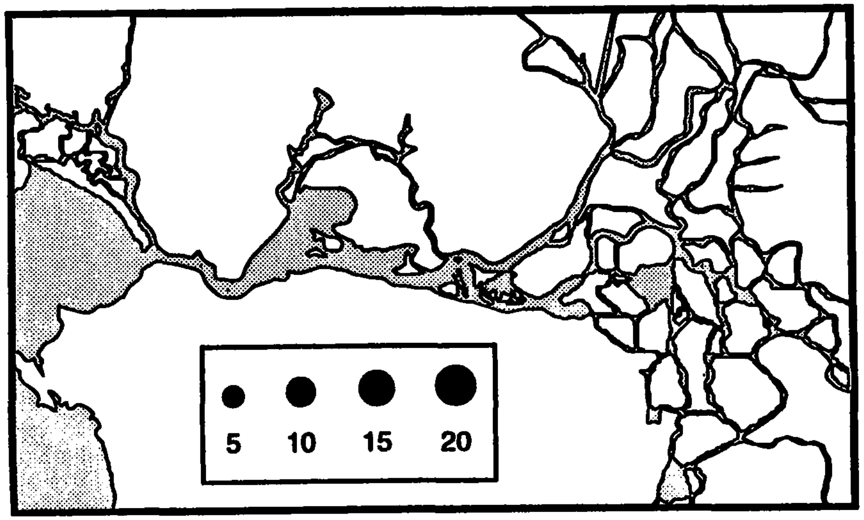

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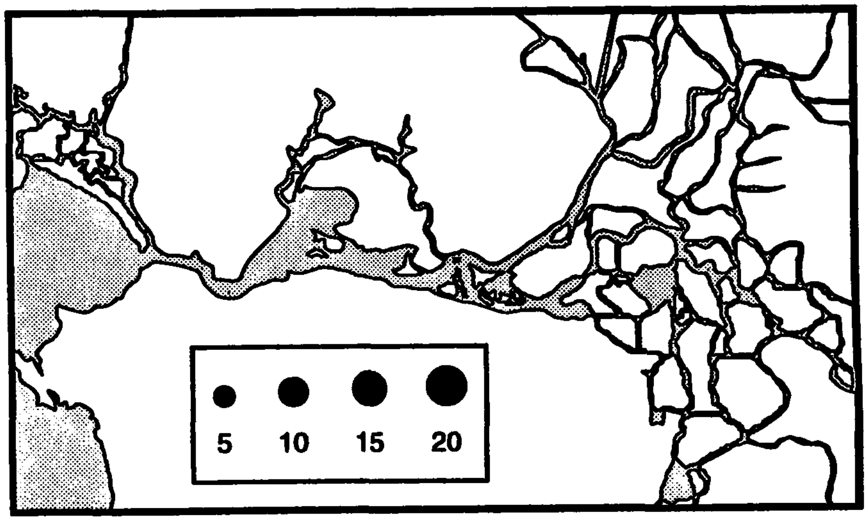
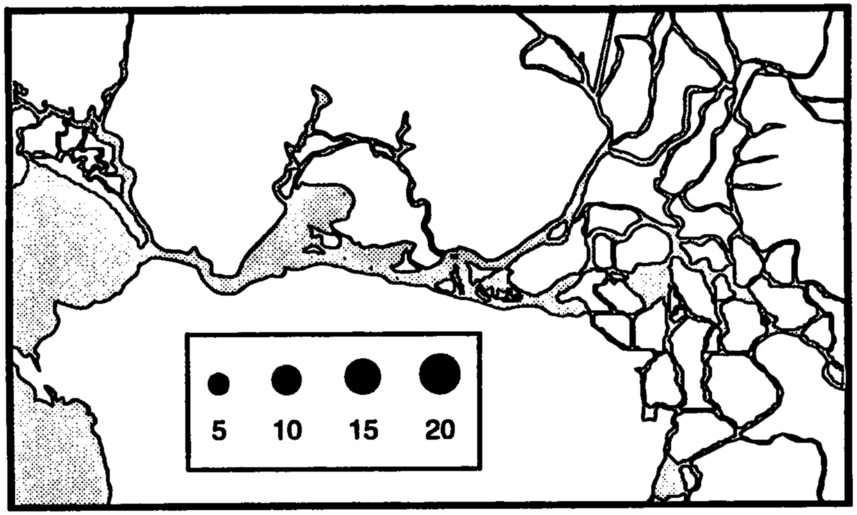


Starry Flounder - 1989

SEPTEMBER



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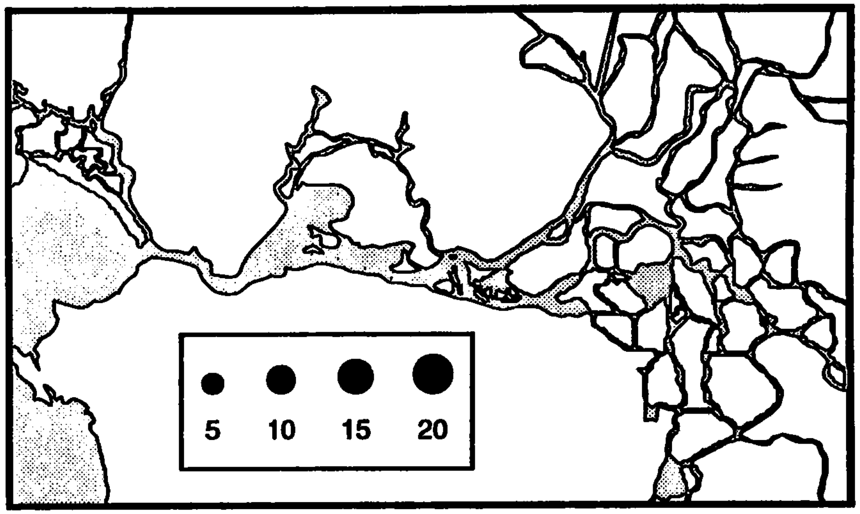

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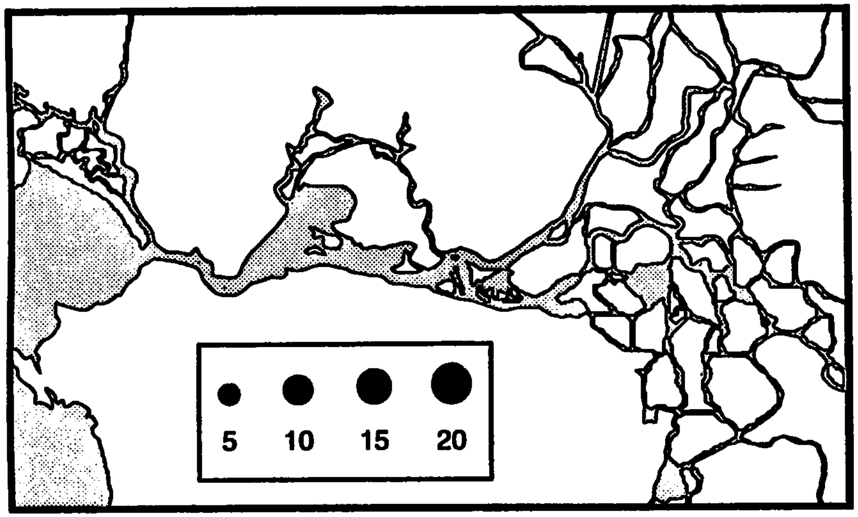

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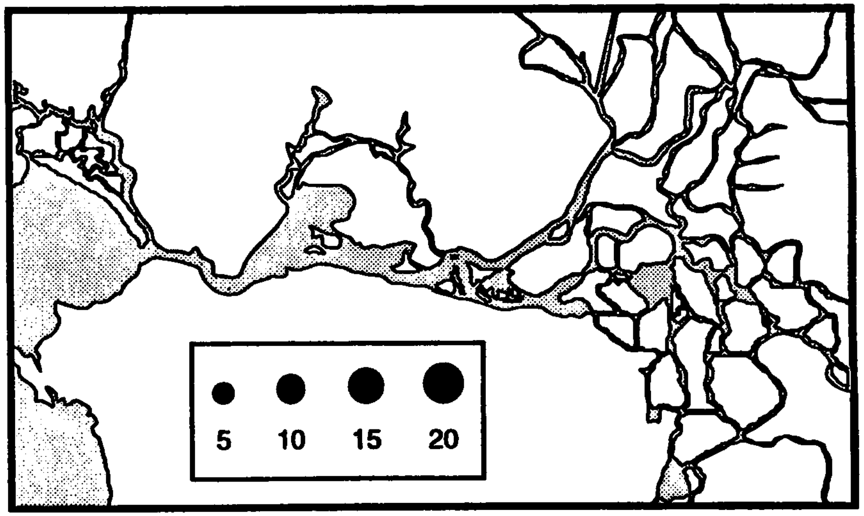


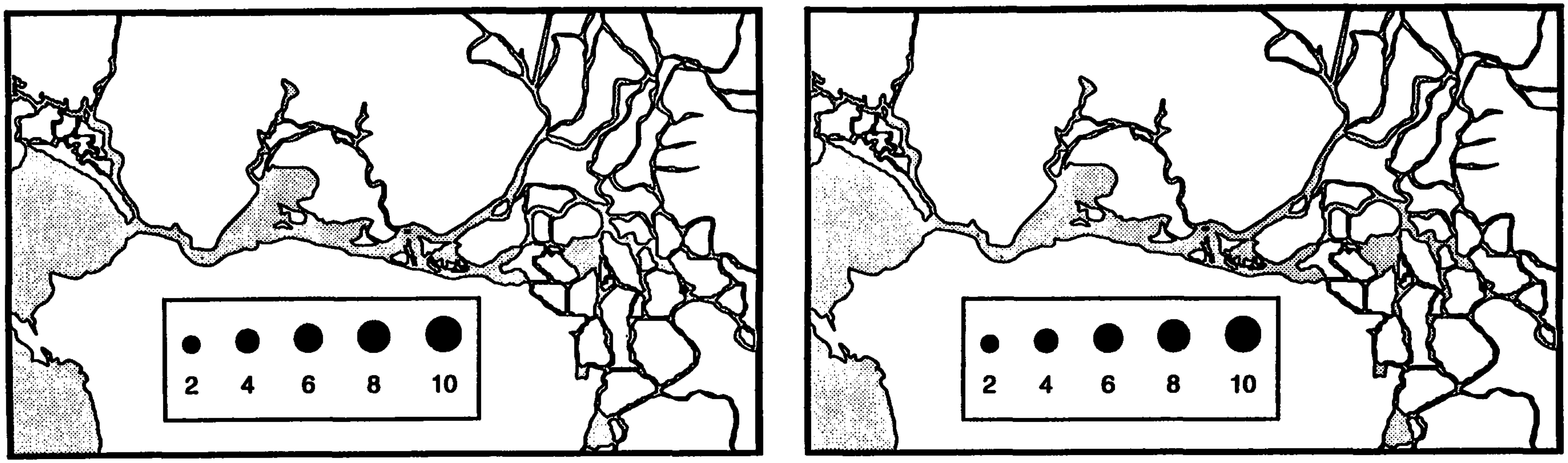
Starry Flounder - 1990

Appendix A-5

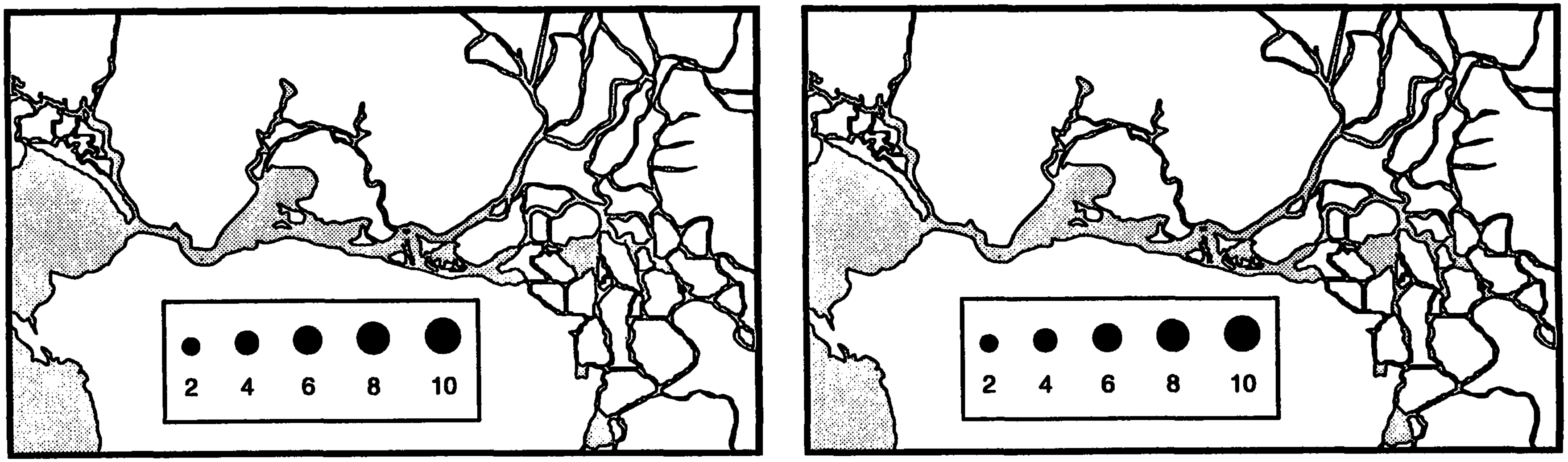
Spatial Abundance Maps for Selected Species Sampled in Midwater Trawl Survey, 1977 - 1990

Sacramento Splittail

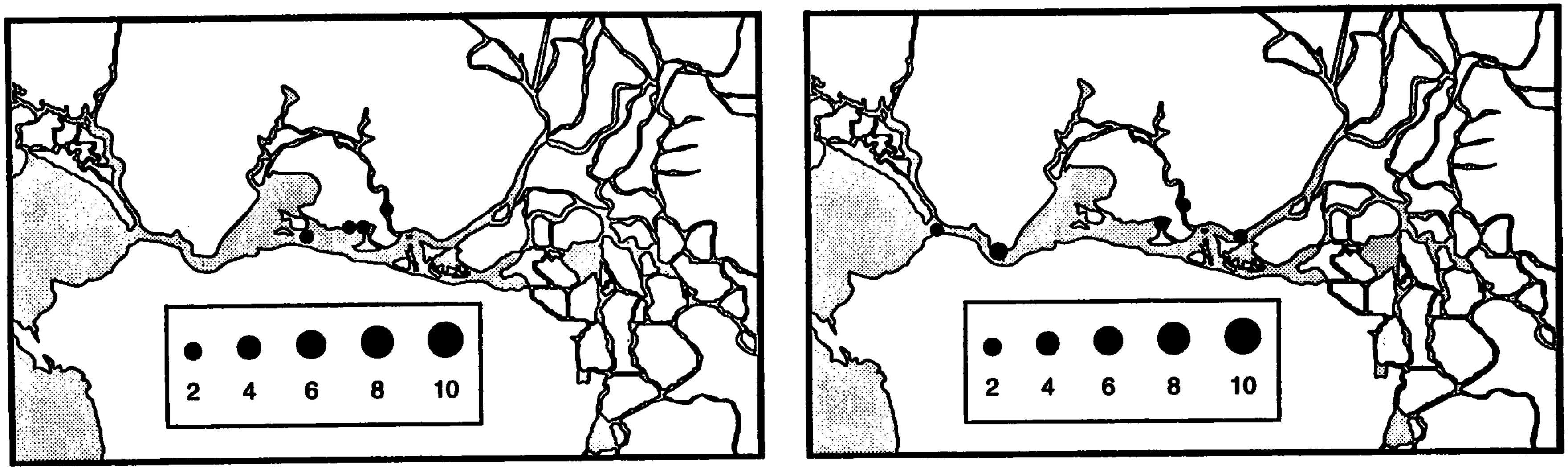
SEPTEMBER **OCTOBER**



NOVEMBER **DECEMBER**

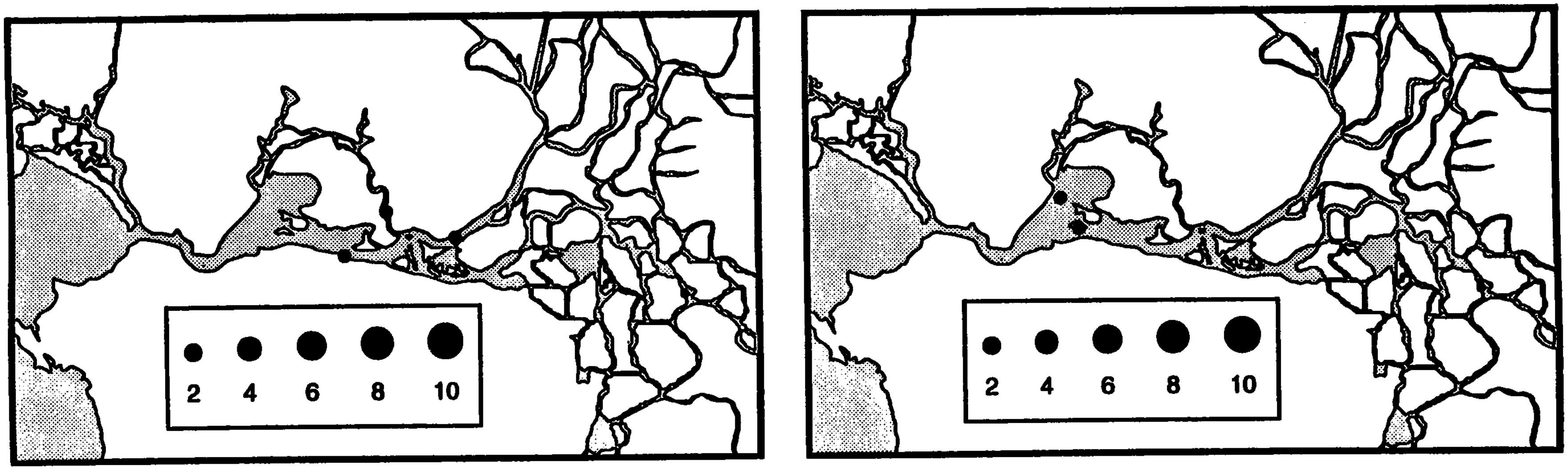


Splittail - 1977



SEPTEMBER

OCTOBER

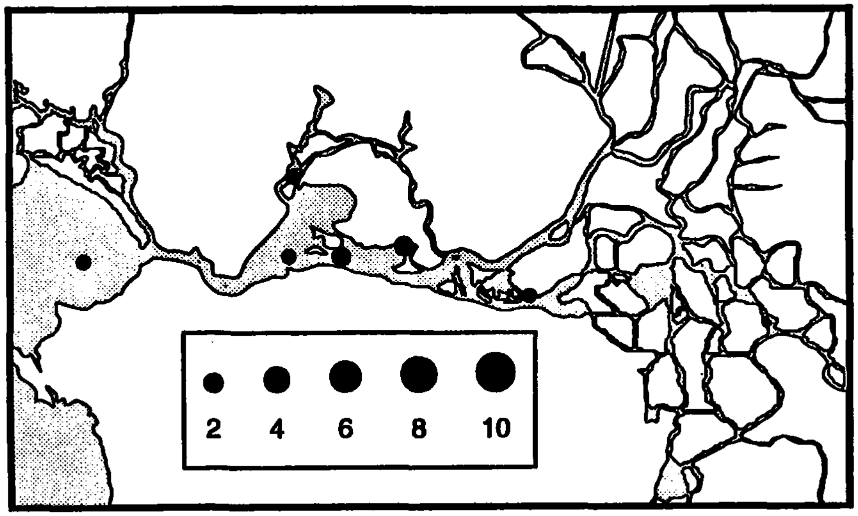


NOVEMBER

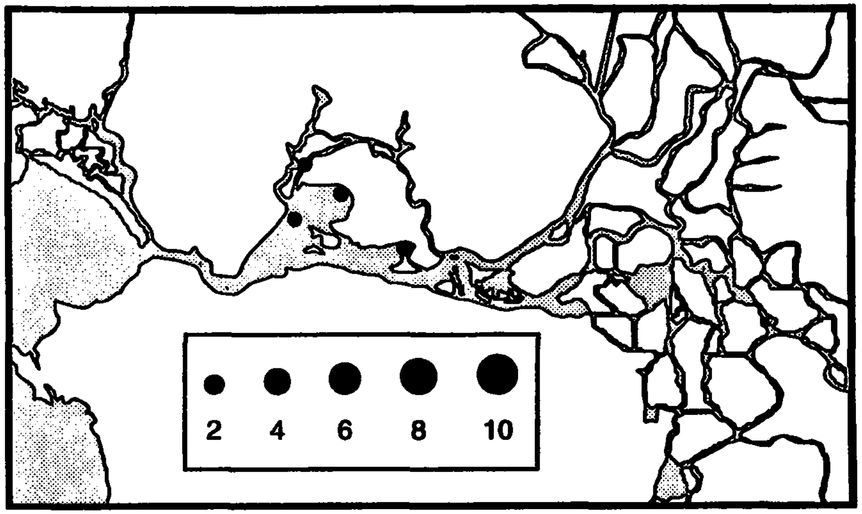
DECEMBER

Splittail - 1978

SEPTEMBER



OCTOBER



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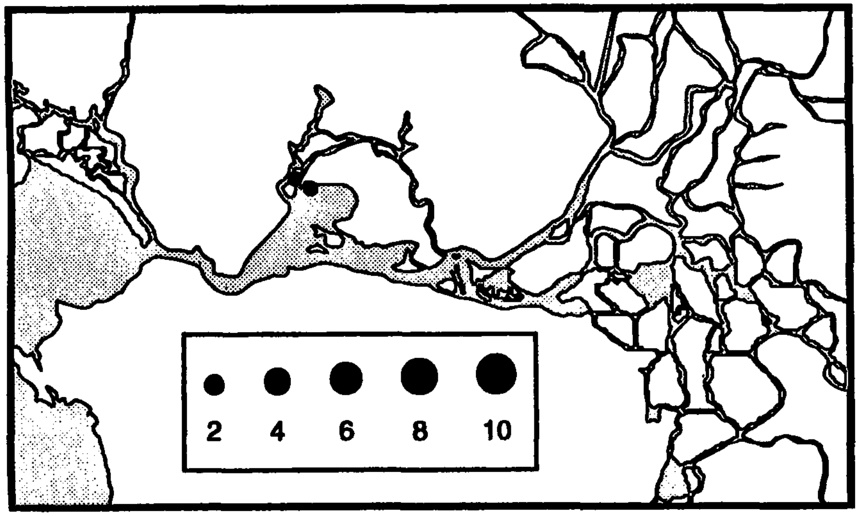

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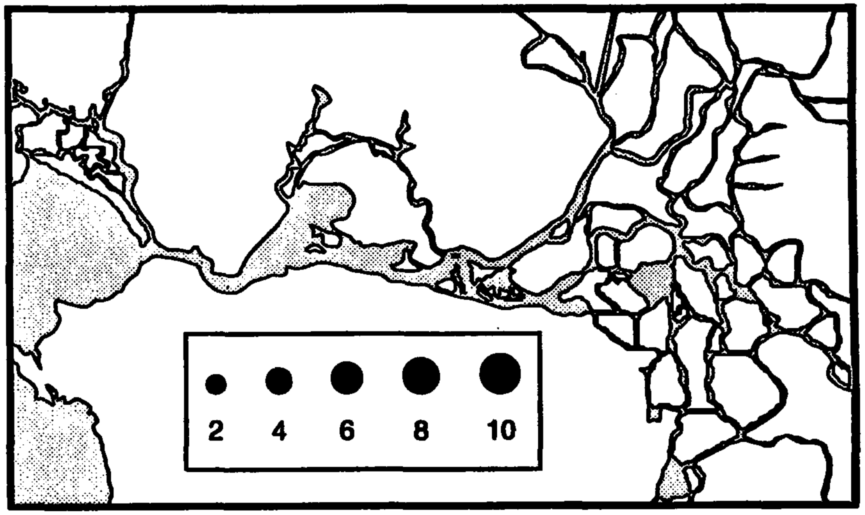
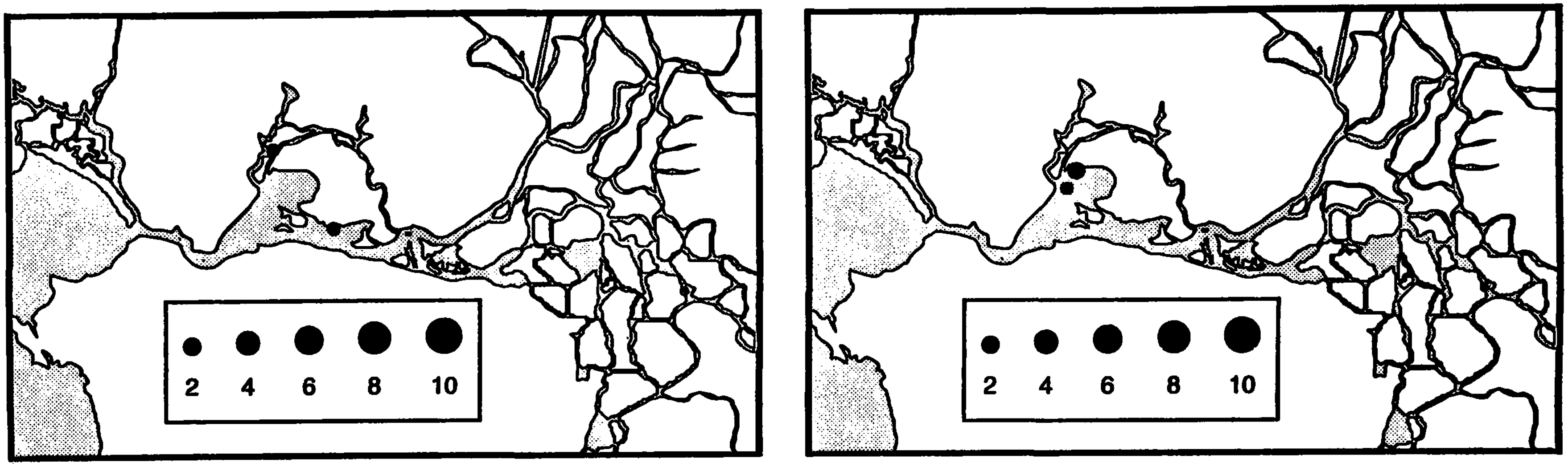
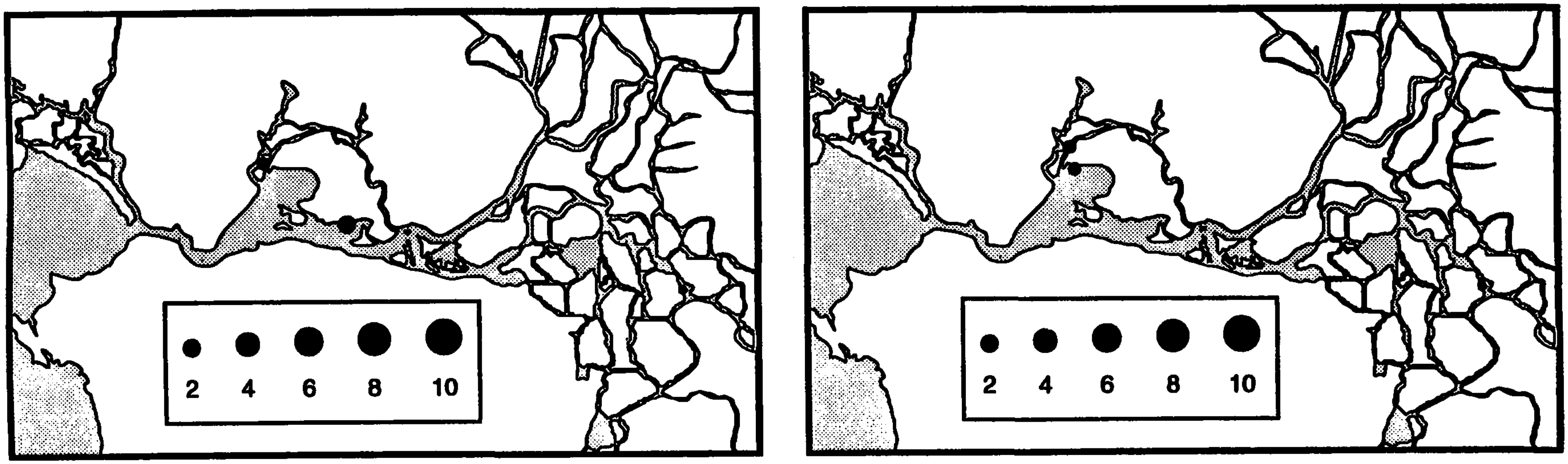


Splittail - 1980



SEPTEMBER

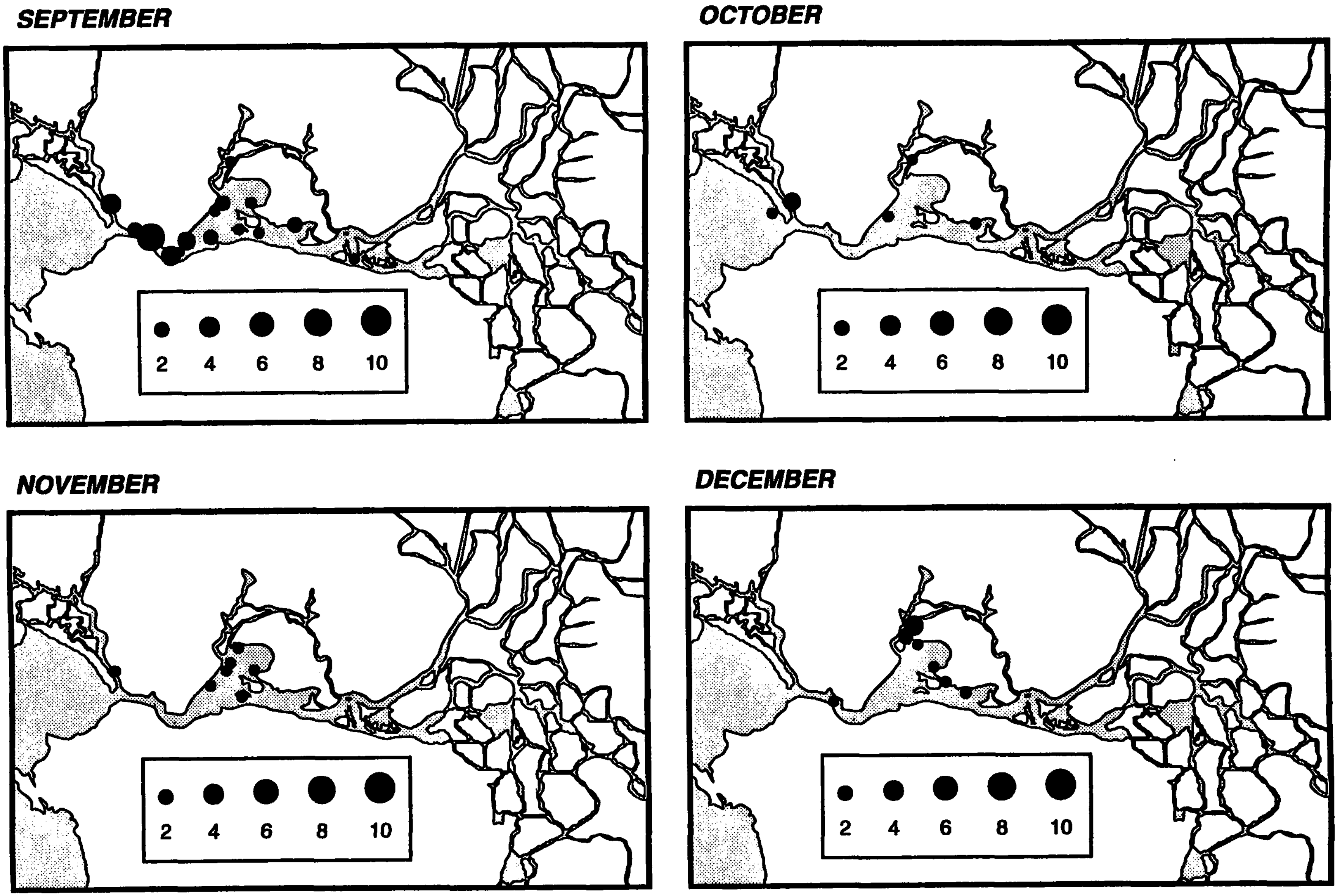
OCTOBER



NOVEMBER

DECEMBER

Splittail - 1981



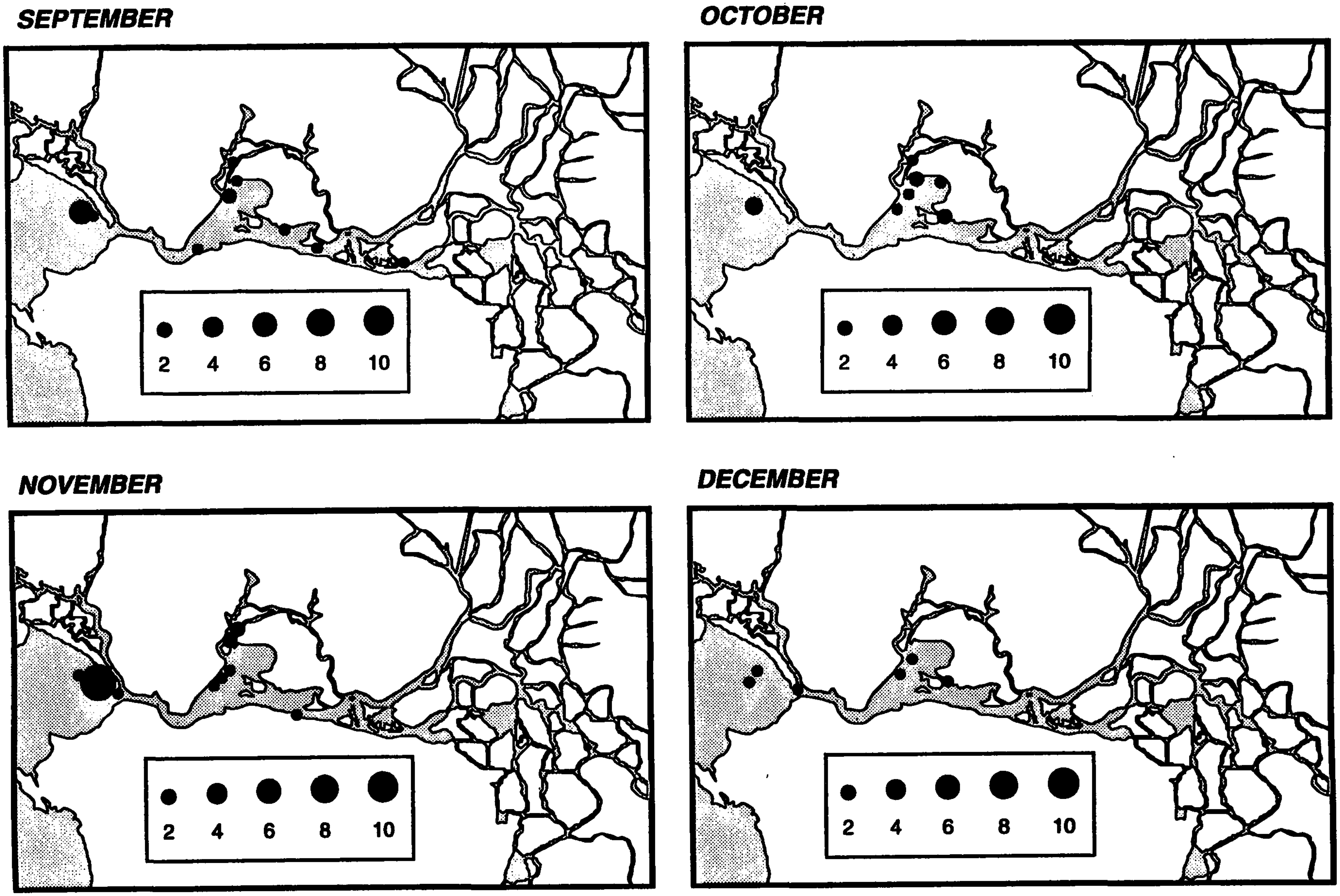
SEPTEMBER

OCTOBER

NOVEMBER

DECEMBER

Splittail - 1982



SEPTEMBER

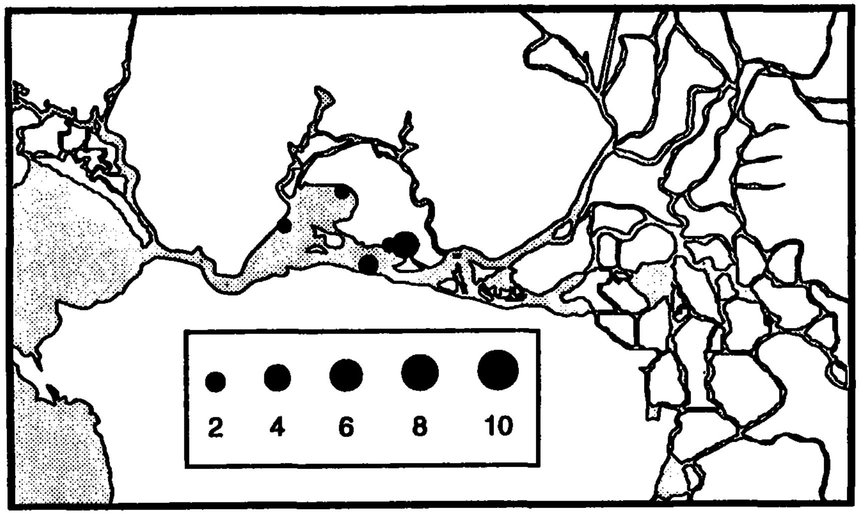
OCTOBER

NOVEMBER

DECEMBER

Splittail - 1983

SEPTEMBER



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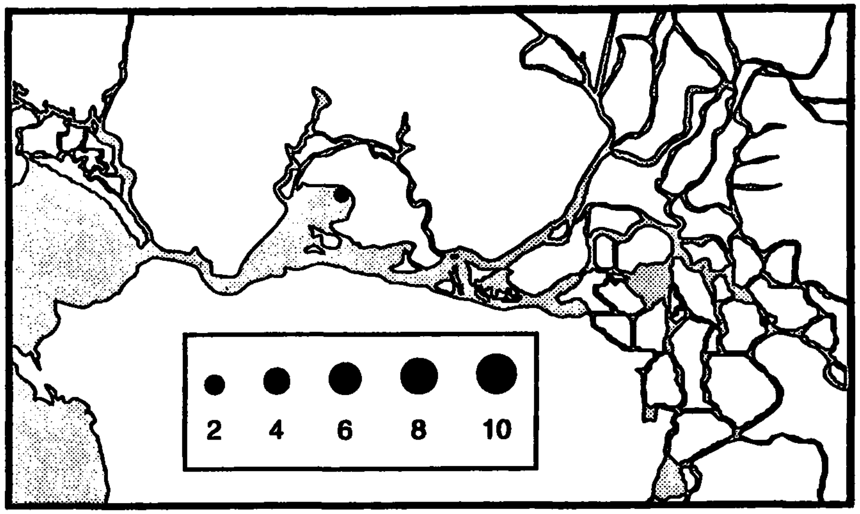

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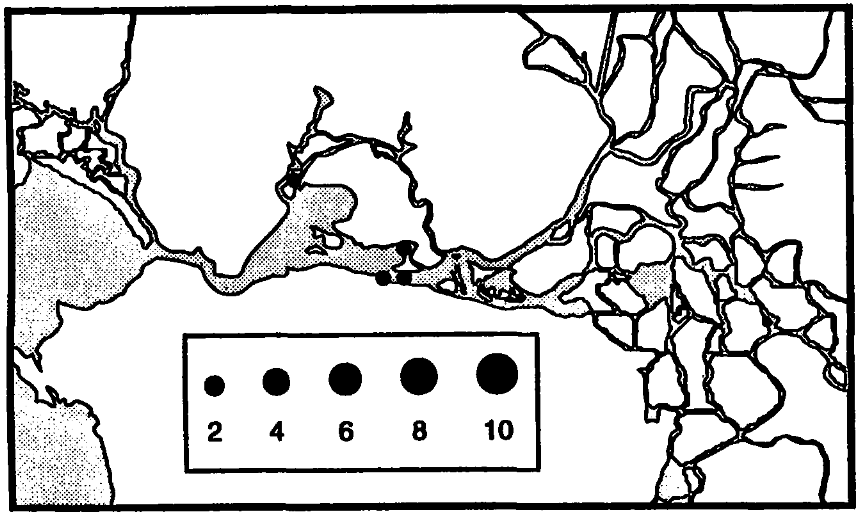

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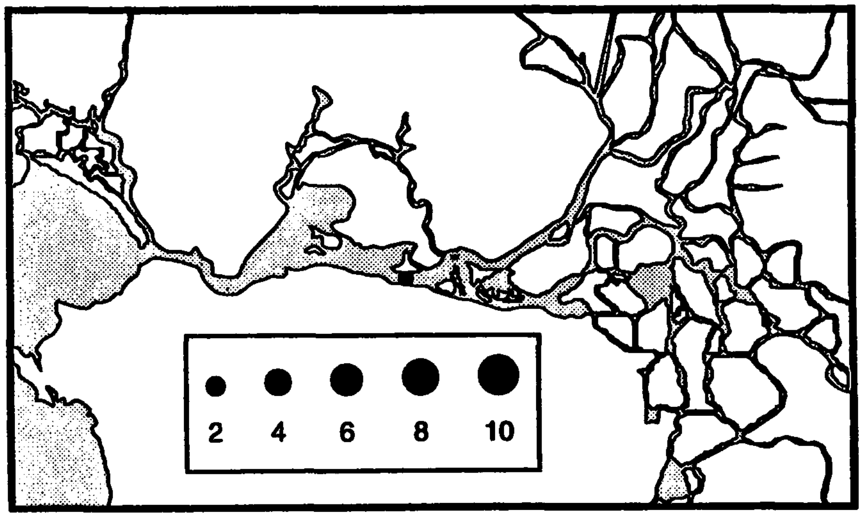
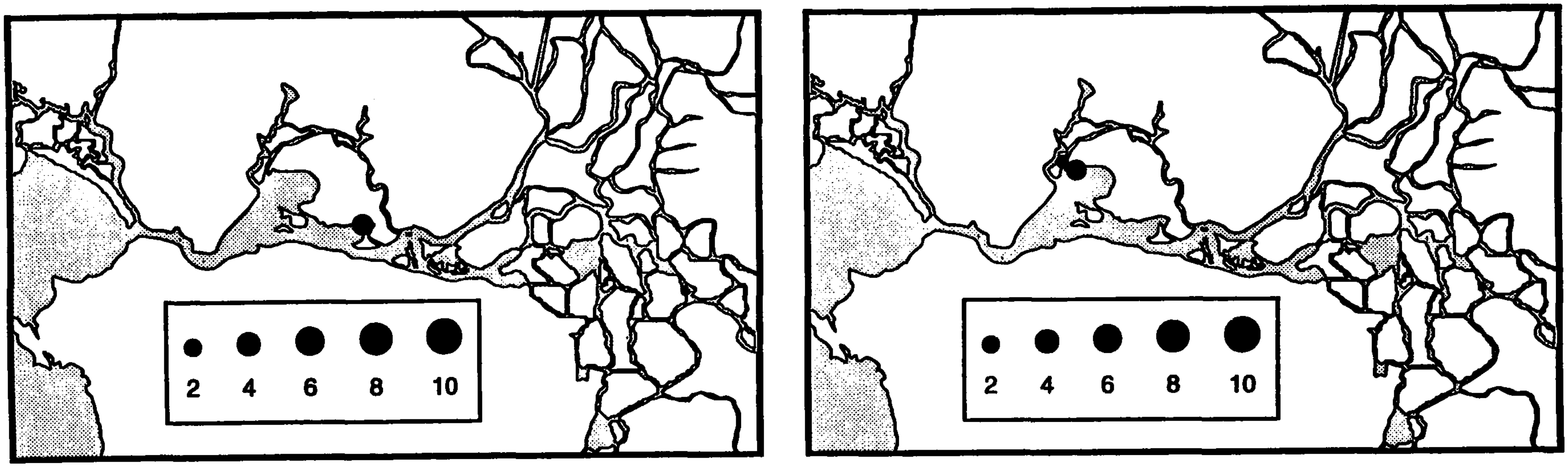
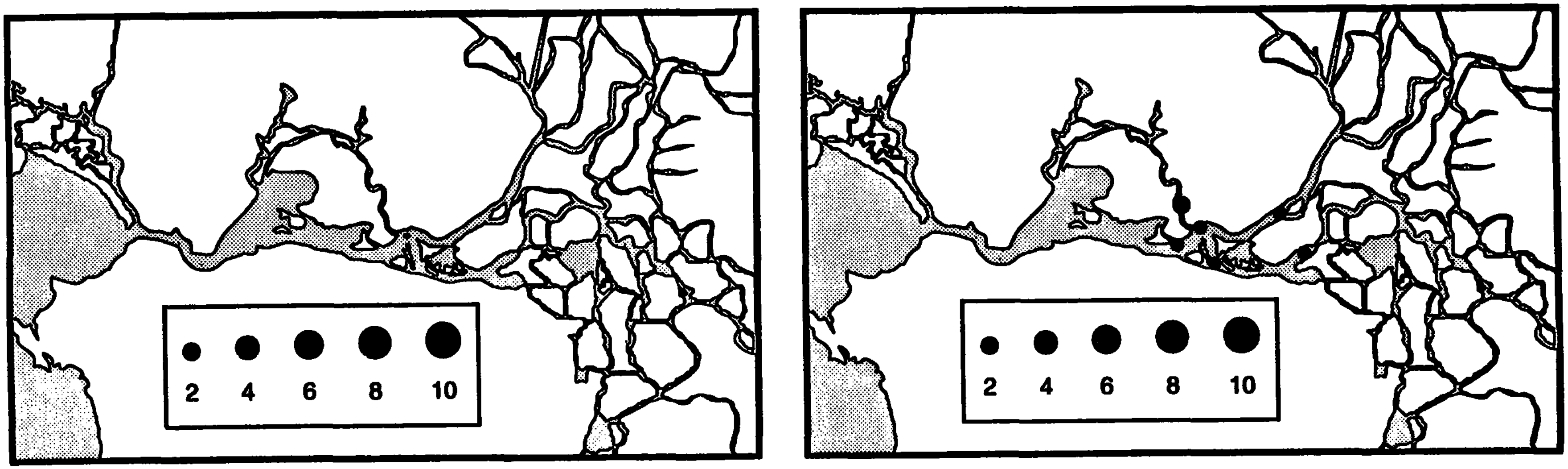


Splittail - 1984


SEPTEMBER

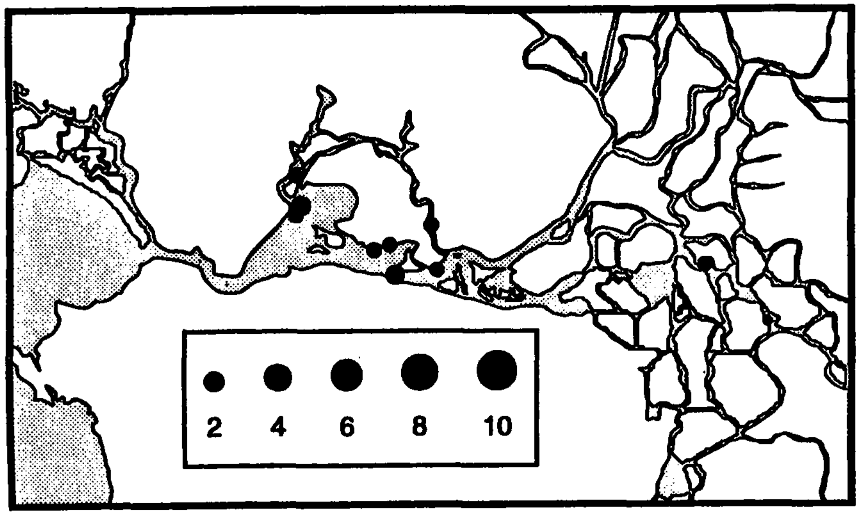
OCTOBER


NOVEMBER

DECEMBER

Splittail - 1985

SEPTEMBER



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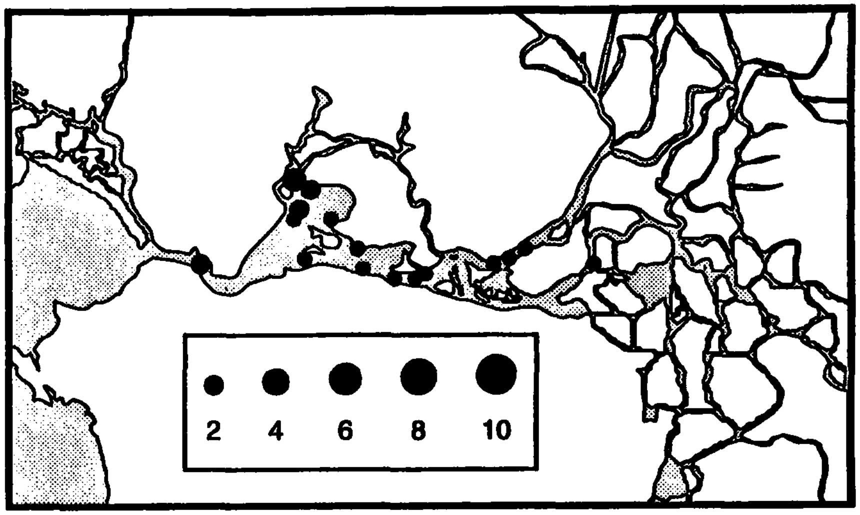

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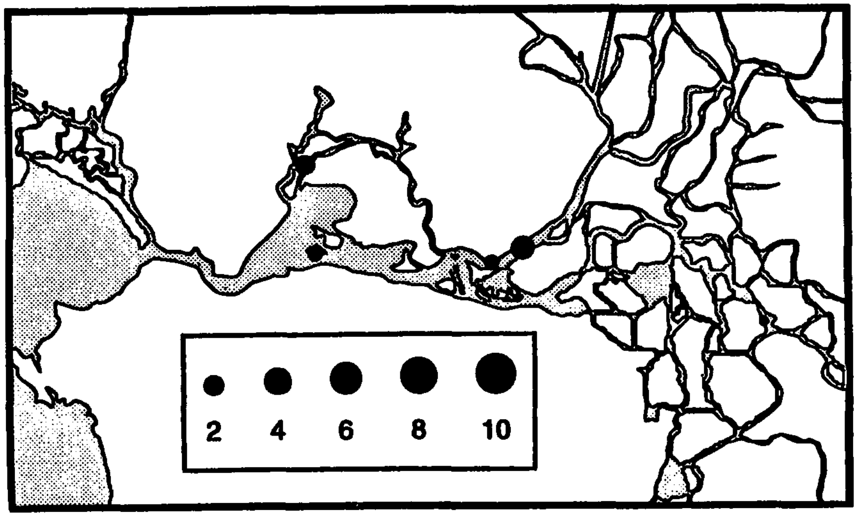

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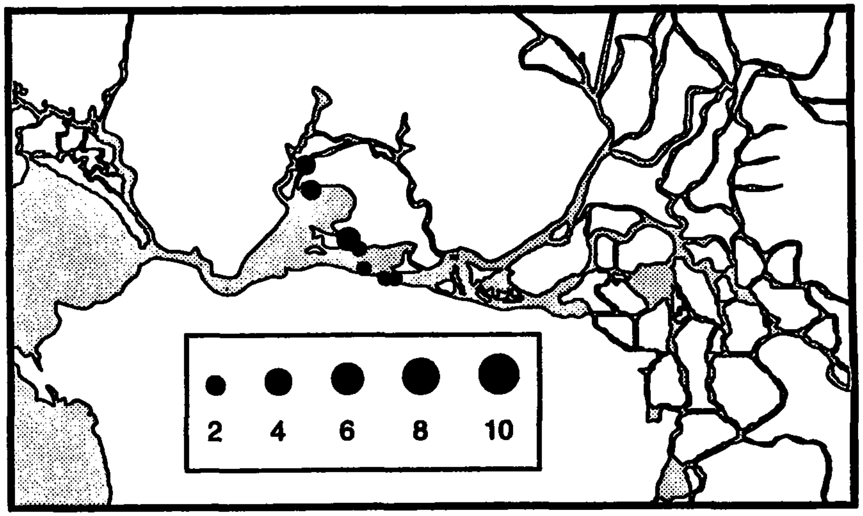
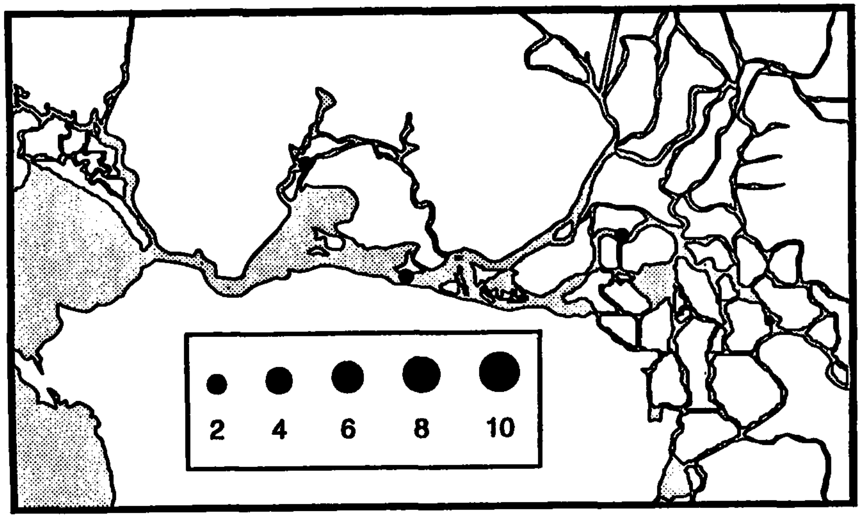


Splittail - 1986

SEPTEMBER



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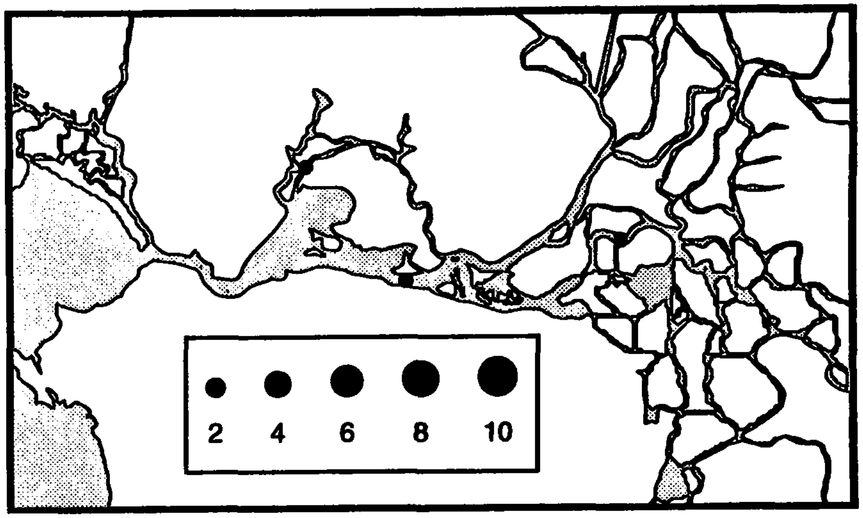

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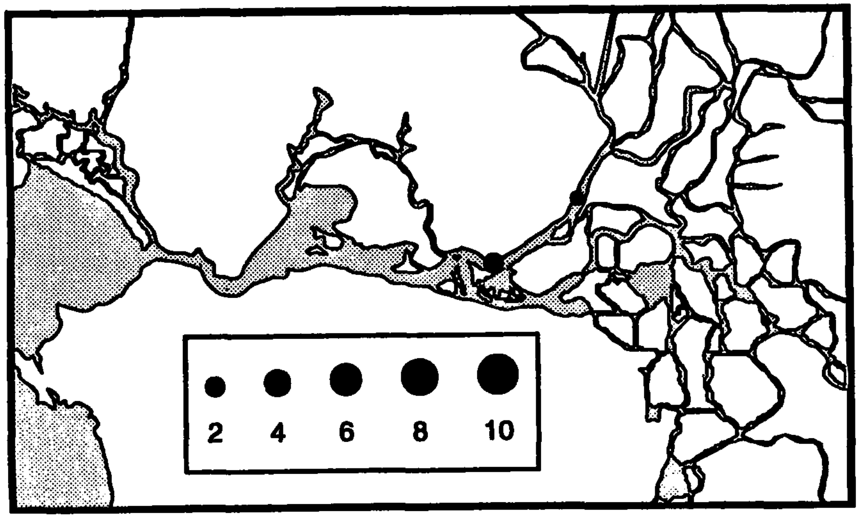

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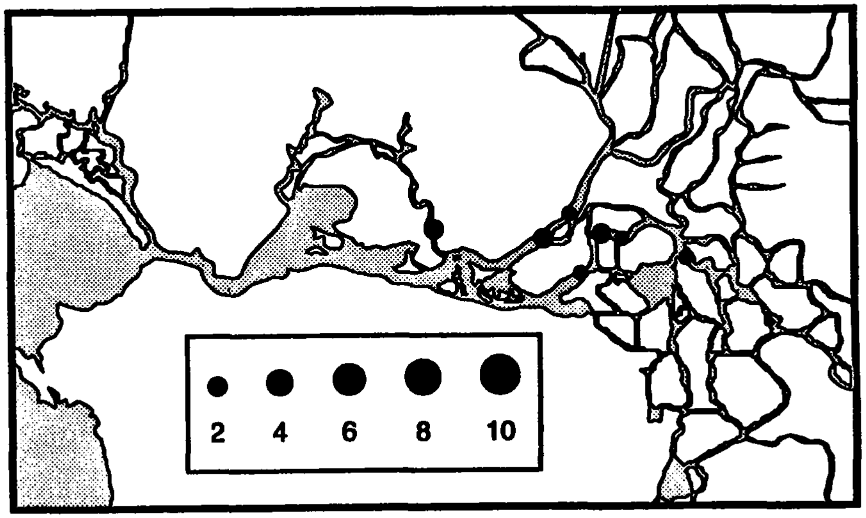
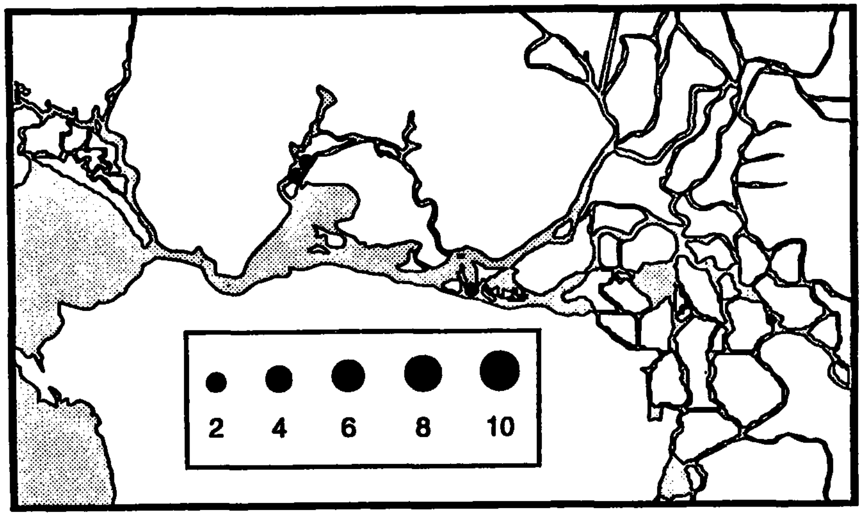


Splittail - 1987

SEPTEMBER



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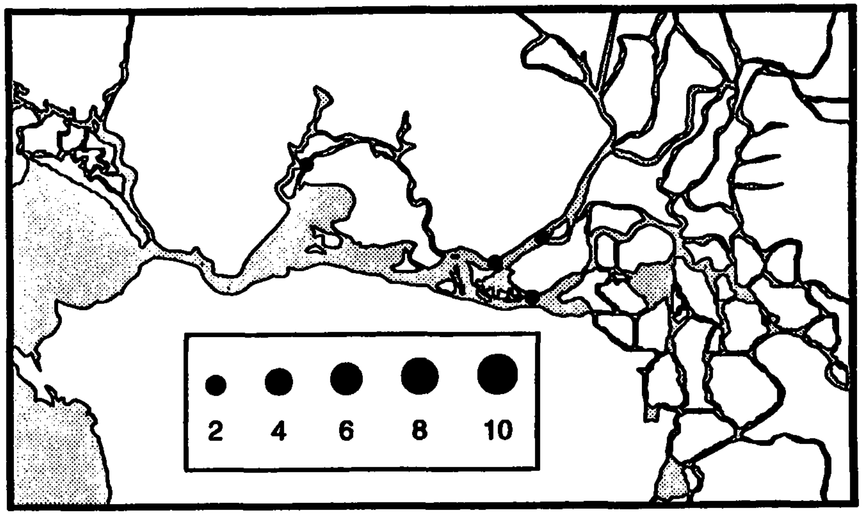

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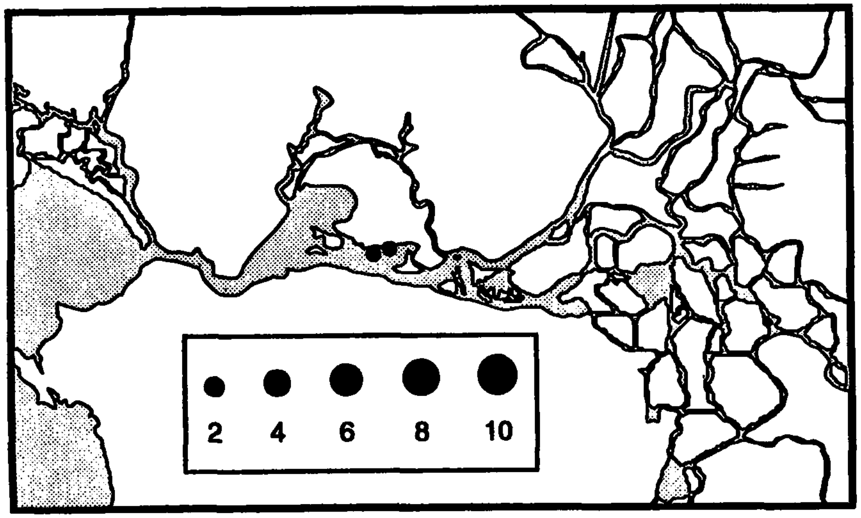

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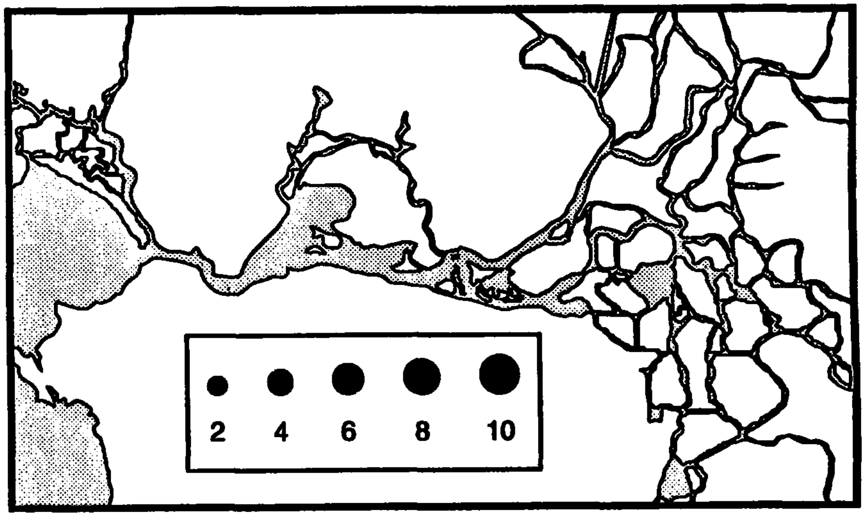
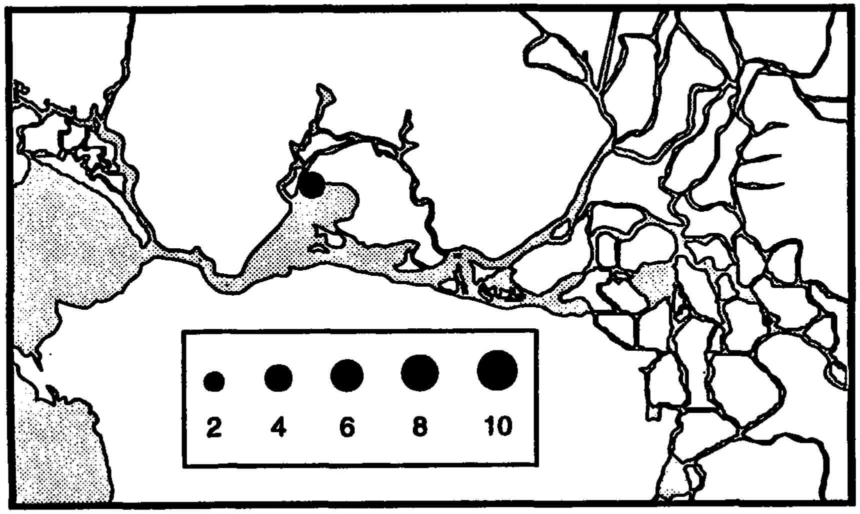


Splittail - 1988

SEPTEMBER



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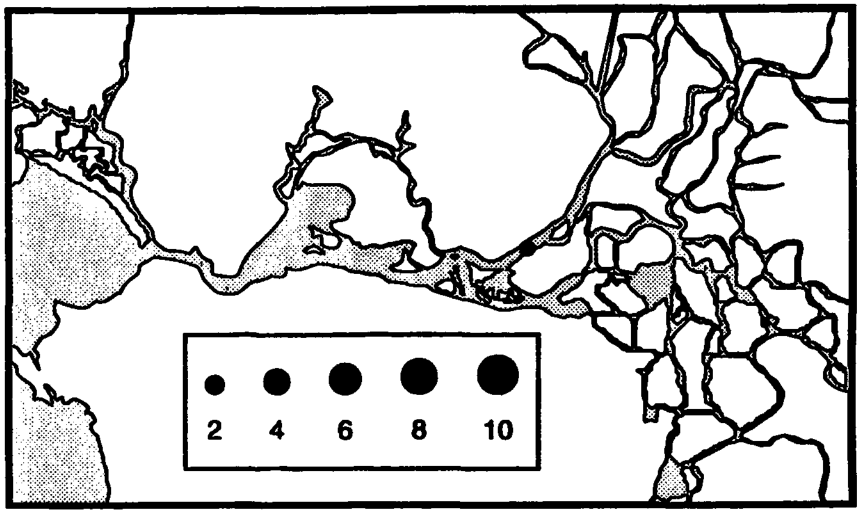

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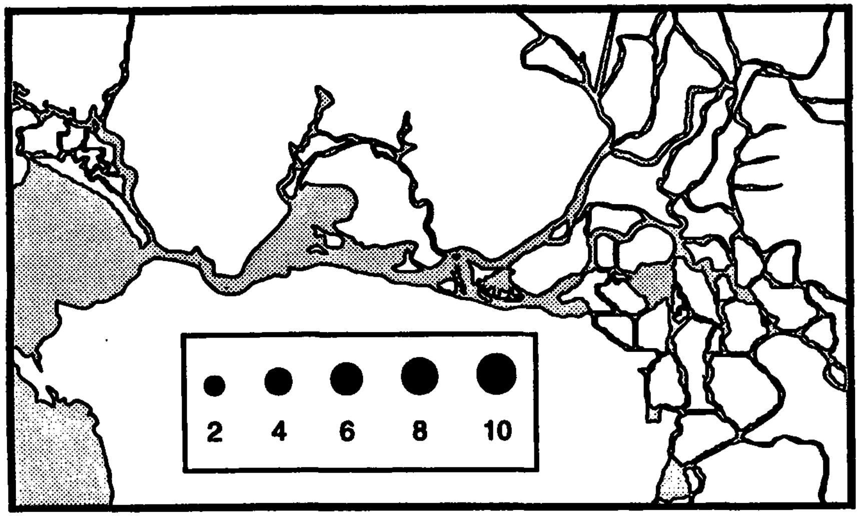

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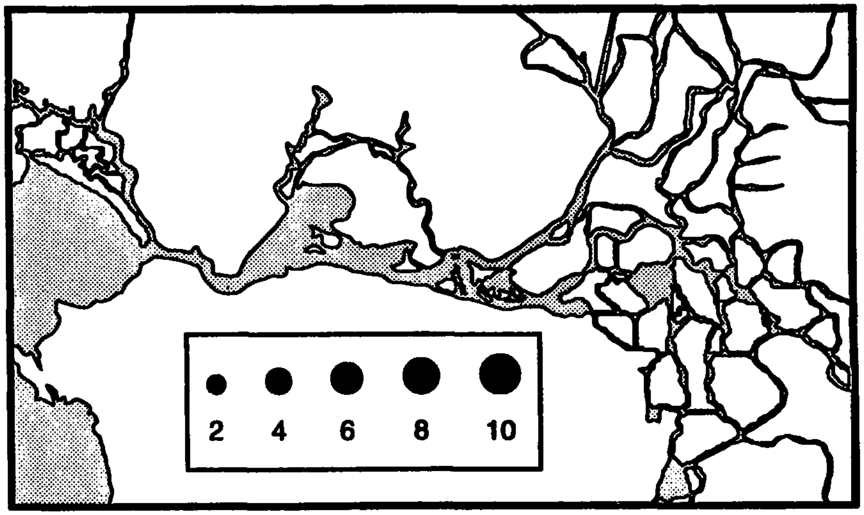
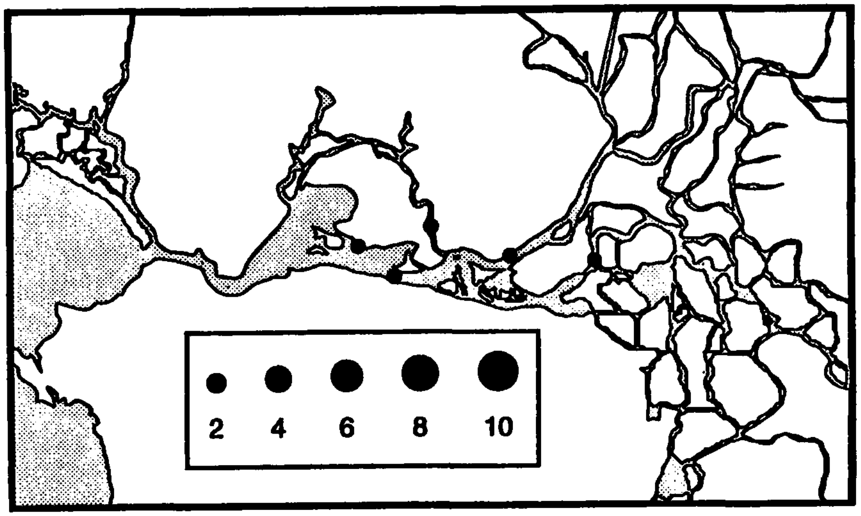


Splittail - 1989

SEPTEMBER



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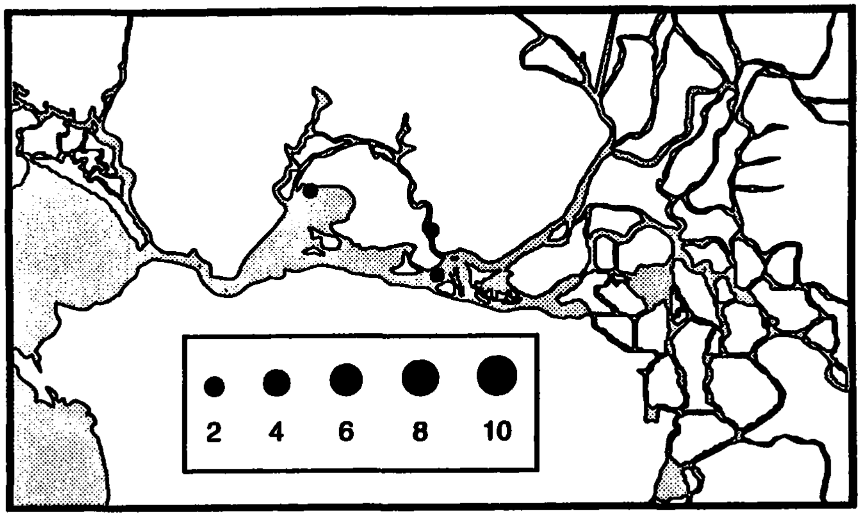

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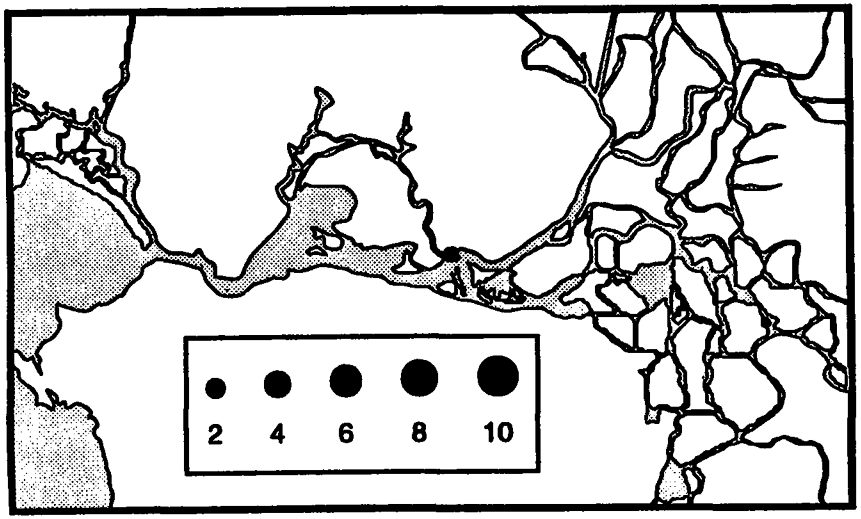

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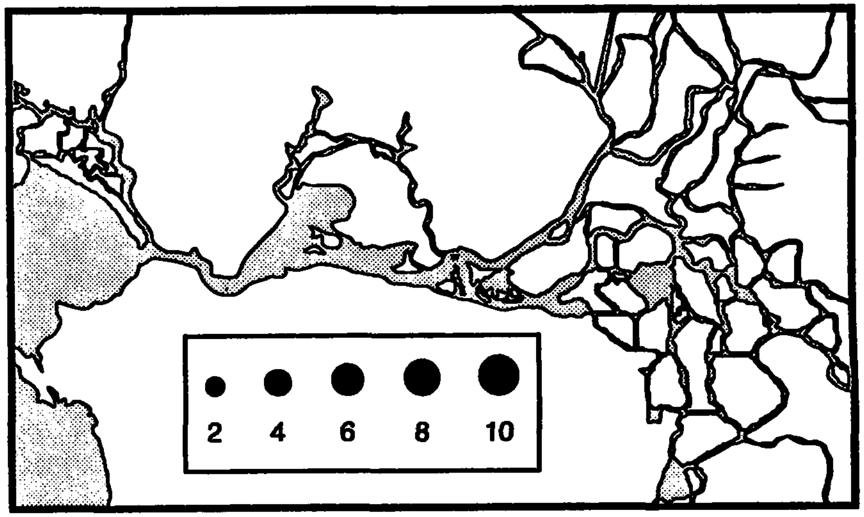
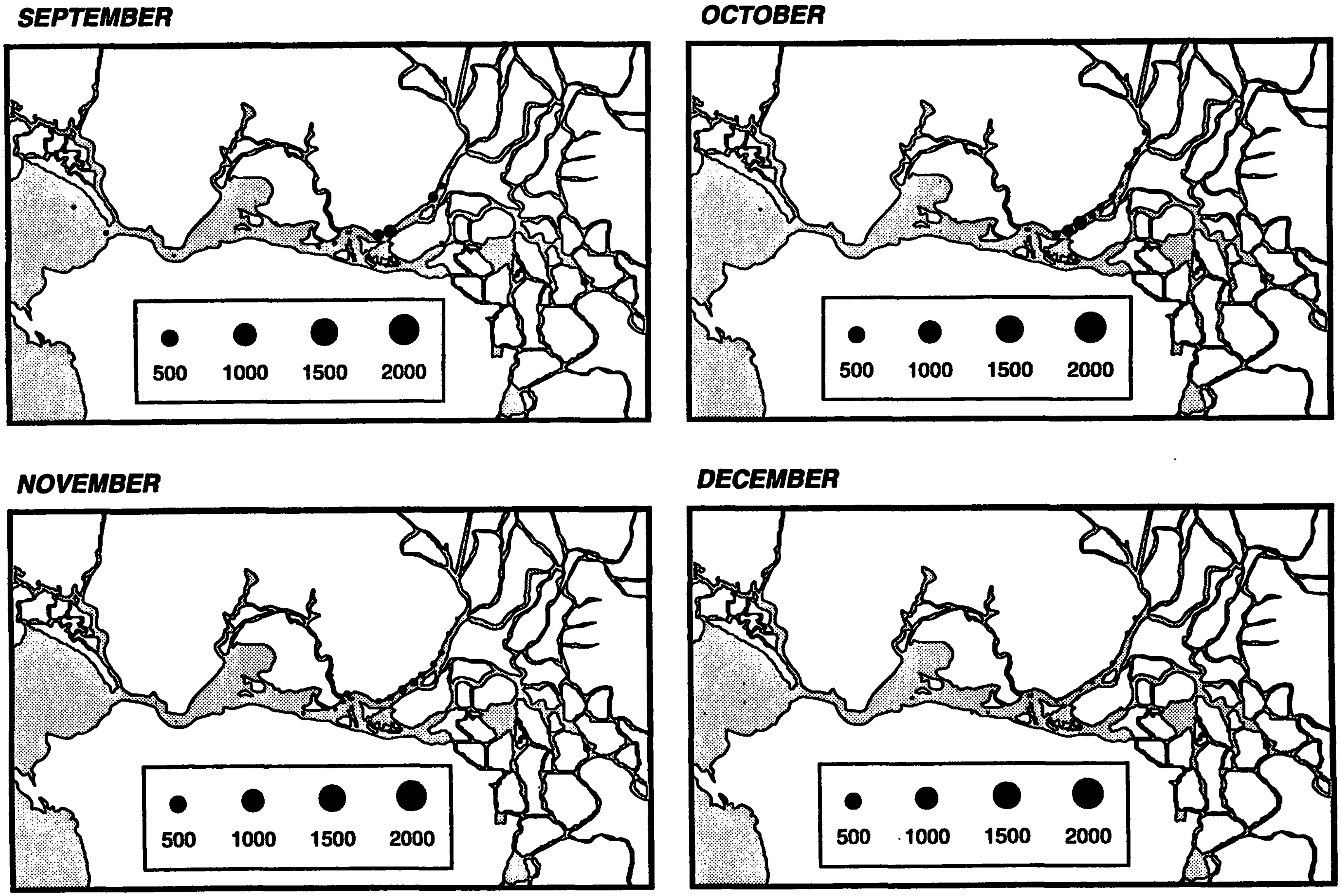


Splittail - 1990

Appendix A-6

Spatial Abundance Maps for Selected Species Sampled in Midwater Trawl Survey, 1977 - 1990

Crangon shrimp



SEPTEMBER

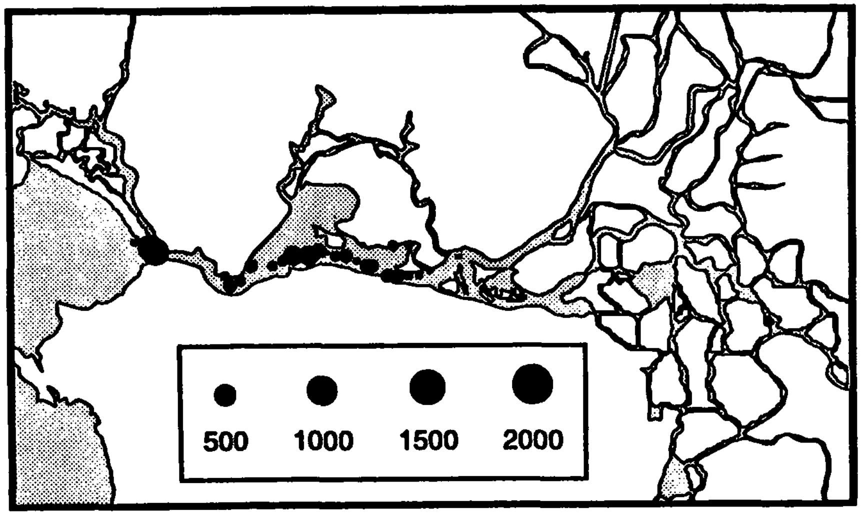
OCTOBER

NOVEMBER

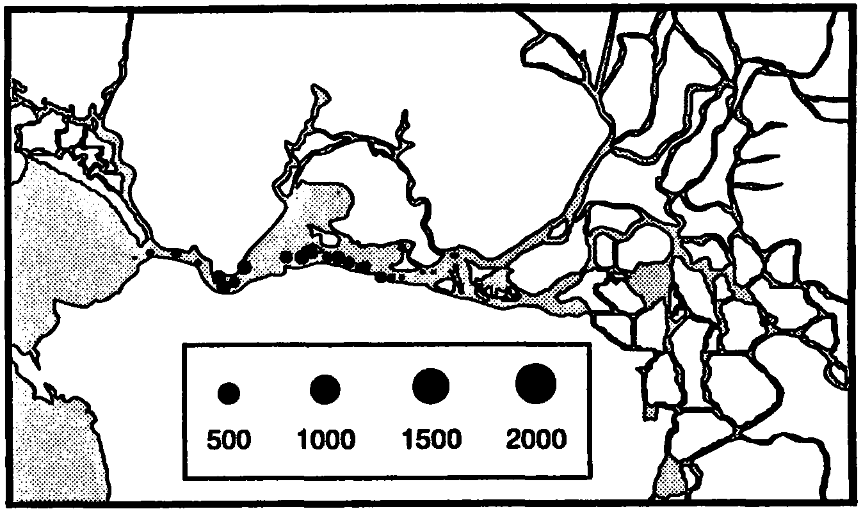
DECEMBER

Crangon Shrimp - 1977

SEPTEMBER



OCTOBER



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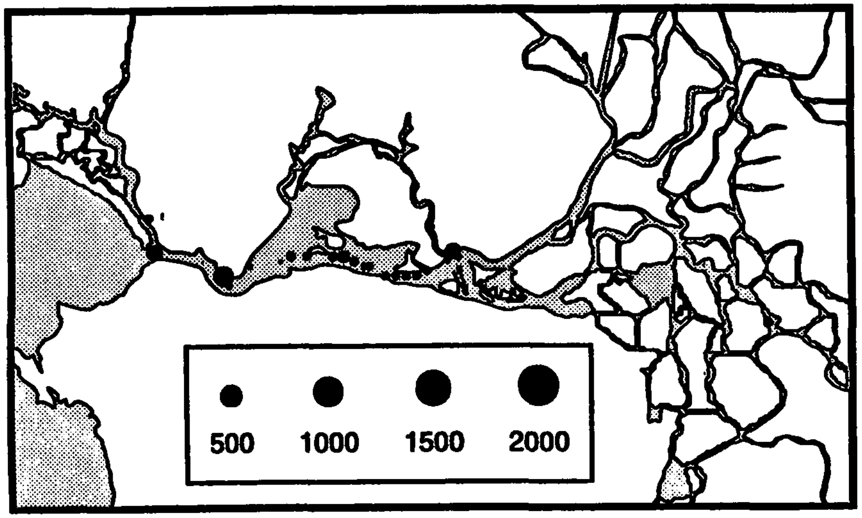
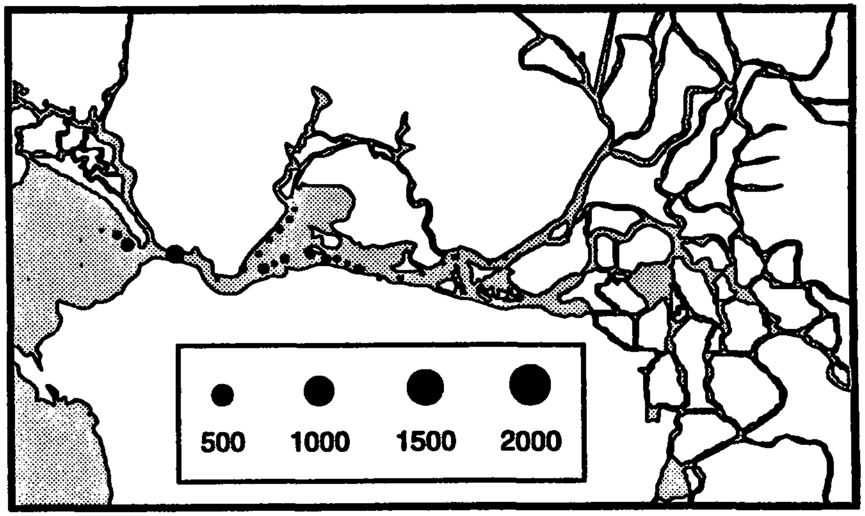
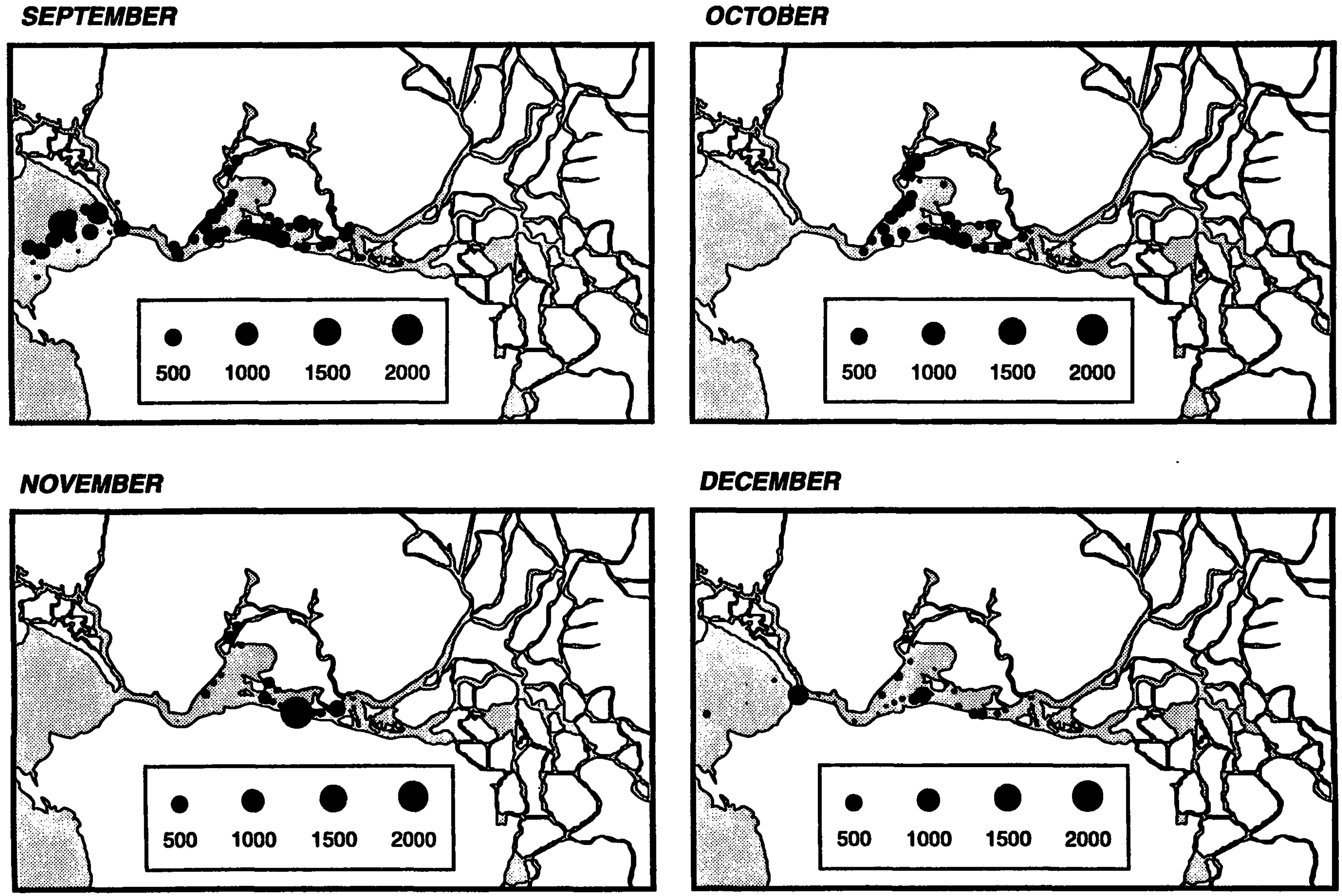


DECEMBER

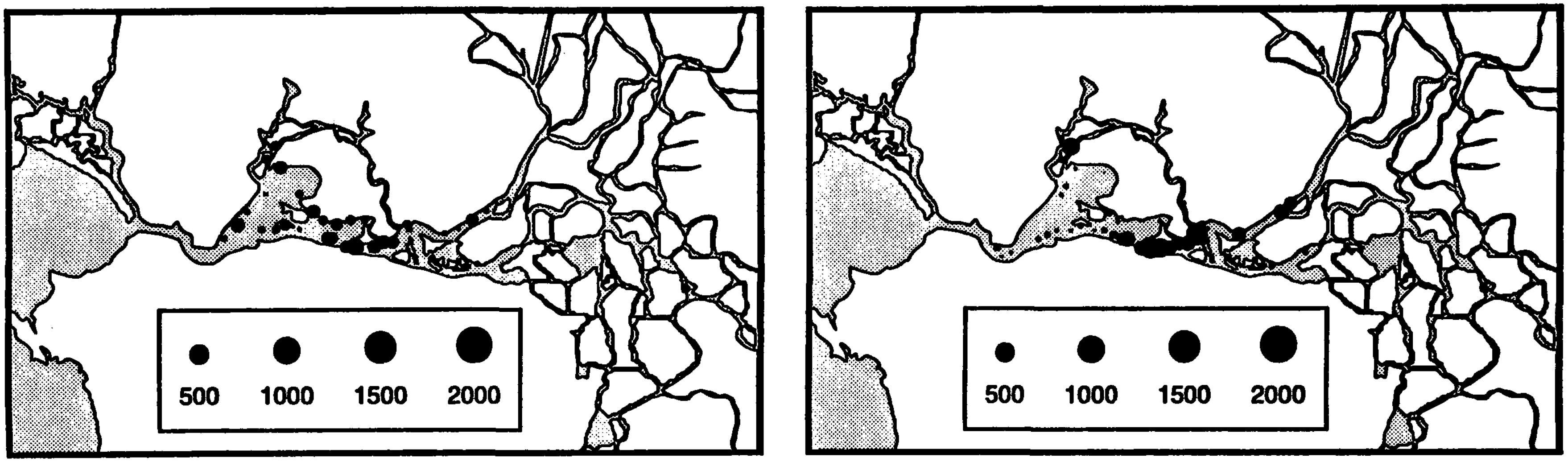


Crangon Shrimp - 1978

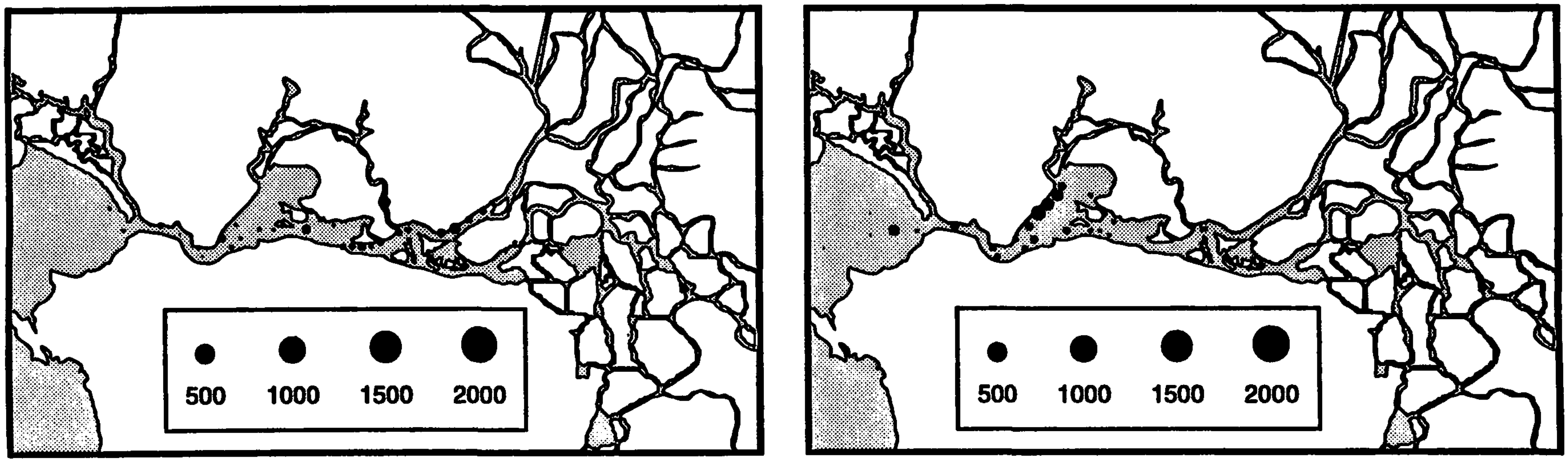


Crangon Shrimp - 1980

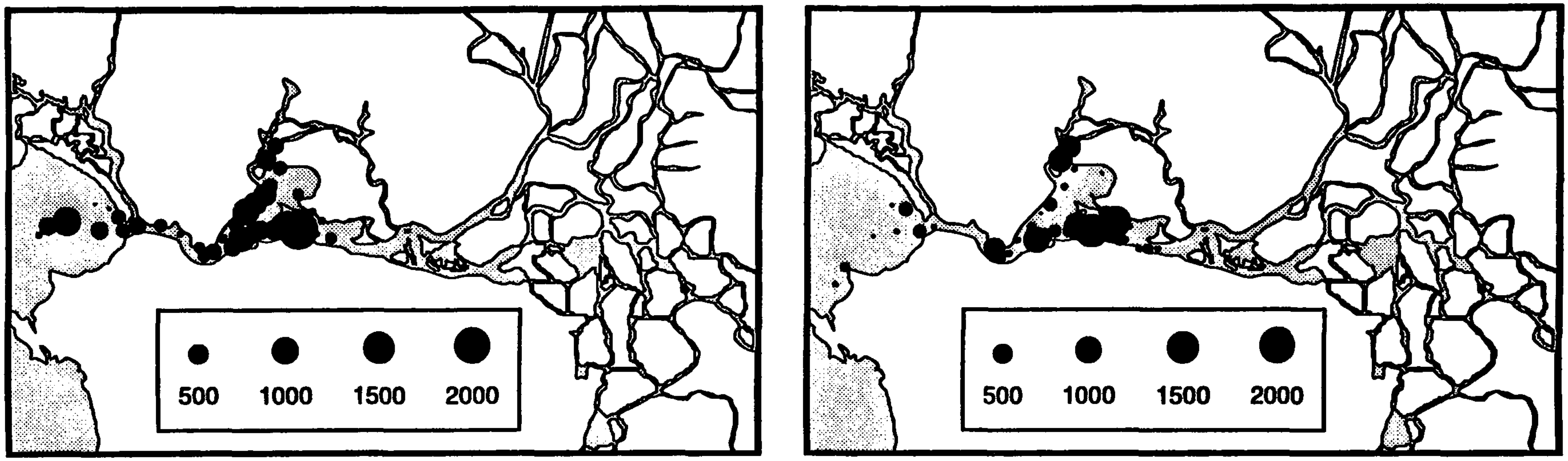
SEPTEMBER OCTOBER



NOVEMBER DECEMBER

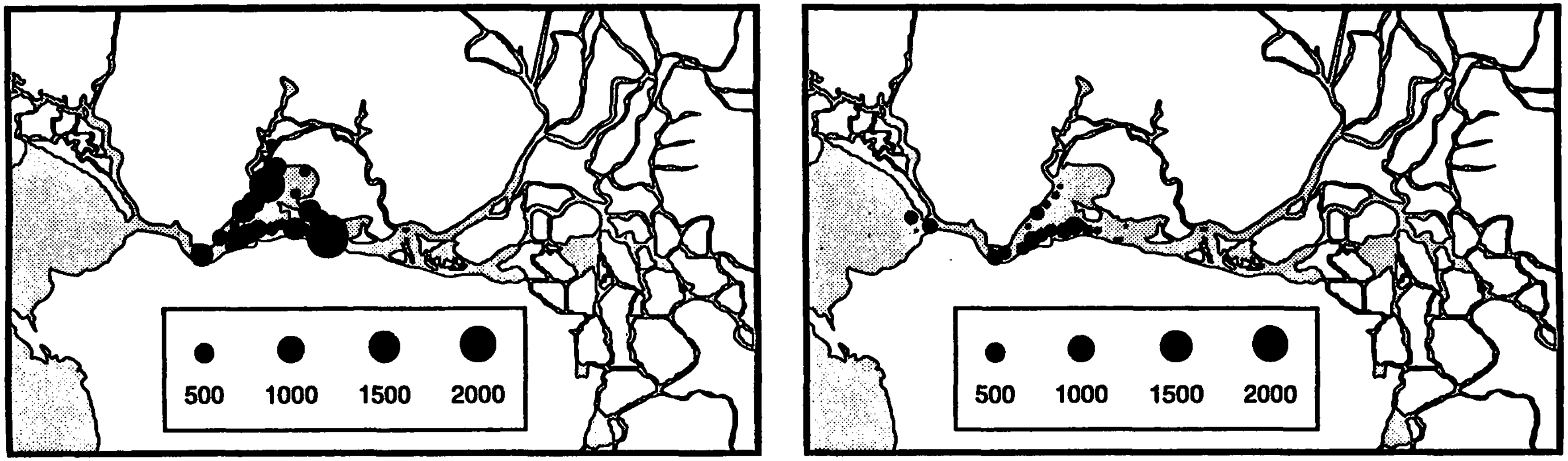


Crangon Shrimp - 1981



SEPTEMBER

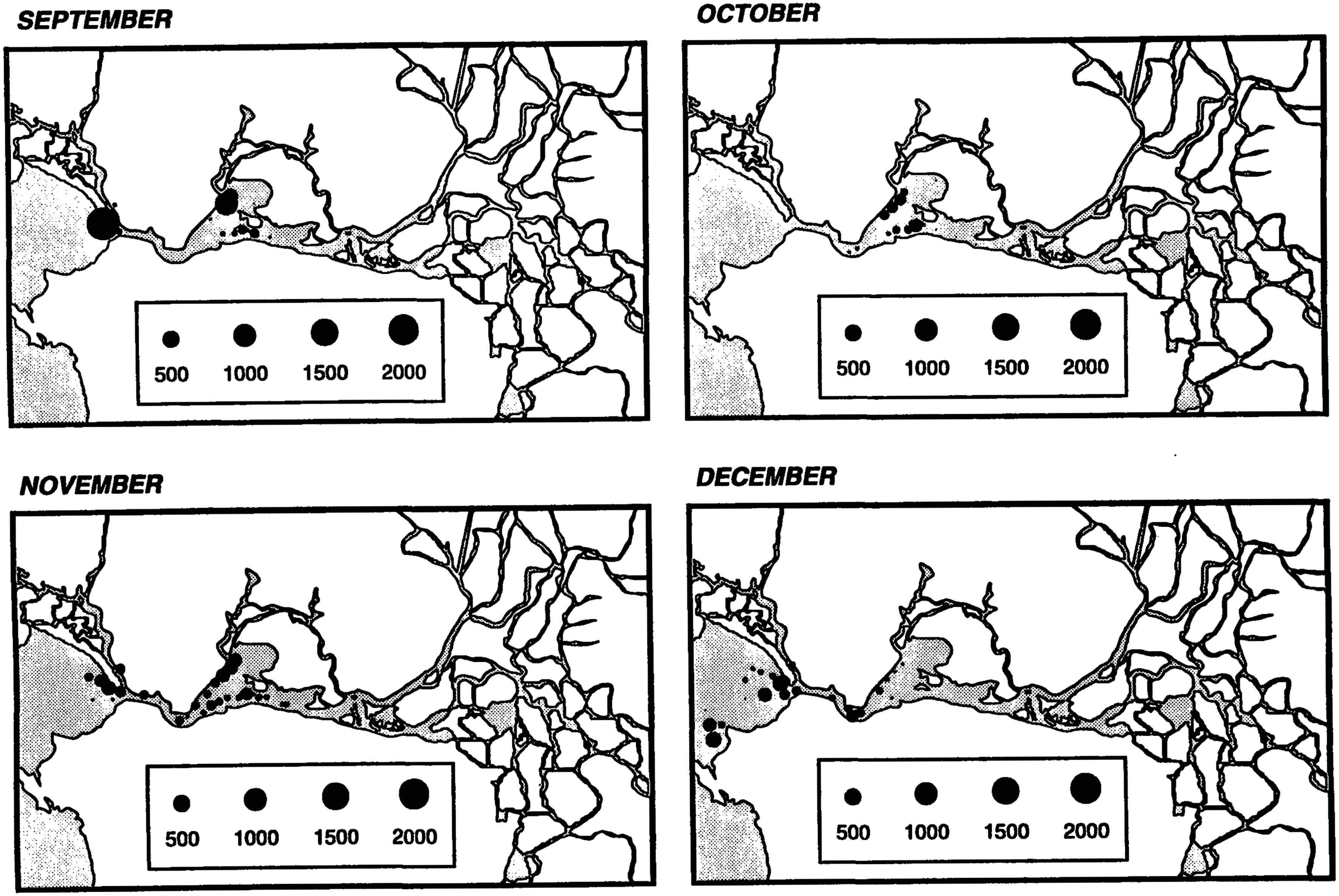
OCTOBER



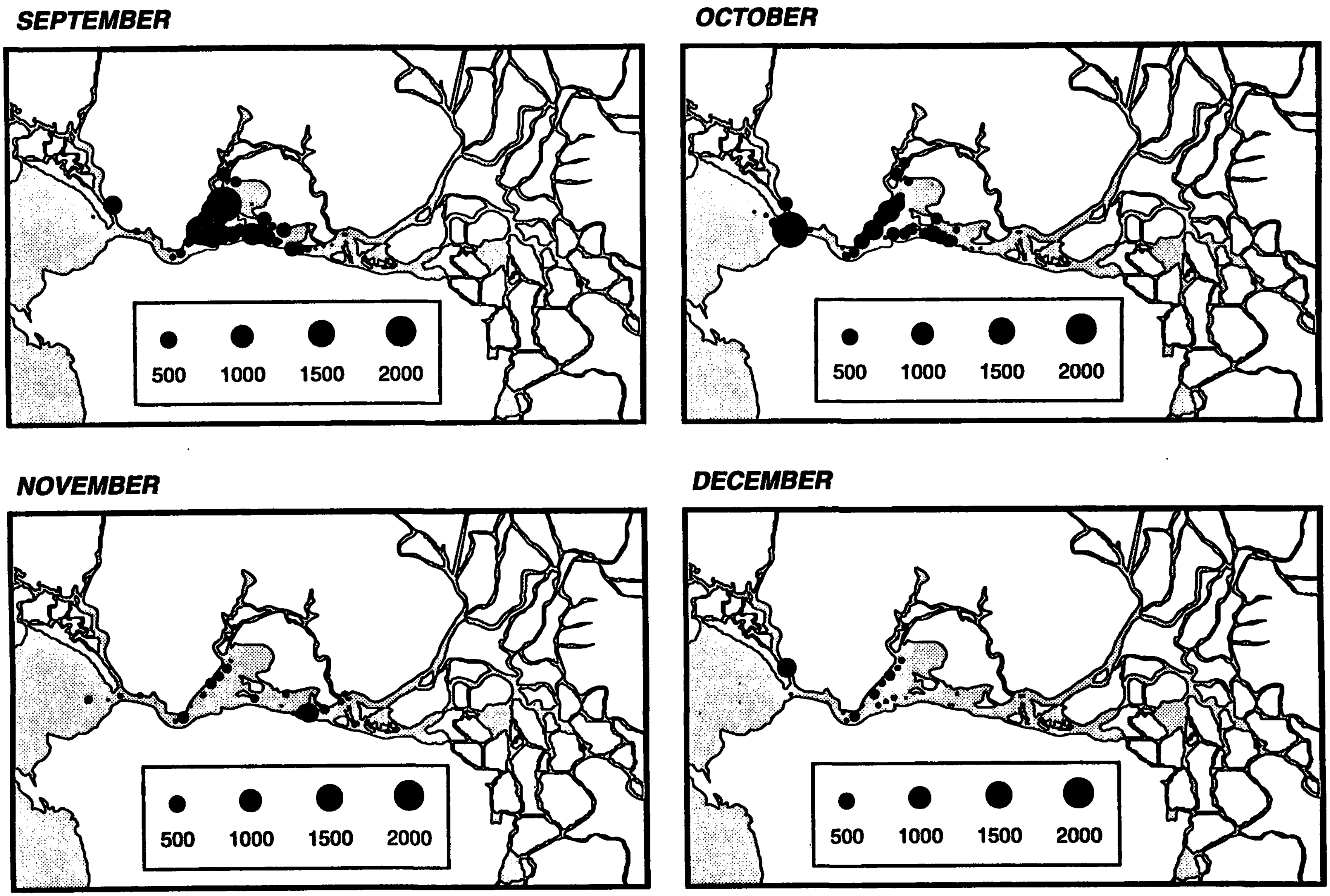
NOVEMBER

DECEMBER

Crangon Shrimp - 1982



Crangon Shrimp - 1983

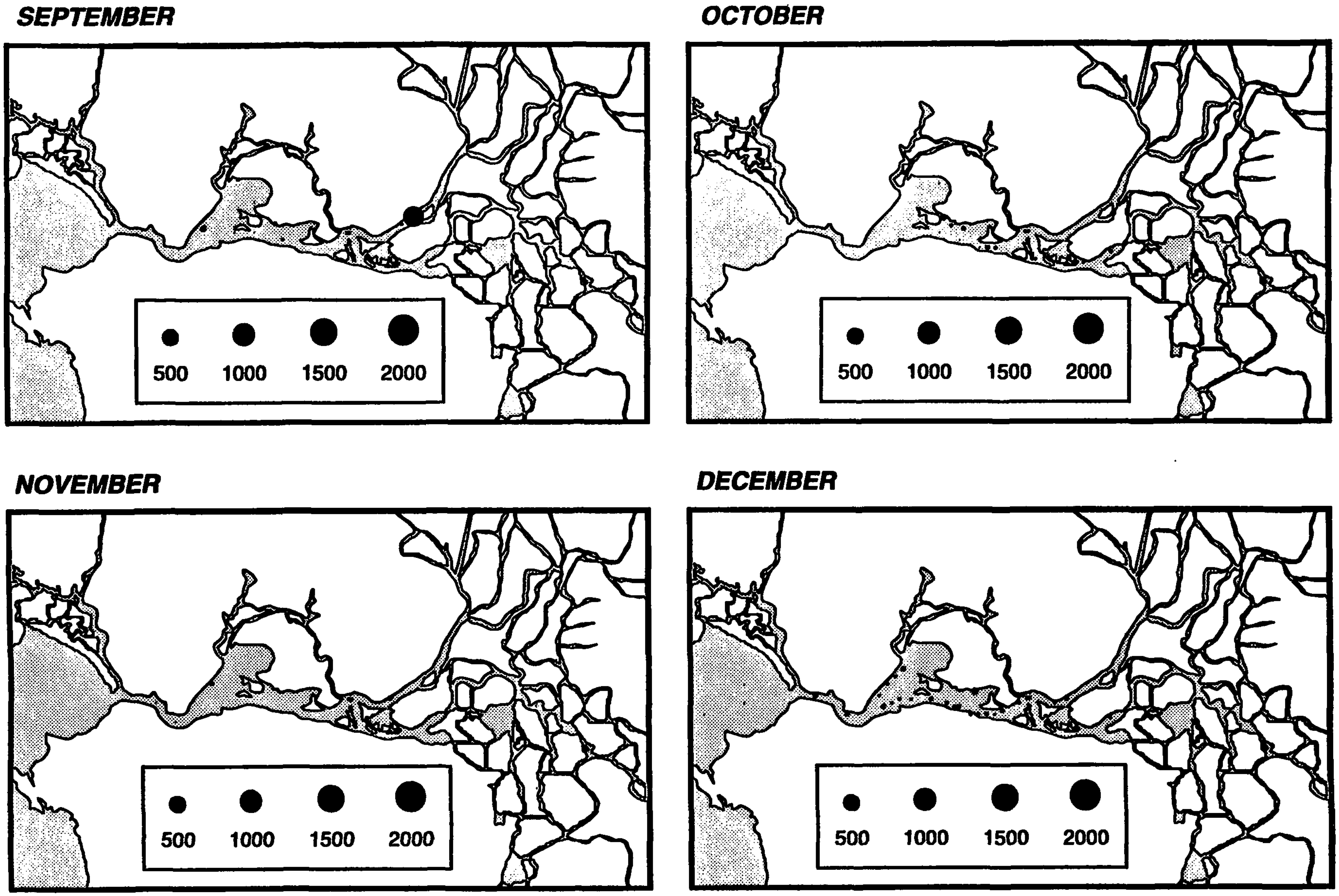

SEPTEMBER

OCTOBER

NOVEMBER

DECEMBER

Crangon Shrimp - 1984



SEPTEMBER

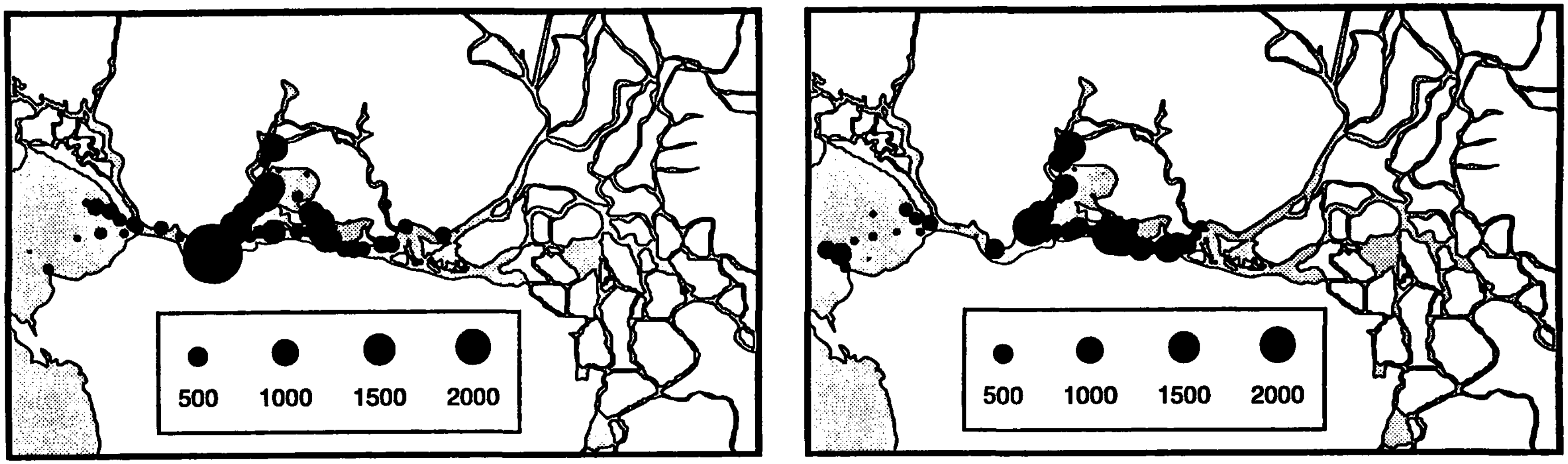
OCTOBER

NOVEMBER

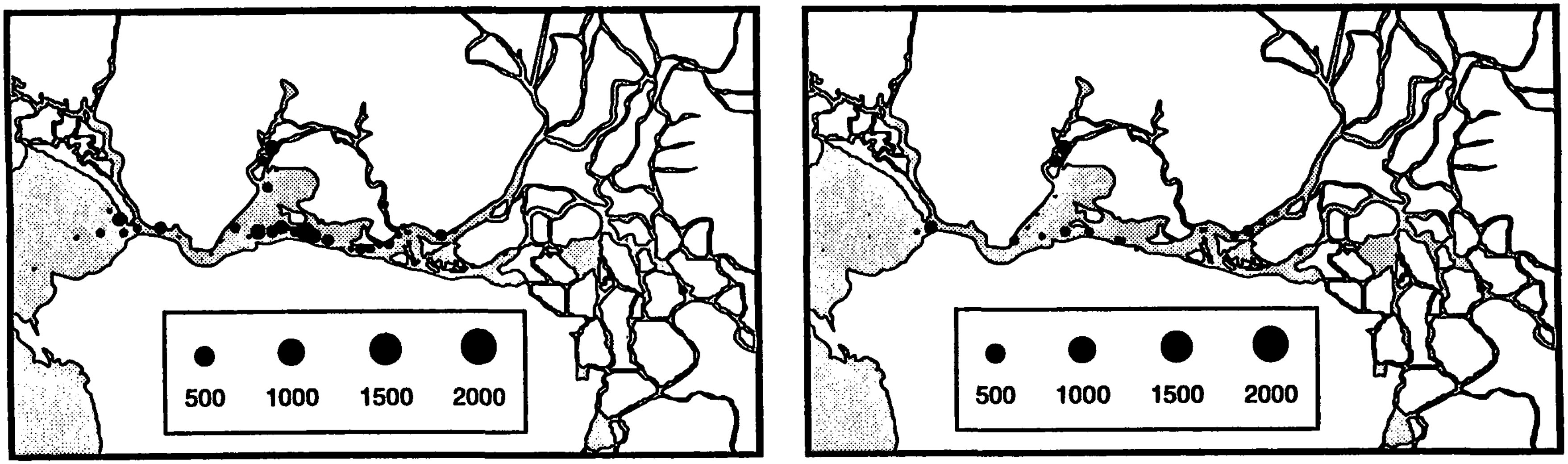
DECEMBER

Crangon Shrimp - 1985

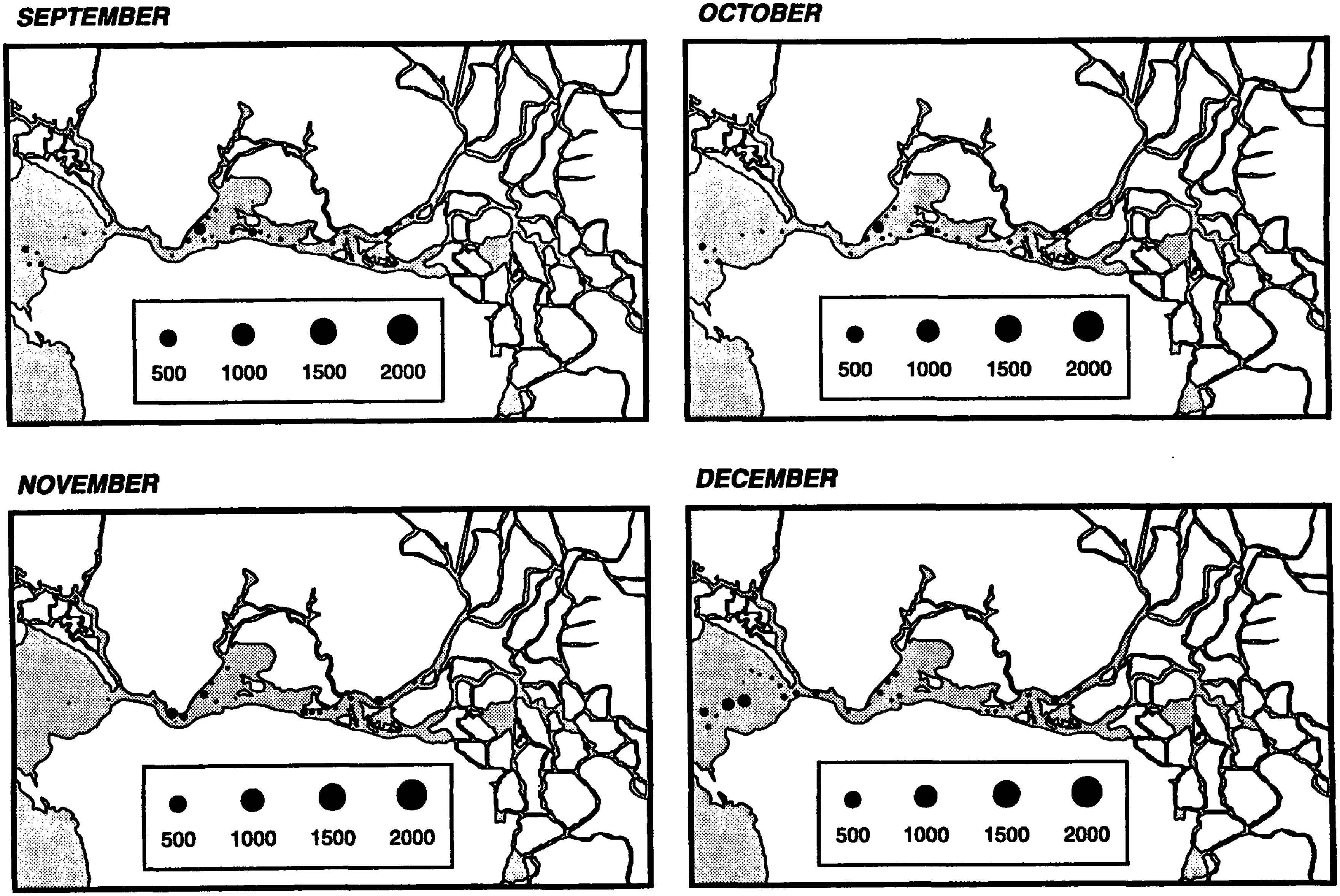
SEPTEMBER ***OCTOBER***



NOVEMBER ***DECEMBER***

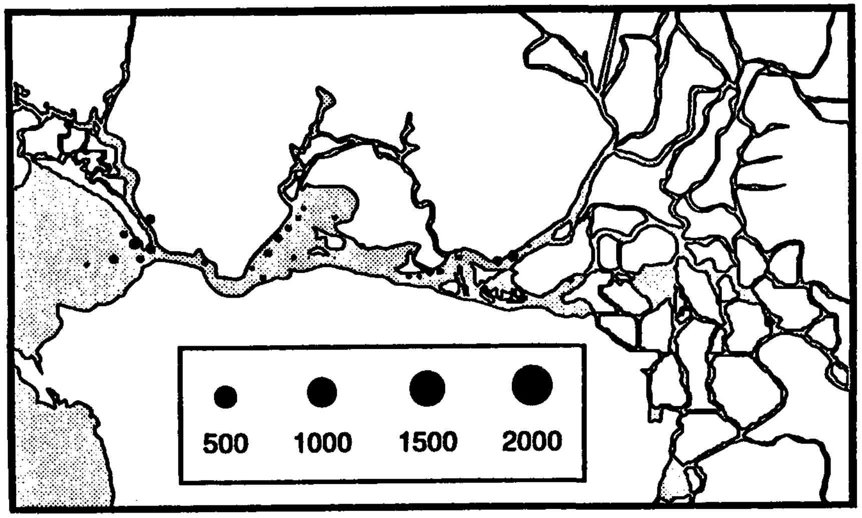


Crangon Shrimp - 1986

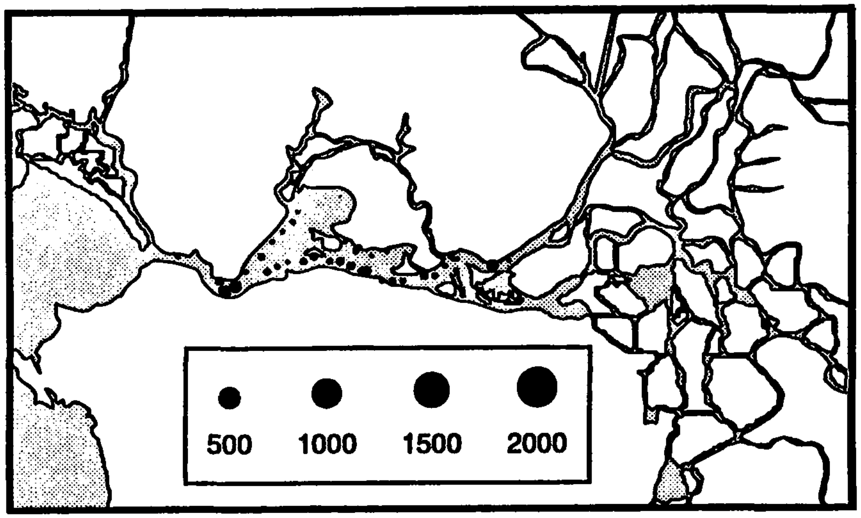


Crangon Shrimp - 1987

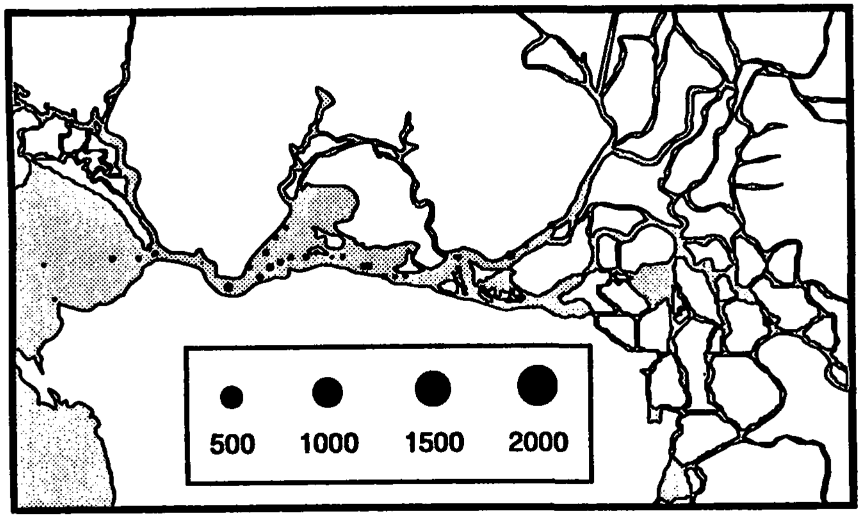
SEPTEMBER



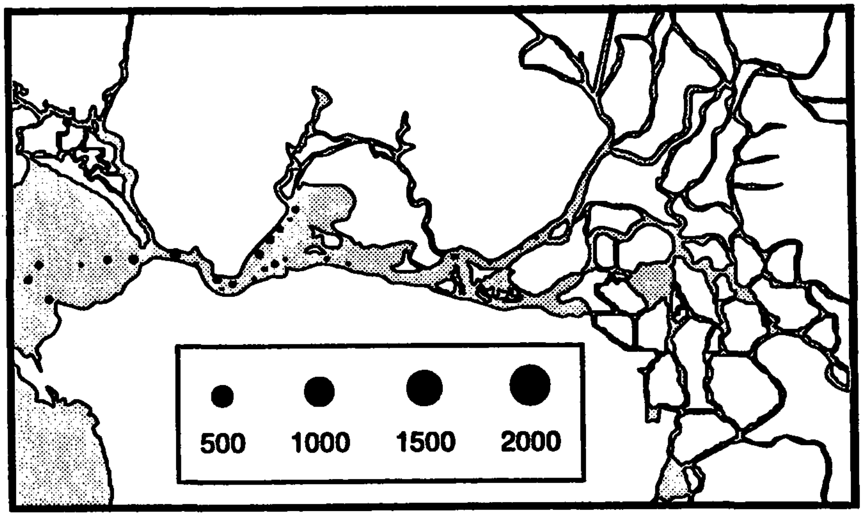
OCTOBER



NOVEMBER

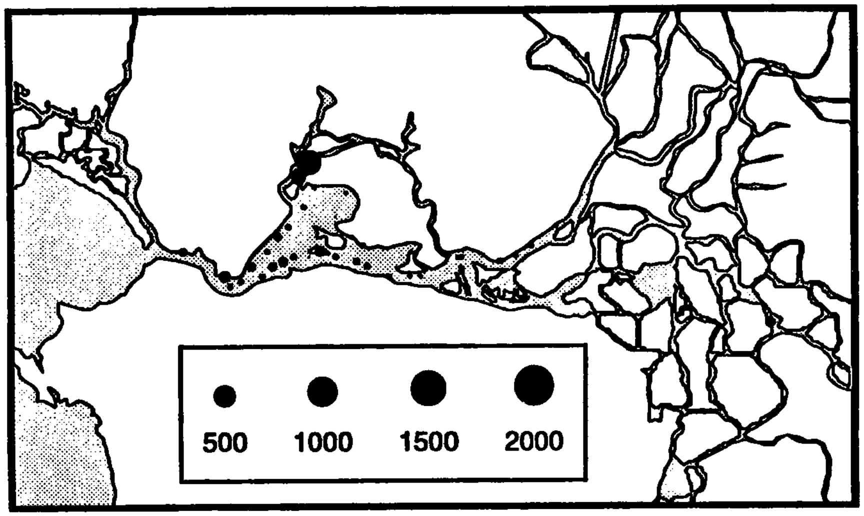


DECEMBER

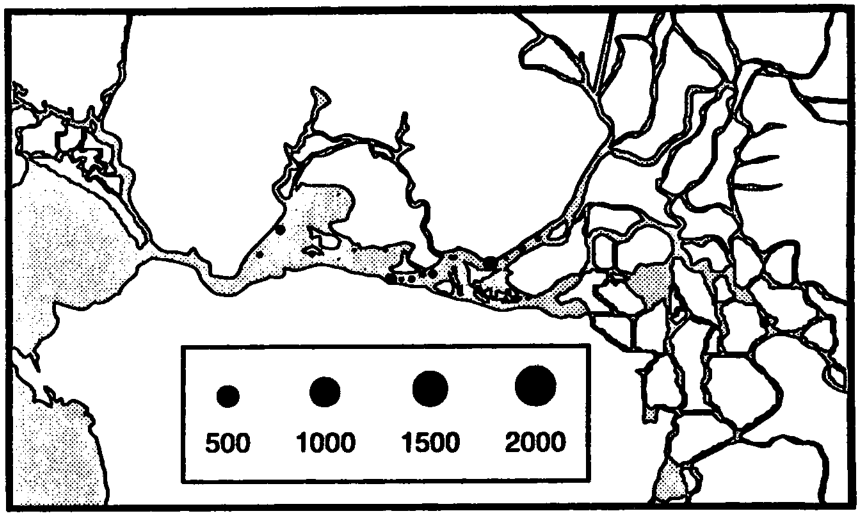


Crangon Shrimp - 1988

SEPTEMBER



OCTOBER



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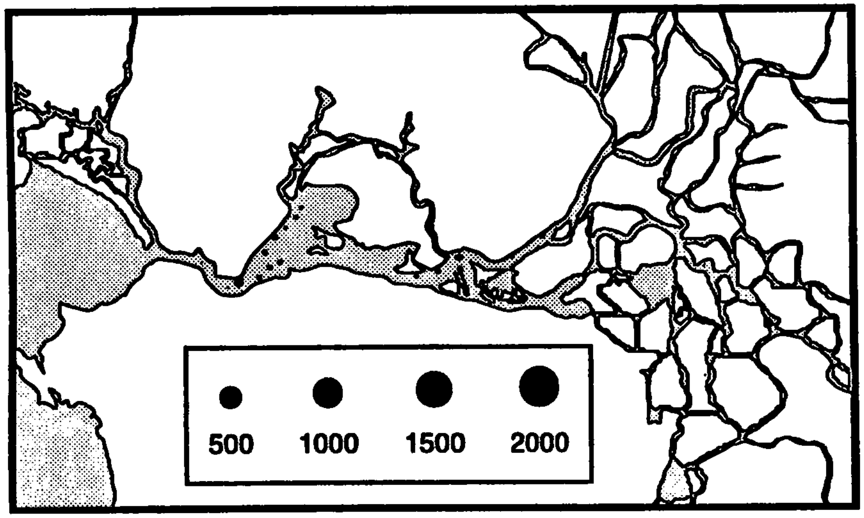
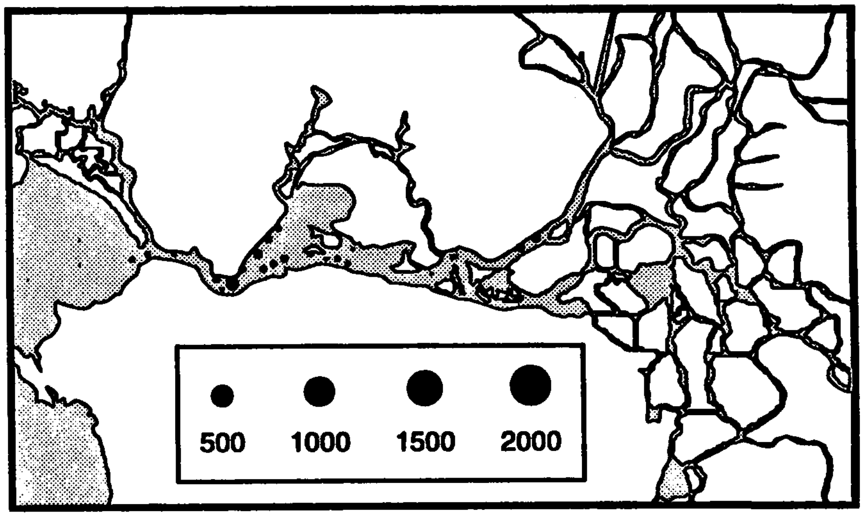
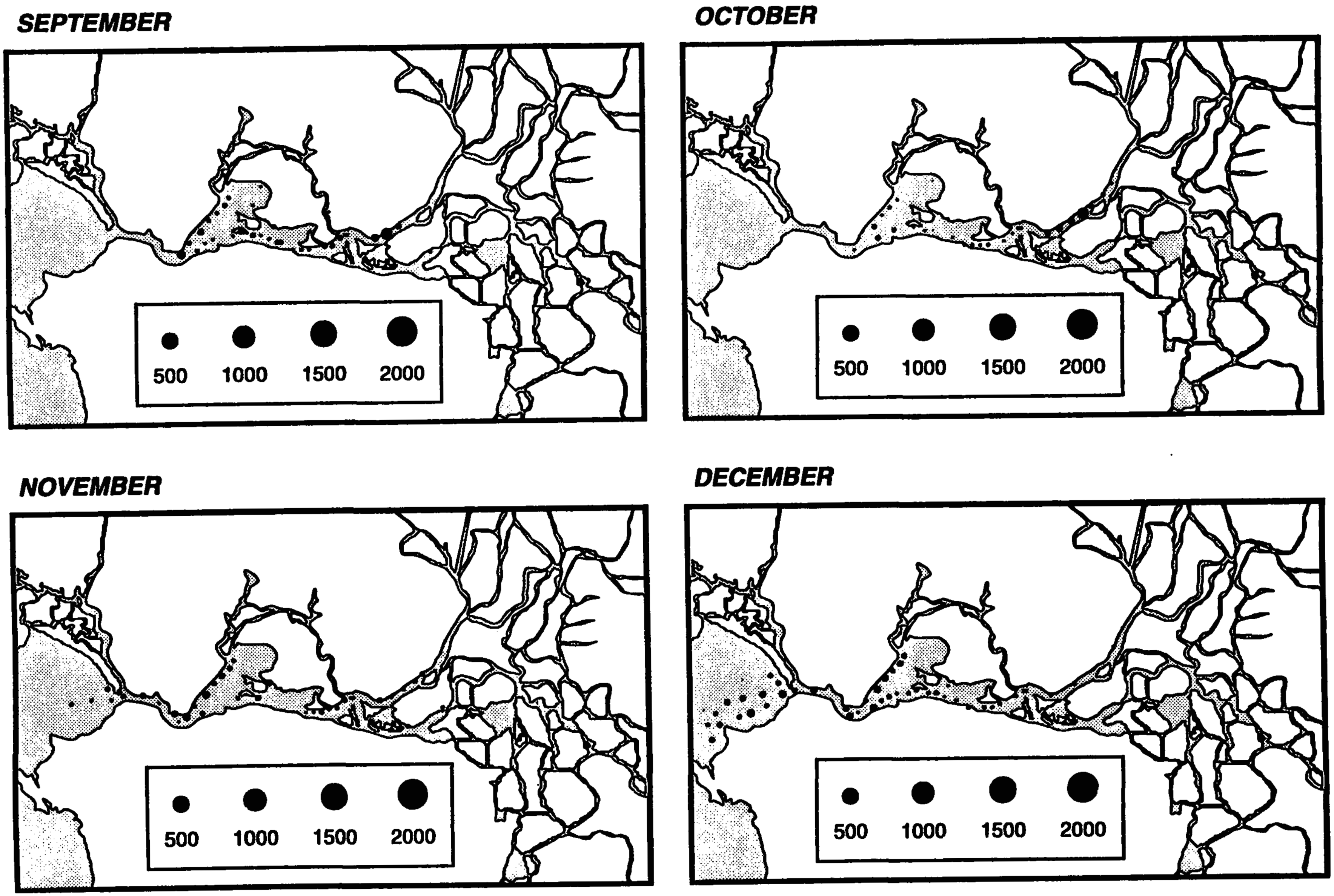


DECEMBER



Crangon Shrimp - 1989



Crangon Shrimp - 1990

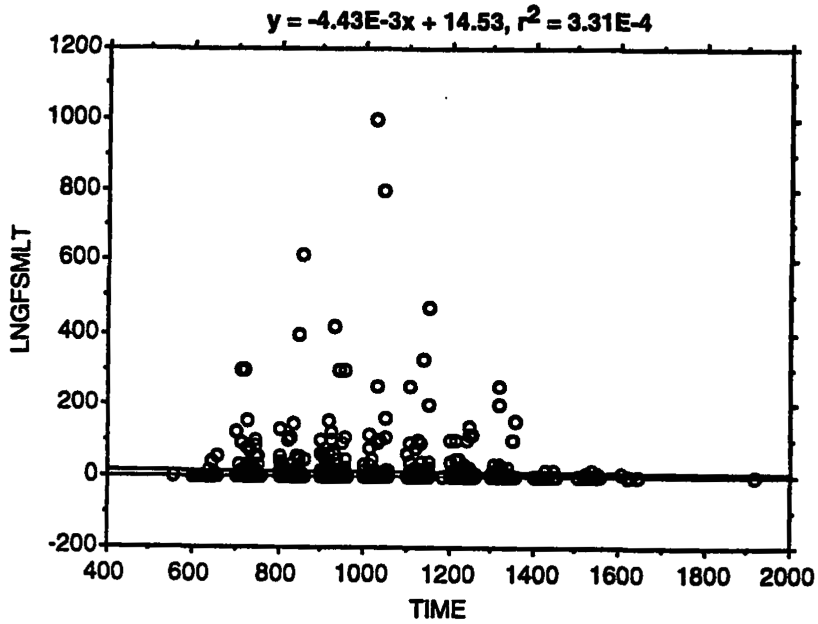
Appendix B

Analysis of Environmental Factors Potentially Influencing Midwater Trawl Catch Abundance Data

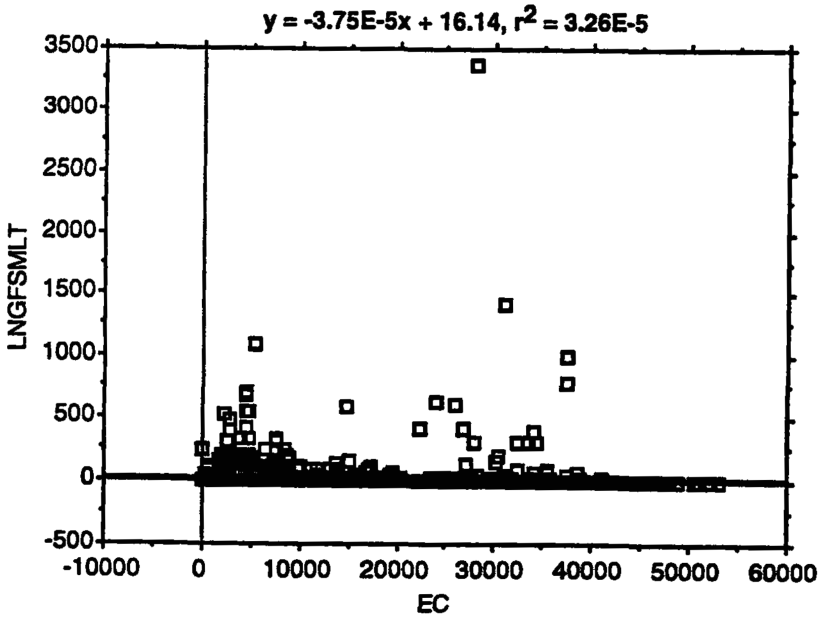
Appendix B-1

Analysis of Environmental Factors Potentially Influencing Midwater Trawl Catch Abundance Data

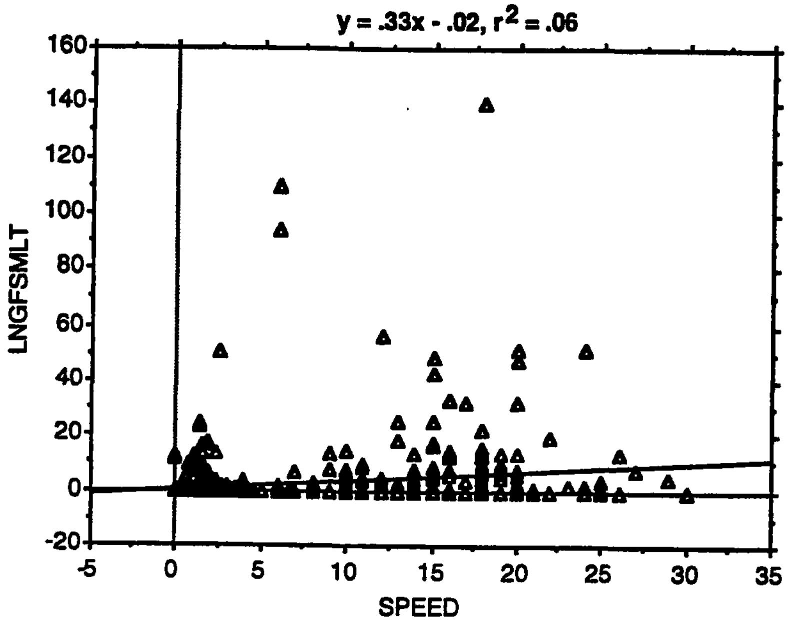
Longfin Smelt



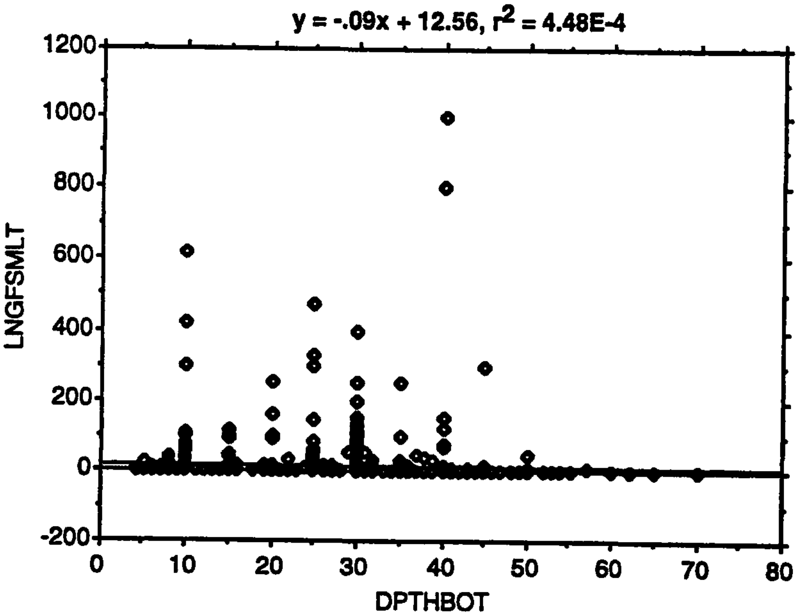
Longfin smelt catch abundance versus time of day, September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



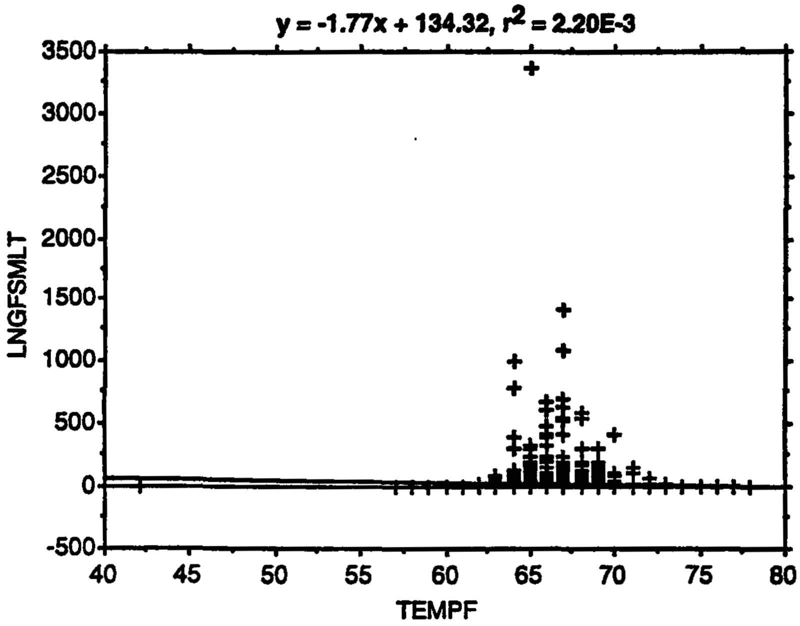
Longfin smelt catch abundance versus electroconductivity (μS/cm), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



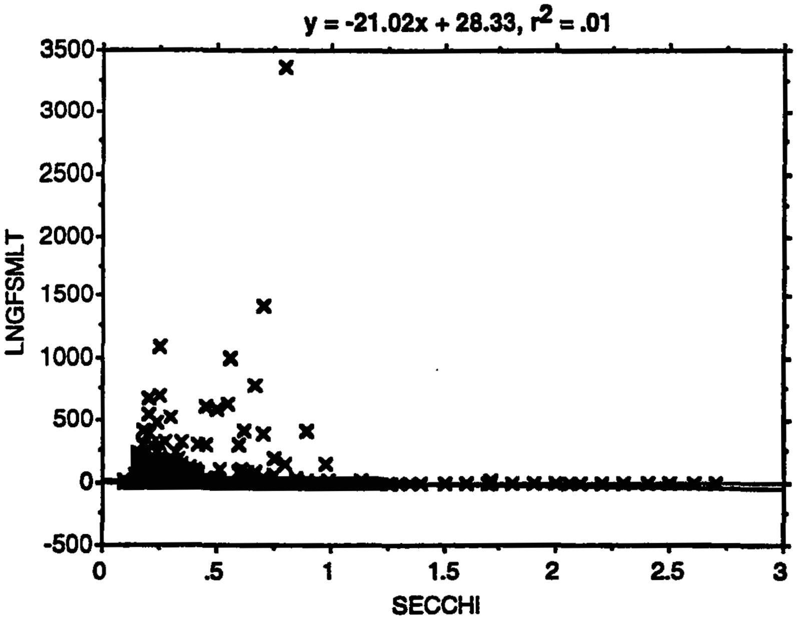
Longfin smelt catch abundance versus boat speed, September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



Longfin smelt catch abundance versus bottom depth (ft), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



Longfin smelt catch abundance versus water temperature (° F), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).

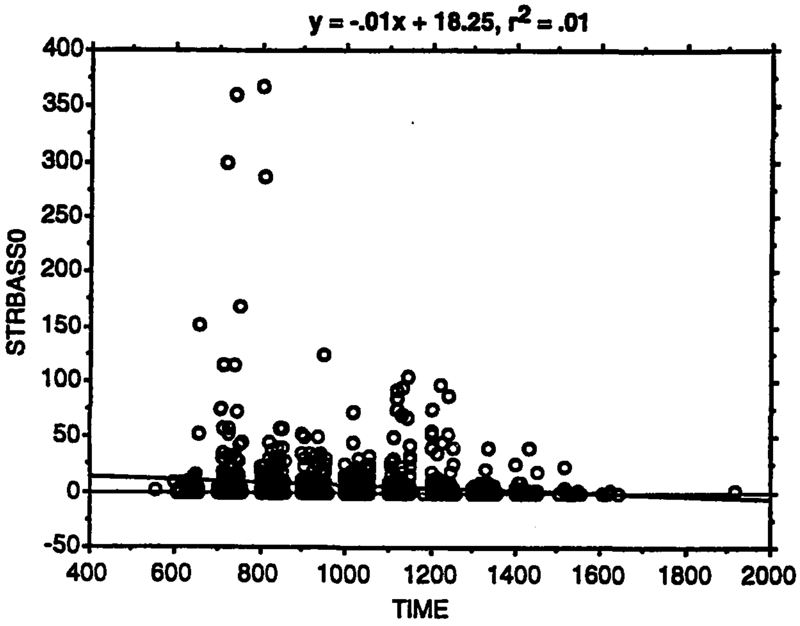


Longfin smelt catch abundance versus secchi disk depth (meters), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).

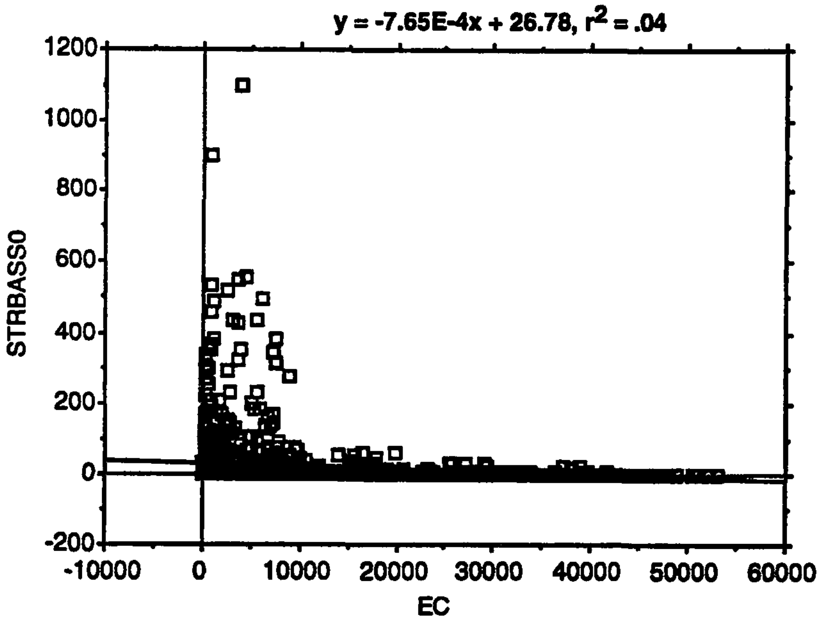
Appendix B-2

Analysis of Environmental Factors Potentially Influencing Midwater Trawl Catch Abundance Data

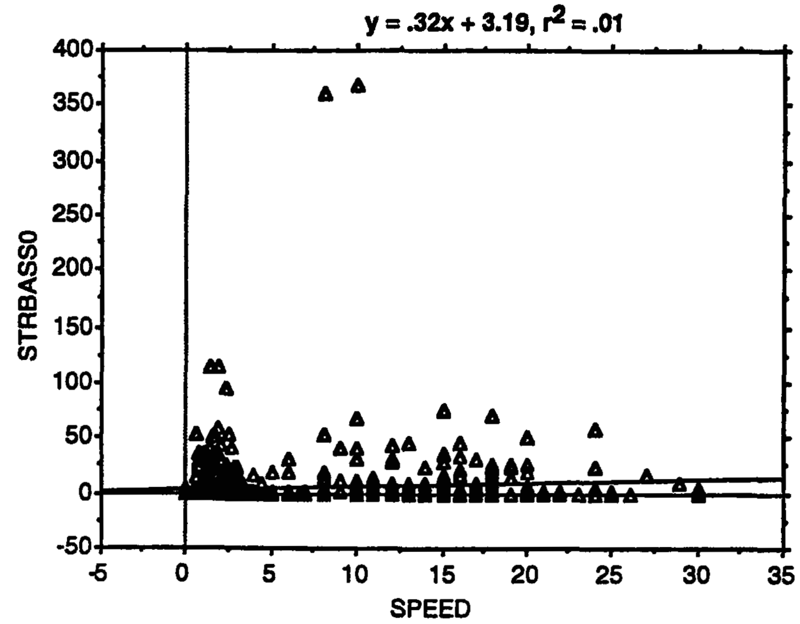
Striped Bass (age 0+)



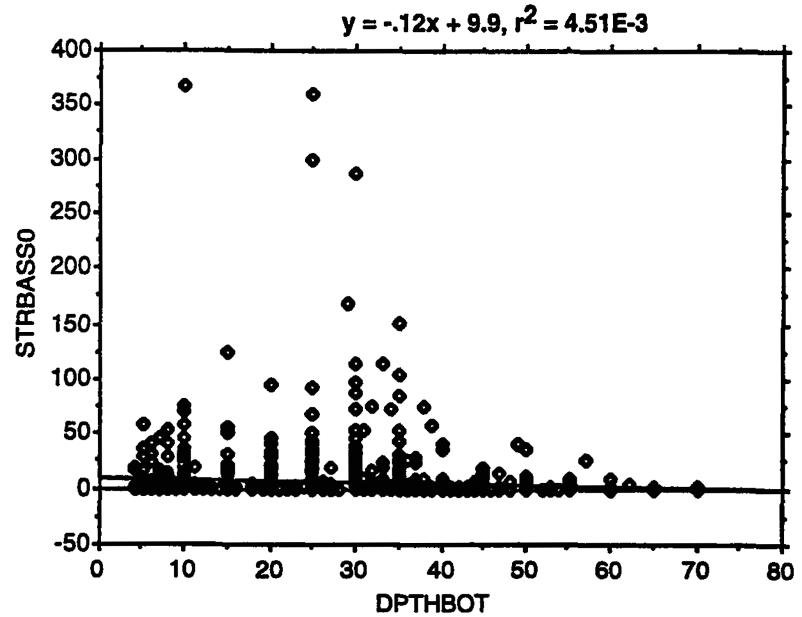
Striped bass (age 0+) catch abundance versus time of day, September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



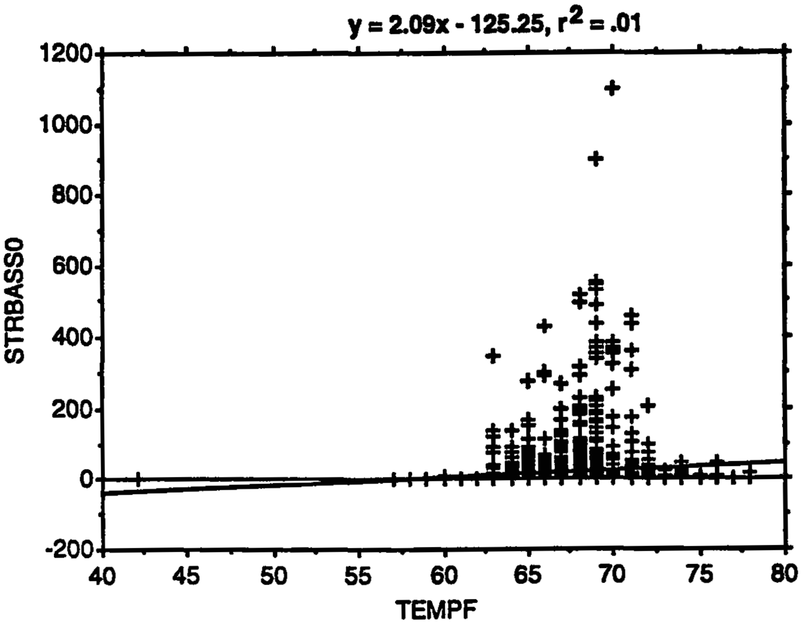
Striped bass (age 0+) catch abundance versus electroconductivity (μS/cm), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



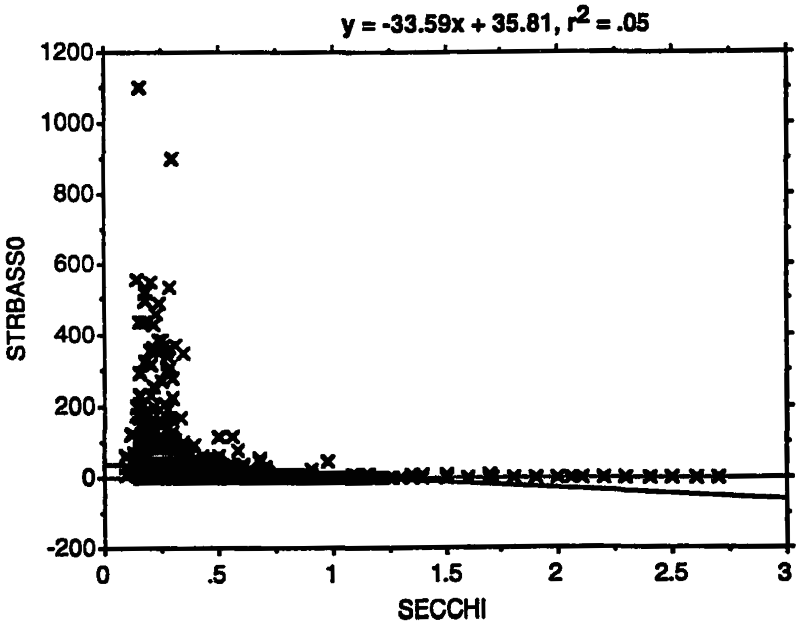
Striped bass (age 0+) catch abundance versus boat speed, September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



Striped bass (age 0+) catch abundance versus bottom depth (ft), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



Striped bass (age 0+) catch abundance versus water temperature (° F), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).

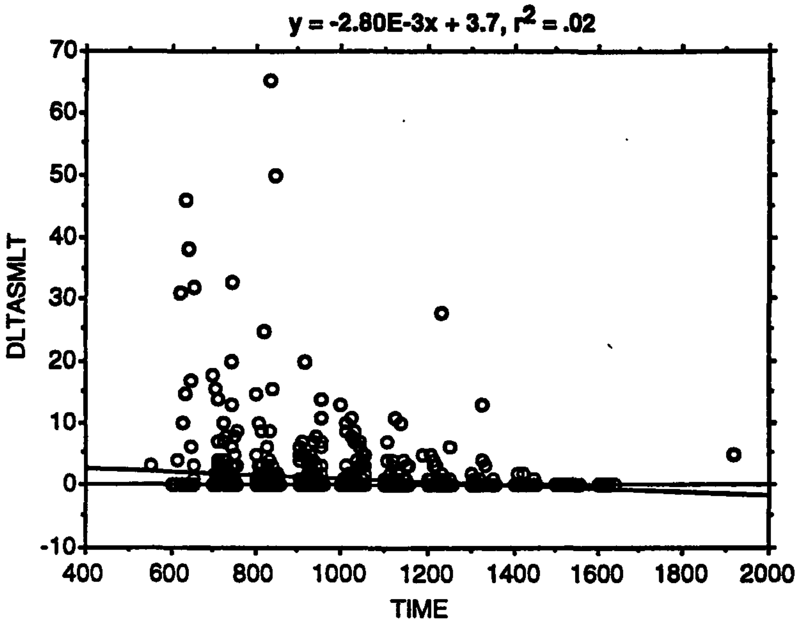


Striped bass (age 0+) catch abundance versus secchi disk depth (meters), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).

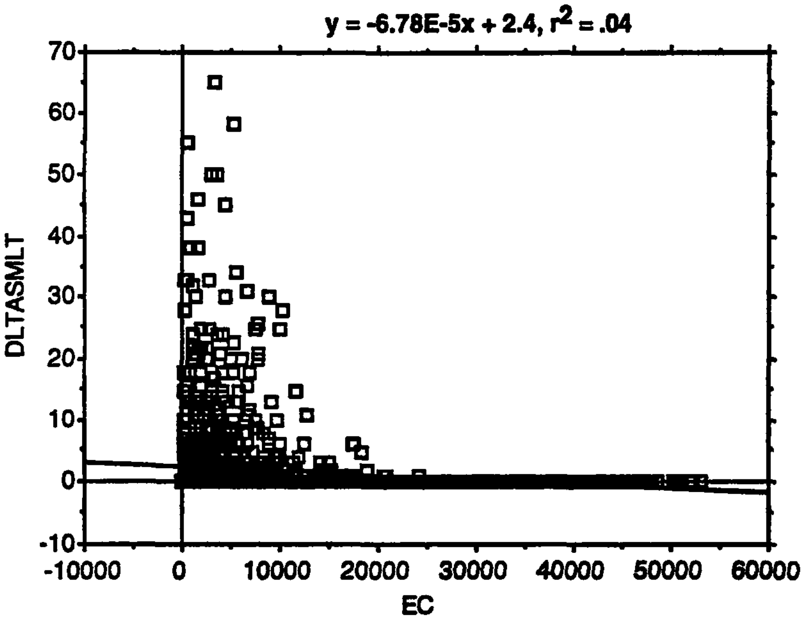
Appendix B-3

Analysis of Environmental Factors Potentially Influencing Midwater Trawl Catch Abundance Data

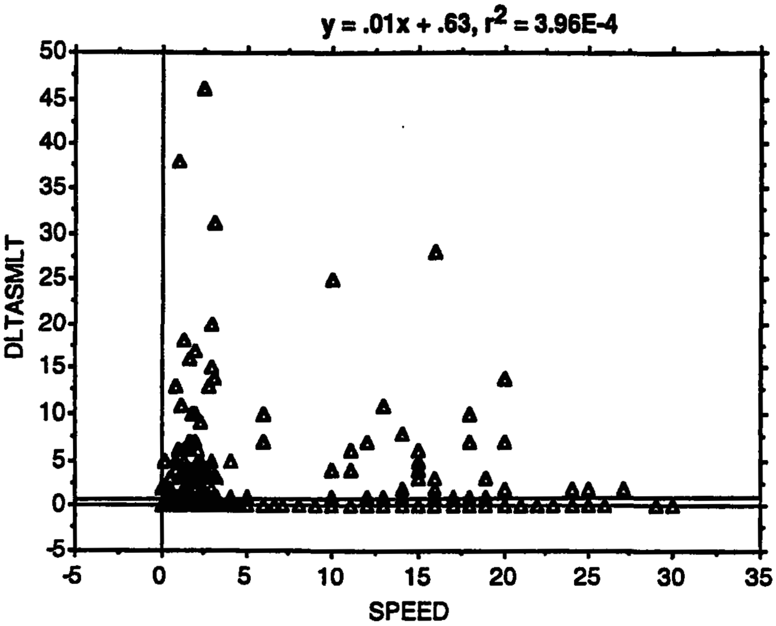
Delta Smelt



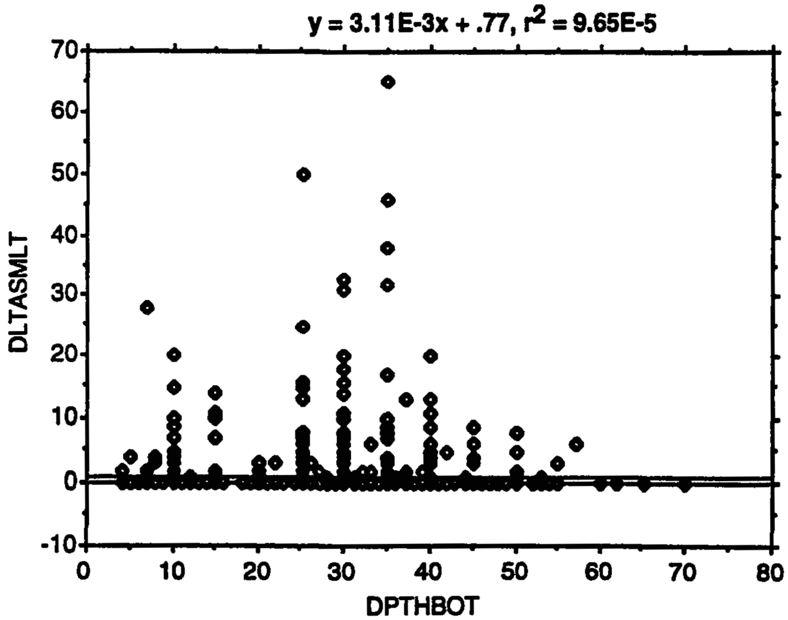
Delta smelt catch abundance versus time of day, September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



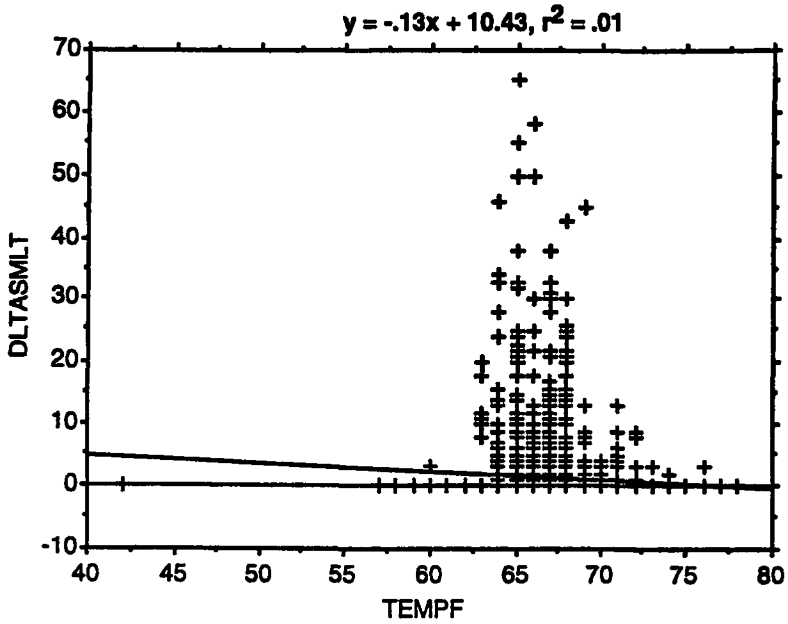
Delta smelt catch abundance versus electroconductivity (μS/cm), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



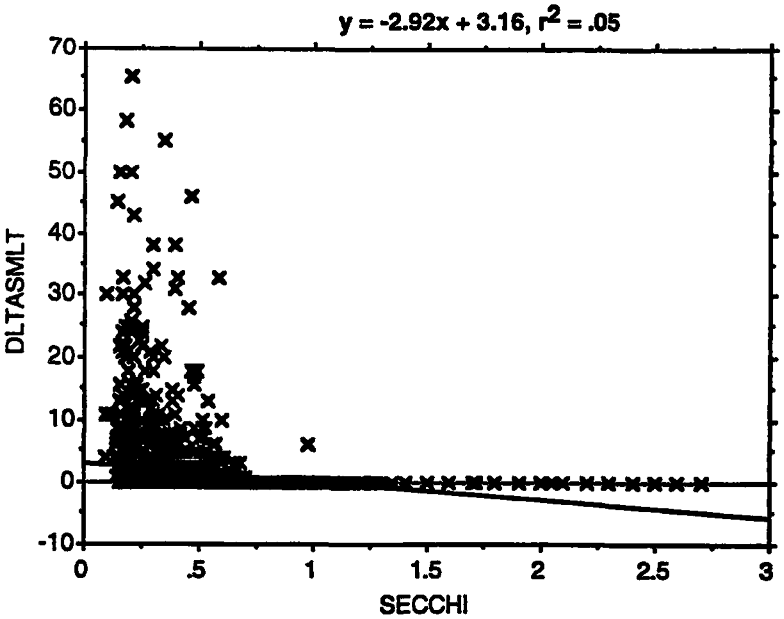
Delta smelt catch abundance versus boat speed, September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



Delta smelt catch abundance versus bottom depth (ft), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



Delta smelt catch abundance versus water temperature (° F), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).

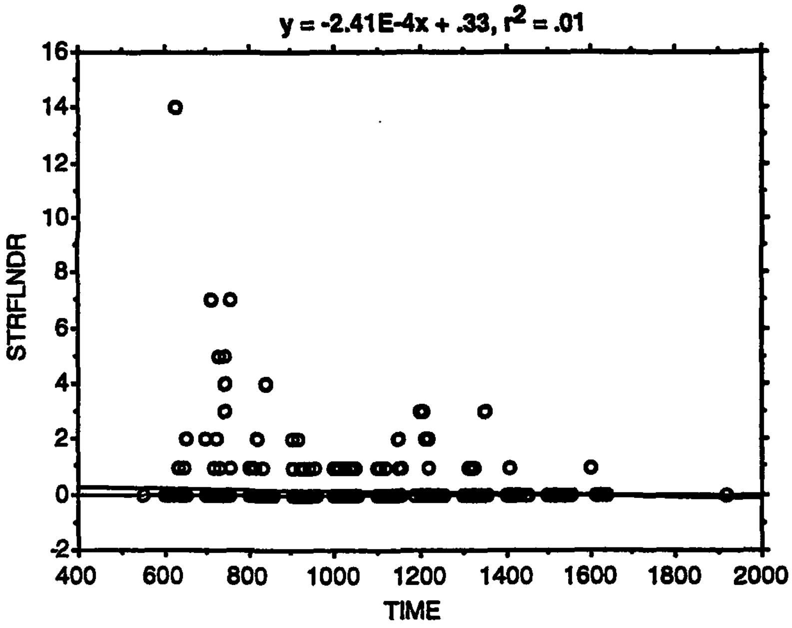


Delta smelt catch abundance versus secchi disk depth (meters), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).

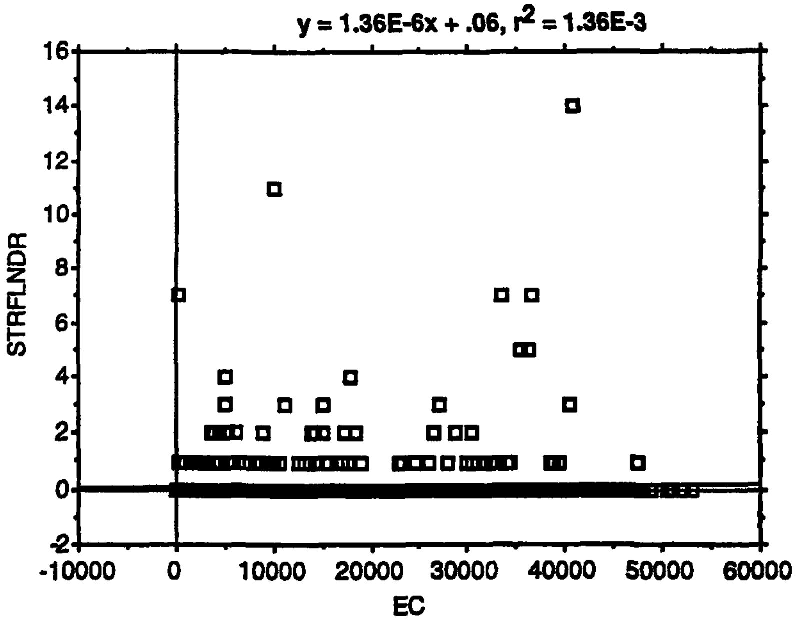
Appendix B-4

Analysis of Environmental Factors Potentially Influencing Midwater Trawl Catch Abundance Data

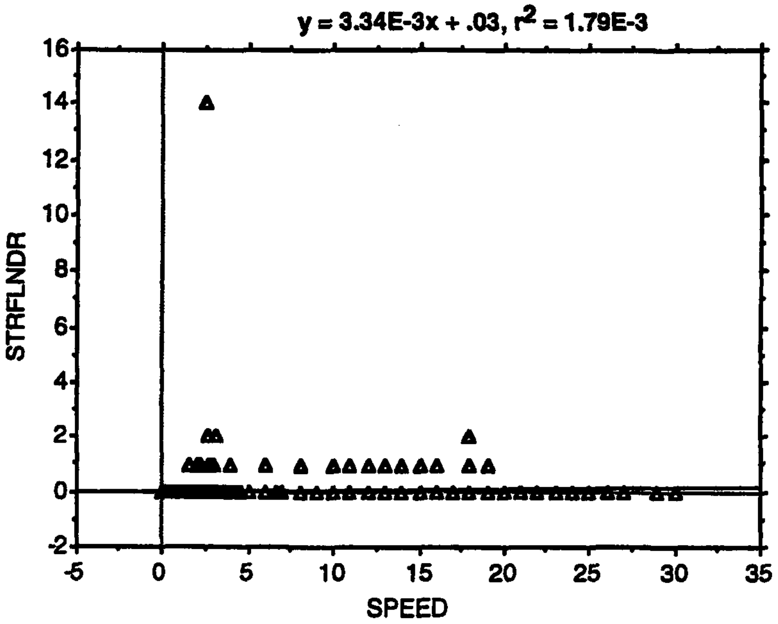
Starry Flounder



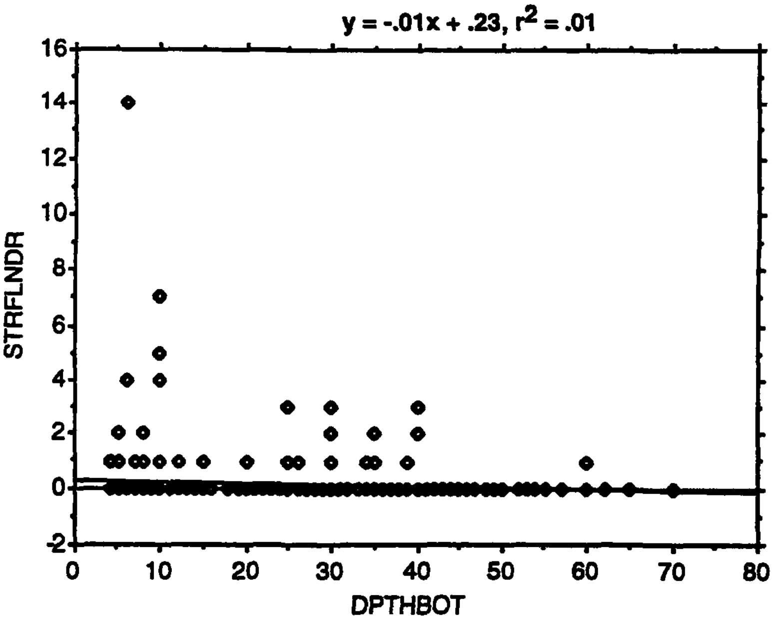
Starry Flounder catch abundance versus time of day, September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



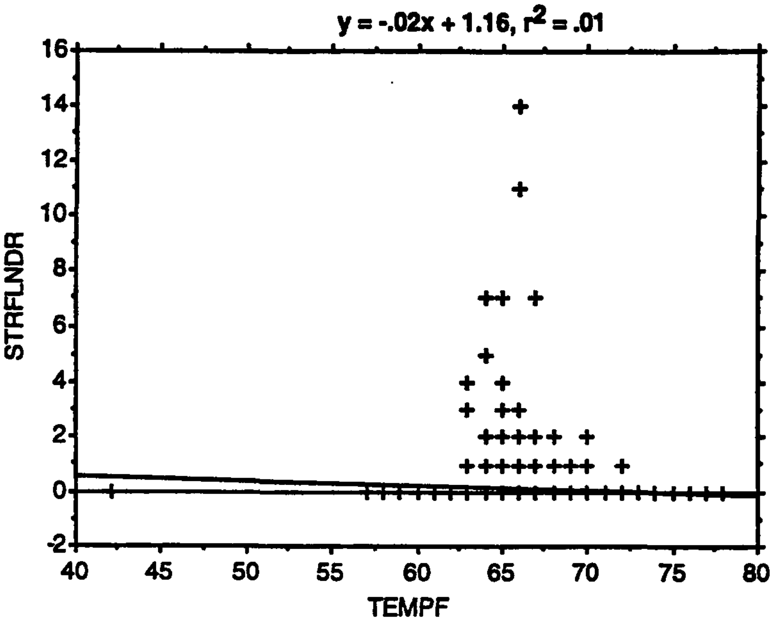
Starry Flounder catch abundance versus electroconductivity (μS/cm), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



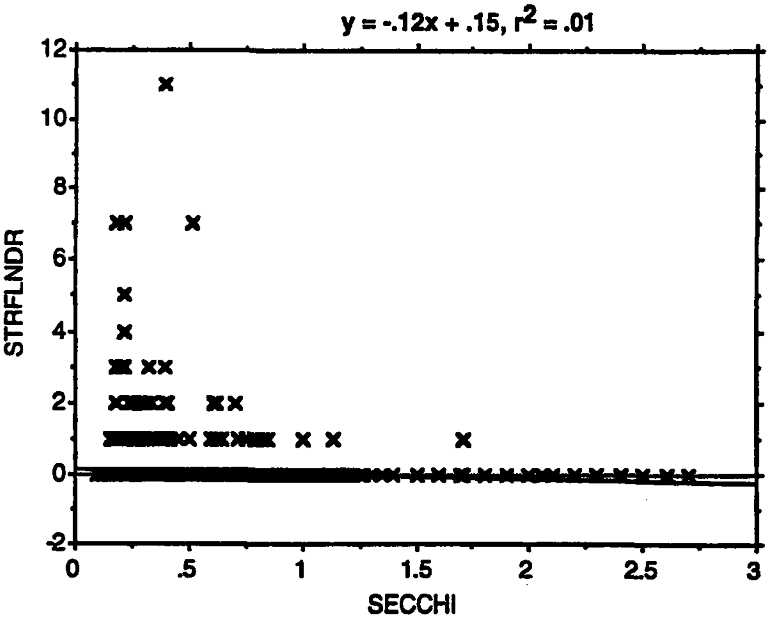
Starry Flounder catch abundance versus boat speed, September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



Starry Flounder catch abundance versus bottom depth (ft), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).



Starry Flounder catch abundance versus water temperature (° F), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).

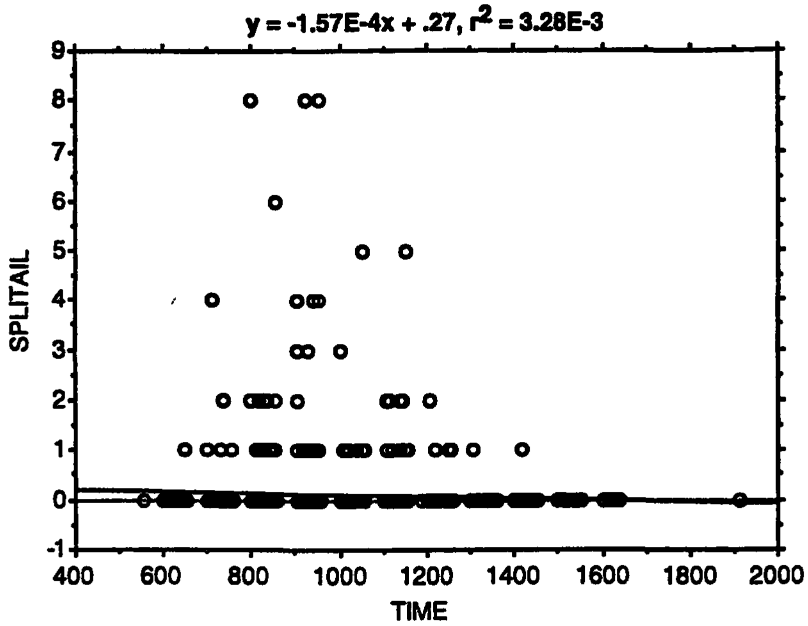


Starry Flounder catch abundance versus secchi disk depth (meters), September midwater trawl survey data 1967-92 (source: California Dept. of Fish and Game midwater trawl study).

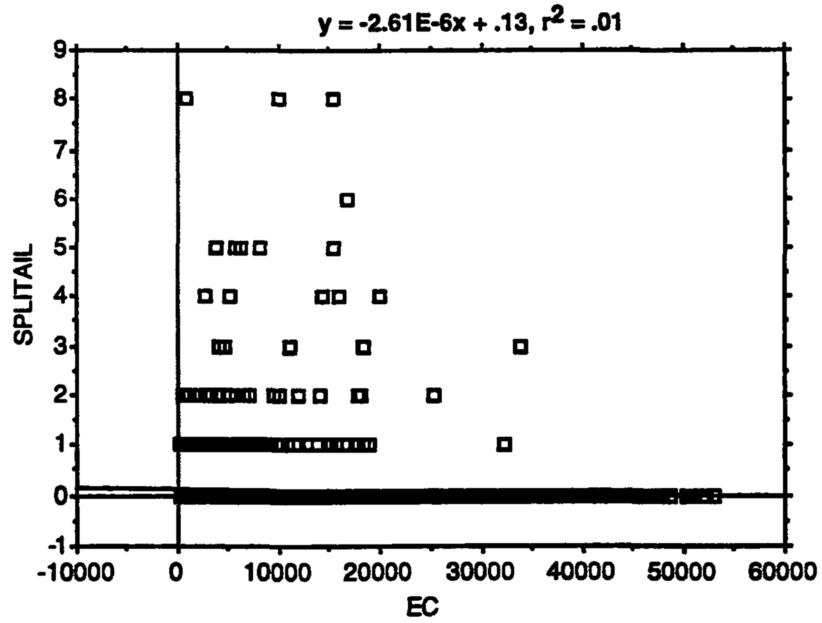
Appendix B-5

Analysis of Environmental Factors Potentially Influencing Midwater Trawl Catch Abundance Data

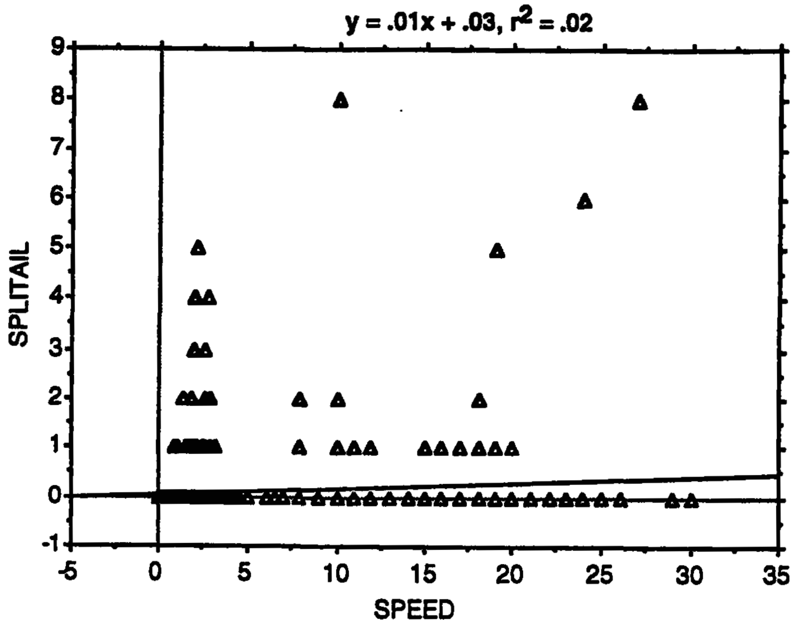
Sacramento Splittail



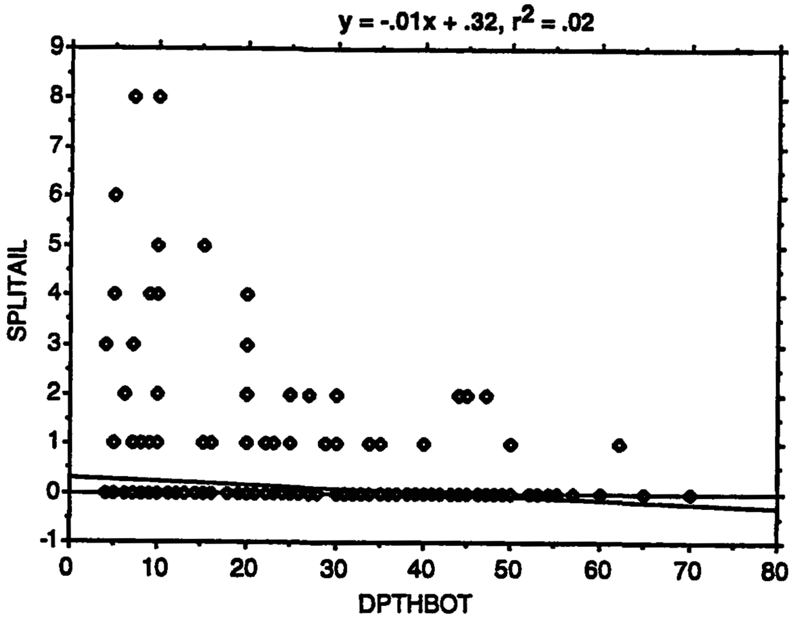
Sacramento splittail catch abundance versus time of day, September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



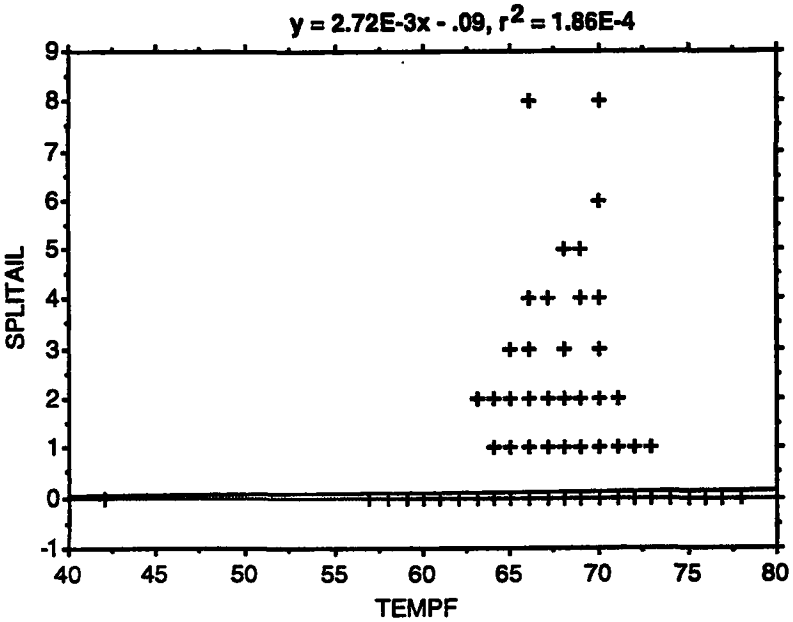
Sacramento splittail catch abundance versus electroconductivity (μS/cm), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



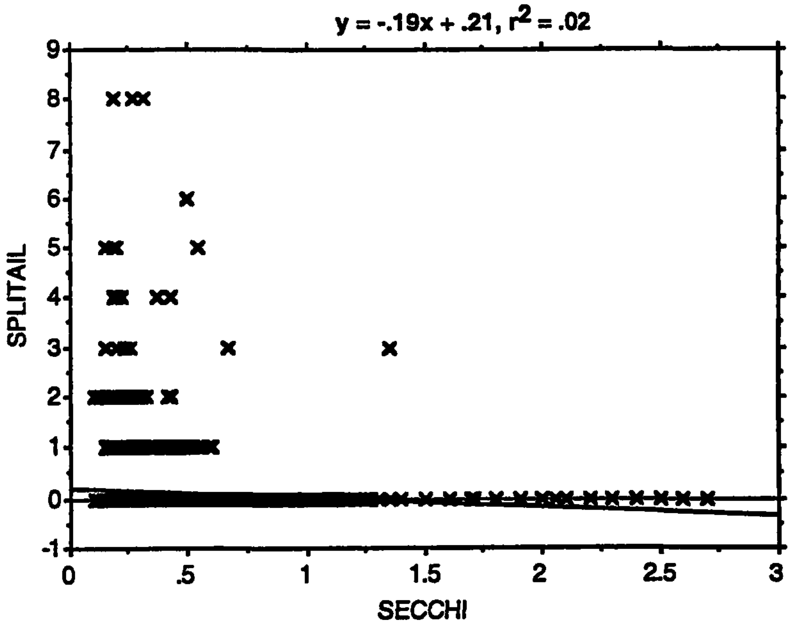
Sacramento splittail catch abundance versus boat speed, September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



Sacramento splittail catch abundance versus bottom depth (ft), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



Sacramento splittail catch abundance versus water temperature (° F), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).

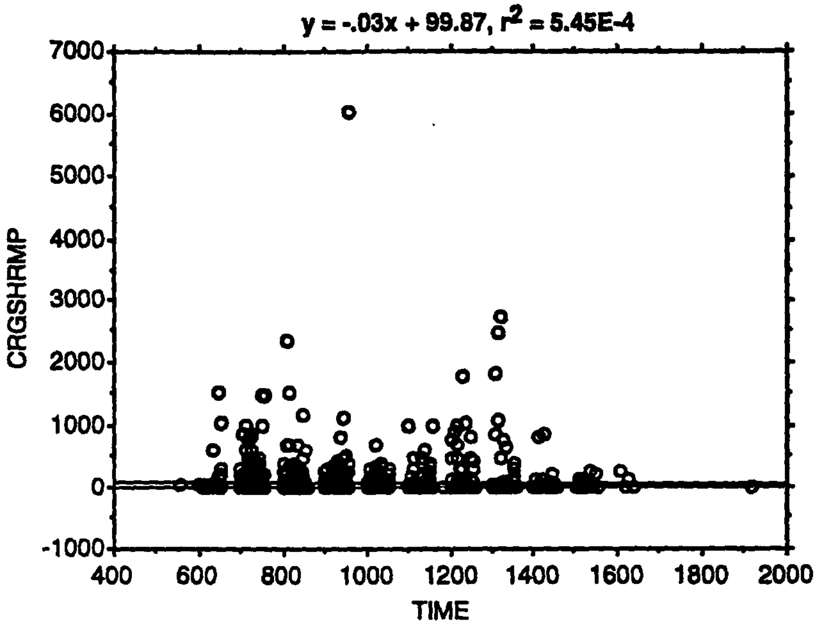


Sacramento splittail catch abundance versus secchi disk depth (meters), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).

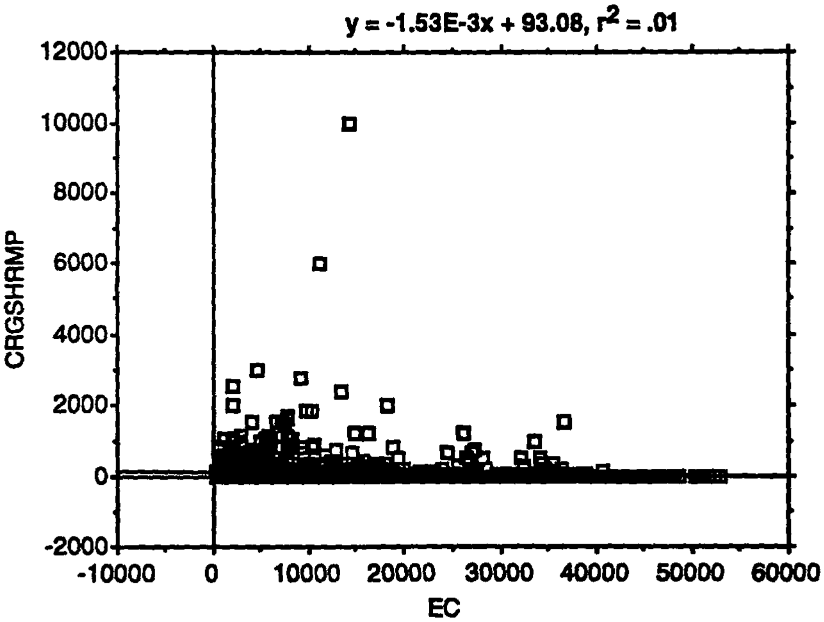
Appendix B-6

Analysis of Environmental Factors Potentially Influencing Midwater Trawl Catch Abundance Data

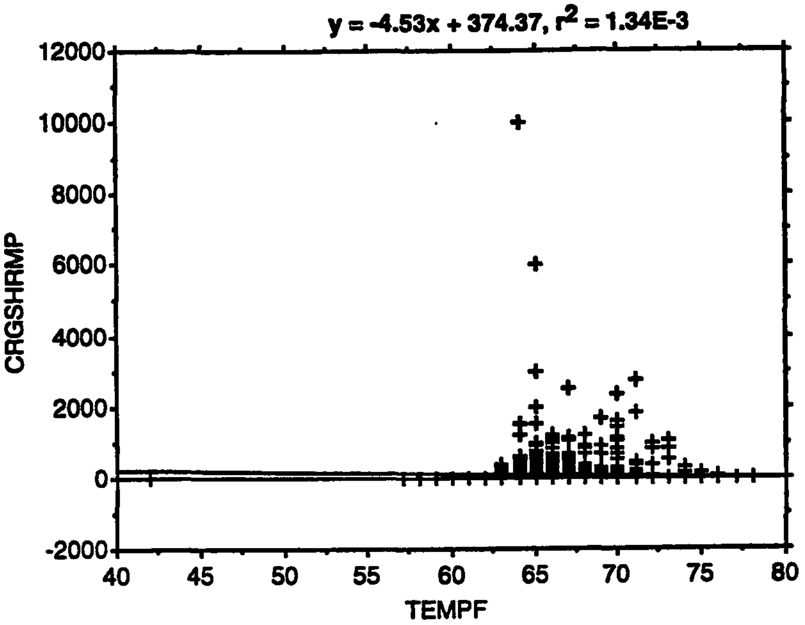
Crangon shrimp



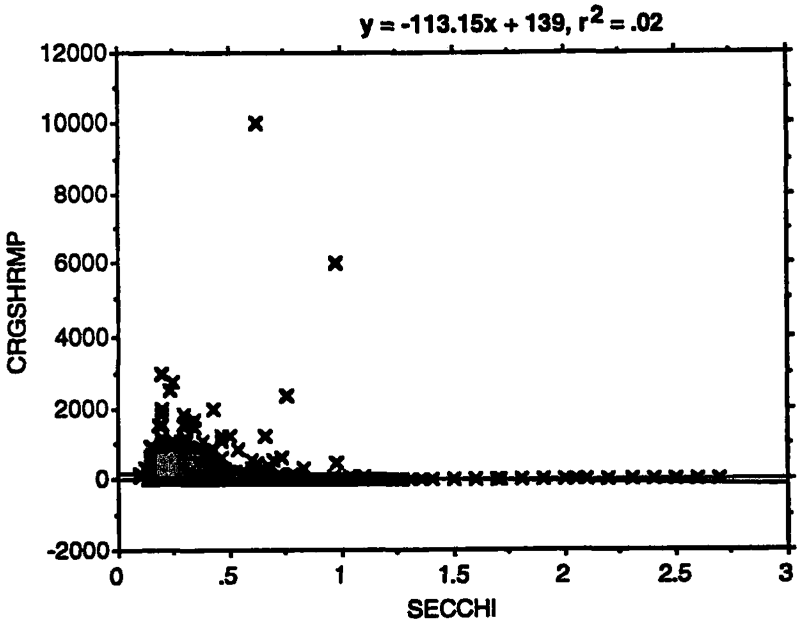
Crangon catch abundance versus time of day, September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



Crangon catch abundance versus electroconductivity (μS/cm), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



Crangon catch abundance versus water temperature (° F), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).



Crangon catch abundance versus secchi disk depth (meters), September midwater trawl survey data 1967-92 (source: Calif. Dept. of Fish and Game midwater trawl study).