AN ANALYSIS OF FISH AND INVERTEBRATE DATA RELATED TO THE ESTABLISHMENT OF MINIMUM FLOWS FOR THE TAMPA BYPASS CANAL

Prepared for

The Southwest Florida Water Management District
2379 Broad Street
Brooksville, Florida 34609-6899
Project Manager: Michael S. Flannery

by

Ernst Peebles, Ph.D.
University of South Florida
College of Marine Science
140 Seventh Avenue South
St. Petersburg, Florida 33701-5016

October 2004

TABLE OF CONTENTS

SUMMARY

Quantitative ecological criteria are needed to establish minimum flows and levels for rivers and streams within the Southwest Florida Water Management District (SWFWMD), as well as for the more general purpose of improving overall management of regulated aquatic ecosystems. As part of the approach to obtaining these criteria, biological databases from two surveys were analyzed to investigate fish and invertebrate responses to inflows from the Tampa Bypass Canal (TBC) into the Palm River and McKay Bay. Biological collections during the Water and Air Research (WAR) surveys, which were funded by the City of Tampa and the West Coast Regional Water Supply Authority (presently Tampa Bay Water, Inc.), were conducted for two complete years starting in October 1991. The WAR study produced data for 118 seine deployments and 144 plankton-net deployments within McKay Bay and the Palm River. Collections by Tampa Bay Water's Hydro-Biological Monitoring Program (HBMP) commenced in May, 2000 and were ongoing at the time of writing. Four years of HBMP data were available for the present analyses. The HBMP produced data for 756 seine deployments, 325 trawl deployments, and 768 plankton deployments within McKay Bay and the Palm River. Together, the two studies provided data from 2,111 biological samples collected over a six-year period.

The general objective of the analyses was to determine the extent to which the Palm River-McKay Bay area was being used as nursery habitat by estuarine-dependent fishes and invertebrates, with emphasis on those species that are economically or ecologically important. The selected assemblage included 12 fishes (bay anchovy, rainwater killifish, *Menidia* spp, snook, spotted seatrout, sand seatrout, spot, southern kingfish, red drum, striped mullet, clown goby and hogchoker) and three crustaceans (pink shrimp, blue crab and daggerblade grass shrimp). Most species favored shallow Palm River waters over shallow McKay Bay waters, whereas deep McKay Bay waters were favored over deep Palm River waters. Mud was generally preferred over sand bottom, with both mud and sand both being preferred over rocks and oysters. Shorelines with shrubs and trees ranked highest among shoreline types, with beaches

being ranked lowest.

The distributions of the selected species were mapped and then compared with the distributions of 18 classes of potential prey types, four types of competitor/predator and two types of parasite. Pink shrimp and blue crabs were most abundant near the mouth of the Palm River, as were juvenile sand seatrout. Cumaceans, crab larvae, the crab *Pinnixa sayana*, amphipods and mysids are potential prey types that were also abundant in this area. However, other primarily benthic and infaunal food resources were not evaluated and may be relevant to the distributions of pink shrimp and blue crabs.

A second area of fish and invertebrate concentration was along shorelines at the upper end of the Palm River (below S-160). This area had relatively high densities of young bay anchovy, snook, spot, red drum, striped mullet, clown goby and hogchoker. All except the clown goby are estuarine-dependent; the clown goby is generally considered to be an estuarine resident. It is clear that many economically and ecologically important species are attempting to use the Palm River as nursery habitat, despite the dramatic alterations that have been made to its physical habitat, water quality and freshwater inflow pattern. A possible reason for the apparent preference for the upper Palm River is the abundance of certain prey types, such as grass shrimp, juvenile bay anchovies, the mysid *Americamysis almyra* and polychaetes. An alternative explanation is an olfaction-based attraction to chemical cues that are either delivered or created by freshwater inflows.

A separate objective was to determine if releases from the TBC were significantly changing community structure in the estuary. Similarities among samples were compared across seasons, inflow levels, and locations along the estuarine gradient. Bray-Curtis dissimilarity was plotted (multidimensional scaling, MDS) and compared across these factors while looking at four biological groups: seine catch, trawl catch, ichthyoplankton catch, and invertebrate plankton catch. Dissimilarities suggested by the MDS plots were investigated using ANOSIM, a nonparametric multivariate analog to ANOVA.

Three types of change in community structure were detected. The first and most consistent change was seasonal, with ichthyoplankton demonstrating the strongest seasonal change. The second was change in invertebrate plankton composition caused by washout during high-inflow events. Average densities of small, truly planktonic organisms such as calanoid copepods tended to decrease during high-inflow months. The introduction of freshwater organisms was not a large contributor to changes in community structure during high-inflow months. The third and perhaps most significant change was in the shallow-water fish fauna. There were substantial differences in the compositions of the seine catches from McKay Bay and the Palm River, with the Palm River yielding more estuarine-dependent and estuarine-resident species (in agreement with the other analyses).

Releases from the TBC were not found to cause large-scale changes in community structure within the Palm River and McKay Bay as a whole, when examined at a monthly or annual scale. However, the close association between many estuarine-dependent species and the area immediately below S-160 suggests that releases attract these animals either directly or indirectly. Survival rates in the Palm River could be compared to those in other tidal rivers to determine if the Palm River's attractiveness is beneficial or detrimental to estuarine-dependent animals.

The distributions of 25 taxa from the plankton-net collections were observed to shift in response to changes freshwater inflow. More than 60% of these shifts were upstream shifts in response to increasing inflow. The upstream shifts appeared to be related to two-layered estuarine circulation, as described for the area by the Luther and Meyers (2004) hydrodynamic model. Planktonic animals, including fish eggs, appeared to be entrained in landward moving bottom water that transported them from McKay Bay into the Palm River during times of elevated inflow (100-400 cfs).

Abundances of 34 taxa from the plankton-net collections changed in response to changing inflow. Most decreased in number as inflows increased. Polychaetes, which are worms that normally live within the bottom substrate, increased in abundance during elevated inflows, but this appeared to be caused by individuals moving from the substrate into the water column, probably in an effort to avoid the oxygen-depleted bottom waters that tend to form during periods of elevated inflow. The mysid

Americamysis almyra, bay anchovy juveniles and pink shrimp juveniles increased in abundance after periods of increased inflow. All three have been observed to have positive inflow-abundance responses in other Southwest Florida estuaries. The mysid and bay anchovy juveniles are important prey for young estuarine-dependent fishes that use tidal rivers as nursery habitat, and the pink shrimp is an economically important species. It was estimated that an average inflow of 11 cfs would be required to maintain these species at 50% of their abundance at median inflow (46 cfs), with the median inflow being based on the this project's survey period. Regressions are presented that allow percent abundance to be recalculated relative to reference inflow levels (i.e., medians) from alternative index periods.

Elevated inflows (>100 cfs) moved the gelatinous predator *Mnemiopsis mccradyi* downstream and reduced its overall number. This ctenophore is a highly efficient predator on fish eggs and larvae and competes with larval and juvenile fishes for zooplankton prey. The inflow effects on *Mnemiopsis* distribution and abundance therefore enhance the Palm River as nursery habitat. Elevated inflows also tended to push another important fish predator, the sea nettle *Chrysaora quinquecirrha*, out of the Palm River and into McKay Bay, but the abundance of this animal tended to increase in conjunction with downstream displacement.

In general, organisms' responses to freshwater inflow into the Palm River and McKay Bay were more subtle than those observed in other estuarine areas of Southwest Florida. The abundance of mysids and bay anchovy juveniles in the Palm River/McKay Bay estuarine system changed in response to inflow, but these changes affected abundances were the lowest observed among seven estuarine areas surveyed using identical methods.

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

This project was conducted to support the establishment of minimum flows for the Tampa Bypass Canal by the Southwest Florida Water Management District (SWFWMD). Minimum flows are defined in Florida Statutes (373.042) as the “limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.” In the process of establishing minimum flows, the SWFWMD evaluates the effects of freshwater inflows on ecological resources and processes in receiving estuaries.

The Tampa Bypass Canal (TBC) was constructed in the 1960s and 70s by the U.S. Army Corps of Engineers as part of a flood-control system. Flood waters from the Hillsborough River are diverted away from Temple Terrace and Tampa and into the TBC and the adjoining Lower Hillsborough Flood Detention Area. Five water-control structures in the TBC system are used by the SWFWMD to manage water levels. The downstream-most structure, S-160, releases water into the Tampa Bay estuary via the Palm River, McKay Bay and East Bay (Fig. 1.2.1). The Palm River was channelized and dredged to 4-5 m depth to increase its conveyance during floods, and this has led to poor vertical mixing of bottom waters and chronic benthic hypoxia. Brown (1971) predicted that estuarine fishes and invertebrates in McKay Bay, which is only 4 km^2 in size, would be negatively impacted by sudden releases of large amounts of fresh water from S-160. Soon after completion of the TBC flood-control system, Price and Schlueter (1985) conducted a three-year fish survey of lower McKay Bay, and concluded that large releases from S-160 were responsible for reductions in the abundance of young estuarine-dependent fishes. They also suggested that releases from S-160 may change the overall fish community structure within McKay Bay. The present study uses a more extensive database to investigate these issues.

The findings of this project will be used by the SWFWMD to evaluate the fish nursery function of the Palm River and McKay Bay in relation to freshwater inflows from the TBC. It is not the purpose of this project to determine the level of effect that constitutes significant harm, as that determination will be made by the Governing Board of the SWFWMD.

1.1 Objectives

The principal objectives were: (1) to describe habitats used by economically and ecologically important species, (2) to describe distributions of economically and ecologically important species and to compare these with the distributions of potential prey organisms, and (3) to determine how freshwater inflows influence aquatic community structure and the distribution and abundance of estuarine animals. All objectives apply to the Palm River and McKay Bay as a collective estuarine ecosystem.

1.2 Summary of Biological Collection Efforts

Biological collections during the Water and Air Research (WAR) surveys, which were funded by the City of Tampa and the West Coast Regional Water Supply Authority (presently Tampa Bay Water, Inc.), were conducted for two complete years starting in October 1991. Collections by Tampa Bay Water's Hydro-Biological Monitoring Program (HBMP) commenced in May, 2000 and were ongoing at the time of writing. Four years of HBMP data were available for the present analyses. Both the WAR and HBMP studies included sampling programs for phytoplankton (or chlorophyll *a*) and benthic macroinvertebrates. The biological collection effort reported here is limited to seine, trawl, and plankton net deployments that primarily targeted fish but also collected invertebrates. There are discrepancies between the WAR and HBMP studies that place restrictions on their comparison. These restrictions are discussed according to gear type. In all cases, variation in catch rate caused by variation in effort was removed by dividing catch by effort to produce catch-per-unit-effort (CPUE).

1.2.1 **Seine deployments.** The seine specifications were comparable between the WAR and HBMP studies, but deployment methods and effort distributions differed. Both studies used 21-23 m bag seines with 3.2 mm mesh. In the WAR study and in the Palm River portion of the HBMP, the seine was set in a semicircular fashion against the shoreline, sweeping a bottom area of ~68 m^2. HBMP seine deployments in McKay Bay were made in open water by deploying the net from a boat, pulling it against the current for 9 m, and then encircling it to cover a total of ~140 m² of bottom area. During the two-year WAR survey, there were five seine deployments per month at fixed shoreline locations (stations), with two (40%) in McKay Bay and three (60%) in the Palm River (Fig. 1.2.1), producing a total of 118 samples (station 20 in McKay Bay was not sampled during November 1992 or June 1993). HBMP seine deployment locations were determined using a stratified-random design, with the typical bias in effort distribution between McKay Bay (62%) and the Palm River (38%) being opposite the WAR effort bias. There were 16 seine deployments per month during the HBMP, except during the first two months (May-June, 2000), when there were 18 per month because two extra offshore seines in McKay Bay were substituted for trawl deployments there. The total number of seine deployments during the first four years of the HBMP was 756. Because of the larger number of deployments and the larger swept area of the open water sets, the monthly seine effort during the HBMP was more than five times larger than that of the WAR study (1,808 vs. 340 m²). WAR seine samples were processed by personnel at the Florida Museum of Natural History in Gainesville, whereas HBMP seine samples were collected and processed by personnel employed by the Fisheries-Independent Monitoring (FIM) program at the Florida Fish and Wildlife Research Institute (FWRI) in St. Petersburg. The taxonomic resolution used by each group was comparable for most of the abundant fishes (mojarras being a notable exception), yet because invertebrates in the seine catch were not enumerated during the WAR study, community-level analysis of seine catch composition was limited to fishes. In summary, the uncorrected differences between the WAR and HBMP seine surveys were:

- The distribution of the WAR seine collections was biased toward the Palm River, whereas the HBMP seine effort was biased toward McKay Bay
- The location of seine stations was fixed in the WAR study and randomized in the HBMP
- There were no offshore seine deployments during the WAR study, whereas all HBMP seine collections from McKay Bay were of the offshore type.

1.2.2 **Trawl deployments.** There were no trawl deployments during the WAR surveys. During the HBMP, FIM personnel made seven trawl deployments per month,

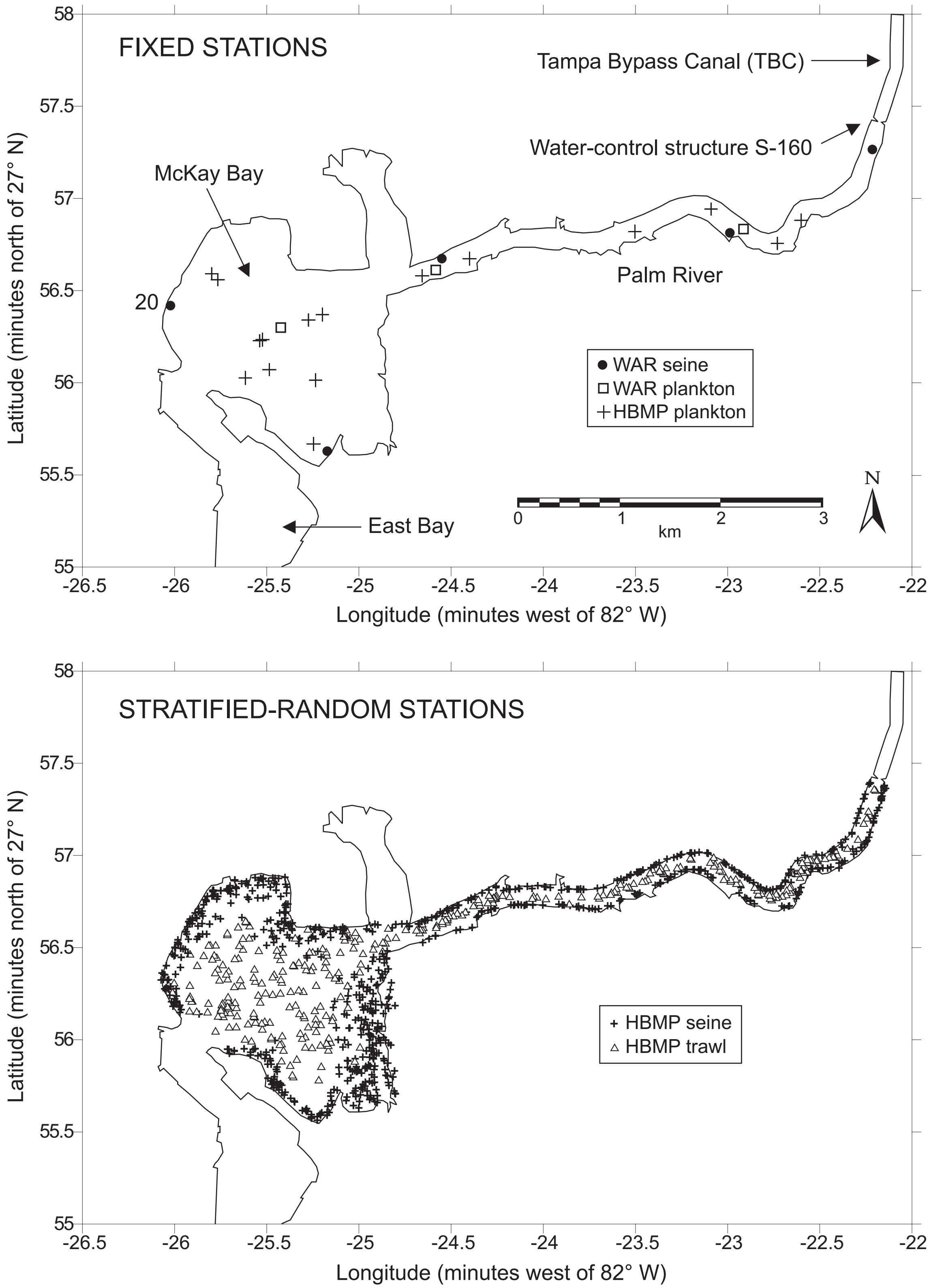


Fig. 1.2.1. Map of survey area and station locations.

except during the first two months (May-June, 2000), when there were five deployments per month. Trawl deployment locations were determined using a stratified-random design, with the typical distribution being four deployments in McKay Bay (57%) and three deployments in the Palm River (43%). The total number of trawl deployments during the first four years of the HBMP was 325. The 6.1 m otter trawl had 38 mm stretched mesh, a 3.2 mm mesh liner and a tickler chain. It was towed for five minutes in either an arc or a straight line at an average speed of 0.6 m s^{-1}, resulting in an average tow length of 181 m and an average swept area of 723 m^2. Effort was calculated by multiplying the observed width of the deployed trawl (4 m) by the length of tow recorded with each deployment.

1.2.3 **Plankton-net deployments.** The gear and deployment methods used to collect plankton during the WAR and HBMP studies were identical, but the spatial distribution of effort was different. During the WAR study, replicate plankton tows were made at three fixed locations each month, with one (33%) in McKay Bay and two (66%) in the Palm River, producing a total of 144 samples. During the HBMP, 10 single tows (63%) were made each month in McKay Bay, and 6 (37%) were made in the Palm River, producing a total of 768 tows during the program's first four years. The taxonomic resolution used for ichthyoplankton identification was identical during the WAR and HBMP studies, but the taxonomic resolution for invertebrates during the WAR study was too coarse to permit community-level comparisons with HBMP invertebrate plankton. The gear consisted of a 0.5 m mouth diameter, 500 µm mesh, conical (3:1) plankton net equipped with a three-point bridle, a flowmeter (General Oceanics model 2030R), a one-liter plastic cod-end jar and a 9 kg (20 lb.) weight. The net was deployed between low slack and high slack tide, with sampling beginning within two hours after sunset and typically ending less than four hours later. Tow duration was five minutes, with tow time being divided equally among bottom, mid-water and surface depths. Tow speed was approximately 1.3 m s^{-1}, resulting in a tow length of about 400 m over water and a typical filtration of 70-80 m^3 (average =74 m^3). All fishes were classified according to developmental stage (Fig. 1.2.3) as

preflexion larval stage: the period between hatching and notochord flexion; the tip of the straight notochord is the most distal osteological feature.

flexion larval stage: the period during notochord flexion; the upturned notochord or urostyle is the most distal osteological feature.

postflexion larval stage: the period between completion of flexion and the juvenile stage; the hypural bones are the most distal osteological feature.

metamorphic stage (clupeid fishes): the stage after postflexion stage during which body depth increases to adult proportions (ends at juvenile stage).

juvenile stage: the period beginning with attainment of meristic characters and body shape comparable to adult fish and ending with sexual maturity.

Crab larvae were classified as zoea stage if they possessed rostral and dorsal or posterolateral spines. Shrimp larvae were classified as mysis stage until the uropods differentiated into exopods and endopods (5 total elements in the telsonic fan), after which they were classified as postlarvae until they reached the juvenile stage. The juvenile stage, which followed the megalops and postlarval stages, was characterized by resemblance to small (immature) adults.

In many fish species, the juvenile stage is difficult to distinguish from other stages. At its lower limit, the juvenile stage may lack a clear developmental juncture that distinguishes it from the postflexion or metamorphic stage. Likewise, at its upper limit, more than one length at maturity may be reported for a single species or the reported length at maturity may differ between males and females. To avoid inconsistency in the staging process, length-based staging conventions were applied to the more common taxa. These staging conventions agree with stage designations used by the U.S. Fish and Wildlife Service (e.g., Jones et al. 1978). The list in Table 2.4.1 is comprehensive, representing the conventions that have been required to date by various surveys. Some of the species or stages in the list were not encountered during the surveys covered by this report.

Table 1.2.3. Length-based staging conventions used to define developmental stage limits. Fish lengths are standard length (SL) and shrimp length is total length.

Postflexion-juvenile transition (mm):	
Lucania parva	10
Menidia spp.	10
Eucinostomus spp.	10
Lagodon rhomboides	10
Bairdiella chrysoura	10
Cynoscion arenarius	10
Cynoscion nebulosus	10
Sciaenops ocellatus	10
Menticirrhus spp.	10
Leiostomus xanthurus	15
Orthopristis chrysoptera	15
Achirus lineatus	5
Trinectes maculatus	5
Gobiesox strumosus	5
Diapterus plumieri	10
Prionotus spp.	10
Symphurus plagiusa	10
Anchoa mitchilli	15
Sphoeroides spp.	10
Chilomycterus shoepfi	10
Lepomis spp.	10
Micropterus salmoides	10
Membras martinica	10
Chloroscombrus chrysurus	10
Hemicaranx amblyrhynchus	10
Micropogonias undulatus	15
Chaetodipterus faber	5

Juvenile-adult transition (mm):	
Anchoa mitchilli	30
Lucania parva	15
Gambusia holbrooki	15
Heterandria formosa	10
Menidia spp.	35
Eucinostomus spp.	50
Gobiosoma bosc	20
Gobiosoma robustum	20
Microgobius gulosus	20
Microgobius thalassinus	20
Gobiesox strumosus	35
Trinectes maculatus	35
Palaemonetes pugio	20
Membras martinica	50
Syngnathus spp.	80
Poecilia latipinna	30
Anchoa hepsetus	75

Metamorph-juvenile transition (mm):	
Brevoortia spp.	30
Dorosoma petenense	30

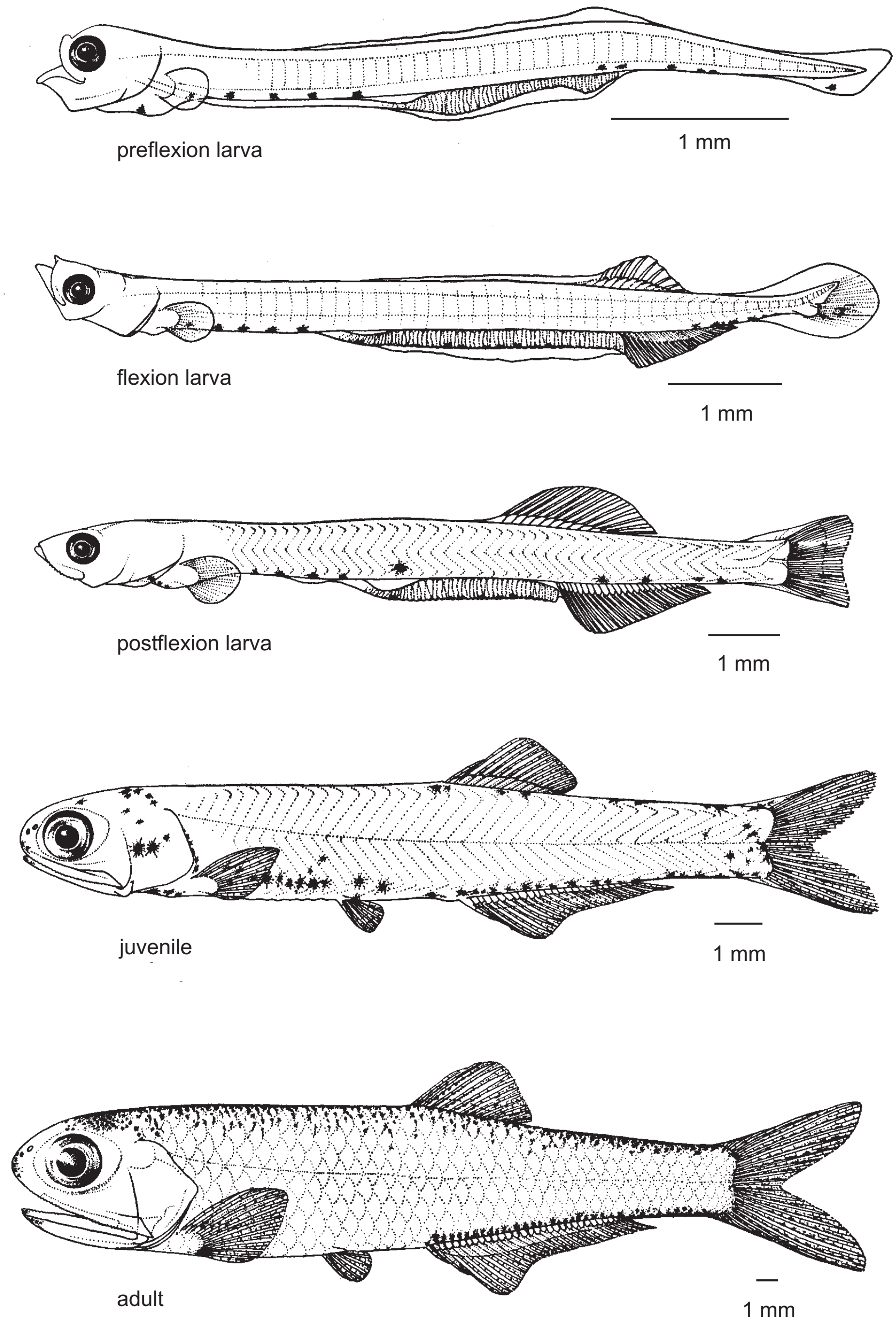


Fig. 1.2.3. Fish-stage designations, using the bay anchovy as an example. Specimens measured 4.6, 7.0, 10.5, 16 and 33 mm standard length.

1.2.4 **Classification by Habitat and Diet.** A literature search was used to develop a classification system for describing the habitats and diets of fishes and invertebrates collected during the WAR and HBMP surveys. In all cases, classifications that were supported by existing data from the Tampa Bay area, including data from SWFWMD-sponsored biological surveys, took precedence over classifications that were based on reports from other geographic locations. Aside from this effort to include local data, general distributions (Table 1.2.4) were largely obtained from FishBase, an online database that was initially developed in collaboration with the Food and Agriculture Organization of the United Nations (FAO), and is presently supported by a consortium of research institutions (http://www.fishbase.org/). General distributions were grouped into the following classes:

fresh water: species that are largely restricted to fresh water. Some are salt tolerant and may occur in estuarine waters, but their population centers are nevertheless located within freshwater habitats.

coastal marine: species that occupy a diversity of coastal habitats without having a clear affinity for low salinities. Members of this group are often more abundant in estuary-influenced areas than in euhaline areas (>30 psu), yet they do not show clear patterns of estuarine dependence as defined below. Some members of this group are highly euryhaline and may even invade fresh water, but they are not known to consistently congregate in low-salinity habitats.

estuarine: species that tend to spend their entire life cycle within low-salinity habitats, without undergoing predictable migrations to other habitats (= estuarine residents).

estuarine-dependent: species in which the adults, eggs, and larvae are most abundant in higher salinities and the juveniles are most abundant in relatively lower salinities (= estuarine transients); the adults of some species may also be common in reduced salinity habitats, but migrate to higher salinities to spawn. The extent of habitat shift is species-specific and is dependent on the lengths of local estuarine gradients. Estuarine dependence is a matter of degree and may be either subtle or pronounced. For example, the young of some coastal marine species are most abundant at the mouths of estuaries, yet they remain in moderately high salinities. In the present classification system, only those species with pronounced estuarine dependence are classified as such.

Juvenile and adult subhabitat (Table 1.2.4) was determined from FishBase and searches of Aquatic Sciences and Fisheries Abstracts (ASFA1, Cambridge Scientific Abstracts: http://www.csa.com/). The following classes were used:

benthic: species that tend to rest on or swim above the bottom substrate (= demersal).

pelagic: species that tend to occupy the water column.

benthopelagic: species that spend part of the time on or near the bottom and part of the time in the water column.

intertidal: species that tend to occupy very shallow habitats such as those occurring in marshes and other intertidal areas

structure-oriented (struct.-oriented): species that orient strongly to structures such as emergent or submerged vegetation, oyster reefs, rocks, or manmade structures. Some structure is also intertidal.

As with other classifications, data from SWFWMD-sponsored and other local surveys took precedence over non-local sources, and figured prominently in the classification of spawning habitat for local fishes. Sources for spawning location included FishBase, Jones et al. (1978) and ASFA1 searches. Members of the same genus or family tend to have similar spawning habits, which allows reasonable inference of spawning location when such locations are unknown. Spawning habitats were classified as:

fresh water: freshwater species (none of the species in Table 1.2.4 are diadromous).

inshore: species that spawn within the interiors of coastal embayments and near coastal inlets.

nearshore: species that spawn in the deeper, saline parts of large embayments such as in lower Tampa Bay and/or on the continental shelf within the coastal boundary layer (CBL). The division between the CBL and offshore waters is marked by a strong reduction in chlorophyll *a* concentration to levels below >0.5 mg m^3. The CBL boundary tends to occur 30-50 km (~20-30 mi) offshore of the mouth of Tampa Bay.

offshore: species that spawn beyond the CBL (see above), either on the continental shelf or in association with oceanic currents.

Diet classifications were derived from FishBase and ASFA1 searches. Diet studies conducted by Darnell (1961), Carr and Adams (1973), and Peebles and Hopkins (1992) were also notably useful for making comparisons among species. Pink shrimp and blue crab diets were classified according to discussions by Fantle et al. (1999) and Schwamborn and Criales (2000). Darnell (1961) reported contributions of marsh grass detritus (primarily derived from *Spartina alterniflora*) to the diets of a diversity of estuarine animals. This diet item was widely variable in importance, but appeared to be present in all of the organisms examined by Darnell. The predominance of marsh grass detritus in the Darnell study appears to be related to the predominance of this type of marsh within Darnell's study location (Lake Pontchartrain, Louisiana). Therefore, vascular plant detritus was not listed as a diet constituent in Table 1.2.4 unless it was also reported to be important in studies conducted outside *Spartina*-dominated areas. In general, species that consume bottom-oriented prey are also likely to ingest vascular plant detritus. As with the assumption of similarity in spawning habitat among closely related species, diets were sometimes inferred to be similar to those of closely related species. The following diet classes were used:

phtyoplankton (phytopl.): all planktonic microalgae

plants: seagrasses

algae: epiphytes, benthic microalgae, macroalgae

detritus: vascular plant detritus, marine snow, and unidentifiable material thought to be organic in origin. Because partially digested microalgae resembles detritus, the two may be difficult to distinguish from each other.

insects: primarily insect larvae or pupae

zooplankton (zoopl.): calanoid and cyclopoid copepods, clodocerans, larval decapods, gelatinous organisms

infauna: organisms that typically live within the substrate, such as worms and most bivalves (excluding oysters and mussels)

benthic microfauna (benth. microf.): peracarid crustaceans (mysids, amphipods, cumaceans, isopods, tanaids), ostracods, harpacticoid copepods. Most of these organisms vertically migrate into the water column under certain combinations of tide and time-of-day.

benthic macrofauna (benth. macrof.): benthic crabs, decapod shrimps, gastropods, oysters, mussels, and strongly benthic fishes, such as gobies.

nekton: fishes and squids that typically swim in the water column

Most of the species in Table 1.2.4 are coastal marine, estuarine, or estuarine-dependent in their general distribution. They occupy the water column and bottom waters with similar frequencies and tend to spawn in inshore and nearshore waters. Diets are strongly oriented toward benthic prey.

Table 1.2.4 (page 1 of 4). Habitat and diet characteristics of the pink shrimp, blue crab and fishes collected during the WAR and HBMP surveys. (i) indicates that the classification is inferred (see text for class descriptions).

Species	General Distribution	Juv. & Adult Subhabitat	Spawning Habitat	Juv. & Adult Principal diet	Notes
pink shrimp (Farfantepenaeus duorarum)	est.-dependent	benthic	offshore	benth. macrof., infauna, algae, detritus	5
blue crab (Callinectes sapidus)	est.-dependent	benthic	nearshore	infauna, benth. micro- & macrof.	5
Atlantic stingray (Dasyatis sabina)	estuarine	benthic	nearshore	infauna, benth. macrof.	
bluntnose stingray (Dasyatis say)	coastal marine	benthic	nearshore	infauna, benth. macrof. (i)	
smooth butterfly ray (Gymnura micrura)	coastal marine	benthic	nearshore (i)	infauna, benth. macrof.	
cownose ray (Rhinoptera bonasus)	coastal marine	benthopelagic	nearshore (i)	infauna, benth. macrof., nekton	
ladyfish (Elops saurus)	coastal marine	pelagic	offshore	nekton, benth. macrof.	2
bonefish (Albula vulpes)	coastal marine	benthic	offshore (i)	benth. macrof.	3
menhaden (Brevoortia spp.)	est.-dependent	pelagic	nearshore	phytopl., detritus	1, 4
threadfin shad (Dorosoma petenense)	fresh water	pelagic	fresh water	phytopl., zoopl.	1
Atlantic thread herring (Opisthonema oglinum)	coastal marine	pelagic	nearshore	zoopl., phytopl.	1, 4
scaled sardine (Harengula jaguana)	coastal marine	pelagic	nearshore	zoopl., benth. microf.	1, 4
striped anchovy (Anchoa hepsetus)	coastal marine	pelagic	nearshore	zoopl.	1, 4
bay anchovy (Anchoa mitchilli)	est.-dependent	pelagic	inshore	zoopl., benth. microf.	1
Cuban anchovy (Anchoa cubana)	coastal marine	pelagic	nearshore (i)	zoopl. (i)	
inshore lizardfish (Synodus foetens)	coastal marine	benthic	offshore	nekton, benth. macrof.	
gafftopsail catfish (Bagre marinus)	coastal marine	benthic	nearshore (i)	benth. micro- & macrof., nekton	
hardhead catfish (Arius felis)	coastal marine	benthic	inshore	benth. macrof., infauna	
gulf toadfish (Opsanus beta)	coastal marine	struct.-oriented	inshore	benth. macrof., nekton (i)	
skilletfish (Gobiesox strumosus)	coastal marine	struct.-oriented	inshore	benth. microf. (i)	
halfbeak (Hyporhamphus unifasciatus)	coastal marine	pelagic	inshore	plants, zoopl., benth. microf.	
halfbeak (Hyporhamphus meeki)	coastal marine	pelagic	inshore (i)	plants, zoopl., benth. microf. (i)	
Atlantic needlefish (Strongylura marina)	coastal marine	pelagic	inshore	nekton	
redfin needlefish (Strongylura notata)	coastal marine	pelagic	inshore (i)	nekton	
timucu (Strongylura timucu)	coastal marine	pelagic	inshore (i)	nekton	
sheepshead minnow (Cyprinodon variegatus)	coastal marine	intertidal	inshore	algae, detritus, benth. microf.	
striped killifish (Fundulus majalis)	estuarine	intertidal	inshore	benth. micro- & macrof.	

Notes: 1= important forage fish, 2 = minor sport fish, 3 = major sport fish, 4 = sought for use as bait, 5 = commercial fishery species

Table 1.2.4 (page 2 of 4). Habitat and diet characteristics of the pink shrimp, blue crab and fishes collected during the WAR and HBMP surveys. (i) indicates that the classification is inferred (see text for class descriptions).

Species	General Distribution	Juv. & Adult Subhabitat	Spawning Habitat	Juv. & Adult Principal diet	Notes
gulf killifish (Fundulus grandis)	estuarine	intertidal	inshore	benth. micro- & macrof., algae	4
Seminole killifish (Fundulus seminolis)	fresh water	intertidal	inshore	benth. micro- & microf. (i)	
rainwater killifish (Lucania parva)	estuarine	intertidal	inshore	benth. microf. (i)	
bluefin killifish (Lucania goodei)	fresh water	intertidal	fresh water	benth. microf. (i)	
diamond killifish (Adinia xenica)	coastal marine	intertidal	inshore	algae, detritus, benth. microf. (i)	
goldspotted killifish (Floridichthys carpio)	coastal marine	intertidal	inshore	zoopl.	
eastern mosquitofish (Gambusia holbrooki)	fresh water	intertidal	fresh water	insects	6
sailfin molly (Poecilia latipinna)	fresh water	intertidal	fresh water	algae, plants	6
least killifish (Heterandria formosa)	fresh water	intertidal	fresh water	infauna, zoopl., plants	
rough silverside (Membras martinica)	estuarine	pelagic	inshore	zoopl.	
silversides (Menidia spp.)	estuarine	pelagic	inshore	benth. microf., zoopl.	
dusky pipefish (Syngnathus floridae)	coastal marine	struct.-oriented	inshore	zoopl., benth. microf.	
chain pipefish (Syngnathus louisianae)	coastal marine	struct.-oriented	inshore	benth. microf., zoopl.	
gulf pipefish (Syngnathus scovelli)	estuarine	struct.-oriented	inshore	zoopl., benth. microf.	
leopard searobin (Prionotus scitulus)	coastal marine	benthic	nearshore (i)	benth. microf.	
bighead searobin (Prionotus tribulus)	coastal marine	benthic	nearshore	benth. macrof.	
snook (Centropomus undecimalis)	est.-dependent	struct.-oriented	inshore	benth. macrof., nekton	3
redear sunfish (Lepomis microlophus)	fresh water	struct.-oriented	fresh water	benth. macrof. (esp. mollusks)	2
largemouth bass (Micropterus salmoides)	fresh water	struct.-oriented	fresh water	benth. macrof., nekton	3
blue runner (Caranx crysos)	coastal marine	pelagic	offshore	nekton	2, 4
Atlantic bumper (Chloroscombrus chrysurus)	coastal marine	pelagic	nearshore	zoopl.	
leatherjacket (Oligoplites saurus)	coastal marine	pelagic	inshore	benth. micro- & macrof., nekton, zoopl.	
Florida pompano (Trachinotus carolinus)	coastal marine	benthic	offshore	infauna, benth. macrof.	3
bluntnose jack (Hemicaranx amblyrhynchus)	coastal marine	pelagic	offshore	nekton	
silver jenny (Eucinostomus gula)	coastal marine	benthic	nearshore	infauna, benth. macrof.	
tidewater mojarra (Eucinostomus harengulus)	estuarine	benthic	nearshore	infauna	
striped mojarra (Diapterus plumieri)	estuarine	benthic	nearshore	infauna, detritus, benth. macrof.	

Notes: 1= important forage fish, 2 = minor sport fish, 3 = major sport fish, 4 = sought for use as bait, 5 = commercial fishery species

Table 1.2.4 (page 3 of 4). Habitat and diet characteristics of the pink shrimp, blue crab and fishes collected during the WAR and HBMP surveys. (i) indicates that the classification is inferred (see text for class descriptions).

Species	General Distribution	Juv. & Adult Subhabitat	Spawning Habitat	Juv. & Adult Principal diet	Notes
pigfish (Orthopristis chrysoptera)	coastal marine	benthic	nearshore	benth. macrof., infauna	2, 4
pinfish (Lagodon rhomboides)	coastal marine	struct.-oriented	offshore	benth. macrof., nekton, algae, plants	
sheepshead (Archosargus probatocephalus)	coastal marine	struct.-oriented	nearshore	benth. micro- & macrof.	2
spotted seatrout (Cynoscion nebulosus)	coastal marine	benthopelagic	inshore	nekton, benth. macrof.	3
sand seatrout (Cynoscion arenarius)	est.-dependent	benthopelagic	inshore	nekton, benth. macrof.	2
silver perch (Bairdiella chrysoura)	estuarine	benthopelagic	inshore	benth. micro- & macrof., nekton	2
spot (Leiostomus xanthurus)	est.-dependent	benthic	offshore	benth. microf., infauna	2
southern kingfish (Menticirrhus americanus)	coastal marine	benthic	nearshore	benth. macrof., infauna	2
northern kingfish (Menticirrhus saxatilis)	coastal marine	benthic	nearshore	benth. macrof., infauna	2
Atlantic croaker (Micropogonias undulatus)	est.-dependent	benthic	offshore	benth. macrof., infauna	2
black drum (Pogonias cromis)	est.-dependent	benthic	inshore	benth. macrof.	2
red drum (Sciaenops ocellatus)	est.-dependent	benthic	nearshore	benth. macrof., nekton	3
Atlantic spadefish (Chaetodipterus faber)	coastal marine	struct.-oriented	offshore	benth. macrof., zoopl.	
tilapias (Tilapia spp.)	fresh water	benthic	fresh water	phytopl., plants, detritus	
striped mullet (Mugil cephalus)	est.-dependent	benthopelagic	offshore	algae, benth. microf., detritus	5
fantail mullet (Mugil gyrans)	coastal marine	benthopelagic	nearshore	algae, benth. microf., detritus (i)	
Florida blenny (Chasmodes saburrae)	coastal marine	benthic	inshore	benth. microf., detritus	
blenny (Hypleurochilus caudovittatus)	coastal marine	benthic	nearshore (i)	benth. microf., detritus (i)	
naked goby (Gobiosoma bosc)	est.-dependent	benthic	inshore	benth. microf., zoopl. (i)	
code goby (Gobiosoma robustum)	est.-dependent	benthic	inshore	benth. microf., zoopl.	
twoscale goby (Gobiosoma longipala)	coastal marine	benthic	inshore	benth. microf., zoopl. (i)	
clown goby (Microgobius gulosus)	estuarine	benthic	inshore	benth. microf., detritus	
green goby (Microgobius thalassinus)	coastal marine	benthic	inshore	benth. microf., detritus (i)	
frillfin goby (Bathygobius soporator)	coastal marine	benthic	inshore	benth. microf., detritus (i)	
harvestfish (Peprilus alepidotus)	coastal marine	pelagic	offshore	zoopl., detritus, nekton	
gulf flounder (Paralichthys albigutta)	coastal marine	benthic	nearshore	nekton, benth. micro- & macrof.	2
hogchoker (Trinectes maculatus)	est.-dependent	benthic	inshore	infauna, benth. microf.	

Notes: 1= important forage fish, 2 = minor sport fish, 3 = major sport fish, 4 = sought for use as bait, 5 = commercial fishery species

Table 1.2.4 (page 4 of 4). Habitat and diet characteristics of the pink shrimp, blue crab and fishes collected during the WAR and HBMP surveys. (i) indicates that the classification is inferred (see text for class descriptions).

Species	**General Distribution**	**Juv. & Adult Subhabitat**	**Spawning Habitat**	**Juv. & Adult Principal diet**	**Notes**
lined sole (Achirus lineatus)	estuarine	benthic	inshore	infauna, benth. microf.	
blackcheek tonguefish (Symphurus plagiusa)	estuarine	benthic	nearshore	infauna, benth. microf.	
southern puffer (Sphoeroides nephelus)	coastal marine	struct.-oriented	nearshore	benth. macrof., detritus	
striped burrfish (Chilomycterus schoepfi)	coastal marine	struct.-oriented	offshore	benth. macrof.	

Notes: 1= important forage fish, 2 = minor sport fish, 3 = major sport fish, 4 = sought for use as bait, 5 = commercial fishery species

2.0 TECHNICAL ANALYSES

2.1 Habitat Associations Observed for Selected Fishes and Invertebrates

The stratified random design of the FWRI HBMP surveys allows comparison of organism CPUE (ind./area) among different depths, bottom types and shoreline types. Analysis of habitat associations was limited to species that have economic or ecological importance, provided such species were collected in sufficient number. Fifteen species were selected based on these criteria. The pink shrimp, blue crab, and striped mullet were selected because they are estuarine-dependent species that support commercial fisheries. All frequently collected recreational sport fishes identified in Table 1.2.4 were also included. The daggerblade grass shrimp, bay anchovy, and *Menidia* spp. were included due to their abundance in the catch and their ecological importance as forage for economically important species. The clown goby was also very abundant, and was included to help represent the strongly benthic fish community. The hogchoker, although not particularly abundant, also helped represent the strongly benthic group, and had the additional desirable features of estuarine-dependence and a tendency to move farther upstream than other estuarine-dependent species. The abundant rainwater killifish was selected to represent the intertidal fish community.

2.1.1 **Methods.** Catch (individuals) and effort (m^2 swept by seines or trawls) were summed within categories for location (McKay Bay vs. Palm River), gear type, bottom type and shoreline type at deployment. Considered together, gear type and location produced four combinations: shallow McKay Bay waters were represented by offshore seines; deep McKay Bay waters were represented by trawls, shallow Palm River waters were represented by shoreline seines, and deep Palm River waters were represented by trawls. There were four principal bottom types in the FWRI database: mud, sand, rocks and oysters. There was a much wider diversity of shoreline descriptions. These were reduced by aggregating according to Matheson et al. (2004), which resulted in the following classes:

mangrove: red mangrove, black mangrove, white mangrove

emergent marsh: needlerush, smooth cordgrass, cattail, arrowhead

small terrestrial vegetation: leather fern, palmetto

shrubs/trees: Brazilian pepper, wax myrtle, oaks, pines

hard shoreline: seawall, rip-rap, docks, rocks, oysters

open shoreline: beach

CPUE was calculated and ranked for each of the 15 selected species and 14 habitat categories (4 location/depth categories, 4 bottom types, and 6 shoreline types). Average ranks were calculated for each category in order to characterize the habitat associations for the selected assemblage as a whole. The use of ranks allowed each of the selected species to contribute equally to the overall habitat association for the selected assemblage.

2.1.2 **Results and Discussion.**

Species-specific results and effort summaries are presented in Table 2.1.1. In general, shallow Palm River waters were favored over shallow McKay Bay waters (Table 2.1.2), whereas deep McKay Bay waters were favored over deep Palm River waters (it should be kept in mind that the seine deployments were made against the shoreline in the Palm River and offshore, but often very close to the shoreline, within McKay Bay). Mud was preferred over sand bottom, with both mud and sand being preferred over rocks and oysters. Shorelines with shrubs and trees ranked highest, probably because this shoreline type was common in the Palm River. Conversely, mangroves ranked lower, presumably because this was a common shoreline type in McKay Bay, including the lower part of McKay Bay where fish densities tended to be low (see Section 2.2). Open shoreline (beach) appeared to be the least preferred shoreline type.

Table 2.1.1 (page 1 of 8). Habitat associations for selected fishes and invertebrates. The classes within each category are ranked by decreasing catch-per-unit-effort (CPUE). Data are from the FWRI HBMP surveys.

Pink shrimp, *Farfantepenaeus duorarum*

		Collection frequency	Catch (individuals)	Effort (m^2)	CPUE (ind./m^2 x 100)
Location/ depth:	McKay Bay shallow (offshore seine)	137	542	66,360	0.817
	TBC shore (shoreline seine)	40	135	19,176	0.704
	McKay Bay deep (trawl)	122	744	134,602	0.553
	TBC deep (trawl)	37	185	100,507	0.184
Bottom: (seine only)	Mud	186	802	42,792	1.874
	Sand	80	269	40,212	0.669
	Oysters	1	1	1,168	0.086
	Rocks	0	0	1,224	0.000
Shoreline: (seine only)	small terrestrial vegetation	4	8	756	1.058
	hard shoreline	40	198	20,840	0.950
	emergent marsh	17	46	6,120	0.752
	mangrove	105	408	54,524	0.748
	open shoreline	1	3	416	0.721
	shrubs/trees	6	7	1,840	0.380

Daggerblade grass shrimp, *Palaemonetes pugio*

		Collection frequency	Catch (individuals)	Effort (m^2)	CPUE (ind./m^2 x 100)
Location/ depth:	TBC shore (shoreline seine)	260	115,492	19,176	602.274
	McKay Bay shallow (offshore seine)	95	757	66,360	1.141
	McKay Bay deep (trawl)	5	14	134,602	0.010
	TBC deep (trawl)	0	0	100,507	0.000
Bottom: (seine only)	Mud	186	802	42,792	1.874
	Sand	80	269	40,212	0.669
	Oysters	1	1	1,168	0.086
	Rocks	0	0	1,224	0.000
Shoreline: (seine only)	shrubs/trees	29	20,726	1,840	1126.413
	mangrove	172	69,469	54,524	127.410
	emergent marsh	26	7,567	6,120	123.644
	small terrestrial vegetation	10	840	756	111.111
	hard shoreline	116	17,636	20,840	84.626
	open shoreline	0	0	416	0.000

Table 2.1.1 (page 2 of 8). Habitat associations for selected fishes and invertebrates. The classes within each category are ranked by decreasing catch-per-unit-effort (CPUE). Data are from the FWRI HBMP surveys.

		Collection frequency	Catch (individuals)	Effort (m^2)	CPUE (ind./m^2 x 100)
	Blue crab, *Callinectes sapidus*				
Location/ depth:	TBC shore (shoreline seine)	86	131	19,176	0.683
	McKay Bay deep (trawl)	159	506	134,602	0.376
	McKay Bay shallow (offshore seine)	101	170	66,360	0.256
	TBC deep (trawl)	42	93	100,507	0.093
Bottom: (seine only)	Mud	168	266	42,792	0.622
	Sand	76	140	40,212	0.348
	Oysters	1	1	1,168	0.086
	Rocks	1	1	1,224	0.082
Shoreline: (seine only)	open shoreline	4	6	416	1.442
	shrubs/trees	11	19	1,840	1.033
	small terrestrial vegetation	4	5	756	0.661
	hard shoreline	50	89	20,840	0.427
	mangrove	86	149	54,524	0.273
	emergent marsh	7	7	6,120	0.114
	Bay anchovy, *Anchoa mitchilli*				
Location/ depth:	TBC shore (shoreline seine)	166	532,691	19,176	2777.905
	McKay Bay shallow (offshore seine)	202	48,210	66,360	72.649
	TBC deep (trawl)	33	3,182	100,507	3.166
	McKay Bay deep (trawl)	65	3,221	134,602	2.393
Bottom: (seine only)	Mud	378	422,046	42,792	986.273
	Rocks	9	11,004	1,224	899.020
	Sand	157	354,164	40,212	880.742
	Oysters	8	4,695	1,168	401.969
Shoreline: (seine only)	shrubs/trees	18	36,463	1,840	1981.685
	hard shoreline	92	187,302	20,840	898.762
	mangrove	219	351,691	54,524	645.021
	small terrestrial vegetation	8	1,186	756	156.878
	emergent marsh	26	4,244	6,120	69.346
	open shoreline	0	0	416	0.000

Table 2.1.1 (page 3 of 8). Habitat associations for selected fishes and invertebrates. The classes within each category are ranked by decreasing catch-per-unit-effort (CPUE). Data are from the FWRI HBMP surveys.

		Collection frequency	Catch (individuals)	Effort (m^2)	CPUE (ind./m^2 x 100)
	Rainwater killifish, *Lucania parva*				
Location/ depth:	TBC shore (shoreline seine)	131	3,420	19,176	17.835
	McKay Bay shallow (offshore seine)	133	6,663	66,360	10.041
	McKay Bay deep (trawl)	4	8	134,602	0.006
	TBC deep (trawl)	0	0	100,507	0.000
Bottom: (seine only)	Rocks	12	753	1,224	61.520
	Mud	250	11,946	42,792	27.916
	Sand	121	3,301	40,212	8.209
	Oysters	4	50	1,168	4.281
Shoreline: (seine only)	shrubs/trees	15	582	1,840	31.630
	emergent marsh	23	821	6,120	13.415
	mangrove	133	6,416	54,524	11.767
	hard shoreline	82	2,185	20,840	10.485
	small terrestrial vegetation	7	65	756	8.598
	open shoreline	1	1	416	0.240
	Silversides, *Menidia spp.*				
Location/ depth:	TBC shore (shoreline seine)	374	111,527	19,176	581.597
	McKay Bay shallow (offshore seine)	220	15,802	66,360	23.813
	McKay Bay deep (trawl)	2	2	134,602	0.001
	TBC deep (trawl)	0	0	100,507	0.000
Bottom: (seine only)	Oysters	16	15,645	1,168	1339.469
	Rocks	20	6,238	1,224	509.641
	Sand	310	74,654	40,212	185.651
	Mud	482	61,486	42,792	143.686
Shoreline: (seine only)	small terrestrial vegetation	13	3,152	756	416.931
	hard shoreline	187	50,231	20,840	241.032
	shrubs/trees	30	4,265	1,840	231.793
	emergent marsh	49	7,747	6,120	126.585
	mangrove	304	61,696	54,524	113.154
	open shoreline	4	189	416	45.433

Table 2.1.1 (page 4 of 8). Habitat associations for selected fishes and invertebrates. The classes within each category are ranked by decreasing catch-per-unit-effort (CPUE). Data are from the FWRI HBMP surveys.

Snook, *Centropomus undecimalis*

		Collection frequency	Catch (individuals)	Effort (m^2)	CPUE (ind./m^2 x 100)
Location/ depth:	TBC shore (shoreline seine)	17	41	19,176	0.214
	McKay Bay shallow (offshore seine)	1	1	66,360	0.002
	TBC deep (trawl)	0	0	100,507	0.000
	McKay Bay deep (trawl)	0	0	134,602	0.000
Bottom: (seine only)	Mud	20	62	42,792	0.145
	Rocks	1	1	1,224	0.082
	Sand	7	10	40,212	0.025
	Oysters	0	0	1,168	0.000
Shoreline: (seine only)	shrubs/trees	2	3	1,840	0.163
	small terrestrial vegetation	1	1	756	0.132
	hard shoreline	5	22	20,840	0.106
	mangrove	9	15	54,524	0.028
	emergent marsh	1	1	6,120	0.016
	open shoreline	0	0	416	0.000

Spotted seatrout, *Cynoscion nebulosus*

		Collection frequency	Catch (individuals)	Effort (m^2)	CPUE (ind./m^2 x 100)
Location/ depth:	TBC shore (shoreline seine)	22	36	19,176	0.188
	McKay Bay shallow (offshore seine)	43	93	66,360	0.140
	McKay Bay deep (trawl)	10	23	134,602	0.017
	TBC deep (trawl)	0	0	100,507	0.000
Bottom: (seine only)	Mud	66	140	42,792	0.327
	Rocks	1	3	1,224	0.245
	Oysters	1	2	1,168	0.171
	Sand	30	54	40,212	0.134
Shoreline: (seine only)	small terrestrial vegetation	5	10	756	1.323
	emergent marsh	8	10	6,120	0.163
	hard shoreline	18	32	20,840	0.154
	mangrove	33	76	54,524	0.139
	shrubs/trees	1	1	1,840	0.054
	open shoreline	0	0	416	0.000

Table 2.1.1 (page 5 of 8). Habitat associations for selected fishes and invertebrates. The classes within each category are ranked by decreasing catch-per-unit-effort (CPUE). Data are from the FWRI HBMP surveys.

Sand seatrout, *Cynoscion arenarius*

		Collection frequency	Catch (individuals)	Effort (m²)	CPUE (ind./m² x 100)
Location/ depth:	McKay Bay deep (trawl)	91	1,121	134,602	0.833
	TBC shore (shoreline seine)	24	83	19,176	0.433
	TBC deep (trawl)	44	423	100,507	0.421
	McKay Bay shallow (offshore seine)	74	254	66,360	0.383
Bottom: (seine only)	Mud	108	402	42,792	0.939
	Oysters	1	6	1,168	0.514
	Sand	40	126	40,212	0.313
	Rocks	1	1	1,224	0.082
Shoreline: (seine only)	small terrestrial vegetation	2	10	756	1.323
	emergent marsh	8	28	6,120	0.458
	mangrove	70	245	54,524	0.449
	hard shoreline	14	49	20,840	0.235
	shrubs/trees	1	1	1,840	0.054
	open shoreline	0	0	416	0.000

Spot, *Leiostomus xanthurus*

		Collection frequency	Catch (individuals)	Effort (m²)	CPUE (ind./m² x 100)
Location/ depth:	TBC shore (shoreline seine)	73	11,071	19,176	57.734
	McKay Bay shallow (offshore seine)	47	2,754	66,360	4.150
	McKay Bay deep (trawl)	31	2,626	134,602	1.951
	TBC deep (trawl)	13	1,023	100,507	1.018
Bottom: (seine only)	Mud	126	21,582	42,792	50.435
	Rocks	5	166	1,224	13.562
	Oysters	3	95	1,168	8.134
	Sand	47	2,692	40,212	6.695
Shoreline: (seine only)	emergent marsh	11	2,602	6,120	42.516
	hard shoreline	37	3,550	20,840	17.035
	mangrove	64	7,569	54,524	13.882
	open shoreline	2	19	416	4.567
	shrubs/trees	3	3	1,840	0.163
	small terrestrial vegetation	1	1	756	0.132

Table 2.1.1 (page 6 of 8). Habitat associations for selected fishes and invertebrates. The classes within each category are ranked by decreasing catch-per-unit-effort (CPUE). Data are from the FWRI HBMP surveys.

Southern kingfish, *Menticirrhus americanus*

		Collection frequency	Catch (individuals)	Effort (m^2)	CPUE (ind./m^2 x 100)
Location/ depth:	McKay Bay shallow (offshore seine)	66	216	66,360	0.325
	McKay Bay deep (trawl)	82	345	134,602	0.256
	TBC shore (shoreline seine)	12	21	19,176	0.110
	TBC deep (trawl)	20	49	100,507	0.049
Bottom: (seine only)	Mud	96	372	42,792	0.869
	Sand	29	50	40,212	0.124
	Rocks	0	0	1,224	0.000
	Oysters	0	0	1,168	0.000
Shoreline: (seine only)	hard shoreline	22	113	20,840	0.542
	mangrove	47	112	54,524	0.205
	small terrestrial vegetation	1	1	756	0.132
	emergent marsh	4	7	6,120	0.114
	shrubs/trees	1	1	1,840	0.054
	open shoreline	0	0	416	0.000

Red drum, *Sciaenops ocellatus*

		Collection frequency	Catch (individuals)	Effort (m^2)	CPUE (ind./m^2 x 100)
Location/ depth:	TBC shore (shoreline seine)	51	184	19,176	0.960
	McKay Bay shallow (offshore seine)	41	214	66,360	0.322
	McKay Bay deep (trawl)	3	27	134,602	0.020
	TBC deep (trawl)	2	3	100,507	0.003
Bottom: (seine only)	Sand	47	298	40,212	0.741
	Mud	88	180	42,792	0.421
	Rocks	0	0	1,224	0.000
	Oysters	0	0	1,168	0.000
Shoreline: (seine only)	shrubs/trees	7	76	1,840	4.130
	hard shoreline	35	213	20,840	1.022
	small terrestrial vegetation	2	5	756	0.661
	mangrove	42	86	54,524	0.158
	emergent marsh	5	8	6,120	0.131
	open shoreline	0	0	416	0.000

Table 2.1.1 (page 7 of 8). Habitat associations for selected fishes and invertebrates. The classes within each category are ranked by decreasing catch-per-unit-effort (CPUE). Data are from the FWRI HBMP surveys.

		Collection frequency	Catch (individuals)	Effort (m²)	CPUE (ind./m² x 100)
	Striped mullet, *Mugil cephalus*				
Location/ depth:	TBC shore (shoreline seine)	67	1,703	19,176	8.881
	McKay Bay shallow (offshore seine)	19	369	66,360	0.556
	McKay Bay deep (trawl)	1	1	134,602	0.001
	TBC deep (trawl)	0	0	100,507	0.000
Bottom: (seine only)	Oysters	5	91	1,168	7.791
	Mud	68	2,390	42,792	5.585
	Sand	46	785	40,212	1.952
	Rocks	0	0	1,224	0.000
Shoreline: (seine only)	emergent marsh	10	681	6,120	11.127
	shrubs/trees	8	121	1,840	6.576
	open shoreline	1	15	416	3.606
	hard shoreline	27	681	20,840	3.268
	mangrove	35	569	54,524	1.044
	small terrestrial vegetation	4	4	756	0.529
	Clown goby, *Microgobius gulosus*				
Location/ depth:	TBC shore (shoreline seine)	227	3,599	19,176	18.768
	McKay Bay shallow (offshore seine)	348	5,177	66,360	7.801
	TBC deep (trawl)	24	62	100,507	0.062
	McKay Bay deep (trawl)	36	79	134,602	0.059
Bottom: (seine only)	Mud	580	8,634	42,792	20.177
	Sand	266	4,316	40,212	10.733
	Rocks	5	73	1,224	5.964
	Oysters	6	50	1,168	4.281
Shoreline: (seine only)	emergent marsh	46	1,209	6,120	19.755
	small terrestrial vegetation	8	147	756	19.444
	shrubs/trees	28	310	1,840	16.848
	hard shoreline	133	2,176	20,840	10.441
	mangrove	347	4,856	54,524	8.906
	open shoreline	3	16	416	3.846

Table 2.1.1 (page 8 of 8). Habitat associations for selected fishes and invertebrates. The classes within each category are ranked by decreasing catch-per-unit-effort (CPUE). Data are from the FWRI HBMP surveys.

	Hogchoker, *Trinectes maculatus*	Collection frequency	Catch (individuals)	Effort (m^2)	CPUE (ind./m^2 x 100)
Location/ depth:	TBC shore (shoreline seine)	48	119	19,176	0.621
	McKay Bay shallow (offshore seine)	16	46	66,360	0.069
	TBC deep (trawl)	13	20	100,507	0.020
	McKay Bay deep (trawl)	13	20	134,602	0.015
Bottom: (seine only)	Mud	52	114	42,792	0.266
	Sand	34	101	40,212	0.251
	Oysters	1	1	1,168	0.086
	Rocks	1	1	1,224	0.082
Shoreline: (seine only)	emergent marsh	7	44	6,120	0.719
	shrubs/trees	6	12	1,840	0.652
	hard shoreline	17	35	20,840	0.168
	small terrestrial vegetation	1	1	756	0.132
	mangrove	31	68	54,524	0.125
	open shoreline	0	0	416	0.000

Table 2.1.2. Summary of habitat associations for an assemblage of 15 selected economically and ecologically important fishes and invertebrates. These are the average category ranks from the species-specific results presented in Table 2.1.1. Low ranks indicate high preference.

	Average rank
Location/depth:	
Palm River shore (shoreline seine)	1.27
McKay Bay shallow (offshore seine)	2.07
McKay Bay deep (trawl)	2.97
Palm River deep (trawl)	3.70
Bottom type (seine only):	
Mud	1.40
Sand	2.60
Rocks	3.00
Oysters	3.00
Shoreline type (seine only):	
shrubs/trees	2.87
hard shoreline	3.00
emergent marsh	3.00
small terrestrial vegetation	3.07
mangrove	3.80
open shoreline	5.27

2.2 Spatial Distributions of Selected Fishes and Invertebrates

2.2.1 **Methods.** Seine and trawl catches were represented as CPUE (ind./m²) within 31 sampling zones. A grid of 28 hexagonal zones represented McKay Bay and 3 zones of similar length, arranged end to end, represented the Palm River. The average latitude and longitude of all gear-specific deployments (regardless of catch) were calculated to represent the geographic center of effort within each zone. Gear-specific effort was summed for each zone, and total catch was divided by total effort. Contour plots were generated for all taxa selected in Section 2.1 (Kriging, linear semivariogram model, Surfer 7, Golden Software 1999). If the catch was negligible for a specific gear type, contouring was not performed for that gear type. Contouring was also performed on organisms collected by plankton net (fixed stations) that are known to be (1) prey for juvenile fishes, (2) predators on fish eggs, larvae or juveniles, (3) competitors with fish for zooplankton prey and (4) parasites on young fishes.

2.2.2 **Results and Discussion.** The contouring results are presented in Figs. 2.2.1-2.2.47. When comparing the paired seine and trawl results in these figures, note differences in the CPUE scales for the two gear types; for fishes in particular, differences in scale were often large.

Pink shrimp and blue crabs were most abundant near the mouth of the Palm River, as were juvenile sand seatrout. Juvenile sand seatrout generally prefer channels and other deep areas over shallow areas. Copepods, cumaceans, crab larvae, the crab *Pinnixa sayana*, ostracods and the planktonic shrimp *Lucifer faxoni* were the prey types associated with the mouth of the Palm River. Amphipods and mysids were also fairly abundant in this area. Most fish are well into the process of reducing their dietary dependence on zooplankton by the time they enter low-salinity areas. For this reason, it is not likely that the copepods, crab larvae and planktonic shrimp were attractants for most species. An exception is the expected coincidence between the bay anchovy trawl catch and copepods. The bay anchovy consumes zooplankton during its larval stages, shifts to a more benthic diet during the juvenile stage (15-30 mm SL), and then reverses the trend to include more zooplankton, as well as peracarid crustaceans, during the adult period. A large proportion of the bay anchovy trawl catch in McKay Bay was adults, whereas the catch within the Palm River contained a larger proportion of juveniles.

A second area of concentration was the upper end of the Palm River (below S-160). This area had relatively high densities of bay anchovy, snook, spot, red drum, striped mullet, clown goby, and hogchoker. All except the clown goby are estuarine-dependent; the clown goby is generally considered to be an estuarine resident. Concentrations in the upper Palm River were primarily evident in the seine catch. In general, trawl densities for these concentrating species were much lower and indicated that these species were more abundant in McKay Bay, if they were present in the trawl catches at all. As with the bay anchovy, the spot caught by trawl in McKay Bay were larger than those caught by seine in the Palm River, and were already involved in the rebound migration seaward.

There were few prey distributions that could offer an explanation for fish concentration below S-160. Grass shrimp and juvenile bay anchovies are likely to be attractive to young snook and red drum and were abundant at this location. The mysid *Americamysis almyra* is known to be an important prey item for young, estuarine-dependent sport fishes. *A. almyra* is responsible for the higher mysid densities below S-160, which agrees with this species' tendency to be most abundant in areas that are influenced by freshwater inflow. Mysid densities in other parts of the study area are composites of several species, including species that do not directly associate with freshwater inflow.

Spot tend to consume nematodes, harpacticoid copepods and polychaetes during the early juvenile period. Nematodes and harpacticoid copepods are minute benthic animals that would not have been sampled well by the relatively large-meshed plankton net. Polychaetes were abundant in the Palm River, but it is possible that high polychaete densities in the water column are partly symptomatic of benthic hypoxia rather than being an indication of high infaunal polychaete densities.

A large part of the hogchoker's diet consist of worms, including polychaetes, and there was very good agreement between the distribution of polychaetes and the hogchoker. The hogchoker typically invades oligohaline and freshwater areas during the juvenile stage, where the diet is more likely to include oligochaete rather than polychaetes worms.

Juvenile striped mullet are likely to be feeding on algae and benthic microfauna. As in the case of the hogchoker, striped mullet frequently invade fresh water during the juvenile stage.

It is interesting that the area below S-160 also appears to be relatively free of two of the more common fish parasites (Fig. 2.2.46-2.2.47). These two parasites are associated with schooling pelagic species such as juvenile bay anchovies and menhaden. Densities of predatory jellyfish in the Palm River (Fig. 2.2.42) were probably high enough to substantially affect pelagic fish survival.

While there is some evidence of elevated food resource availability in the Palm River, an alternative explanation for the concentration of estuarine-dependent species below S-160 is an olfaction-based attraction to chemical cues that are either delivered or created by freshwater inflow. If food resource availability is actually inadequate there, then survival rates will be lower, and this will be reflected by an absence of larger individuals. This question could be addressed by using the length data in the FIM database to compare apparent survival rates in the Palm River with those of other tidal rivers.

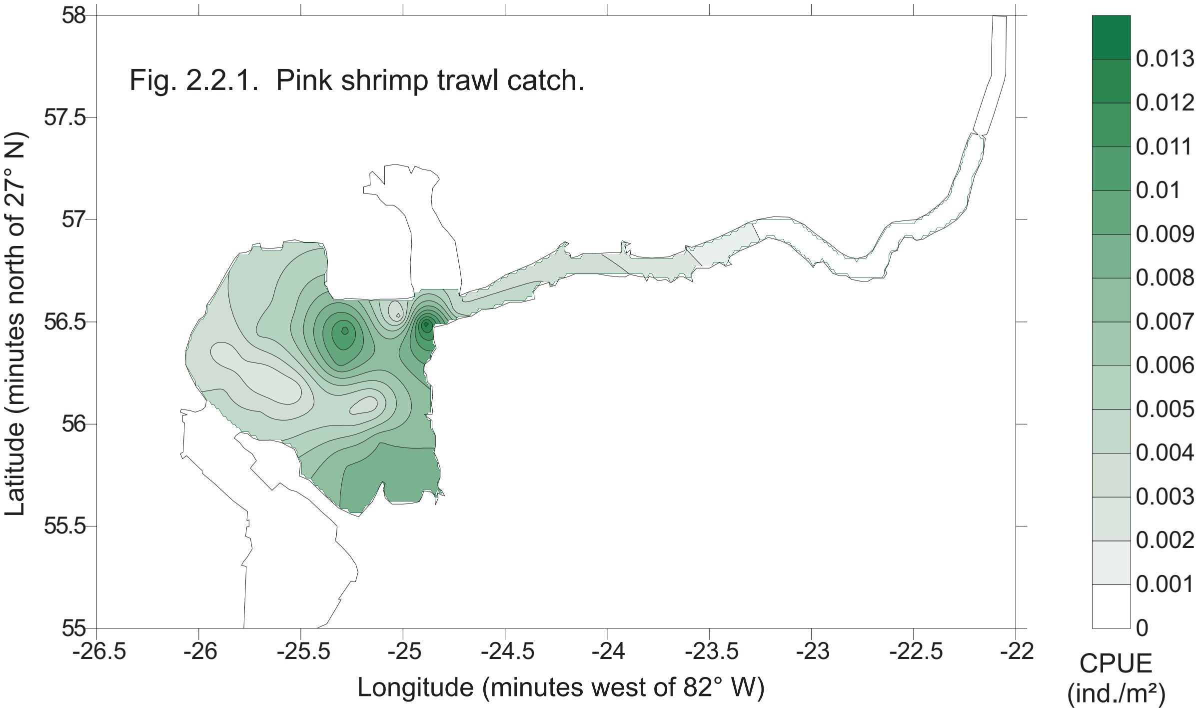


Fig. 2.2.1. Pink shrimp trawl catch.
Latitude (minutes north of 27° N)
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.013
0.012
0.011
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
CPUE
(ind./m²)

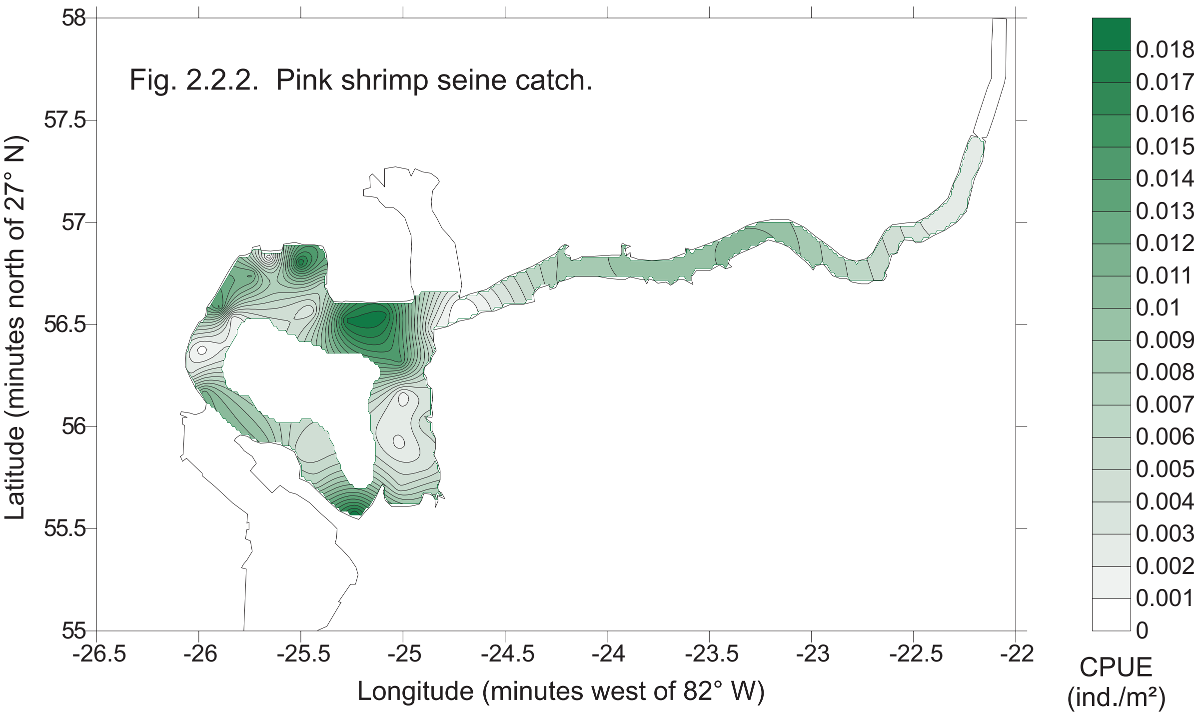


Fig. 2.2.2. Pink shrimp seine catch.
Latitude (minutes north of 27° N)
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
CPUE
(ind./m²)

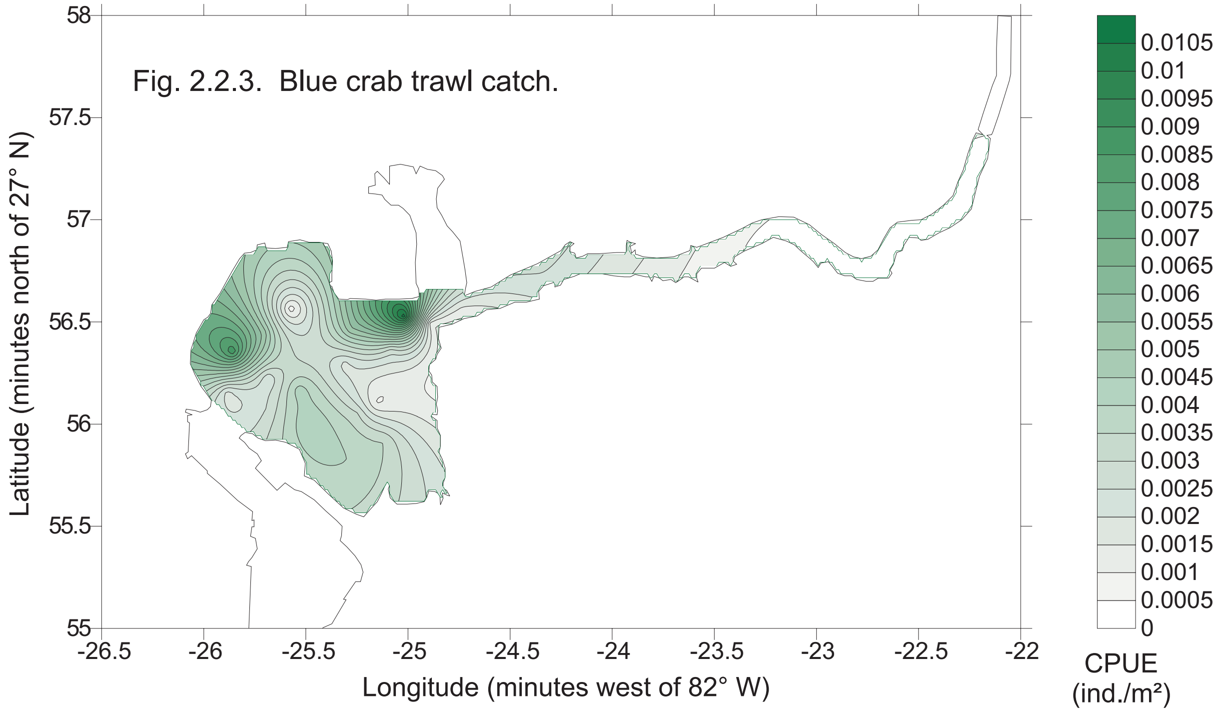


Fig. 2.2.3. Blue crab trawl catch.
58
57.5
57
56.5
56
55.5
55
Latitude (minutes north of 27° N)
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.0105
0.01
0.0095
0.009
0.0085
0.008
0.0075
0.007
0.0065
0.006
0.0055
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
CPUE
(ind./m²)

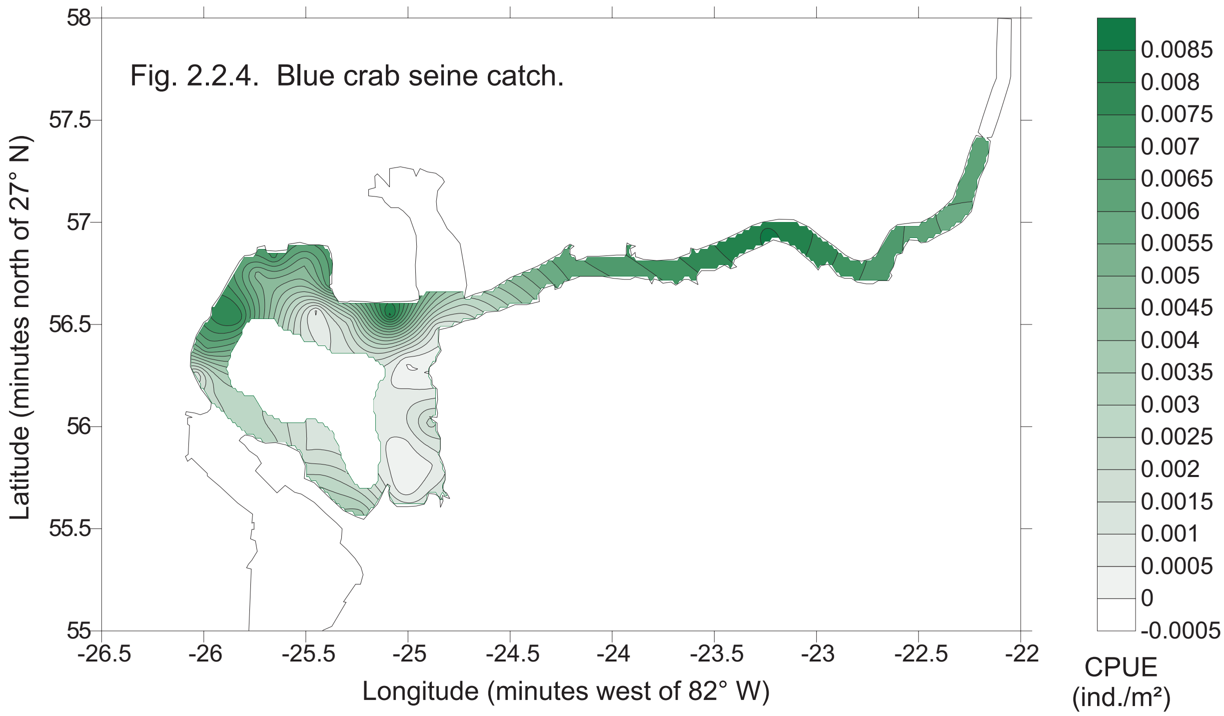


Fig. 2.2.4. Blue crab seine catch.
58
57.5
57
56.5
56
55.5
55
Latitude (minutes north of 27° N)
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.0085
0.008
0.0075
0.007
0.0065
0.006
0.0055
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
-0.0005
CPUE
(ind./m²)

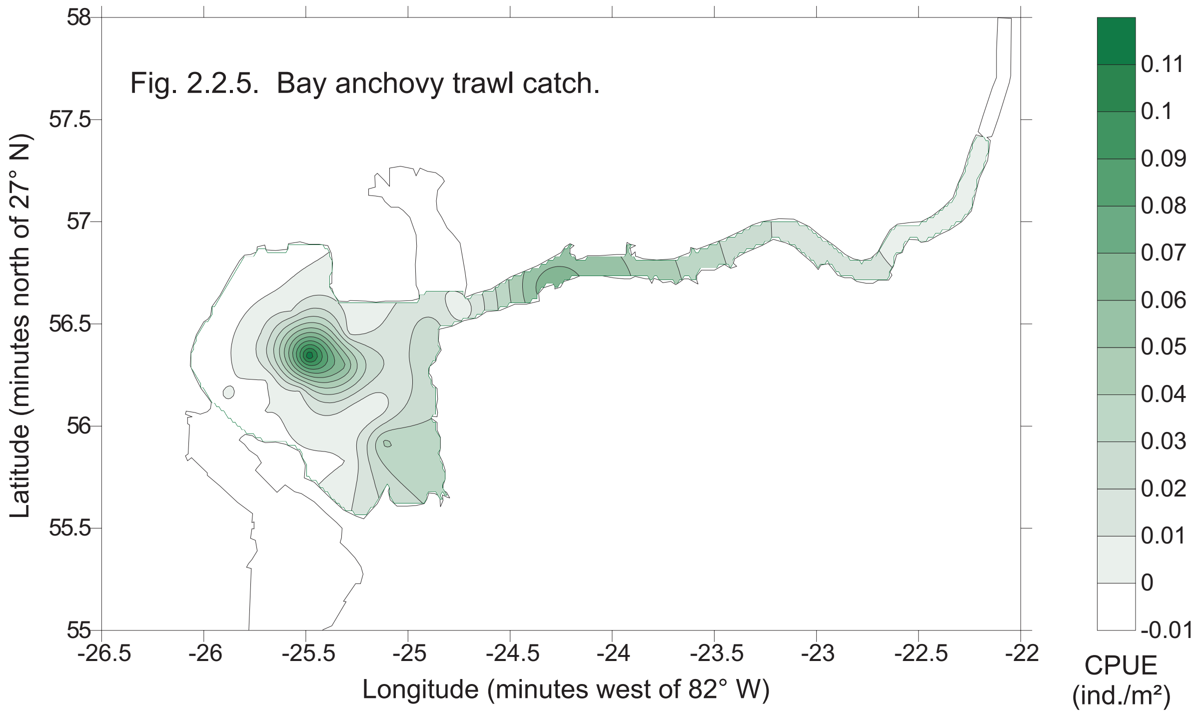


Fig. 2.2.5. Bay anchovy trawl catch.
58
57.5
57
56.5
56
55.5
55
Latitude (minutes north of 27° N)
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
CPUE
(ind./m²)

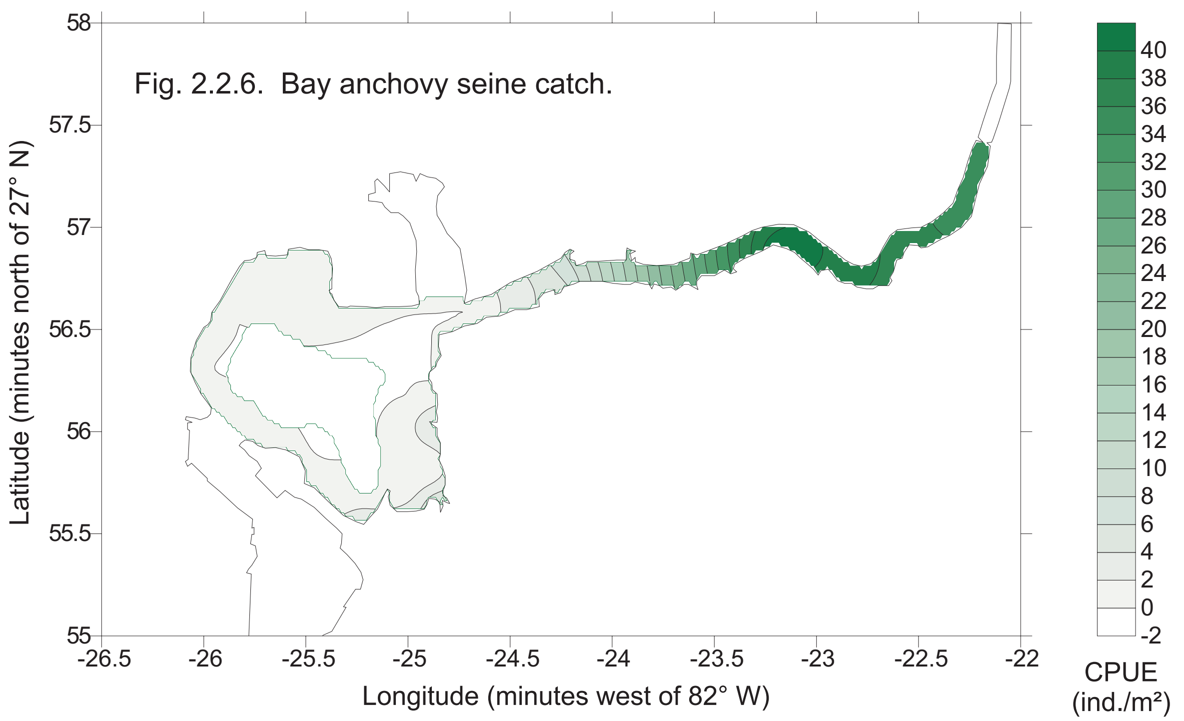


Fig. 2.2.6. Bay anchovy seine catch.
58
57.5
57
56.5
56
55.5
55
Latitude (minutes north of 27° N)
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
CPUE
(ind./m²)

Rainwater killifish trawl catch was negligible
(see Table 2.1.1).

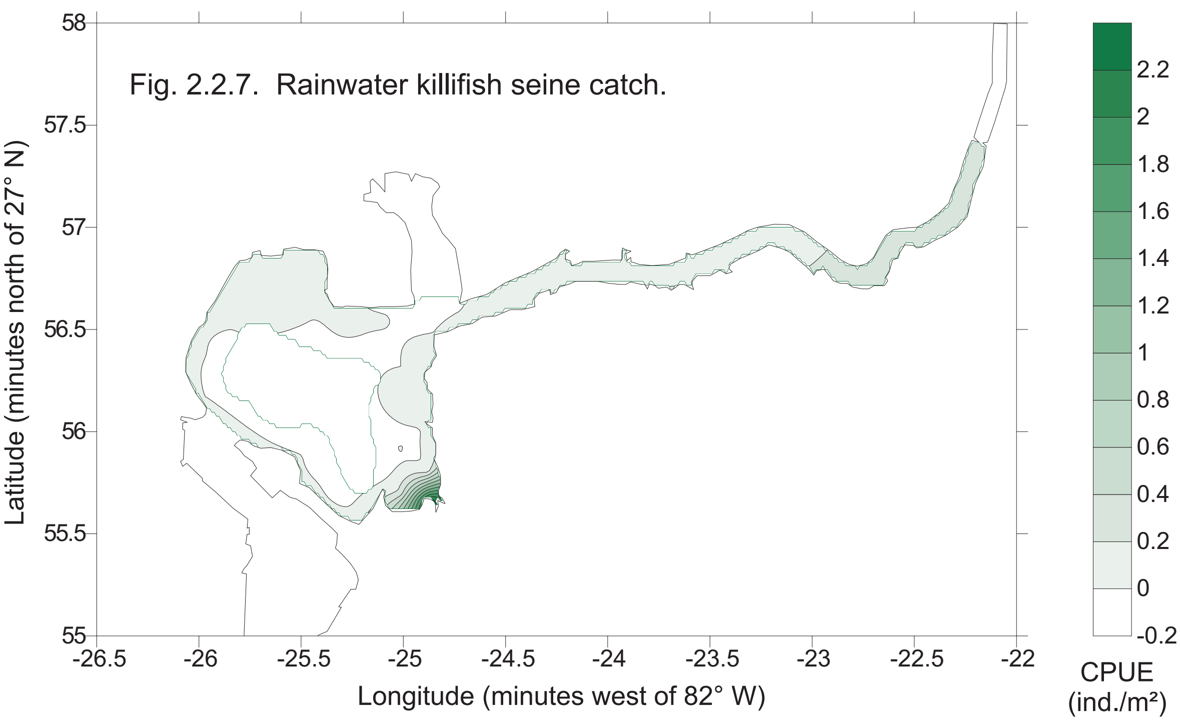
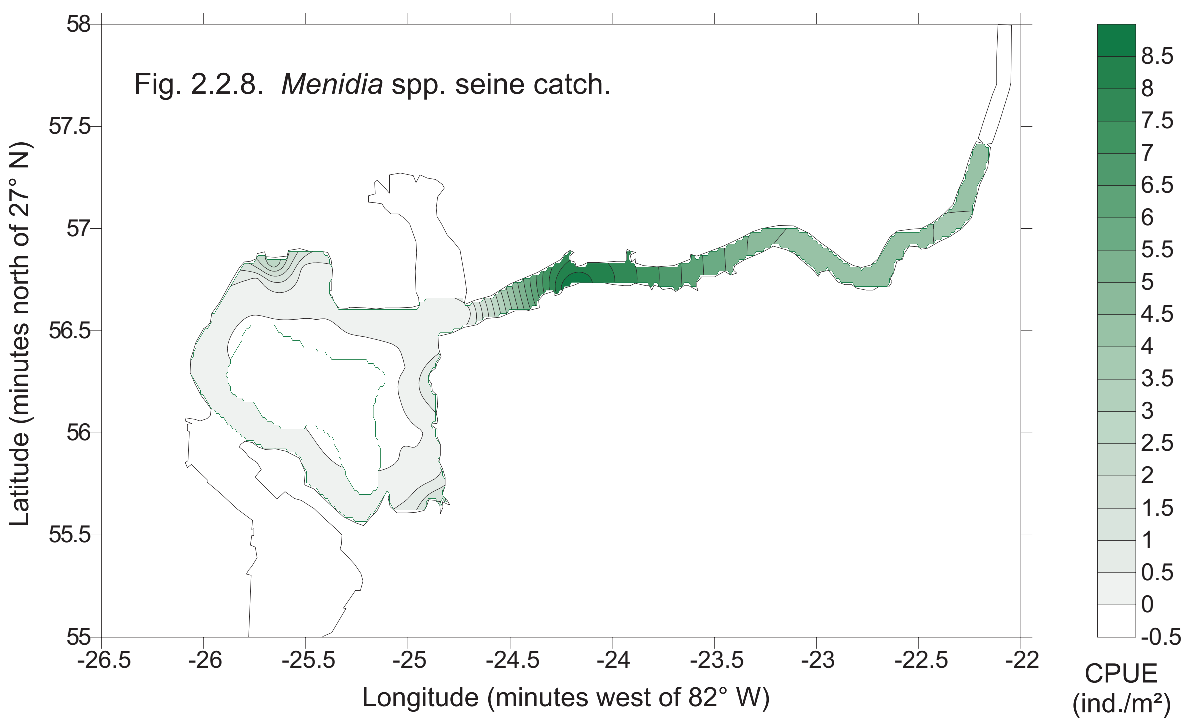


Fig. 2.2.7. Rainwater killifish seine catch.

Menidia spp. trawl catch was negligible
(see Table 2.1.1).



Snook trawl catch was zero
(see Table 2.1.1).

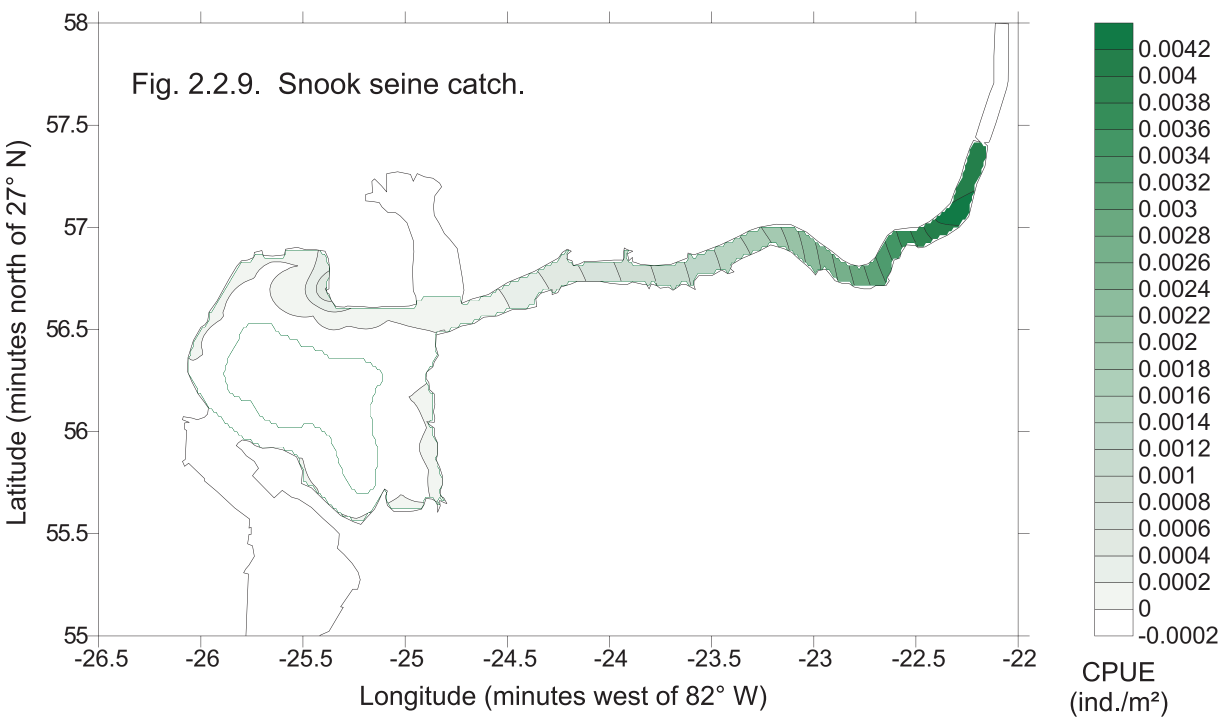


Fig. 2.2.9. Snook seine catch.

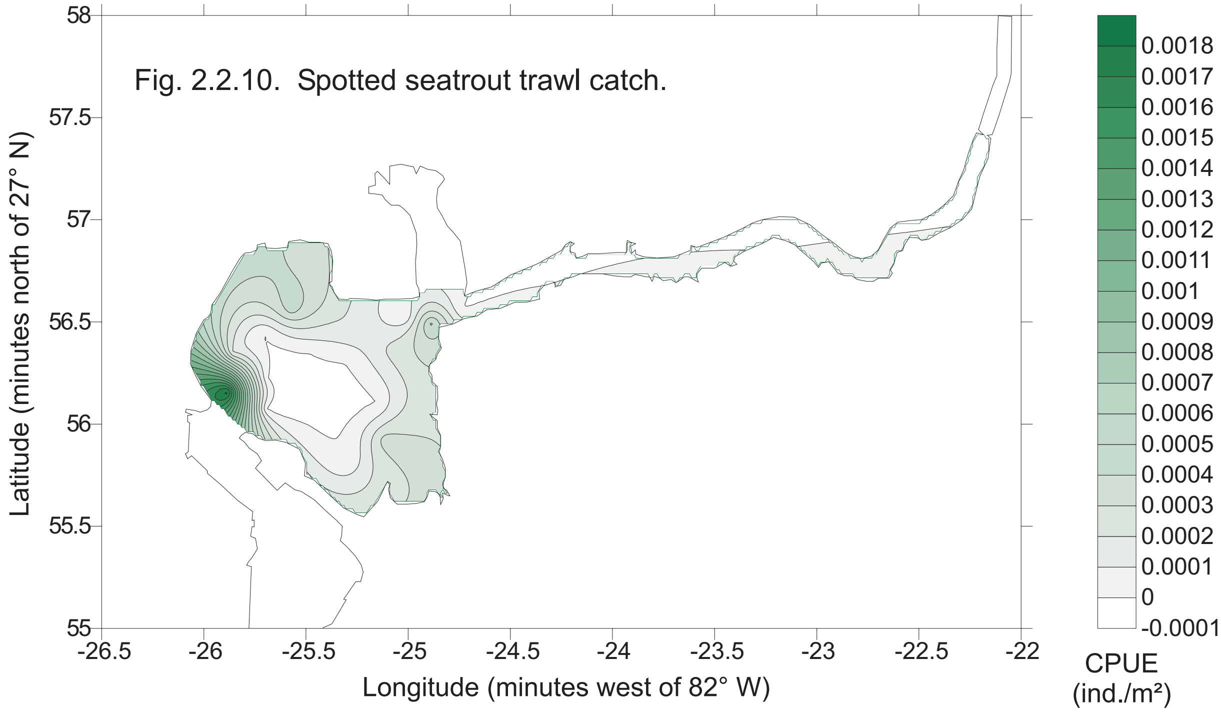


Fig. 2.2.10. Spotted seatrout trawl catch.
Latitude (minutes north of 27° N)
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.0018
0.0017
0.0016
0.0015
0.0014
0.0013
0.0012
0.0011
0.001
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
-0.0001
CPUE
(ind./m²)

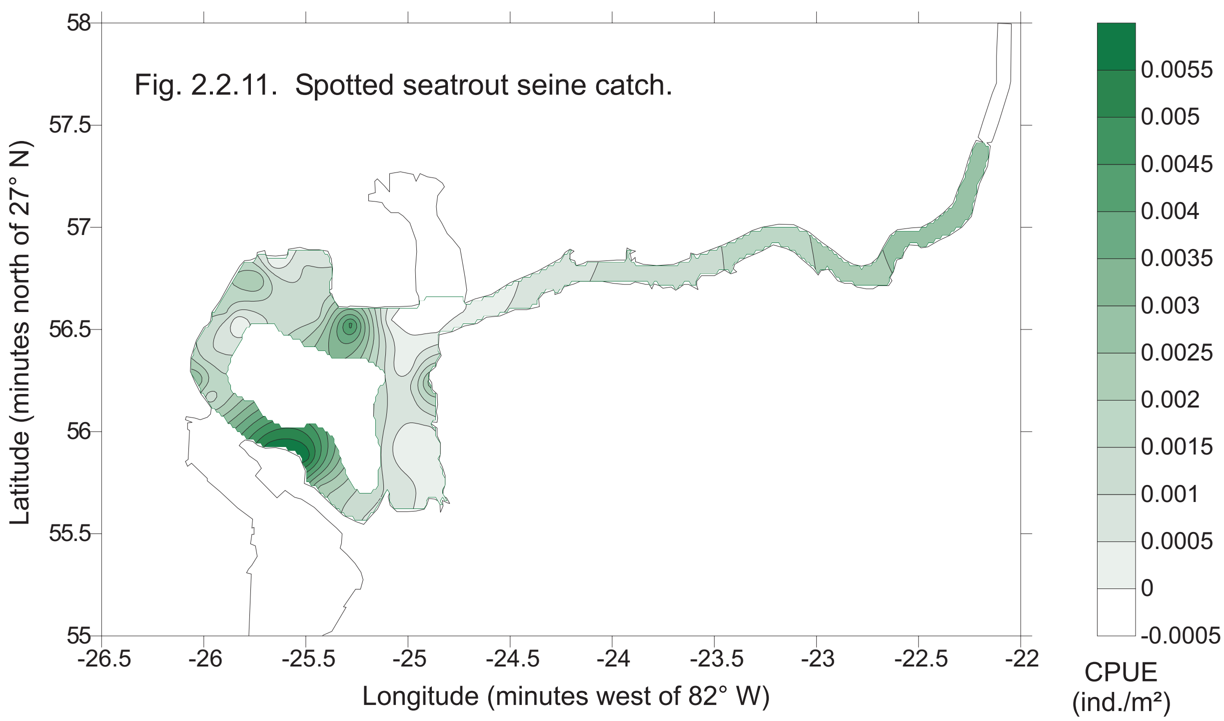


Fig. 2.2.11. Spotted seatrout seine catch.
Latitude (minutes north of 27° N)
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.0055
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
-0.0005
CPUE
(ind./m²)

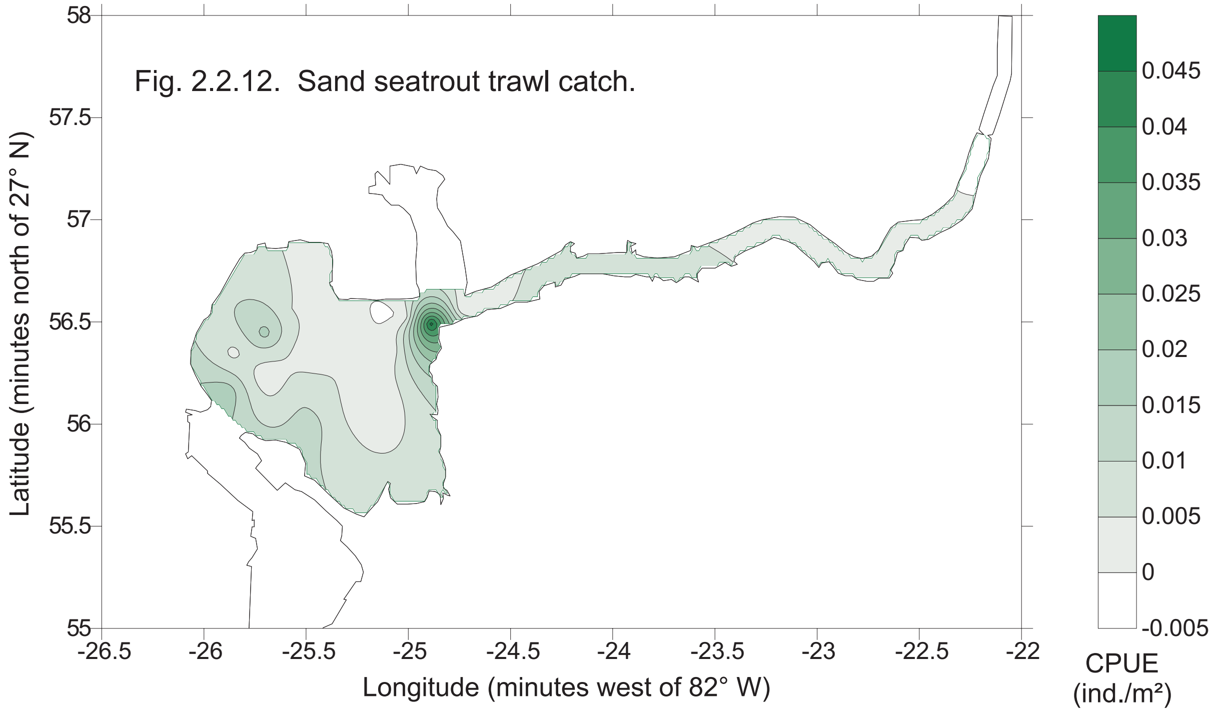


Fig. 2.2.12. Sand seatrout trawl catch.
58
57.5
57
56.5
56
55.5
55
Latitude (minutes north of 27° N)
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
CPUE
(ind./m²)

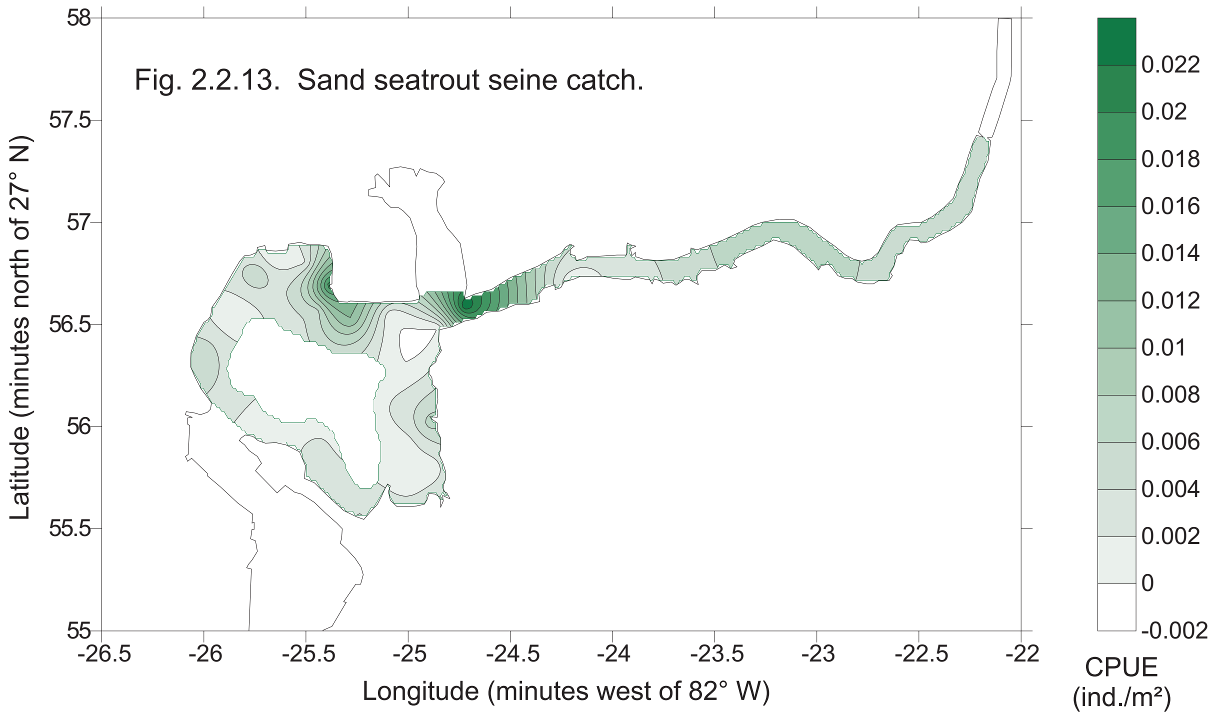


Fig. 2.2.13. Sand seatrout seine catch.
58
57.5
57
56.5
56
55.5
55
Latitude (minutes north of 27° N)
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
CPUE
(ind./m²)

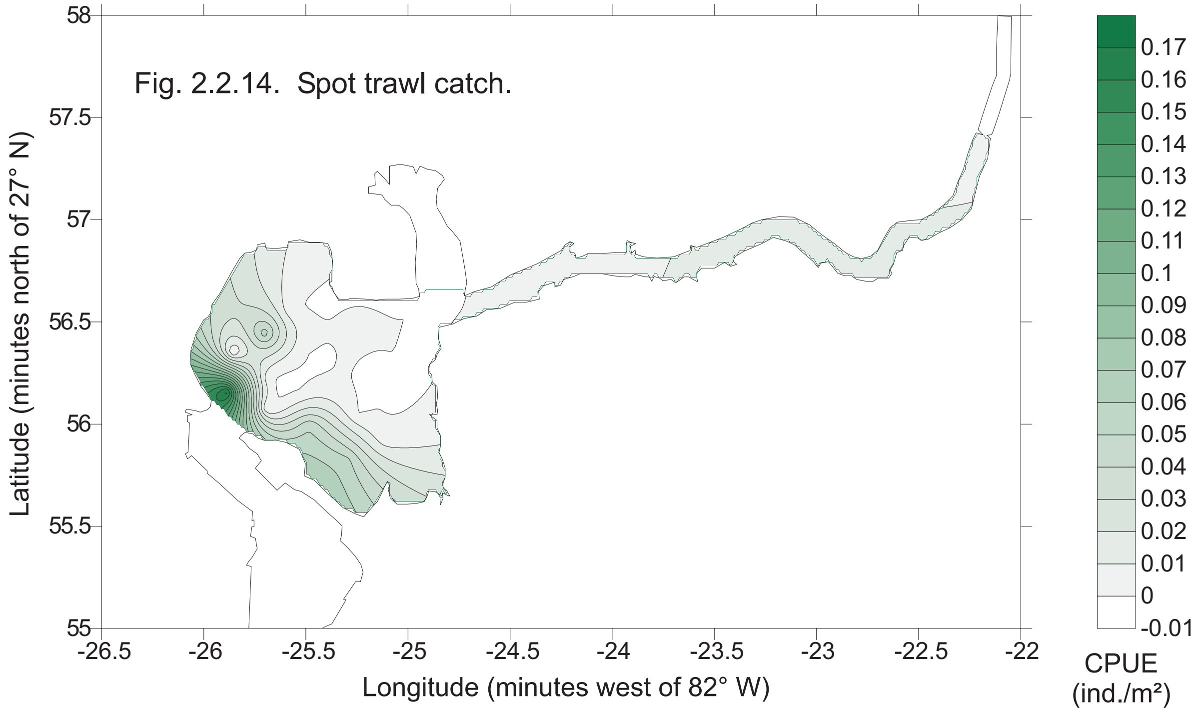


Fig. 2.2.14. Spot trawl catch.
Latitude (minutes north of 27° N)
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
CPUE
(ind./m²)

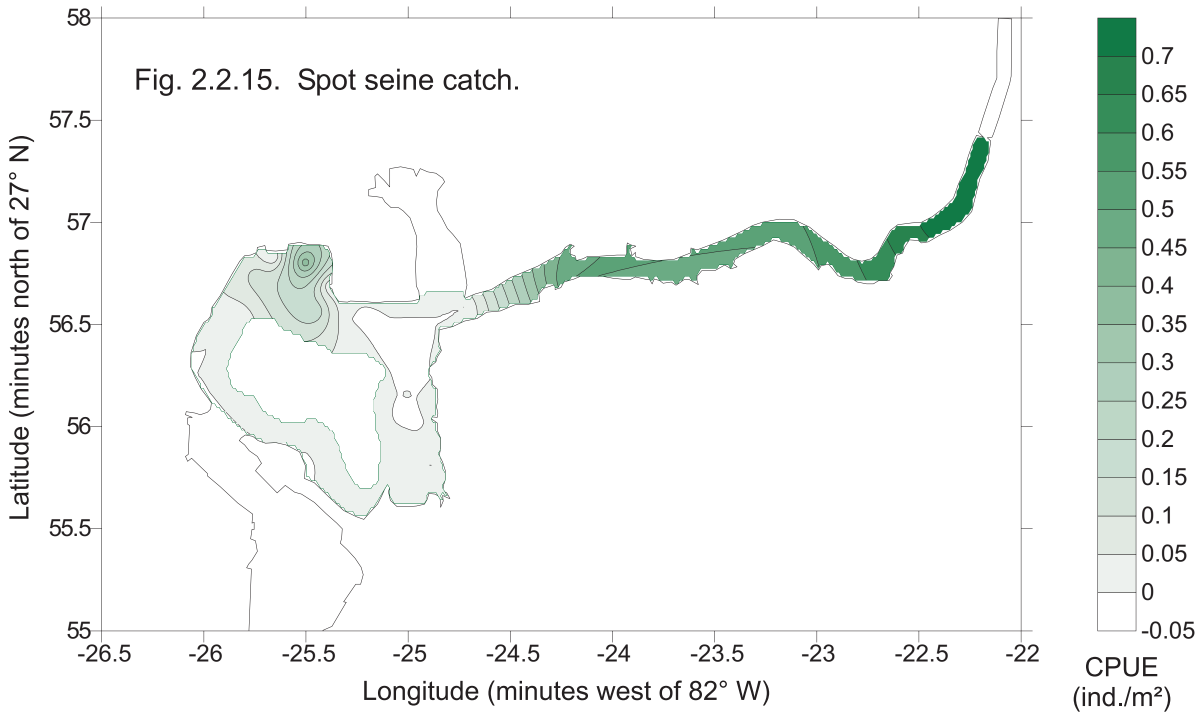


Fig. 2.2.15. Spot seine catch.
Latitude (minutes north of 27° N)
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Longitude (minutes west of 82° W)
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
CPUE
(ind./m²)

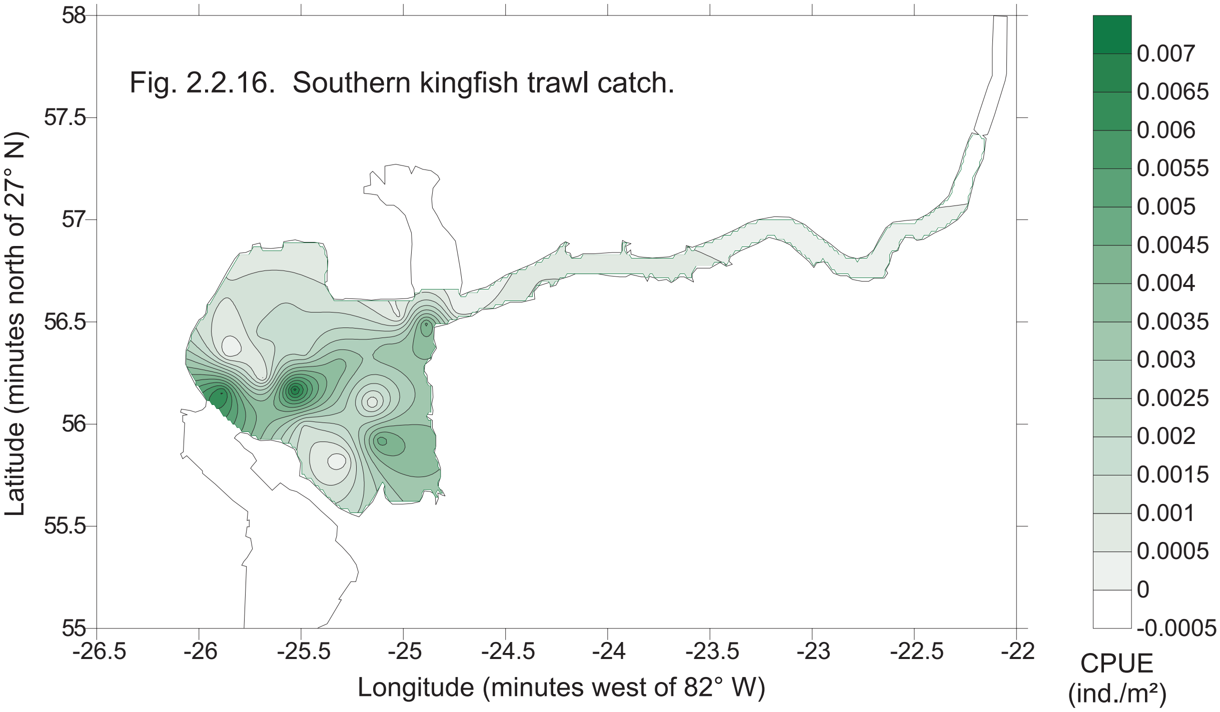


Fig. 2.2.16. Southern kingfish trawl catch.
Latitude (minutes north of 27° N)
Longitude (minutes west of 82° W)
CPUE (ind./m²)
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
0.007
0.0065
0.006
0.0055
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
-0.0005

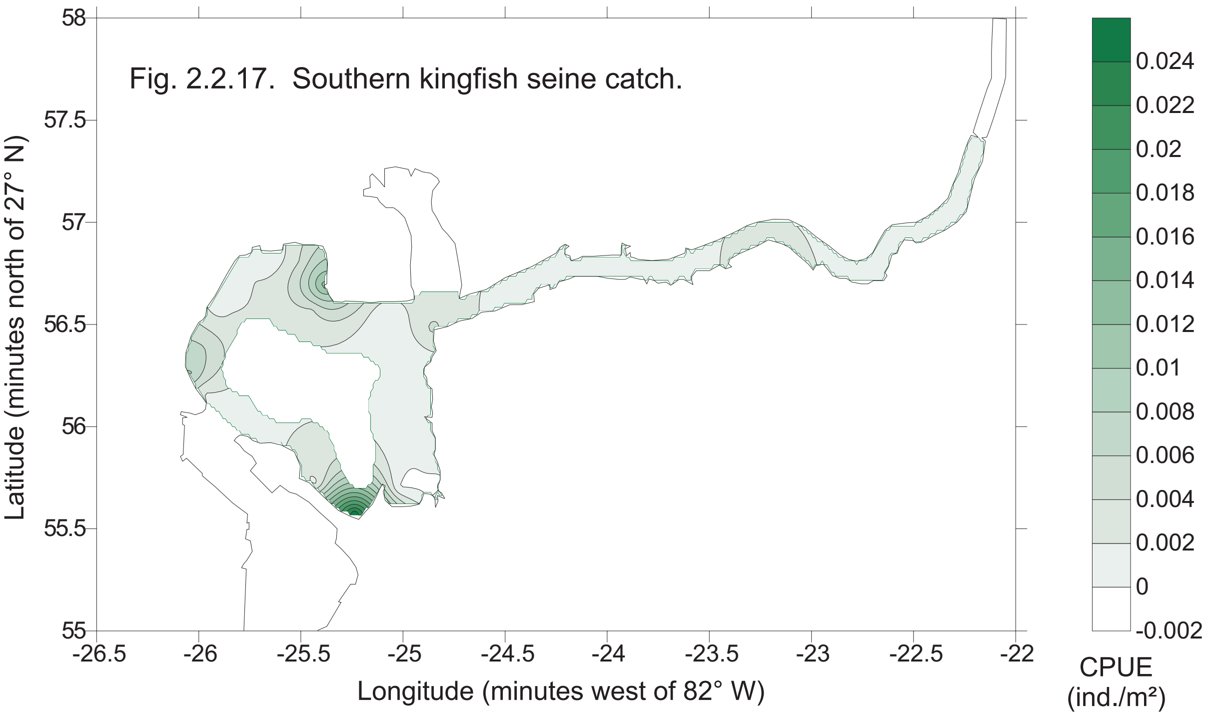
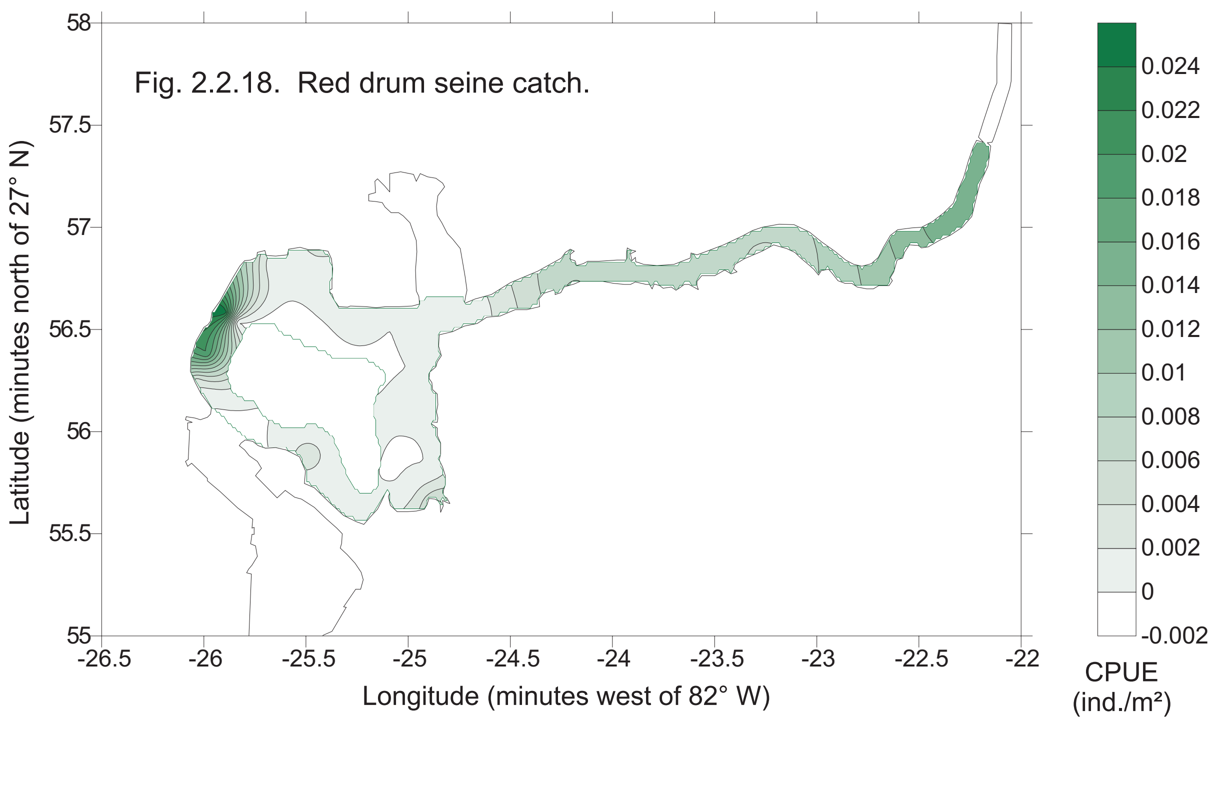
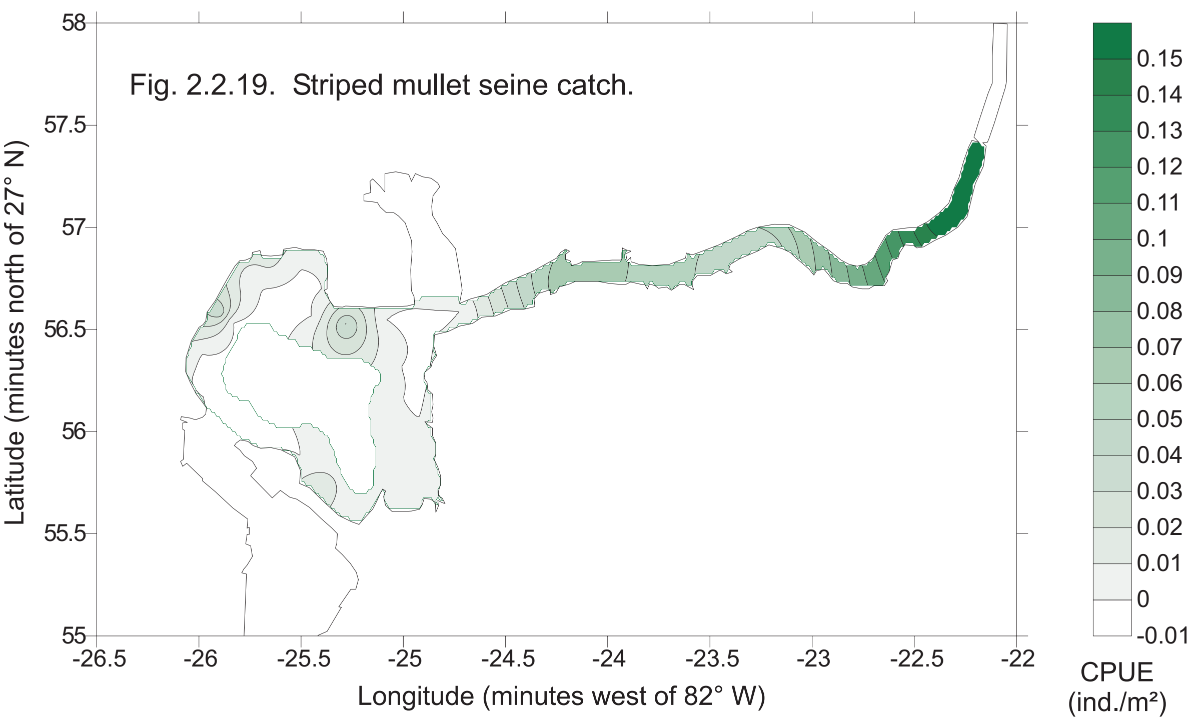


Fig. 2.2.17. Southern kingfish seine catch.
Latitude (minutes north of 27° N)
Longitude (minutes west of 82° W)
CPUE (ind./m²)
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002

Red drum trawl catch was negligible
(see Table 2.1.1).



Striped mullet trawl catch was negligible
(see Table 2.1.1).



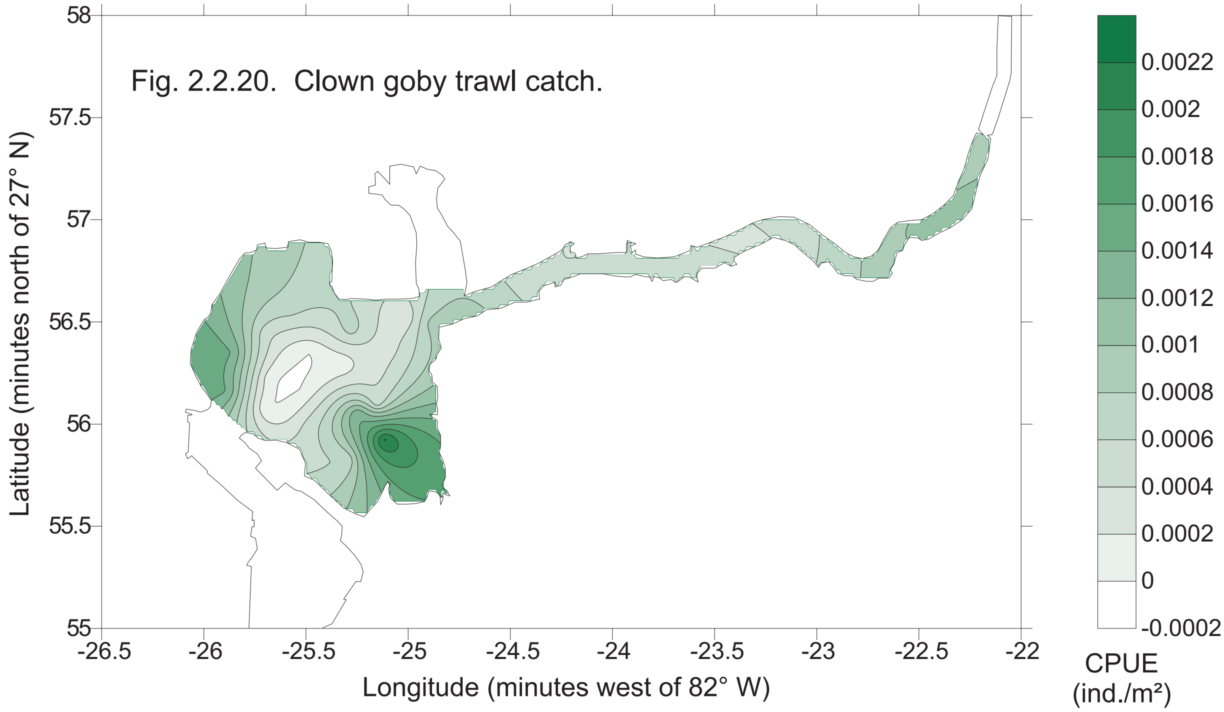


Fig. 2.2.20. Clown goby trawl catch.
Latitude (minutes north of 27° N)
Longitude (minutes west of 82° W)
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
0.0022
0.002
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
-0.0002
CPUE
(ind./m²)

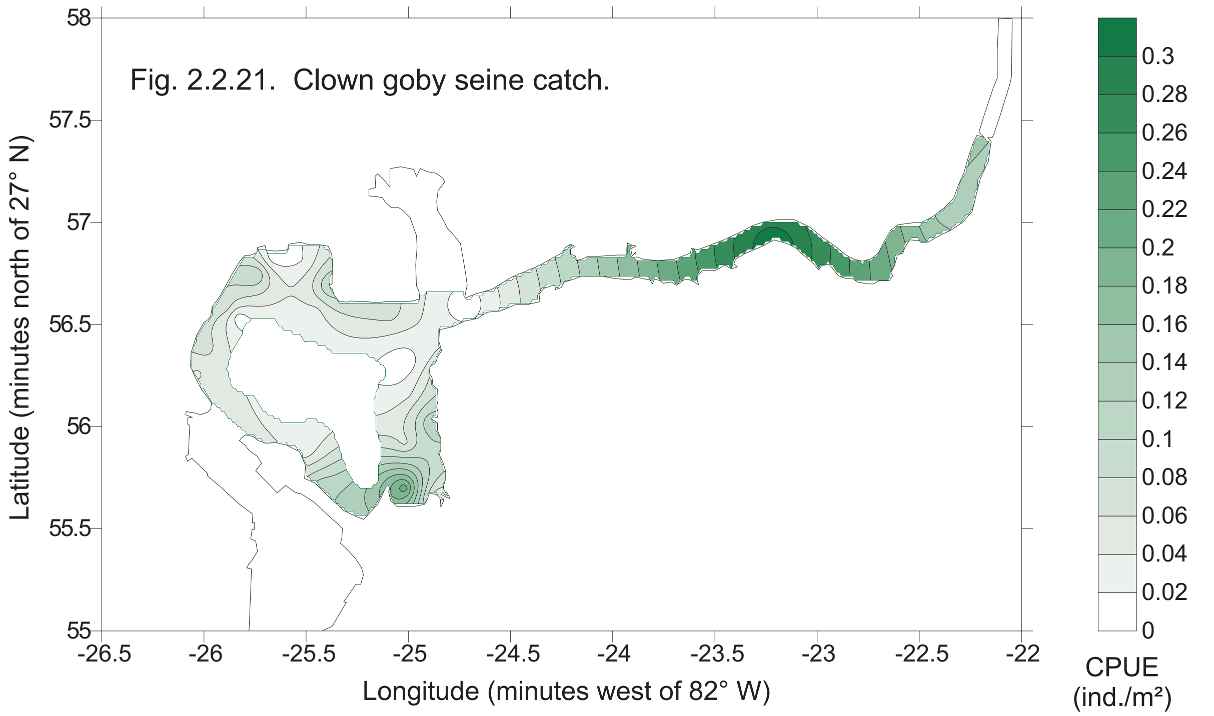


Fig. 2.2.21. Clown goby seine catch.
Latitude (minutes north of 27° N)
Longitude (minutes west of 82° W)
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
CPUE
(ind./m²)

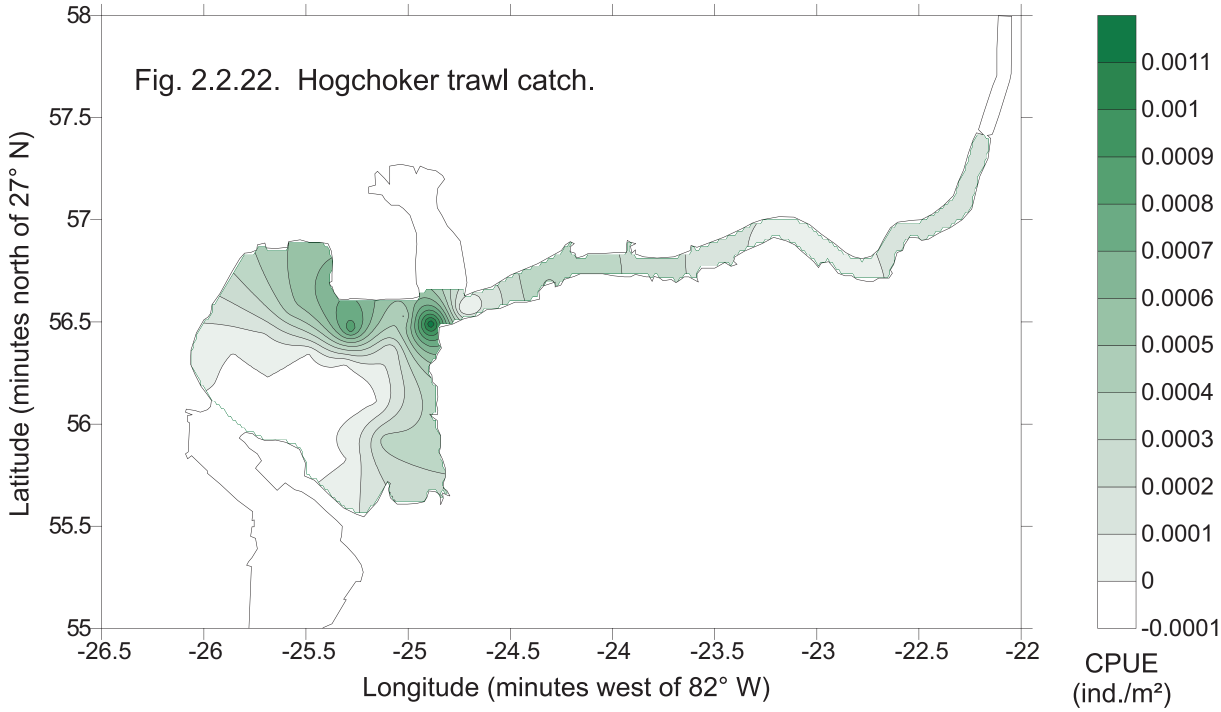


Fig. 2.2.22. Hogchoker trawl catch.

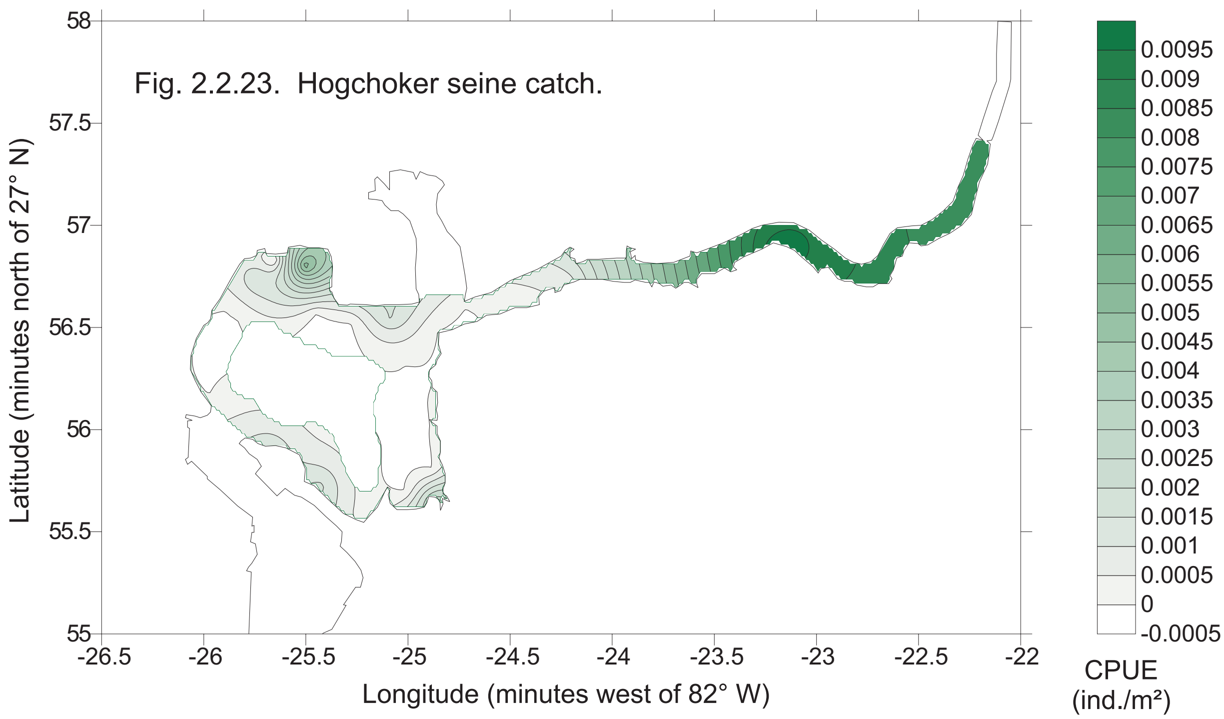


Fig. 2.2.23. Hogchoker seine catch.

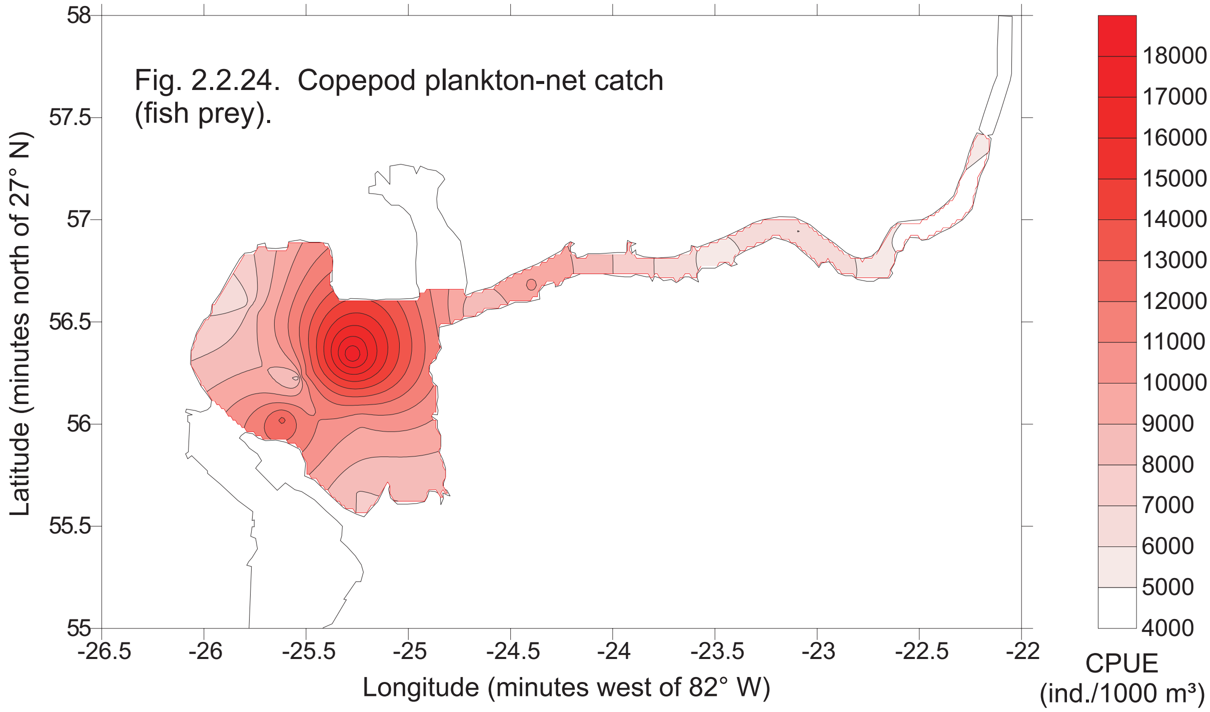


Fig. 2.2.24. Copepod plankton-net catch (fish prey).

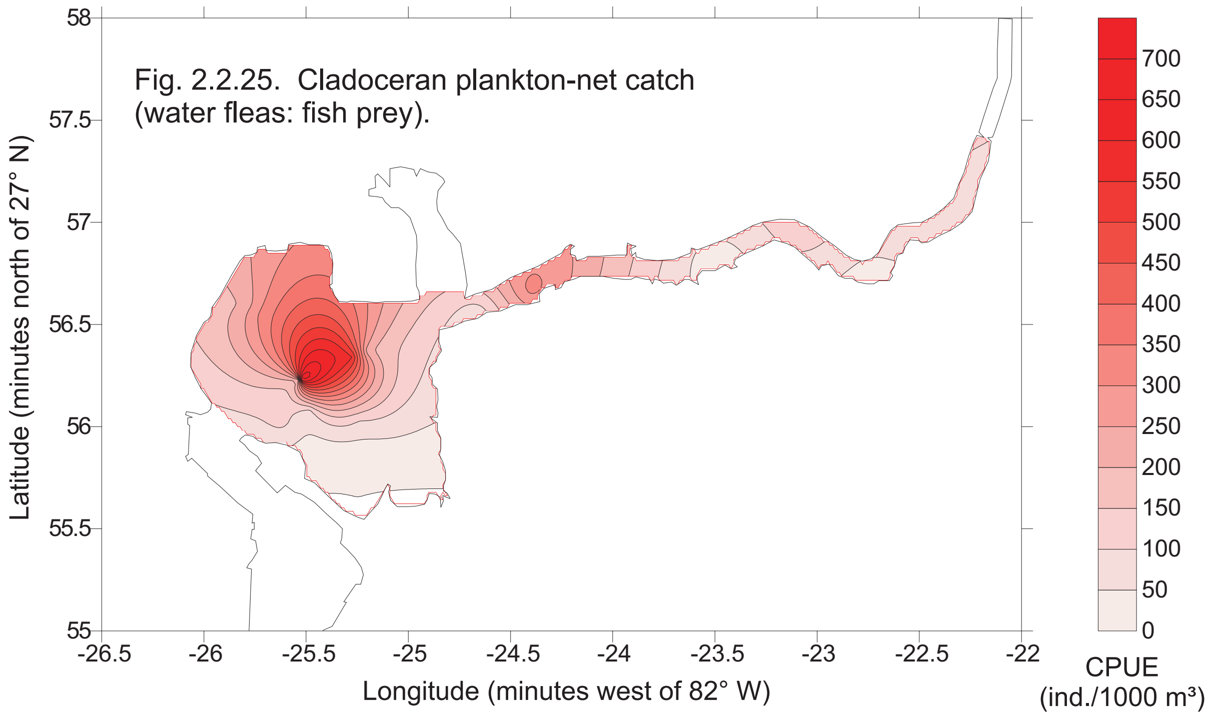


Fig. 2.2.25. Cladoceran plankton-net catch (water fleas: fish prey).

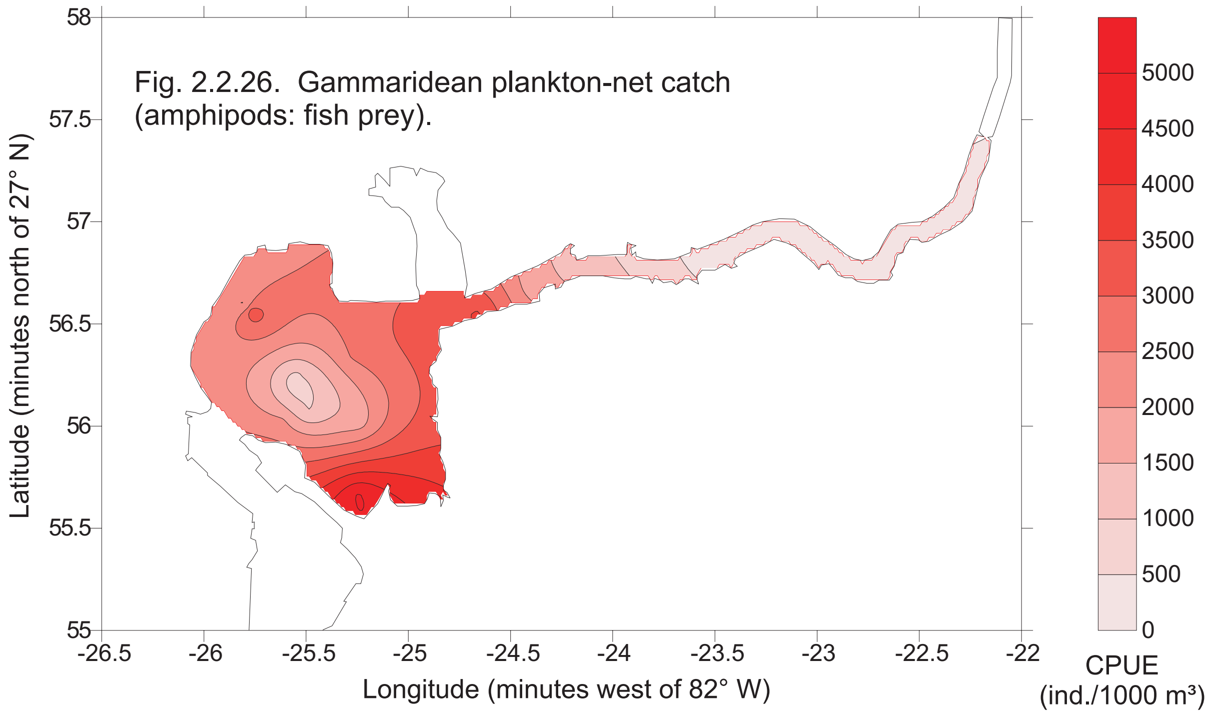


Fig. 2.2.26. Gammaridean plankton-net catch (amphipods: fish prey).

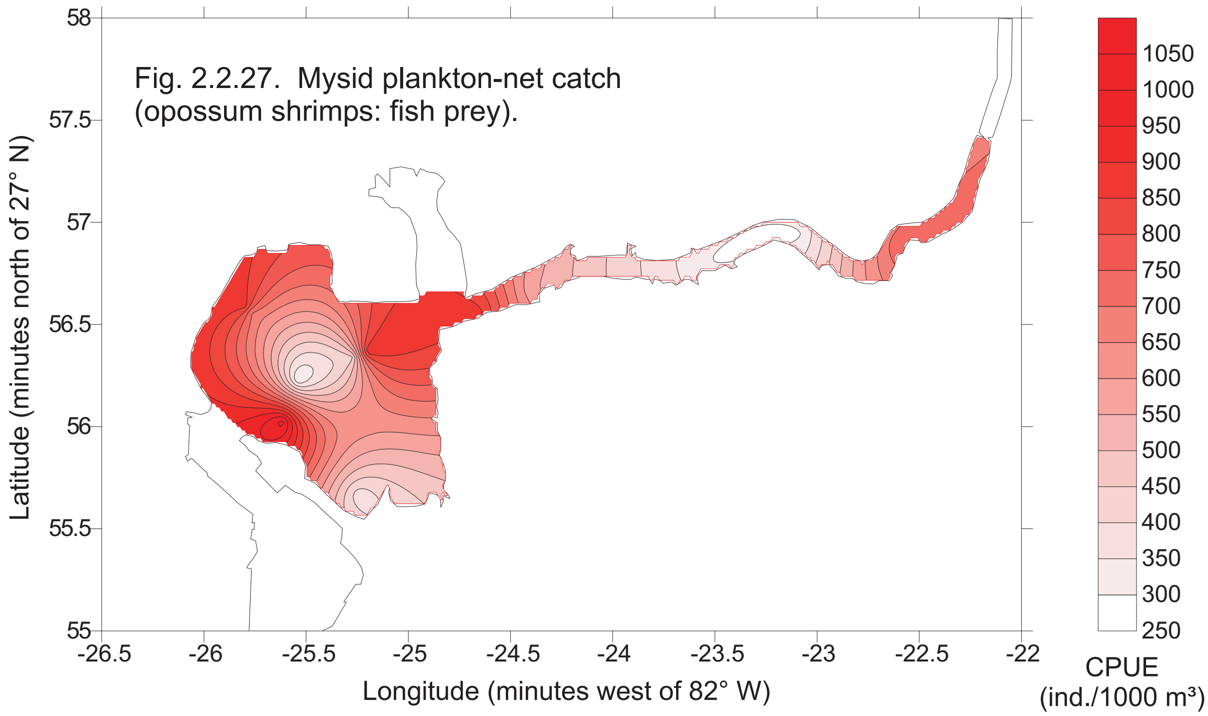


Fig. 2.2.27. Mysid plankton-net catch (opossum shrimps: fish prey).

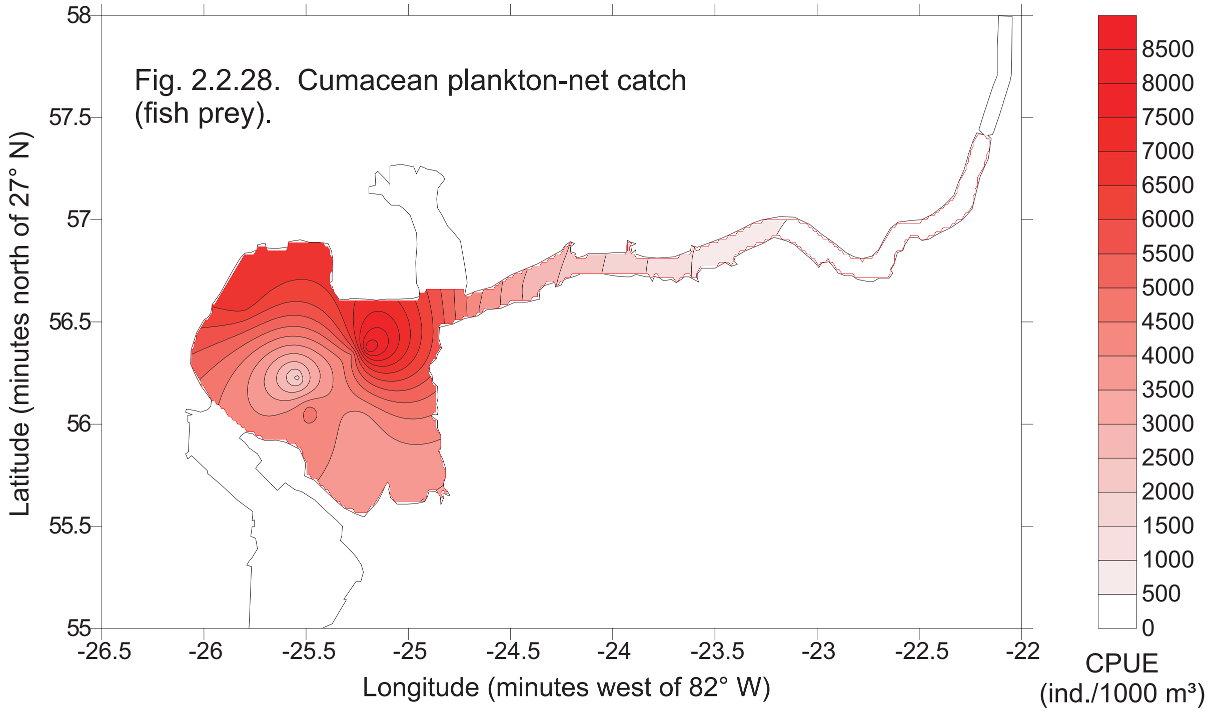


Fig. 2.2.28. Cumacean plankton-net catch
(fish prey).
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Latitude (minutes north of 27° N)
Longitude (minutes west of 82° W)
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
CPUE
(ind./1000 m³)

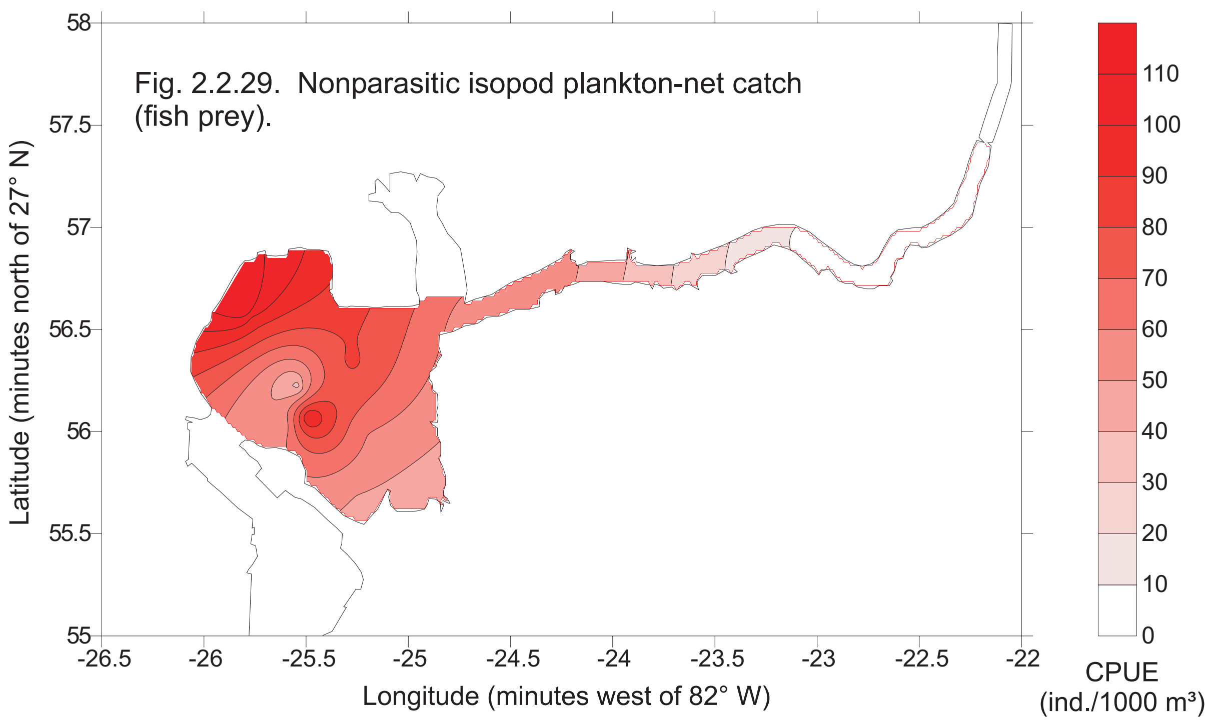


Fig. 2.2.29. Nonparasitic isopod plankton-net catch
(fish prey).
58
57.5
57
56.5
56
55.5
55
-26.5
-26
-25.5
-25
-24.5
-24
-23.5
-23
-22.5
-22
Latitude (minutes north of 27° N)
Longitude (minutes west of 82° W)
110
100
90
80
70
60
50
40
30
20
10
0
CPUE
(ind./1000 m³)

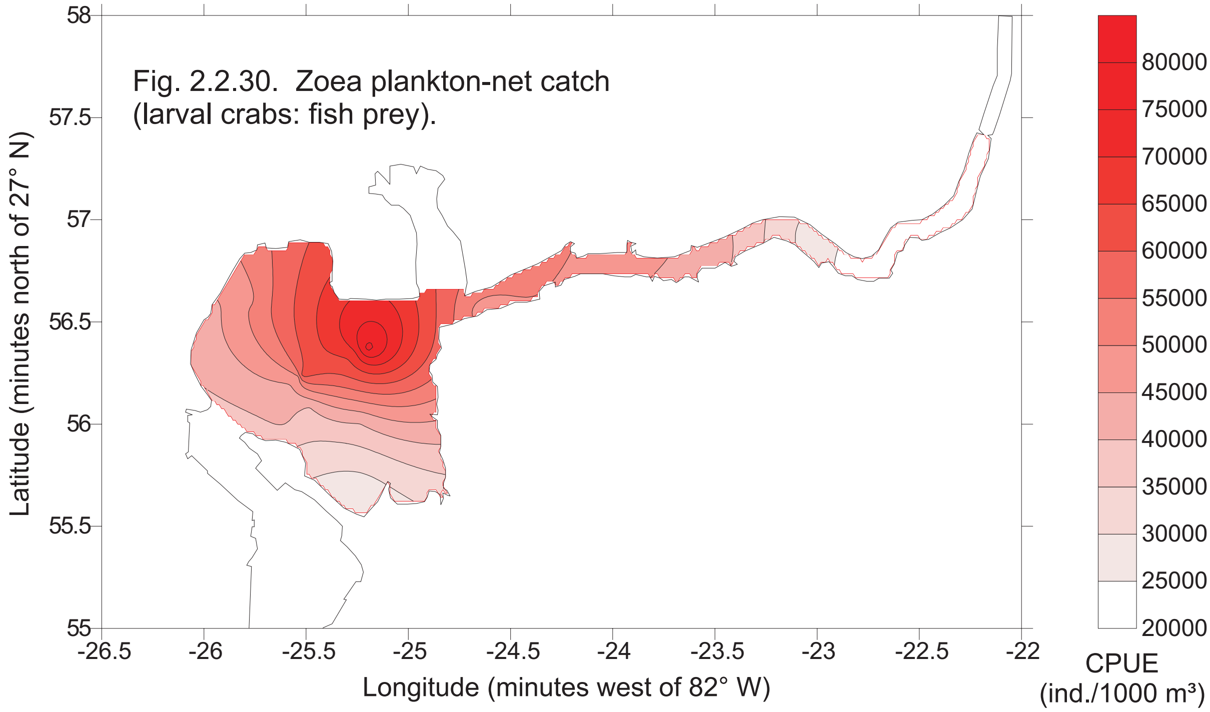


Fig. 2.2.30. Zoea plankton-net catch (larval crabs: fish prey).

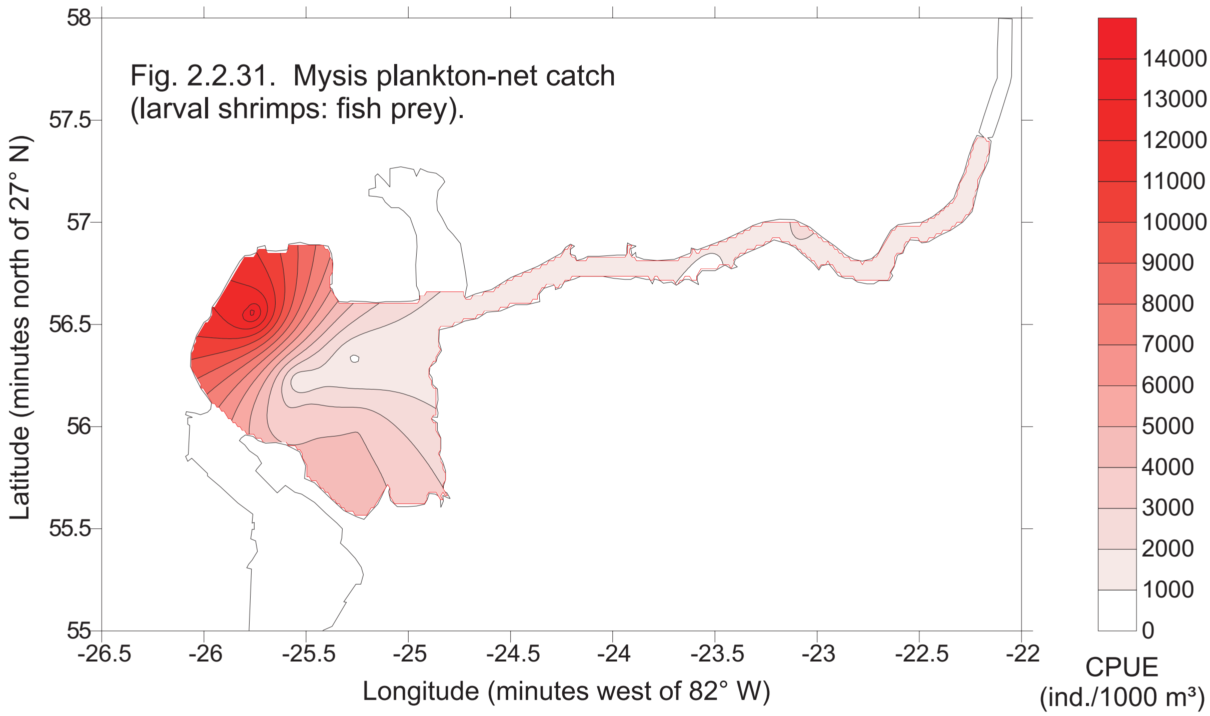


Fig. 2.2.31. Mysis plankton-net catch (larval shrimps: fish prey).

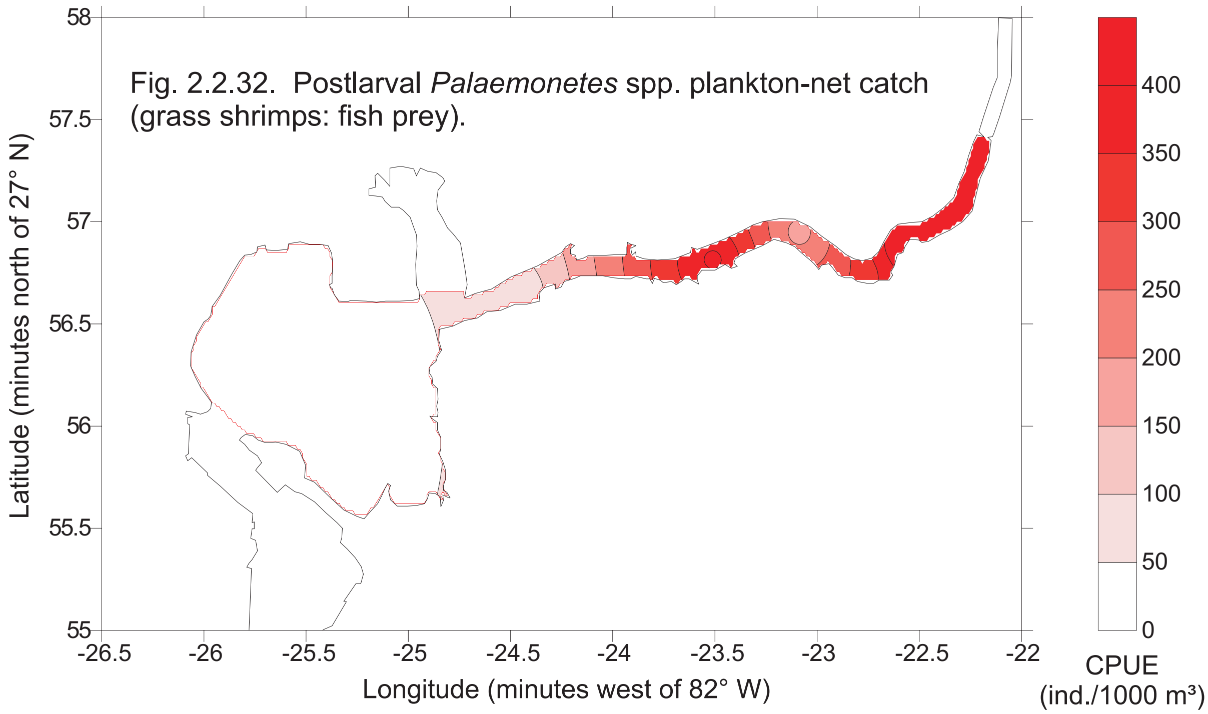


Fig. 2.2.32. Postlarval *Palaemonetes* spp. plankton-net catch (grass shrimps: fish prey).

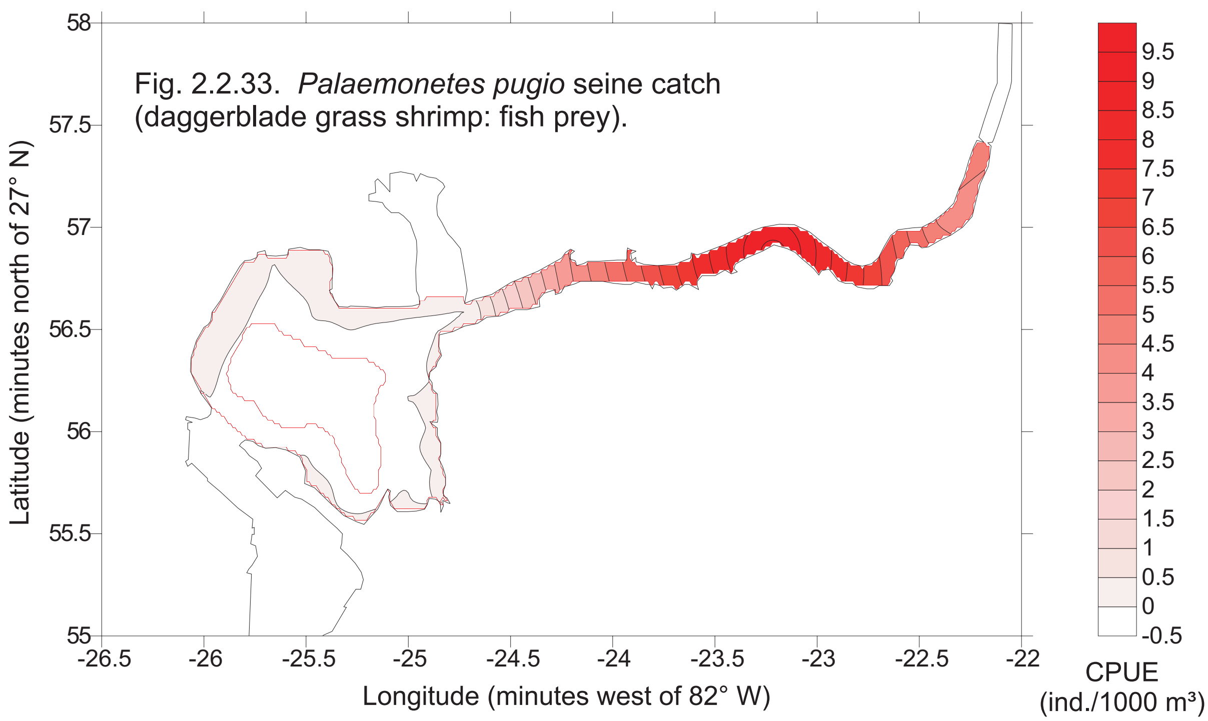


Fig. 2.2.33. *Palaemonetes pugio* seine catch (daggerblade grass shrimp: fish prey).

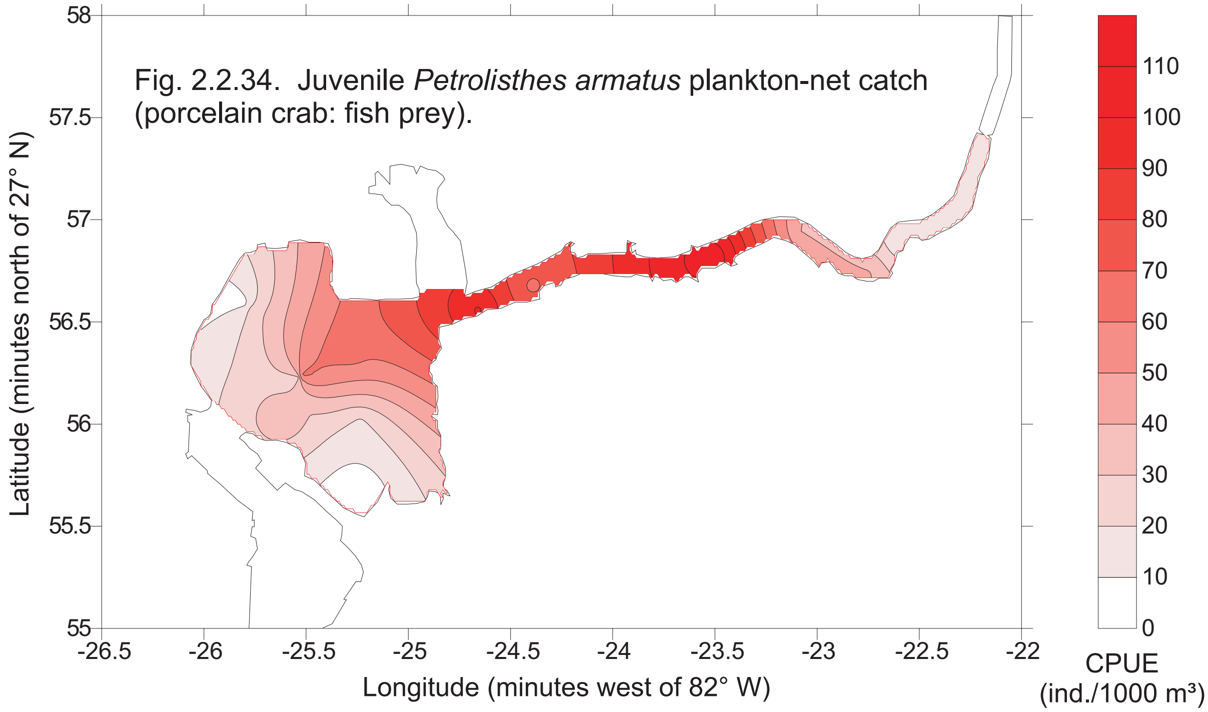


Fig. 2.2.34. Juvenile *Petrolisthes armatus* plankton-net catch (porcelain crab: fish prey).

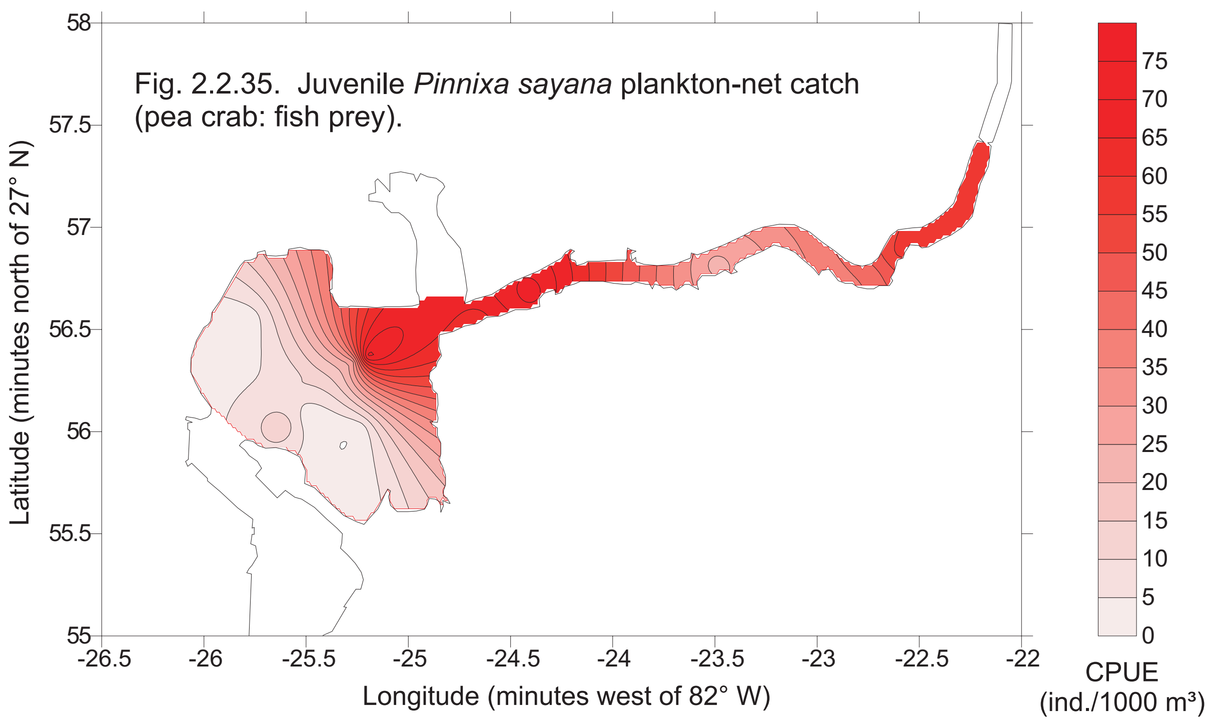


Fig. 2.2.35. Juvenile *Pinnixa sayana* plankton-net catch (pea crab: fish prey).

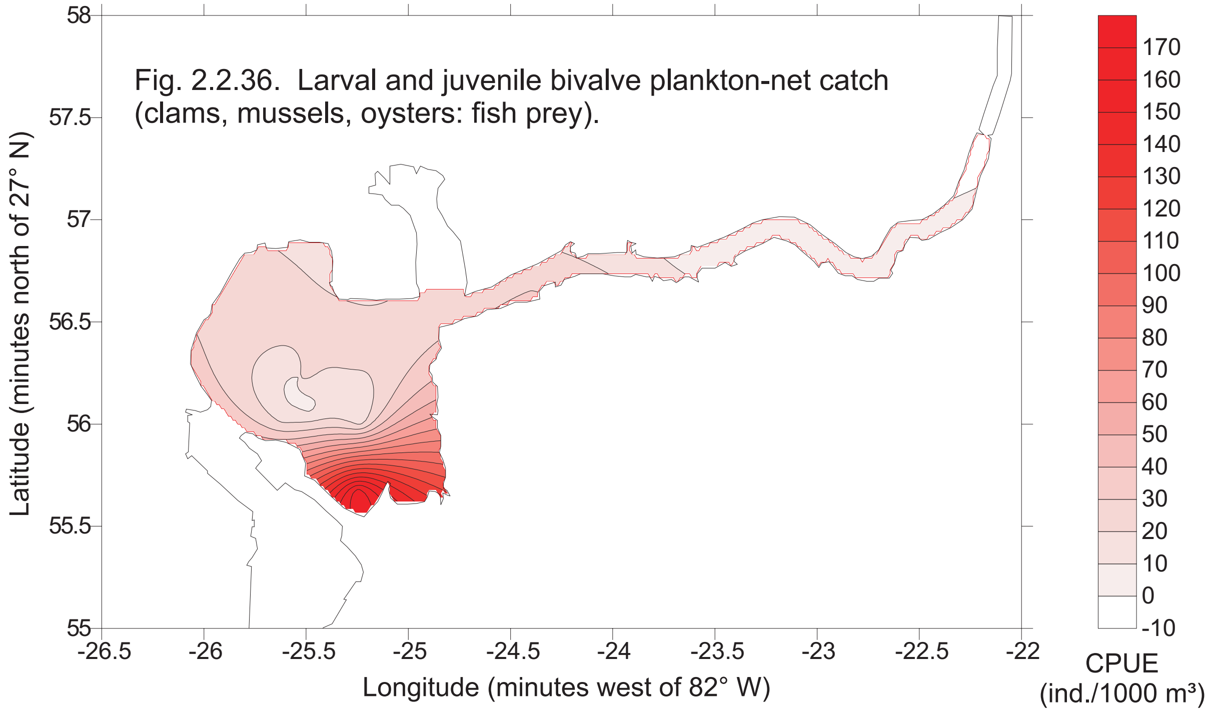


Fig. 2.2.36. Larval and juvenile bivalve plankton-net catch (clams, mussels, oysters: fish prey).

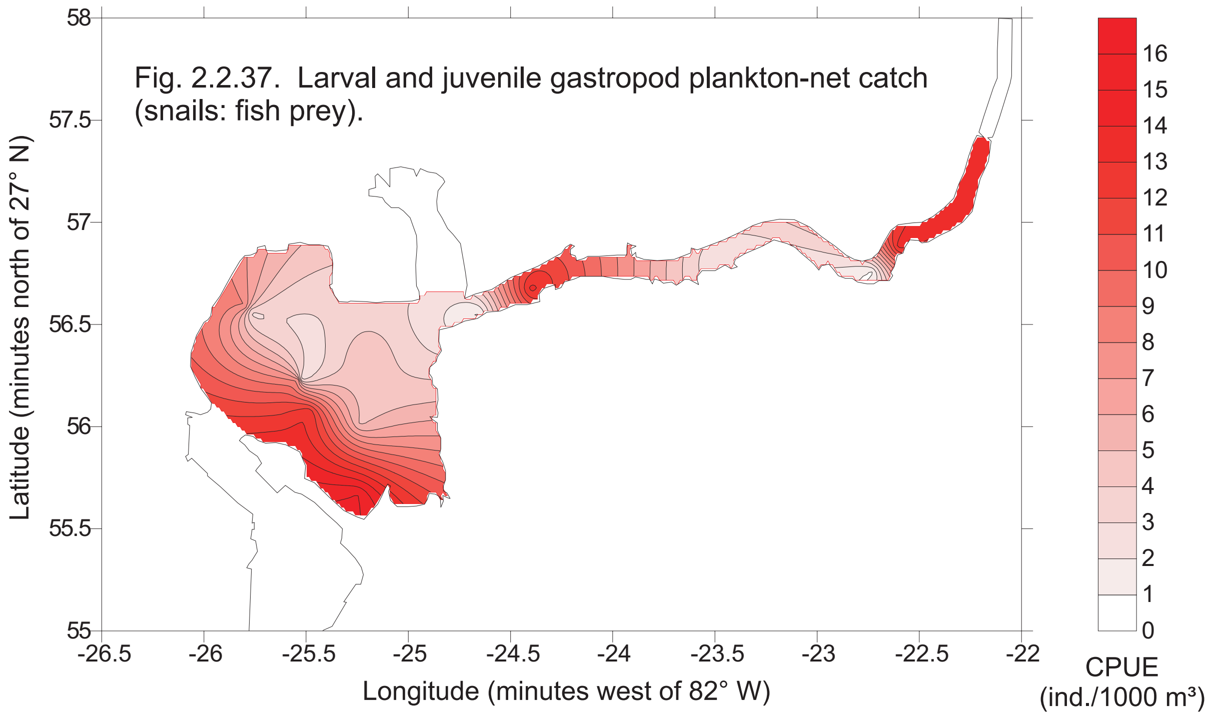


Fig. 2.2.37. Larval and juvenile gastropod plankton-net catch (snails: fish prey).

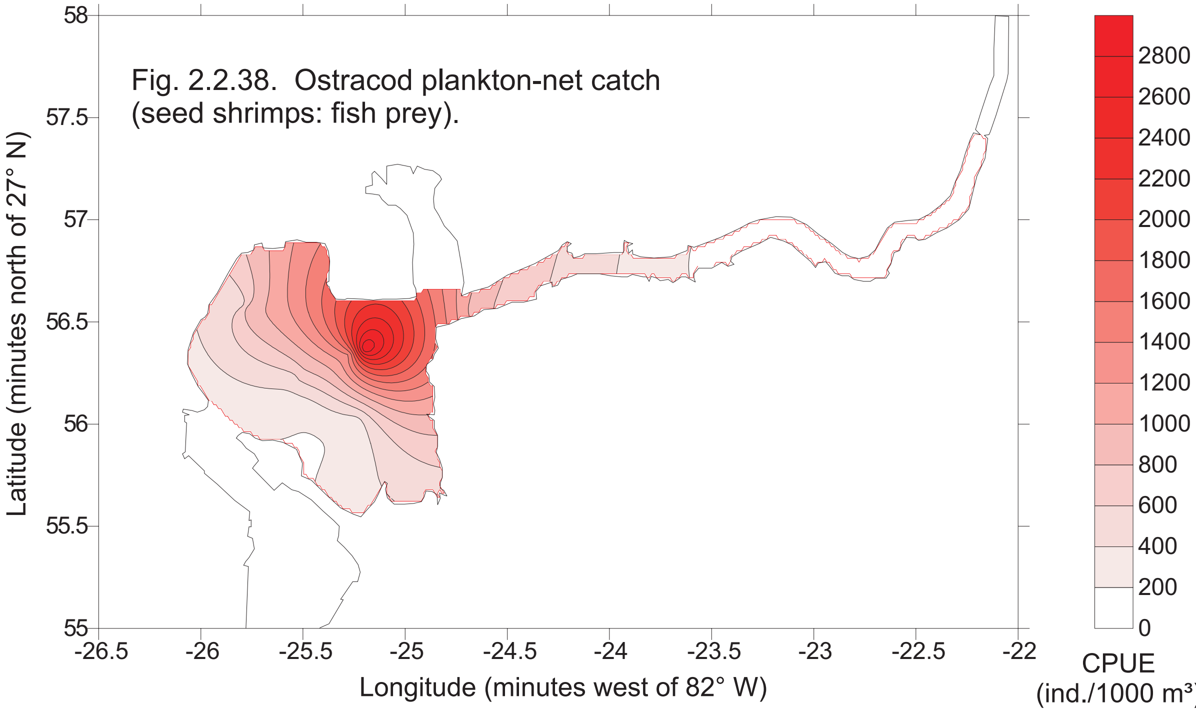


Fig. 2.2.38. Ostracod plankton-net catch (seed shrimps: fish prey).

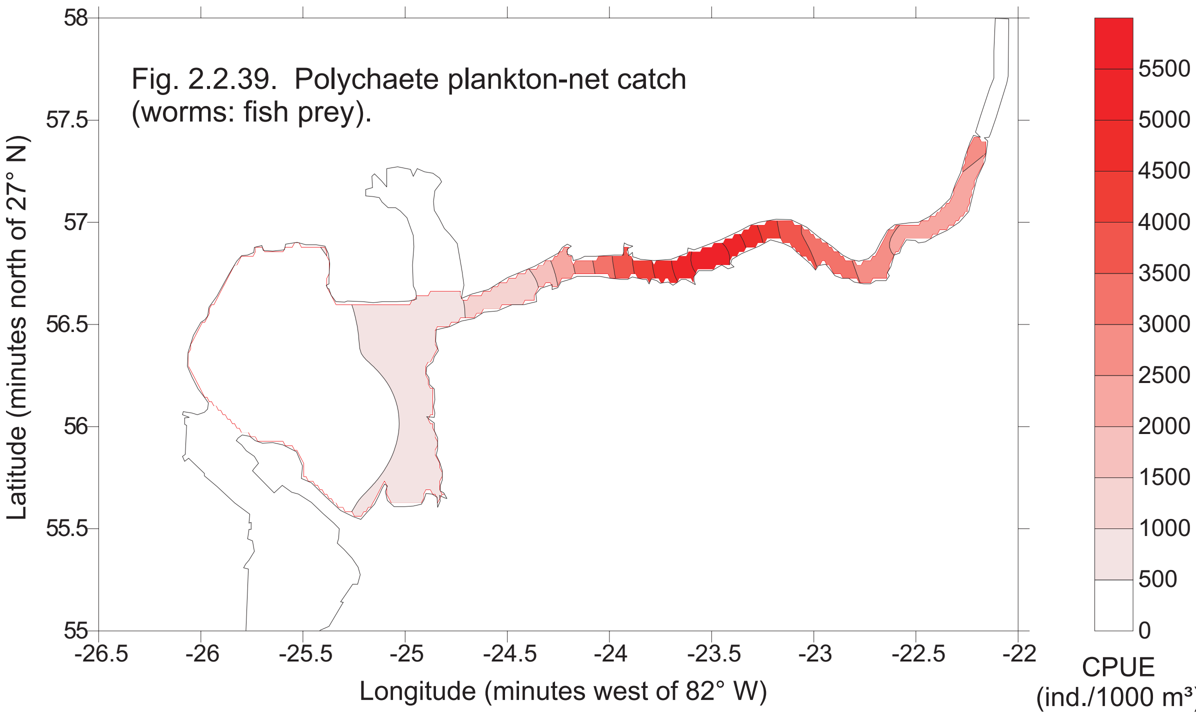


Fig. 2.2.39. Polychaete plankton-net catch (worms: fish prey).

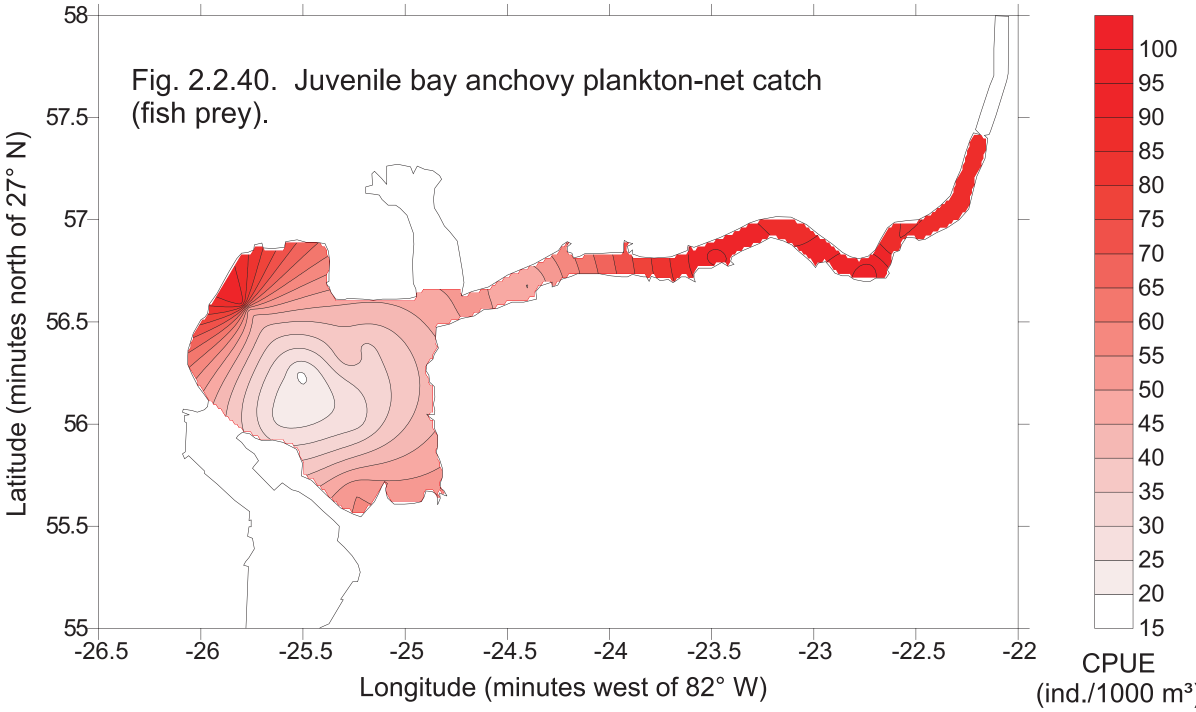


Fig. 2.2.40. Juvenile bay anchovy plankton-net catch (fish prey).

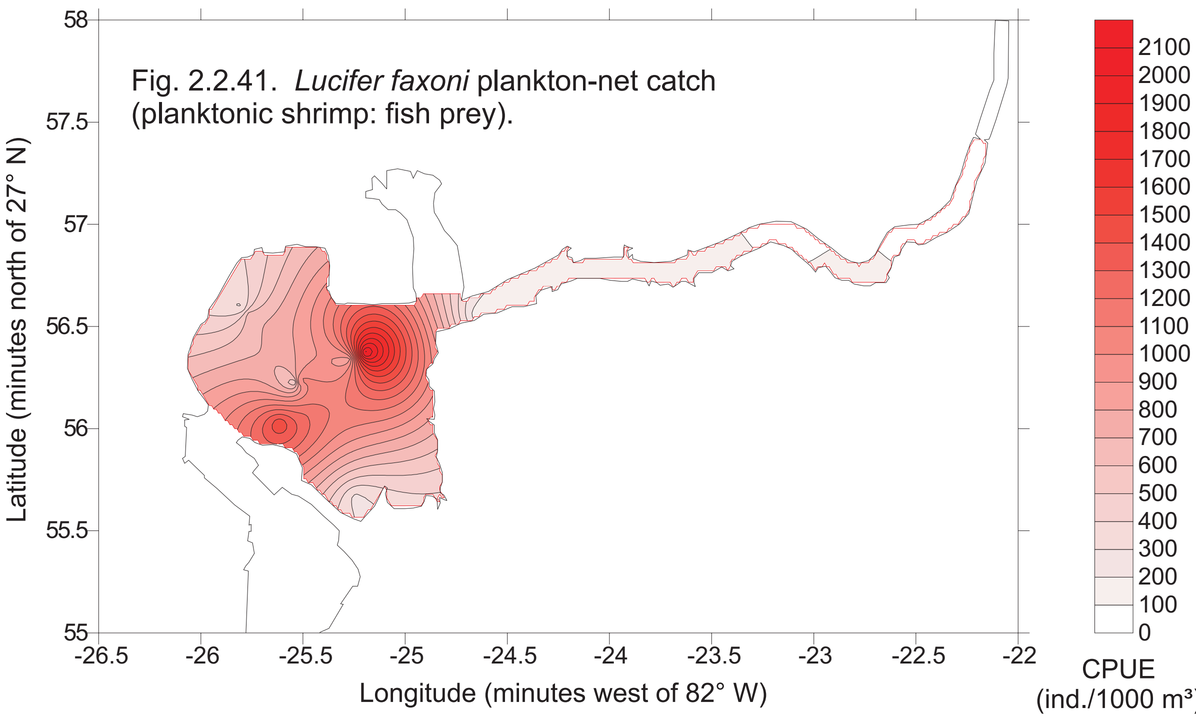


Fig. 2.2.41. *Lucifer faxoni* plankton-net catch (planktonic shrimp: fish prey).

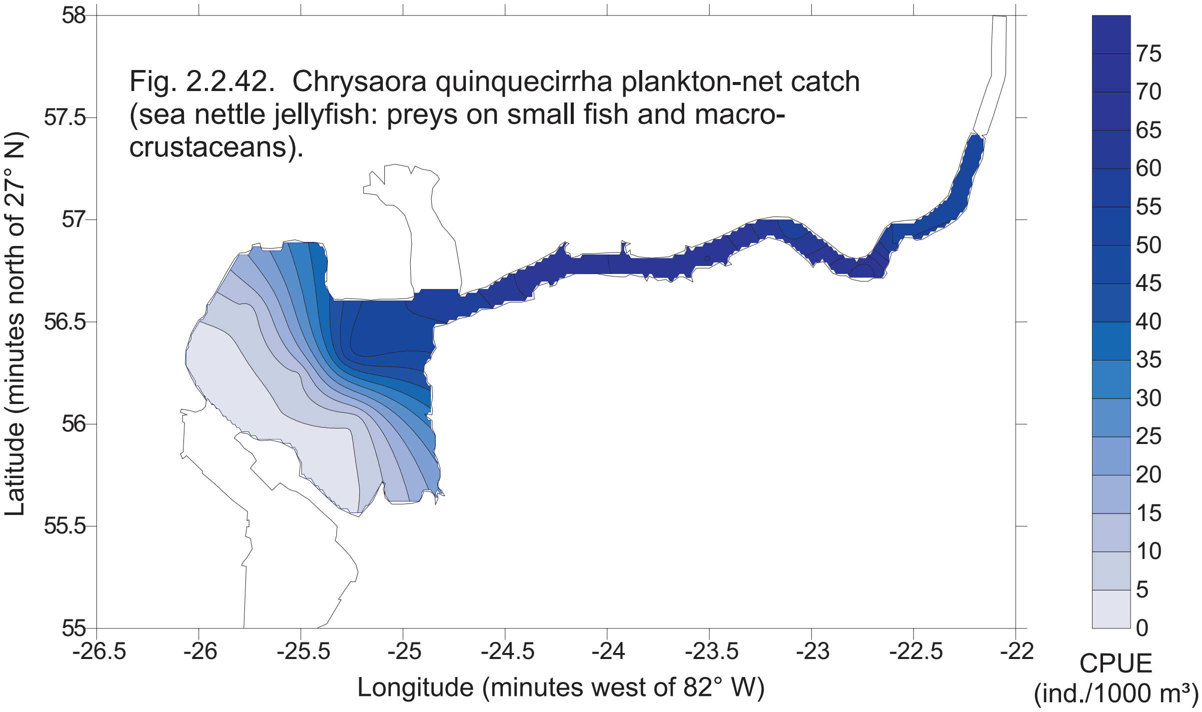


Fig. 2.2.42. Chrysaora quinquecirrha plankton-net catch (sea nettle jellyfish: preys on small fish and macro-crustaceans).

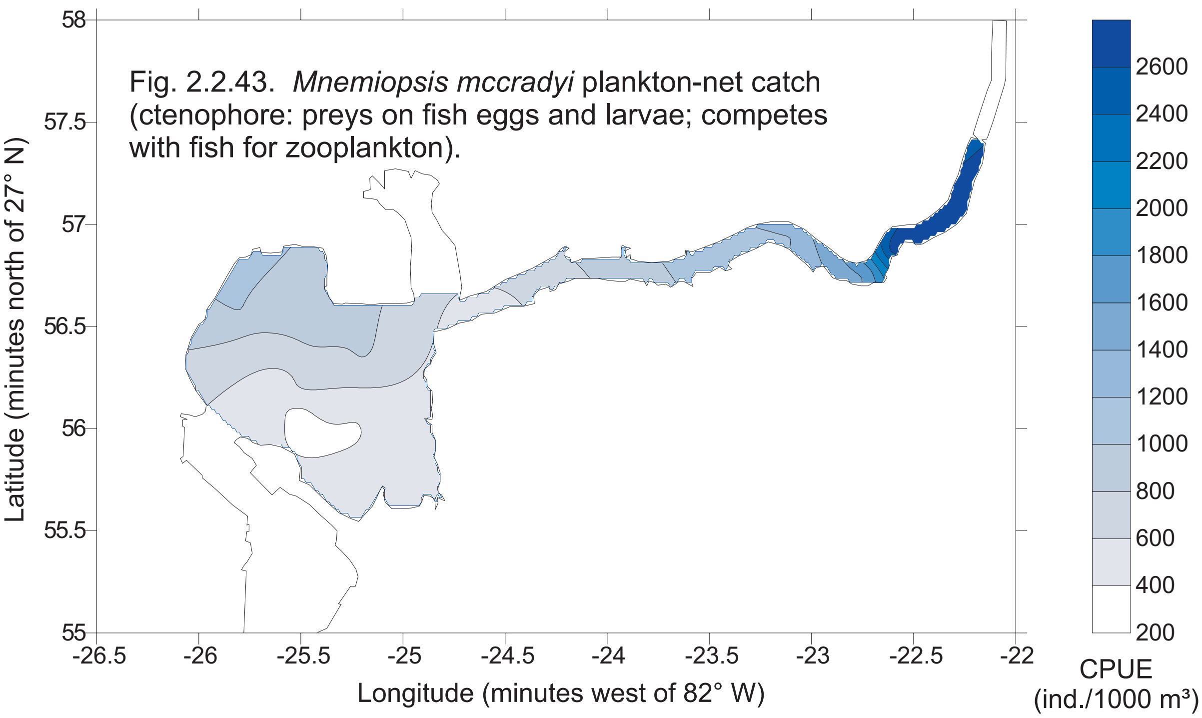


Fig. 2.2.43. *Mnemiopsis mccradyi* plankton-net catch (ctenophore: preys on fish eggs and larvae; competes with fish for zooplankton).

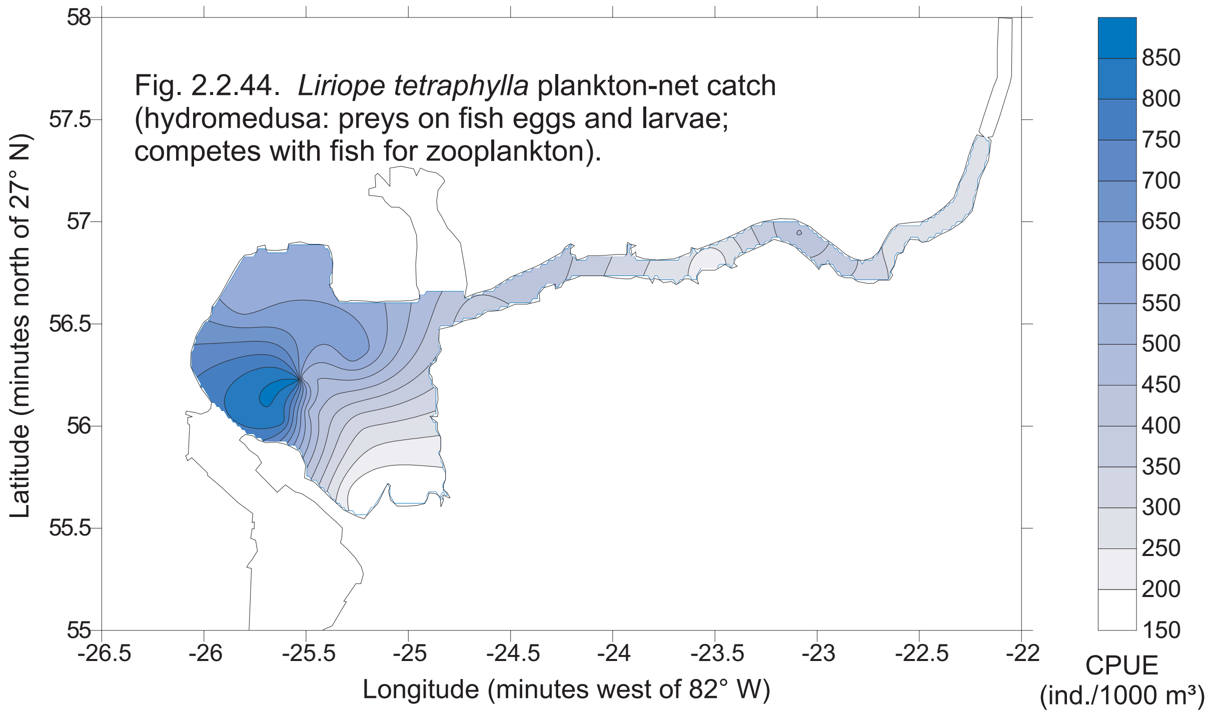


Fig. 2.2.44. *Liriope tetraphylla* plankton-net catch (hydromedusa: preys on fish eggs and larvae; competes with fish for zooplankton).

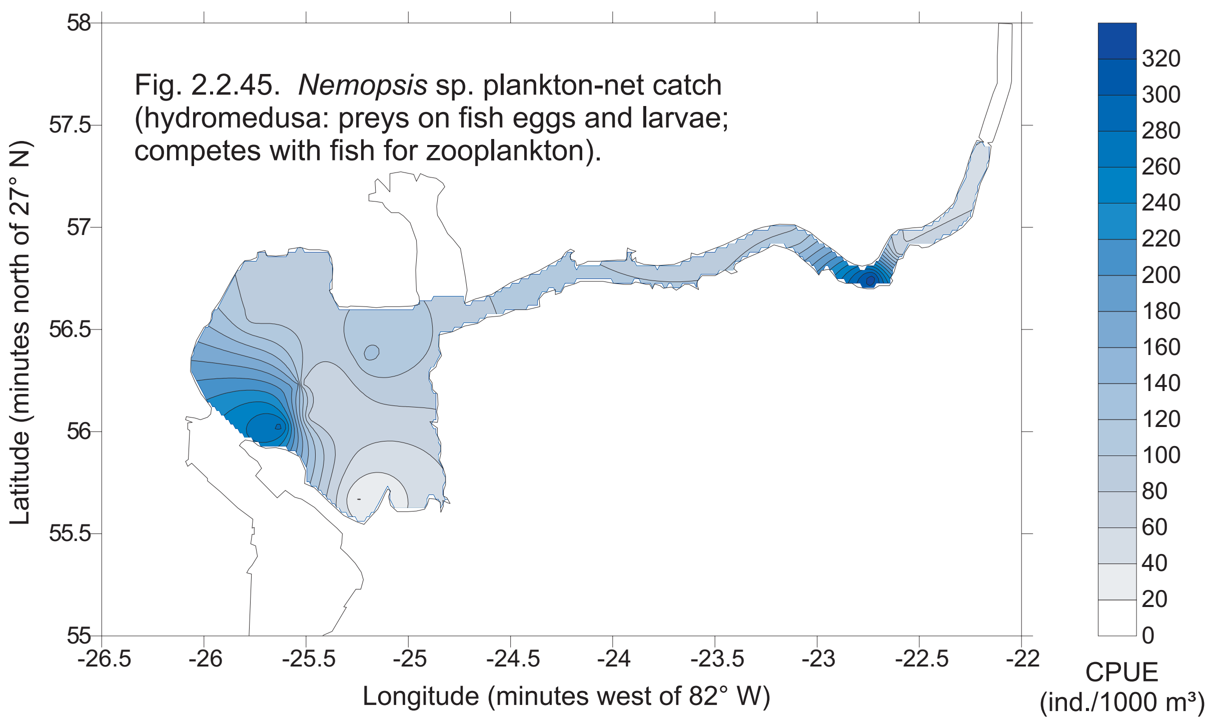


Fig. 2.2.45. *Nemopsis* sp. plankton-net catch (hydromedusa: preys on fish eggs and larvae; competes with fish for zooplankton).

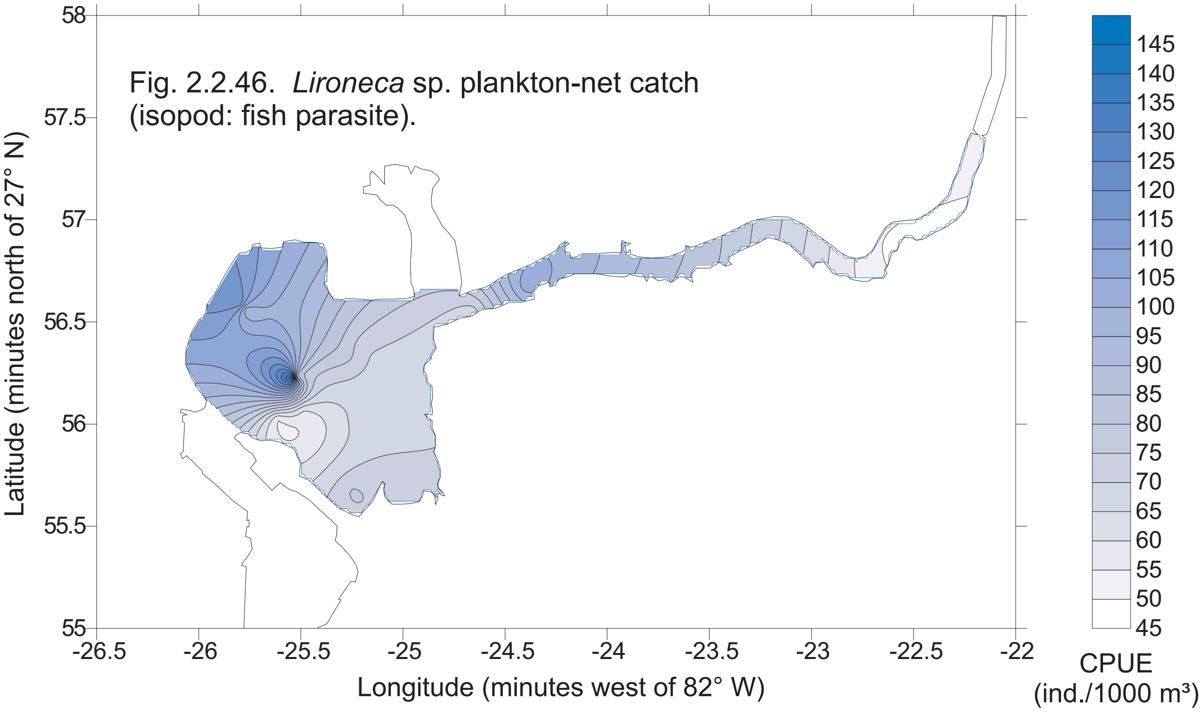


Fig. 2.2.46. *Lironeca* sp. plankton-net catch (isopod: fish parasite).

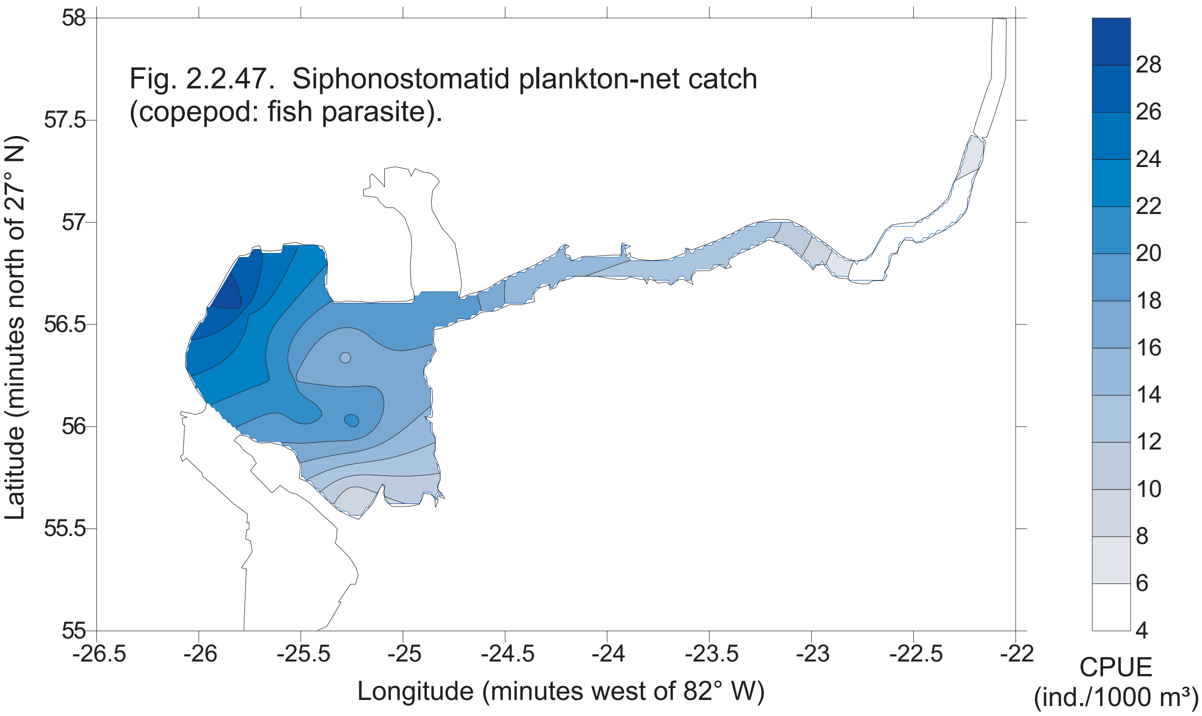


Fig. 2.2.47. Siphonostomatid plankton-net catch (copepod: fish parasite).

2.3 Community Structure: Change by Season

2.3.1 **Methods.** Community structure was investigated by comparing Bray-Curtis similarity of catch composition among factors that represent seasons (months), years and locations along the estuarine gradient (factor effects). Bray-Curtis similarity was calculated from square-root transformed CPUE for each gear type, and was plotted using a method that depicts the relative dissimilarities among samples as linear distances on a two-dimensional plot (non-metric multidimensional scaling, or MDS). As the name implies, the axes in non-metric MDS plots are unitless, and the location of each sample does not relate to the axes. Sample location on an MDS plot is relevant only to the locations of other samples. A stress coefficient is calculated to indicate the quality of the two-dimensional representation of relative dissimilarity, with lower values indicating better representation. Stress coefficients between 0.10 an 0.20 indicate that general trends are depicted reliably on the MDS plot, but smaller details should not be relied upon (Clarke and Warwick 2001).

When a general trend in a factor effect was depicted in MDS plots, the factor effect was tested for statistical significance using the one-way ANOSIM procedure in PRIMER 5 (Plymouth Routines in Multivariate Ecological Research). ANOSIM (Clarke and Green 1988) is analogous to ANOVA. Ranked similarities within replicates are compared with ranked similarities across a factor (season, year, location) to generate a global test statistic, *R*, which ranges between 0 and 1. Values near 1 indicate that replicates are more similar to each other than they are to replicates within other factor classes. *R* is also generated for pairwise comparisons between factor classes. Significance is calculated by determining the likelihood of obtaining an *R* value equal to or larger than the one observed. Such probabilities are acquired by repeatedly and randomly reassigning factor classes to the catch data, each time recalculating *R*, until the sample size is large enough to create a random-factor frequency distribution for *R* (for computational efficiency, the number of randomized permutations was limited to 999). The ratio of the number of equal or higher values of *R* to the total number in the frequency distribution is the probability that the original value of *R* is different from zero. In other words, if random factor reclassification creates an equal or larger *R* value only

2% of the time, then there is a 98% chance that *R* is greater than zero. As with ANOVA, the significance of *R* increases with the number of replicates within each factor class. Therefore, provided *R* is significantly different from zero (p<0.05), its absolute value is much more informative than its probability level (Clarke and Warwick 2001).

The results of these nonparametric, multivariate methods are dependent on the type of mathematical transformation that is applied to the catch data prior to analysis. Four groups were considered in the multivariated analyses: seine catch, trawl catch, invertebrate plankton catch and ichthyoplankton catch. For each of these four groups, log-log regressions of CPUE standard deviation against average CPUE produced slopes that ranged from 0.86 to 0.95 (r^2 range: 0.93-0.99) and had an average of 0.91. This value indicates that log transformation would most successfully standardize the CPUE variances for the four groups. Variance standardization is relevant to any parametric statistics that may be calculated from these data, but it is not relevant to the nonparametric methods that were applied at the community level. Moreover, because log transformation would also give each species nearly equal influence on apparent community structure, it was not considered desirable. The default square-root transformation offered by PRIMER 5 was used. It provides a compromise between de-emphasizing abundant species and overwhelming the influence of species with midrange abundance. All community-level results, therefore, should be interpreted with awareness that they reflect square-root transformation. The irregularity of the taxonomic aggregation used in the invertebrate plankton analyses is not ideal (many animals are represented at the species level, whereas others are aggregated), but the original taxonomic structure was kept in order to maintain the maximum amount of information available for making community-level distinctions.

In comparisons among months, each month was represented by replicates in the form of observations made during the same month of different years, with each year's observation being the aggregated month's samples divided by the month's collection effort. Collection effort was either swept area (seine and trawl) or volume filtered (plankton net). All months had six replicates from different years, except for April seine and trawl collections, which had five (FWRI started their portion of the HBMP in May 2000).

2.3.2 **Results and Discussion.**

2.3.2.1 Seine Catch: Change by Season

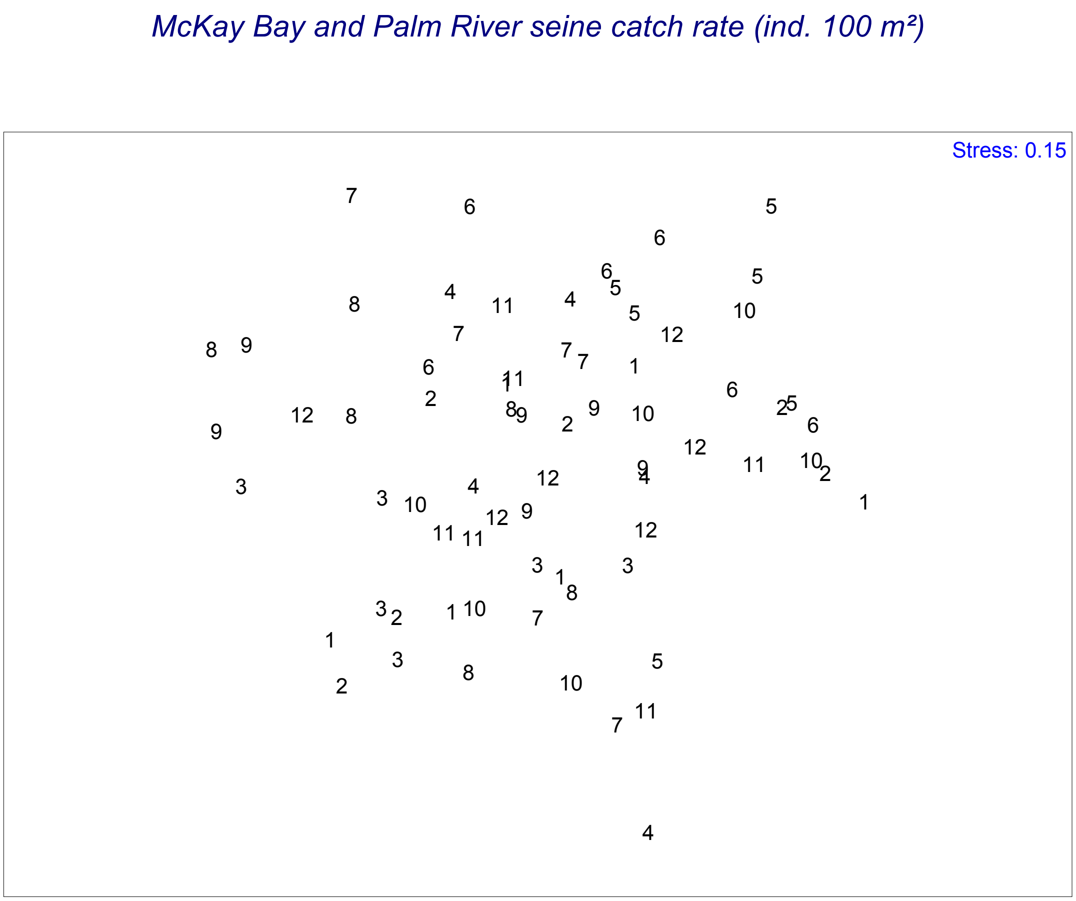


Fig. 2.3.2.1. Similarity among monthly seine samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to month.

The seine catch had the least amount of seasonality of the four gear types (ANOSIM global R=0.12, p=0.002). This relative lack of responsiveness is shared by the trawl catch because the fish and invertebrates collected by these two gears are vulnerable to collection for many months after they settle from the plankton. This contrasts with the stronger seasonality observed in the ichthyoplankton community, which more closely corresponds with the adult spawning season. There were 13 significant pairwise monthly dissimilarities in the seine data out of a possible 66 (Table

2.3.2.1).

2.3.2.2 Trawl Catch: Change by Season

McKay Bay and Palm River trawl catch rate (ind./100 m²)

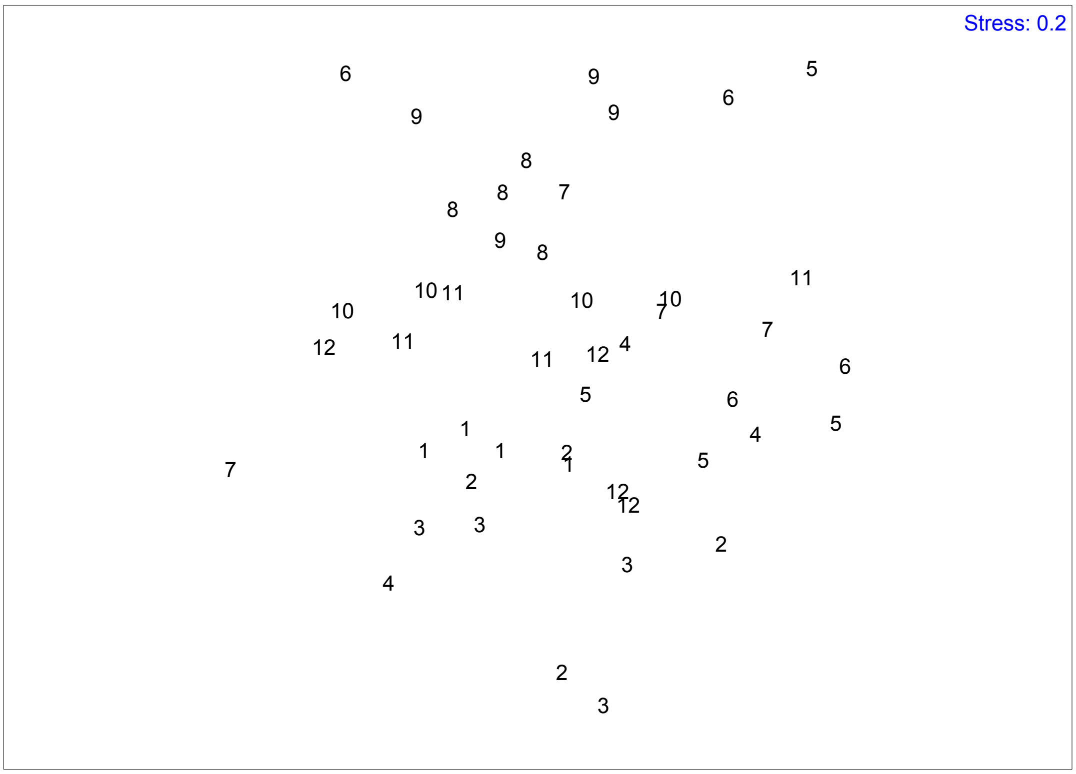


Fig. 2.3.2.2. Similarity among monthly trawl samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to month.

Seasonal variation in trawl catch is apparent in Fig. 2.3.2.2 (ANOSIM global R=0.26, p=0.001). There were 24 significant pairwise monthly dissimilarities in the trawl data out of a possible 66 (Table 2.3.2.1).

2.3.2.3 Plankton-net Fish Catch: Change by Season

McKay Bay and Palm River ichthyoplankton catch (ind./1000 m³)

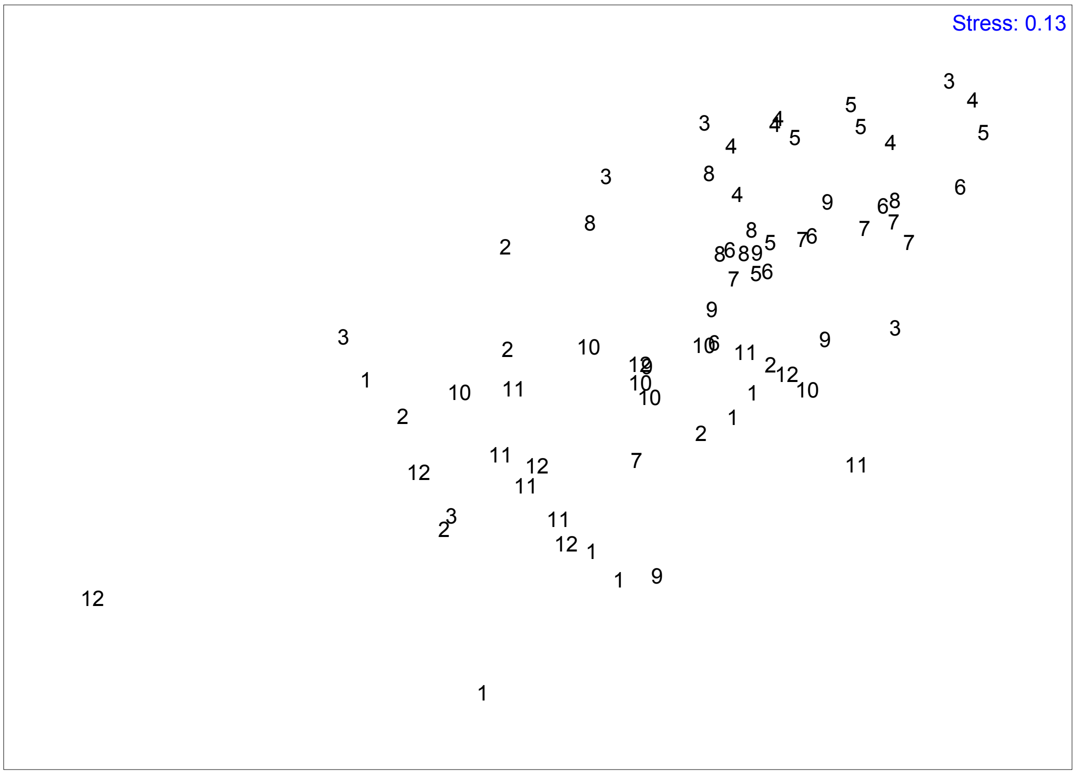


Fig. 2.3.2.3. Similarity among monthly ichthyoplankton samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to month.

Seasonal variation in the ichthyoplankton catch was the largest observed (ANOSIM global R=0.32, p=0.001), yet there was nevertheless substantial compositional overlap among adjacent months. There were 40 significant pairwise monthly dissimilarities in the ichthyoplankton data out of a possible 66 (Table 2.3.2.1).

2.3.2.4 Plankton-net Invertebrate Catch: Change by Season

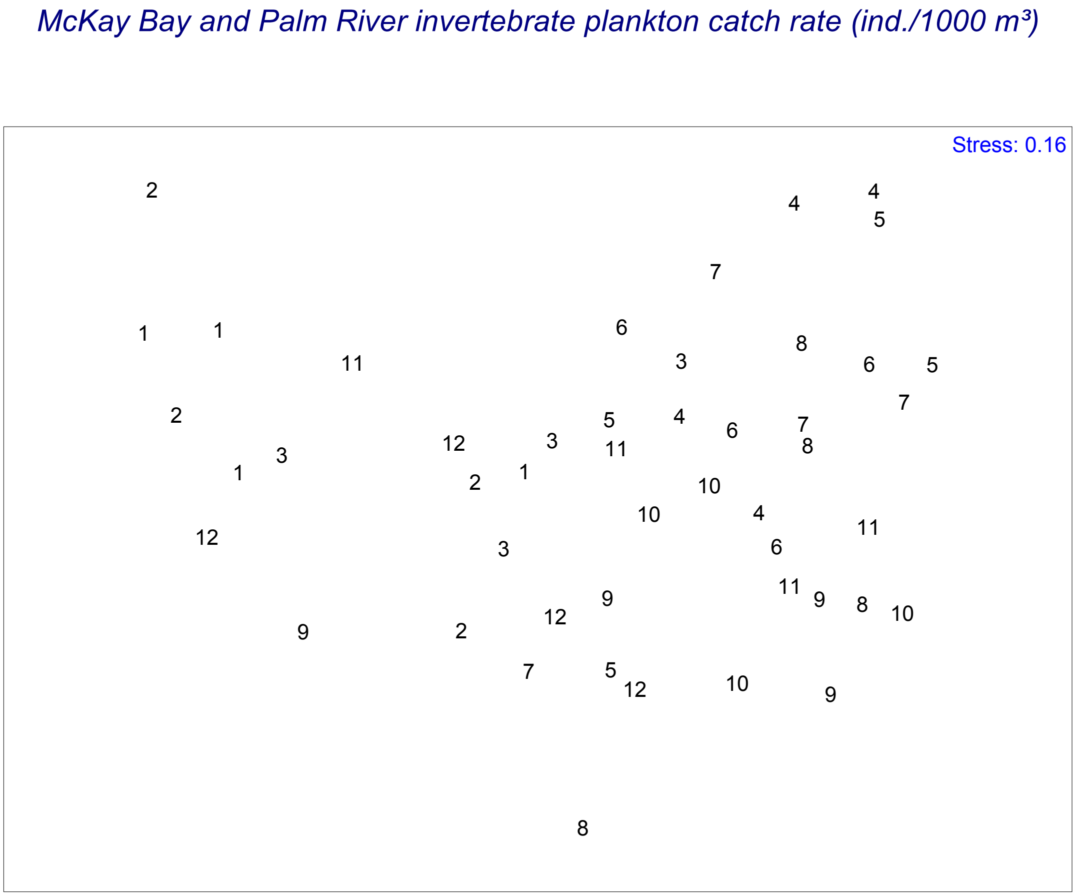


Fig. 2.3.2.4. Similarity among monthly ichthyoplankton samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to month.

Seasonal variation in the invertebrate plankton catch was evident, but low (ANOSIM global R=0.27, p=0.002). Many of the non-larval forms of plankton are present year-round, although numbers tend to decrease during winter. There were 21 significant pairwise monthly dissimilarities in the invertebrate plankton catch out of a possible 66 (Table 2.3.2.1).

Table 2.3.2.1 (page 1 of 3). Significant ($p<0.05$) community dissimilarity apparent from pairwise monthly ANOSIM comparisons.

Catch type	Compared months	R statistic	Probability	Possible permutations	Actual permutations	Number > or = observed R
seine	10, 3	0.31	0.024	462	462	11
seine	11, 5	0.39	0.024	462	462	11
seine	12, 3	0.26	0.041	462	462	19
seine	12, 5	0.25	0.037	462	462	17
seine	1, 5	0.28	0.041	462	462	19
seine	2, 8	0.23	0.045	462	462	21
seine	3, 5	0.75	0.002	462	462	1
seine	3, 6	0.73	0.002	462	462	1
seine	3, 7	0.28	0.032	462	462	15
seine	4, 5	0.28	0.032	462	462	15
seine	5, 8	0.58	0.004	462	462	2
seine	5, 9	0.32	0.009	462	462	4
seine	6, 8	0.37	0.013	462	462	6
trawl	5, 8	0.51	0.029	35	35	1
trawl	5, 9	0.67	0.029	35	35	1
trawl	5, 1	0.47	0.029	35	35	1
trawl	5, 3	0.35	0.029	35	35	1
trawl	6, 1	0.41	0.029	35	35	1
trawl	6, 2	0.33	0.029	35	35	1
trawl	6, 3	0.33	0.029	35	35	1
trawl	8, 10	0.41	0.029	35	35	1
trawl	8, 11	0.43	0.029	35	35	1
trawl	8, 12	0.66	0.029	35	35	1
trawl	8, 1	0.98	0.029	35	35	1
trawl	8, 2	0.77	0.029	35	35	1
trawl	8, 3	0.81	0.029	35	35	1
trawl	8, 4	0.59	0.029	35	35	1
trawl	9, 12	0.65	0.029	35	35	1
trawl	9, 1	0.81	0.029	35	35	1
trawl	9, 2	0.88	0.029	35	35	1
trawl	9, 3	0.93	0.029	35	35	1
trawl	9, 4	0.65	0.029	35	35	1
trawl	10, 1	0.55	0.029	35	35	1
trawl	10, 2	0.48	0.029	35	35	1
trawl	10, 3	0.53	0.029	35	35	1
trawl	11, 3	0.37	0.029	35	35	1
trawl	1, 4	0.56	0.029	35	35	1
ichthyoplankton	10, 1	0.19	0.032	462	462	15
ichthyoplankton	10, 3	0.30	0.011	462	462	5
ichthyoplankton	10, 4	0.88	0.002	462	462	1
ichthyoplankton	10, 5	0.72	0.002	462	462	1
ichthyoplankton	10, 6	0.42	0.009	462	462	4
ichthyoplankton	10, 7	0.46	0.013	462	462	6
ichthyoplankton	10, 8	0.59	0.002	462	462	1
ichthyoplankton	11, 4	0.84	0.002	462	462	1

Table 2.3.2.1 (page 2 of 3). Significant ($p<0.05$) community dissimilarity apparent from pairwise monthly ANOSIM comparisons.

Catch type	Compared months	R statistic	Probability	Possible permutations	Actual permutations	Number > or = observed R
ichthyoplankton	11, 5	0.77	0.002	462	462	1
ichthyoplankton	11, 6	0.63	0.004	462	462	2
ichthyoplankton	11, 7	0.49	0.011	462	462	5
ichthyoplankton	11, 8	0.65	0.002	462	462	1
ichthyoplankton	11, 9	0.32	0.037	462	462	17
ichthyoplankton	12, 4	0.72	0.002	462	462	1
ichthyoplankton	12, 5	0.66	0.002	462	462	1
ichthyoplankton	12, 6	0.55	0.002	462	462	1
ichthyoplankton	12, 7	0.42	0.013	462	462	6
ichthyoplankton	12, 8	0.45	0.004	462	462	2
ichthyoplankton	12, 9	0.22	0.037	462	462	17
ichthyoplankton	1, 4	0.77	0.002	462	462	1
ichthyoplankton	1, 5	0.75	0.002	462	462	1
ichthyoplankton	1, 6	0.61	0.002	462	462	1
ichthyoplankton	1, 7	0.50	0.009	462	462	4
ichthyoplankton	1, 8	0.60	0.002	462	462	1
ichthyoplankton	1, 9	0.27	0.028	462	462	13
ichthyoplankton	2, 4	0.80	0.002	462	462	1
ichthyoplankton	2, 5	0.78	0.002	462	462	1
ichthyoplankton	2, 6	0.67	0.002	462	462	1
ichthyoplankton	2, 7	0.59	0.004	462	462	2
ichthyoplankton	2, 8	0.61	0.002	462	462	1
ichthyoplankton	2, 9	0.32	0.026	462	462	12
ichthyoplankton	3, 5	0.22	0.024	462	462	11
ichthyoplankton	3, 6	0.25	0.024	462	462	11
ichthyoplankton	3, 7	0.20	0.043	462	462	20
ichthyoplankton	3, 8	0.24	0.024	462	462	11
ichthyoplankton	4, 6	0.48	0.009	462	462	4
ichthyoplankton	4, 7	0.43	0.009	462	462	4
ichthyoplankton	4, 8	0.44	0.009	462	462	4
ichthyoplankton	4, 9	0.48	0.004	462	462	2
ichthyoplankton	5, 9	0.24	0.026	462	462	12
invertebrate zooplankton	4, 9	0.64	0.029	35	35	1
invertebrate zooplankton	4, 12	0.66	0.029	35	35	1
invertebrate zooplankton	4, 1	0.77	0.029	35	35	1
invertebrate zooplankton	4, 2	0.71	0.029	35	35	1
invertebrate zooplankton	5, 1	0.63	0.029	35	35	1
invertebrate zooplankton	5, 2	0.44	0.029	35	35	1
invertebrate zooplankton	6, 12	0.70	0.029	35	35	1
invertebrate zooplankton	6, 1	0.83	0.029	35	35	1
invertebrate zooplankton	6, 2	0.74	0.029	35	35	1
invertebrate zooplankton	6, 3	0.51	0.029	35	35	1
invertebrate zooplankton	7, 12	0.54	0.029	35	35	1
invertebrate zooplankton	7, 1	0.76	0.029	35	35	1
invertebrate zooplankton	7, 2	0.69	0.029	35	35	1

Table 2.3.2.1 (page 3 of 3). Significant ($p<0.05$) community dissimilarity apparent from pairwise monthly ANOSIM comparisons.

Catch type	Compared months	R statistic	Probability	Possible permutations	Actual permutations	Number > or = observed R
invertebrate zooplankton	8, 12	0.57	0.029	35	35	1
invertebrate zooplankton	8, 1	0.82	0.029	35	35	1
invertebrate zooplankton	8, 2	0.58	0.029	35	35	1
invertebrate zooplankton	8, 3	0.59	0.029	35	35	1
invertebrate zooplankton	9, 3	0.44	0.029	35	35	1
invertebrate zooplankton	10, 1	0.88	0.029	35	35	1
invertebrate zooplankton	10, 2	0.65	0.029	35	35	1
invertebrate zooplankton	12, 3	0.31	0.029	35	35	1

2.4 Community Structure: Change by Year

Inter-annual comparisons of community structure avoid the seasonality issues that are apparent in Section 2.3. The primary objective of these comparisons is to detect inflow-related influences on community structure. Although emphasis was at the annual level, monthly inflow values were also plotted as a potential complement to detection and understanding of inter-annual differences.

2.4.1 **Methods.** The analytical approach was the same as the approach used in Section 2.3. Each year had replicates in the form of 12 observations made during different months within the year, with each monthly observation being the aggregated month's samples divided by the month's total effort. Exceptions were the seine and trawl collections during survey year HBMP1, which started in May rather than April, and therefore had 11 replicates instead of 12. Two metrics were used as indicators of inter-annual difference in inflow level: average annual inflow and the number of days where the inflow was above the median (78 cfs) for the collective six-year period of the WAR and HBMP studies.

2.4.2 **Results and Discussion.**

2.4.2.1 Yearly Inflow Variation

The total inflow hydrograph is plotted in Fig. 2.4.1. This figure also identifies the rankings of the six years according to two different inflow metrics. The two ranking methods produced very different results. Average water quality during the HBMP is presented in Fig. 2.4.2, which identifies a first-order decrease in salinity over time. Bottom dissolved oxygen (DO) was lower during the latter part of the HBMP, which is a time when inflows were generally elevated.

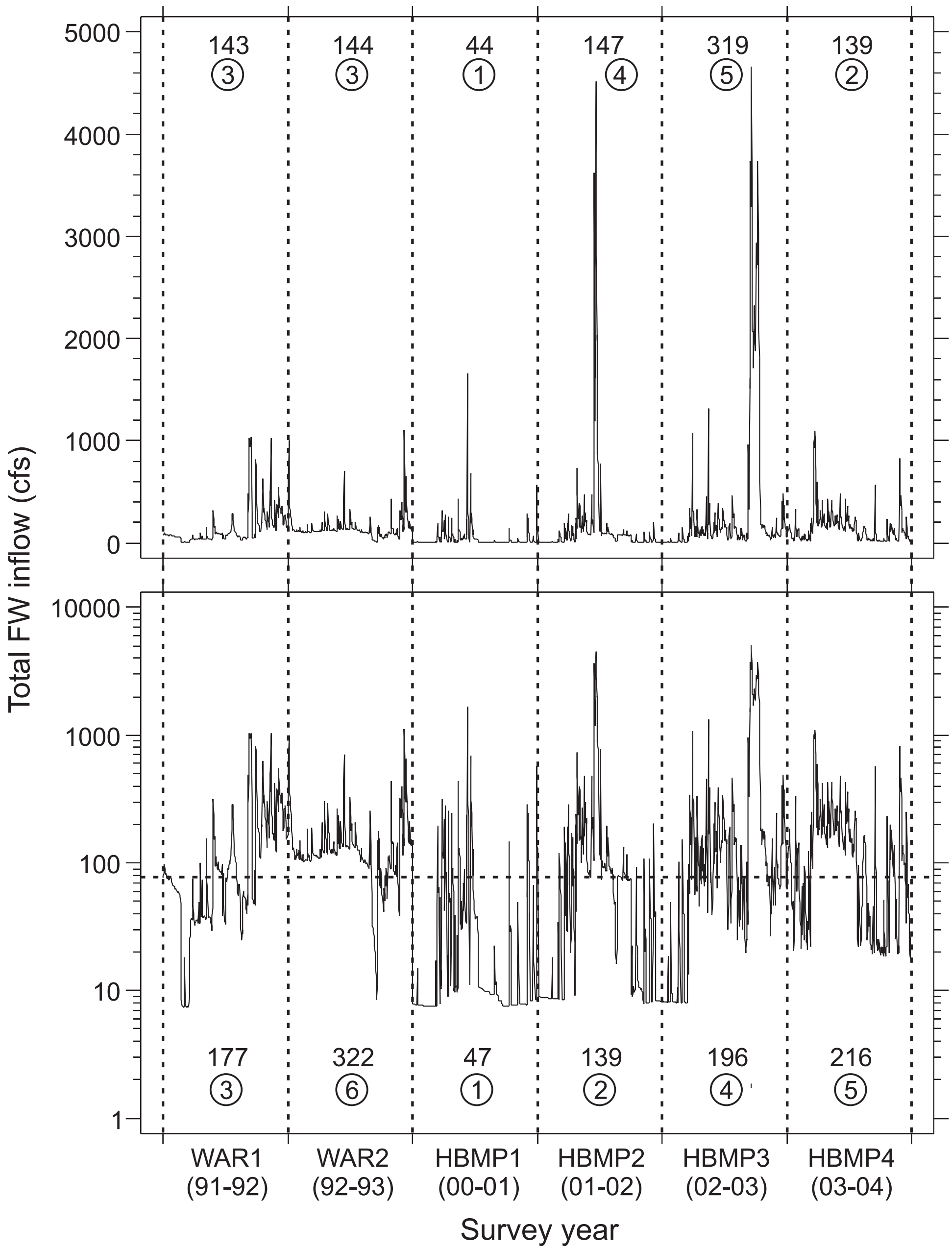


Fig. 2.4.1 Inflow hydrograph for survey years. Inflow includes gauged inflows at S-160, estimated ungauged inflows and estimated base flows. Inflow is graphed using a log scale in the lower panel, with the median inflow for all survey years, 78 cfs, indicated by a horizontal dashed line. Average inflows and associated ranks (circled) are identified on the upper panel, and numbers of high-inflow days (inflow >78 cfs) and associated ranks are identified in the lower panel. High numerical ranks indicate wetter years.

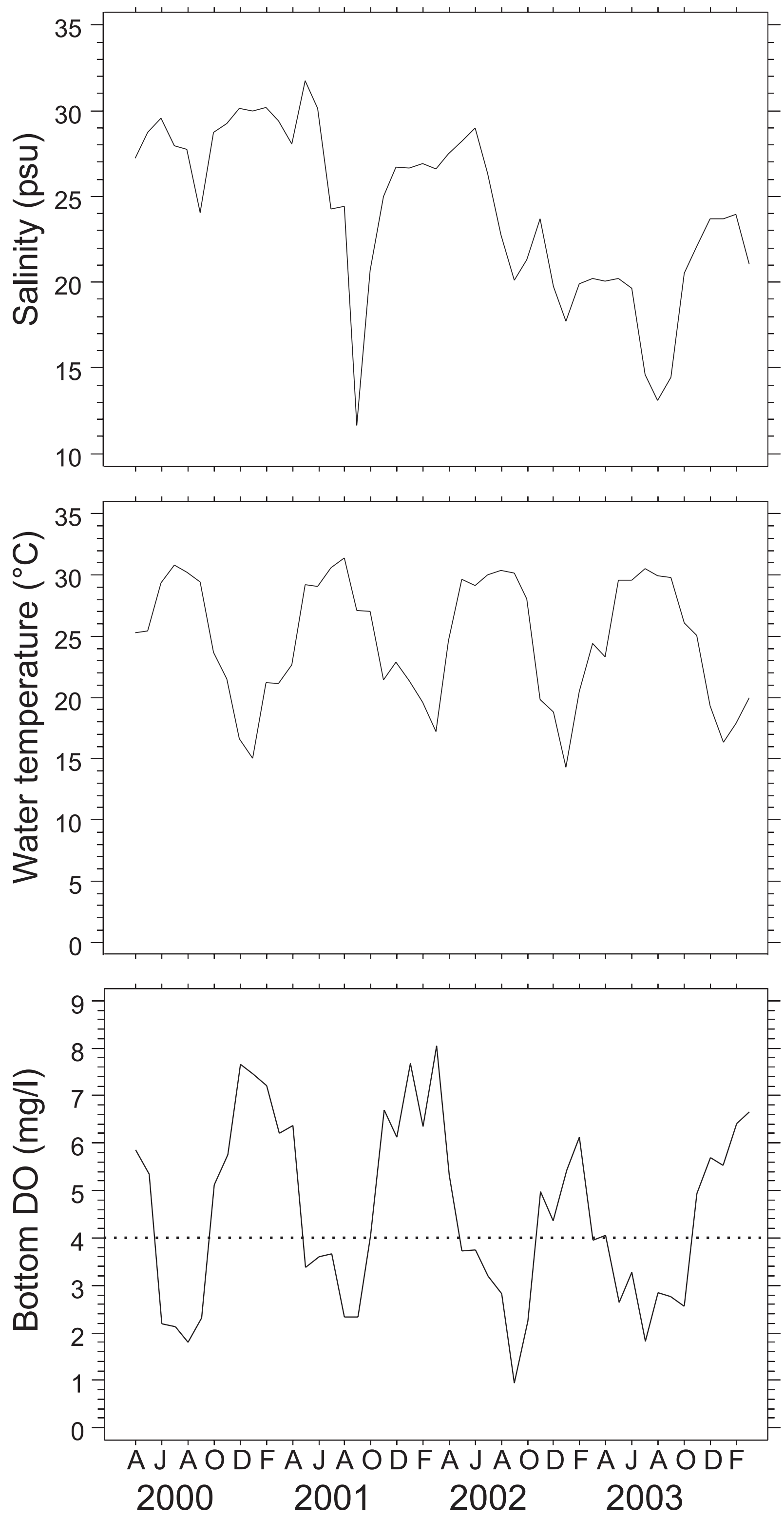


Fig. 2.4.2. Average water quality conditions during the HBMP.

2.4.2.2 Seine Catch: Change by Year

McKay Bay and Palm River seine catch rate (ind. 100 m²)

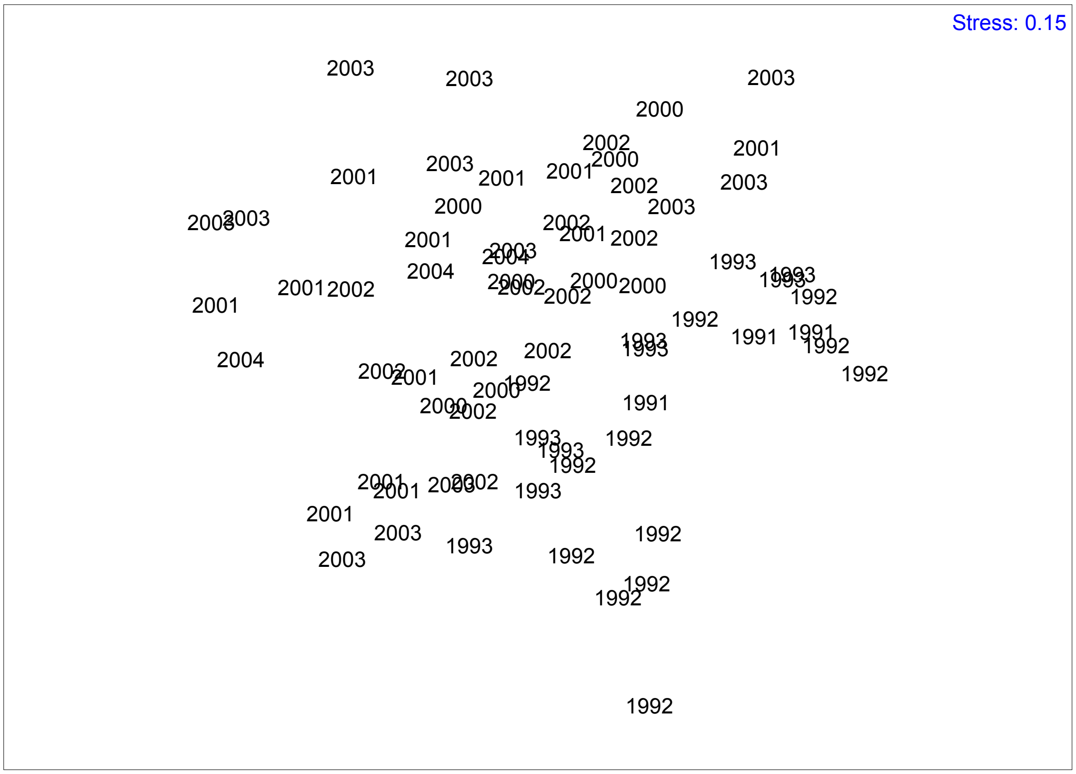


Fig. 2.4.2.2. Similarity among monthly seine samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to calendar year.

Fig. 2.4.2.2 suggests that the composition of the seine catch changed between the early 1990s and the early 2000s (ANOSIM global R=0.21, p=0.001). However, this may have been caused by the fact that collection efforts during the early 1990s were biased toward the Palm River, whereas those in the early 2000s were biased toward McKay Bay. The differences were largely caused by differences in catches of the bay anchovy, *Menidia* spp. and various killifishes, most of which tend to be more abundant in the Palm River (Table 2.4.2.1).

Table 2.4.2.1. Example comparisons of WAR and HBMP seine catches for species that collectively contributed >90% to dissimilarity between years. Included values are average abundance (Av.Abund, as ind./100 m²), average dissimilarity (Av.Diss), the ratio of average dissimilarity to the standard deviation of similarity (Diss/SD) and percent contribution to total dissimilarity (Contrib%).

Groups 1991 & 2000
Average dissimilarity = 73.18

Species	Group 1991 Av.Abund	Group 2000 Av.Abund	Av.Diss	Diss/SD	Contrib%
Anchoa mitchilli	4167.06	691.34	54.40	2.21	74.35
Menidia spp.	286.96	88.83	4.71	1.05	6.44
Floridichthys carpio	151.67	15.13	3.75	1.15	5.12
Fundulus majalis	133.53	5.42	2.76	1.54	3.77
Cyprinodon variegatus	60.88	20.45	1.55	0.99	2.12

Groups 1992 & 2002
Average dissimilarity = 78.20

Species	Group 1992 Av.Abund	Group 2002 Av.Abund	Av.Diss	Diss/SD	Contrib%
Anchoa mitchilli	2273.08	447.08	38.41	1.29	49.12
Menidia spp.	186.80	218.90	10.72	0.89	13.71
Fundulus majalis	132.33	7.55	7.53	0.86	9.63
Floridichthys carpio	123.07	21.73	5.26	0.65	6.72
Cyprinodon variegatus	88.68	6.96	3.75	0.97	4.80
Lucania parva	134.23	14.83	3.24	0.66	4.14
Pogonias cromis	55.49	0.01	3.09	0.30	3.95

Groups 1991 & 2001
Average dissimilarity = 82.53

Species	Group 1991 Av.Abund	Group 2001 Av.Abund	Av.Diss	Diss/SD	Contrib%
Anchoa mitchilli	4167.06	582.48	58.81	1.95	71.26
Menidia spp.	286.96	190.22	7.34	0.94	8.89
Floridichthys carpio	151.67	7.97	4.67	1.04	5.65
Fundulus majalis	133.53	4.12	3.18	1.38	3.85
Cyprinodon variegatus	60.88	2.07	2.18	0.98	2.64

McKay Bay and Palm River seine catch rate (ind. 100 m²)

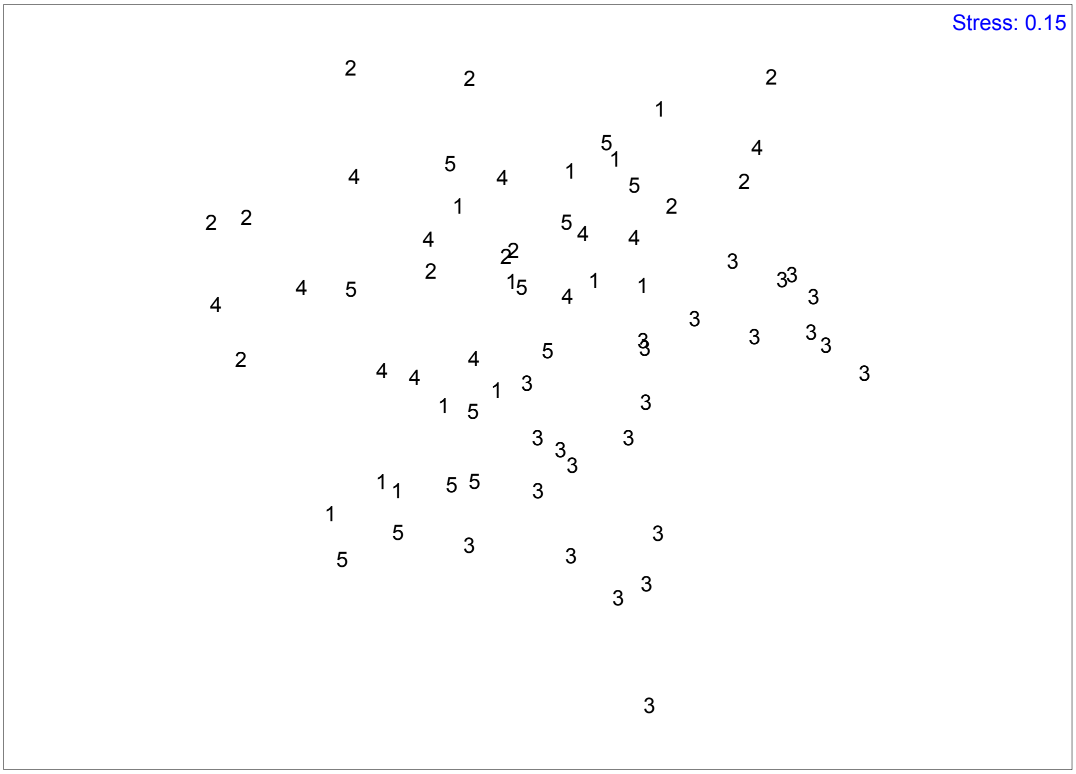


Fig. 2.4.2.3. Similarity among monthly seine samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to average annual inflow rank.

Neither of the annual inflow metrics indicate that the difference between the 1990s and 2000s is inflow related (Figs. 2.4.2.3 and 2.4.2.4). The three high-inflow months in Fig. 2.4.3.5 were very similar to samples from low-inflow months, suggesting that inflow does not have a strong effect on overall seine-catch composition within the study area when the study area is considered as a whole.

McKay Bay and Palm River seine catch rate (ind. 100 m²)

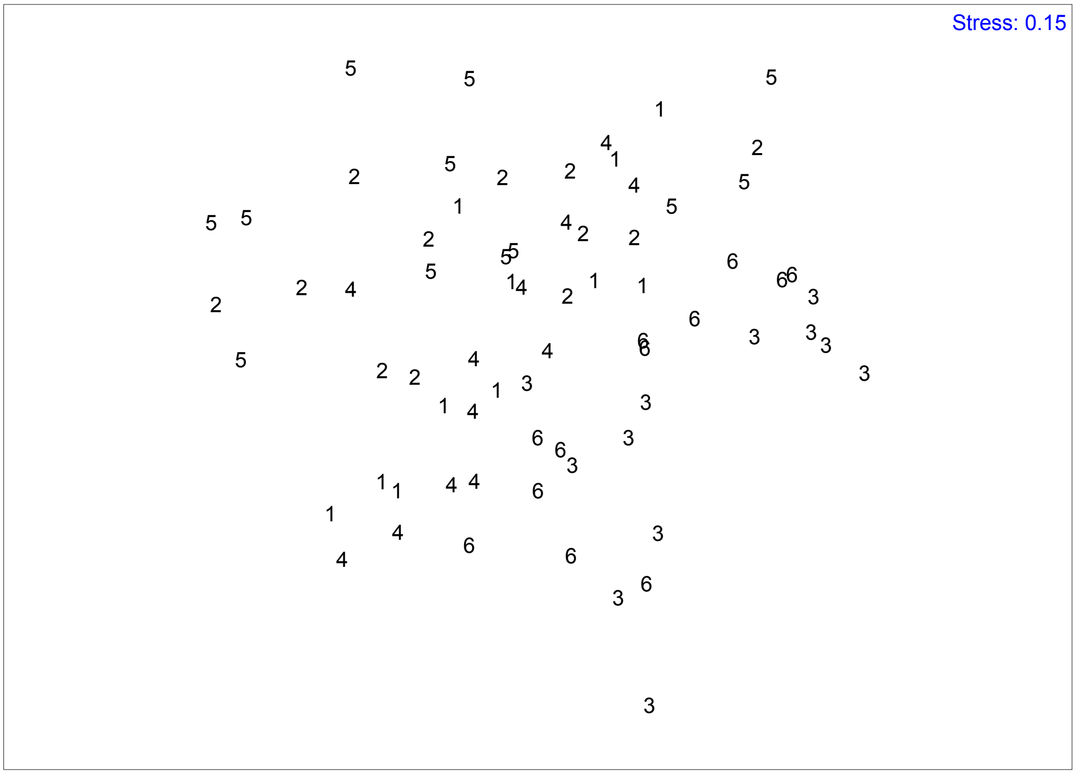


Fig. 2.4.2.4. Similarity among monthly trawl samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to an annual inflow ranking based on the number of days with higher-than-median inflow.

McKay Bay and Palm River seine catch rate (ind. 100 m²)

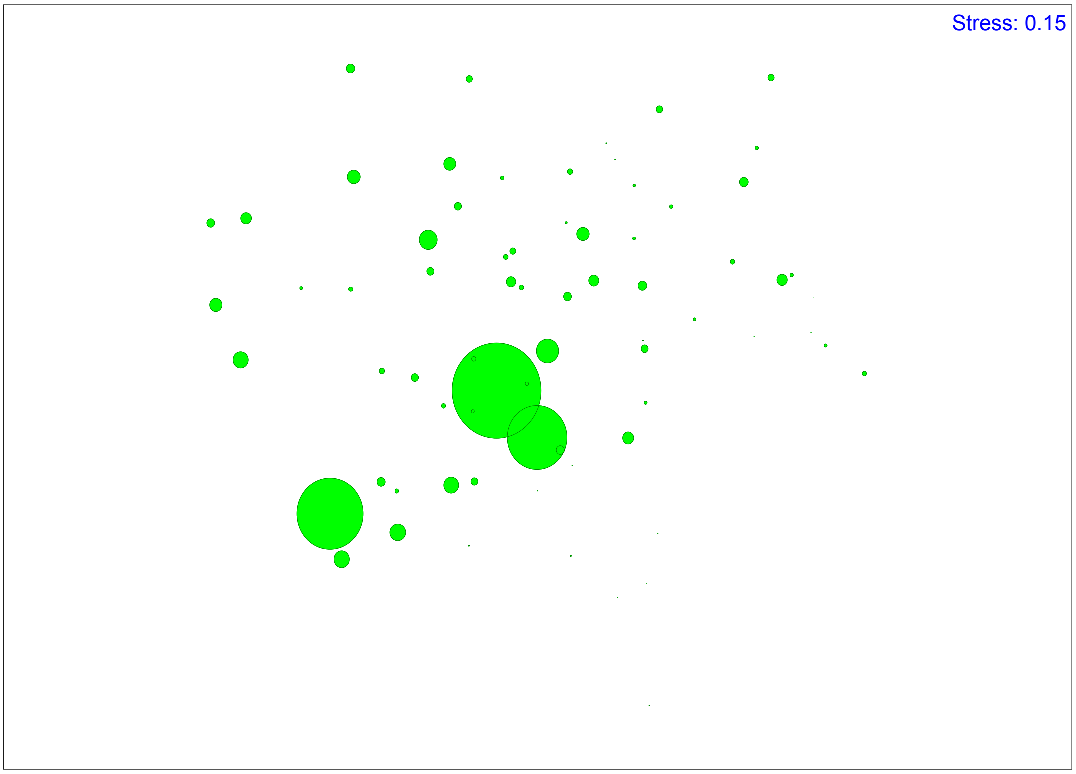


Fig. 2.4.2.5. Similarity among monthly trawl samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with bubble size being proportionate to average monthly inflow.

2.4.2.3 Trawl Catch: Change by Year

McKay Bay and Palm River trawl catch rate (ind./100 m²)

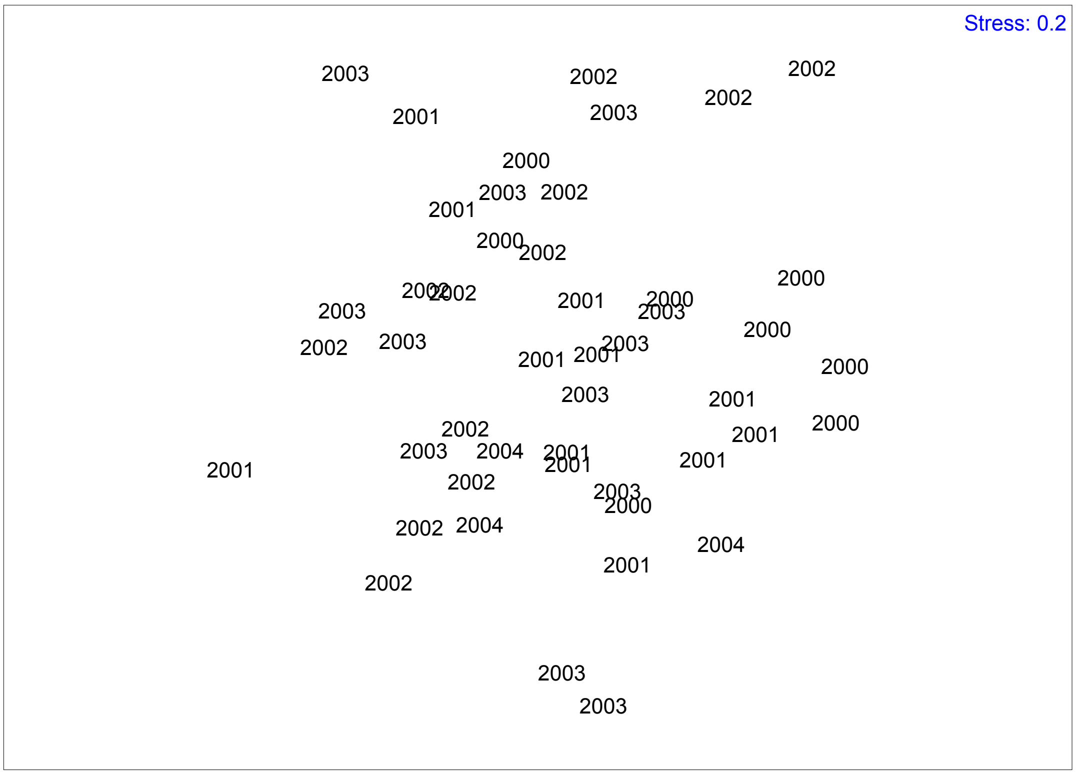


Fig. 2.4.2.6. Similarity among monthly trawl samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to calendar year.

Variation in trawl catch among HBMP calendar years was small (ANOSIM global R=0.15, p=0.002). There were no inter-annual trends in trawl catch composition that could be related to inflow (Figs. 2.4.2.6-2.4.6.8). The two high-inflow months in Fig. 2.4.2.9 were very similar to samples from low-inflow months, suggesting that inflow does not have a strong effect on overall trawl-catch composition within the study area when the study area is considered as a whole.

McKay Bay and Palm River trawl catch rate (ind./100 m²)

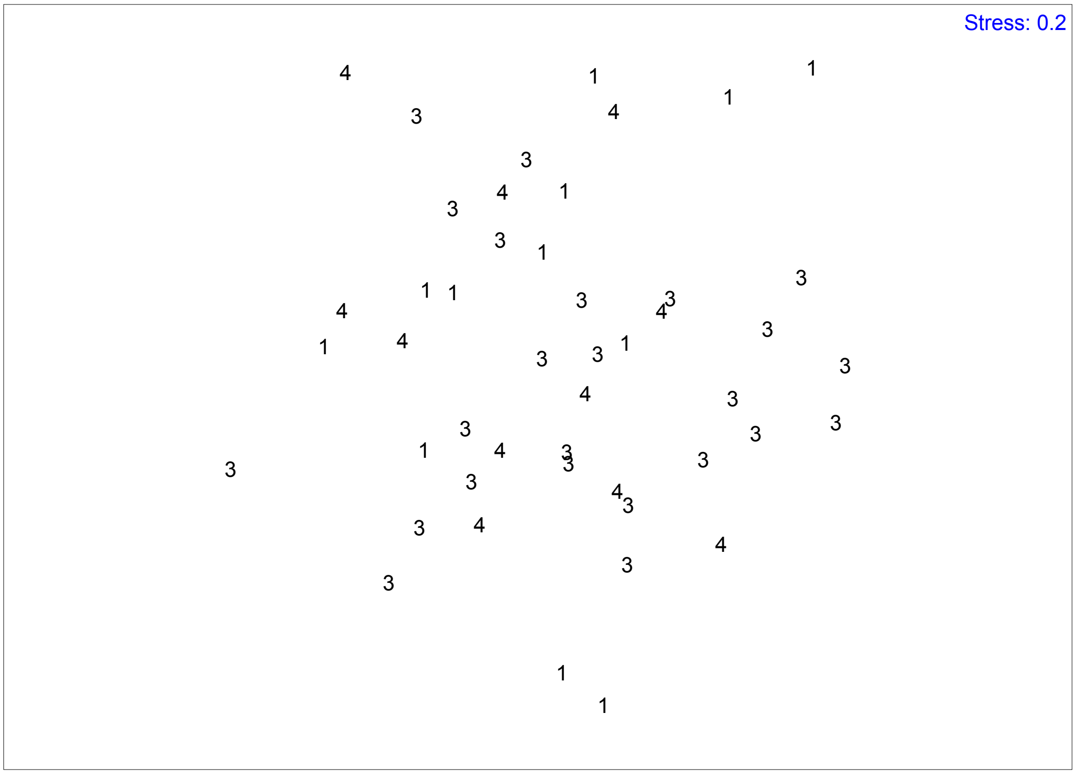


Fig. 2.4.2.7. Similarity among monthly trawl samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to average annual inflow rank.

McKay Bay and Palm River trawl catch rate (ind./100 m²)

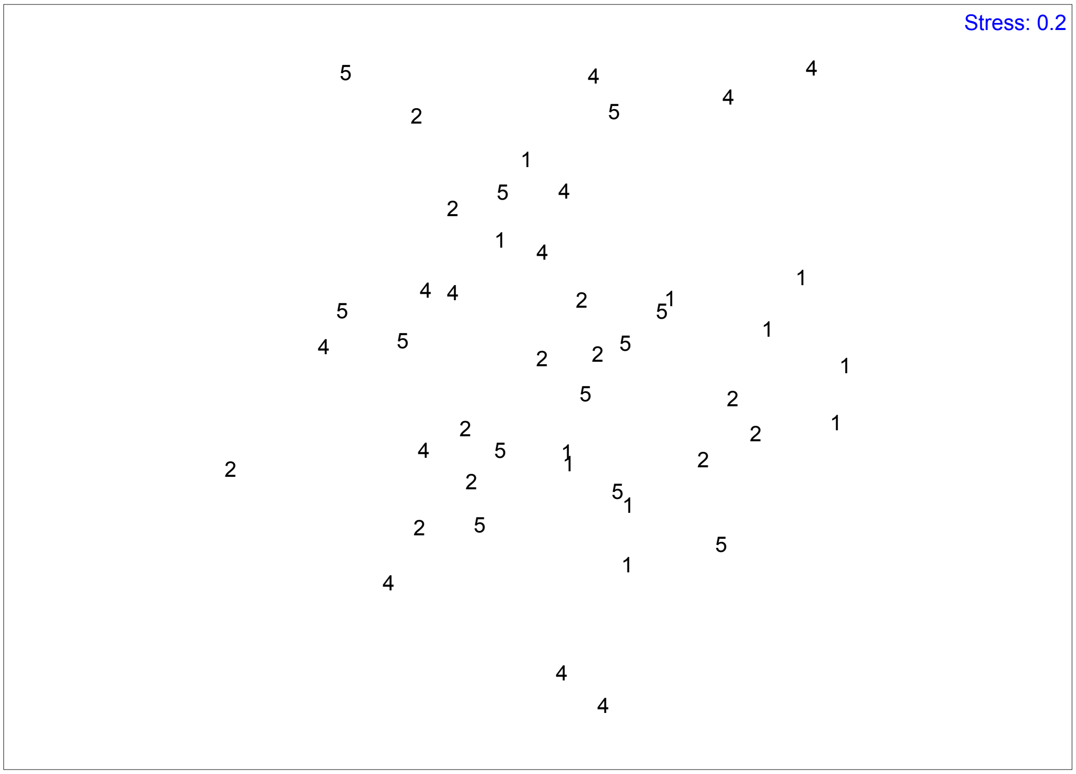


Fig. 2.4.2.8. Similarity among monthly trawl samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to an annual inflow ranking based on the number of days with higher-than-median inflow.

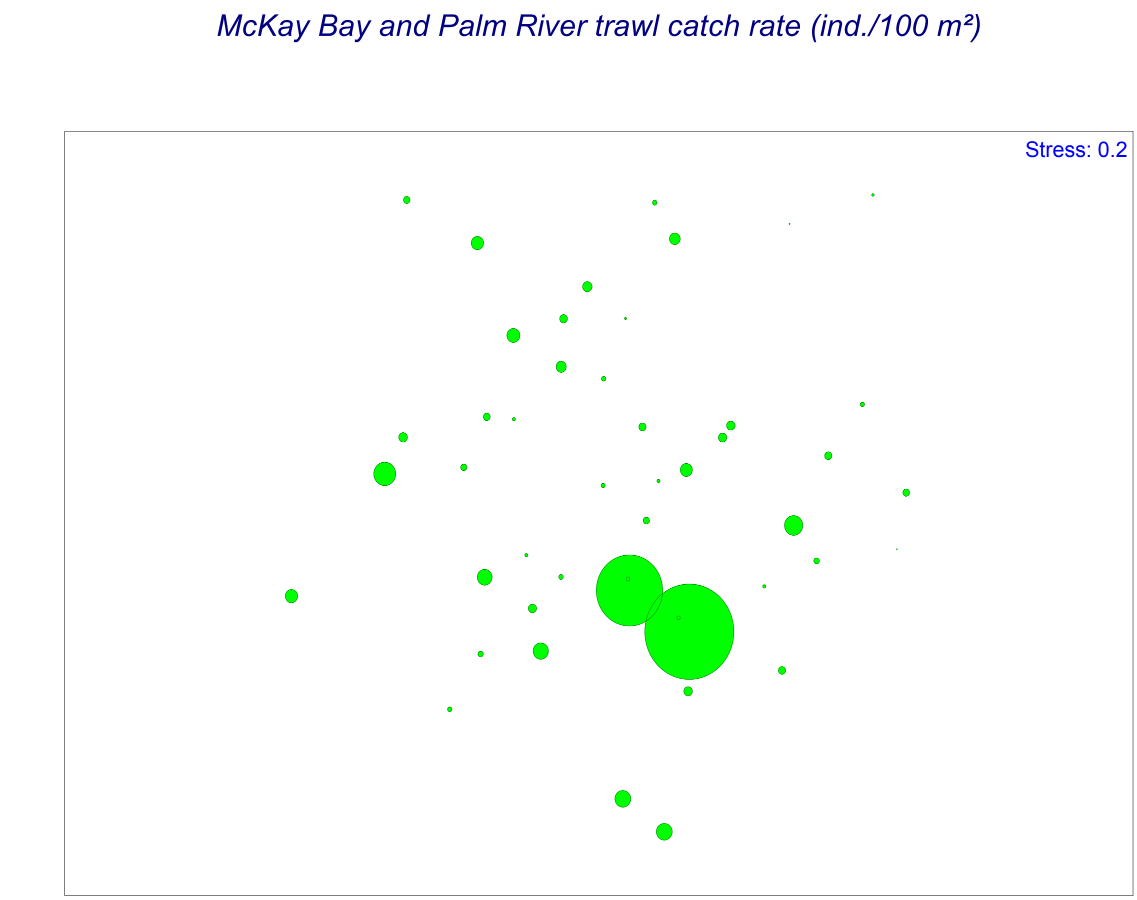


Fig. 2.4.2.9. Similarity among monthly trawl samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with bubble size being proportionate to average monthly inflow.

2.4.2.4 Plankton-net Fish Catch: Change by Year

McKay Bay and Palm River ichthyoplankton catch (ind./1000 m³)

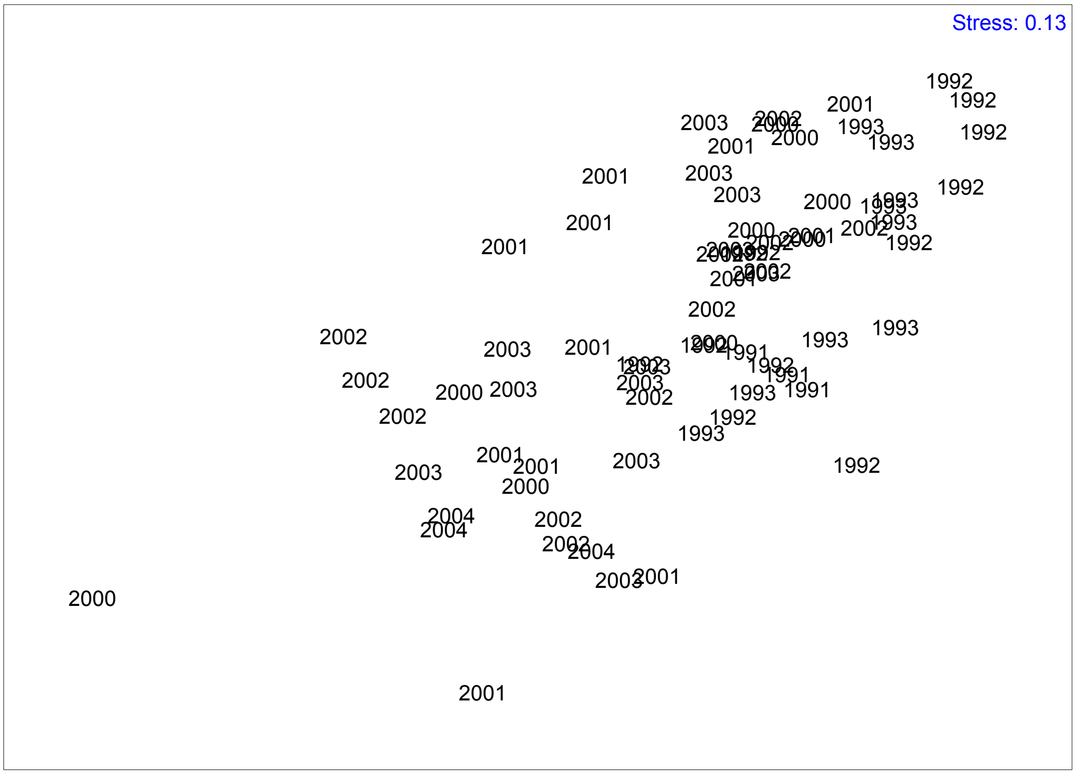


Fig. 2.4.2.10. Similarity among monthly ichthyoplankton samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to calendar year.

As in the case of the seine data, Fig. 2.4.2.10 suggests that the composition of the ichthyoplankton community changed between the early 1990s and the early 2000s, although the overall variation among years was not large (ANOSIM global R=0.12, p=0.003). This shift was not due to differences in methodology, and all samples were processed by the same person (E. Peebles). However, the difference could be caused by differences in station distribution. Pairwise comparisons among years did not identify a consistent compositional difference between the two periods, except that bay anchovy juveniles (*Anchoa mitchilli*) and postlarval gobies (*Gobiosoma* spp.) were consistently

Table 2.4.2.2. Example comparisons of WAR and HBMP ichthyoplankton catches for species that collectively contributed >90% to dissimilarity between years. Included values are average abundance (Av.Abund, as ind./1000 m²), average dissimilarity (Av.Diss), the ratio of average dissimilarity to the standard deviation of similarity (Diss/SD) and percent contribution to total dissimilarity (Contrib%).

Groups 1991 & 2000

Average dissimilarity = 90.92

	Group 1991	Group 2000			
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%
Anchoa mitchilli juv.	1817.87	50.67	33.96	1.39	37.35
fish eggs, percomorph	422.26	2558.88	26.76	1.16	29.43
Anchoa mitchilli eggs	0.00	2273.34	12.58	0.53	13.84
Anchoa spp. preflex.	0.00	941.35	5.78	0.63	6.35
Gobiosoma spp. postfl.	153.69	29.37	2.78	1.14	3.05

Groups 1992 & 2002

Average dissimilarity = 87.81

	Group 1992	Group 2002			
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%
fish eggs, percomorph	23324.56	2739.75	37.46	1.23	42.66
Anchoa mitchilli juv.	3825.14	45.89	19.56	0.74	22.27
Anchoa mitchilli eggs	27597.96	1297.89	17.68	0.64	20.13
Gobiosoma spp. postfl.	1202.34	28.68	2.27	0.78	2.58
Anchoa mitchilli postfl.	464.56	53.45	1.83	0.42	2.08
gobiid flex.	1002.47	15.73	1.56	0.87	1.78

Groups 1991 & 2001

Average dissimilarity = 91.16

	Group 1991	Group 2001			
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%
Anchoa mitchilli juv.	1817.87	26.02	43.53	1.94	47.75
fish eggs, percomorph	422.26	1369.22	18.56	1.44	20.36
Anchoa mitchilli eggs	0.00	1950.62	10.22	0.49	11.21
Anchoa spp. preflex.	0.00	1870.09	4.64	0.38	5.09
Gobiosoma spp. postfl.	153.69	25.54	3.49	1.45	3.83
Anchoa spp. flex.	0.00	313.28	1.96	0.40	2.15

more abundant in the WAR catches (Table 2.4.2.2).

Neither of the annual inflow metrics explained the WAR-HBMP difference (Figs. 2.4.2.11-2.4.2.12). Three outlying observations were associated with high average inflows at a monthly scale (Fig. 2.4.2.13), suggesting an inflow effect. The catch in these three months (March 1993, December 2000, January 2001) was collectively compared to the nearest (in MDS space) low-inflow samples from the same months (March 1992, December 2003 and January 2004). The comparison appears in Table 2.4.2.3. The principal effect appears to be a strong reduction in spawning within the study area during high-inflow periods, coupled with an increase in the number of bay anchovy juveniles.

Table 2.4.2.3. Comparison of aggregate ichthyoplankton catch from three outlying high-inflow months in Fig. 2.4.2.13 with the aggregate catch from three nearby low-inflow months, including species that collectively contributed >90% to dissimilarity between groups. Included values are average abundance (Av.Abund, as ind./1000 m²), average dissimilarity (Av.Diss), the ratio of average dissimilarity to the standard deviation of similarity (Diss/SD) and percent contribution to total dissimilarity (Contrib%).

Groups Low-inflow & High-inflow

Average dissimilarity = 95.10

Species	Low-inflow Av.Abund	High-inflow Av.Abund	Av.Diss	Diss/SD	Contrib%
Anchoa mitchilli juv.	476.77	3740.27	25.48	0.94	26.80
Anchoa mitchilli eggs	65583.08	0.00	24.45	0.67	25.71
fish eggs, percomorph	18847.80	3629.53	17.23	0.88	18.12
Membras martinica preflex.	0.00	66.17	10.77	0.48	11.33
Anchoa mitchilli ad.	34.04	10.35	6.51	0.70	6.85
Gobiesox strumosus preflex.	19.88	4.66	2.39	0.39	2.51

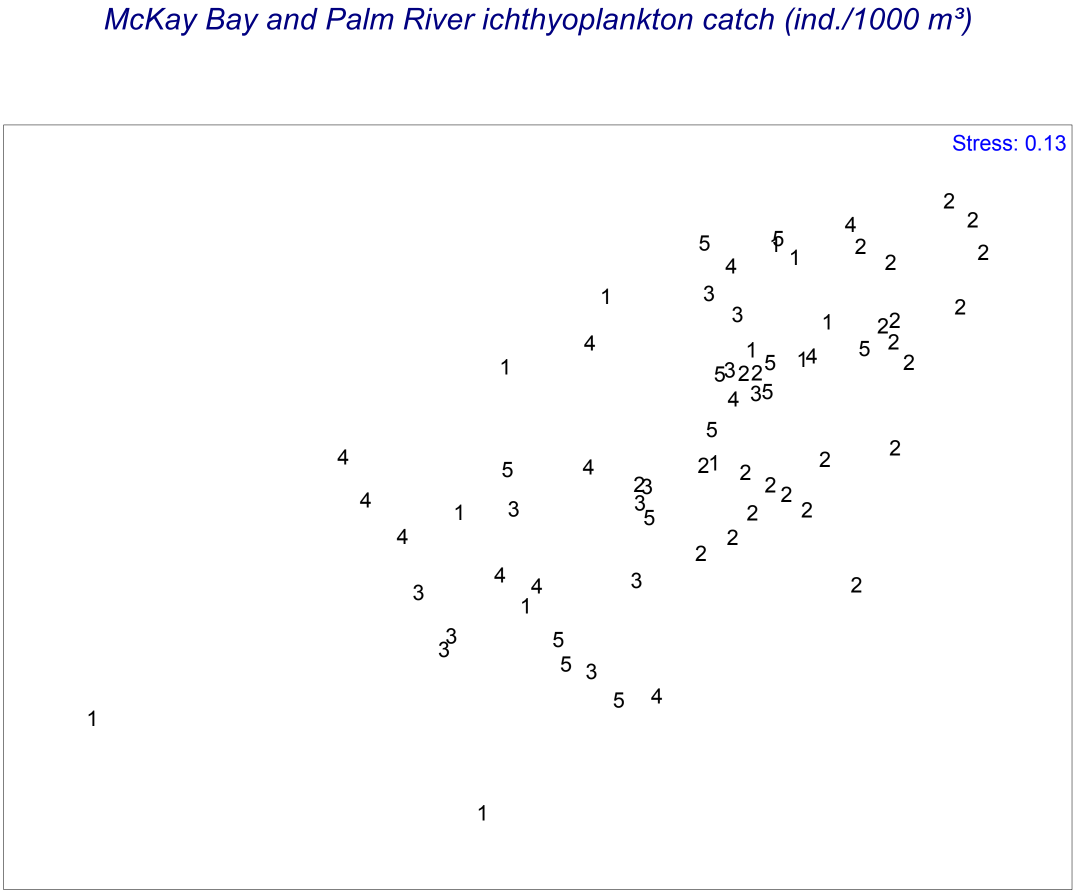


Fig. 2.4.2.11. Similarity among monthly ichthyoplankton samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to average annual inflow rank.

McKay Bay and Palm River ichthyoplankton catch (ind./1000 m³)

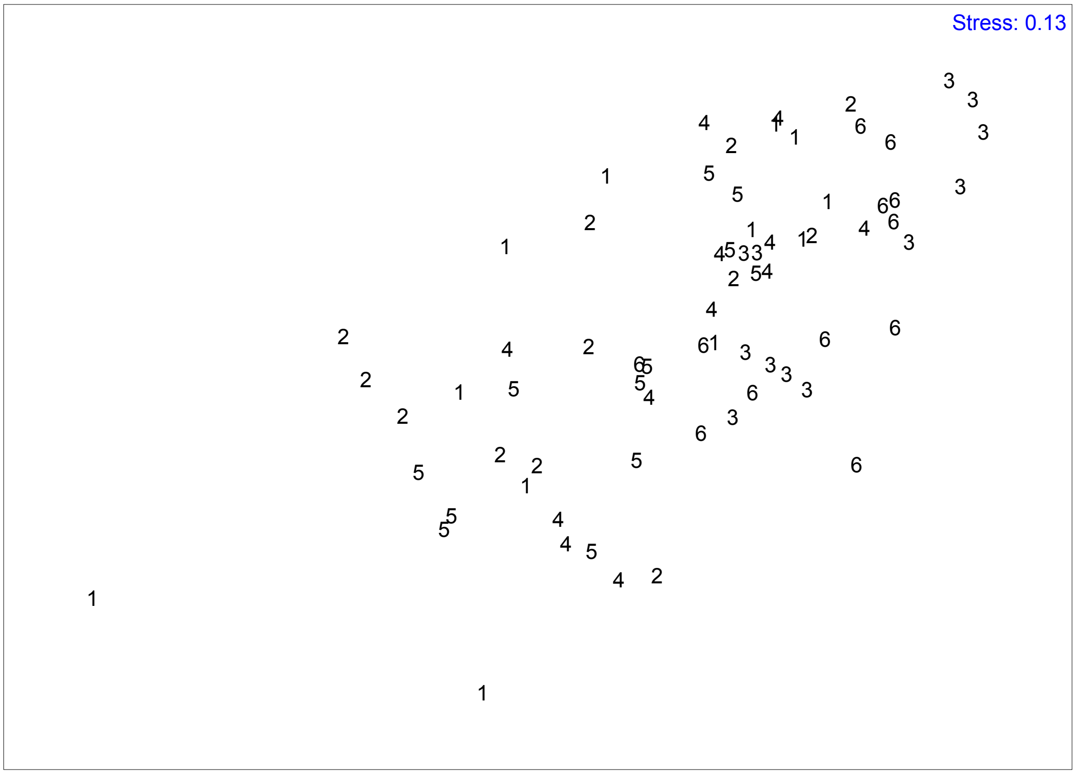


Fig. 2.4.2.12. Similarity among monthly ichthyoplankton samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to an annual inflow ranking based on the number of days with higher-than-median inflow.

McKay Bay and Palm River ichthyoplankton catch (ind./1000 m³)

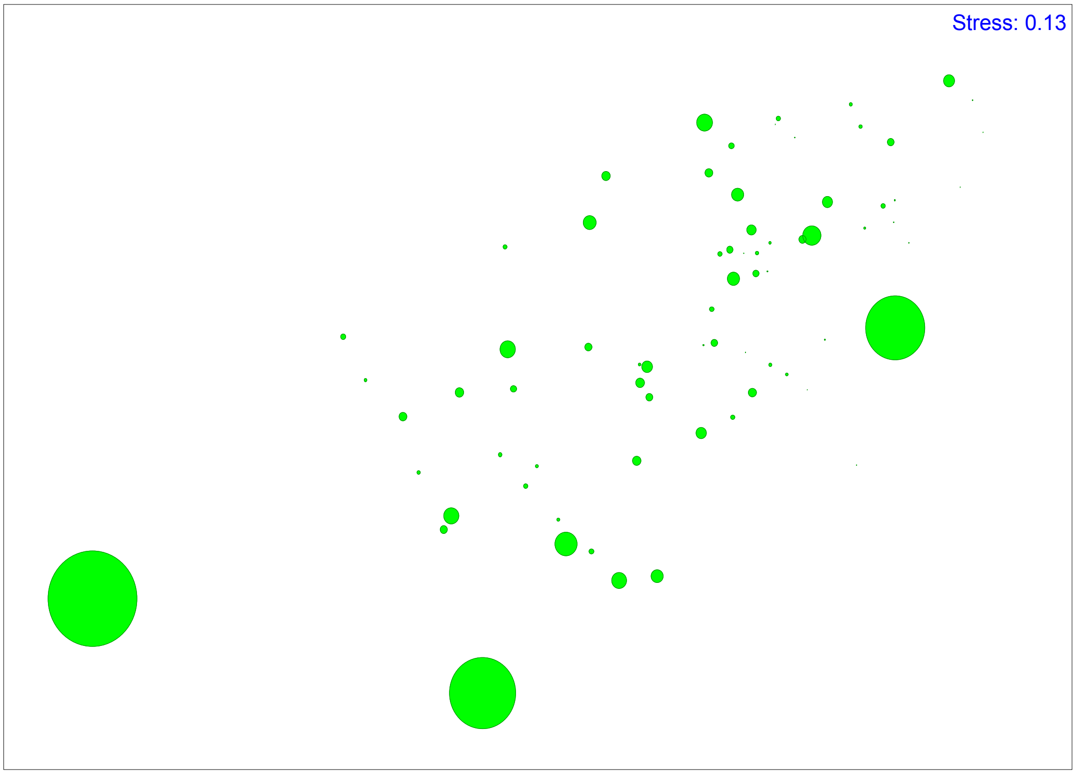


Fig. 2.4.2.13. Similarity among monthly ichthyoplankton samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with bubble size being proportionate to average monthly inflow.

2.4.2.5 Plankton-net Invertebrate Catch: Change by Year

McKay Bay and Palm River invertebrate plankton catch rate (ind./1000 m³)

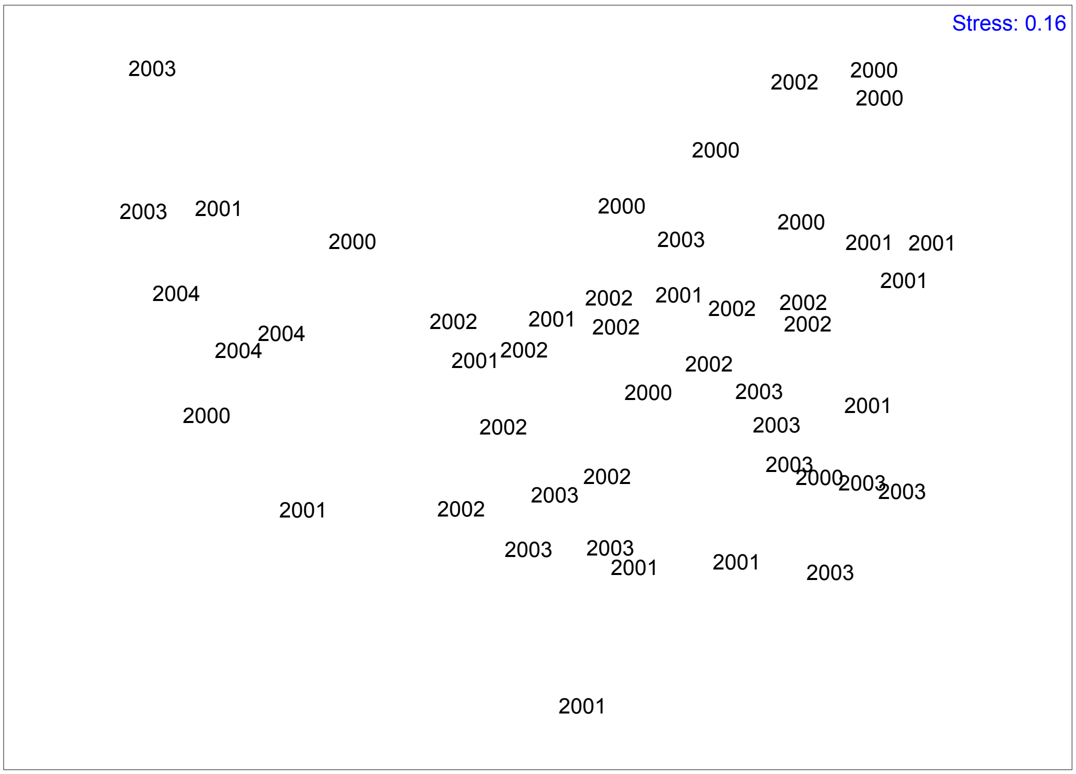


Fig. 2.4.2.14. Similarity among monthly invertebrate plankton samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to calendar year.

Differences in the invertebrate zooplankton community among years were minimal (ANOSIM global R=0.16, p=0.002), and neither of the annual inflow metrics identified any trends (Figs. 2.4.2.11-2.4.2.12). Two observations that were associated with high average inflows at a monthly scale (Fig. 2.4.2.13) were examined more closely. The catch in these months (December 2000 and January 2001) was collectively compared to the nearest (in MDS space) low-inflow samples from the same months (December 2003 and January 2004). The comparison appears in Table 2.4.2.4. The principal effect appears to be a washout effect, where the high inflows reduced the abundance of most types of planktonic animals.

Table 2.4.2.4. Comparison of aggregate invertebrate plankton catch from two high-inflow months in Fig. 2.4.2.17 with the aggregate catch from two nearby low-inflow months, including species that collectively contributed >90% to dissimilarity between groups. Included values are average abundance (Av.Abund, as ind./1000 m²), average dissimilarity (Av.Diss), the ratio of average dissimilarity to the standard deviation of similarity (Diss/SD) and percent contribution to total dissimilarity (Contrib%).

Groups Low-inflow & High-inflow

Average dissimilarity = 61.49

	Low-inflow	High-inflow			
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%
decapod zoeae, UID	4206.31	248.00	13.72	0.93	22.31
cumaceans	5596.46	2984.91	13.58	1.05	22.08
chaetognaths, sagittid	2324.69	456.36	6.75	1.12	10.97
amphipods, gammaridean	283.05	1435.07	5.89	1.03	9.59
Acartia tonsa	1489.87	193.62	5.12	1.03	8.33
Parasterope pollex	5.83	992.35	4.24	1.05	6.89
Mnemiopsis mccradyi	474.57	872.82	3.76	1.45	6.12
Labidocera aestiva	1084.96	12.36	3.67	0.89	5.97

McKay Bay and Palm River invertebrate plankton catch rate (ind./1000 m³)

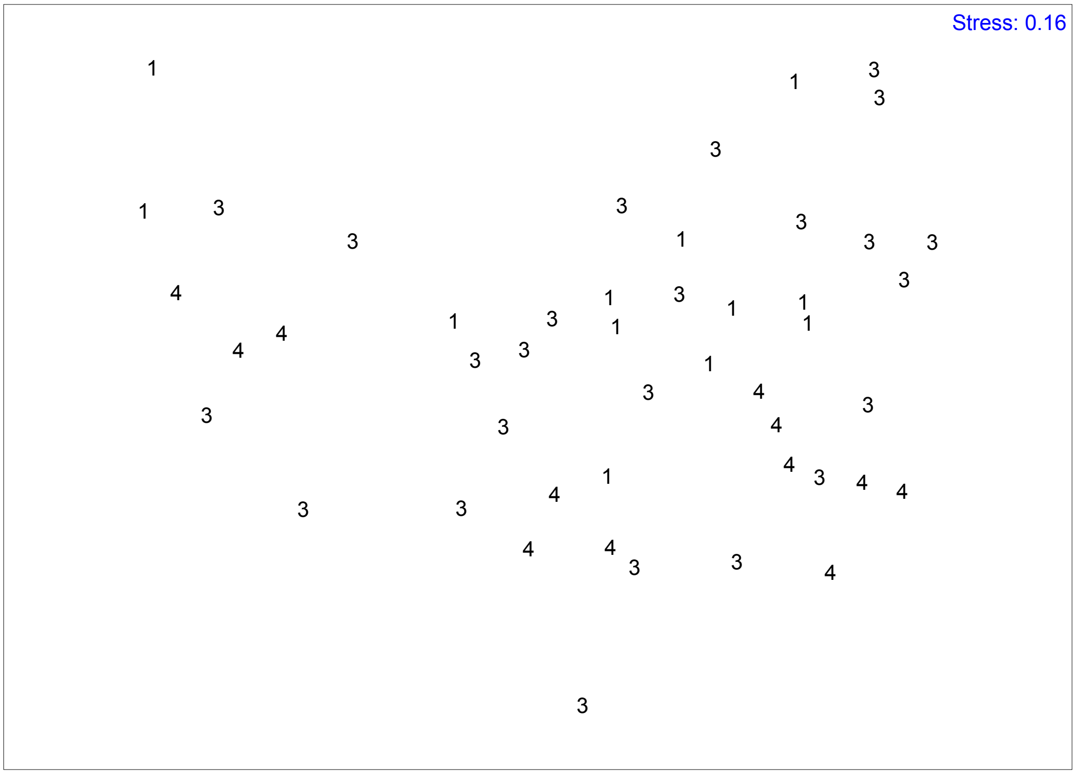


Fig. 2.4.2.15. Similarity among monthly invertebrate plankton samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to average annual inflow rank.

McKay Bay and Palm River invertebrate plankton catch rate (ind./1000 m³)

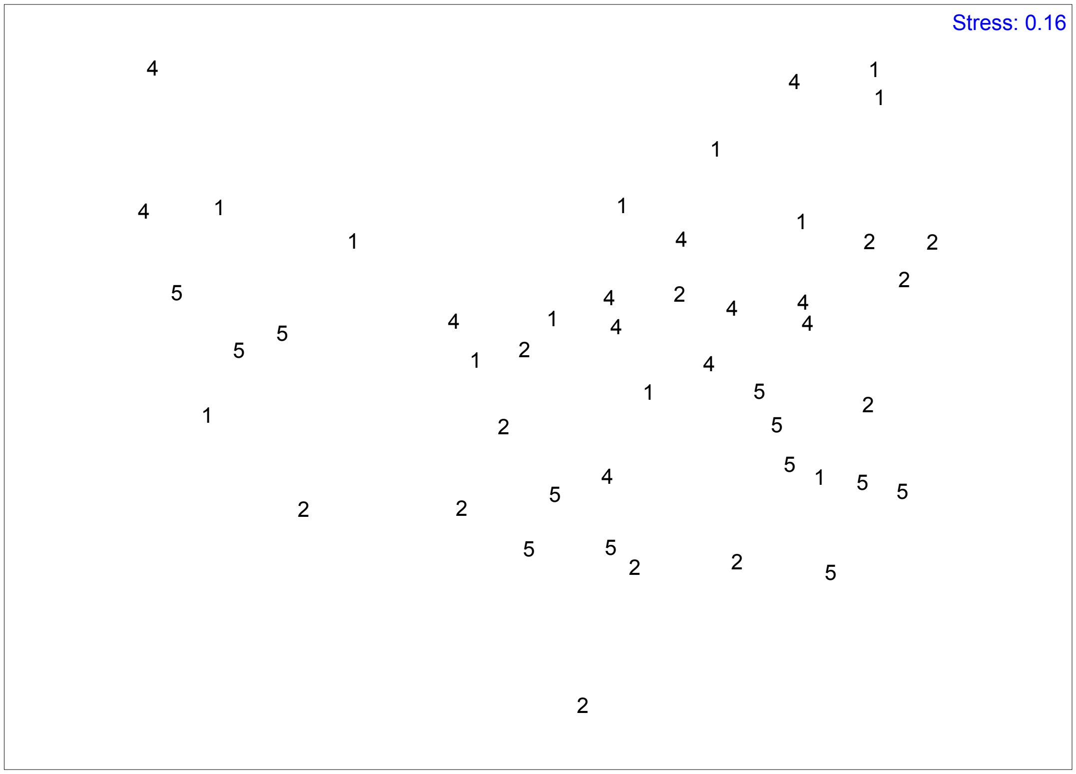


Fig. 2.4.2.16. Similarity among monthly invertebrate plankton samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to an annual inflow ranking based on the number of days with higher-than-median inflow.

McKay Bay and Palm River invertebrate plankton catch rate (ind./1000 m³)

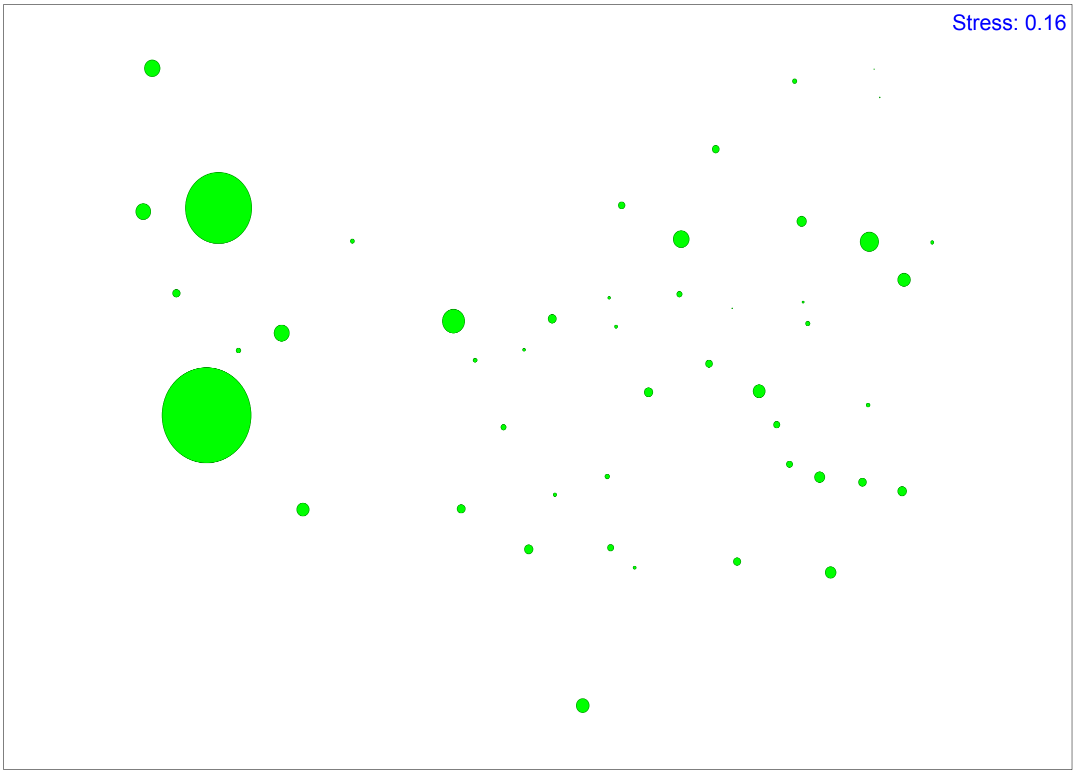


Fig. 2.4.2.17. Similarity among monthly invertebrate plankton samples (distance between samples is proportionate to Bray-Curtis dissimilarity), with bubble size being proportionate to average monthly inflow.

2.5 Community Structure: Change Along the Estuarine Gradient

2.5.1 **Methods.** The study area was divided into five contiguous zones to allow comparisons along the estuarine gradient. McKay Bay was bisected at -82˚25.4' to create landward and seaward zones within the bay, and the Palm River was zoned according to the three approximately equal divisions used by the HBMP to stratify sampling. The resulting five zones were numbered with zone 1 at the seaward end of McKay Bay and zone 5 in the Palm River below S-160. Each zone had replicates in the form of 12 observations made during different months, with each monthly observation being the aggregated month's catch divided by the month's total effort. The analytical approach was otherwise the same as that used in Sections 2.3 and 2.4.

2.5.2 **Results and Discussion.**

2.5.2.1 Estuarine Gradients

The data in Figs. 2.5.1-2.5.4 are from HBMP plankton-net surveys. Water temperature was highest is those shallow areas of McKay Bay that were less influenced by tidal incursions of cooler water from East Bay, which is much deeper than McKay Bay. On Florida's west coast, runoff from recent rains is generally cooler than estuarine water. The reduced temperature at the upper end of the Palm River could have been caused by runoff or possibly by contributions of spring water from the bottom of the TBC. The salinity gradient was slight, averaging about 4 psu in range. There was a strong gradient in dissolved oxygen concentrations at the bottom, with hypoxic concentrations (<4 mg /l) being typical in the Palm River. As the result of runoff of slightly acidic surface water, coupled with high levels of respiration within the Palm River, there was also a gradient in pH of about 0.4 pH units in average range.

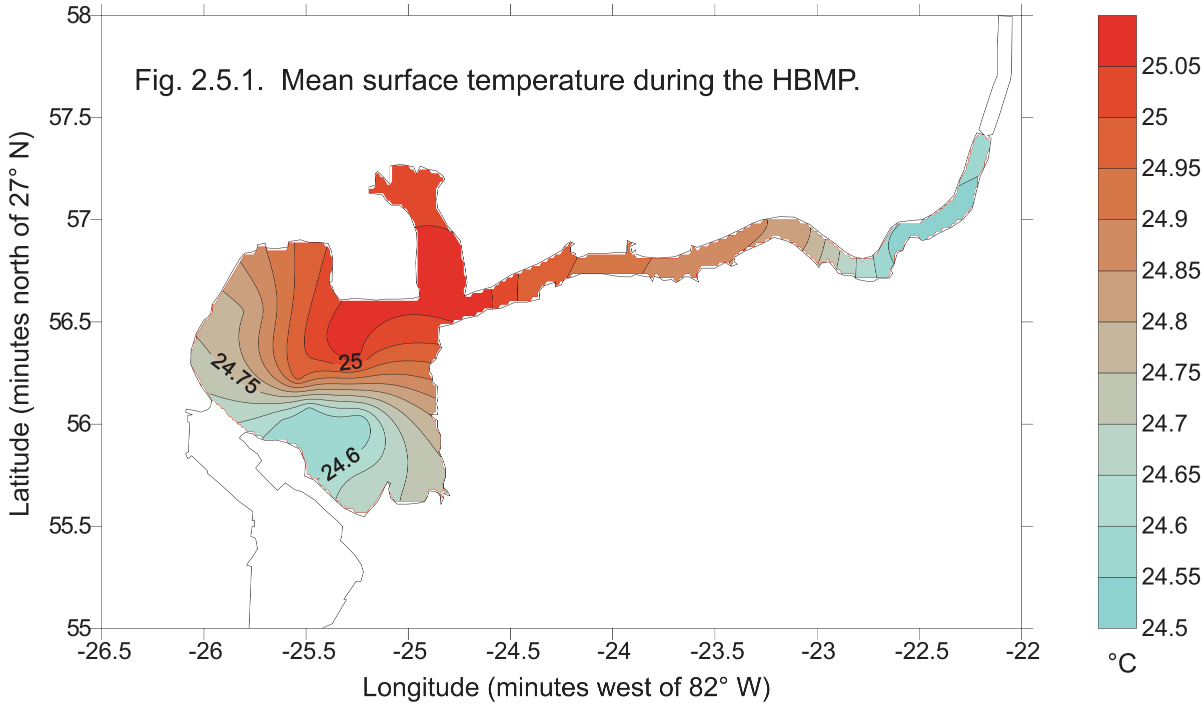


Fig. 2.5.1. Mean surface temperature during the HBMP.

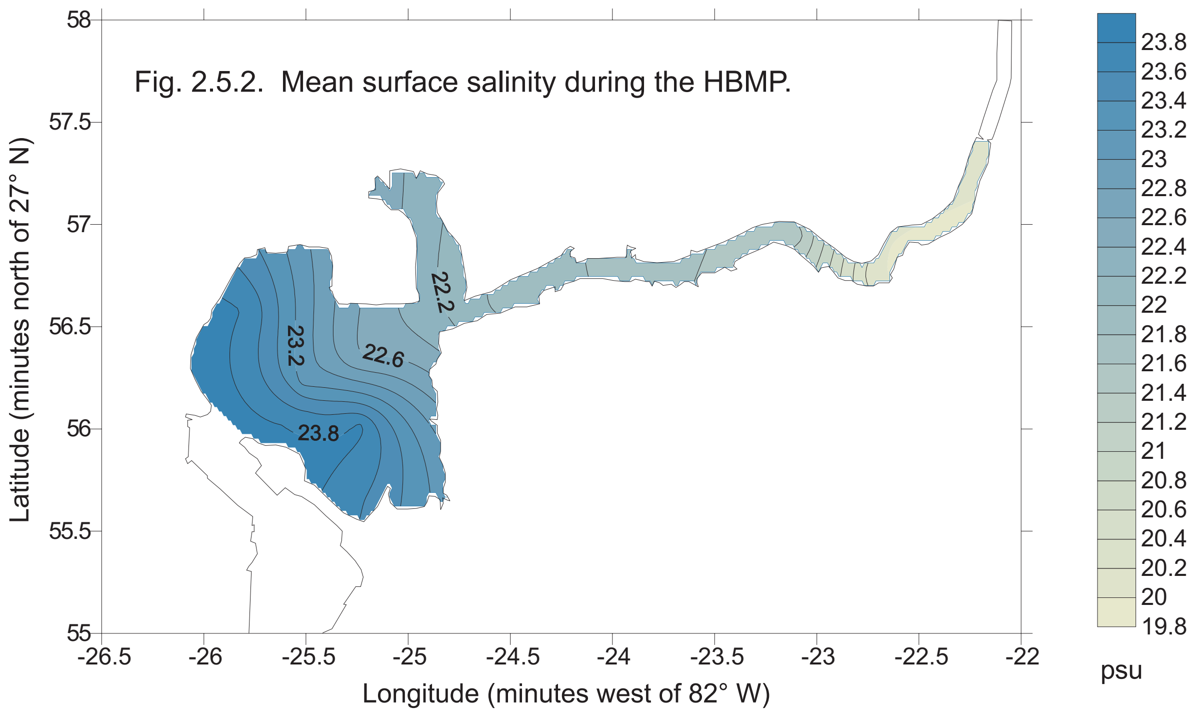


Fig. 2.5.2. Mean surface salinity during the HBMP.

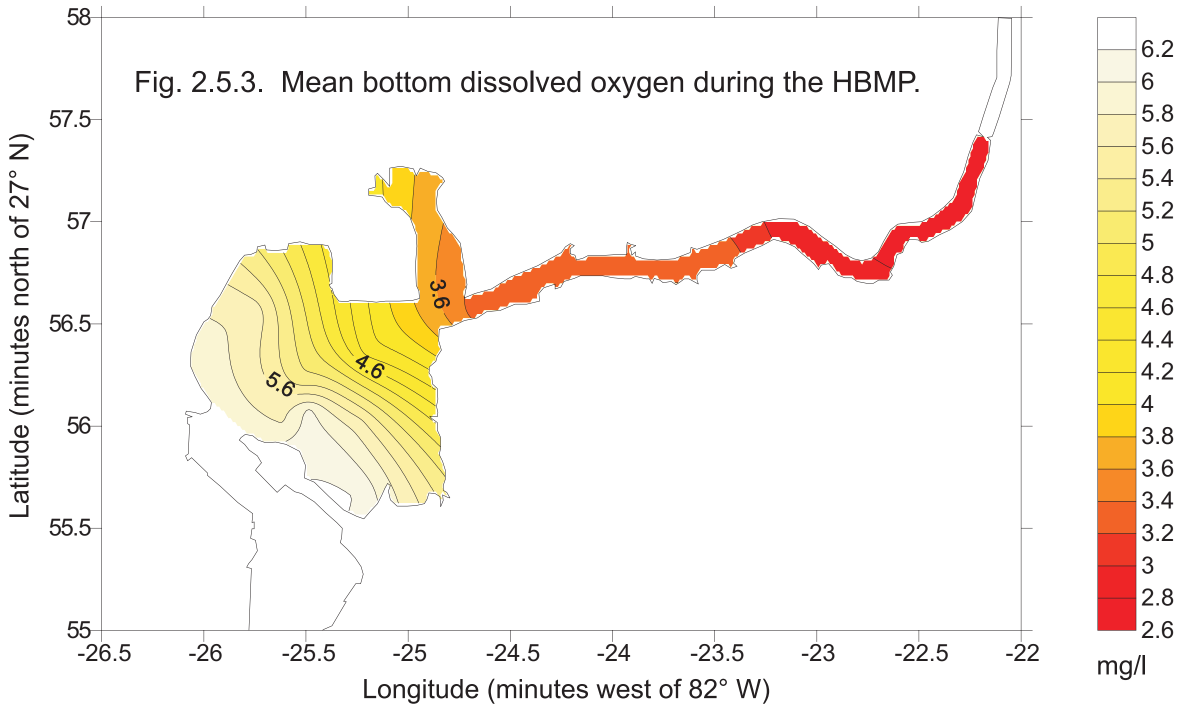


Fig. 2.5.3. Mean bottom dissolved oxygen during the HBMP.

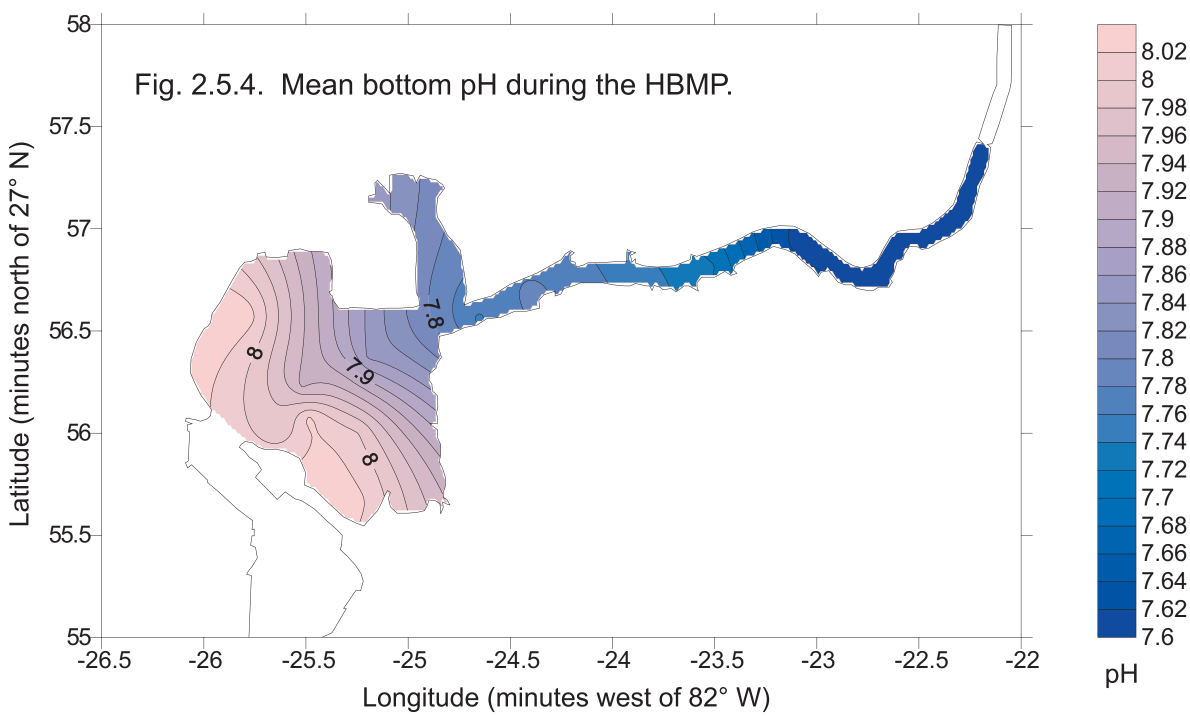


Fig. 2.5.4. Mean bottom pH during the HBMP.

2.5.2.2 Seine Catch: Change Along the Estuarine Gradient

Fig. 2.5.2.1. Similarity among monthly seine samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to position along the gradient.

The seine catch fell into two groups: McKay Bay and the Palm River (Fig. 2.5.2.1). ANOSIM confirmed this relatively strong difference (global R=0.50, p=0.001). Within each group, seasonality appeared to cause much more variation than did average monthly variation in inflow (Figs. 2.5.2.2 and 2.5.2.3). The differences between McKay Bay and the Palm River were caused by higher relative abundances of both estuarine-dependent and estuarine resident species in the Palm River (Table 2.5.2.1).

Table 2.5.2.1. Example comparisons of seine catches for species that collectively contributed >90% to dissimilarity between gradient zones. Included values are average abundance (Av.Abund, as ind./100 m²), average dissimilarity (Av.Diss), the ratio of average dissimilarity to the standard deviation of similarity (Diss/SD) and percent contribution to total dissimilarity (Contrib%).

Zones 1 & 5

Average dissimilarity = 93.92

Species	Zone 1 Av.Abund	Zone 5 Av.Abund	Av.Diss	Diss/SD	Contrib%
Anchoa mitchilli	33.71	3505.63	37.28	1.17	39.69
Menidia spp_	19.49	401.22	18.27	1.00	19.45
Palaemonetes pugio	1.67	428.89	18.09	0.97	19.26
Leiostomus xanthurus	9.15	78.99	4.08	0.63	4.34
Poecilia latipinna	0.02	46.93	3.16	0.62	3.36
Cyprinodon variegatus	0.04	42.85	2.82	0.66	3.00
Fundulus majalis	0.09	21.75	2.00	0.70	2.13

Zones 2 & 4

Average dissimilarity = 91.77

Species	Zone 2 Av.Abund	Zone 4 Av.Abund	Av.Diss	Diss/SD	Contrib%
Anchoa mitchilli	105.14	4107.97	36.35	1.07	39.61
Palaemonetes pugio	0.62	968.40	22.79	0.80	24.84
Menidia spp_	28.03	469.67	20.06	0.87	21.86
Floridichthys carpio	1.98	59.65	2.53	0.68	2.76
Leiostomus xanthurus	0.25	50.31	1.84	0.47	2.00

Zones 1 & 3

Average dissimilarity = 93.78

Species	Zone 1 Av.Abund	Zone 3 Av.Abund	Av.Diss	Diss/SD	Contrib%
Menidia spp_	19.49	973.05	37.19	1.31	39.65
Palaemonetes pugio	1.67	374.50	21.32	0.87	22.73
Anchoa mitchilli	33.71	595.60	19.09	0.77	20.36
Floridichthys carpio	1.66	67.95	4.92	0.73	5.25
Leiostomus xanthurus	9.15	49.17	3.11	0.46	3.31

McKay Bay and Palm River seine catch rate (ind./100 m²)

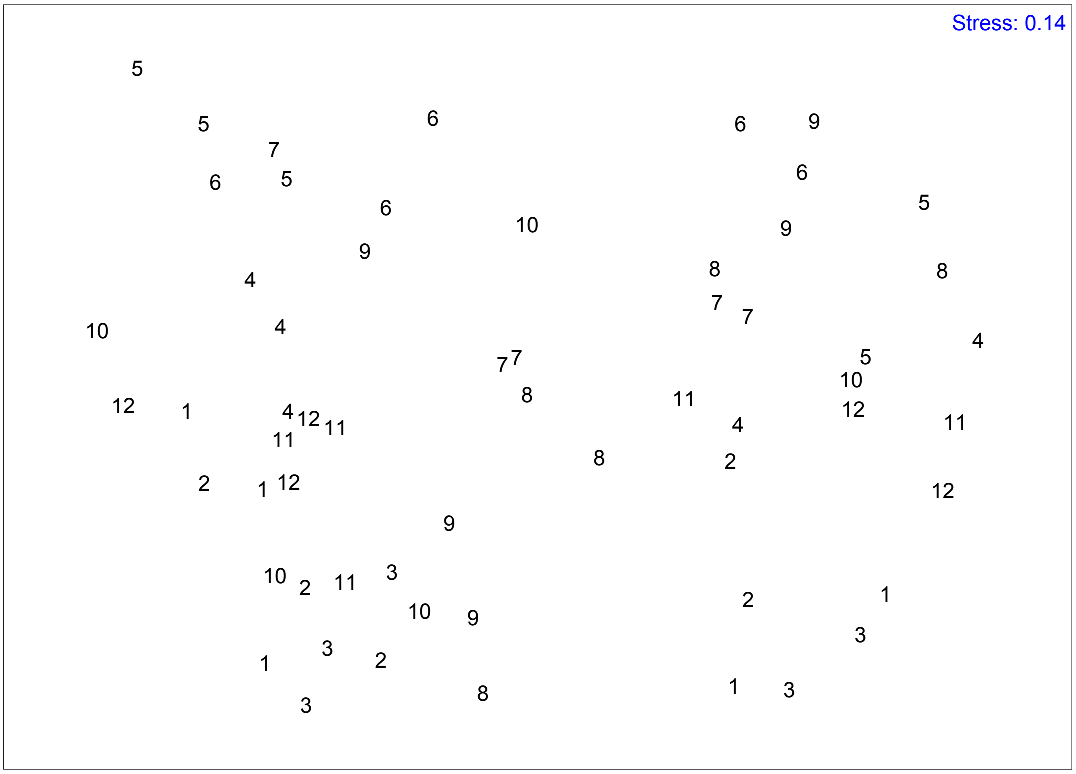


Fig. 2.5.2.2. Similarity among monthly seine samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to month.

McKay Bay and Palm River seine catch rate (ind./100 m²)

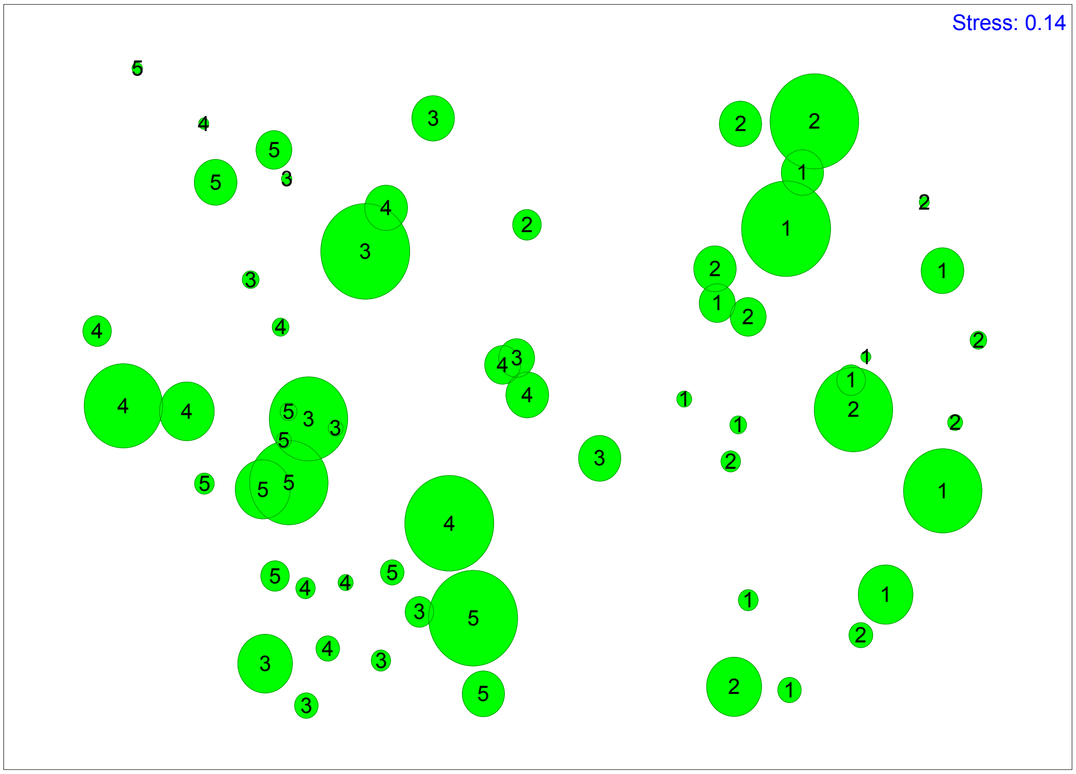


Fig. 2.5.2.3. Similarity among monthly seine samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with bubble size being proportionate to average monthly inflow. Numbers in bubbles are locations along the gradient.

2.5.2.3 Trawl Catch: Change Along the Estuarine Gradient

McKay Bay and Palm River trawl catch rate (ind./100 m²)

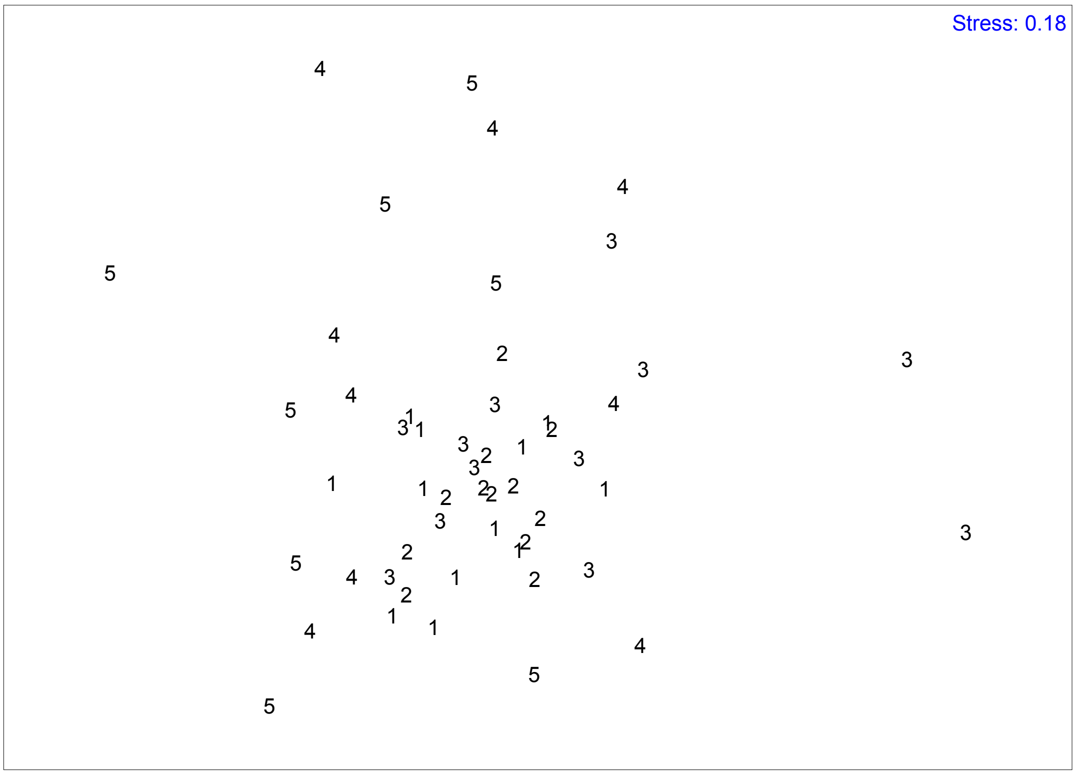


Fig. 2.5.2.4. Similarity among monthly trawl samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to position along the gradient.

Gradient-related changes in the trawl catch were less evident than those observed in the seine catch (ANOSIM global R=0.22, p=0.001), with some catches from seaward zones 1 and 2 being very similar to catches from zones 4 and 5 (Fig. 2.5.2.4). It is likely that the trawl assemblage is similar over large areas of the study area, but that the animals is this assemblage avoid the Palm River when it is hypoxic. In zone 5 (below S-160), trawl catches were zero 15% of the time. As with the seine catch, seasonality explained much more variation than did average monthly variation in inflow (Figs. 2.5.2.5 and 2.5.2.6).

McKay Bay and Palm River trawl catch rate (ind./100 m²)

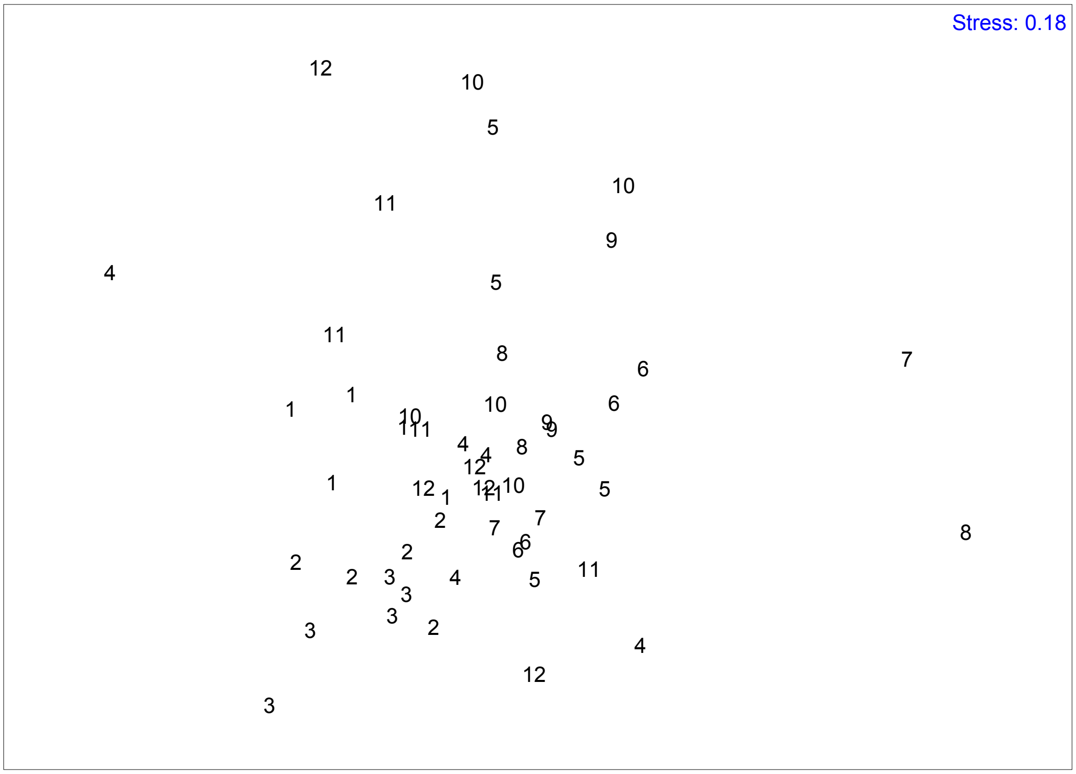


Fig. 2.5.2.5. Similarity among monthly trawl samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to month.

McKay Bay and Palm River trawl catch rate (ind./100 m²)

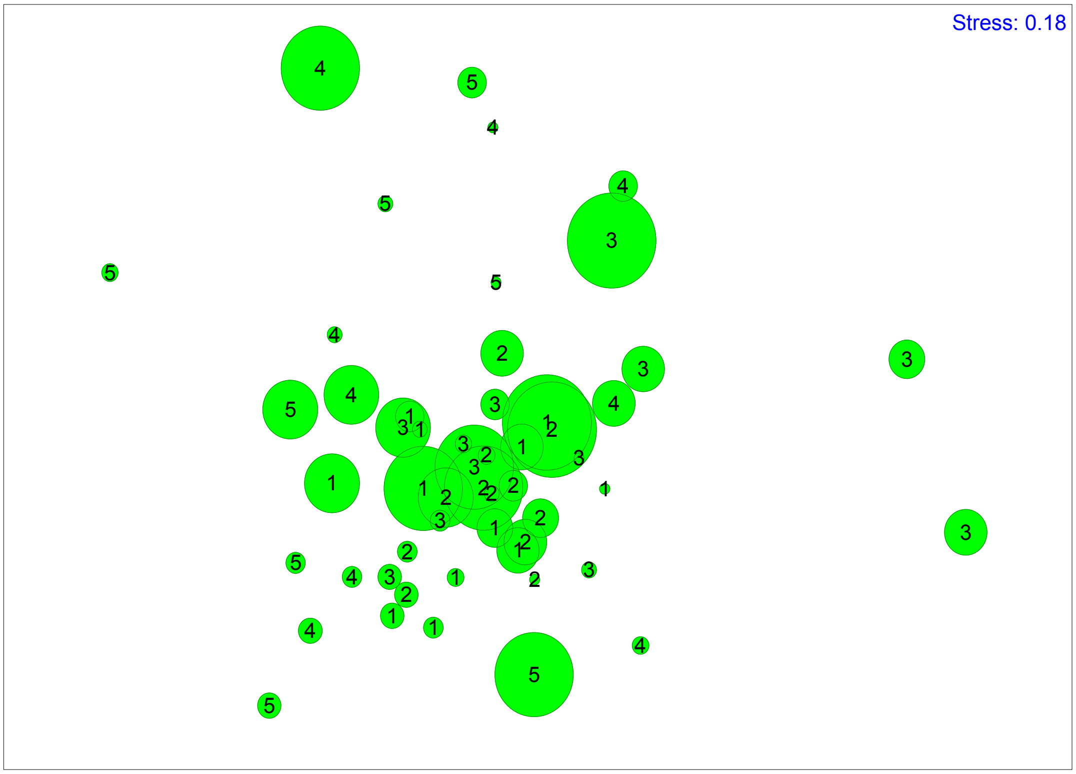


Fig. 2.5.2.6. Similarity among monthly trawl samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with bubble size being proportionate to average monthly inflow. Numbers in bubbles are locations along the gradient.

2.5.2.4 Plankton-net Fish Catch: Change Along the Estuarine Gradient

McKay Bay and Palm River ichthyoplankton catch rate (ind./1000 m³)

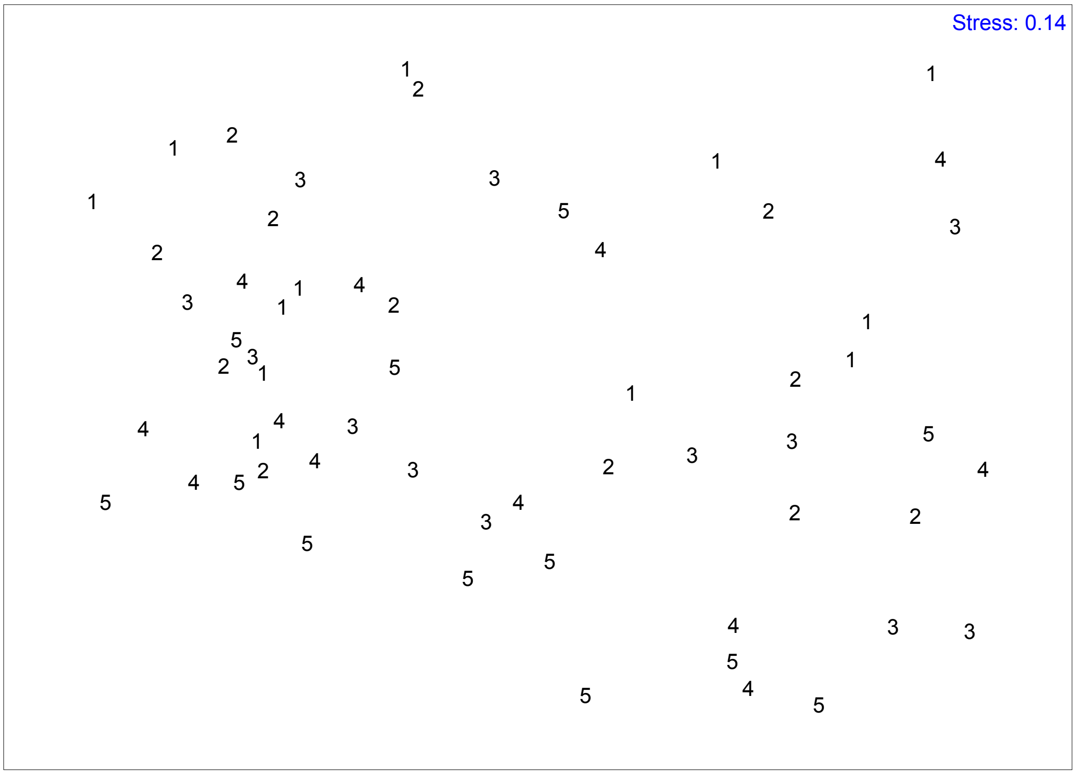


Fig. 2.5.2.7. Similarity among monthly ichthyoplankton samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to position along the gradient.

The estuarine gradient did not explain variation in the ichthyoplankton catch composition (ANOSIM global R was near zero and was not significant). Average monthly inflow (Fig. 2.5.2.9) also did not have an effect. Instead, seasonality (Fig. 2.5.2.8) explained much of the variation. The ichthyoplankton community of McKay Bay often extends into the Palm River. Bay anchovy eggs, for example, are usually more abundant within McKay Bay, but their distribution will extend into the Palm River during dry periods (Peebles 2002).

McKay Bay and Palm River ichthyoplankton catch rate (ind./1000 m³)

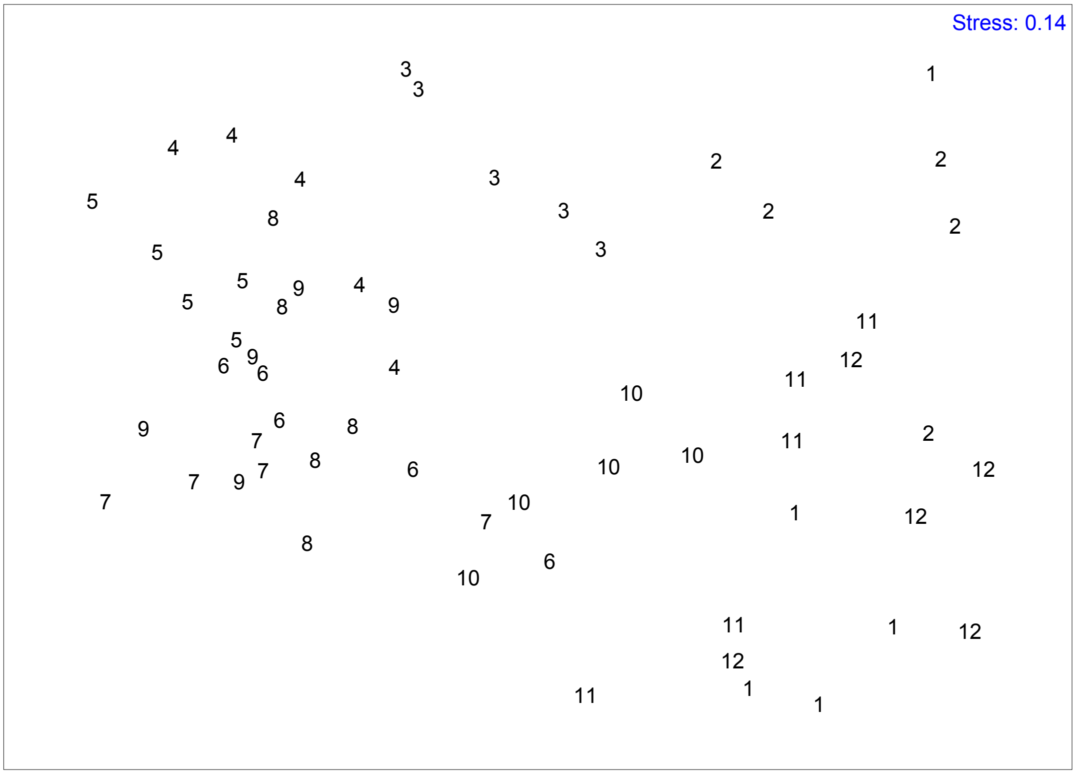


Fig. 2.5.2.8. Similarity among monthly ichthyoplankton samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to month.

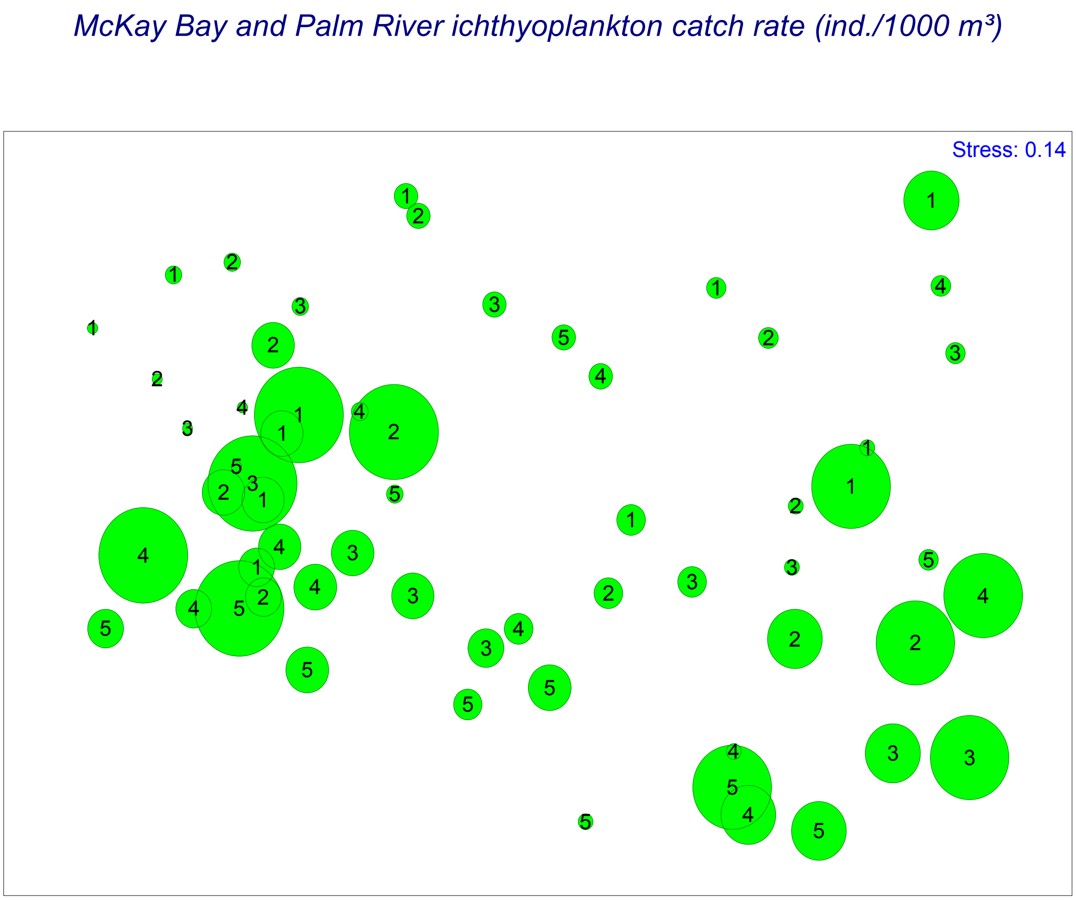


Fig. 2.5.2.9. Similarity among monthly ichthyoplankton samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with bubble size being proportionate to average monthly inflow. Numbers in bubbles are locations along the gradient.

2.5.2.5 Plankton-net Invertebrate Catch: Change Along the Estuarine Gradient

McKay Bay and Palm River invertebrate plankton catch rate (ind./1000 m³)

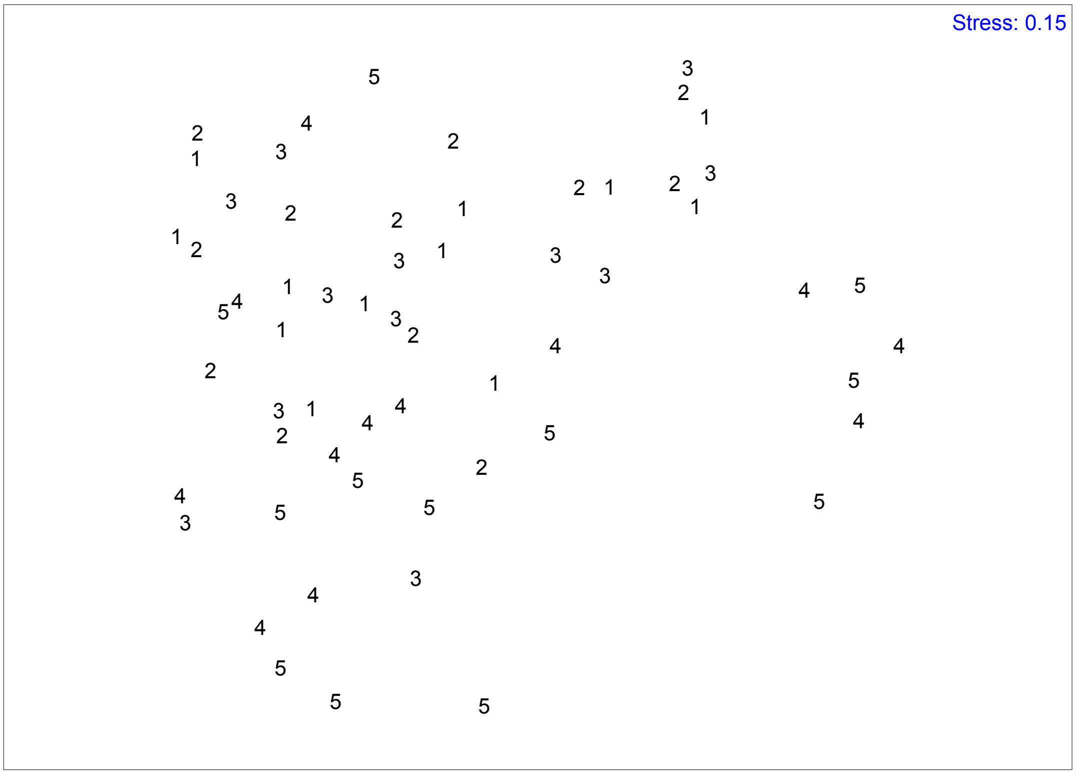


Fig. 2.5.2.10. Similarity among monthly invertebrate plankton samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to position along the gradient.

The gradient effect observed for invertebrate zooplankton was extremely weak (ANOSIM global R=0.10, p=0.003). However, the relationship with average monthly inflow (Fig. 2.5.2.12) produced an interesting pattern; high-inflow and low-inflow months were generally aggregated with some suggestion of a gradient between the two groups. The spread within the groups was largely seasonal (Fig. 2.5.2.11), with winter-spring being placed toward the top and right and summer and fall being placed toward the bottom and left. The large bubbles in Fig. 2.5.2.12 (high-inflow months) contain observations from every zone in the gradient, but these high-inflow samples are otherwise similar to each other. In other words, during high-inflow months, the composition of the invertebrate zooplankton catch in any part of the estuarine gradient may resemble that of any other part of the gradient. The same is true for the low-inflow months that are grouped at the top left of Fig. 2.5.2.12.

September had the highest average inflow and May had the lowest. The months June, July and October were intermediate. These warm-season months were compared to find the compositional cause of the dissimilarity (Table 2.5.2.2). None of the differences in Table 2.5.2.2 were attributed to freshwater organisms, which is an observation that held true when all 66 possible monthly pairings were examined at the >90% contribution level. As a group, truly planktonic organisns such as calanoid copepods (*Labidocera aestiva*, *Acartia tonsa*, *Centropages velificatus*) and the larvacean *Oikopleura dioica* tended to decrease during the wet season and rebound in October. This is the same washout-effect observed in Section 2.4.2.5. The remaining taxa appear to have had inconsistent responses.

Table 2.5.2.2 (page 1 of 2). Comparisons of invertebrate zooplankton catches for taxa that collectively contributed >90% to dissimilarity between wet, dry and transitional months during the warm season. Included values are average abundance (Av.Abund, as ind./1000 m²), average dissimilarity (Av.Diss), the ratio of average dissimilarity to the standard deviation of similarity (Diss/SD) and percent contribution to total dissimilarity (Contrib%).

Months May & July

Average dissimilarity = 44.93

	May	July			
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%
decapod zoeae	43130.95	91788.92	19.35	2.33	43.06
chaetognaths, sagittid	21819.01	14494.39	5.44	1.81	12.11
Labidocera aestiva	12039.56	438.59	4.72	1.90	10.50
Oikopleura dioica	13371.14	8032.69	3.60	1.35	8.02
Acartia tonsa	10434.02	4703.24	2.30	1.75	5.12
cumaceans	4497.58	3609.26	1.80	1.16	4.00
cirriped nauplius stage	4467.35	973.53	1.58	1.22	3.52
decapod mysis larvae	3476.70	4317.85	1.42	1.25	3.16
Mnemiopsis mccradyi	8.04	2227.58	0.85	2.79	1.90

Months May & September

Average dissimilarity = 55.70

	May	September			
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%
decapod zoeae	43130.95	19101.39	13.92	2.09	25.00
Oikopleura dioica	13371.14	10.18	7.26	2.12	13.04
Labidocera aestiva	12039.56	138.45	7.13	1.72	12.80
Acartia tonsa	10434.02	462.54	5.42	4.06	9.74
chaetognaths, sagittid	21819.01	21739.47	5.41	1.52	9.71
polychaetes	100.95	6995.16	3.18	0.69	5.71
cirriped nauplius stage	4467.35	8.88	2.60	1.32	4.66
decapod mysis larvae	3476.70	4373.96	2.17	0.97	3.90
cumaceans	4497.58	624.97	2.00	0.97	3.58
decapod megalopae	722.59	2444.84	1.17	0.80	2.10

Table 2.5.2.2 (page 2 of 2). Comparisons of invertebrate zooplankton catches for taxa that collectively contributed >90% to dissimilarity between wet, dry and transitional months during the warm season. Included values are average abundance (Av.Abund, as ind./1000 m²), average dissimilarity (Av.Diss), the ratio of average dissimilarity to the standard deviation of similarity (Diss/SD) and percent contribution to total dissimilarity (Contrib%).

Months September & October

Average dissimilarity = 44.38

Species	September Av.Abund	October Av.Abund	Av.Diss	Diss/SD	Contrib%
chaetognaths, sagittid	21739.47	26769.32	10.94	1.48	24.64
decapod zoeae	19101.39	21716.13	6.25	1.74	14.08
Acartia tonsa	462.54	8461.02	6.17	2.99	13.90
Oikopleura dioica	10.18	5173.42	4.04	1.17	9.11
polychaetes	6995.16	419.85	4.00	0.72	9.01
decapod mysis larvae	4373.96	1540.45	3.00	0.99	6.77
decapod megalopae	2444.84	588.80	1.56	0.80	3.52
Liriope tetraphylla	264.41	2176.48	1.53	1.90	3.45
Labidocera aestiva	138.45	1672.42	1.17	2.35	2.63
Centropages velificatus	1.66	1020.20	0.77	1.03	1.74
Americamysis almyra	997.63	39.03	0.72	2.01	1.61

McKay Bay and Palm River invertebrate plankton catch rate (ind./1000 m³)

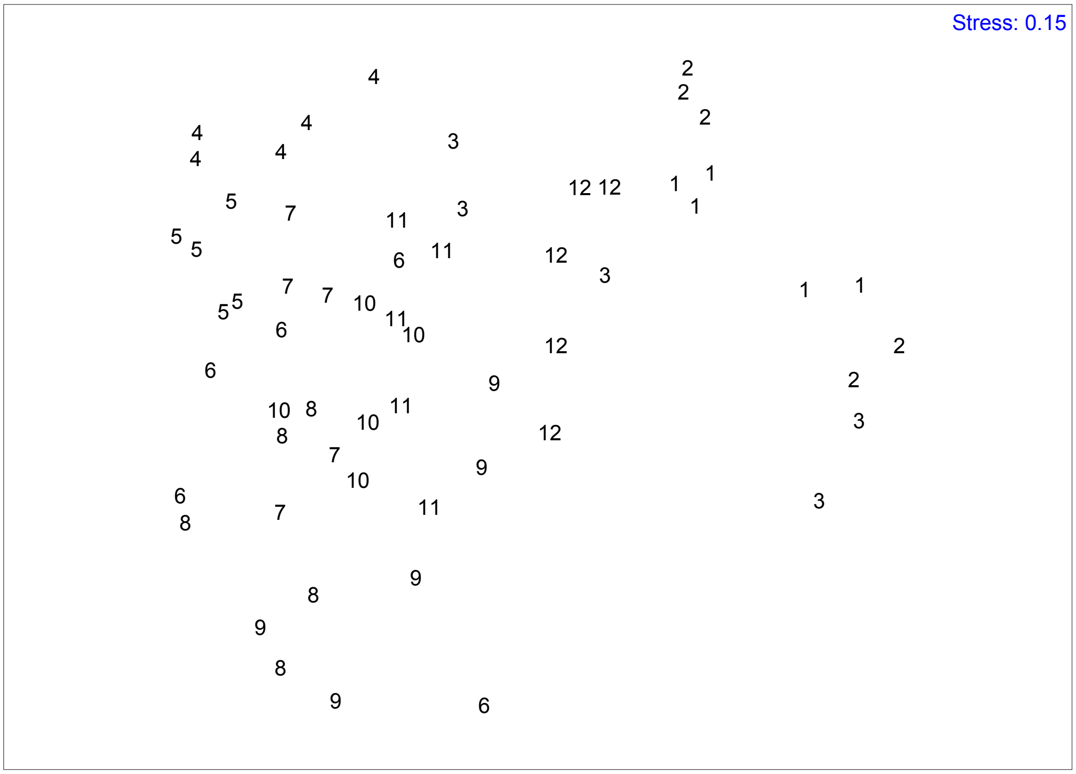


Fig. 2.5.2.11. Similarity among monthly invertebrate plankton samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with samples labeled according to month.

McKay Bay and Palm River invertebrate plankton catch rate (ind./1000 m³)

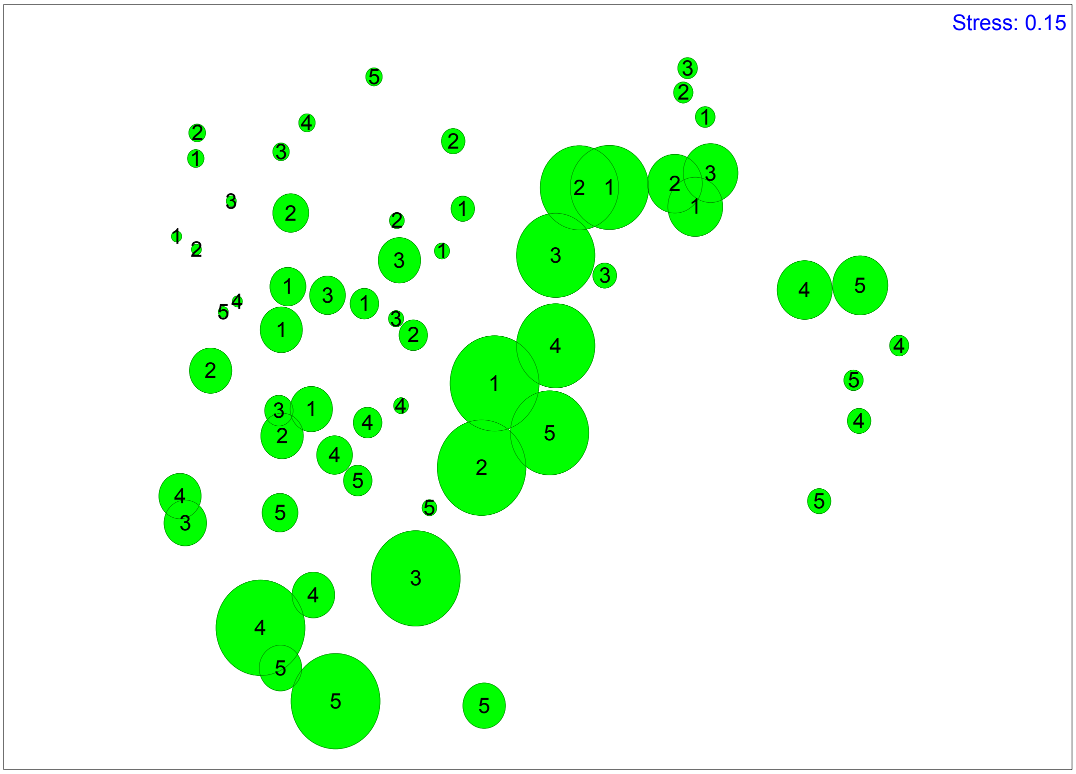


Fig. 2.5.2.12. Similarity among monthly invertebrate plankton samples that have been classified by position on the estuarine gradient (distance between samples is proportionate to Bray-Curtis dissimilarity), with bubble size being proportionate to average monthly inflow. Numbers in bubbles are locations along the gradient.

2.6 Inflow-Associated Changes in Organism Distribution and Abundance

2.6.1 **Methods.** The central geographic tendency for plankton-net catch CPUE was calculated as a weighted mean

$$km_U = \frac{\Sigma(km \cdot U)}{\Sigma U} ,$$

where *km* is distance from McKay Bay's southwestern entrance and *U* is CPUE (= organism density as ind./m^{-3}).

The total number of organisms in the HBMP survey area during each collection effort was estimated by summing the products of mean organism density ($\bar{U}$) and tide-corrected water volume (*V*) from the five zones defined in Section 2.5

$$N = \Sigma(\bar{U} \cdot V) .$$

Zone volume and surface area were represented by dimensions from 141 cells in the Luther and Meyers (2004) hydrodynamic model, excluding cells from unsampled regions (32 cells from East Bay and 12 cells from the upper arm of McKay Bay). The upper elevation of these cells is mean lower low water (MLLW). Verified water-level data from NOAA Station 8726667 (CSX Rockport, McKay Bay Entrance, MLLW tidal datum) were used to estimate mean water level during individual collections, which was multiplied by the summed zone surface area to correct zone volumes at MLLW to date and time-specific volumes.

Blue crabs and pink shrimp are bottom-dwelling animals that are collected in a reasonably quantitative manner by the trawling methods used during the HBMP. To investigate these economically important species' abundance responses to inflow, abundance was estimated by summing the products of mean organism density ($\bar{U}$, as No. m^{-2}, see Section 1.2.2) and zone surface area (*A*) from the Luther and Meyers (2004) hydrodynamic model

$$N = \Sigma(\overline{U} \cdot A) \ .$$

Regressions were performed for km_U on total inflow (*F*, see Fig 2.4.1) and *N* on *F*. *N* and *F* were Ln-transformed prior to regression, which greatly improved normality (see also Section 2.3.1). Plankton data from the September 2000 HBMP survey were excluded because this survey was completed using two collection efforts that were weeks apart, and inflows had fluctuated during the interval between the two efforts. The remaining 47 monthly plankton-net surveys were completed during one night each. All regressions were limited to taxa that were encountered during a minimum of 10 surveys. Twelve linear and nonlinear regression models were evaluated for each taxon. In these regressions, *F* was represented by same-day inflow and by mean inflows extending as far back as 118 days prior to the sampling date. A large percentage of the trawl surveys were completed over 2-d periods; the second day was used as the starting point for calculating previous mean inflows. The combinations of consecutive dates that produced the strongest correlations were used to model the km_U and *N* responses to *F* for each taxon. This approach provided an indication of the temporal responsiveness of the various taxa to inflow variations. An organism was considered to be responsive if the regression slope was significantly different from zero at $p<0.05$.

The time frame of an individual abundance response provides some degree of insight into the mechanism that causes the response (Robins et al., in press). Response mechanisms can be divided into three general categories based on the length of the lag in the abundance correlation with inflow: catchability, recruitment, and stock. The lag ranking for these response categories is catchability<recruitment<stock, where catchability has a lag measured in days, recruitment has a lag similar to the age of the recruit stage, and stock has a lag similar to the age of reproducing adults. In the context of fisheries research, the term *catchability* has historically referred to the selectivity of a specific gear type, but has recently been used to describe animals' vulnerability to the gear caused by the animals' movement into or away from the area where the gear is being deployed (Robins et al., in press). In its original usage, the term *recruit* was applied to young fish that had recently entered a fishery. Its usage has

broadened over the years to allow it to apply to the addition of young individuals to any population or geographic area.

Catchability response to inflow. The fastest inflow-abundance mechanism involves distribution shifts, such as animals moving into the surveyed area from adjacent areas (i.e., from the direction of the shore, from the benthic substratum, or from areas seaward or landward of the surveyed area). Such behavior could represent either involuntary flushing or an integral part of a mechanism for deliberate relocation in order to maintain associations with favorable water qualities or prey concentrations. Animals may redistribute themselves by moving into the tidal river from the seaward direction, either as larvae that are carried upstream by the vigorous two-layered circulation that is often associated with high freshwater inflows, or as older stages that are actively following olfactory trails that are created or distributed by inflows (Kristensen 1964, Odum 1970, Benfield and Aldrich 1991). In all types of redistribution response, the result is likely to be a relatively fast change in catch rate. Numbers simply increase because the animals' redistribution caused them to be more likely to be collected. It is likely that some redistributions take longer than a few days, especially for benthic animals or animals that take advantage of two-layered estuarine circulation to move longer distances from seaward spawning grounds into the tidal river. The catchability responses of planktonic animals are not likely to be of interest to resource managers, except when they involve the delivery of recruits or their prey to essential habitat such as nurseries.

Recruitment response to inflow. The second group of responses takes longer to become evident in the catch data. These are primarily changes in reproductive output by the parent generation and improved survival of the spawned progeny (fast growth is generally accepted as being an inherent part of high survival rates). Egg production is energetically expensive for most aquatic animals, and may therefore vary as a function of adult energy intake (Rothschild 1986). If adults spawn more intensively at a seaward location during high-inflow periods as a response to better food supply, then the resulting increase in progeny will be evident at the point when these progeny move into the tidal river and congregate there, barring intervention by predation or hydrodynamic factors. Likewise, if inflow positively affects survival during an extended period of life, then the effect will require time before it becomes evident in the catch data. At various places around the world, correlations between fisheries yields and freshwater inflows have been shown to be lagged by the average age of the individuals in the catch (Drinkwater 1986). The ages of animals in the plankton-net catch are highly variable, but the vast majority are less than four months old. Recruitment responses can result from either increased reproductive output or increased survival, and are of interest to resource managers because they represent changes in population size. The hallmark of a recruitment response is a time lag in the correlation with inflow that is similar to the age of the catch.

Stock response to inflow. The dynamics of an adult stock have an obvious, but highly variable, impact on recruitment. If the abundance of recruits is tied to the dynamics of the parent stock, and the parent stock responds favorably to inflow, then an inflow response may result that is scaled to the age of the parent stock. Positive inflow effects may take a long time to accrue to the point of detection, and therefore it is possible to have a stock response in the absence of a recruitment response. In the present context, detecting a stock response involves the indirect measurement of the adult stock's population response to inflow, using the abundance of its progeny as a proxy. In short-lived species, stock response could be confused with lags that are associated with the time required for trophic cascades to develop in response to inflow.

Types of recruitment response. Given that growth rate is inherently coupled with survival (Takasuka et al. 2004), the two principal types of positive recruitment response are increases in parental reproductive output and increases in the survival of progeny. The method of evaluating mean inflow effects by using progressively longer inflow periods will detect both reproductive and survival responses. However, if the response is reproductive in nature, a lag representing a discrete period near spawning may produce a stronger correlation. Correlations based on either continuous or discrete lags will both tend to center on the age of the animals in question, provided survival responses are somewhat consistently distributed between hatching and collection. If, on the other hand, there are one or more critical survival periods within this period, then the correlation may be biased toward a period that is shorter than the average age. An example of this would be high variability in survival at the point when a larva settles from the plankton onto substrate. If freshwater inflow affects success during settlement (e.g., by providing a better food supply, fewer predators, reduced predator visibility, etc.), then the correlation may be strongest at a lag equivalent to the time between settlement and capture.

2.6.2 **Results and Discussion.**

2.6.2.1 Distribution and Abundance Responses

Inflow-associated distribution shifts were observed in 25 plankton-net taxa (Table 2.6.2.1, Appendix A), and abundance responses were observed in 34 plankton-net taxa (Table 2.6.2.2, Appendix B). Taxa that had positive abundance responses that were scaled to both catchability (very short or no lag) and recruitment (lag similar to age of recruits) have two lags represented in Table 2.6.2.2. For all responses, a linear model provided either better fit or fit that was comparable to other models, although the average fit was generally lower than that observed in other estuarine systems (Peebles and Flannery 1992, Peebles 2002a,b, Peebles 2004). Nine of the distribution responses were of the “expected” type, where downstream movement was observed as a response to increased inflow (negative slopes in Table 2.6.2.1), and 16 were of the opposite type, where organisms appeared to move against the tidally averaged direction of flow (positive slopes in Table 2.6.2.1). Downstream movement during increased inflows has been the overwhelmingly dominant type of distribution response documented by similar studies, although the studies cited above were largely limited to the tidal rivers themselves, with little or no sampling in the rivers’ receiving basins. One or more of the 16 upstream-shift responses may be spurious (e.g., bay anchovy eggs), yet the large proportion of total shifts that have an upstream direction suggests that the

Table 2.6.2.1. Plankton-net-based organism distribution (km_U) responses to mean freshwater inflow (Ln *F*), ranked by linear regression slope (*b*). Other regression statistics are sample size (*n*), intercept (*a*), slope probability (*p*) and fit (r^2, as %). *DW* identifies where serial correlation is possible (x indicates p<0.05 for Durbin-Watson statistic). *d* is the number of daily inflow values used to calculate mean freshwater inflow.

Description	Common Name	*n*	*a*	*b*	*p*	r^2	*DW*	*d*
Palaemonetes pugio juveniles	daggerblade grass shrimp	10	-1.450	1.074	0.0208	51		1
Saphirella spp.	copepods	17	-1.617	0.824	0.0200	31		86
Gobiosoma spp. postflexion larvae	gobies	31	1.005	0.540	0.0378	14	x	118
Anchoa mitchilli postflexion larvae	bay anchovy	31	0.407	0.449	0.0422	13		52
polychaetes	sand worms, tube worms	46	1.028	0.445	0.0030	18		1
decapod mysis	shrimp larvae	47	0.106	0.438	0.0001	30	x	1
Pseudodiaptomus coronatus	copepod	40	0.218	0.406	0.0382	11	x	118
Anchoa mitchilli eggs	bay anchovy	16	-0.195	0.363	0.0099	39		6
Parasterope pollex	ostracod, seed shrimp	46	0.081	0.325	0.0005	25	x	62
chaetognaths, sagittid	arrow worms	45	0.967	0.325	0.0191	12	x	1
fish eggs, percomorph	fish eggs	32	0.104	0.308	0.0226	16		6
decapod zoeae	crab larvae	47	0.778	0.293	0.0033	18	x	1
Americamysis stucki	opossum shrimp, mysid	28	0.429	0.276	0.0401	15	x	84
Erichsonella attenuata	isopod	18	0.377	0.241	0.0420	23		65
amphipods, gammaridean	amphipods	47	0.893	0.178	0.0188	12	x	1
Anchoa mitchilli adults	bay anchovy	47	0.678	0.143	0.0314	10	x	10
Munna reynoldsi	isopod	20	1.663	-0.140	0.0365	22	x	65
Oikopleura dioica	larvacean	38	2.270	-0.197	0.0488	10		2
Lironeca sp.	parasitic isopod	47	2.729	-0.220	0.0105	14		21
ostracods, podocopid	seed shrimps	29	3.717	-0.517	0.0209	18		25
Limulus polyphemus larvae	horseshoe crab	17	4.510	-0.633	0.0001	65		3
Mnemiopsis mccradyi	comb jelly, ctenophore	26	6.540	-0.758	0.0063	27	x	1
Chrysaora quinquecirrha	sea nettle jellyfish	28	7.320	-0.771	0.0033	29		14
Leptochela serratorbita	shrimp	13	5.642	-0.867	0.0103	13		14
cirriped cypris	barnacle larvae	19	6.267	-0.957	0.0041	19		45

Table 2.6.2.2. Plankton-net-based organism abundance responses to mean freshwater inflow (Ln *N* vs. Ln *F*), ranked by linear regression slope (*b*). Other regression statistics are sample size (*n*), intercept (*a*), slope probability (*p*) and fit (r^2, as %). *DW* identifies where serial correlation is possible (x indicates $p<0.05$ for Durbin-Watson statistic). *d* is the number of daily inflow values used to calculate mean freshwater inflow. *Anchoa mitchilli* juveniles and *Americamysis almyra* appeared to have more than one lag time in their positive responses to inflow; regressions are presented for each lag time, the duration of which is indicated by *d*.

Description	Common Name	*n*	*a*	*b*	*p*	r^2	*DW*	*d*
polychaetes	sand worms, tube worms	46	10.800	0.846	0.0001	30		14
Harrieta faxoni	isopod	15	9.871	0.748	0.0109	40		2
Americamysis almyra	opossum shrimp, mysid	44	9.514	0.745	0.0009	23	x	1
Chrysaora quinquecirrha	sea nettle	28	9.471	0.731	0.0009	35		1
Americamysis almyra	opossum shrimp, mysid	44	9.841	0.639	0.0121	14	x	22
Anchoa mitchilli juveniles	bay anchovy	41	10.551	0.529	0.0012	24		2
Anchoa mitchilli juveniles	bay anchovy	41	10.930	0.433	0.0199	13	x	25
Sphaeroma quadridentata	isopod	23	8.543	0.425	0.0154	25		34
foraminiferans	foraminiferans	20	8.300	0.415	0.0301	24	x	18
ostracods, podocopid	ostracods, seed shrimps	29	8.685	0.368	0.0299	16		52
Anchoa mitchilli adults	bay anchovy	47	9.768	0.355	0.0071	15		3
Lolliguncula brevis juveniles	bay squid	23	10.770	-0.259	0.0291	21		17
Syngnathus scovelli juveniles	gulf pipefish	19	11.561	-0.412	0.0035	40	x	118
Cynoscion arenarius preflexion larvae	sand seatrout	13	11.515	-0.433	0.0113	46		1
Chasmodes saburrae postflexion larvae	Florida blenny	10	11.640	-0.454	0.0224	50		3
amphipods, caprellid	skeleton shrimps	26	13.067	-0.492	0.0260	19		93
blenniid preflexion larvae	blennies	36	12.985	-0.529	0.0096	18		22
decapod mysis	shrimp larvae	47	18.738	-0.571	0.0029	18	x	118
Parasterope pollex	ostracod, seed shrimp	46	16.738	-0.595	0.0438	9	x	118
Anchoa mitchilli postflexion larvae	bay anchovy	31	15.125	-0.647	0.0118	20	x	55
Microgobius spp. postflexion larvae	gobies	22	13.902	-0.660	0.0163	26		114
Eusarsiella zostericola	ostracod, seed shrimp	37	14.130	-0.692	0.0011	27		118
alphaeid postlarvae	snapping shrimps	31	15.178	-0.696	0.0061	23		84
Mnemiopsis mccradyi	comb jelly, ctenophore	26	17.336	-0.734	0.0498	15		64
Squilla empusa larvae	mantis shrimp	22	13.986	-0.742	0.0082	30		118
decapod zoeae	crab larvae	47	22.172	-0.766	0.0079	15	x	94
Chasmodes saburrae flexion larvae	Florida blenny	13	13.104	-0.768	0.0046	53		21
cumaceans	cumaceans	47	19.355	-0.782	0.0035	17	x	15
Evadne tergestina	water flea	15	15.789	-0.959	0.0269	32		2
cirriped nauplius stage	barnacles	31	16.718	-1.077	0.0256	16		92
Anchoa mitchilli eggs	bay anchovy	16	19.012	-1.163	0.0478	25		12
fish eggs, percomorph	sciaenid eggs (primarily)	32	19.612	-1.166	0.0029	26	x	96
Anchoa spp. preflexion larvae	anchovies	25	18.746	-1.285	0.0040	31		44
Anchoa spp. flexion larvae	anchovies	26	18.797	-1.326	<0.0001	55		49

phenomenon is real.

Three mechanisms could cause the upstream shift in distribution as a response to increased inflow: (1) an increase in two-layered circulation that convects plankton into the Palm River from McKay Bay, (2) movement of bottom-dwelling taxa from the substrate into the water column of the Palm River as a response to inflow-induced benthic hypoxia (i.e., hypoxia caused by increased density stratification), and (3) organism behaviors that cause movement towards the freshwater inflow signal. The third mechanism could be brought about by swimming toward the freshwater signal or, in the case of smaller animals with weaker swimming capabilities, by rising into the water column during flood tides whenever the freshwater signal is strong (selective tidal-stream transport).

Mechanisms 2 and 3 are active (behavioral), whereas mechanism 1 is passive. Percomorph eggs are primarily composed of the eggs of sciaenid fishes (seatrouts, silver perch, southern kingfish). These eggs act as passive particles except for having non-neutral buoyancies that are influenced by water density. When 6-d mean inflows were <100 cfs, percomorph eggs were exclusively centered within McKay Bay (20 observations). Unlike McKay Bay, the Palm River is atypical of the locations where these fishes spawn. Most of Florida's sciaenids spawn within open coastal waters, including bays and the embayment-like mouths of funnel-shaped tidal rivers. However, when mean inflows were in the 100-400 cfs range, percomorph fish eggs were sometimes centered within the Palm River or near its mouth (6 observations). Percomorph eggs were largely missing from both McKay Bay and the Palm River when inflows in excess of 400 cfs were sustained, and there was a negative relationship between the total numbers of percomorph eggs and inflow (Table 2.6.2.2). Collectively, these observations suggest that the upstream movement of eggs was caused by two-layered circulation. The Palm River becomes strongly stratified as inflows from S160 increase. When the Palm River is strongly stratified, water from McKay Bay crosses the sill near the mouth of the Palm River and moves upstream along the bottom of the Palm River towards S160 (Luther and Meyers 2004). This landward-moving water mass entrains plankton, including fish eggs. A less plausible explanation is that spawning adults were attracted to the Palm River when inflows were moderately elevated, but spawned less once they arrived. A short deployment of a recording hydrophone during the transition from dry to wet season would distinguish between the two explanations. Sciaenid fishes in spawning aggregations make audible calls. If the eggs in the Palm River originate from within the Palm River, sciaenid calling will also be clearly evident there.

Of the 16 taxa that appeared to move upstream during elevated inflows, all except two decreased in number as inflows increased. Adult bay anchovies (>30 mm SL), which are not planktonic yet are frequently collected by plankton nets deployed at night, were almost always centered within McKay Bay rather than in the Palm River. They approached the mouth of the Palm River during elevated inflow periods and their numbers increased, presumably due to immigration from other parts of Tampa Bay (in conformity with mechanism 3). The only taxon that “moved” into the interior of the Palm River and became more abundant there during periods of increased inflow was juvenile and adult polychaetes. It is likely that these primarily benthic animals were refugees from the benthic hypoxia that forms during wet periods (mechanism 2). Rising into the water column in areas most affected by benthic hypoxia (see Fig. 2.5.3) would cause these animals to appear to be moving upstream and increasing in number during wet periods.

Given the propensity for the survey area to harbor high densities of gelatinous predators (ctenophores, jellyfishes, and hydromedusae), inflow effects on the distribution and abundance of these organisms is of particular interest. The ctenophore (comb-jelly) *Mnemiopsis mccradyi* is a predator on fish eggs and larvae (Purcell 1985, Purcell and Arai 2001), and this species often had very high densities in the upper Palm River (Fig. 2.2.43), particularly during spring and summer. Elevated inflows (generally >100 cfs) caused *Mnemiopsis* to move downstream and to generally decrease in total number. The sea nettle *Chrysaora quinquecirrha*, a large, voracious predator on juvenile fishes that is exceedingly abundant within the Palm River (Fig. 2.2.42), also moved downstream during periods of elevated flow, but increased in number rather than decreasing as *Mnemiopsis* did. There were no trends in the distributions and abundances of the hydromedusae *Liriope tetraphylla* and *Nemopsis* sp., as both of these tended to be most abundant in lower McKay Bay near its connection with East

Bay (Figs. 2.2.44 and 2.2.45).

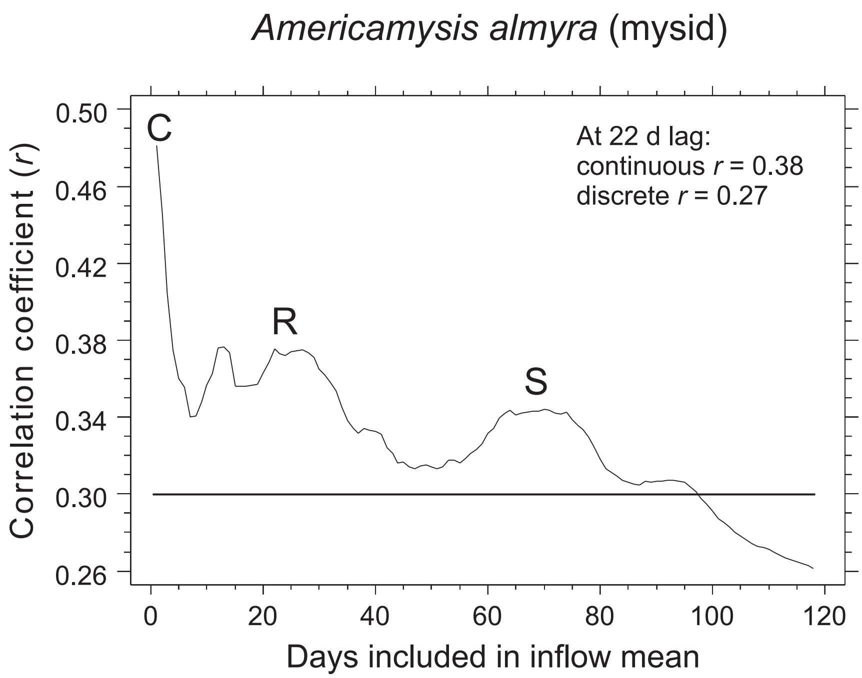
The positive abundance responses of the mysid *Americamysis almyra*, bay anchovy juveniles, and pink shrimp juveniles are of particular interest. The responses of the first two animals, which were collected by plankton net, are described in Table 2.6.2.2. The regression for the trawl-based pink shrimp abundance response is

$$\text{Ln } N = 7.486 + 0.42(\text{Ln } F_{60}),\ (n = 44,\ r^2 = 0.18,\ p = 0.004)\ ,$$

where F_{60} is the mean inflow during the 60 d prior to collection. Trawl-based blue crab abundance responses were negative and highly irregular. However, separate examination of the responses of juveniles, adult males, and adult females would be required before a lack of positive inflow response by the blue crab could be confirmed.

The responses of the mysid and bay anchovy are noteworthy because these two species are biomass dominants that are important prey for the juvenile estuarine-dependent fishes that use tidal rivers as nursery habitat (Peters and McMichael 1987, McMichael et al. 1989, Peebles and Hopkins 1993). The pink shrimp is a species with considerable economic value that has been previously shown to have a positive, lagged abundance response to inflow (Browder 1985). The mysid and bay anchovy had multiple peaks in their lagged abundance response (Fig. 2.6.2.1), the first of which being so short that it is highly likely to have been a catchability response. Each had a secondary peak that generally coincided with the approximate ages of the animals (i.e., a recruitment response), although the anchovy lag was at the young end of the age distribution observed in other areas (Peebles 2002a). This could be an indication that survival rates were reduced in the Palm River and McKay Bay, or it could indicate that local inflow histories had their first impact on late-stage larvae that were arriving in the area from the seaward direction. In all three species, the apparent recruitment response was more strongly correlated with long-term average inflows than with daily inflows of similar lag (continuous vs. discrete correlations, Fig. 2.6.2.1), suggesting that the responses were the products of continued exposure to inflow rather than responses to distinct inflow events. This is consistent with inflow effects on survival.

The recruitment responses of these three species are plotted together in Fig.



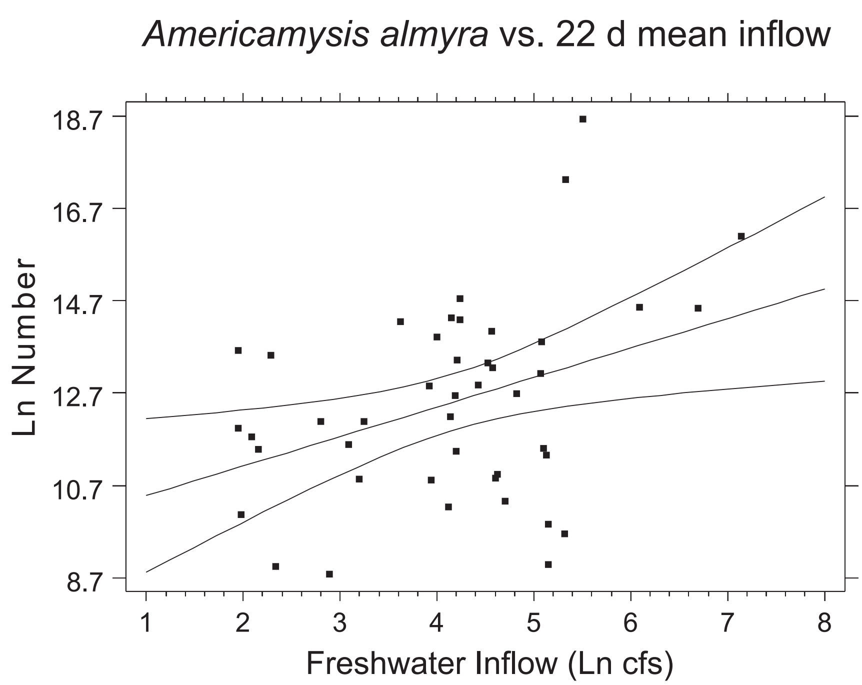
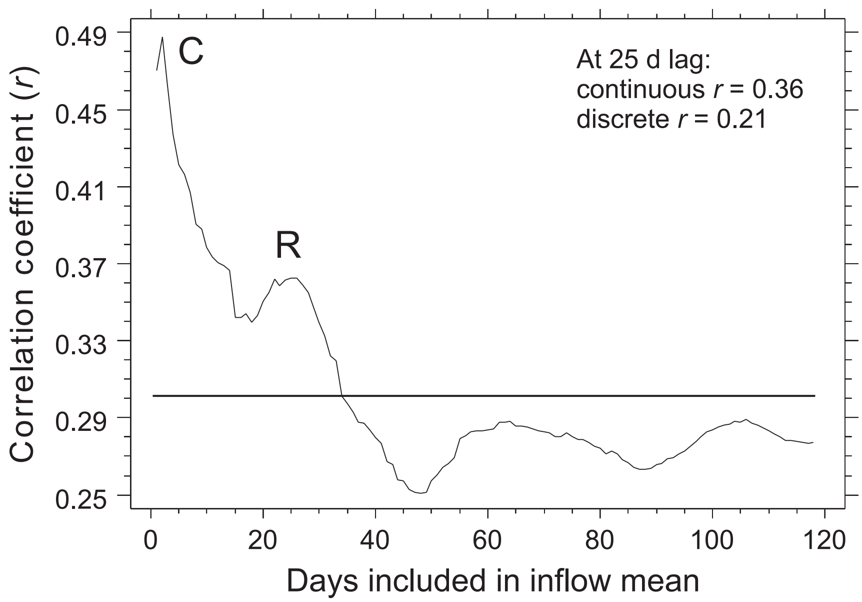


Fig. 2.6.2.1. Positive organism abundance (Ln *N*) responses to mean freshwater inflow (Ln *F*) over variable periods. The horizontal line in the top figure identifies the 5% probability threshold for *r*. *C* = catchability response, *R* = presumptive recruitment response and *S* = presumptive stock response. The regression plot for a lag at *R* (bottom figure) includes 95% confidence limits for estimated means (see Table 2.6.2.2 and Appendix B).

Anchoa mitchilli juveniles (bay anchovy, 15-30 mm SL)



Anchoa mitchilli juveniles vs. 25 d mean inflow

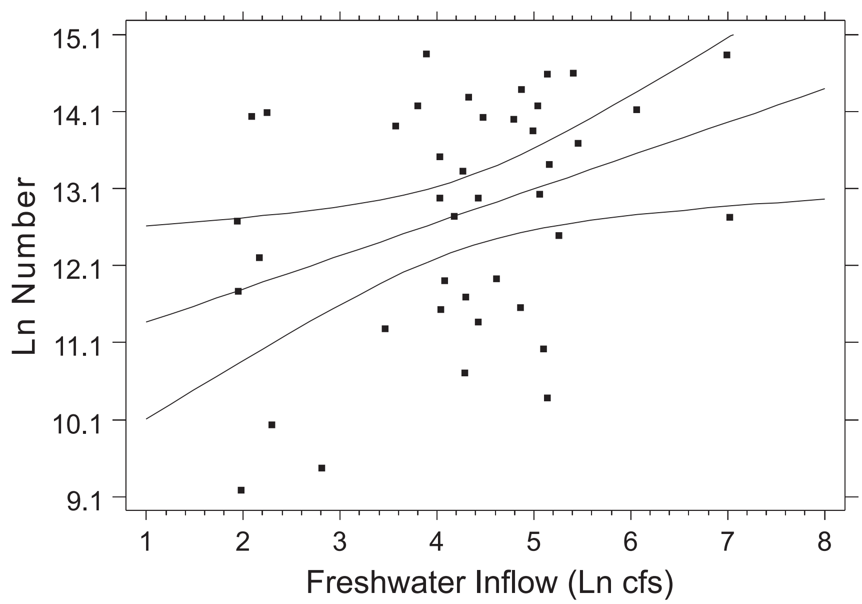
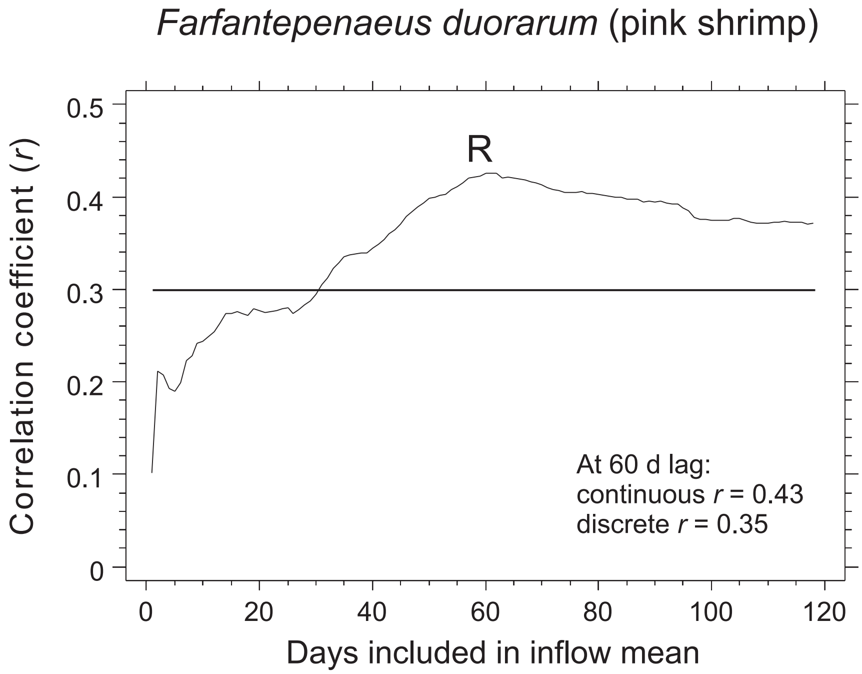


Fig. 2.6.2.1. (cont.)



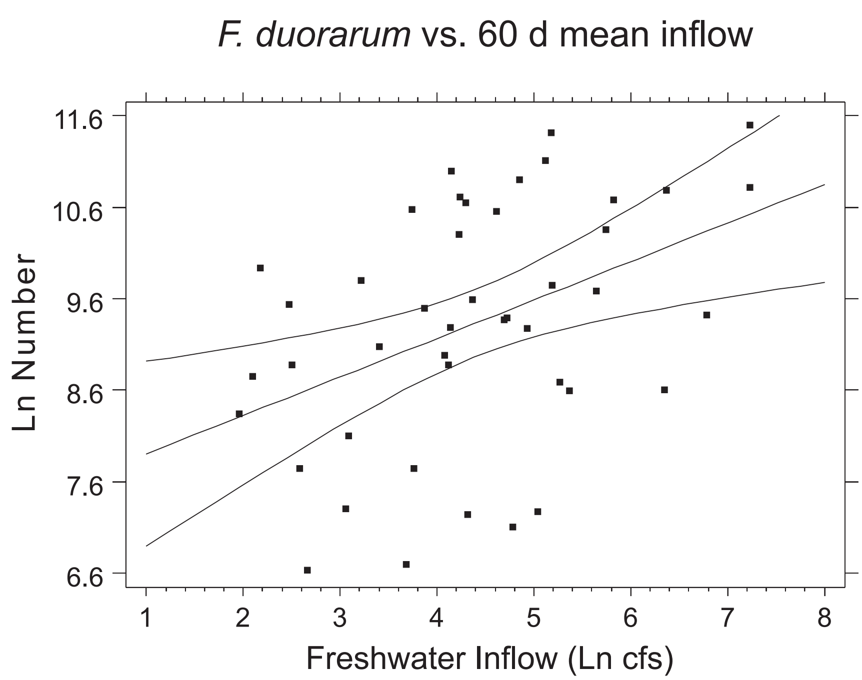


Fig. 2.6.2.1. (cont.)

2.6.2.2, which illustrates a method for evaluating the effect of different inflow rates on the abundances of organisms relative to a “typical” abundance (abundance at the median inflow of a selected index period). The y-intercepts for the three regressions are higher than those observed in the tidal Alafia River (Peebles 2004), suggesting that a certain amount of background abundance would be present in the absence of inflow. How long this background abundance would persist in the long-term absence of inflow is not known. In general, the distribution and abundance responses to inflow were apparent for a number of taxa, but they were irregular (poor regression fit), and the overall abundances of some estuarine and estuarine-dependent taxa were low relative to other estuarine areas (Fig. 2.6.2.3).

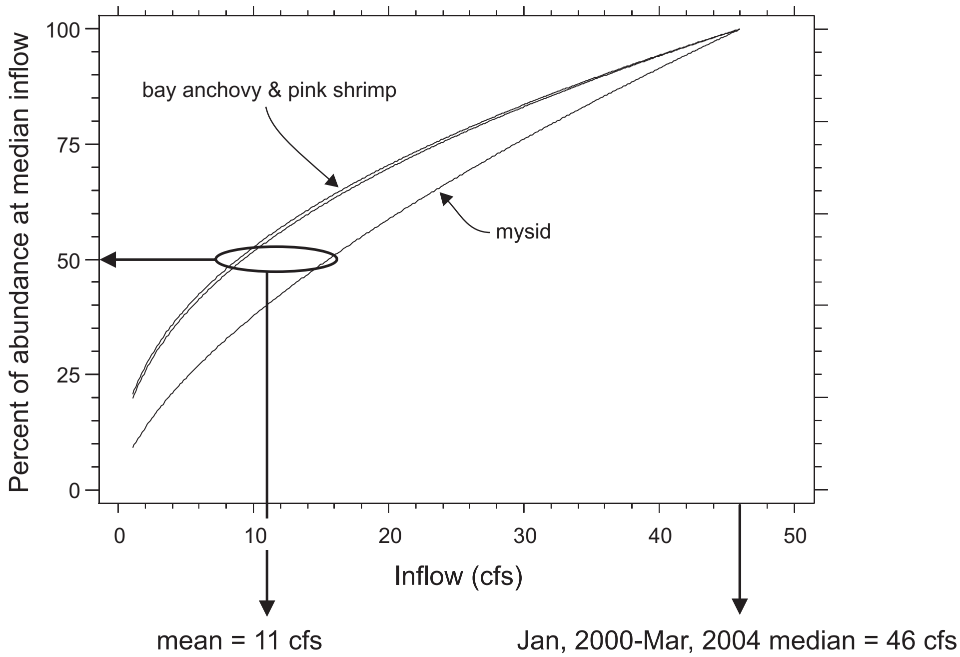


Fig. 2.6.2.2. Method for estimating the percentage of a standard reference abundance. The standard reference abundance is the abundance at median inflow, to which the abundances from regressions in Fig. 2.6.2.1 can be standardized. In this example, 11 cfs would be the average inflow required to maintain 50% of typical abundance. Note that inflow is total estimated inflow and is therefore not limited to discharges from S-160.

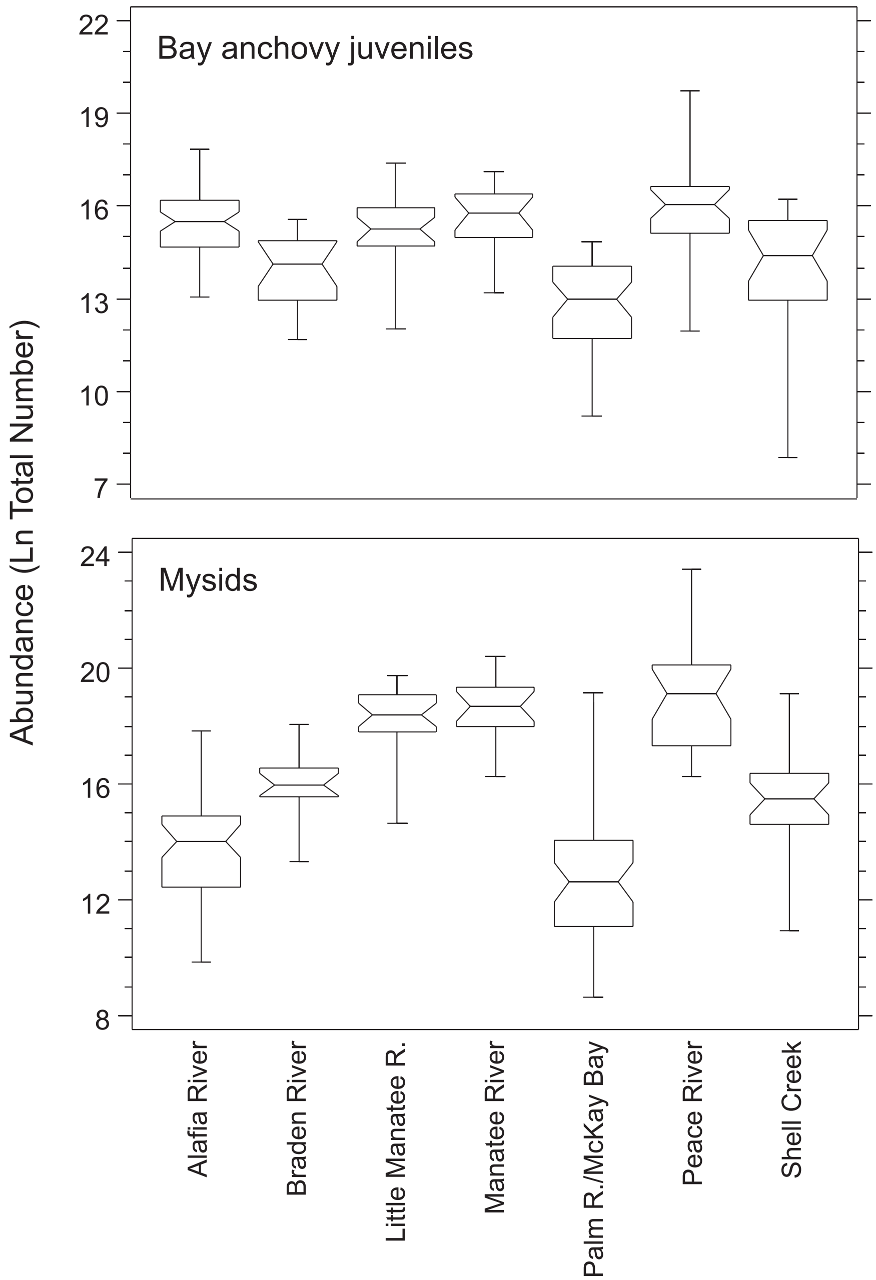


Fig. 2.6.2.3. Comparison of bay anchovy and mysid abundance among Southwest Florida estuaries. Whiskers delimit total ranges, boxes delimit interquartile ranges (middle 50%), and notches identify medians. These two taxa were selected for comparison because several studies have shown them to have consistently positive abundance responses to freshwater inflow. Although all mysids are grouped together here, recent studies at higher taxonomic resolution have indicated that the mysid *Americamysis almyra* is primarily responsible for the positive inflow response among mysids. *A. almyra* and bay anchovy juveniles are important prey items for juvenile estuarine-dependent fishes that congregate within tidal rivers.

3.0 CONCLUSIONS

1. Most of the species in the McKay Bay and Palm River are coastal marine, estuarine, or estuarine dependent in general distribution. They tend to spawn in inshore and nearshore waters and have diets that are strongly oriented toward benthic prey.

2. Habitat preferences of a selected assemblage of 15 economically and ecologically important species were compared (pink shrimp, daggerblade grass shrimp, blue crab, bay anchovy, rainwater killifish, *Menidia*, snook, spotted seatrout, sand seatrout, spot, southern kingfish, red drum, striped mullet, clown goby, hogchoker). In terms of relative abundance, many favored shallow Palm River waters over shallow McKay Bay waters, whereas deep McKay Bay waters were favored over deep Palm River waters. Mud was generally preferred over sand bottom, with both mud and sand being preferred over rocks and oysters. Shorelines with shrubs and trees ranked highest among shoreline types, with beaches being ranked lowest.

3. Most organisms appeared to avoid the deeper, hypoxic Palm River waters.

4. Pink shrimp and blue crabs were most abundant near the mouth of the Palm River, as were juvenile sand seatrout. Cumaceans, crab larvae, the crab *Pinnixa sayana*, amphipods and mysids are potential prey types that were also abundant in this area. Other, primarily benthic and infaunal food resources were not evaluated and may be relevant to the distributions of pink shrimp and blue crabs.

5. A second area of fish and invertebrate concentration was the upper end of the Palm River below S-160. This area had relatively high densities of bay anchovy, snook, spot, red drum, striped mullet, clown goby and hogchoker. All except the clown goby are estuarine-dependent; the clown goby is generally considered to be an estuarine resident. Concentrations in the upper Palm River were evident

in the seine catch. In general, trawl densities for these species were much lower and indicated that these species were more abundant in McKay Bay, if they were present in the trawl catches at all. Grass shrimp, juvenile bay anchovies, the mysid *Americamysis almyra* and polychaetes were relatively abundant in the upper Palm River. An alternative explanation for the concentration of estuarine-dependent species below S-160 is an olfaction-based attraction to chemical cues that are either delivered or created by freshwater inflows.

6. The area below S-160 also appears to be relatively free of two of the more common fish parasites, siphonostomatid copepods and the isopod *Lironeca* sp., but had densities of the highly predatory jellyfish *Chrysaora quinquecirrha* that appear to be high enough to substantially affect pelagic fish survival.

7. Three types of change in community structure were detected. The first and most consistent change was seasonal, with ichthyoplankton demonstrating the strongest seasonal change. The second was change in invertebrate plankton composition caused by washout during exceptionally high inflow events. Average densities of small, truly planktonic organisms such as calanoid copepods tended to decrease during high-inflow months. The introduction of freshwater organisms was not a large contributor to changes in community structure during high-inflow months (using non-standardized, square-root-transformed abundances). The third and perhaps most significant change was in the shallow-water fish fauna. There were substantial differences in the compositions of the seine catches from McKay Bay and the Palm River, with the Palm River yielding more estuarine-dependent and estuarine-resident species. Part of this difference could be attributed to differences in gear deployment methods. However, most trends appeared to be spatially continuous, rather than disjointed between the palm River and McKay Bay, and many species had CPUE trends within the Palm River (highest CPUE upstream) where deployment methods were uniform.

8. It is clear that many economically and ecologically important species, including such prominent species as the blue crab, pink shrimp, red drum and snook, are attempting to use the Palm River-McKay Bay estuary as nursery habitat, despite the dramatic alterations that have been made to its physical habitat, water quality and freshwater inflow pattern.

9. The distributions of 25 taxa from the plankton-net collections were observed to shift in response to changes freshwater inflow. More than 60% of these shifts were upstream shifts in response to increasing inflow. The upstream shifts appeared to be related to two-layered estuarine circulation, as described for the area by the Luther and Meyers (2004) hydrodynamic model. Planktonic animals, including fish eggs, appeared to be entrained in landward moving bottom water that transported them from McKay Bay into the Palm River during times of elevated inflow (100-400 cfs).

10. Abundances of 34 taxa from the plankton-net collections changed in response to changing inflow. Most decreased in number as inflows increased. Polychaetes, which are worms that normally live within the bottom substrate, increased in abundance during elevated inflows, but this appeared to be caused by individuals moving from the substrate into the water column, probably in an effort to avoid the oxygen-depleted bottom waters that tend to form during periods of elevated inflow. The mysid *Americamysis almyra*, bay anchovy juveniles and pink shrimp juveniles increased in abundance after periods of increased inflow. All three have been observed to have positive inflow-abundance responses in other Southwest Florida estuaries. The mysid and bay anchovy juveniles are important prey for young estuarine-dependent fishes that use tidal rivers as nursery habitat, and the pink shrimp is an economically important species. It was estimated that an average inflow of 11 cfs would be required to maintain these species at 50% of their abundance at median inflow (46 cfs), with the median inflow being based on the this project’s survey period. Regressions are presented that allow percent abundance to be recalculated relative to reference inflow levels (i.e., medians)

from alternative index periods.

11. Elevated inflows (>100 cfs) moved the gelatinous predator *Mnemiopsis mccradyi* downstream and reduced its overall number. This ctenophore is a highly efficient predator on fish eggs and larvae and competes with larval and juvenile fishes for zooplankton prey. The inflow effects on *Mnemiopsis* distribution and abundance therefore enhance the Palm River as nursery habitat. Elevated inflows also tended to push another important fish predator, the sea nettle *Chrysaora quinquecirrha*, out of the Palm River and into McKay Bay, but the abundance of this animal tended to increase in conjunction with downstream displacement.

12. In general, organisms' responses to freshwater inflow into the Palm River and McKay Bay were more subtle than those observed in other estuarine areas of Southwest Florida. The abundance of mysids and bay anchovy juveniles in the Palm River/McKay Bay estuarine system changed in response to inflow, but these changes affected abundances were the lowest observed among seven estuarine areas surveyed using identical methods.

REFERENCES

Benfield, M. C. and Aldrich, D. V. 1991. A laminar-flow choice chanber for testing the responses of postlarval penaeids to olfactants. *Contrib. Mar. Sci.* 32, 73-88.

Browder, J. A. 1985. Relationship between pink shrimp production on the Tortugas grounds and water flow patterns in the Florida Everglades. *Bull. Mar. Sci.* 37, 839-856.

Brown, L. N. 1971. Environmental statement (biological) regarding Tampa Bypass Canal (C-135), Harney Canal (C-136), Lower Hillsborough Flood Detention Area and levee 112(S). Southwest Florida Water Management District, Brooksville, Florida.

Carr, W. E. S. and Adams, C. A. 1973. Food habits of juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River, Florida. *Trans. Amer. Fish. Soc.* 102, 511-540.

Clarke, K. R. and Green, R. H. 1988. Statistical design and analysis for a 'biological effects' study. *Mar. Ecol. Prog. Ser.* 46, 213-226.

Clarke, K. R. and Warwick, R. M. 2001. *Change in marine communities: an approach to statistical analysis and interpretation*, 2nd edition. PRIMER-E: Plymouth, UK.

Darnell, R. M. 1961. Trophic spectrum of an estuarine community, based on studies of Lake Pontchartrain, Louisiana. *Ecology* 42, 553-568.

Drinkwater, K. F. 1986. On the role of freshwater outflow on coastal marine ecosystems - a workshop summary. In *The Role of Freshwater Outflow in Coastal Marine Ecosystems*. S. Skreslet. (ed.) pp. 429-438. Springer-Verlag: Berlin.

Fantle, M. S., Dittel, A. I., Schwalm, S. M., Epifanio, C. E., and Fogel, M. L. 1999. A food web analysis of the juvenile blue crab, *Callinectes sapidus*, using stable isotopes in whole animals and individual amino acids. *Oecologia* 120, 416-426.

Jones, P. W., Martin, F. D., and Hardy, J. D. 1978. Development of Fishes of the Mid-Atlantic Bight - an atlas of egg, larval, and juvenile stages, Vol 1, Acipenseridae through Ictaluridae. U.S. Fish Wildl. Serv. Biol. Rep. FWS/OBS-78/12.

Kristensen, I. 1964. Hypersaline bays as an environment of young fish. *Proc. Gulf and Carib. Fish. Inst.* 16, 139-142.

Luther, M. E. and Meyers, S. D. 2004. Hydrodynamic simulations of circulation and dependent physical parameters in the Palm River and McKay Bay. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District.

McMichael Jr., R. H., Peters, K. M., and Parsons, G. R. 1989. Early life history of the snook, *Centropomus undecimalis*, in Tampa Bay, Florida. *Northeast Gulf Sci.* 10, 113-

125.

Odum, W. E. 1970. Insidious alteration of the estuarine environment. *Trans. Am. Fish. Soc.* 99, 836-850.

Peebles, E. B. 2004. An analysis of freshwater inflow effects on the early stages of fish and their invertebrate prey in the Alafia River estuary. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District.

Peebles, E. B. 2002a. An assessment of the effects of freshwater inflows on fish and invertebrate habitat use in the Manatee-Braden estuary. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District.

Peebles, E. B. 2002b. An assessment of the effects of freshwater inflows on fish and invertebrate habitat use in the Peace River and Shell Creek estuaries. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District.

Peebles, E. B. 2002c. Temporal resolution of biological and physical influences on bay anchovy *Anchoa mitchilli* egg abundance near a river-plume frontal zone. *Mar. Ecol. Prog. Ser.* 237, 257-269.

Peebles, E. B. and Flannery, M. S. 1992. *Fish nursery use of the Little Manatee River estuary Florida: Relationships with freshwater discharge*. Southwest Florida Water Management District: Brooksville, Florida.

Peebles, E. B and Hopkins, T. L. 1993. Feeding habits of eight fish species from Tampa Bay, with observations on opportunistic predation. Report prepared by the University of South Florida Department of Marine Science for the Florida Marine Research Institute, Florida Department of Environmental Protection, St. Petersburg, Florida.

Peters, K. M. and McMichael Jr., R. H. 1987. Early life history of the red drum, *Sciaenops ocellatus* Pisces: Sciaenidae in Tampa Bay, Florida. *Estuaries* 10, 92-107.

Purcell, J. E. 1985. Predation on fish eggs and larvae by pelagic cnidarians and ctenophores. *Bull Mar Sci* 37, 739-755.

Purcell, J. E. and Arai, M. N. 2001. Interactions of pelagic cnidarians and ctenophores with fish: a review. *Hydrobiologia* 451, 27-44.

Robins, J. B., Halliday, I. A., Staunton-Smith, J., Mayer, D. G., and Sellin, M. J. (in press). Freshwater flow requirements of estuarine fisheries in tropical Australia: a review of the state of knowledge and application of a suggested approach. *Mar. Freshw. Res.*

Rothschild, B. J. 1986. *Dynamics of Marine Fish Populations*. Harvard University Press: Cambridge, Mass.

Schwamborn, R. and Criales, M. M. 2000. Feeding strategy and daily ration of juvenile pink shrimp *Farfantepenaeus duorarum* in a South Florida seagrass bed. *Mar. Bio.* 137, 139-147.

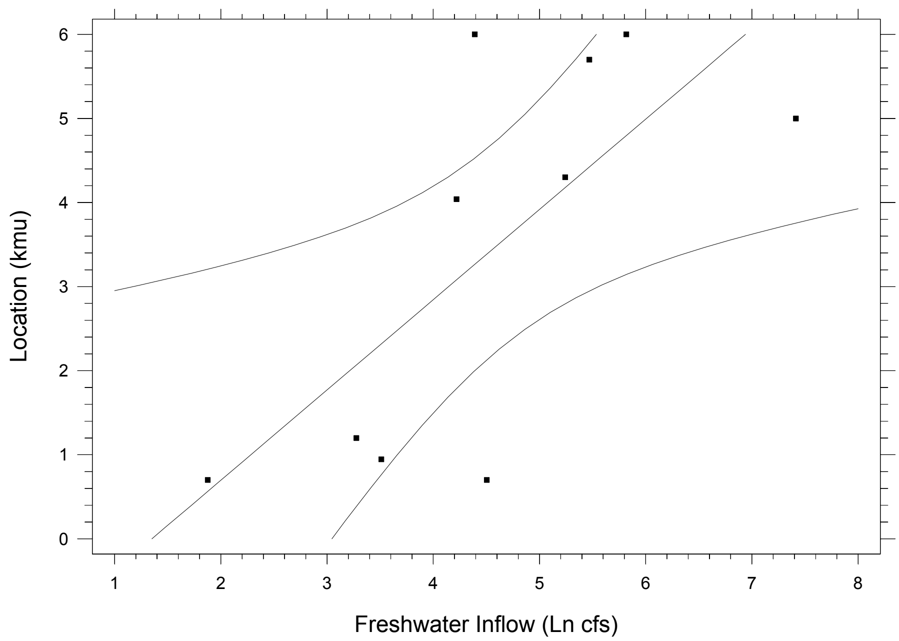
Takasuka, A., Aoki, I., and Mitani, I. 2004. Three synergistic growth-related mechanisms in the short-term survival of larval Japanese anchovy *Engraulis japonicus* in Sagami Bay. *Mar. Ecol. Prog. Ser.* 270, 217-228.

Tsou, T. and Matheson, R. E. Jr. 2002. Seasonal changes in the nekton community of the Suwannee River estuary and the potential impacts of freshwater withdrawal. *Estuaries* 25, 1372-1381.

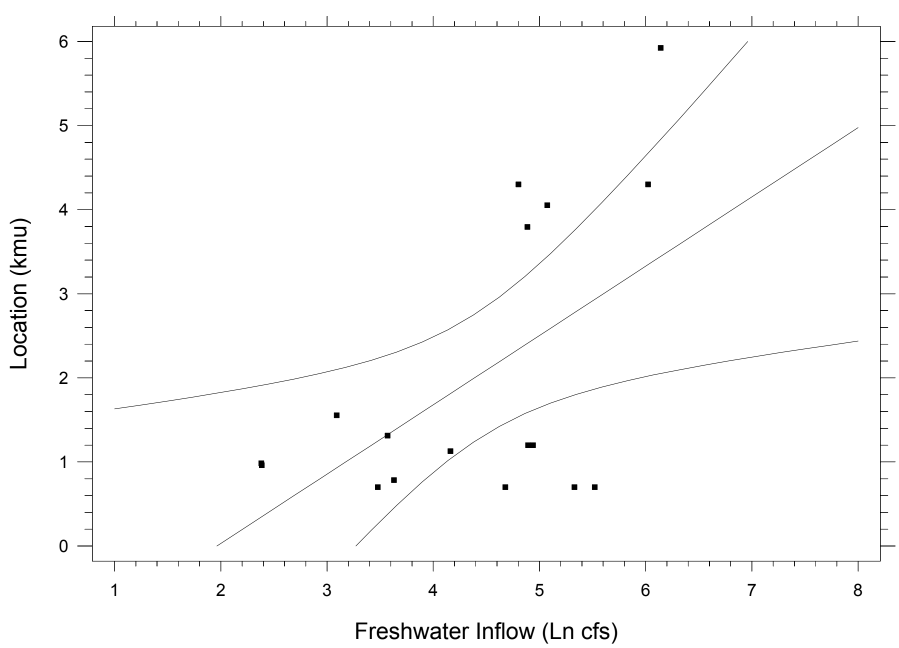
Appendix A:

Plots of the regressions in Table 2.6.2.1

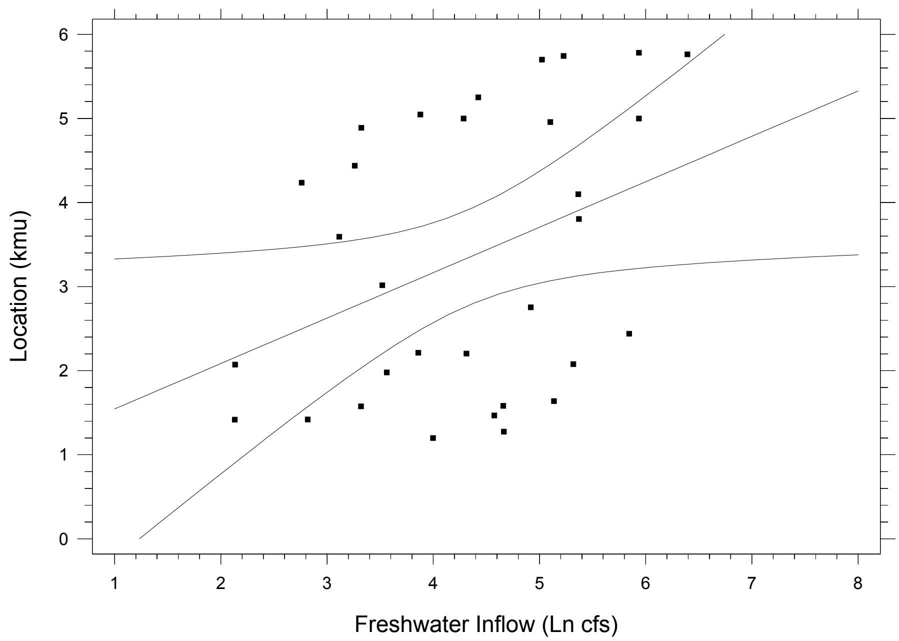
Palaemonetes pugio juveniles



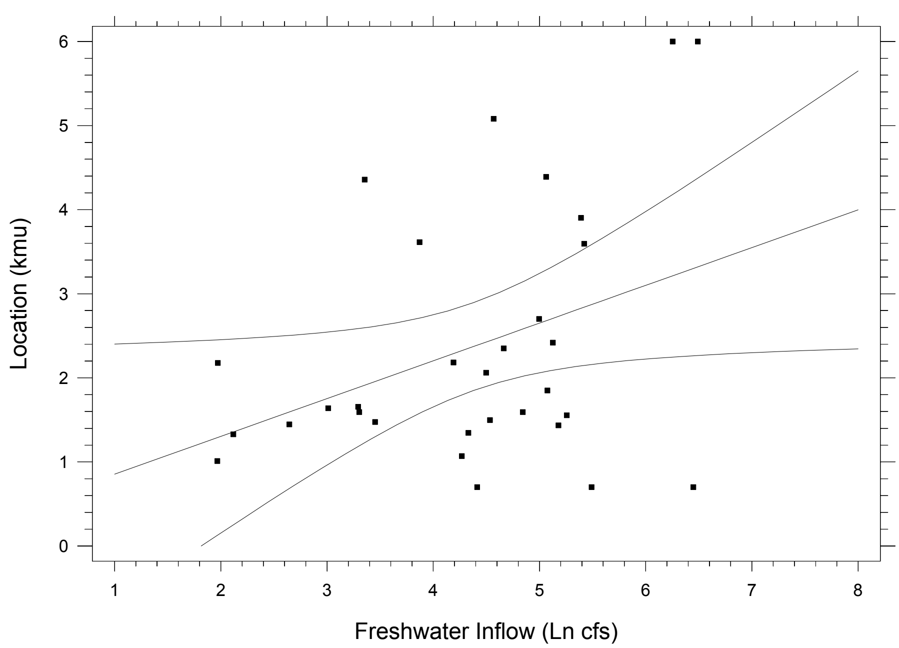
Saphirella spp.



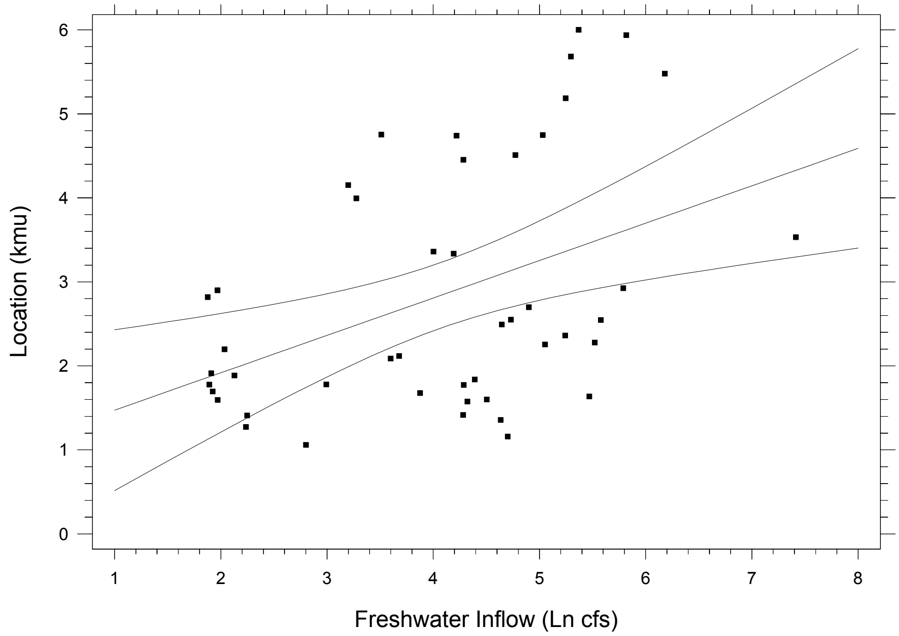
Gobiosoma spp.



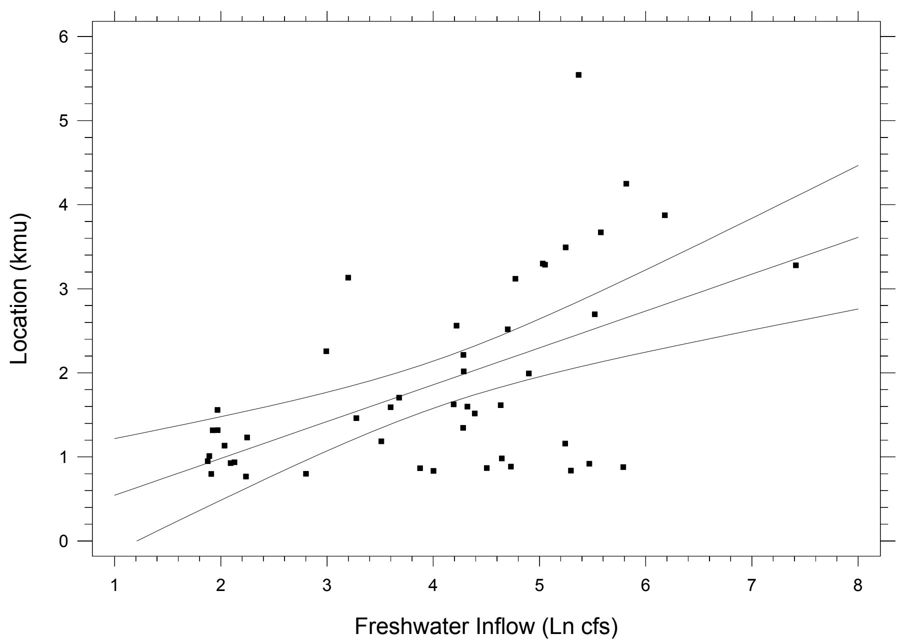
Anchoa mitchilli postflexion larvae

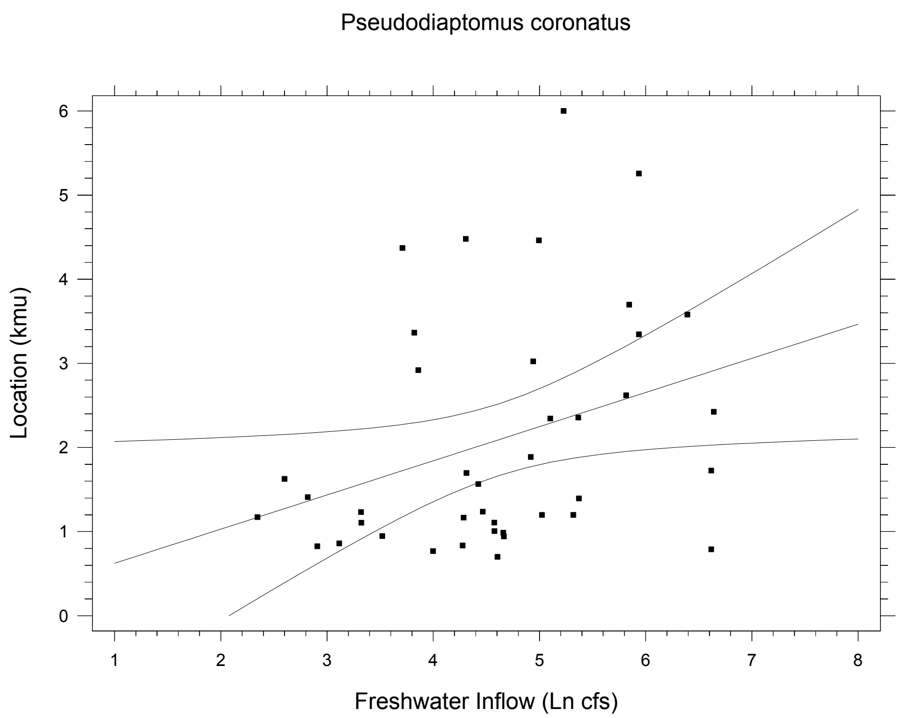


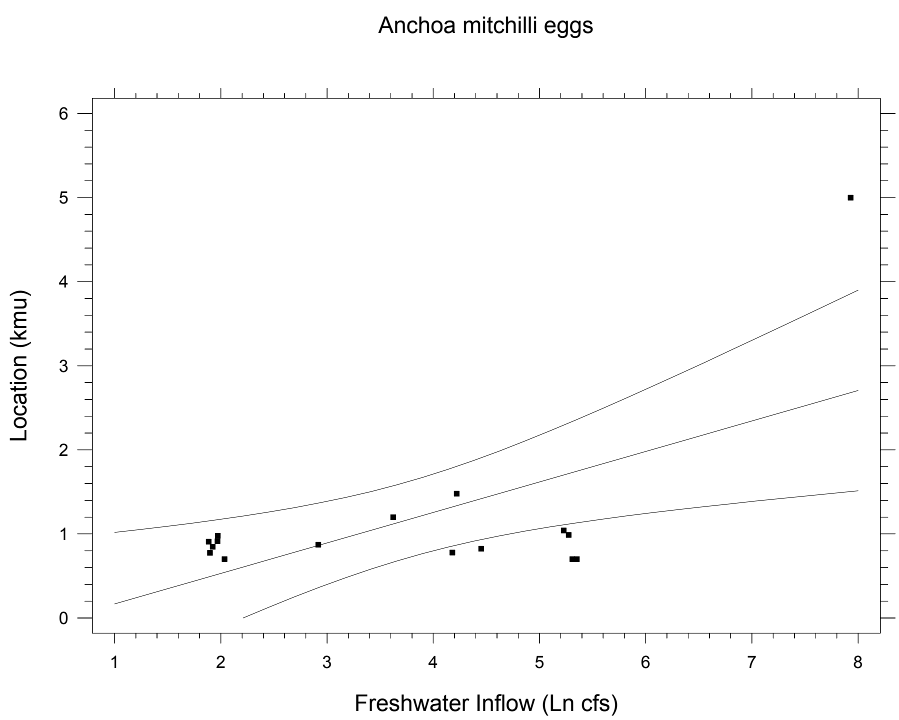
polychaetes

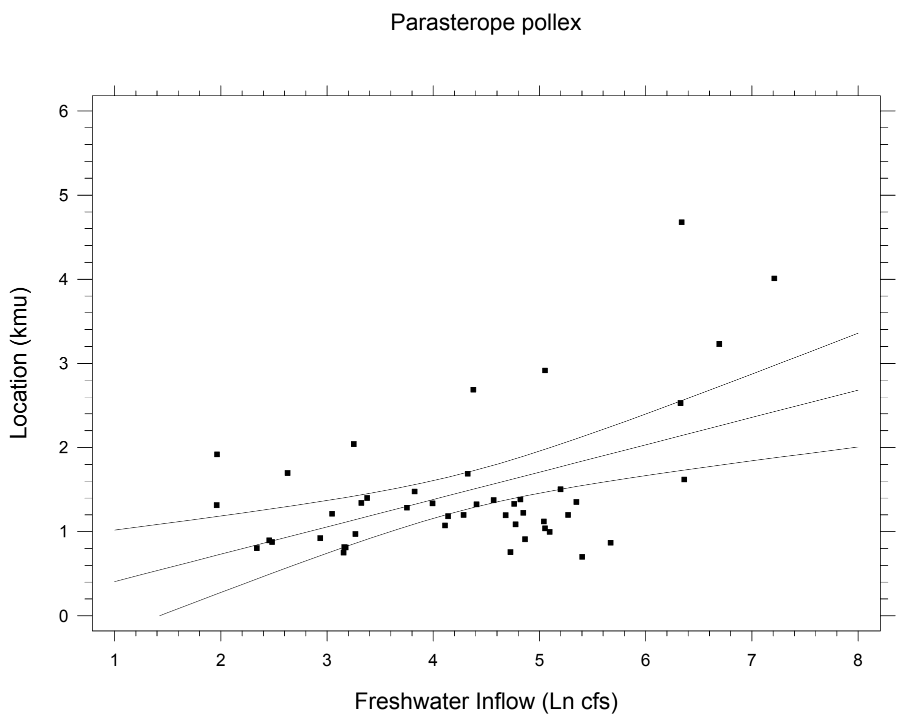


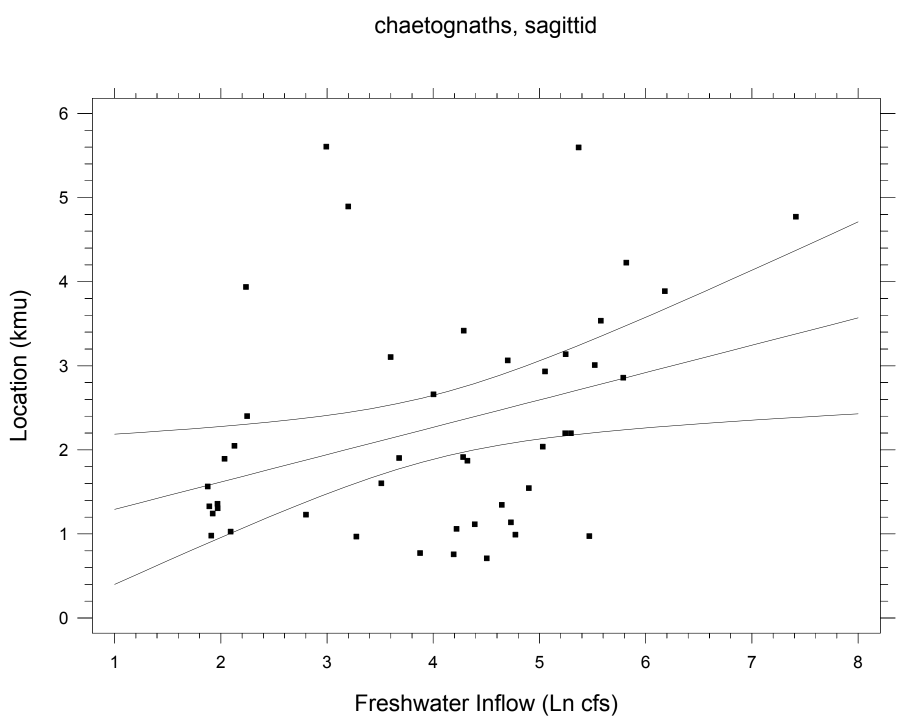
decapod mysis



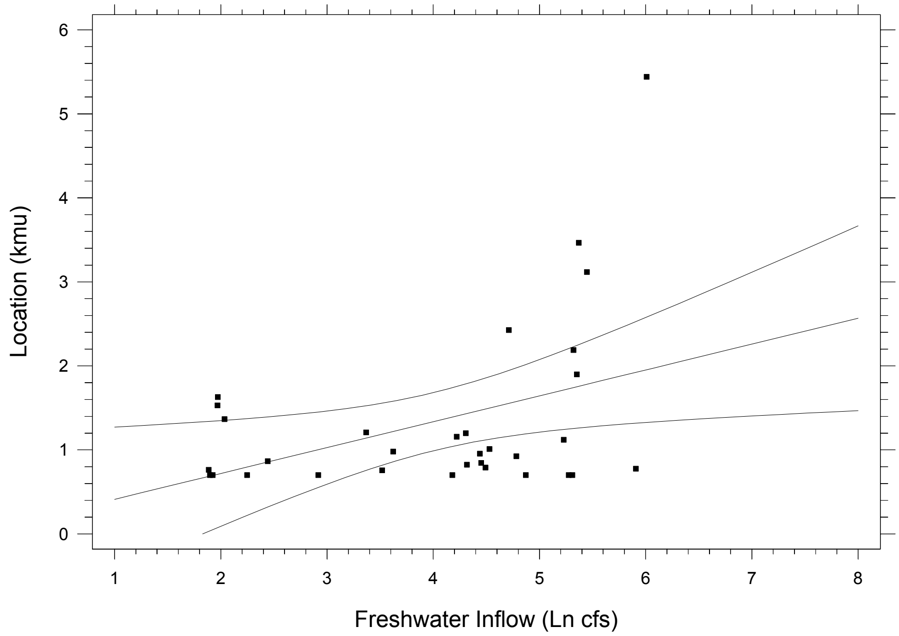

Pseudodiaptomus coronatus
Location (kmu)
Freshwater Inflow (Ln cfs)


Anchoa mitchilli eggs
Location (kmu)
Freshwater Inflow (Ln cfs)

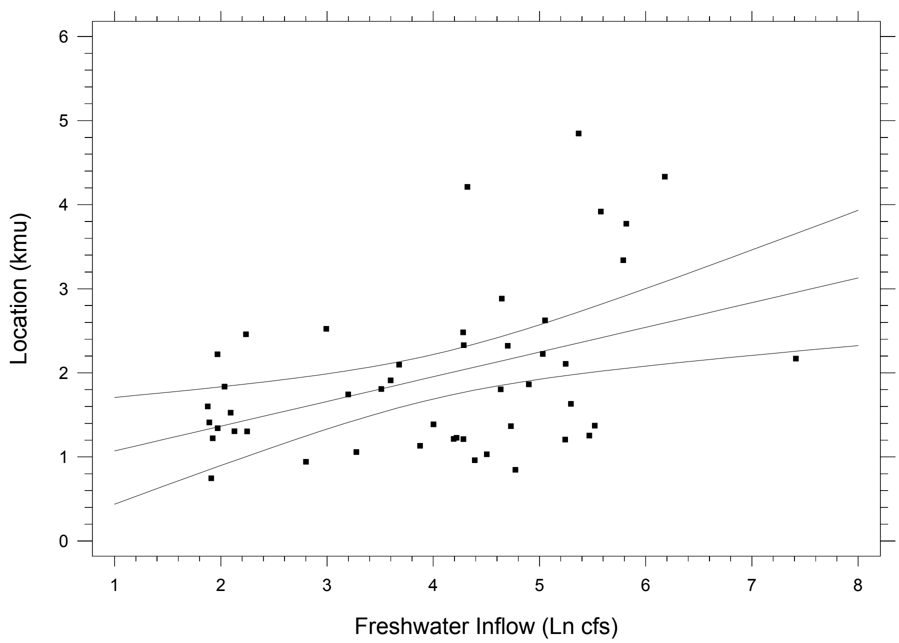

Parasterope pollex
Location (kmu)
Freshwater Inflow (Ln cfs)

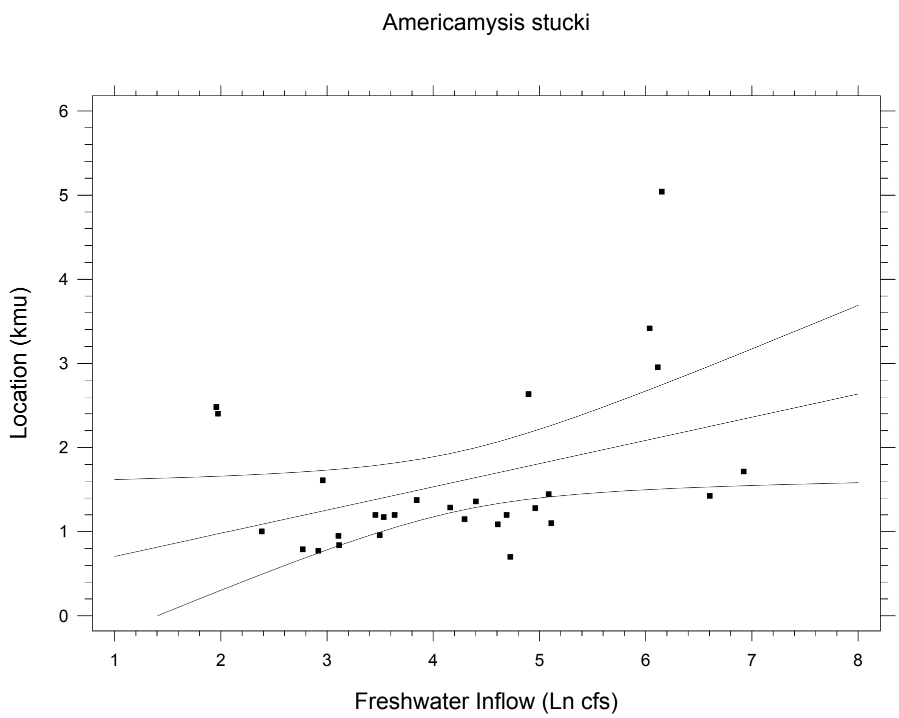

chaetognaths, sagittid
Location (kmu)
Freshwater Inflow (Ln cfs)

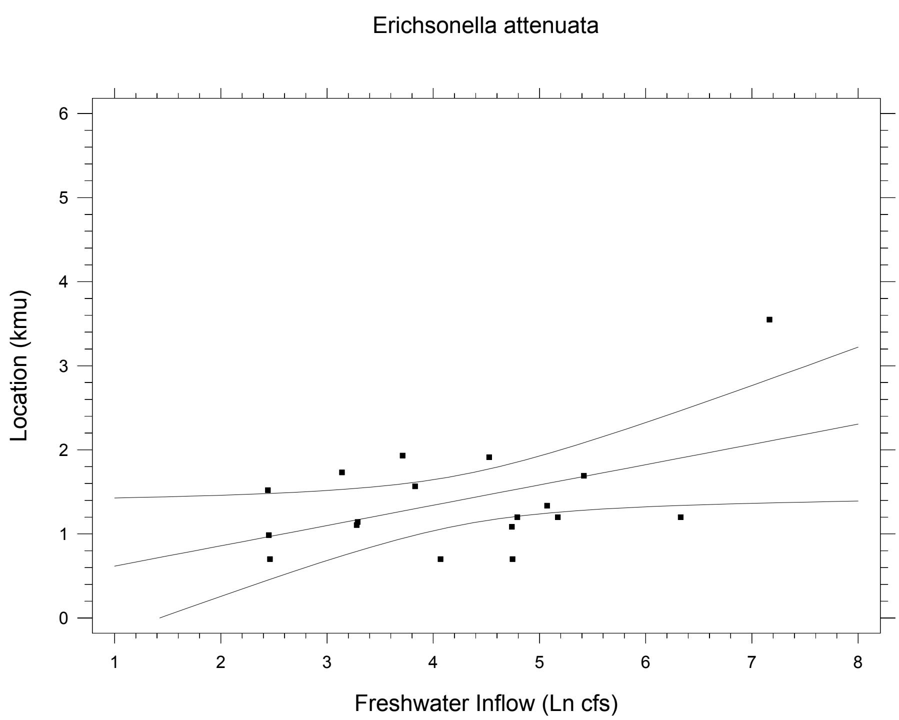
fish eggs, percomorph



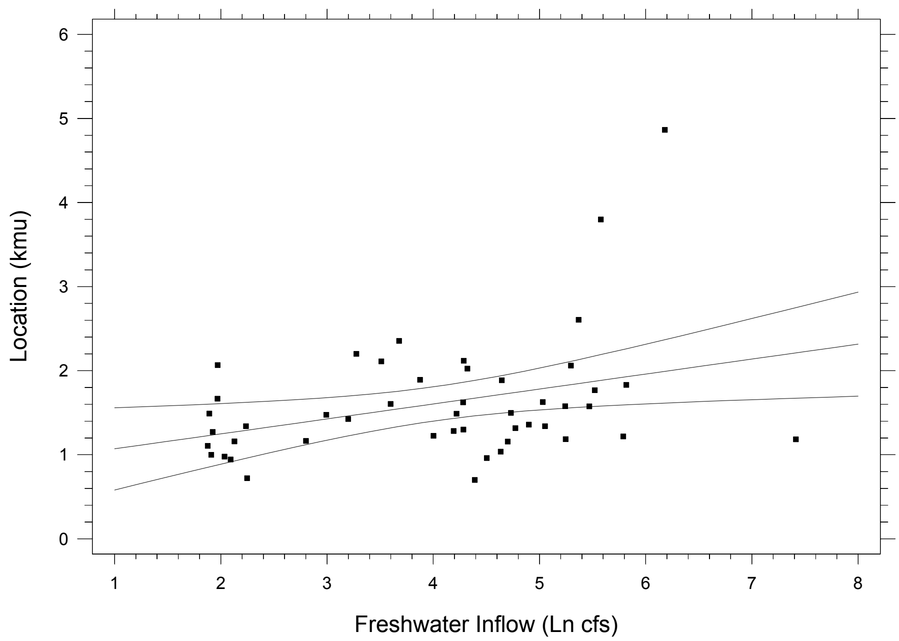
decapod zoeae, unidentified



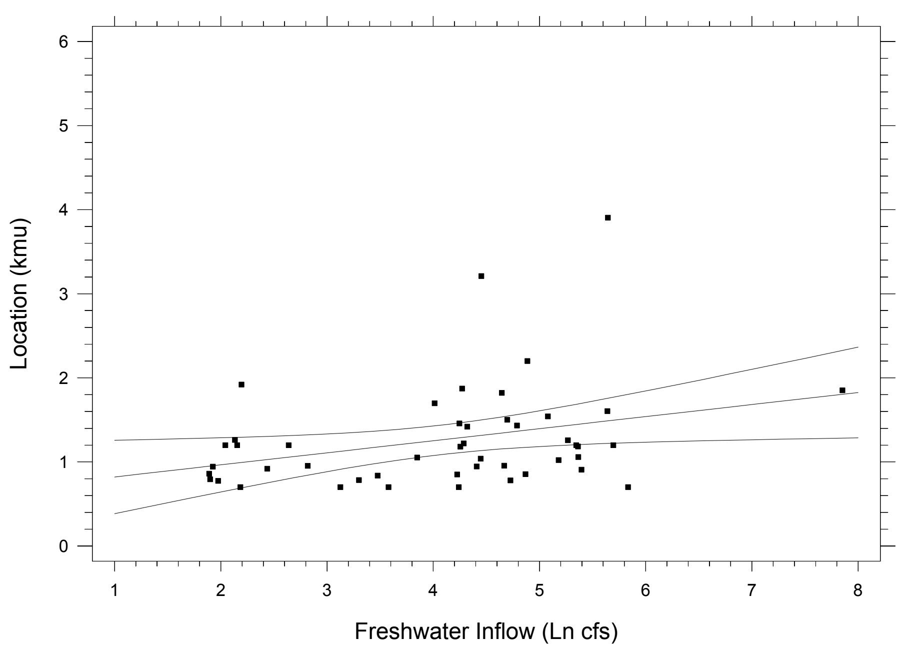

Americamysis stucki
Location (kmu)
Freshwater Inflow (Ln cfs)
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8


Erichsonella attenuata
Location (kmu)
Freshwater Inflow (Ln cfs)
0
1
2
3
4
5
6
1
2
3
4
5
6
7
8

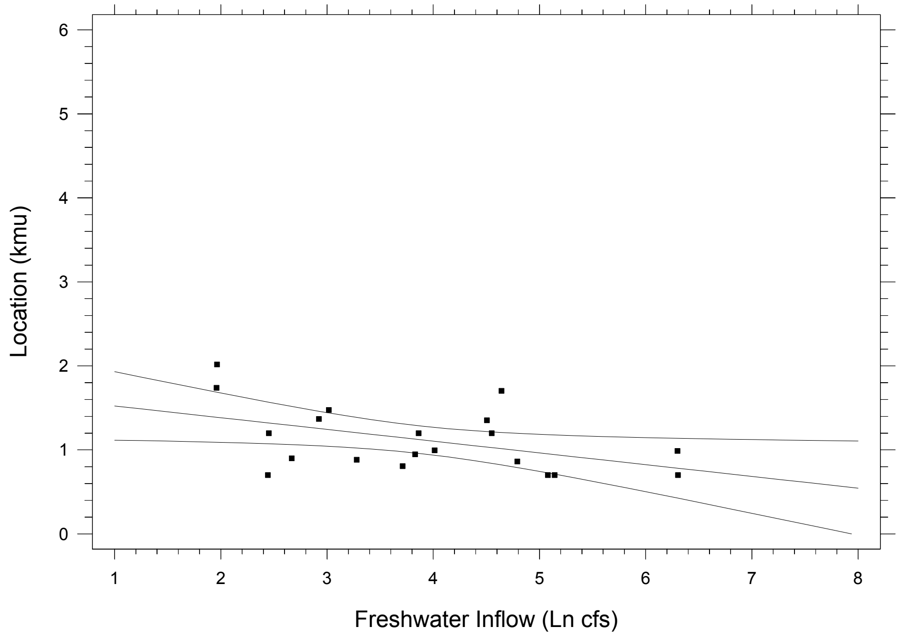
amphipods, gammaridean



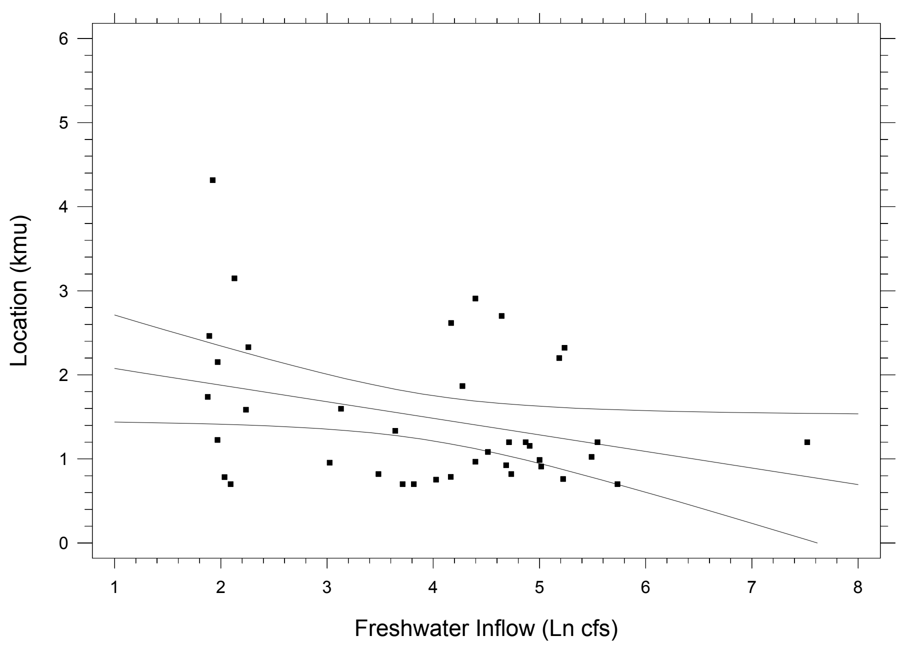
Anchoa mitchilli adults



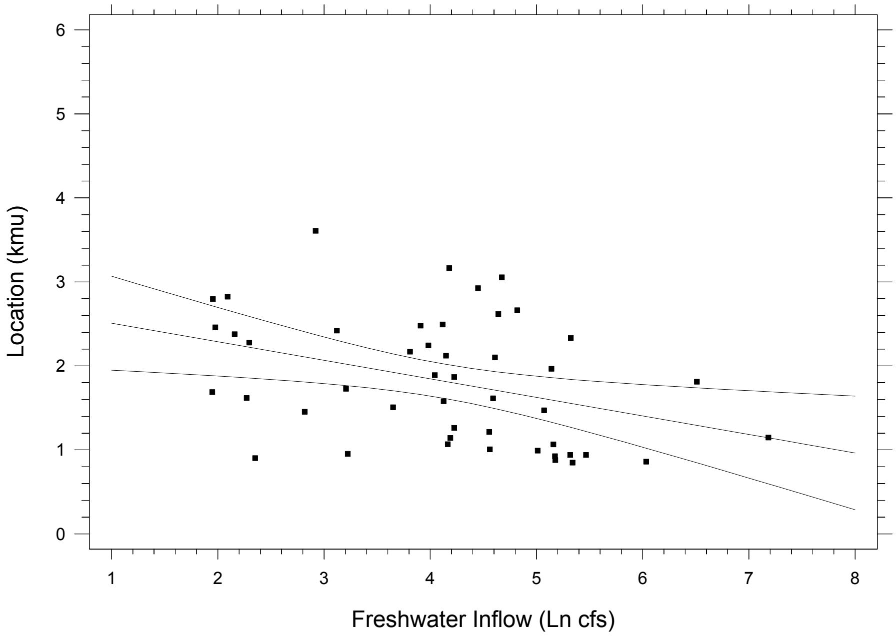
Munna reynoldsi



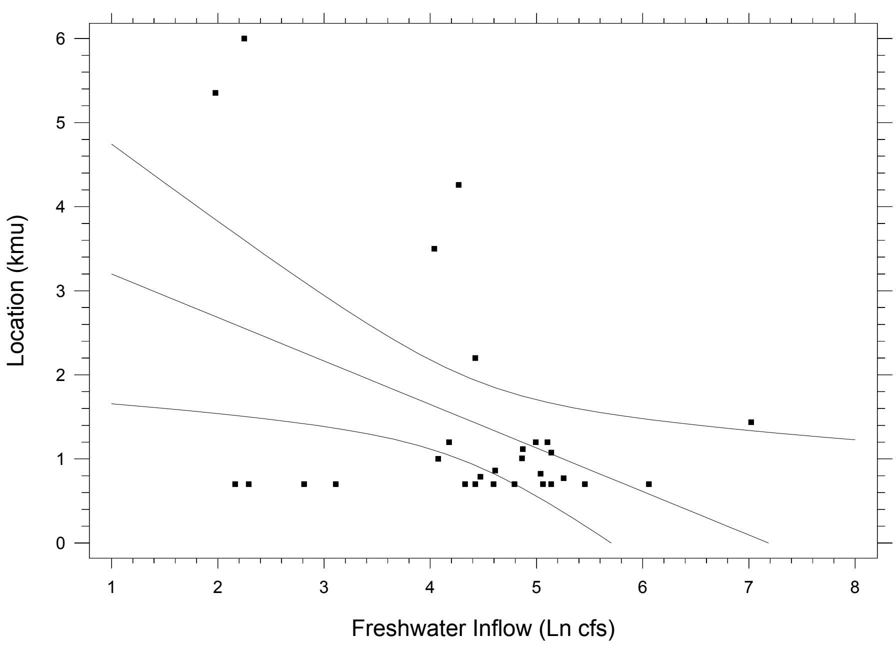
Oikopleura dioica



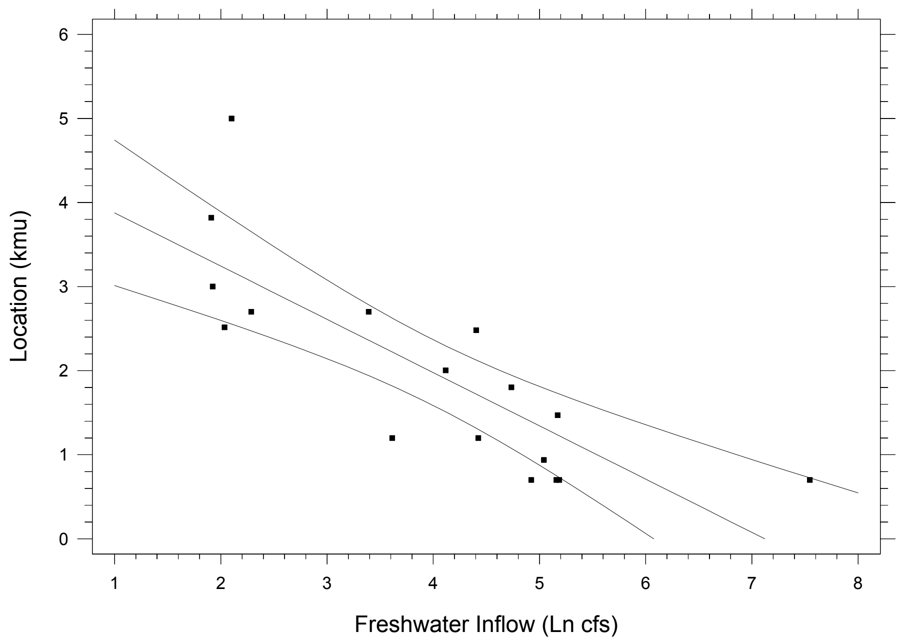
Lironeca sp.



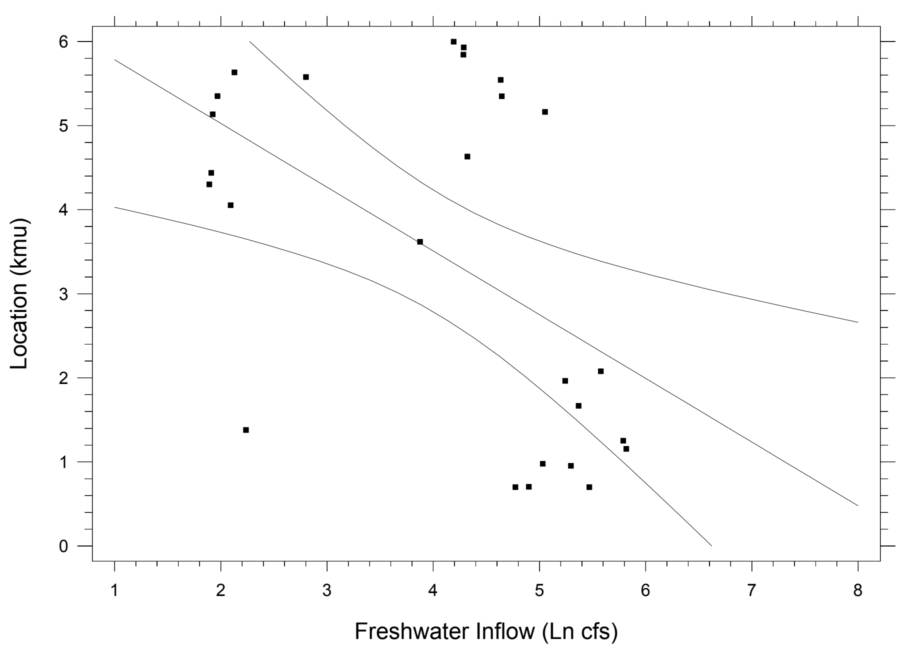
ostracods, podocopid



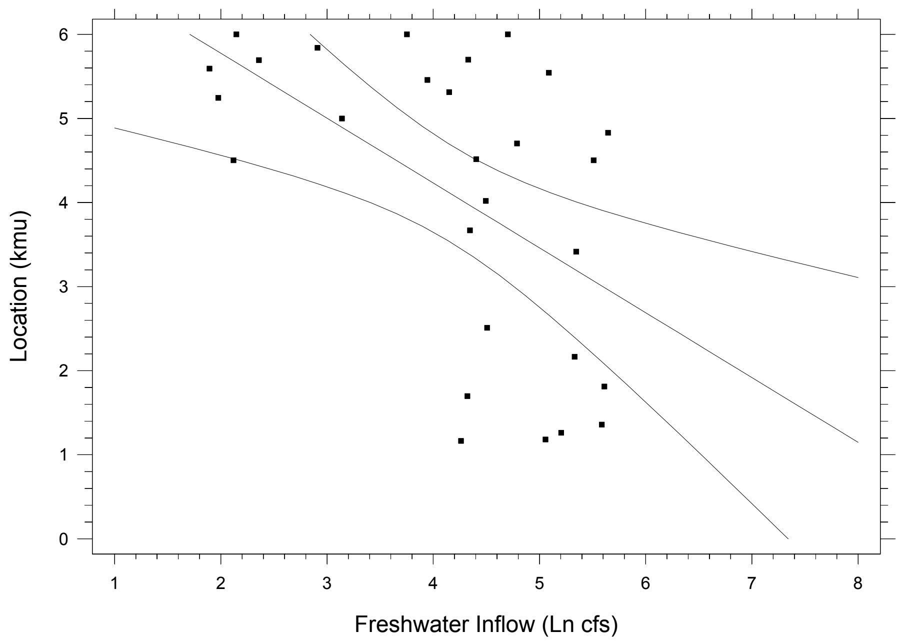
Limulus polyphemus larvae



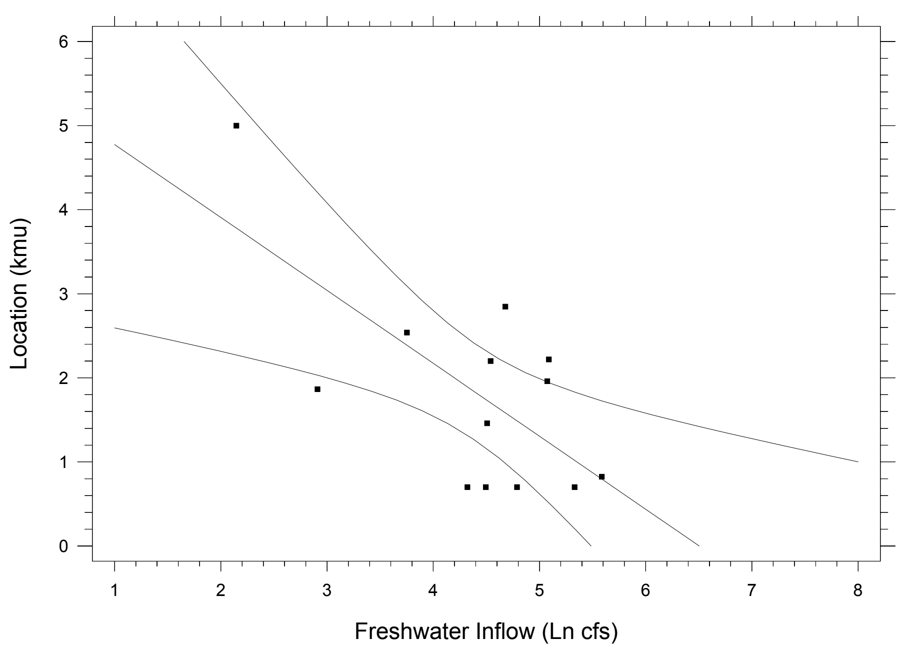
Mnemiopsis mccradyi



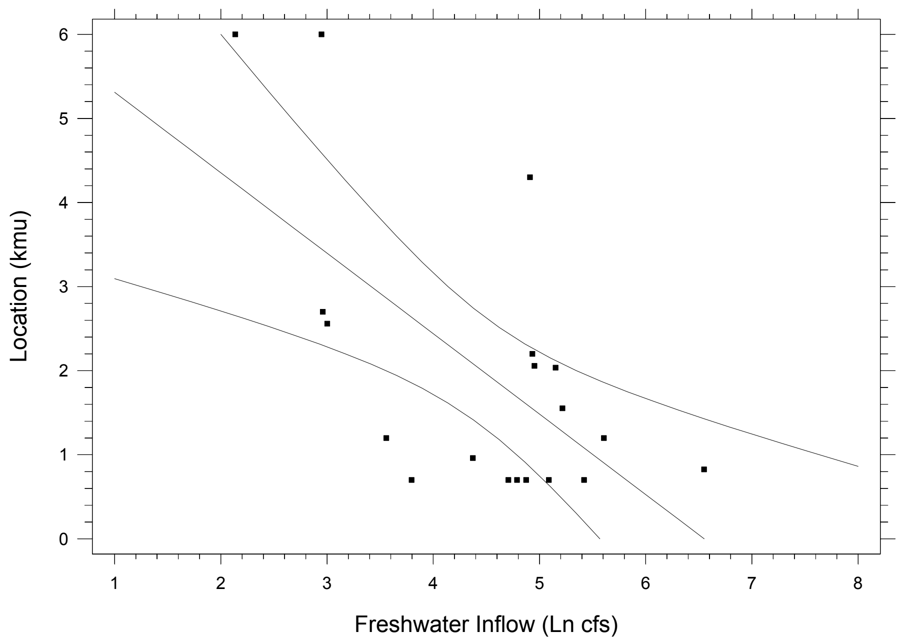
Chrysaora quinquecirrha



Leptochela serratorbita



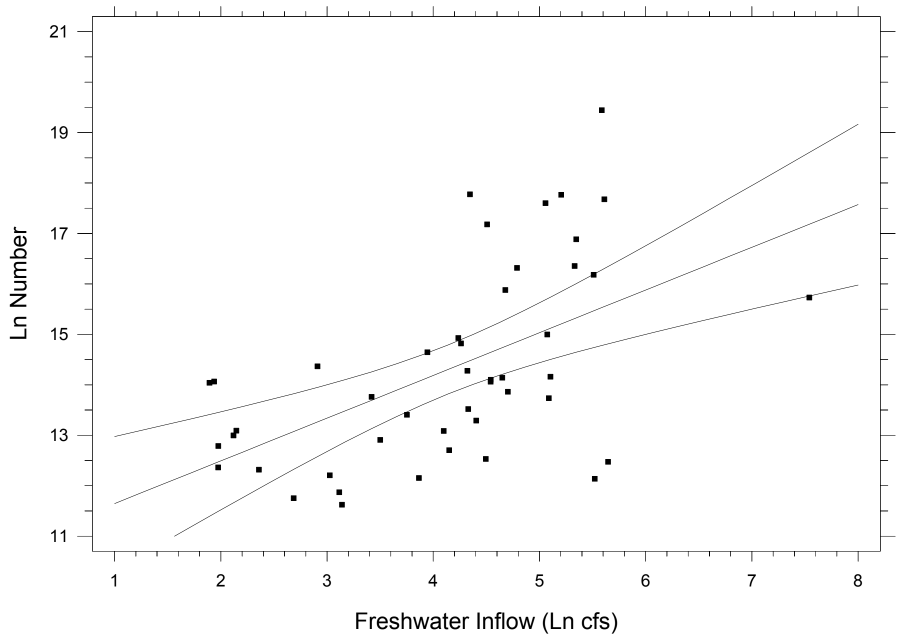
cirriped cypris



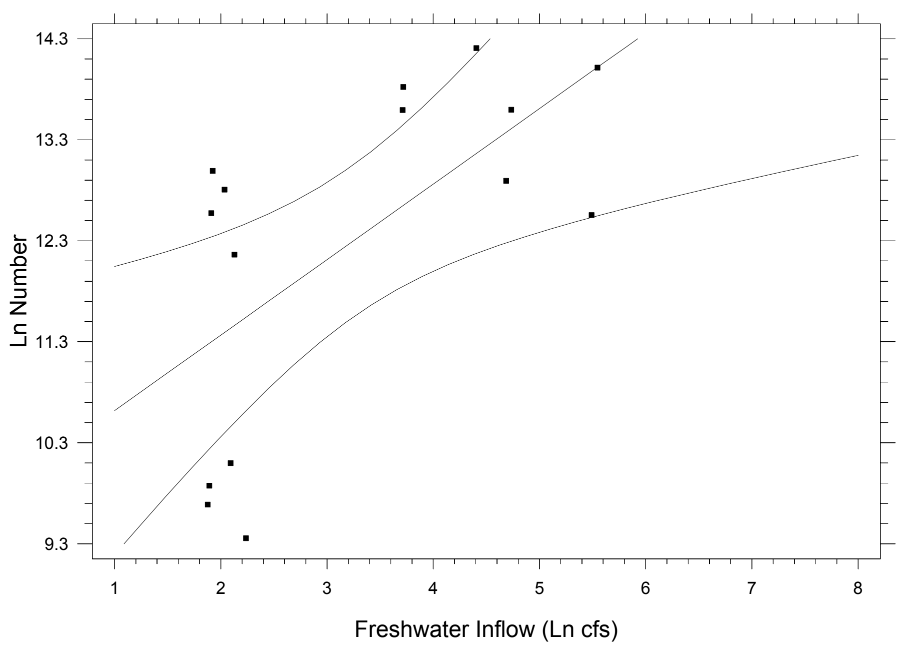
Appendix B:

Plots of the regressions in Table 2.6.2.2

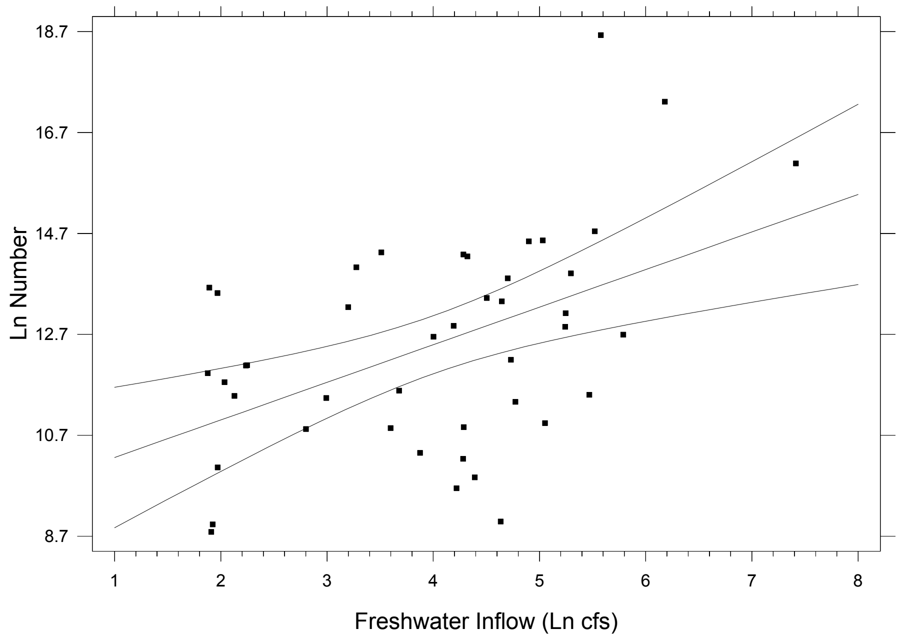
polychaetes



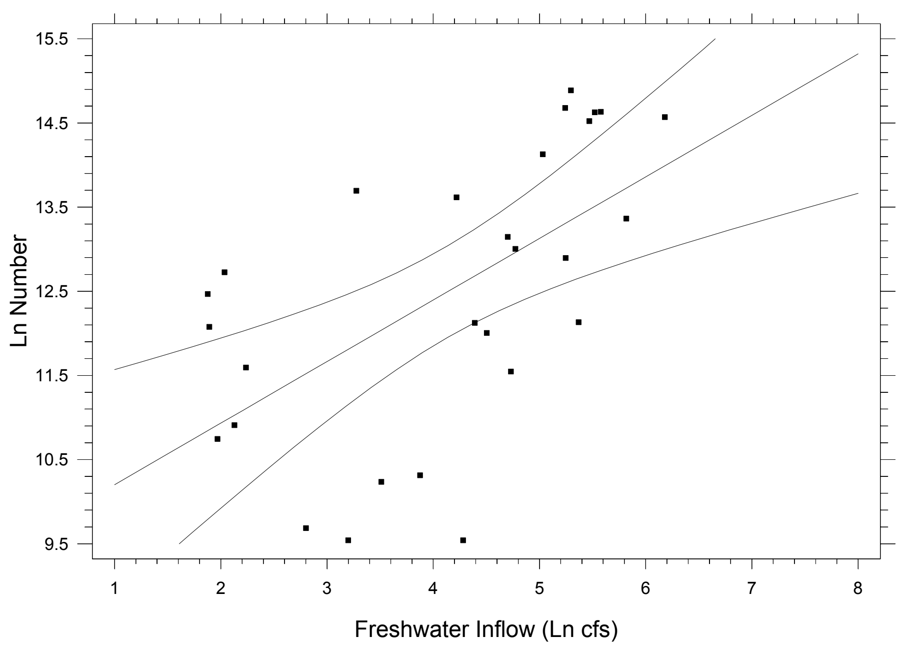
Harrieta faxoni

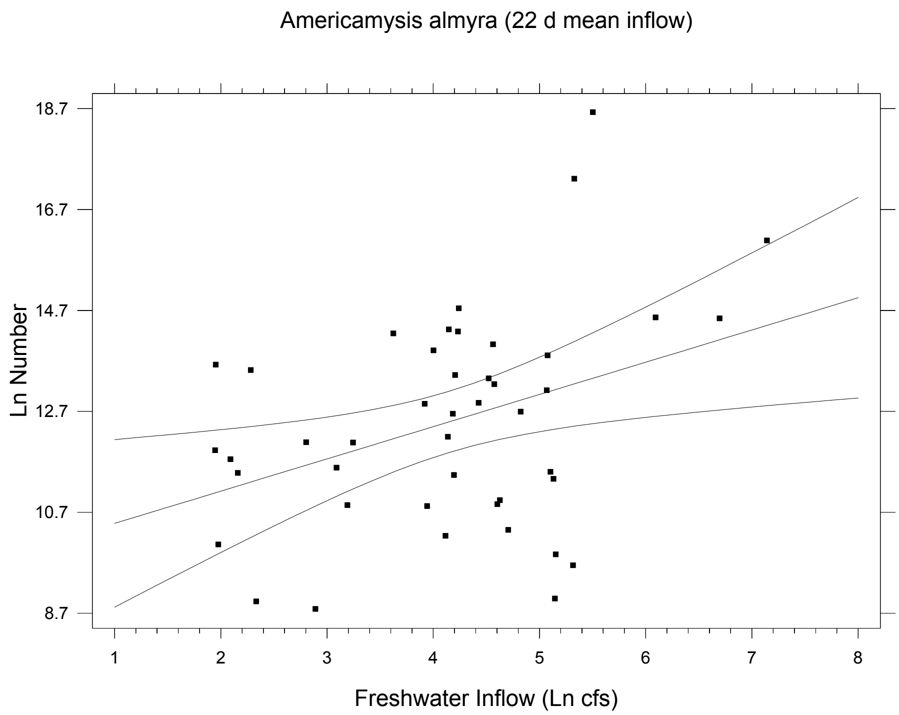


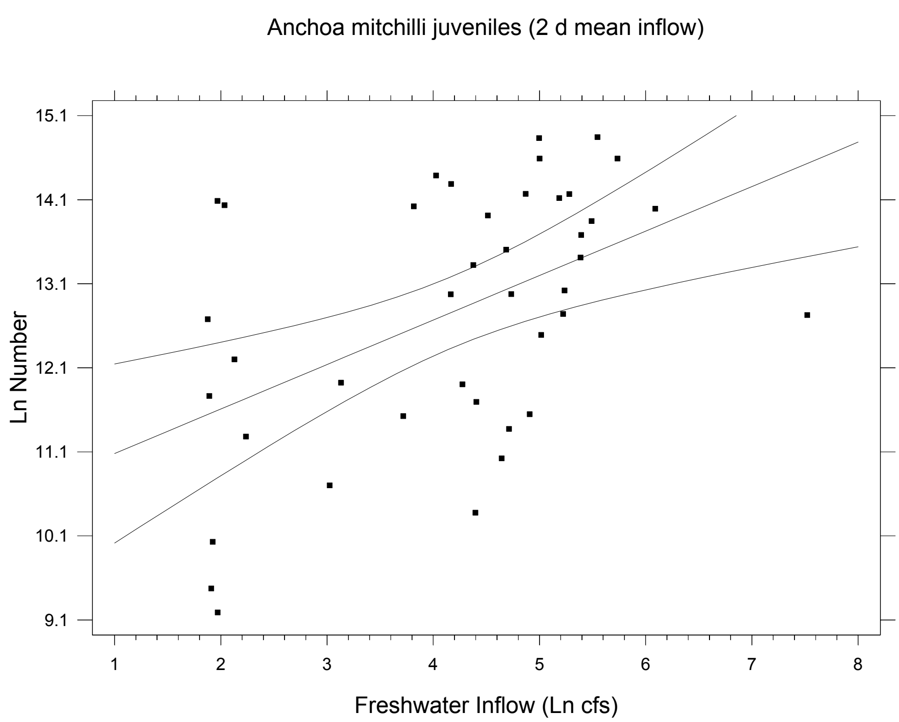
Americamysis almyra (same-day inflow)



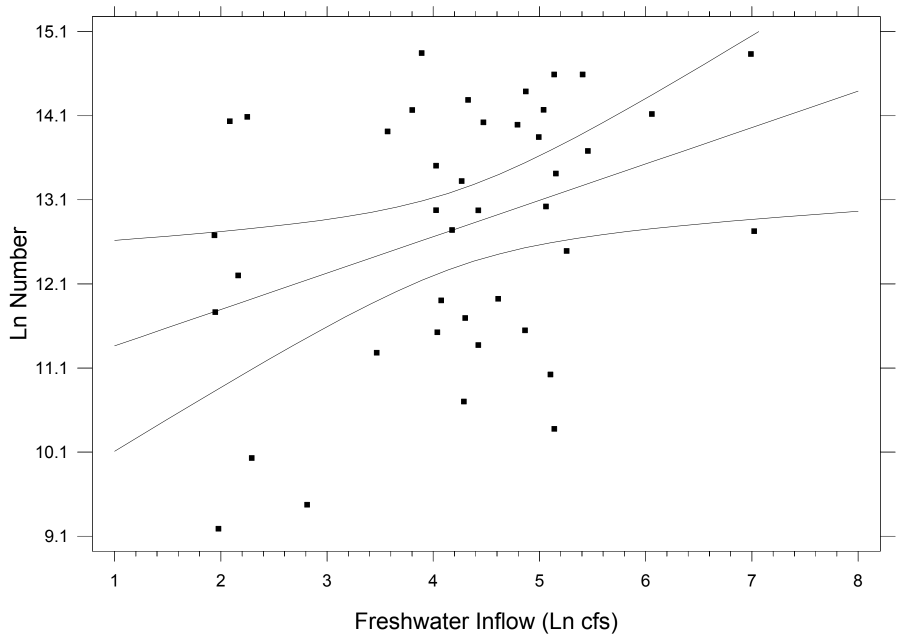
Chrysaora quinquecirrha



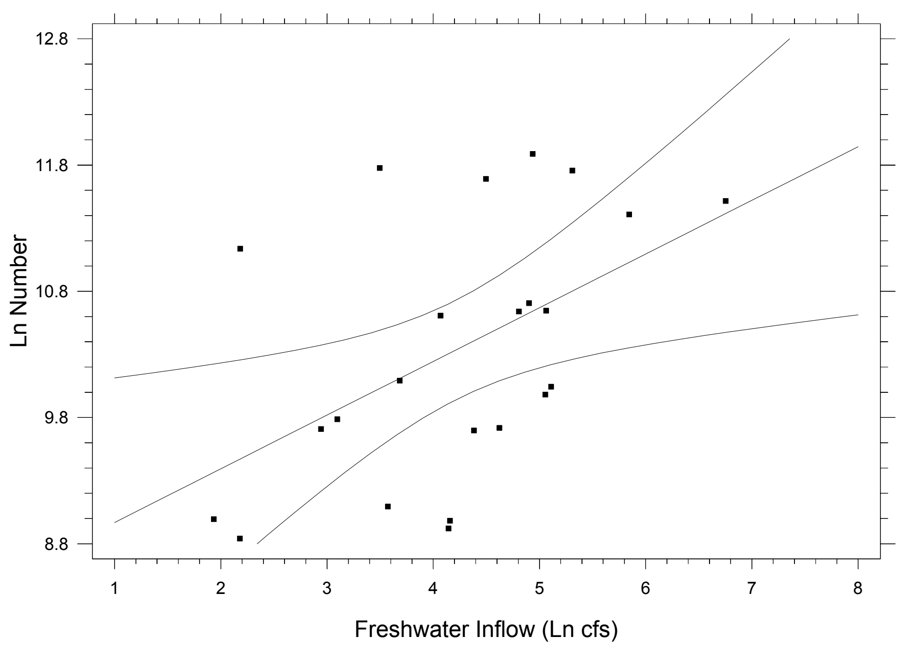

Americamysis almyra (22 d mean inflow)
Ln Number
Freshwater Inflow (Ln cfs)
18.7
16.7
14.7
12.7
10.7
8.7
1
2
3
4
5
6
7
8


Anchoa mitchilli juveniles (2 d mean inflow)
Ln Number
Freshwater Inflow (Ln cfs)
15.1
14.1
13.1
12.1
11.1
10.1
9.1
1
2
3
4
5
6
7
8

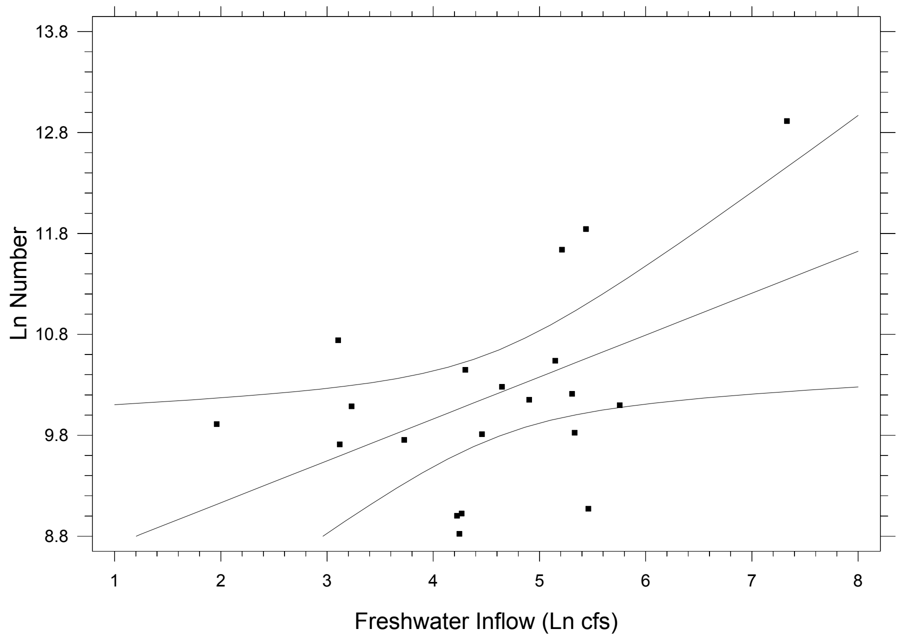
Anchoa mitchilli juveniles (25 d mean inflow)



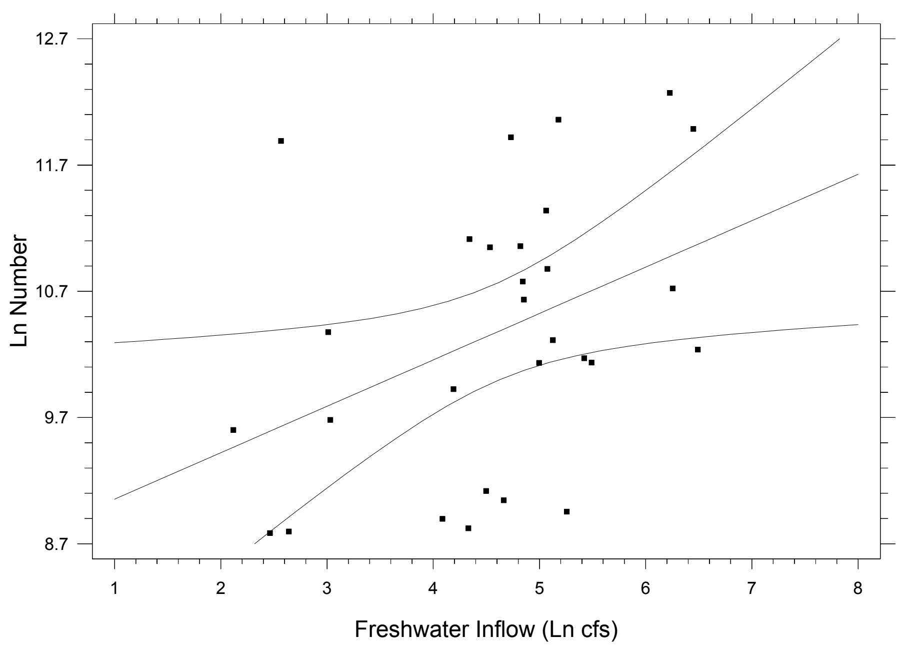
Sphaeroma quadridentata



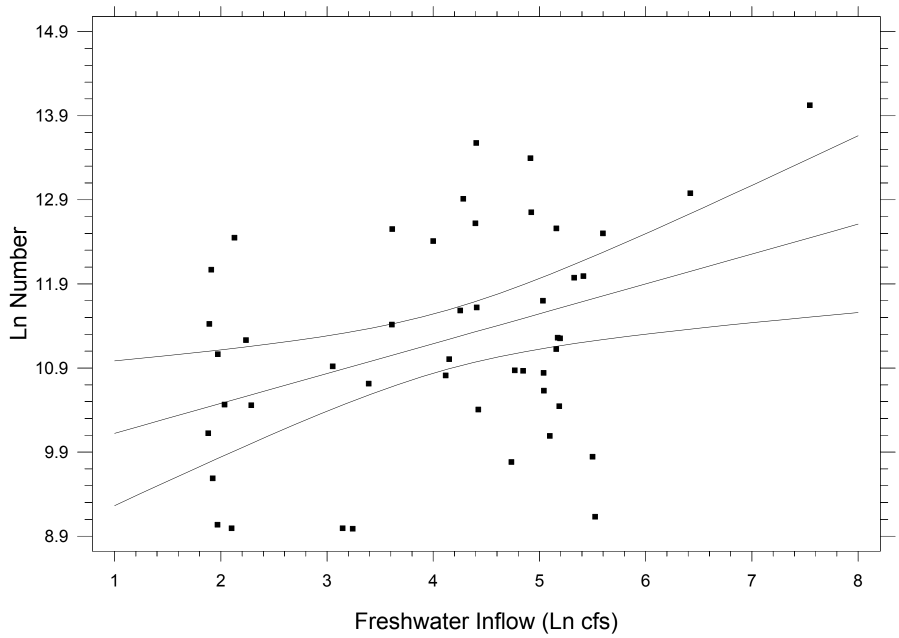
foraminiferans



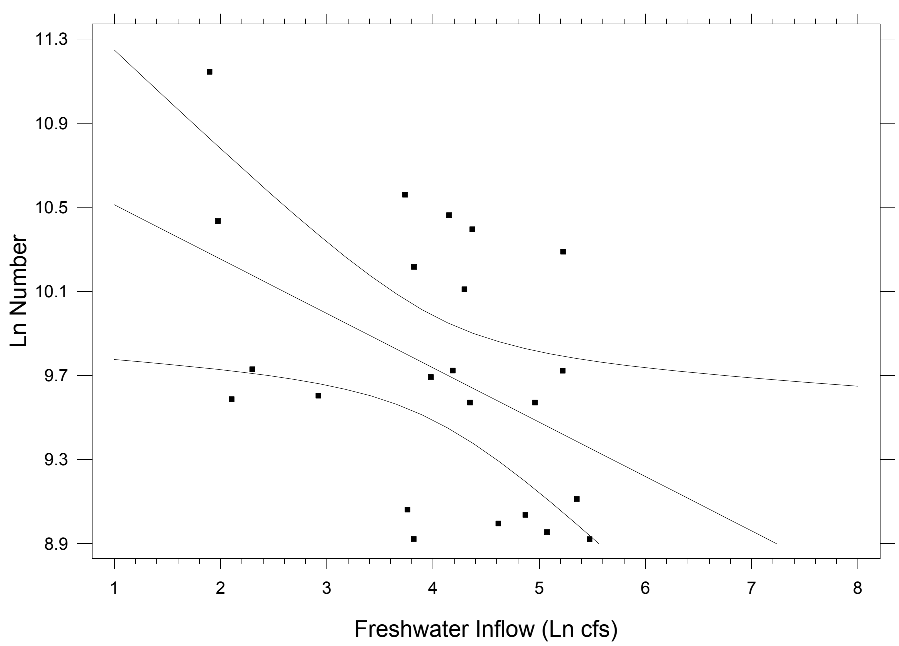
ostracods, podocopid



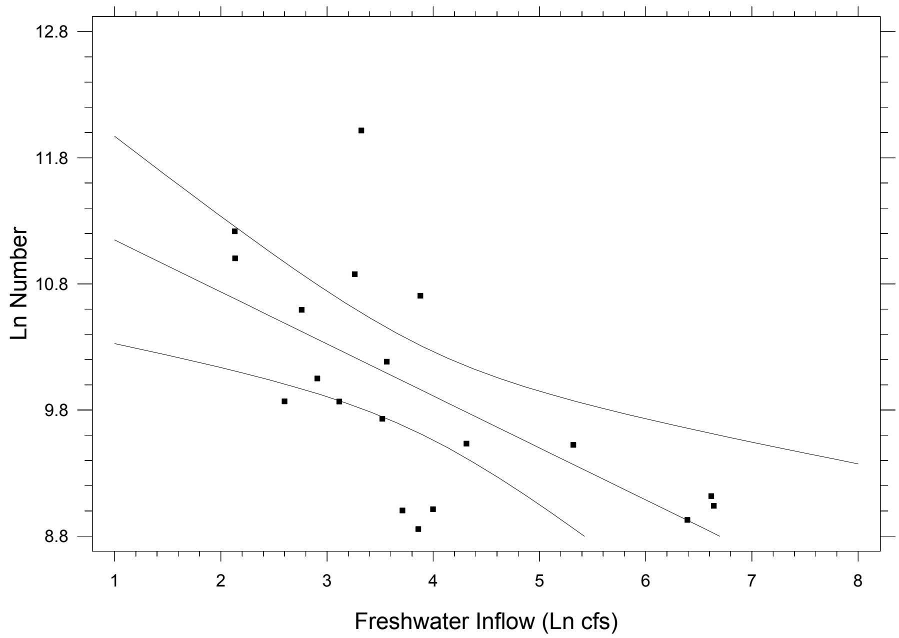
Anchoa mitchilli adults



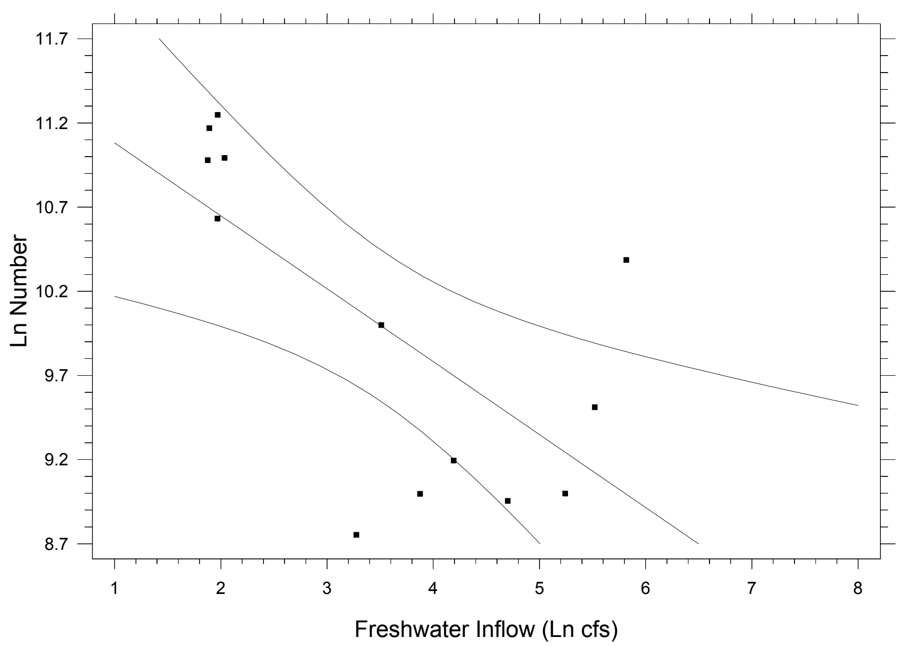
Lolliguncula brevis juveniles



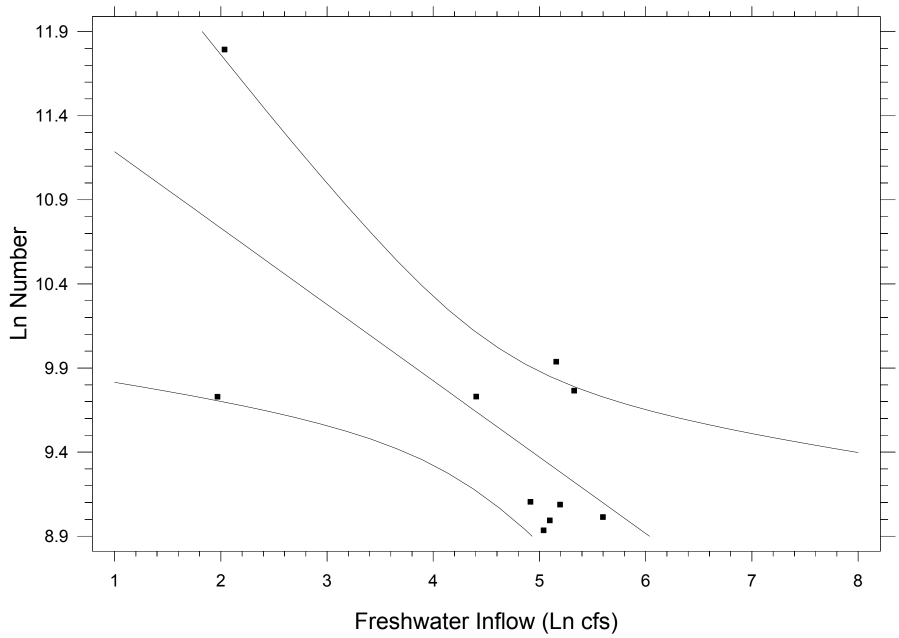
Syngnathus scovelli juveniles



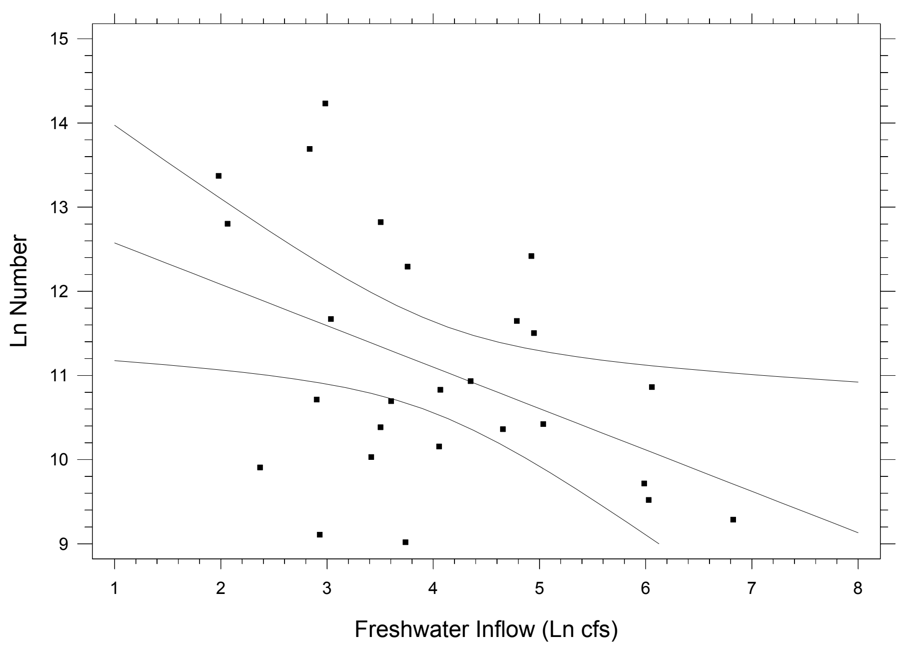
Cynoscion arenarius preflexion



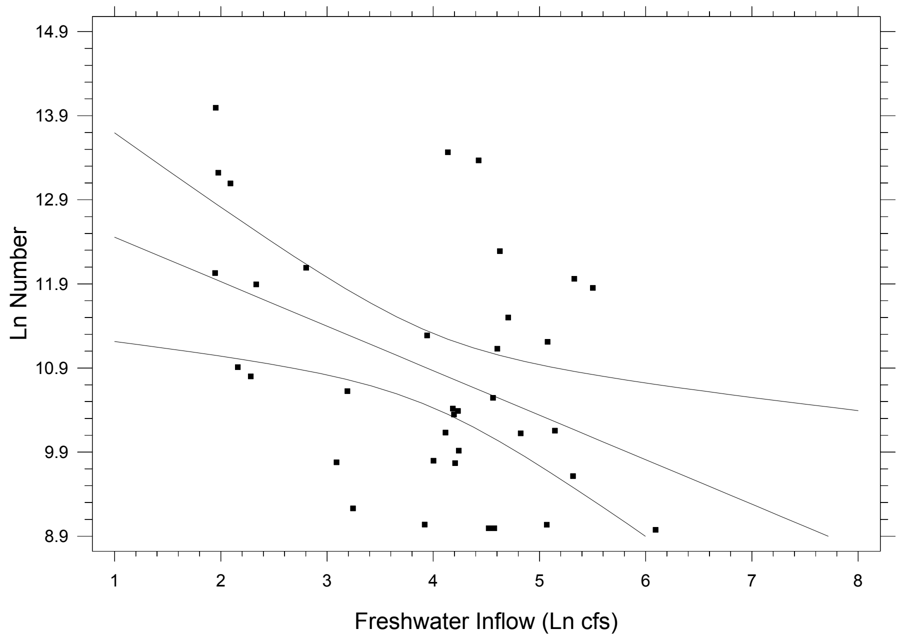
Chasmodes saburrae postflexion



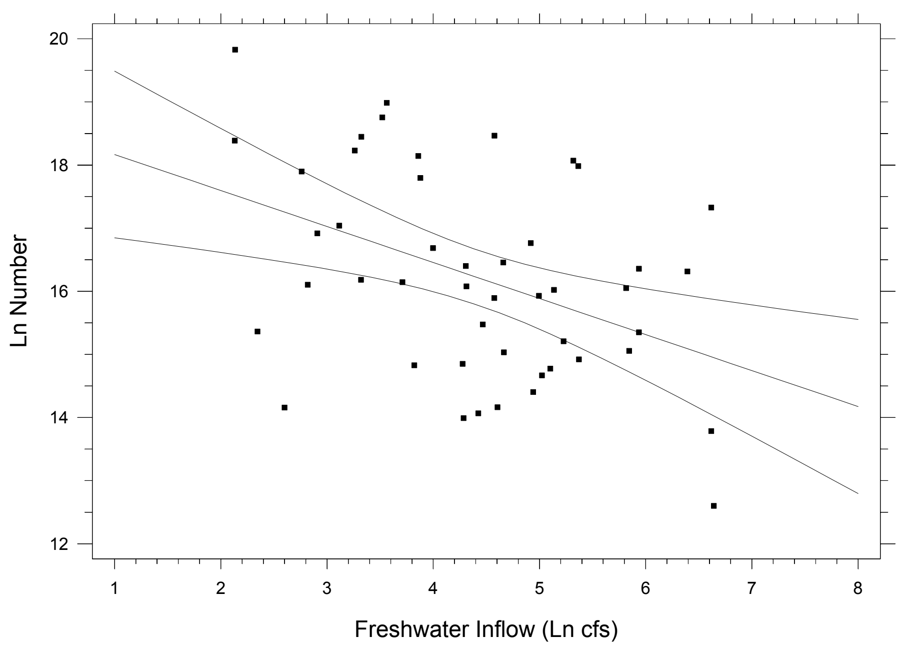
amphipods, caprellid



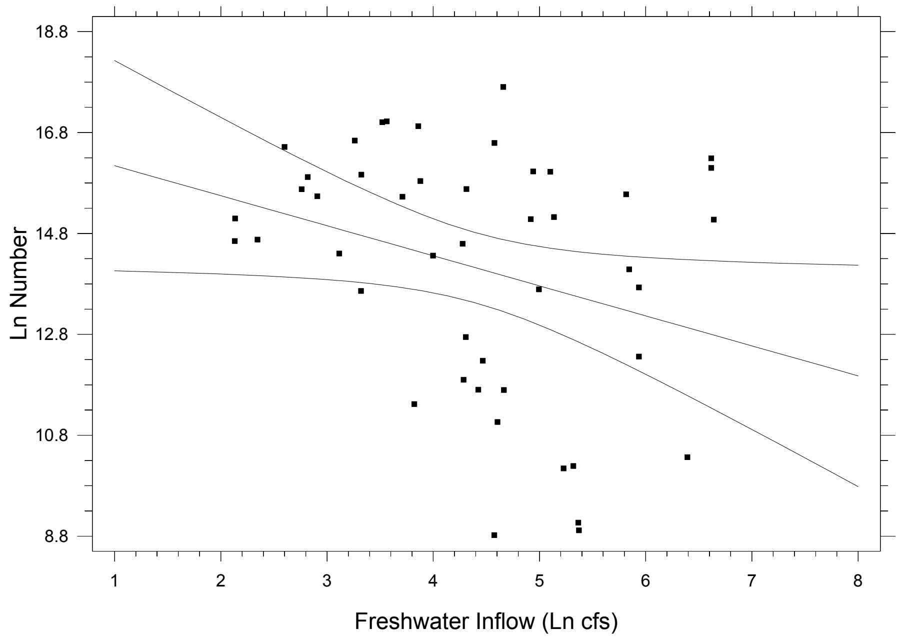
blenniid preflexion larvae



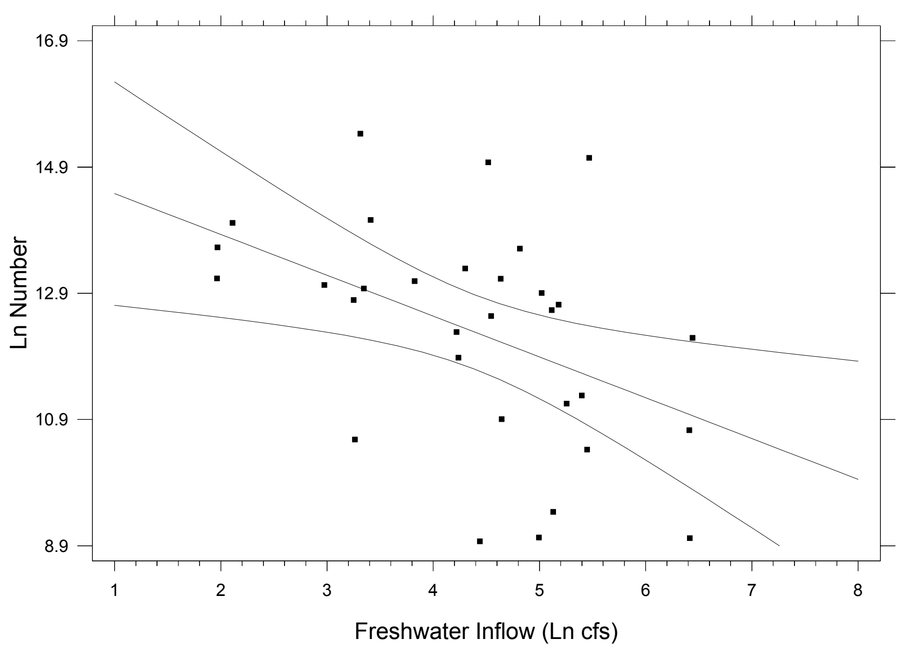
decapod mysis



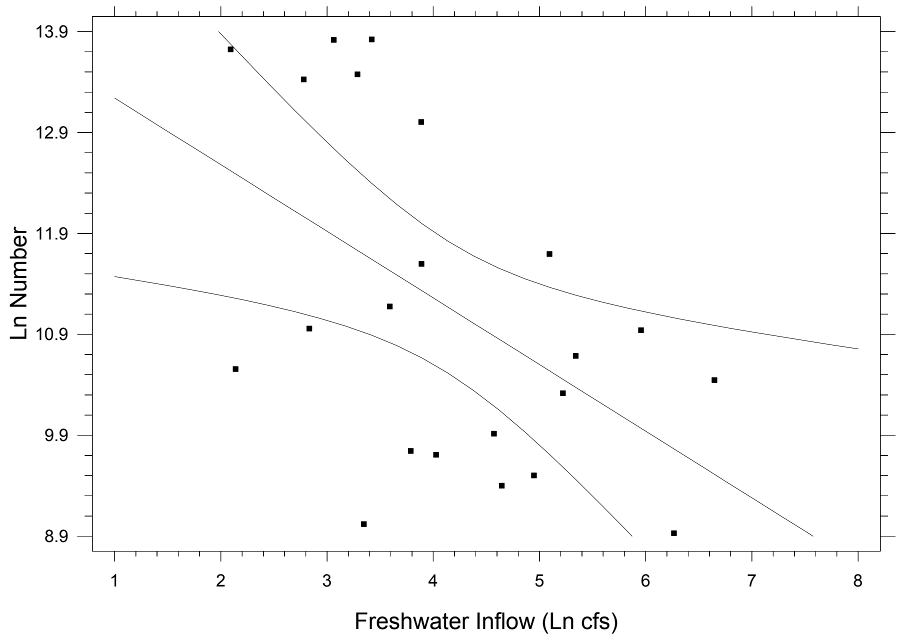
Parasterope pollex



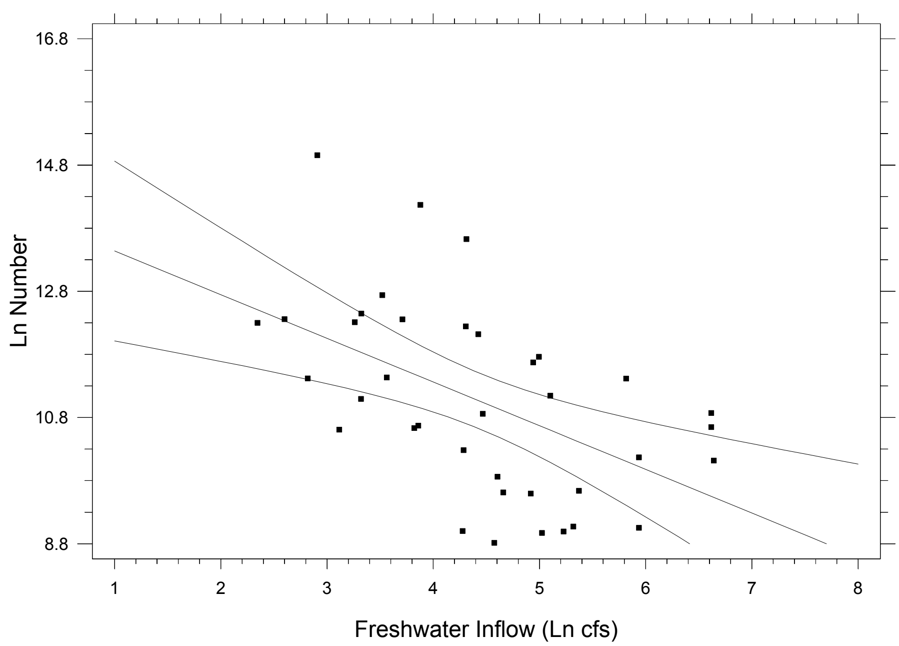
Anchoa mitchilli postflexion larvae



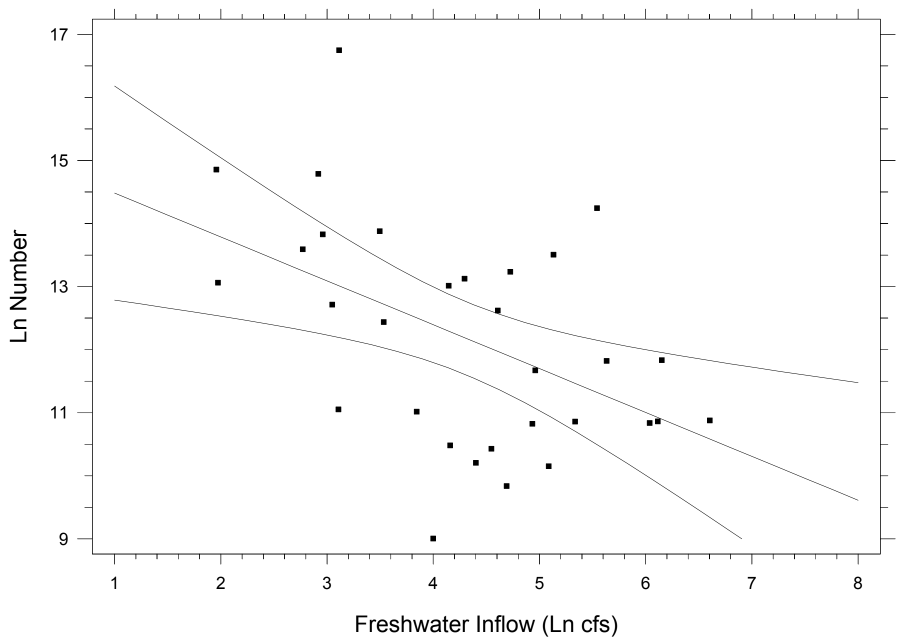
Microgobius spp. postflexion larvae



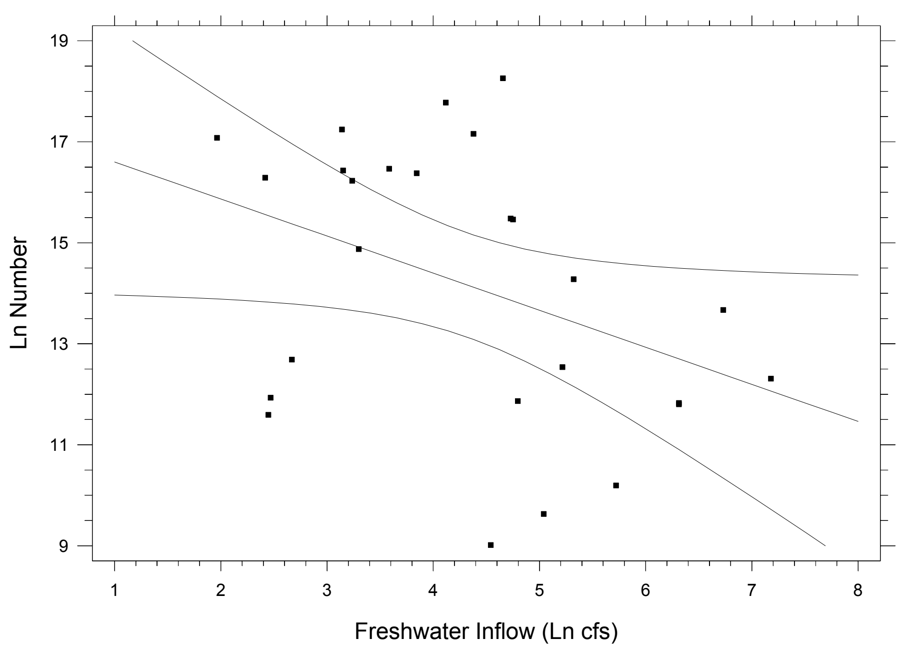
Eusarsiella zostericola



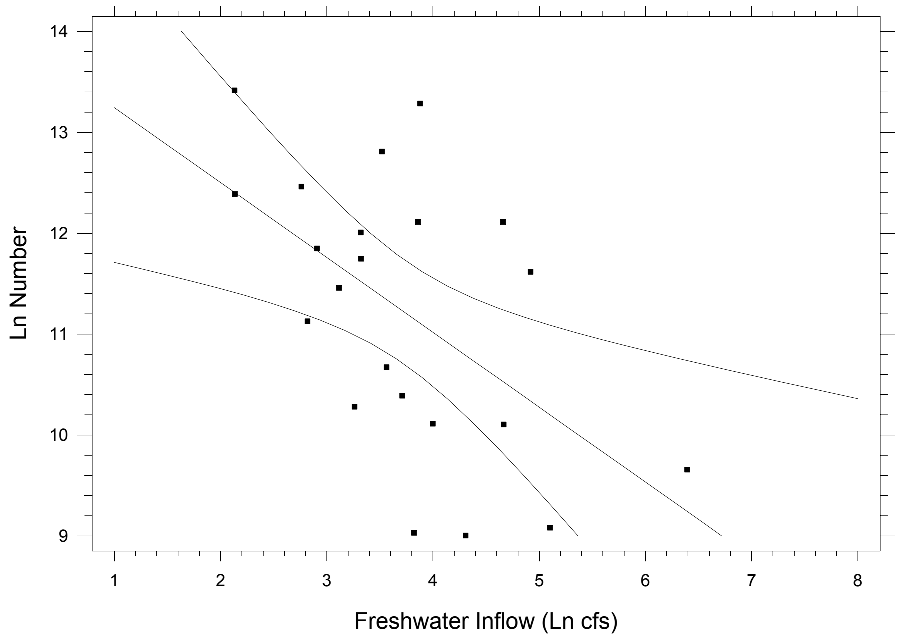
alphaeid postlarvae



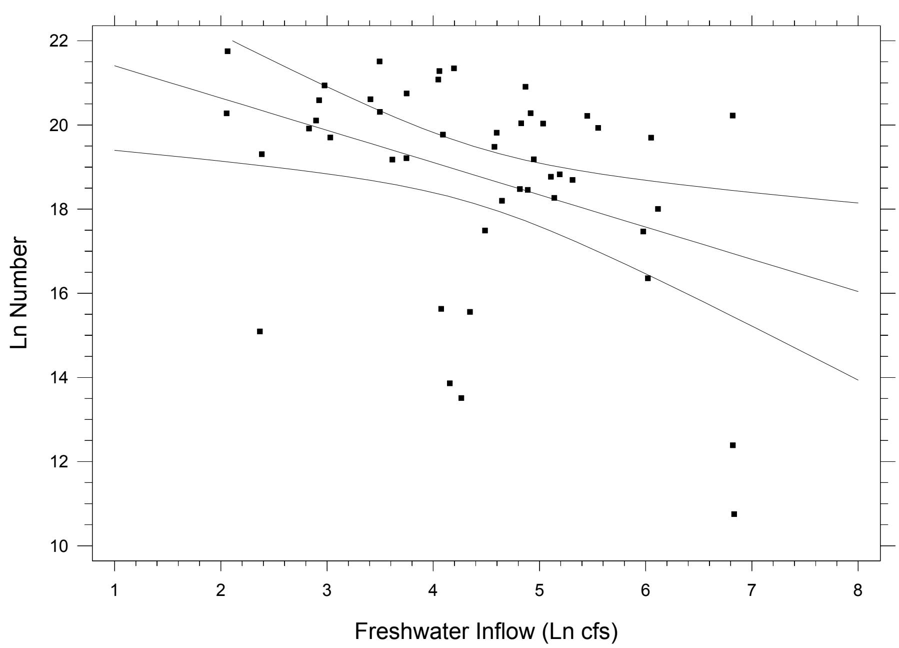
Mnemiopsis mccradyi

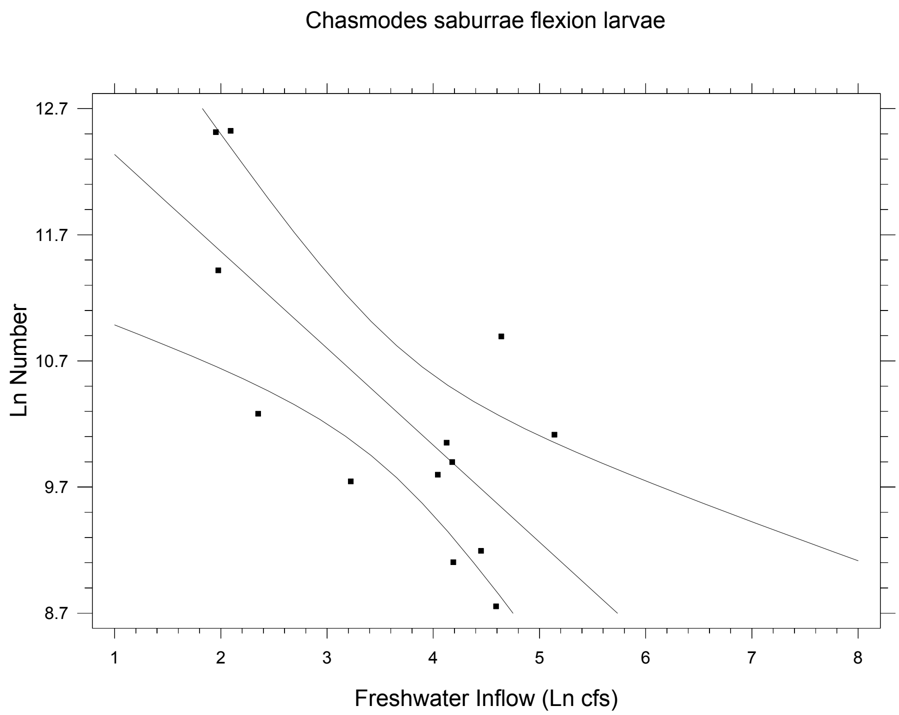


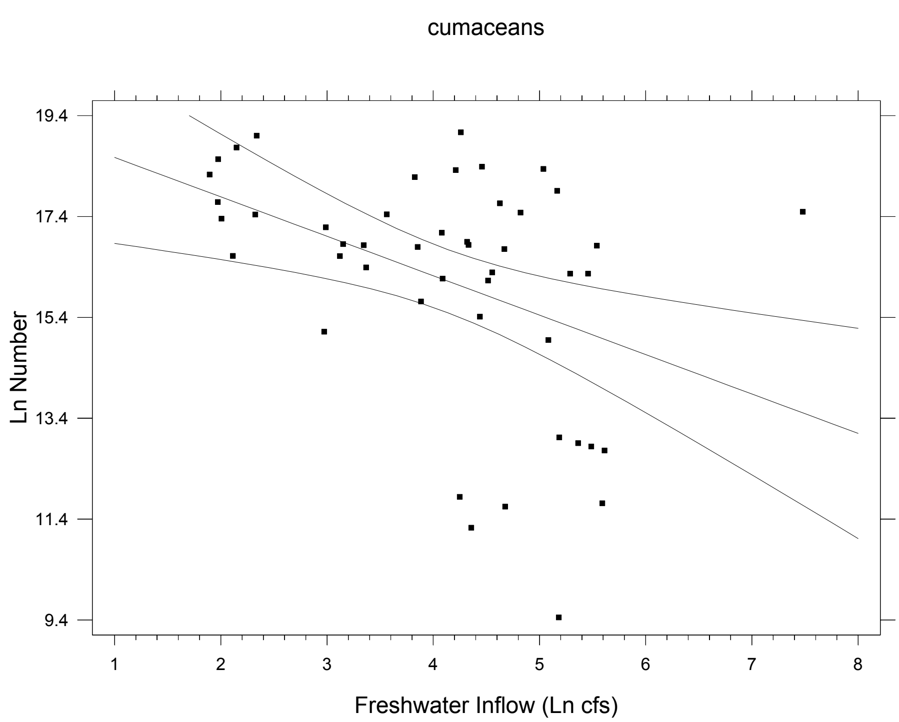
Squilla empusa larvae



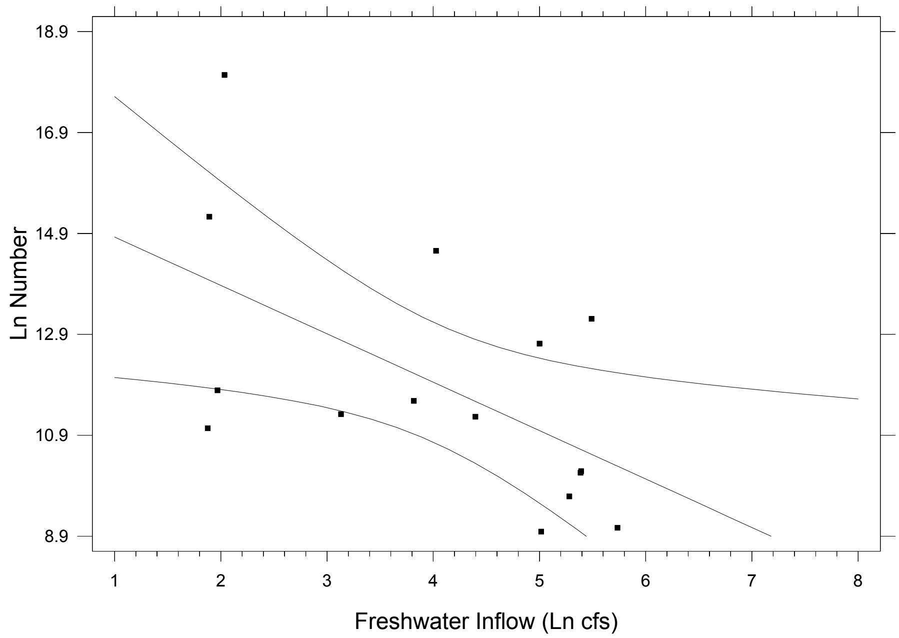
decapod zoeae



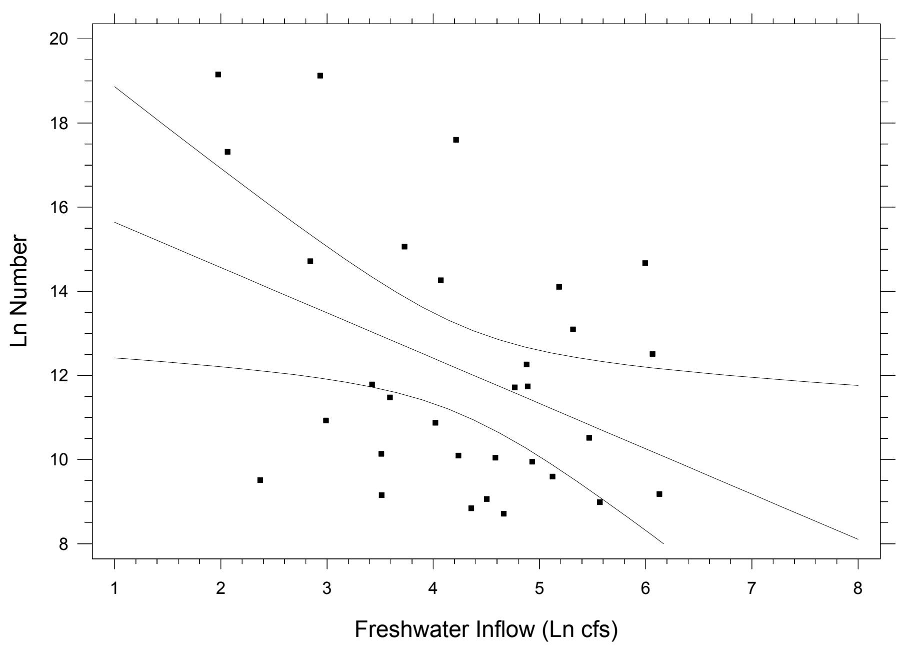

Chasmodes saburrae flexion larvae
12.7
11.7
10.7
9.7
8.7
Ln Number
1
2
3
4
5
6
7
8
Freshwater Inflow (Ln cfs)


cumaceans
19.4
17.4
15.4
13.4
11.4
9.4
Ln Number
1
2
3
4
5
6
7
8
Freshwater Inflow (Ln cfs)

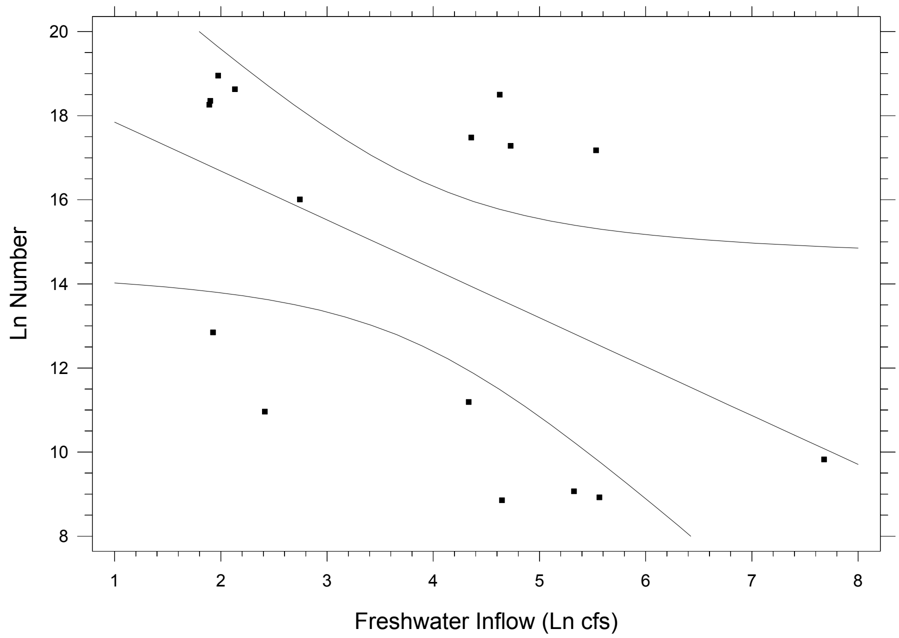
Evadne tergestina



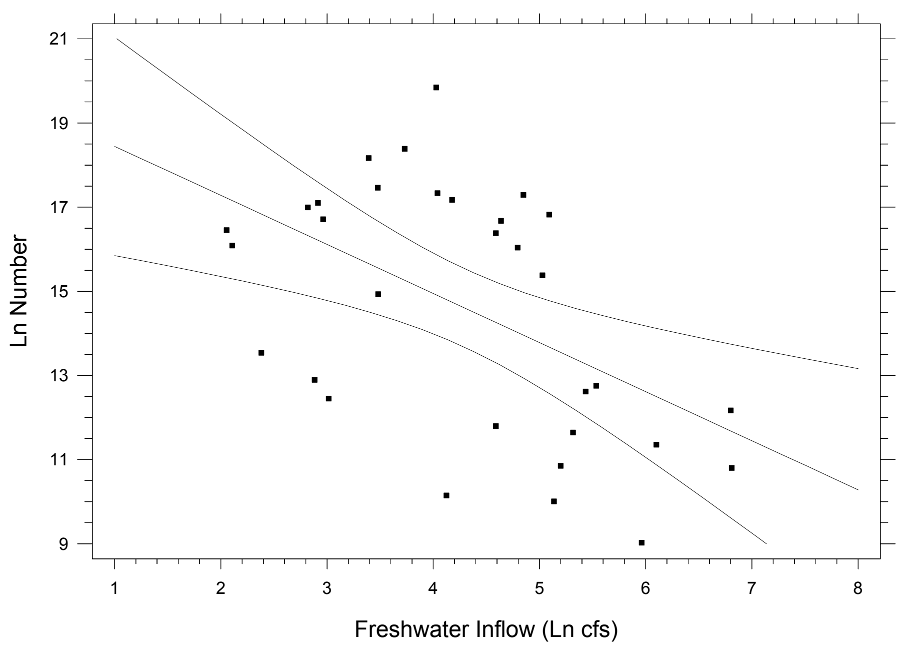
cirriped nauplius stage

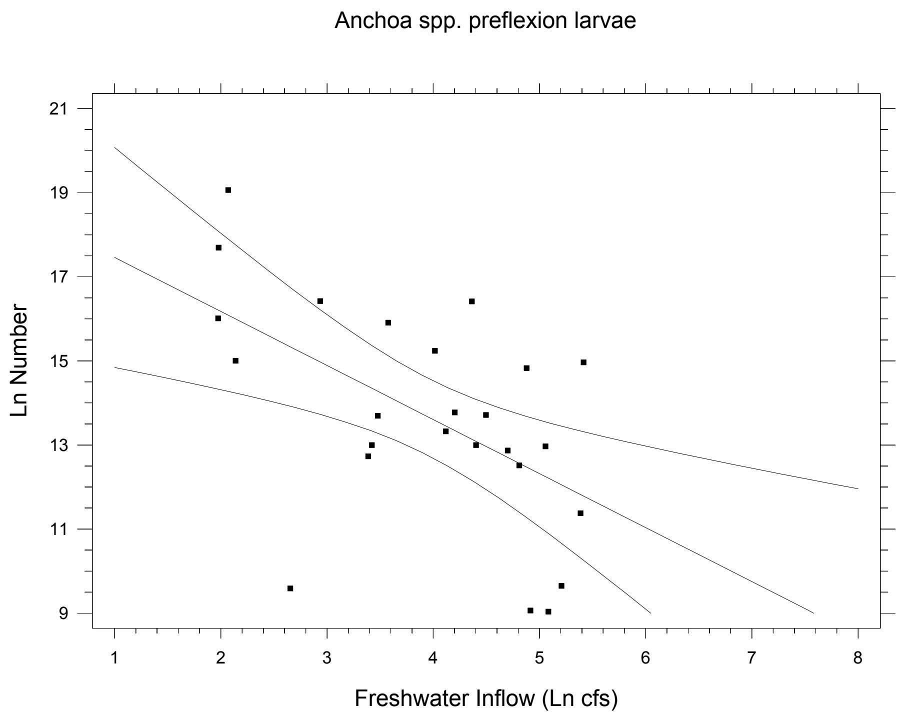


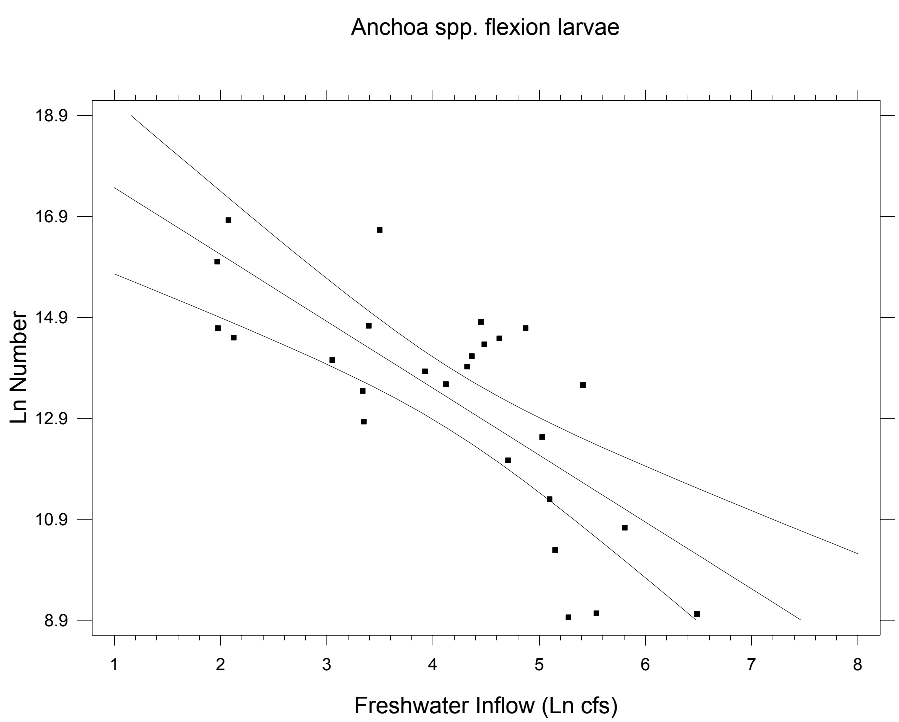
Anchoa mitchilli eggs



fish eggs, percomorph




Anchoa spp. preflexion larvae
Ln Number
21
19
17
15
13
11
9
1
2
3
4
5
6
7
8
Freshwater Inflow (Ln cfs)


Anchoa spp. flexion larvae
Ln Number
18.9
16.9
14.9
12.9
10.9
8.9
1
2
3
4
5
6
7
8
Freshwater Inflow (Ln cfs)