

FRESHWATER INFLOW EFFECTS
ON FISHES AND INVERTEBRATES
IN THE HILLSBOROUGH RIVER ESTUARY

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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, the impacts of managed freshwater inflows on downstream estuaries are being assessed. A 57-month study of freshwater inflow effects on habitat use by estuarine organisms in the tidal Hillsborough River was started in April 2000 as part of Tampa Bay Water's ongoing Hydro-Biological Monitoring Program for the Tampa Bypass Canal/Alafia Water Supply Project.

The general objective of the present data analysis was to identify patterns of estuarine habitat use and organism abundance under variable freshwater inflow conditions and to evaluate responses to low inflow conditions and localized hypoxia (low dissolved oxygen concentrations). Systematic monitoring was performed to develop a predictive capability for evaluating potential impacts of proposed freshwater withdrawals and, in the process, to contribute to baseline data. The predictive aspect involves development of regressions that describe variation in organism distribution and abundance as a function of natural variation in inflows and salinity. These regressions can be applied to any proposed alterations of freshwater inflows or salinity that fall within the range of natural variation documented during the data collection period.

For sampling purposes, the lengthwise axis of the tidal Hillsborough River was divided into six zones from which plankton net, seine net and trawl samples were taken on a monthly basis. Salinity, water temperature, dissolved oxygen, and pH measurements were taken in association with each net deployment. Daily freshwater inflow estimates for the Hillsborough River estuary were derived from gauged dam releases, gauged inflows from Sulphur Springs, and a model of local ungauged flows to the tidal river.

A large body of descriptive habitat-use information was generated and is presented in accompanying appendices. In general, observed habitat-use patterns are consistent with findings from other tidal rivers on Florida's west coast. However, the Hillsborough River differs from most other rivers in the area with regard to the rate at which its geometric volume increases with distance downstream. Residence times can be short and discharge velocities can be high throughout the tidal river's length, causing many estuarine animals to leave the river when inflows are elevated. When inflows cease, estuarine animals return to the river, but then must face problems with low dissolved oxygen levels and blooms of gelatinous predators (hydromedusae and ctenophores) that occur in stagnant waters. The gelatinous predators compete with young fish for prey and may prey directly upon the smaller larval stages of fishes and crustaceans.

The plankton-net fish catch was dominated by bay anchovy juveniles (*Anchoa mitchilli*) and postflexion stage gobies. Gobies of the genus *Gobiosoma* were the dominant gobies in the Hillsborough River, with *Microgobius* spp. being of secondary importance. Other abundant fishes were menhadens (*Brevoortia* spp.), skilletfish (*Gobiesox strumosus*), silversides (*Menidia* spp.), blennies (primarily *Chasmodes saburrae*) and the hogchoker (*Trinectes maculatus*). The plankton-net invertebrate catch was dominated by larval crabs (decapod zoeae, primarily *Rhithropanopeus harrisi*), hydromedusae (primarily *Clytia* sp.), calanoid copepods (primarily *Acartia tonsa* and *Labidocera aestiva*), mysids (primarily *Americamysis almyra*), chaetognaths (*Sagitta tenuis* and *Ferosagitta hispida*), the freshwater cyclopoid copepod *Mesocyclops edax*, gammaridean amphipods, polychaete worms (primarily nereids), the parasitic isopod *Lironeca* sp., larval shrimps (primarily *Palaemonetes*) and dipteran insect larvae (esp. *Chaoborus punctipennis*).

Shoreline seine fish collections were dominated by bay anchovy, silversides, menhadens, eastern mosquitofish (*Gambusia holbrooki*), spot (*Leiostomus xanthurus*), rainwater killifish (*Lucania parva*), sailfin molly (*Poecilia latipinna*), and striped mullet (*Mugil cephalus*). The trawl fish catch from the channel was mostly composed of spot,

hogchoker, bay anchovy, sand seatrout (*Cynoscion arenarius*) and southern kingfish (*Menticirrhus americanus*). Invertebrates collected by seines were dominated by daggerblade grass shrimp (*Palaemonetes pugio*); invertebrate trawl catches primarily consisted of blue crab (*Callinectes sapidus*), daggerblade grass shrimp, and pink shrimp (*Farfantepenaeus duorarum*).

Fishes that spawned very near or within the tidal Hillsborough River, as indicated by the presence of eggs or early-stage larvae, were the bay anchovy, striped anchovy (*Anchoa hepsetus*), silversides, killifishes (*Fundulus* spp.), Florida blenny (*Chasmodes saburrae*), naked goby (*Gobiosoma bosc*), code goby (*G. robustum*), green goby (*Microgobius thalassinus*), clown goby (*M. gulosus*) and the frillfin goby (*Bathygobius soporator*).

Estuarine-dependent taxa are spawned at seaward locations and invade tidal rivers during the late larval or early juvenile stage, whereas *estuarine-resident* taxa are present within tidal rivers throughout their life cycles. Estuarine-dependent taxa that use the tidal river as a nursery area are the numerical dominants in the Hillsborough River. Overall, seven of the ten most abundant taxa in the river channel and five of the ten most abundant taxa in nearshore habitats are estuarine-dependent. These include both offshore-spawning taxa (i.e., menhadens, spot, striped mullet, red drum [*Sciaenops ocellatus*], blue crab, pink shrimp, pinfish [*Lagodon rhomboides*], and mojarras) and estuarine spawning taxa (i.e., striped mojarra [*Diapterus plumieri*], sand seatrout, hogchoker, and bay anchovy). Based on seine and trawl data, the juvenile nursery habitats for selected species were characterized in terms of preference for the shoreline or channel, type of shoreline, physical location (distance from the river mouth), and salinity.

Lowest richness (number of taxa) in the plankton-net catch was observed from July through February. The abundances of many estuarine organisms decreased with the onset of the summer rainy season. Alteration of inflows would appear to have the lowest potential for impacting many taxa during the period from November through February, which is the period when the fewest estuarine taxa are present in Tampa Bay

waters. The highest potential for impacting the greatest number of taxa would appear to be from April to June, a time of year when naturally low inflows are coupled with increasing use of the estuary as nursery habitat. The potential for impact is species-specific. During fall, winter, and early spring, for example, there could be impact on red drum and menhadens because these fishes recruit to tidal river nursery habitats during these times. Other species, such the bay anchovy, are present year-round.

The number of taxa collected by seine was generally highest from May through July and lowest in fall/winter (December/January). The pattern was less clear in the trawl data, but taxonomic richness was generally highest in May. Thus the period from May to July seems to have the greatest potential for negative effects of anthropogenic change to the tidal river inflow. Offshore-spawning species (e.g., economically important species such as red drum, striped mullet, pink shrimp, and blue crab, and ecologically important taxa such as mojarras) generally had peaks in recruitment during late fall and winter, whereas estuarine spawners (e.g., economically important silver perch and sand seatrout, and ecologically important bay anchovy and hogchoker) and residents (e.g., economically important largemouth bass [*Micropterus salmoides*] and ecologically important killifishes) generally recruited from spring to early fall.

Approximately half (49%) of the 108 plankton-net taxa evaluated for distribution responses to freshwater inflow exhibited significant responses. All except two of these were negative responses, indicating that the predominant response to increased inflow was movement downstream. Although response lags ranged from 1 to 120 d, most were 10 d or less, and many were 5 d or less. The taxa with the most predictable distribution responses ($r^2 > 50\%$) were estuarine-dependent and estuarine-resident animals (i.e., they were not freshwater animals). Among the 51 negative relationships, the steeper slopes tended to have higher r^2 values and also tended to have larger intercepts. These results collectively suggest that the estuarine animals that penetrate far into the tidal river during low inflow periods respond to inflow increases in a stronger, more predictable manner than freshwater organisms below the dam or higher-salinity

organisms near the river mouth. The planktonic hydromedusa *Clytia* sp. had the strongest distribution response to inflow.

Nearly one-third (32%) of the 69 seine and trawl taxon-size class combinations ('pseudo-species') evaluated for distributional responses to freshwater inflow exhibited significant responses. In all cases, taxa moved downstream with increasing inflow. Estuarine-resident taxa responded most strongly to inflow averaged over medium to long-term lag periods (90–365 days). Estuarine-dependent taxa that spawn within Tampa Bay tended to be most strongly associated with short inflow lags (0–14 days), whereas estuarine-dependent taxa that spawn offshore in the Gulf of Mexico responded to lags that were relatively evenly distributed over inflow periods from 0–365 days.

Distribution responses and abundance responses are sometimes inter-related. Approximately half (51%) of the 108 plankton-net taxa evaluated for abundance responses to freshwater inflow exhibited significant responses. These were largely split between freshwater taxa that were introduced by inflows (positive responses) and higher-salinity taxa that moved out of the river and into Hillsborough Bay during high inflow periods (negative responses). The negative distribution responses of most estuarine-dependent juveniles (i.e., their movement into Hillsborough Bay during high inflows) reduced abundances in the Hillsborough River even though total numbers of these species in the river and bay may have been responding favorably to inflows. Hogchoker juveniles, on the other hand, remained in the river during relatively high inflow periods and tended to increase in number. As in other tidal rivers, hogchoker juveniles occurred farther upstream than other estuarine-dependent juvenile fishes. Hogchoker juveniles did not exhibit a measurable downstream movement in response to inflow, regardless of the data source used (plankton net, seine, or trawl). The positive abundance response by hogchoker juveniles was lagged by 47-d, which is comparable to the general age of these fish.

Freshwater inflow had a strong distributional effect on the hydromedusa *Clytia* sp. that resulted in a strong reduction in its abundance. Because hydromedusae compete with and consume the early stages of fishes, their rapid displacement

downstream and away from tidal river nursery habitats can be considered a beneficial effect of increased inflow. When hydromedusa blooms were present, the biomass and diversity of the plankton community was usually strongly reduced. The inflow levels that reduce hydromedusa numbers are generally lower than the inflow levels that reduce fish abundance.

Among the 69 pseudo-species considered in the abundance response regressions for seine and trawl catch, abundances of 49% were significantly related to inflow. The most common response was decreased abundance with increased inflow, typified by a precipitous decline of high-salinity animals (e.g., striped anchovy) with higher inflows, although there were positive relationships to increased inflow in several resident and offshore-spawning taxa. Juvenile spot, for example, were quite rare at lower inflows but greatly increased in abundance with increased inflow, perhaps due to enhanced attraction by substances emanating from the tidal river and its watershed or improved density-driven transport mechanisms. Maximum or minimum abundance at intermediate levels of inflow was also seen in several residents and offshore spawners. The strongest abundance-inflow relationships incorporated longer lags for residents and shorter lags for estuarine spawners but were well distributed among lag periods for offshore spawners.

Inflow responses of stenohaline (strictly freshwater) and euryhaline (salt-tolerant) groups of freshwater taxa in the upper reaches of the study area (above the confluence with Sulphur Springs) were similar: decreased inflow tended to lead to movement upstream, decreased abundance, and decreased taxonomic richness. Components of both types of freshwater groups might be established below the dam with relatively small, consistent, long-term increases in inflow. In particular, inflows >20–30 cfs appeared to be important for increasing abundance and taxonomic richness. The establishment of a permanent freshwater zone below the dam would be beneficial to estuarine species even if a permanent freshwater community is not created. Many estuarine and marine species recruit to oligohaline waters during their juvenile life-history stages. Even in the highly altered Hillsborough River, economically important

species (e.g., snook) utilize these low-salinity habitats when they are available.

Compression of the oligohaline zone near the base of the dam may lead to crowding of species seeking low-salinity habitats. Community structure upstream of the confluence with Sulphur Springs underwent considerable change from July to September in 2000 and 2001, coincident with increased inflows caused by dam release. Upon reduction of inflows in October, the community generally reverted to a structure more similar to that of July.

Negative dissolved oxygen (DO) anomalies were strongest in the upper reaches of the tidal river. In a forward stepwise multiple regression that included depth, location (km from mouth), bottom pH and surface-to-bottom differences in salinity and temperature, pH was the first variable selected, explaining 58% of the variation in DO anomaly at the bottom. Because pH is indicative of CO₂ concentration, these results suggest that the benthic hypoxia in the upper part of the tidal Hillsborough River is primarily caused by high ratios of community respiration to primary production. Physical factors such as density stratification appear to play a secondary role.

Organisms tended to avoid areas of hypoxia, with evidence - albeit weak evidence - of shoreline seine catches being marginally elevated in association with decreasing oxygen concentration in the adjacent channel habitat. Both relative abundance and taxon richness of organisms in the channel habitat decreased with decreasing oxygen concentration, particularly in hypoxic conditions (i.e., dissolved oxygen ≤ 2 mg l⁻¹). Hypoxia was rare in the nearshore habitat, so that no conclusions on the relationship of seine-caught species to low dissolved oxygen could be drawn.

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Rivers export nutrients, detritus and other productivity-promoting materials to the estuary and sea. Freshwater inflows also strongly influence the stratification and circulation of coastal waters, which in itself may have profound effects on the coastal ecosystem (Mann and Lazier 1996). Estuary-related fisheries constitute a very large portion of the total weight of the U.S. fisheries yield (66% of finfish and shellfish harvest, Day et al. 1989; 82% of finfish harvest, Imperial et al. 1992). The contribution of estuary-related fisheries is consistently high among U.S. states that border the Gulf of Mexico, where the estimates typically exceed 80% of the total weight of the catch (Day et al. 1989). Examples from around the world indicate that these high fisheries productivities are not guaranteed, however. In many locations, large amounts of fresh water have been diverted from estuaries to generate hydroelectric power or to provide water for agricultural and municipal use. Mann and Lazier (1996) reviewed cases where freshwater diversions were followed by the collapse of downstream fisheries in San Francisco Bay, the Nile River delta, James Bay (Canada), and at several inland seas in the former U.S.S.R. Sinha et al. (1996) documented a reversal of this trend where an increase in fisheries landings followed an increase in freshwater delivery to the coast.

Fishery yields around the world are often positively correlated with freshwater discharge at the coast (Drinkwater 1986, Grimes 2001). These correlations are strongest when they are lagged by the age of the harvested animal. In south Florida, Browder (1985) correlated 14 years of pink shrimp landings with lagged water levels in the Everglades. Correlations between river discharge and fisheries harvests have also been identified for various locations in the northern and western Gulf of Mexico (Day et al. 1989, Grimes 2001). Surprisingly, discharge-harvest correlations sometimes extend to non-estuarine species. Sutcliffe (1972, 1973) reported lagged correlations between discharge of the St. Lawrence River and the harvest of non-estuarine species such as American lobster and haddock. In recognition of the potential complexities behind these correlations, Drinkwater (1986) advised that the effect of freshwater inflows be considered on a species-by-species basis.

Fresh water's influence on the coastal ecosystem extends beyond its immediate effects on fisheries. Because of the intricate nature of many food-web interactions, changes in the abundance of even a single species may be propagated along numerous pathways, some anticipated and some not, eventually causing potentially large changes in the abundance of birds, marine mammals and other groups of special concern (Christensen 1998, Okey and Pauly 1999). Mann and Lazier (1996) concluded "one lesson is clear: a major change in the circulation pattern of an estuary brought about by damming the freshwater flows, a tidal dam, or other engineering projects may well have far-reaching effects on the primary and secondary productivity of the system."

This project was conducted to support the establishment of minimum flows for the Hillsborough River estuarine system 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 for an estuarine system, the SWFWMD evaluates the effects of the freshwater inflows on ecological resources and processes in the receiving estuary. The findings of this project will be used by the SWFWMD to evaluate the fish and shellfish nursery function of the Hillsborough River estuary in relation to freshwater inflows. 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

There were several objectives for this project. One was to produce a descriptive database that could serve as a baseline for comparison with future ecological change. These baseline data provide seasonality records that identify the times of year when the risk of adverse impacts would be greatest for specific organisms.

A principal objective was to develop regressions to model the distribution and abundance responses of estuarine organisms to variations in freshwater inflows and salinity. The resulting models would then be available for evaluating proposed minimum

flows or the potential impacts of proposed freshwater management plans. These regression models were developed for estuarine fish and shellfish and for invertebrate prey groups that sustain young fishes while they occupy estuarine nursery habitats.

The Hillsborough River is dammed, and discharges from the dam can be regulated to some extent. Dam releases establish a freshwater fish and invertebrate community in the upper tidal river that otherwise disappears during sustained dry periods. Dam releases may also influence the severe benthic hypoxia (dissolved oxygen $<2.0 \text{ mg l}^{-1}$) that has been frequently observed in the tidal portion of the river. The ecological value of low-level estuarine inflows (e.g., $<50 \text{ cfs}$), either as dam release or as water routed to the base of the dam from other sources, was evaluated in the context of organism abundance, organism distribution, and community structure. Hypoxia's influence on organism distribution and abundance was also investigated.

2.0

METHODS

2.1

Study Area

The tidal portion of the Hillsborough River (Fig. 2.1.1) is a geographically small, microtidal, drowned-river-valley estuary that connects to the Gulf of Mexico via Hillsborough Bay and Tampa Bay. At the river mouth, the mixed, mainly semi-diurnal tide has a range of <1.2 m. The Hillsborough River watershed has an area of 1,748 km² (675 mi²) bounded within Pasco, Polk and Hillsborough counties. From its headwaters in the Green Swamp area of Pasco County, the Hillsborough River flows approximately 72 km (45 mi) to Tampa Bay. The City of Tampa uses the Hillsborough River as its principle source of drinking water and has constructed a dam near km 16 (10 mi) to create a reservoir for this purpose. During the period from 1999 to 2004, there was no discharge (<0.3 cfs) from the dam on 51% of days.

Agricultural and urban/built lands comprise 32% and 25% of the river's watershed area, respectively (SWFWMD 2000). Although 22% of the watershed consists of wetlands, wetlands coverage adjacent to the tidal portion of the river is negligible.

TIDAL HILLSBOROUGH RIVER

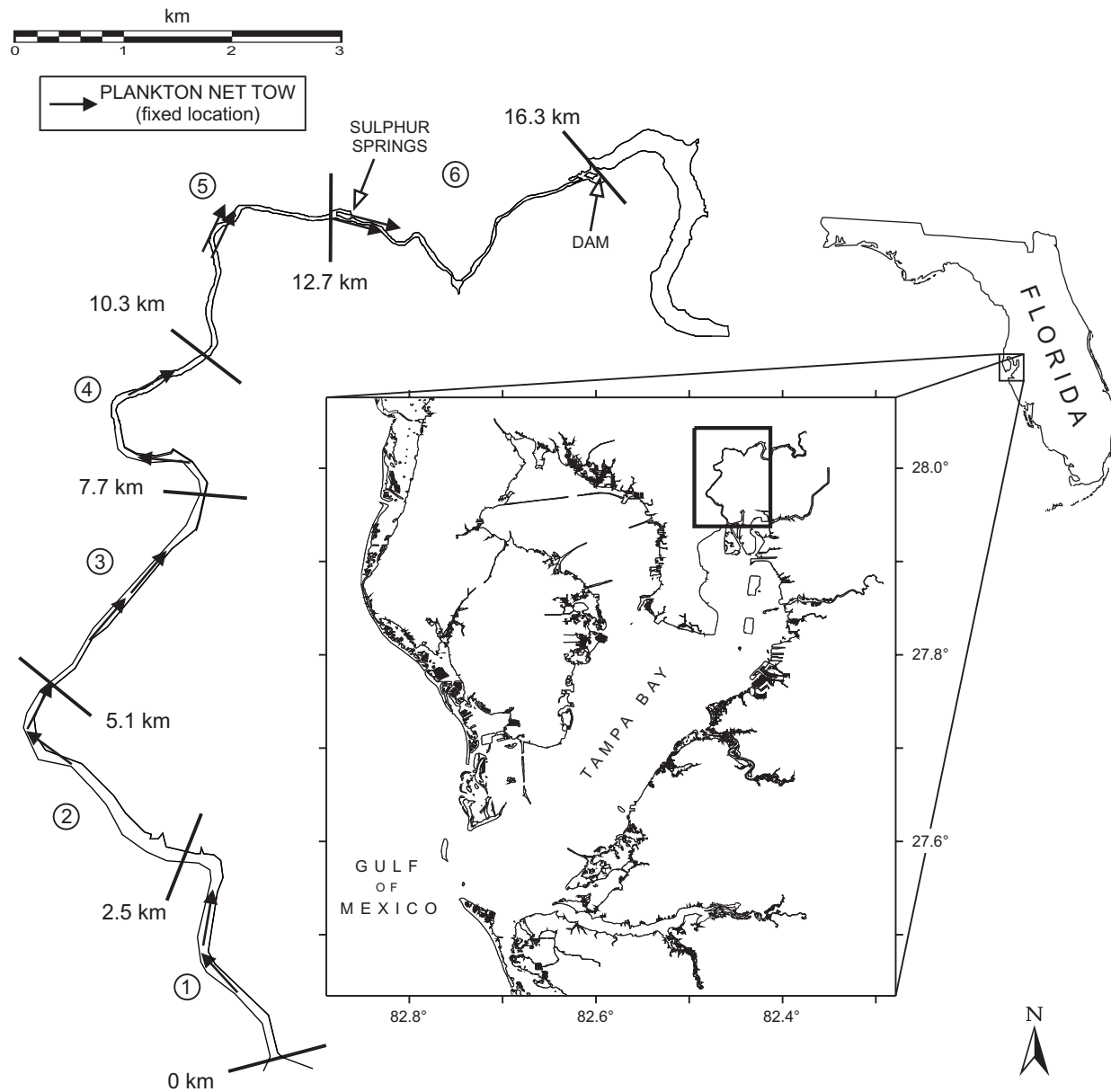


Fig. 2.1.1. Map of survey area, including sampling zones (circled numbers) and zone boundaries (dotted lines).

Three gear types were implemented to monitor organism distributions: a plankton net deployed during nighttime flood tides and a bag seine and otter trawl deployed during the day under variable tide stages. The plankton net surveys were conducted by the University of South Florida College of Marine Science, and the seine and trawl surveys were conducted by the Fisheries-Independent Monitoring (FIM) program of the Fish and Wildlife Research Institute (Florida Fish and Wildlife Conservation Commission).

The small organisms collected at night by the plankton net represent a combination of the zooplankton and hyperbenthos communities. The term “zooplankton” includes all weakly swimming animals that suspend in the water column during one or more life stages. The distribution of such animals is largely subject to the motion of the waters in which they live. The term “hyperbenthos” applies to animals that are associated with the bottom but tend to suspend above it, rising higher into the water column at night or during certain times of year. The permanent hyperbenthos of estuaries (non-transient hyperbenthos) tends to be dominated by peracarid crustaceans, especially mysids and amphipods (Mees et al. 1993).

The faunal mixture that forms in the nighttime water column includes the planktonic eggs and larvae of fishes (ichthyoplankton). One of the most common reasons for using plankton nets to survey estuarine waters is to study ichthyoplankton. Although fish eggs and larvae are the intended focus of such studies, invertebrate plankton and hyperbenthos almost always dominate the samples numerically. The invertebrate catch largely consists of organisms that serve as important food for juvenile estuarine-dependent and estuarine-resident fishes. In an effort to characterize the invertebrate catch more completely, all water-column animals collected by the plankton net were enumerated at a practical taxonomic level.

Seines and trawls were used to survey larger organisms that typically evade plankton nets. Generally speaking, the data from seine hauls document habitat use by shoreline-oriented organisms whereas the data from trawls document habitat use near the bottom of open channel areas. The dominant catch for both gear types is juvenile

fishes, although the adults of smaller species are also commonly caught. The seines and trawls also regularly collect a few of the larger macroinvertebrate species from tidal rivers, notably juvenile and adult blue crabs (*Callinectes sapidus*) and juvenile pink shrimp (*Farfantepenaeus duorarum*).

Monthly sampling began in April (plankton) or May (seine and trawl), 2000, and is ongoing at the time of writing. In the present analyses, the plankton database extends through December, 2004 (57 months), as does the seine and trawl database (56 months). The tidal portion of the Hillsborough River was divided into six collection zones (Fig. 2.1.1, Table 2.2.1). Within each zone, two plankton net tows, two seine hauls and one trawl were made each month. Trawling in the uppermost zone was discontinued after May 2000; this extra monthly haul was thereafter randomly added to each of the other zones.

Table 2.2.1. Distribution of sampling effort within the tidal Hillsborough River for plankton (April 2000-December 2004) and seine and trawl collections (May 2000-December 2004). Zone position is measured relative to the river mouth.

Zone (km)	Plankton	Seine	Trawl
0-2.5	114	111	69
2.5-5.1	114	112	67*
5.1-7.7	114	113*	66*
7.7-10.3	114	112	65
10.3-12.7	114	114*	68
12.8-16.3	114	112	1**
Totals	684	674	336

*Additional samples were collected during a sewage spill in November 2004; these samples are not considered in subsequent analyses.

**Trawling in this zone was discontinued after May 2000.

The locations for seine and trawl deployment were randomly selected within each zone during each survey, whereas the plankton-net collections were made at fixed

stations that were selected using one-time randomization within each zone. The longitudinal position of each station was measured as the distance from the mouth of the tidal river, following the geometric centerline of the channel.

2.3 Plankton Net Specifications and Deployment

The plankton gear consisted of a 0.5-m-mouth-diameter 500- μ m-mesh conical (3:1) plankton net equipped with a 3-pt nylon bridle, a calibrated flow meter (General Oceanics model 2030R or SeaGear model MF315), a 1-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 5 min, with tow time being divided equally among bottom, mid-water and surface depths. The boat towed the net along a nearly constant depth contour that was estimated to be close to the average cross-sectional depth for the local river reach. The fishing depth of the weighted net was controlled by adjusting the length of the tow line while using tachometer readings to maintain a constant line angle. The tow line was attached to a winch located on the gunnel near the transom. Placement of the winch in this location caused asymmetry in the steering of the boat, which caused propeller turbulence to be directed away from the towed net. Tow speed was approximately 1.3 m s⁻¹, resulting in a tow length of >400 m over water and a typical filtration of 70-80 m³. Upon retrieval of the net, the flowmeter reading was recorded and the contents of the net were rinsed into the cod-end jar using an electric wash-down pump and hose with an adjustable nozzle. The samples were preserved in 6-10% formalin in ambient saline.

When ctenophore (comb jelly) volumes exceeded the cod-end jar's capacity, volume indicators on the net panel seams were used to estimate the total volume of ctenophores in the net. If the total volume was <3.0 liters, only the material in the cod-end jar was preserved. If the total volume was >3.0 liters, a second cod-end jar was filled

and preserved by ladling material from inside the net. Abundances of all organisms in the sample were later adjusted to reflect this subsampling method. The net was cleaned between surveys using an enzyme solution that dissolves organic deposits. Salinity, temperature, pH and dissolved oxygen were measured at one-meter intervals from surface to bottom after each plankton-net deployment.

2.4 Seine and Trawl Specifications and Deployment

The gear used in all seine collections was a 21.3-m center-bag seine with 3.2-mm mesh and leads spaced every 150 mm. To deploy the seine, the boat dropped off a member of the seine crew near the shoreline with one end of the seine, and the boat then paid out the net in a semicircle until the boat reached a second drop-off point near the shoreline. The lead line was retrieved simultaneously from both ends, with effort made to keep the lead line in contact with the bottom. This process forced the catch into the bag portion of the seine. Area sampled by each seine collection was approximately 68 m².

The 6.1-m otter trawl had 38-mm stretched mesh, a 3.2-mm mesh liner, and a tickler chain. It was towed in the channel for five minutes in either an arc or a straight line. Tow speed averaged 0.6 m s⁻¹, resulting in a typical tow length of about 180 m. Trawl width averaged 4 m, giving an approximate area sampled by a typical tow of 720 m². Salinity, temperature, pH, and dissolved oxygen were measured at the surface and at 1-m intervals to the bottom in association with each gear deployment.

2.5 Plankton Sample Processing

All aquatic taxa collected by the plankton net were identified and counted, except for invertebrate eggs and organisms that were attached to debris (sessile stages of barnacles, bryozoans, sponges, tunicates and sessile coelenterates). During sorting, the data were entered directly into an electronic database via programmable keyboards

that interfaced with a macro-driven spreadsheet. Photomicrographs of representative specimens were compiled into a reference atlas that was used for quality-control purposes.

Most organisms collected by the plankton net fell within the size range of 0.5-50 mm. This size range spans three orders of magnitude, and includes mesoplankton, macroplankton, micronekton and analogous sizes of hyperbenthos. To prevent larger objects from visually obscuring smaller ones during sample processing, all samples were separated into two size fractions using stacked sieves with mesh openings of 4 mm and 250 μ m. The >4 mm fraction primarily consisted of juvenile and adult fishes, large macroinvertebrates and large particulate organic matter. In most cases, the fishes and macroinvertebrates in the >4 mm fraction could be identified and enumerated without the aid of microscopes. When bay anchovy juveniles were encountered in high numbers (>300), the number present was estimated by counting specimens in a weighed fraction.

A microscope magnification of 7-12X was used to enumerate organisms in the >250 μ m fraction, with zoom magnifications as high as 90X being available for identifying individual specimens. The >250 μ m fraction was usually sorted in two stages. In the first sorting stage, the entire sample was processed as 10-15 ml aliquots that were scanned in succession using a gridded petri dish. Only relatively uncommon taxa ($n < 50$) were enumerated during this first stage. After the entire sample had been processed in this manner, the collective volume of the aliquots was recorded within a graduated mixing cylinder, the sample was inverted repeatedly, and then a single 30-60 ml aliquot was poured. The aliquot volume typically represented about 12-50% of the entire sample volume. The second sorting stage consisted of enumerating the relatively abundant taxa within this single aliquot. The second sorting stage was not required for all samples. The second stage was, however, sometimes extended to less abundant taxa ($n < 50$) that were exceptionally small or were otherwise difficult to enumerate (e.g., some copepods, barnacle nauplii, and the larvacean *Oikopleura dioica*).

2.5.1 Staging Conventions.

All fishes were classified according to developmental stage (Fig. 2.5.1.1), where

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.

Decapod larvae were classified as zoea, megalopa or mysis stages. These terms are used as terms of convenience and should not be interpreted as technical definitions. Planktonic larvae belonging to Anomura and Brachyura (crabs) were called zoea. Individuals from these groups displaying the planktonic to benthic transitional morphologies were classified as megalopae. All other decapod larvae (shrimps) were classified as mysis stages 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 was characterized by resemblance to small (immature) adults. Under this system, the juvenile shrimp stage (e.g., for *Palaemonetes*) is equivalent to the postlarval designation used by some authors.

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 2.5.1.1 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 2.5.1.1. 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):		Juvenile-adult transition (mm):	
<i>Lucania parva</i>	10	<i>Anchoa mitchilli</i>	30
<i>Menidia</i> spp.	10	<i>Lucania parva</i>	15
<i>Eucinostomus</i> spp.	10	<i>Gambusia holbrooki</i>	15
<i>Lagodon rhomboides</i>	10	<i>Heterandria formosa</i>	10
<i>Bairdiella chrysoura</i>	10	<i>Menidia</i> spp.	35
<i>Cynoscion arenarius</i>	10	<i>Eucinostomus</i> spp.	50
<i>Cynoscion nebulosus</i>	10	<i>Gobiosoma bosc</i>	20
<i>Sciaenops ocellatus</i>	10	<i>Gobiosoma robustum</i>	20
<i>Menticirrhus</i> spp.	10	<i>Microgobius gulosus</i>	20
<i>Leiostomus xanthurus</i>	15	<i>Microgobius thalassinus</i>	20
<i>Orthopristis chrysoptera</i>	15	<i>Gobiesox strumosus</i>	35
<i>Achirus lineatus</i>	5	<i>Trinectes maculatus</i>	35
<i>Trinectes maculatus</i>	5	<i>Palaemonetes pugio</i>	20
<i>Gobiesox strumosus</i>	5	<i>Membras martinica</i>	50
<i>Diapterus plumieri</i>	10	<i>Syngnathus</i> spp.	80
<i>Prionotus</i> spp.	10	<i>Poecilia latipinna</i>	30
<i>Symphurus plagiusa</i>	10	<i>Anchoa hepsetus</i>	75
<i>Anchoa mitchilli</i>	15		
<i>Sphoeroides</i> spp.	10		
<i>Chilomycterus shoepfi</i>	10		
<i>Lepomis</i> spp.	10		
<i>Micropterus salmoides</i>	10	Metamorph-juvenile transition (mm):	
<i>Membras martinica</i>	10		
<i>Chloroscombrus chrysurus</i>	10	<i>Brevoortia</i> spp.	30
<i>Hemicaranx amblyrhynchus</i>	10	<i>Dorosoma petenense</i>	30
<i>Micropogonias undulatus</i>	15		
<i>Chaetodipterus faber</i>	5		

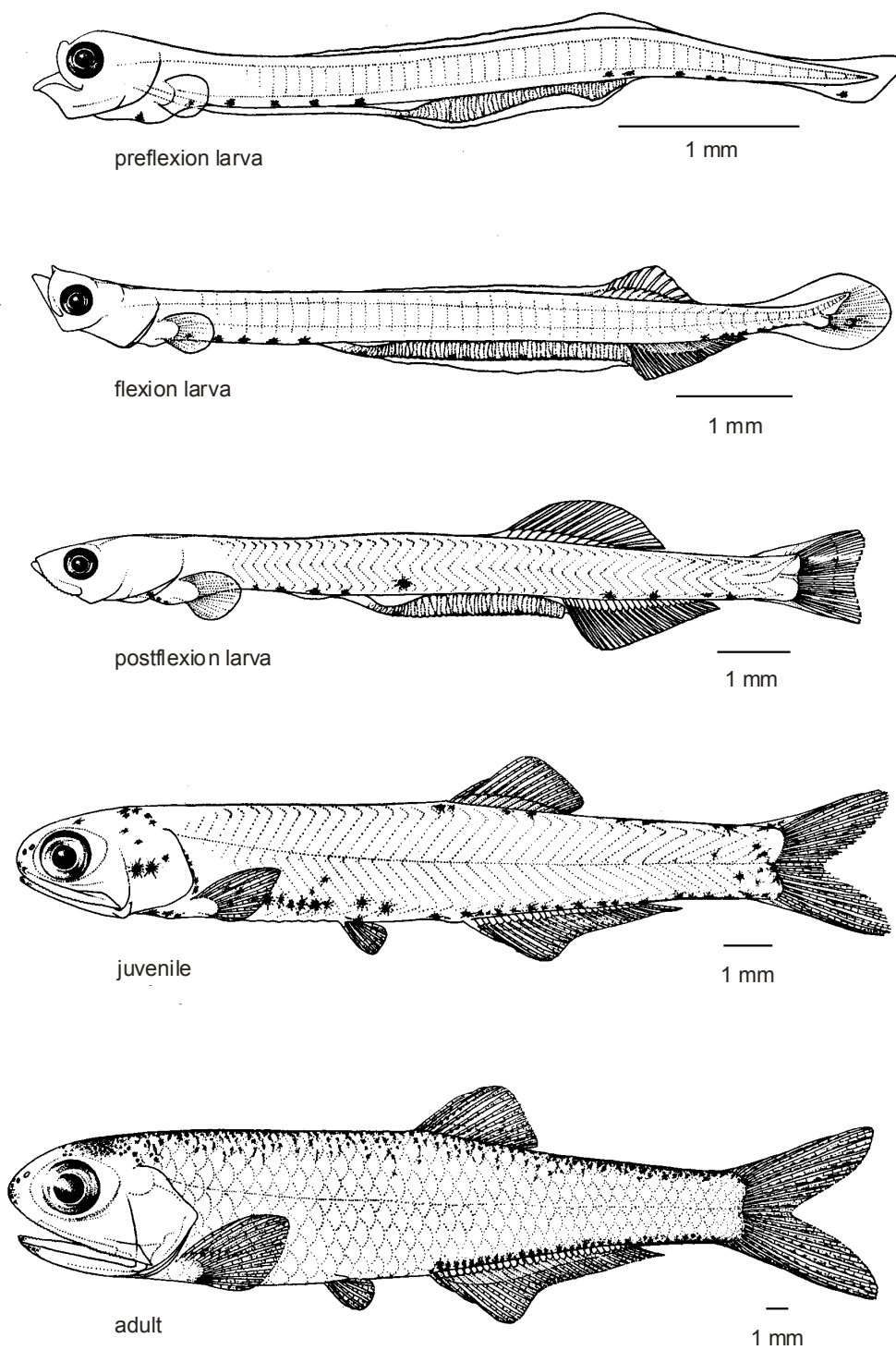


Fig. 2.5.1.1 Fish-stage designations, using the bay anchovy as an example. Specimens measured 4.6, 7.0, 10.5, 16 and 33 mm standard length.

Fish and select crustaceans collected in seine and trawl samples were removed from the net into a bucket and processed onboard. Animals were identified to lowest practical taxonomic category, generally species. Representative samples (three individuals of each species from each gear on each sampling trip) were brought back to the FWC/FWRI laboratory to confirm field identification. Species for which field identification was uncertain were also brought back to the laboratory. A maximum of 10 measurements (mm) were made per taxon, unless distinct cohorts were identifiable, in which case a maximum of 10 measurements were taken from each cohort; for certain economically valuable fish species, twenty individuals were measured. Standard length (SL) was used for fish, post-orbital head length (POHL) for pink shrimp, and carapace width (CW) for crabs. Animals that were not measured were identified and counted. When large numbers of individuals ($> 1,000$) were captured, the total number was estimated by fractional expansion of sub-sampled portions of the total catch split with a modified Motoda box splitter (Winner and McMichael, 1997). Animals not chosen for further laboratory examination were returned to the river.

Due to frequent hybridization and/or extreme difficulty in the identification of smaller individuals, members of several abundant species complexes were not identified to species. We did not separate menhaden, *Brevoortia*, species. *Brevoortia patronus* and *B. smithi* frequently hybridize, and juveniles of the hybrids and the parent species are difficult to identify (Dahlberg, 1970). *Brevoortia smithi* and hybrids may be the most abundant forms in the Tampa Bay areas, especially in tidal rivers (Dahlberg, 1970), and we treated them as one functional group. The two abundant silverside species (genus *Menidia*) tend to hybridize, form all-female clones, and occur in great abundance that renders identification to species impractical due to the nature of the diagnostic characters (Duggins et al., 1986; Echelle and Echelle, 1997; Chernoff, personal communication). Species-level identification of mojarras (genus *Eucinostomus*) was limited to individuals ≥ 40 mm SL due to great difficulty in separating *E. gula* and *E. harengulus* below this size (Matheson, personal observation).

Gobies of the genus *Gobiosoma* (i.e., *G. robustum* and *G. bosc*) used in analyses were limited to individuals ≥ 20 mm SL for the same reason. Similarly, needlefishes (*Strongylura* spp.) other than *S. notata* were only identified to species at lengths ≥ 100 mm SL.

2.7 Data Analysis

2.7.1 Freshwater Inflow (F).

Inflow rates to the lower river used in the analysis include data from three gauged streamflow sites and modeled runoff estimates for the ungauged area below the Hillsborough River dam. All flow rates were expressed as average daily flows in cubic feet per second (cfs). Flows to the lower river from the City of Tampa reservoir are measured by the US Geological Survey (USGS) at site 02304500 (Hillsborough River near Tampa). Streamflow data from this site were used for the period through December 31, 2004. Flows from the reservoir for the remaining period of study, October through December, 2004, were provided by Tampa Bay Water, which also measures total discharge from the reservoir. USGS records for the entire period of study were retrieved for flows from Sulphur Springs (site 023060005). Beginning in 2002, the City of Tampa has periodically diverted flows from Sulphur Springs to near the base of the Hillsborough River dam. Flow rates for spring water diverted to the base of the dam were provided by the City of Tampa Water Department.

Hydrologic loadings have been estimated previously at a monthly frequency for the entire Tampa Bay watershed by the Tampa Bay Estuary Program (TBEP) for the 1985-2003 period (Poe et al. 2005). These estimates were based on hydrologic models relating runoff to land use, soils, and rainfall. The monthly hydrologic loads as estimated by the TBEP were used to estimate daily runoff from the Lower Hillsborough River as follows.

The areas of the TBEP sub-basins draining to the Lower Hillsborough River were summed to provide a total ungauged watershed area. The TBEP monthly hydrologic

loads from the sub-basins were summed to provide total monthly hydrologic loads from the ungauged watershed.

The total monthly hydrologic loads from the ungauged watershed were divided by the total area of the ungauged watershed to derive a monthly-specific unit areal hydrologic load. The unit areal hydrologic load was then divided by the monthly total rainfall to derive a monthly-specific runoff coefficient for the ungauged watershed. The monthly total rainfall was developed for the TBEP using a rainfall surface based on National Weather Service sites within and near the watershed (Poe et al. 2005).

The monthly-specific runoff coefficients were then used to multiply 1) the daily rainfall as measured at the Sulphur Springs gage and 2) the total area of the ungauged watershed as defined by the drainage basins obtained from the City of Tampa. The product of the runoff coefficient, the rainfall, and the area provides the daily runoff from the ungauged watershed of the Lower Hillsborough River.

2.7.2 Organism-Weighted Salinity (S_U).

The central salinity tendency for catch-per-unit-effort (CPUE) was calculated as

$$S_U = \frac{\sum (S \cdot U)}{\sum U}$$

where U is CPUE (No. m^{-3} for plankton data and No. 100 m^{-2} for seine and trawl data) and S is water-column average salinity during deployment.

2.7.3 Center of CPUE (km_U).

The central geographic tendency for CPUE was calculated as

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

where km is distance from the river mouth.

2.7.4 Organism Number (N) and Relative Abundance (\bar{N}).

Using plankton-net data, the total number of organisms in the tidal portion of the river was estimated by summing the products of mean organism density (\bar{U} , as No. m⁻³) and tide-corrected water volume (V) from six volume zones as

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

Volumes corresponding to NGVD were provided by SWFWMD, and these volumes were then adjusted to the actual water level at the time of collection using data from water-level recorders at Sulphur Springs, Platt Street and Rowlett Park.

For seine and trawl data, relative abundance (mean number of fish and selected macroinvertebrates) per 100 m² sampled area (A) was calculated for each month as

$$\bar{N} = \frac{\sum U}{n}$$

where n = number of samples in that month. \bar{N} is also occasionally referred to as CPUE in some instances.

2.7.5 Inflow Response Regressions.

Regressions were run for km_U on F , N on F , and \bar{N} on F . N , \bar{N} , km_U (seine/trawl data only), and F were Ln-transformed prior to regression to improve normality. Regressions using plankton-net data were limited to taxa that were encountered during a minimum of 10 of the 57 monthly 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 120 days prior to the sampling date. The combination of consecutive dates that produced the maximum regression fit was used to model the N and km_U 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 $p < 0.05$.

Seine and trawl regressions were limited to taxa that were abundant and frequently collected, as judged by an Index of Relative Importance $> \sim 0.25$

$$IRI = \frac{\ln(X + 1)}{\left(\frac{n_2}{n_1} \right)}$$

where X = total number of individuals collected, n_2 is the total number of samples, and n_1 is the number of samples in which the species is present (Gilmore, 1988). Monthly length-frequency plots were examined (Appendix C) in order to assign appropriate size classes ('pseudo-species') and recruitment windows for each of these taxa.

Regressions were thus undertaken at the pseudo-species level for a limited recruitment period. Mean inflows extending back as far as 365 d prior to the sampling date were considered, and linear and quadratic regressions were undertaken.

2.7.6 Responses to Low Flow

2.7.6.1 Distribution (km_U) and relative abundance (\bar{N}) responses. Distributional and relative abundance responses to inflows were investigated using regression analyses similar to those described above. The low-inflow analyses were limited to freshwater species in the upper two geographic strata (5 and 6, Fig. 2.1.1) of the study area and only considered inflows at the dam combined with Sulphur Springs' flow that had been diverted to the base of the dam. High variability in abundance and occurrence reduced the utility of species-level analyses, so two freshwater species groups were defined, "Stenohaline" and "Euryhaline" (Table 2.7.1). Stenohaline freshwater species are obligate freshwater organisms and do not adapt well to increases in salinity. Euryhaline freshwater species can tolerate low salinities and are often collected at salinities of 5 psu or greater. In addition to the abundance and distributional response of these species groups to inflows, the response of taxon richness (no. species haul⁻¹) to inflow was also explored.

Table 2.7.1. Stenohaline and euryhaline freshwater species groups

<u>Stenohaline freshwater</u>	<u>Euryhaline freshwater</u>
<i>Amia calva</i>	<i>Dorosoma</i> spp.
<i>Cichlasoma</i> spp.	<i>Fundulus seminolis</i>
<i>Etheostoma fusiforme</i>	<i>Lepisosteus</i> spp.
<i>Fundulus chrysotus</i>	<i>Lepomis macrochirus</i>
<i>Labidesthes sicculus</i>	<i>Lucania goodei</i>
<i>Lepomis auritus</i>	<i>Micropterus salmoides</i>
<i>Lepomis gulosus</i>	
<i>Lepomis marginatus</i>	
<i>Lepomis microlophus</i>	
<i>Lepomis punctatus</i>	
Loricariidae spp.	
<i>Notemigonus crysoleucas</i>	
<i>Notropis maculatus</i>	
<i>Notropis petersoni</i>	
<i>Palaemonetes paludosus</i>	
<i>Pomoxis nigromaculatus</i>	
<i>Xiphophorus</i> spp.	

2.7.6.2 Community structure. Non-metric multidimensional scaling (MDS; Clarke 1993) was used to examine how nekton community structure in the upper two geographic strata (5 and 6) changed through the summers (July–October) of 2000 and 2001. During these periods flow began at low levels and then greatly increased before declining. For this analysis, certain taxa composed of species with contrasting salinity preferences (e.g., *Menidia* spp. and *Gobiosoma* spp.) were excluded from the analysis, as was the very abundant *Anchoa mitchilli*. Data consisted of $\ln(\text{abundance } 100 \text{ m}^{-2} + 1)$ from seines; more abundant taxa were divided into size classes as per the whole-river regression analyses.

2.7.7 Hypoxia Effects

2.7.7.1 Hypoxia and organism distribution. The influence of low dissolved oxygen on organism distribution was examined using two approaches. First, the potential for low dissolved oxygen in the river channel to cause movement of organisms to the margins

of the water body was investigated by regressing abundance or taxon richness of seine-caught animals against mean dissolved oxygen determined during trawling within the same river zone on the same day. Statistical validity of these regressions was determined by tests for homogeneity of variance and normality of residuals. Second, plots of mean abundance and taxon richness in trawls, averaged by river zone, were compared to overlaid plots of mean dissolved oxygen and salinity. These plots included three contrasting dissolved oxygen distributions: 1) hypoxic conditions (i.e., dissolved oxygen $< 2 \text{ mg l}^{-1}$) downstream, with dissolved oxygen increasing with movement upstream; 2) hypoxic conditions upstream, with dissolved oxygen increasing with movement downstream; 3) hypoxic conditions in the middle or near-middle reaches of the trawl sampling universe, with higher dissolved oxygen upstream or downstream of this area.

2.7.7.2 Hypoxia and organism abundance. The relationship between organism abundance or taxon richness in seines/trawls and dissolved oxygen was investigated with linear regressions. Mean dissolved oxygen concentration in the region of the water column sampled by each gear was calculated differently. Since the 21.3-m seines sample the entire water column within the area of the set, mean dissolved oxygen was calculated from all readings obtained at 1-m intervals. Trawls were estimated to have a vertical opening of $\sim 1.8 \text{ m}$, so mean dissolved oxygen was calculated for all readings obtained between the trawl's start depth and start depth minus 1.8 m. Linear regressions were calculated for all individual samples. When statistically significant regressions were found that were not statistically valid, dissolved oxygen was classified into 0.5 PSU categories and regressed against the mean abundance or richness for all samples within that category. Since each dissolved oxygen category was made up of unequal sample sizes, regressions weighted by sample size were used to confirm non-weighted results.

2.7.8 Data Limitations and Gear Biases.

All nets used to sample aquatic organisms are size selective. Small organisms pass through the meshes and large organisms evade the gear altogether. Intermediate-sized organisms are either fully retained or partially retained. When retention is partial, abundance becomes relative. However, temporal or spatial comparisons can still be made because, for a given deployment method and size of organism, the selection process can usually be assumed to have constant characteristics over space and time. The 500- μm plankton gear retains a wide range of organism sizes completely, yet it should be kept in mind that many estimates of organism density and total number are relative rather than absolute. Organism measurements from Little Manatee River and Tampa Bay plankton samples (Peebles 1996) indicate that the following taxa will be collected selectively by 500- μm mesh: marine-derived cyclopoid copepods, some cladocerans, some ostracods, harpacticoid copepods, cirriped nauplii and cypris larvae, the larvacean *Oikopleura dioica*, some decapod zoeae, and some adult calanoid copepods. Taxa that are more completely retained include: cumaceans, chaetognaths, insect larvae, fish eggs, most fish larvae and postlarvae, some juvenile fishes, gammaridean amphipods, decapod mysis larvae, most decapod megalopae, mysids, isopods, and the juveniles and adults of most shrimps. This partitioning represents a very general guide to the relative selectivities of commonly caught organisms.

The plankton nets were deployed during nighttime flood tides because larval fishes and invertebrates are generally more abundant in the water column at night (Colton et al. 1961, Temple and Fisher 1965, Williams and Bynum 1972, Wilkins and Lewis 1971, Fore and Baxter 1972, Hobson and Chess 1976, Alldredge and King 1985, Peebles 1987, Haney 1988, Lyczkowski-Shultz and Steen 1991, Olmi 1994) and during specific tide stages (Wilkins and Lewis 1971, King 1971, Peebles 1987, Olmi 1994, Morgan 1995a, 1995b). Organisms that selectively occupy the water column during flood tides tend to move upstream, and organisms that occupy the water column during all tidal stages tend to have little net horizontal movement other than that caused by net estuarine outflow (Cronin 1982, McCleave and Keckner 1982, Olmi 1994). The plankton catch was therefore biased toward organisms that were either invading the

tidal rivers or were attempting to maintain position within the tidal rivers. This bias would tend to exclude the youngest larvae of some estuarine crabs, which are released at high tide to facilitate export downstream with the ebb tide (Morgan 1995a). However, as the young crabs undergo their return migrations at later larval stages, they become most available for collection during nighttime flood tides (Olmi 1994, Morgan 1995b).

Seines and trawls tend to primarily collect small fish, either adults of small-bodied species or juveniles of larger taxa. Trawls tend to capture larger fish than seines (Nelson and Leffler, 2001), and whether this is due to gear characteristics or preferred use of channel habitat by larger fish is uncertain. Sampling efficiency inevitably varies by species and size class (Rozas and Minello, 1997), but we assume reasonable consistency between samples collected with a given gear type. We acknowledge that movement of various taxa (e.g. killifishes, Cyprinodontidae) into emergent vegetation at high water levels occurs (Rozas and Minello, 1997) and could complicate interpretation of some results.

3.0

RESULTS AND DISCUSSION

3.1

Streamflow Status During Survey Years

The first-order trend in estuarine inflow has been positive since 2000 (Fig. 3.1.1).

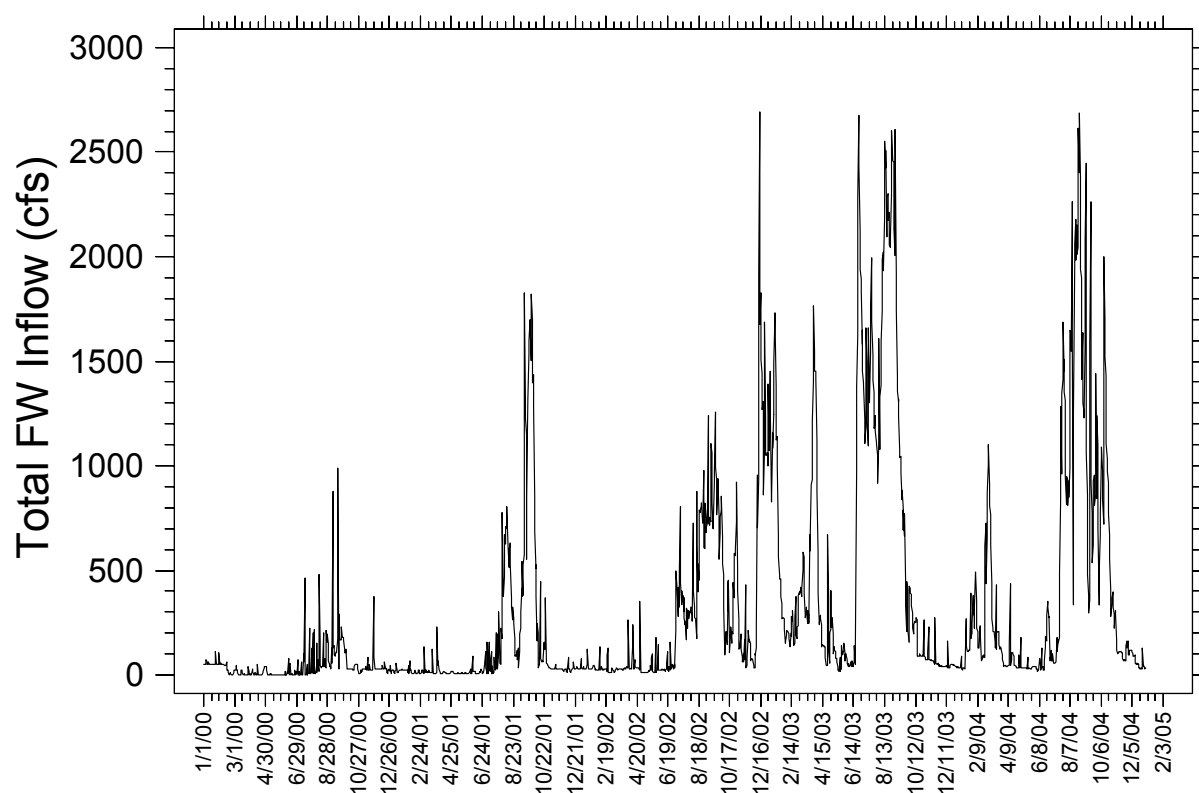


Fig. 3.1.1. Total calculated estuarine inflow (F).

Summary statistics from the electronic meter data are presented in Table 3.2.1. Temperatures underwent seasonal variation within a typical range (Fig. 3.2.1), with the highest values recorded during 2000, which was a La Niña year. Winters were not cold enough to cause fish kills during any year of the survey period. There was a first-order trend of decreasing salinity during the 57-month survey period. With the exception of 2000, all summer rainy seasons caused strong reductions in salinity. Temporal trends in pH were similar to those of salinity, becoming reduced during the summer rainy season, but otherwise remaining within a range that is considered to be safe for estuarine organisms.

Dissolved oxygen (DO) often reached supersaturation levels in the lower Hillsborough River, particularly during winter and spring. Benthic hypoxia was observed throughout the tidal river (Fig. 3.2.2a). However, the strong hypoxia near the river mouth was partly caused by the warmer, saltier water that occurs there. When temperature and salinity effects on DO solubility were taken into consideration, and deviations (anomalies) from expected 100% saturation were calculated, much of the hypoxia near the river mouth was found to be explained by the relatively warm temperatures and high salinities that occurred there (Fig. 3.2.2b). Negative DO anomalies were strongest in the upper reaches of the tidal river (Fig. 3.2.3).

There are a number of potential causes of negative benthic anomalies, including density stratification (circulatory isolation from the air-water interface), depth (distance from the air-water interface), location (distance from waters that are well mixed), and collective organismal respiration rate relative to DO influx or production by primary producers. Fig. 3.2.4 characterizes the behavior of DO anomalies in regard to pH, which has relevance to the ratio of respiration to primary production (R/P). Over a 10-yr period in central Florida, Madsen et al. (1992) recorded an average rainwater pH of 4.6. Carbonate-rich substrates in the watershed may buffer rainwater's acidity to some extent before it enters estuarine waters, yet in the case of the tidal Hillsborough River, inflowing fresh waters were often observed to be slightly acidic (Fig. 3.2.4). When this acidic freshwater influx (<2 psu) was excluded, pH explained 63% of the variation in DO

anomaly at all water depths ($n = 1857$, $p < 0.0001$). In a forward stepwise regression that included depth, location (km from mouth), bottom pH and surface-to-bottom differences in salinity and temperature, pH was the first variable selected, explaining 58% of the variation in DO anomaly at the bottom (Table 3.2.2). Salinity differential had the next largest apparent influence, explaining 7%. Similar results were also obtained for the Alafia River and the Palm-River-McKay bay area. Location, depth and temperature differential all had significant influences, yet their individual contributions were $< 3\%$ in all three estuarine areas. There was no indication of serious multicollinearity among these variables, as variance inflation factors were < 2 for each variable. These results suggest that the benthic hypoxia in the upper part of the tidal Hillsborough River is primarily biological in origin, with physical factors such as density stratification playing a secondary role. A primarily biological source for the benthic hypoxia also explains why benthic hypoxia was notably severe and protracted during 2000, when freshwater inflows were relatively low (Fig. 3.2.2).

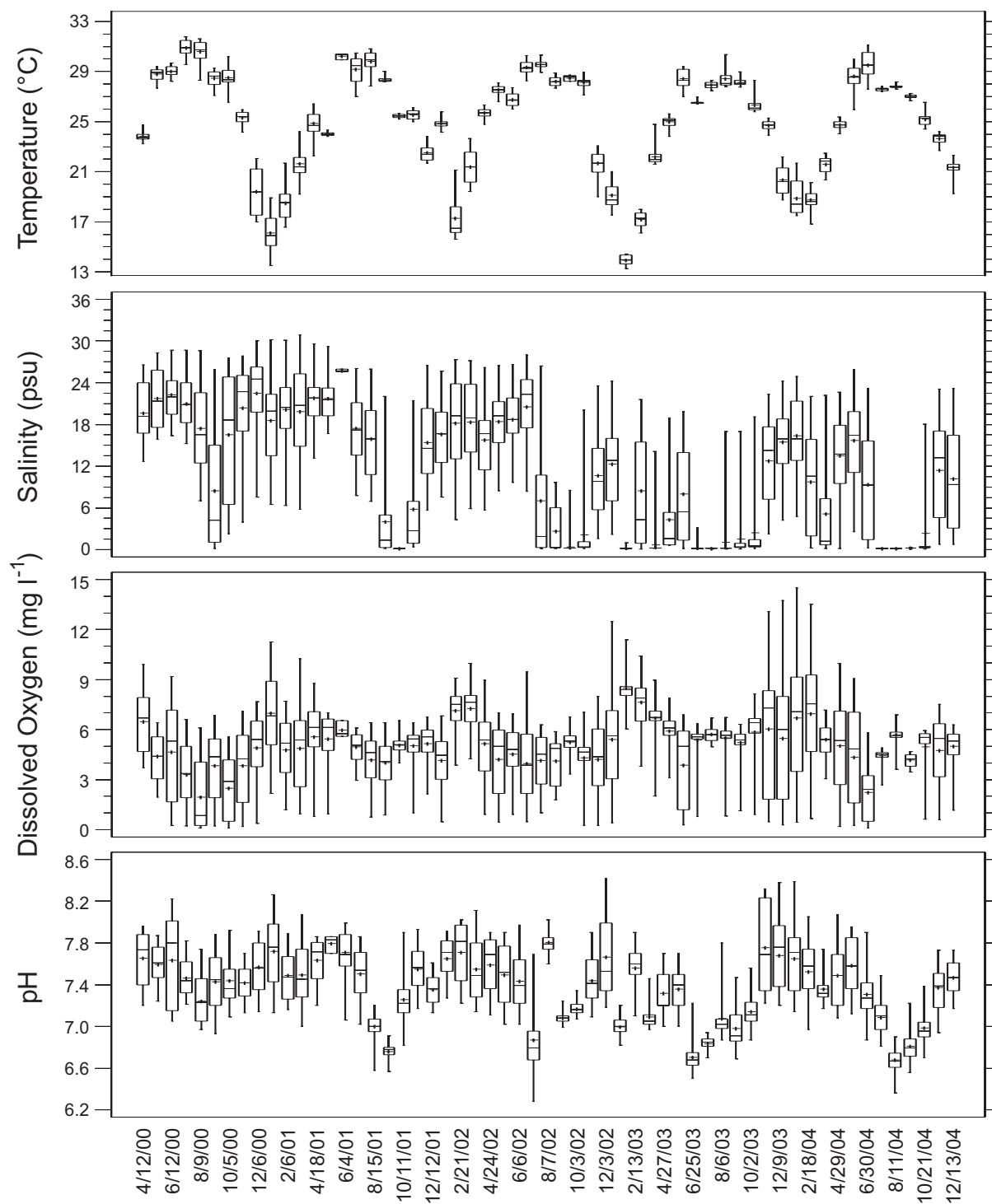


Fig. 3.2.1. Electronic meter data from the plankton-net surveys of the Hillsborough River, where the cross identifies the mean, the horizontal line identifies the median, the box delimits the interquartile range, and the whiskers delimit the total range.

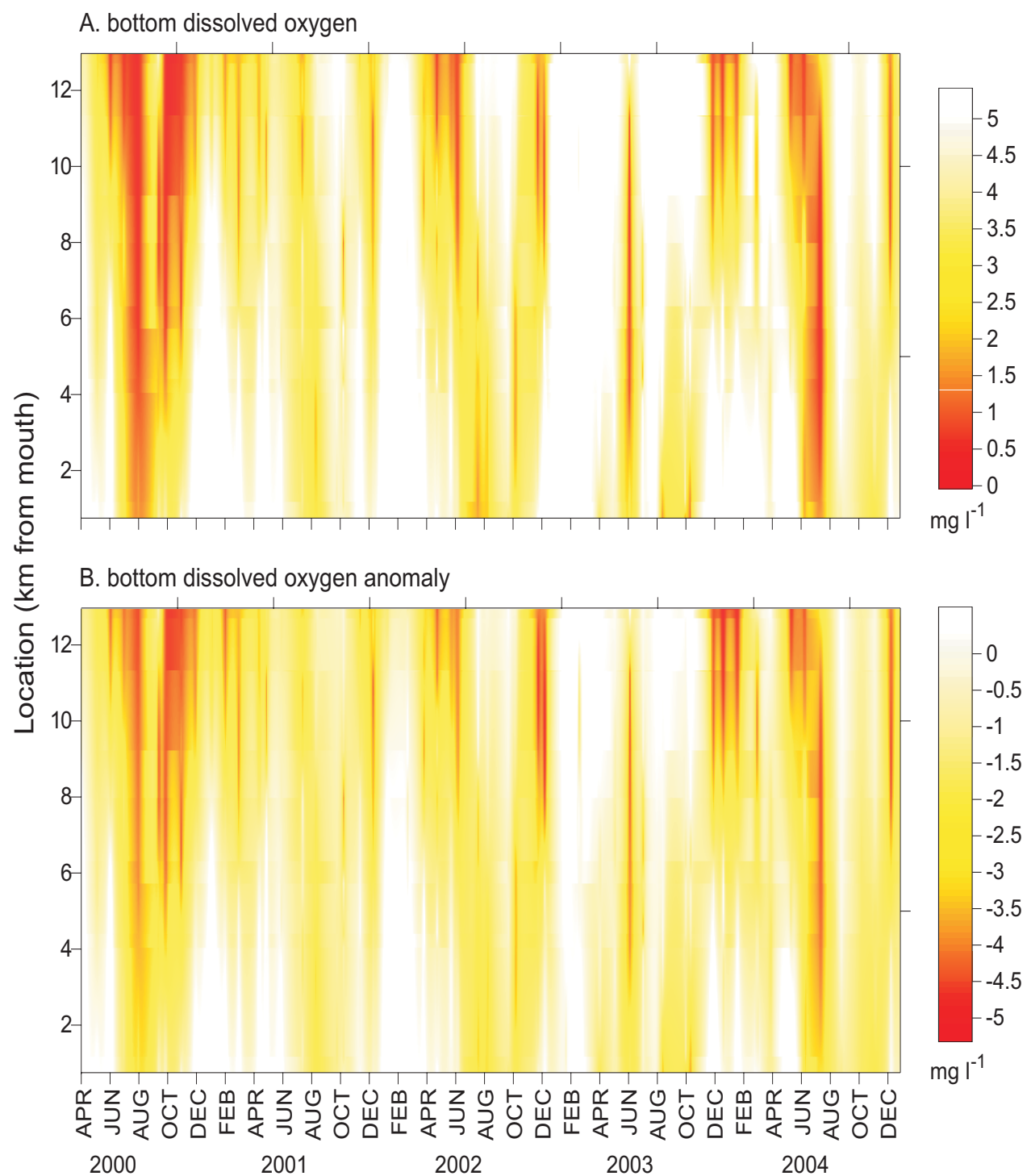


Fig. 3.2.2. Space-time plot for bottom dissolved oxygen characteristics in the tidal Hillsborough River.

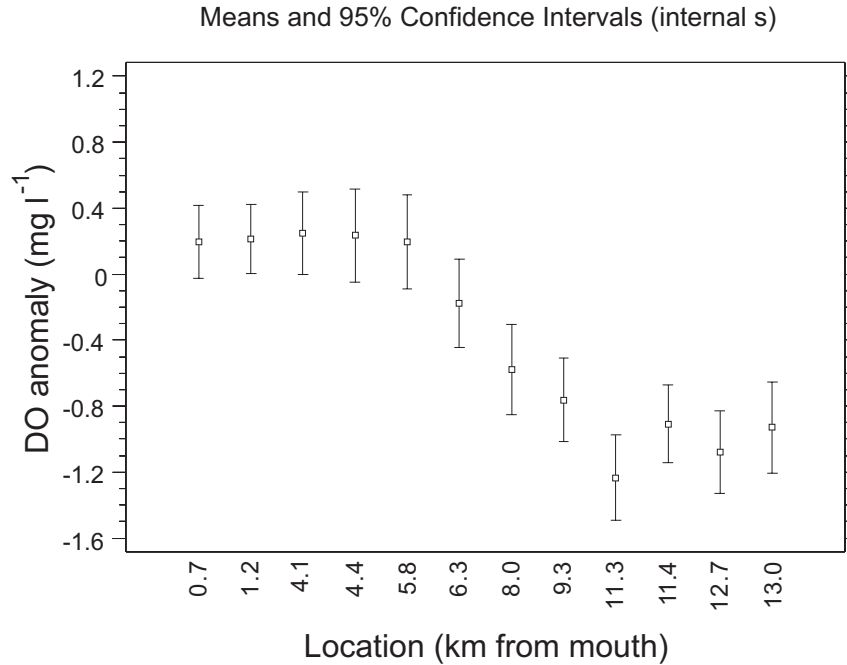


Fig. 3.2.3. Mean dissolved oxygen (DO) anomaly (all depths) at plankton-net collection locations in the tidal Hillsborough River.

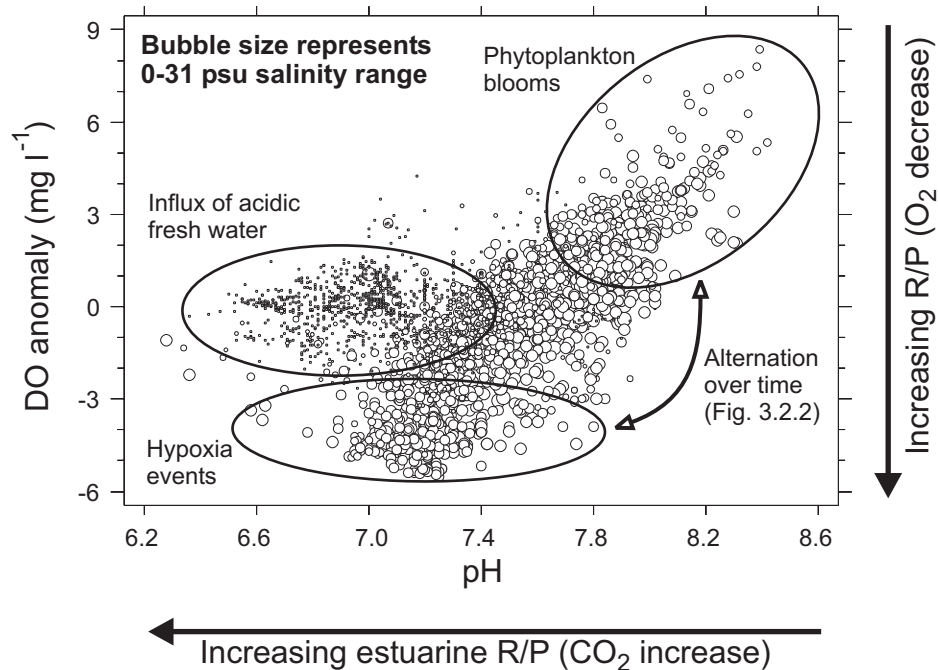


Fig. 3.2.4. Relationships among dissolved oxygen (DO) anomaly, pH, and salinity (all depths and locations), where *R* is respiration and *P* is photosynthesis.

Table 3.2.1. Electronic meter summary statistics during plankton net deployment. Depth is mean depth at deployment. Sample sizes (n) reflect the combination of survey frequency (57 monthly surveys) and depths at which measurements were taken. Measurements were made at surface, bottom, and at one-meter intervals between surface and bottom.

Location (km from mouth)	Depth (m)	Salinity (psu)					Water Temperature (°C)					Dissolved Oxygen (mg/l)					pH				
		n	mean	std. dev.	min.	max.	n	mean	std. dev.	min.	max.	n	mean	std. dev.	min.	max.	n	mean	std. dev.	min.	max.
0.7	2.9	240	18.0	10.1	0.2	30.9	240	25.3	4.4	13.8	31.6	240	5.4	1.9	0.8	10.7	236	7.6	0.4	6.4	8.3
1.2	2.7	232	17.6	10.1	0.2	30.5	232	25.0	4.7	13.5	31.6	232	5.5	1.8	0.3	9.5	229	7.6	0.4	6.5	8.3
4.1	2.7	232	14.0	9.7	0.1	29.7	232	24.8	4.7	14.3	31.8	232	5.6	2.2	0.1	13.5	228	7.5	0.4	6.6	8.4
4.4	2.6	222	13.4	9.3	0.1	28.9	222	24.9	4.4	14.4	31.6	222	5.6	2.3	0.2	12.9	218	7.5	0.4	6.3	8.4
5.8	2.2	203	11.4	8.7	0.1	26.3	203	25.0	4.3	14.3	31.6	203	5.6	2.3	0.1	13.2	200	7.5	0.4	6.5	8.4
6.3	2.6	226	11.7	9.0	0.1	26.6	226	24.9	4.3	14.3	31.6	226	5.3	2.3	0.1	12.8	223	7.4	0.4	6.4	8.3
8.0	2.8	235	10.4	8.4	0.1	25.6	235	25.2	4.0	14.1	31.4	235	4.9	2.3	0.1	14.5	232	7.3	0.3	6.3	8.4
9.3	3.0	246	9.0	8.3	0.1	25.9	246	24.9	4.0	13.9	31.3	246	4.8	2.2	0.1	12.3	242	7.3	0.3	6.6	8.2
11.3	3.4	266	8.4	8.2	0.1	25.2	266	25.1	3.8	13.7	30.9	266	4.3	2.4	0.1	10.2	262	7.2	0.3	6.6	7.9
11.4	3.1	247	7.4	7.9	0.1	25.2	247	25.1	3.7	13.5	30.8	247	4.6	2.1	0.2	11.4	244	7.2	0.3	6.5	7.8
12.7	3.0	248	6.8	7.4	0.1	23.8	248	24.9	3.6	13.3	30.4	248	4.5	2.2	0.2	10.3	245	7.2	0.3	6.6	8.0
13.0	2.9	240	6.5	7.1	0.1	22.9	240	24.8	4.0	13.3	30.3	240	4.7	2.5	0.1	10.4	236	7.1	0.3	6.5	8.0

Table 3.2.2. Results of forward stepwise multiple regression analysis of parameter association with bottom dissolved oxygen anomaly, where *Salinity difference* is bottom minus surface salinity, *Temp. difference* is surface minus bottom temperature, and *Km from mouth* is the location of the water-quality sample relative to the river mouth (Hillsborough and Alafia Rivers) or the entrance to McKay Bay. *VIF* is the variance inflation factor, a measure of correlation among explanatory parameters (multicollinearity) that may interfere with coefficient estimation. $VIF > 10$ is an indication of potentially serious multicollinearity. Samples where bottom salinity was < 2 psu were excluded from this analysis (see text). r^2 is adjusted for degrees of freedom.

	Parameter	Estimate	Std. Error	T-statistic	p	r^2	VIF
Hillsborough River (n=482)	Constant	-28.025	2.080	-13.471	<0.0001		
	Bottom pH	3.800	0.264	14.420	<0.0001	58.3	2.0
	Salinity difference	-0.113	0.013	-8.903	<0.0001	6.5	1.3
	Km from mouth	-0.081	0.018	-4.522	<0.0001	1.5	1.7
	Depth	-0.271	0.072	-3.780	0.0002	0.7	1.1
	Temp. difference	0.209	0.065	3.202	0.0015	0.6	1.1
Alafia River (n=454)	Constant	-29.703	2.064	-14.393	<0.0001		
	Bottom pH	3.986	0.251	15.854	<0.0001	47.8	1.5
	Salinity difference	-0.071	0.013	-5.650	<0.0001	5.1	1.1
	Depth	-0.541	0.094	-5.786	<0.0001	2.9	1.1
	Temp. difference	0.431	0.073	5.874	<0.0001	2.7	1.2
	Km from mouth	0.050	0.023	2.161	0.0312	0.3	1.5
Palm River- McKay Bay (n=552)	Constant	-24.084	2.190	-10.997	<0.0001		
	Bottom pH	3.241	0.260	12.465	<0.0001	40.1	1.5
	Salinity difference	-0.186	0.023	-8.046	<0.0001	5.9	1.4
	Depth	-0.455	0.083	-5.469	<0.0001	2.7	1.3

3.3

Catch Composition

3.3.1 Fishes.

3.3.1.1 Plankton net. Juvenile bay anchovies (*Anchoa mitchilli*) and postflexion stage gobies dominated the plankton-net fish catch (Table A1). The vast majority of larvae identified as *Anchoa* spp. were probably *A. mitchilli* – *A. hepsetus* was relatively uncommon and *A. cubana* was not collected by either the seines or trawls (Tables B1, B2). Gobies of the genus *Gobiosoma* were the dominant gobies in the Hillsborough River, with *Microgobius* spp. being of secondary importance. Other abundant fishes were menhadens (*Brevoortia* spp.), skilletfish (*Gobiesox strumosus*), silversides (*Menidia* spp.), blennies (primarily *Chasmodes saburrae*) and the hogchoker (*Trinectes maculatus*).

3.3.1.2 Seine. The seine catch (Table B1) was dominated by bay anchovy (*Anchoa mitchilli*), silversides (*Menidia* spp.), menhadens (*Brevoortia* spp.), eastern mosquitofish (*Gambusia holbrooki*), spot (*Leiostomus xanthurus*), rainwater killifish (*Lucania parva*), sailfin molly (*Poecilia latipinna*), and striped mullet (*Mugil cephalus*). These taxa comprised nearly 94% of total seine catch of fishes.

3.3.1.3 Trawl. The trawl catch (Table B2) was dominated by spot, hogchoker (*Trinectes maculatus*), bay anchovy, sand seatrout (*Cynoscion arenarius*), and southern kingfish (*Menticirrhus americanus*). These taxa comprised over 77% of total trawl catch.

3.3.2 Invertebrates.

3.3.2.1. Plankton net. The plankton-net invertebrate catch (Table A1) was dominated by larval crabs (decapod zoeae, primarily *Rhithropanopeus harrisi*), hydromedusae (primarily *Clytia* sp.), calanoid copepods (primarily *Acartia tonsa* and *Labidocera aestiva*), mysids (primarily *Americamysis almyra*), chaetognaths (primarily *Sagitta tenuis*

and *Ferosagitta hispida*), the freshwater cyclopoid copepod *Mesocyclops edax*, gammaridean amphipods, polychaete worms (primarily nereids), the parasitic isopod *Lironeca* sp., larval shrimps (primarily *Palaemonetes*) and dipteran larvae (esp. *Chaoborus punctipennis*).

3.3.2.2 Seine. The seine catch (Table B1) was dominated by daggerblade grass shrimp (*Palaemonetes pugio*), which comprised over 97% of the invertebrate catch.

3.3.2.3 Trawl. The trawl catch (Table B2) was dominated by blue crab (*Callinectes sapidus*), daggerblade grass shrimp, and pink shrimp (*Farfantepenaeus duorarum*). These three taxa comprised over 97% of total trawl catch of invertebrates.

3.4 Use of Area as Spawning Habitat

The eggs of the bay anchovy (*Anchoa mitchilli*), striped anchovy (*Anchoa hepsetus*), *Menidia* spp., *Fundulus* spp. and unidentified gobiid and sciaenid fishes were collected from the survey area. Bay anchovy eggs were encountered in very low numbers in 14 samples (total of 179 eggs), whereas only one striped anchovy egg was encountered. The bay anchovy may spawn within the lower tidal Hillsborough River on occasion, but most of the juveniles that congregate within the river probably originate from eggs spawned in nearby Hillsborough Bay or upper Middle Tampa Bay (Peebles et al. 1996).

Many sciaenid eggs cannot be readily identified using visible characteristics. Those found in the lower tidal Hillsborough River could have belonged to several species, yet the early larvae of the sand seatrout (*Cynoscion arenarius*) were the only sciaenid larvae collected regularly. Any of the fishes listed in Table 3.4.1 may spawn within the lower Hillsborough River, with the exception of menhadens (*Brevoortia* spp.).

Preflexion-stage goby larvae were most abundant in river zones 1 and 2, near the river mouth. Species that are likely to spawn near the river mouth (within the river, within nearby shipping channels, or in nearby Hillsborough Bay) include the naked goby

(*Gobiosoma bosc*), the code goby (*G. robustum*), the green goby (*Microgobius thalassinus*), the clown goby (*M. gulosus*) and the frillfin goby (*Bathygobius soporator*). The Florida blenny, *Chasmodes saburrae*, dominated the blenny catch at later larval stages (Table A1), and presumably dominated the pre-flexion stage represented in Table 3.4.1. Many killifishes (*Fundulus* spp.) are estuarine-resident species that spawn within tidal rivers. Their adhesive eggs are spawned in shallow waters and hatch at a relatively advanced stage, the postflexion stage. The collection of a single dislodged *Fundulus* egg and the relative abundance of *F. grandis* postflexion larvae and juveniles (Tables A1, B1) suggest that this species spawns within the tidal Hillsborough River. Small juveniles of live-bearing species such as the eastern mosquitofish (*Gambusia holbrooki*), sailfin molly (*Poecilia latipinna*), chain pipefish (*Syngnathus louisianae*) and gulf pipefish (*S. scovelli*) are also indications that the tidal Hillsborough River is serving as habitat for the earliest stages of these species. A review of trends in spawning habitat among coastal fishes is presented by Peebles and Flannery (1992).

Table 3.4.1. Relative abundance of larval stages for non-freshwater fishes with a collection frequency >10 for the larval-stage aggregate, where *Pre* = preflexion (youngest larval stage), *Flex* = flexion stage (intermediate larval stage) and *Post* = postflexion (oldest larval stage). **X** identifies the most abundant stage and x indicates that the stage was present.

Taxon	Common Name	Pre	Flex	Post
<i>Anchoa</i> spp.	anchovies	X	x	x
<i>Menidia</i> spp.	silversides	X	x	x
Blenniids	Blennies	X	x	x
Gobiids	Gobies	X	x	X
<i>Bathygobius soporator</i>	frillfin goby	X	x	X
<i>Cynoscion arenarius</i>	sand seatrout	X	x	X
<i>Gobiesox strumosus</i>	skilletfish	X	x	X
<i>Trinectes maculatus</i>	hogchoker	X	x	X
<i>Brevoortia</i> spp.	menhaden			X

3.5

Use of Area as Nursery Habitat

Estuarine-dependent taxa that use the tidal river as a nursery area are the numerical dominants in the Hillsborough River: overall, seven of the ten most abundant taxa in the river channel and five of the ten most abundant taxa in nearshore habitats are estuarine-dependent. Twelve of the abundant estuarine-dependent taxa spawn on the continental shelf. Six of these offshore spawners are among the most economically valuable species in Florida, including menhadens, spot, striped mullet, red drum (*Sciaenops ocellatus*), blue crab, and pink shrimp. The other six shelf-spawning species are some of the most abundant members of the nekton community (e.g., pinfish [*Lagodon rhomboides*] and mojarra [*Eucinostomus gula* and *E. harengulus*]). Five additional common estuarine-dependent species spawn within Tampa Bay. Two of these species have relatively minor direct economic value (i.e., striped mojarra [*Diapterus plumieri*], and sand seatrout [*Cynoscion arenarius*]), and two others are among the most abundant species in the system (i.e., hogchoker and bay anchovy).

3.6

Seasonality

3.6.1 Plankton Net.

The number of taxa collected during an individual survey is not a true measure of species richness because many taxa could not be identified to species level. Nevertheless, this index produces a clear seasonal pattern. Specifically, more taxa tend to be collected during the spring and summer months than at other times of year (Fig. 3.6.1.1). Lowest apparent richness was observed from July through February.

Species diversity tends to be highest near the mouths of tidal rivers due to an increased presence of marine-derived species and at the upstream end due to the presence of freshwater species. This creates a low-diversity zone in the middle reaches of the tidal river (Merriner et al. 1976). Freshwater inflow and the seasonal arrival of

young animals can shift this pattern downstream or upstream. Ichthyoplankton underwent a strong decrease in richness during the rainy season, whereas invertebrate richness was enhanced by the addition of freshwater plankton to the assemblage.

For a given species of fish, the length of the spawning season tends to become shorter at the more northerly locations within a species' geographic range, but the time of year when spawning takes place is otherwise consistent for a given species. Among species with long or year-round spawning seasons, local conditions have been observed to have a strong influence on egg production within the spawning season (Peebles 2002c). Local influences include seasonally anomalous water temperature, seasonal variation in the abundance of prey, and seasonal variation in retention or transport of eggs and larvae after spawning. The latter processes (prey availability and retention and transport) are influenced by freshwater inflows to the coast.

Alteration of inflows would appear to have the lowest potential for impacting many taxa during the period from November through February, which is the period when the fewest estuarine taxa are present in Tampa Bay waters. The highest potential to impact many species would appear to be from April to June, a time of year when naturally low inflows are coupled with increasing use of the estuary as nursery habitat. The potential for impact is species-specific. During fall, winter, and early spring, for example, there could be impact on red drum and menhadens because these fishes recruit to tidal river nursery habitats during fall and winter. Other species, such as the bay anchovy, are present year-round (Fig. 3.6.1.2). There is, therefore, no time of year when freshwater inflow management is free from potential impact on estuarine nursery habitat.

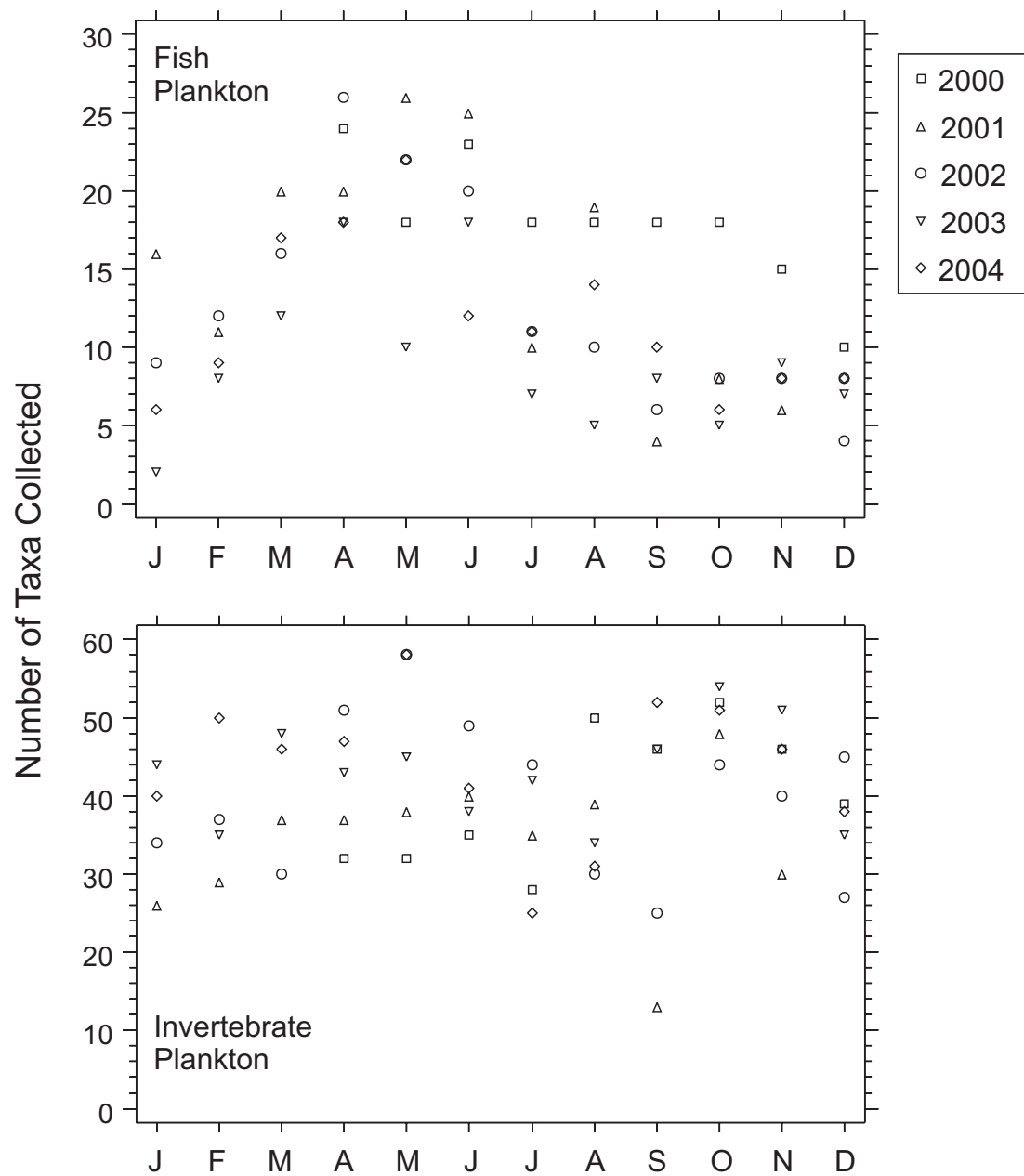


Fig. 3.6.1.1. Number of taxa collected per month by plankton net.

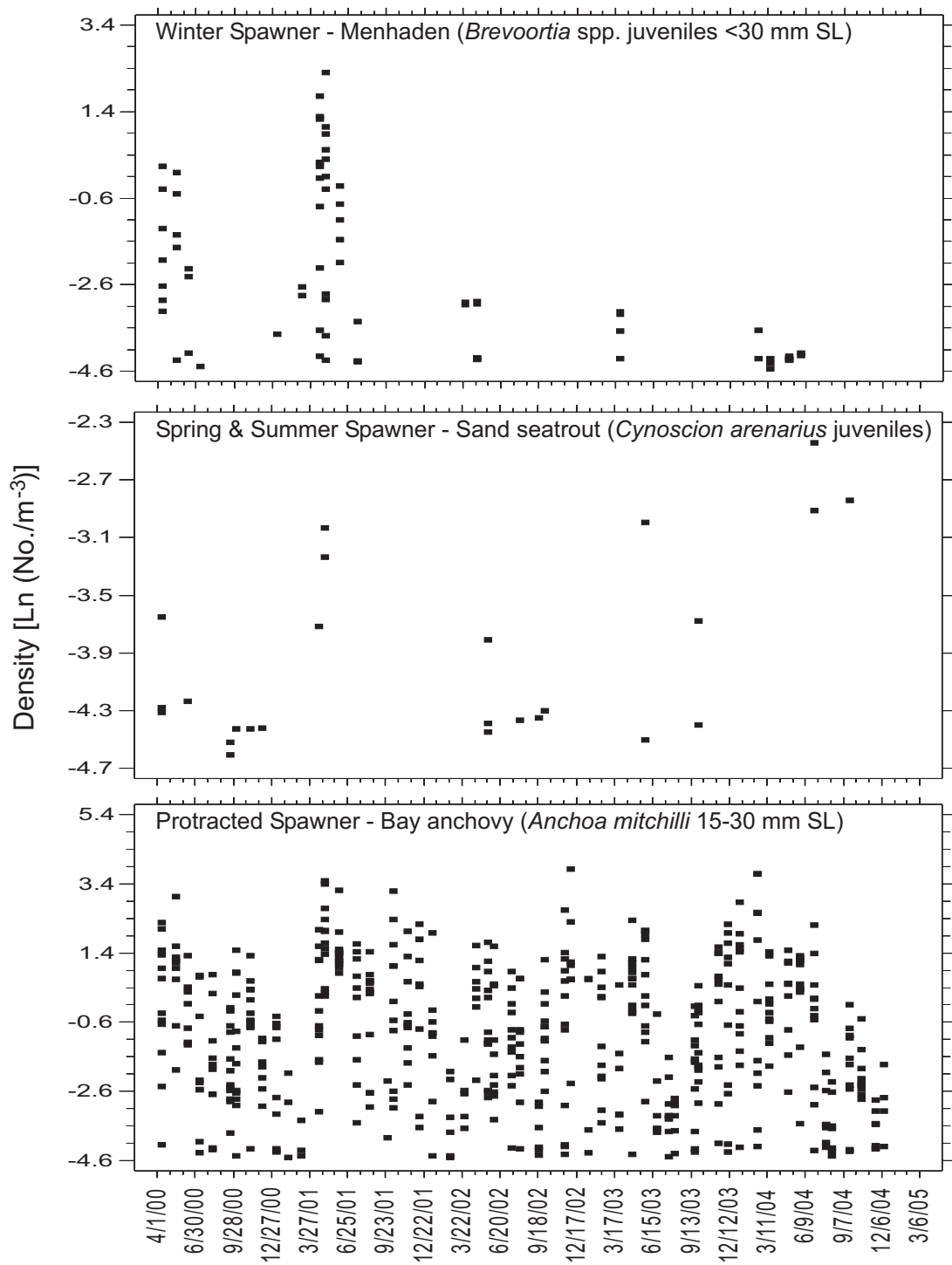


Fig. 3.6.1.2. Examples of species-specific seasonality from plankton-net data.

3.6.2. Seine and Trawl.

A general pattern of relatively high taxonomic richness in early summer (May–July) was evident from seine collections, with reduced richness largely occurring in fall/winter (December–January) (Fig. 3.6.2.1). This pattern is broadly consistent with previous tidal river estuary studies in the region (Alafia: Peebles 2002a; Peace River/Shell Creek: Peebles 2002b). The lack of obvious peaks and troughs in trawl taxon richness data is also consistent with previous studies. Overall abundances and abundances of new recruits of nekton taxa indicate extensive use of the tidal river habitat during all months (Appendix C), but temporal resource partitioning among species is evident. Forty species were deemed abundant enough in either the channel or along the shoreline (i.e., total catch of at least 100 individuals in either habitat) to determine seasonality. If the three months with maximum abundance for each of these species are considered (Fig. 3.6.2.2), then peaks for offshore spawners and residents occur in all months, whereas those for estuarine spawners occur in all months except December. Many species in all three life-history categories are most abundant during spring and early summer, but various residents also have abundance peaks during late summer or early autumn. New recruits (i.e., the smallest individuals in our samples) were abundant for 31 species, and among these species, peak recruitment periods varied markedly among life-history categories (Fig. 3.6.2.3). As with overall abundance, peak recruitment for at least some species occurs during every month. However, recruitment peaks for offshore spawners are concentrated during late autumn and winter, whereas those for estuarine spawners and residents are concentrated during spring to early autumn. This trend was also noted in the Little Manatee River by Peebles and Flannery (1992).

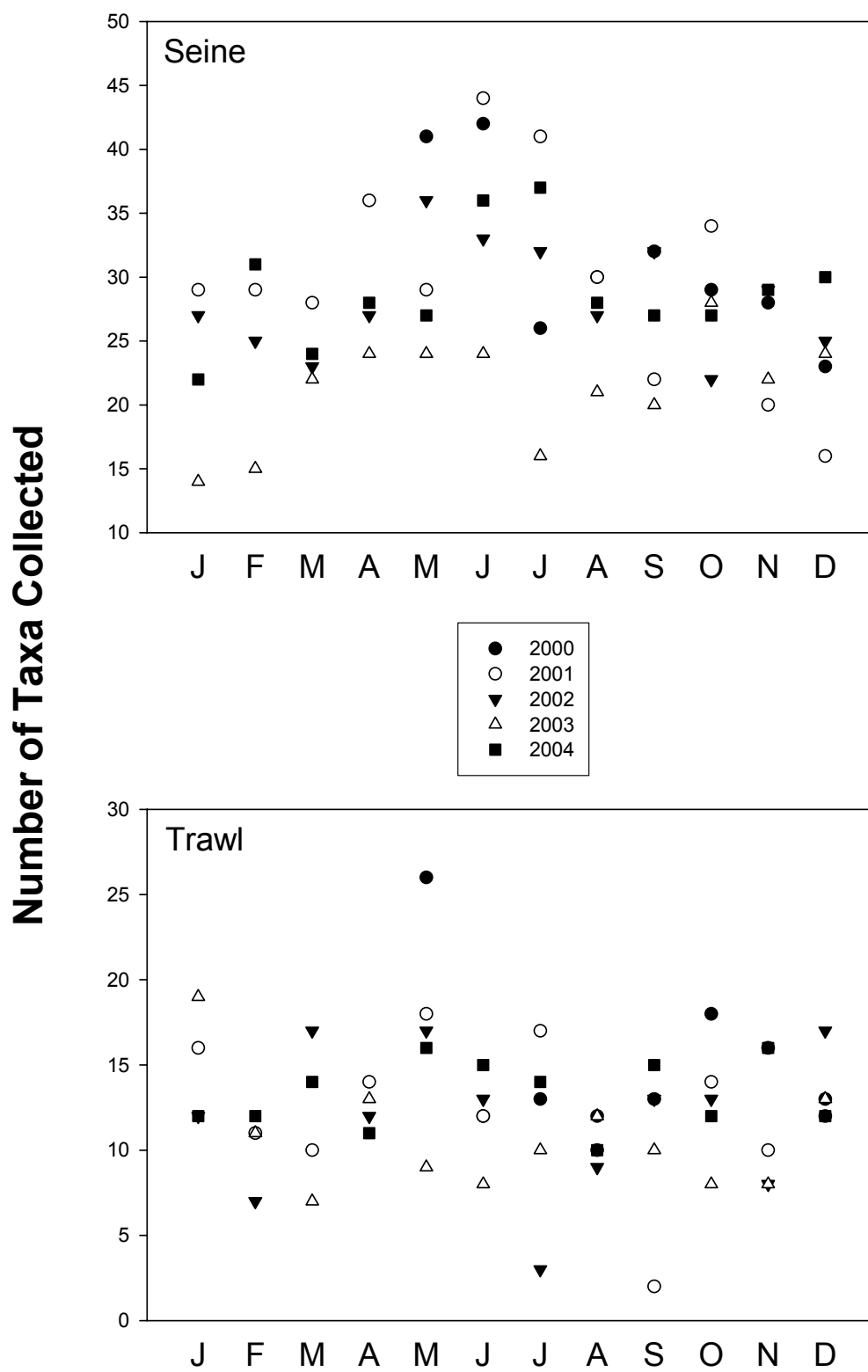


Fig. 3.6.2.1 Number of taxa collected per month by seine and trawl.

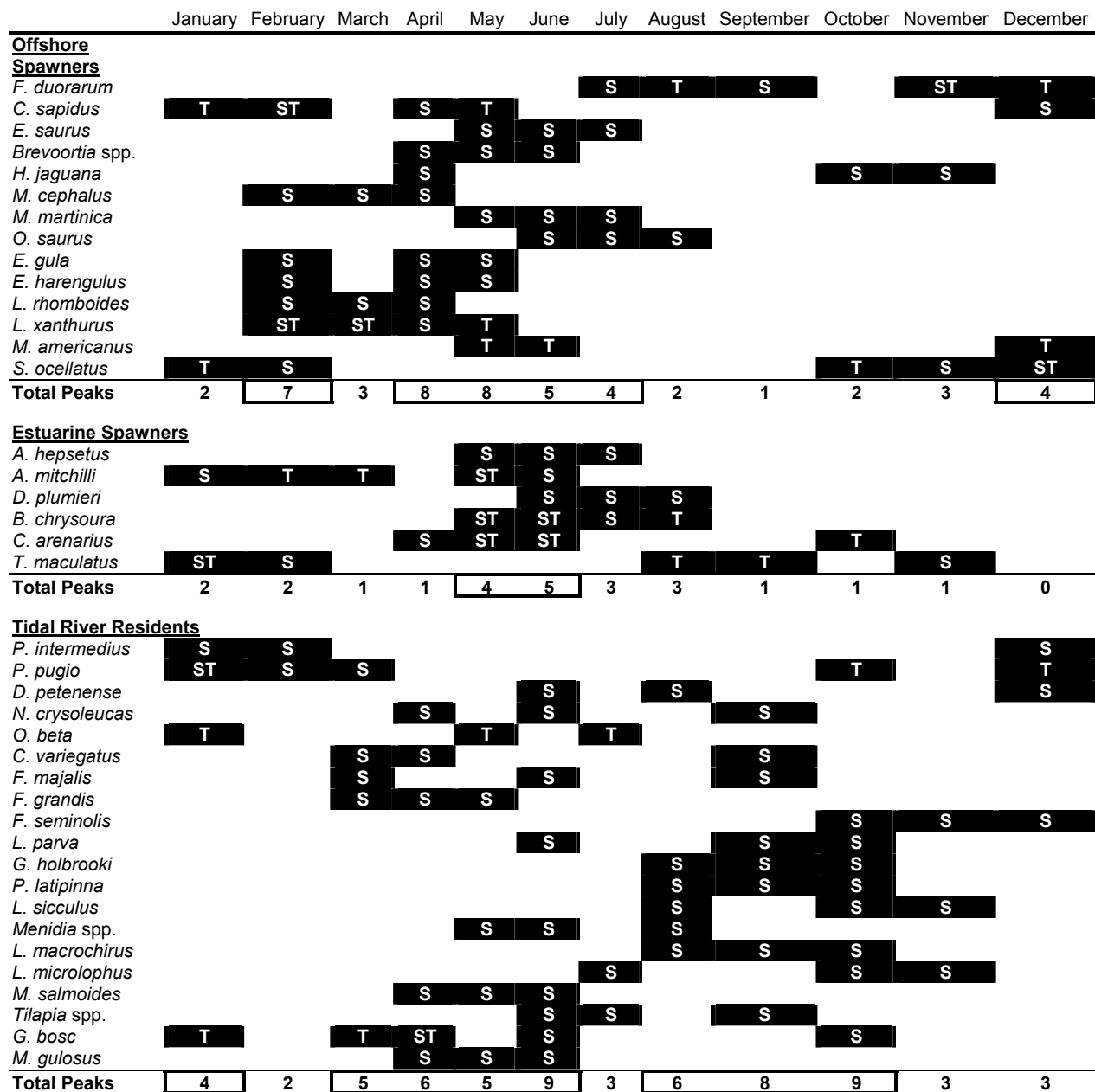


Fig. 3.6.2.2. Top three months of relative abundance for all individuals collected in seines (S) and trawls (T).

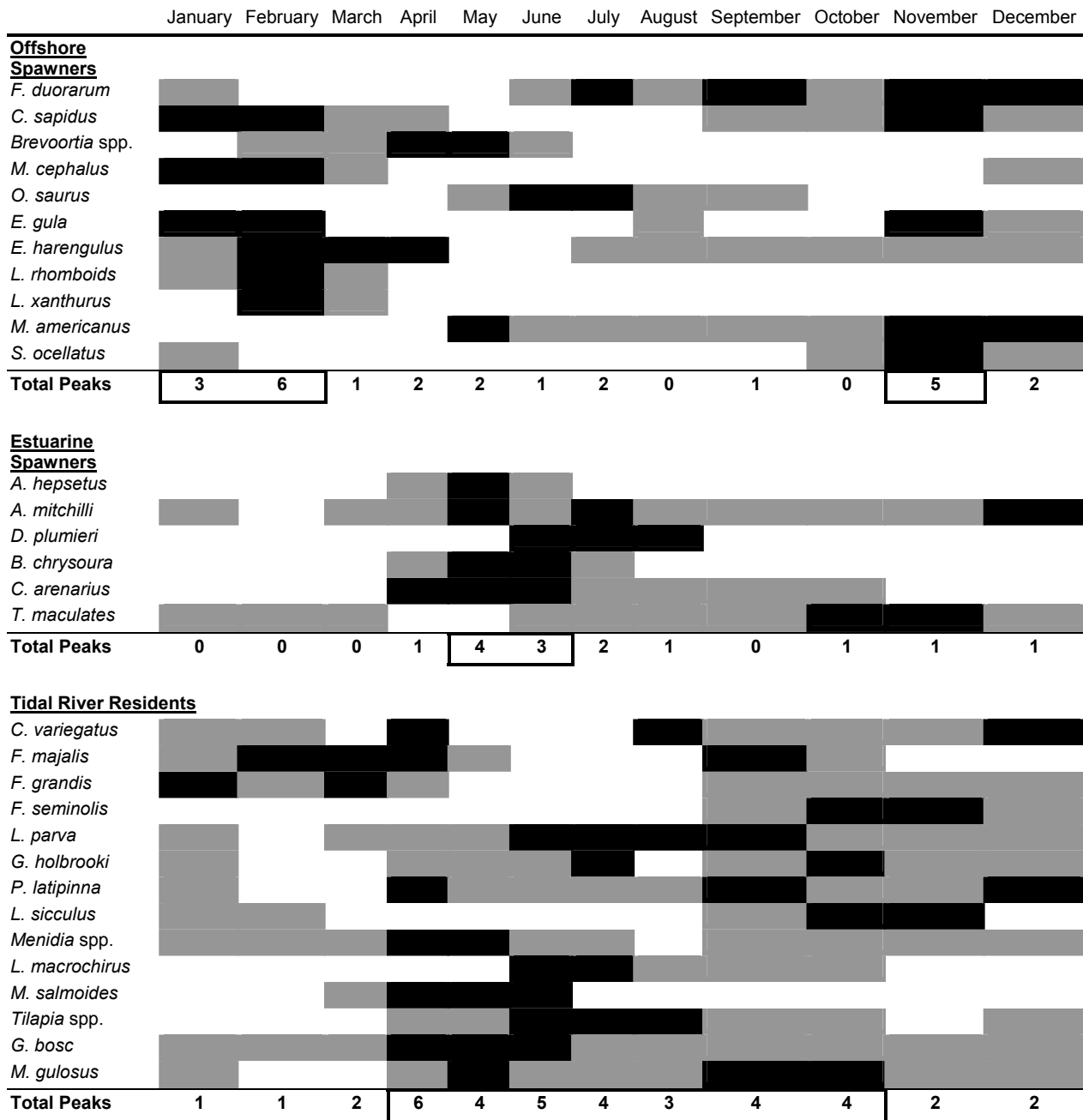


Fig. 3.6.2.3. Months of occurrence (■) and peak abundance (■) for new recruits collected by seine and trawl.

3.7 Distribution (km_u) Responses to Freshwater Inflow

3.7.1 Plankton Net.

Approximately half (49%) the 108 plankton-net taxa evaluated for distribution responses to freshwater inflow exhibited significant responses. All but two of these were negative responses, indicating that the predominant response to increased inflow was movement downstream (Table 3.7.1.1, Appendix F). Although response lags ranged from 1 to 120 d, most were 10 d or less, and many were 5 d or less (Fig. 3.7.1.1).

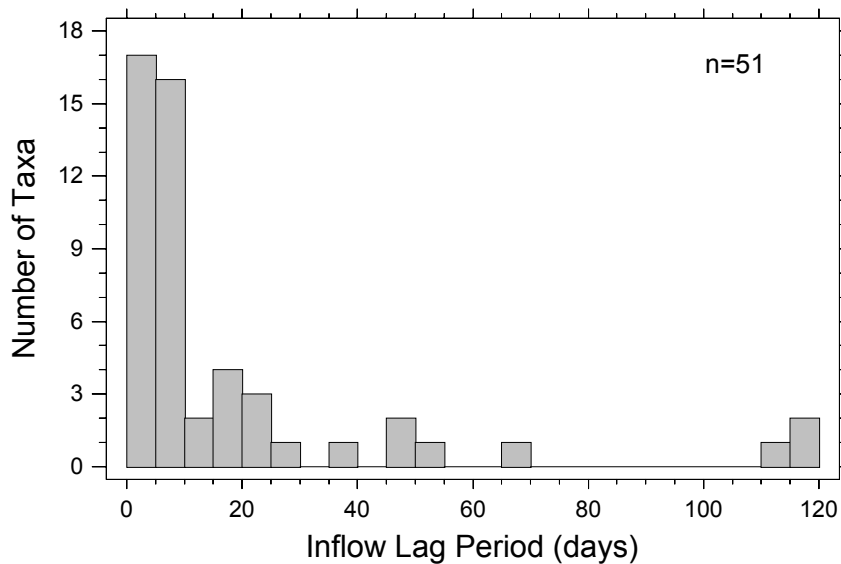


Fig. 3.7.1.1. Distribution response lags (D) for taxa with negative response slopes in Table 3.7.1.1.

The taxa with the most predictable responses ($r^2 > 50\%$), in descending order of predictability, were:

<i>Elops saurus</i> postflexion larvae	ladyfish
Cymothoid sp. a (<i>Lironeca</i>) juveniles	isopod
<i>Brevoortia</i> spp. metamorphs	menhaden
<i>Edotea triloba</i>	isopod
<i>Menidia</i> spp. flexion larvae	silversides
<i>Cynoscion arenarius</i> postflexion larvae	sand seatrout
<i>Clytia</i> sp.	hydromedusa
<i>Palaemonetes pugio</i> juveniles	daggerblade grass shrimp
<i>Cynoscion arenarius</i> juveniles	sand seatrout
<i>Anchoa</i> spp. preflexion larvae	anchovies
trichopteran larvae	caddisflies
<i>Mnemiopsis mccradyi</i>	comb jelly, ctenophore
<i>Limulus polyphemus</i> larvae	horseshoe crab
<i>Syngnathus louisianae</i> juveniles	chain pipefish

With one exception, trichopteran larvae, these are estuarine-dependent and estuarine-resident animals. Among the 51 negative relationships, the steeper slopes tended to have higher r^2 values (Pearson's $r = -0.52$, $p = 0.0001$) and also tended to have larger intercepts ($r = -0.60$, $p < 0.0001$). These results collectively suggest that the estuarine animals that penetrate far into the tidal river during low inflow periods respond to inflow increases in a stronger, more predictable manner than freshwater organisms below the dam or higher-salinity organisms near the river mouth. The planktonic hydromedusa *Clytia* sp. had the strongest slope measured.

Table 3.7.1.1. Plankton-net organism distribution (km_U) responses to mean freshwater inflow ($\ln F$), ranked by linear regression slope. Other regression statistics are sample size (n), intercept ($Int.$), 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	Int.	Slope	P	r^2	DW	D
Acari	water mites	20	-1.324	1.622	0.011	31	x	3
Cumaceans	cumaceans	50	1.145	0.595	0.006	15	x	16
<i>Simocephalus vetulus</i>	water flea	26	13.486	-0.301	0.010	24		2
unidentified <i>Americamysis</i> juveniles	opossum shrimps, mysids	48	6.710	-0.486	0.001	21		2
<i>Parasterope pollex</i>	ostracod, seed shrimp	21	4.894	-0.563	0.044	20		2
<i>Mesocyclops edax</i>	copepod	32	14.208	-0.614	0.042	13		1
<i>Anchoa mitchilli</i> juveniles	bay anchovy	57	8.483	-0.623	0.000	33	x	20
<i>Anchoa</i> spp. flexion larvae	anchovies	21	5.101	-0.643	0.013	29		70
<i>Pinnixa sayana</i> juveniles	pea crab	31	5.230	-0.667	0.000	49		2
<i>Americamysis almyra</i>	opossum shrimp, mysid	52	8.273	-0.673	0.000	39	x	1
<i>Anchoa</i> spp. preflexion larvae	anchovies	19	4.509	-0.680	0.000	57		2
<i>Gobiesox strumosus</i> juveniles	skilletfish	24	7.217	-0.789	0.045	17		52
Hirudinoideans	leeches	26	12.857	-0.818	0.031	18		36
<i>Anopsilana jonesi</i>	Isopod	24	10.930	-0.830	0.008	28	x	1
Polychaetes	sand worms, tube worms	57	11.688	-0.869	0.000	34		7
amphipods, caprellid	skeleton shrimps	18	4.664	-0.873	0.001	48	x	2
<i>Limulus polyphemus</i> larvae	horseshoe crab	17	5.017	-0.882	0.001	55		5
siphonostomatids	parasitic copepods	29	6.357	-0.897	0.026	17		1
<i>Palaemonetes</i> spp. postlarvae	grass shrimp	44	8.707	-0.908	0.002	20		28
decapod megalopae	post-zoea crab larvae	45	8.665	-0.915	0.001	22		8
<i>Cynoscion arenarius</i> juveniles	sand seatrout	16	8.860	-0.946	0.001	58		10
<i>Gambusia holbrooki</i> juveniles	eastern mosquitofish	24	15.646	-0.959	0.013	25		113
<i>Edotea triloba</i>	Isopod	52	8.749	-0.985	0.000	72		9
decapod mysis	shrimp larvae	55	10.189	-0.992	0.000	24		120
<i>Cynoscion arenarius</i> postflexion larvae	sand seatrout	11	6.484	-0.995	0.001	71		1
<i>Diaptomus</i> spp.	copepods	25	14.838	-1.004	0.008	27		9
<i>Acartia tonsa</i>	copepod	40	7.487	-1.013	0.003	21	x	21
odonates, zygopteran larvae	damselflies	20	16.260	-1.050	0.023	25		11
<i>Anchoa mitchilli</i> postflexion larvae	bay anchovy	25	7.215	-1.104	0.000	47	x	7
gastropods, prosobranch	snails	55	15.279	-1.175	0.000	32		50
<i>Cyclops</i> spp.	copepods	22	15.205	-1.179	0.019	25		9
<i>Mnemiopsis mccradyi</i>	comb jelly, ctenophore	10	8.816	-1.205	0.013	55		21
<i>Gobiesox strumosus</i> preflexion larvae	skilletfish	25	7.415	-1.209	0.005	29		20
<i>Palaemonetes pugio</i> adults	daggerblade grass shrimp	40	14.241	-1.230	0.000	47		7
<i>Trinectes maculatus</i> postflexion larvae	hogchoker	25	11.597	-1.235	0.001	40	x	7

Table 3.7.1.1 (cont.).

<i>Description</i>	<i>Common Name</i>	<i>n</i>	<i>Int.</i>	<i>Slope</i>	<i>P</i>	<i>r</i> ²	<i>DW</i>	<i>D</i>
ephemeropteran larvae	mayflies	22	18.564	-1.278	0.001	43		48
<i>Sphaeroma terebrans</i>	isopod	25	14.854	-1.279	0.000	45		19
decapod zoeae	crab larvae	51	10.929	-1.282	0.000	46		8
<i>Lolliguncula brevis</i> juveniles	bay squid	19	7.610	-1.289	0.005	39		4
<i>Syngnathus louisianae</i> juveniles	chain pipefish	15	8.452	-1.291	0.002	52		15
<i>Hargeria rapax</i>	tanaid	12	10.505	-1.380	0.036	37		8
<i>Gobiosoma</i> spp. postflexion larvae	gobies	35	10.300	-1.452	0.005	22		8
<i>Liriope tetraphylla</i>	hydromedusa	13	8.674	-1.476	0.021	39		4
<i>Palaemonetes pugio</i> juveniles	daggerblade grass shrimp	46	14.666	-1.478	0.000	60		17
ostracods, podocopid	ostracods, seed shrimps	40	11.663	-1.490	0.039	11		3
cymothoid sp. a (<i>Lironeca</i>) juveniles	Isopod	50	11.547	-1.566	0.000	84	x	6
<i>Gobiesox strumosus</i> postflexion larvae	skilletfish	17	9.439	-1.585	0.003	46		22
<i>Elops saurus</i> postflexion larvae	ladyfish	10	15.451	-1.796	0.000	87		4
trichopteran larvae	caddisflies	16	21.160	-1.894	0.001	57	x	9
<i>Macrocylops albidus</i>	copepods	13	21.378	-1.899	0.049	31		1
<i>Menidia</i> spp. Flexion larvae	silversides	11	18.446	-1.999	0.001	71		7
<i>Brevoortia</i> spp. metamorphs	menhaden	17	16.145	-2.012	0.000	74	x	120
<i>Clytia</i> sp.	hydromedusa	31	15.836	-2.104	0.000	66		8

3.7.2 Seine and Trawl.

Nearly one-third (32%) of the 69 pseudo-species evaluated for distributional responses to freshwater inflow exhibited significant responses. For the purposes of this discussion, we refer only to the best models for each of the 69 pseudo-species (i.e., statistically significant [$\alpha < 0.05$] models with normally distributed residuals that explain the greatest proportion of the variance [highest r^2 value] for each pseudo-species) (Table 3.7.2.1). Inflow lag periods are characterized as either short (0-14 days), medium (30-60 days), or long (90-365 days). Best models are plotted in Appendix G. All of the significant responses were negative (i.e., animals moved upstream with decreasing freshwater inflow), and more than half of the best models were associated with long inflow lag periods (i.e., average inflow for the 90 to 360 days prior to nekton sample collection) (Fig. 3.7.2.1). All nine best models among residents incorporated long inflow lag periods. Best models among estuarine-dependent estuarine spawners were evenly distributed among the three inflow lag categories, whereas those among estuarine-dependent offshore spawners were weighted towards short inflow lags (0-14 days). Best models explained 13 to 67% of the variability in distribution. The highest r^2 values, >50%, were found among both estuarine-dependent and resident species and incorporated inflow lag periods ranging from 1 (striped anchovy) to 300 days (tilapias) (Appendix G).

Table 3.7.2.1. Best-fit seine and trawl-based pseudo-species distributional response to continuously-lagged mean freshwater inflow ($\ln(\text{cpue})$ vs. $\ln(\text{inflow})$) for the Hillsborough River estuary. Degrees of freedom (df), intercept, slope, probability that the slope is significant (P), and fit (r^2) are provided. The number of days in the continuously-lagged mean inflow is represented by D . An “x” in DW indicates that the Durbin-Watson statistic was significant ($p < 0.05$), a possible indication that serial correlation was present.

Species	Gear	Size	df	Intercept	Slope	P	r^2	DW	D
<i>Farfantepenaeus duorarum</i>	Trawls	0 to 14-mm	14	2.418	-0.377	0.006	0.424		7
<i>Farfantepenaeus duorarum</i>	Trawls	15 to 999-mm	22	2.022	-0.340	0.002	0.363		60
<i>Palaemonetes pugio</i>	Trawls	0 to 999-mm	20	3.470	-0.304	0.012	0.277		360
<i>Elops saurus</i>	Seines	0 to 149-mm	10	3.280	-0.270	0.022	0.424		240
<i>Brevoortia</i> spp.	Seines	0 to 29-mm	14	4.040	-0.612	0.001	0.591		30
<i>Brevoortia</i> spp.	Seines	30 to 999-mm	15	3.642	-0.378	0.001	0.523		210
<i>Anchoa hepsetus</i>	Seines	0 to 34-mm	11	1.787	-0.351	0.002	0.609	x	1
<i>Anchoa hepsetus</i>	Seines	35 to 999-mm	12	3.797	-0.868	0.020	0.374		180
<i>Anchoa mitchilli</i>	Seines	35 to 999-mm	33	2.507	-0.299	0.022	0.150		60
<i>Opsanus beta</i>	Trawls	0 to 999-mm	35	2.328	-0.431	<0.0001	0.333		360
<i>Cyprinodon variegatus</i>	Seines	0 to 29-mm	40	2.686	-0.124	0.002	0.214		180
<i>Cyprinodon variegatus</i>	Seines	30 to 999-mm	36	2.338	-0.083	0.024	0.134		120
<i>Fundulus majalis</i>	Seines	0 to 34-mm	21	2.288	-0.155	0.031	0.203		180
<i>Fundulus seminolis</i>	Seines	0 to 80-mm	15	3.832	-0.217	0.007	0.398		180
<i>Lucania parva</i>	Seines	25 to 999-mm	37	3.277	-0.202	<0.0001	0.378		300
<i>Oligoplites saurus</i>	Seines	0 to 999-mm	17	2.297	-0.275	0.002	0.448		1
<i>Eucinostomus gula</i>	Seines	0 to 999-mm	16	1.574	-0.353	0.021	0.292	x	1
<i>Diapterus plumieri</i>	Seines	0 to 999-mm	32	2.483	-0.120	<0.0001	0.341	x	1
<i>Cynoscion arenarius</i>	Seines	35 to 999-mm	11	2.895	-0.269	0.003	0.574	x	180
<i>Menticirrhus americanus</i>	Trawls	0 to 34-mm	19	3.657	-0.698	<0.0001	0.569		14
<i>Tilapia</i> spp.	Seines	0 to 34-mm	21	3.275	-0.162	0.001	0.434		360
<i>Tilapia</i> spp.	Seines	35 to 999-mm	22	3.849	-0.316	<0.0001	0.671		300

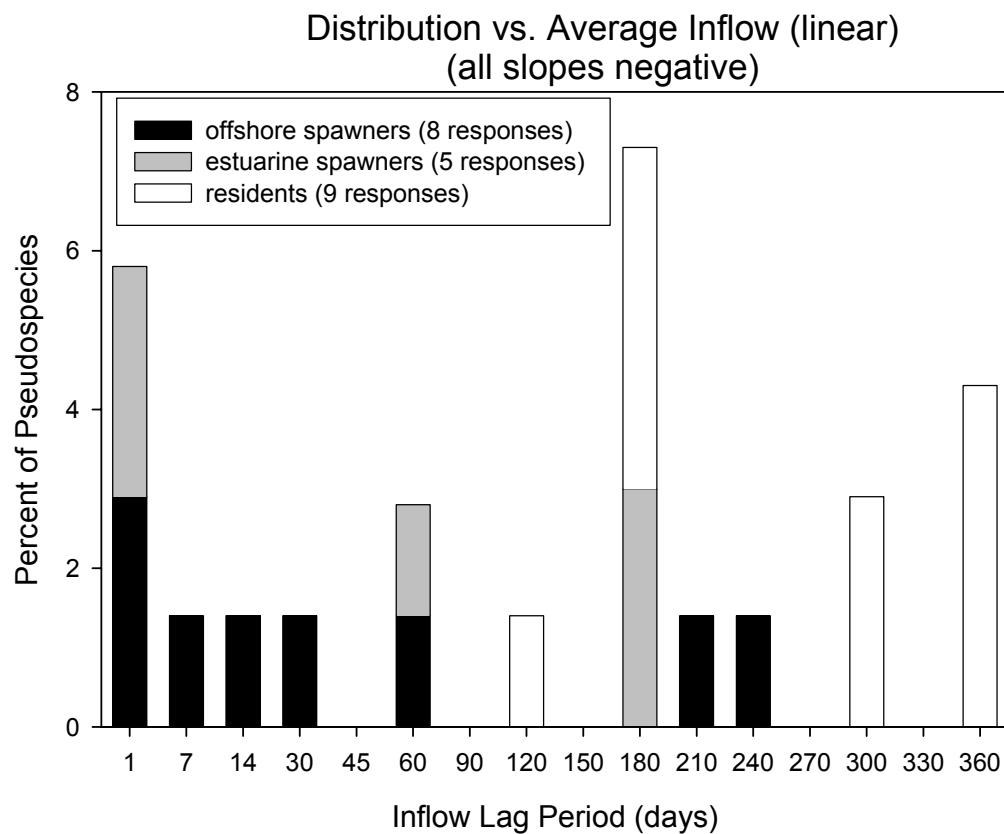


Fig. 3.7.2.1 Summary of linear regression results assessing distribution (km_U) in relation to inflow and lag period.

3.8 Abundance (N , \bar{N}) Responses to Freshwater Inflow

3.8.1 Plankton Net.

Approximately half (51%) the 108 plankton-net taxa evaluated for abundance responses to freshwater inflow exhibited significant responses (Table 3.8.1.1, Appendix H). These were largely split between freshwater taxa that were introduced by inflows (positive responses) and higher-salinity taxa that moved out of the river and into Hillsborough Bay during high inflow periods (negative responses). Polychaetes (primarily nereids), larval silversides (*Menidia* spp.), bay anchovy adults (*Anchoa mitchilli*) and hogchoker juveniles (*Trinectes maculatus*) are estuarine organisms that had positive responses to inflow.

Fig. 3.8.1.1 provides an overview of the abundance responses. Freshwater taxa had low intercepts because they tended to disappear altogether during sustained dry periods, whereas higher-salinity taxa with negative abundance responses tended to be most abundant during low inflow periods. Time lags are summarized in Fig. 3.8.1.2. Very short time lags (e.g., <10 d) are indicative of re-distributions such as movement into the study area, movement from the bottom into the water column, and movement from the shoreline into the channel. Longer lags are more likely to reflect actual changes in population size.

Polychaete distributions were sometimes compatible with a hypoxia avoidance response, wherein abundances were highest immediately downstream of the hypoxic zone that tended to form in the upper tidal river. In agreement with this trend, polychaete abundance was observed to be slightly higher at lower DO levels ($r=-0.29$, $n=57$, $p=0.03$). Although the 10-d time lag in the abundance response to inflow is not indicative of a rapid change in distribution (i.e., moving into the water column to avoid local benthic hypoxia), it may reflect the time required for hypoxia to result from inflow. The overall relationship between polychaete abundance and inflow is somewhat equivocal.

Silversides reproduce in both freshwater and estuarine habitats, and their larvae have been collected from reservoir water as it passed through the dam. Because of this

introduction of individuals from the freshwater side of the dam, the positive response by silversides in the tidal river cannot be definitively attributed to the estuarine portion of the stock.

Bay anchovy adults had the weakest of all of the positive inflow responses, with inflow explaining only 11% of the variation in abundance. Because the 11-d lag in the relationship is much shorter than the age of the adults, the positive response may involve a behavioral redistribution (attraction to the river) rather than a change in local stock size.

The positive response by hogchoker juveniles is more likely to reflect a real change in number because the 47-d lag in the response is in good general agreement with the age of the fish. As in other tidal rivers, hogchoker juveniles in the Hillsborough River tended to occur farther upstream than other estuarine-dependent juvenile fishes (Appendices D & E). They did not exhibit a measurable distribution response, regardless of the data source used (plankton net, seine, or trawl). The negative distribution responses by other estuarine-dependent juveniles cause these species to leave the river during high inflow periods, creating the appearance of reduced number even though total numbers of these species (numbers in both the river and bay) may be responding favorably. The hogchoker, on the other hand, remained in the river during relatively high inflow periods and tended to increase in number.

Freshwater inflow had a strong distributional effect on the hydromedusa *Clytia* sp. that resulted in a strong reduction in its abundance. Because hydromedusae compete with and consume the early stages of fishes (Purcell 1985, Purcell and Arai 2001), their rapid displacement downstream and away from tidal river nursery habitats can be considered to be a beneficial effect of increased inflow. When *Clytia* blooms were present, the biomass and diversity of the plankton community often decreased dramatically (Fig. 3.8.1.3).

Table 3.8.1.1. Abundance responses to mean freshwater inflow ($\ln F$), ranked by linear regression slope. Other regression statistics are sample size (n), intercept ($Int.$), 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.

<i>Description</i>	<i>Common Name</i>	<i>n</i>	<i>Int.</i>	<i>Slope</i>	<i>P</i>	<i>r2</i>	<i>DW</i>	<i>D</i>
<i>Latona setifera</i>	water flea	14	0.045	1.658	0.003	53		120
dipterans, pupae	flies, mosquitoes	40	2.700	1.547	0.000	76		9
ephemeropteran larvae	mayflies	22	1.106	1.469	0.000	66		41
dipterans, chironomid larvae	midges	47	5.014	1.110	0.000	64	x	32
<i>Simocephalus vetulus</i>	water flea	26	4.632	1.012	0.000	52		5
trichopteran larvae	caddisflies	16	3.454	0.973	0.003	48		27
dipteran, <i>Chaoborus punctipennis</i> larvae	phantom midge	34	7.109	0.954	0.000	43	x	6
<i>Ilyocryptus</i> sp.	water flea	22	5.017	0.913	0.018	25		7
<i>Cassidinidea ovalis</i>	isopod	35	5.897	0.781	0.001	28	x	120
Oligochaetes	freshwater worms	31	5.930	0.735	0.000	57		1
<i>Mesocyclops edax</i>	copepod	32	9.423	0.599	0.040	13		6
<i>Sida crystalline</i>	water flea	19	6.367	0.597	0.012	32		1
odonates, zygopteran larvae	damselflies	20	5.061	0.580	0.000	51		35
Acari	water mites	20	5.601	0.573	0.002	44	x	1
ostracods, podocopid	ostracods, seed shrimps	40	6.910	0.508	0.000	40		12
<i>Trinectes maculatus</i> juveniles	hogchoker	29	7.002	0.454	0.005	25		47
dipterans, ceratopogonid larvae	biting midges	13	5.981	0.399	0.041	33		11
<i>Hargeria rapax</i>	tanaid	12	7.074	0.358	0.033	38		4
<i>Menidia</i> spp. flexion larvae	silversides	11	6.294	0.354	0.001	60		120
Hirudinoideans	leeches	26	6.516	0.352	0.000	45		36
Polychaetes	sand worms, tube worms	57	11.568	0.326	0.006	13		10
<i>Sphaeroma terebrans</i>	isopod	25	7.261	0.319	0.017	22		20
gastropods, prosobranch	snails	55	9.045	0.296	0.014	11		19
<i>Menidia</i> spp. preflexion larvae	silversides	38	8.166	0.236	0.008	18	x	1
<i>Anchoa mitchilli</i> adults	bay anchovy	46	8.585	0.222	0.022	11		11
Pelecypods	clams, mussels, oysters	49	10.995	-0.264	0.045	8		120
coleopterans, curculionid adults	beetles	10	9.775	-0.314	0.012	57		1
<i>Edotea triloba</i>	isopod	52	13.418	-0.324	0.017	11	x	6
amphipods, gammaridean	amphipods	57	15.143	-0.330	0.029	8		53
<i>Palaemonetes pugio</i> juveniles	daggerblade grass shrimp	46	11.844	-0.334	0.014	13	x	120
<i>Anchoa mitchilli</i> juveniles	bay anchovy	57	15.565	-0.338	0.002	16	x	1
<i>Americamysis almyra</i>	opossum shrimp, mysid	52	15.014	-0.358	0.045	8	x	1
<i>Brevoortia</i> spp. postflexion larvae	menhaden	10	10.735	-0.399	0.027	48	x	1
<i>Parasterope pollex</i>	ostracod, seed shrimp	21	11.223	-0.409	0.005	35		1
<i>Cyclops</i> spp.	copepods	22	11.889	-0.425	0.042	19		3

Table 3.8.1.1. (cont.)

<i>Description</i>	<i>Common Name</i>	<i>n</i>	<i>Int.</i>	<i>Slope</i>	<i>P</i>	<i>r2</i>	<i>DW</i>	<i>D</i>
<i>Microgobius</i> spp. flexion larvae	gobies	31	11.741	-0.450	0.005	24		23
<i>Gobiesox strumosus</i> preflexion larvae	skilletfish	25	11.950	-0.454	0.034	18		51
decapod megalopae	post-zoea crab larvae	45	15.529	-0.558	0.011	14	x	16
<i>Palaemonetes</i> spp. postlarvae	grass shrimp	44	14.379	-0.589	0.004	18	x	51
<i>Brevoortia</i> spp. metamorphs	menhaden	17	12.328	-0.612	0.034	27	x	4
decapod mysis	shrimp larvae	55	16.183	-0.620	0.000	32		36
<i>Anchoa mitchilli</i> postflexion larvae	bay anchovy	25	13.774	-0.696	0.034	18		6
<i>Petrolisthes armatus</i> juveniles	porcelain crab	18	13.953	-0.708	0.012	34		120
<i>Limulus polyphemus</i> larvae	horseshoe crab	17	12.310	-0.732	0.043	25		119
gobiid preflexion larvae	gobies	40	14.785	-0.739	0.000	28		6
<i>Labidocera aestiva</i>	copepod	39	15.659	-0.804	0.004	21	x	2
chaetognaths, sagittid	arrow worms	47	17.308	-0.941	0.000	29	x	24
<i>Squilla empusa</i> larvae	mantis shrimp	15	13.174	-0.958	0.017	37		8
cymothoid sp. a (<i>Lironeca</i>) juveniles	isopod	50	16.713	-0.971	0.000	65	x	6
gobiid flexion larvae	gobies	39	15.846	-1.000	0.000	51		7
<i>Acartia tonsa</i>	copepod	40	17.327	-1.014	0.005	19		1
<i>Gobiosoma</i> spp. postflexion larvae	gobies	35	16.385	-1.030	0.002	27	x	15
decapod zoeae	crab larvae	51	21.593	-1.047	0.000	34	x	8
cirriped nauplius stage	barnacles	13	13.901	-1.055	0.017	42		12
<i>Clytia</i> sp.	hydromedusa	31	21.768	-1.630	0.000	54		69

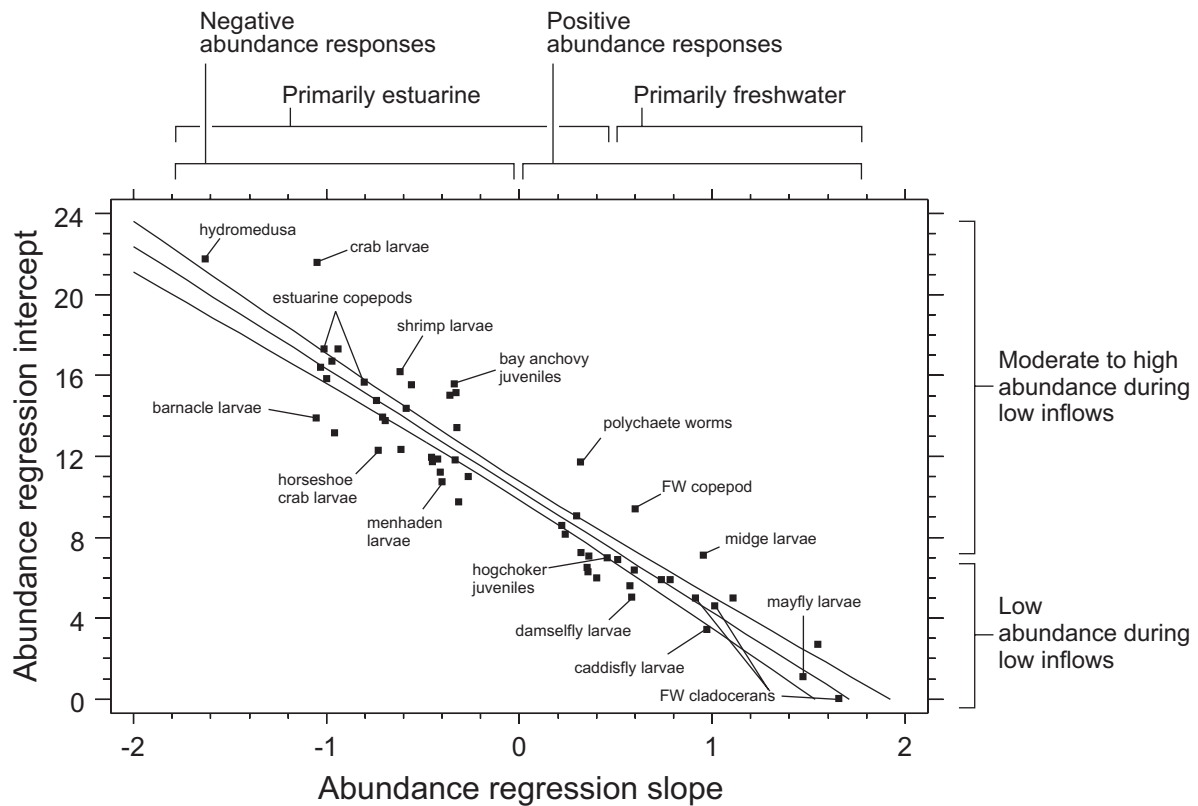


Fig. 3.8.1.1. Relationship between intercepts and slopes of plankton-net taxa in Table 3.8.1.1, described by the regression $Intercept = 10.3125 + 6.0291 * Slope$ ($n=55$, $r^2=88\%$, $p<0.0001$), with 95% confidence limits for predicted means.

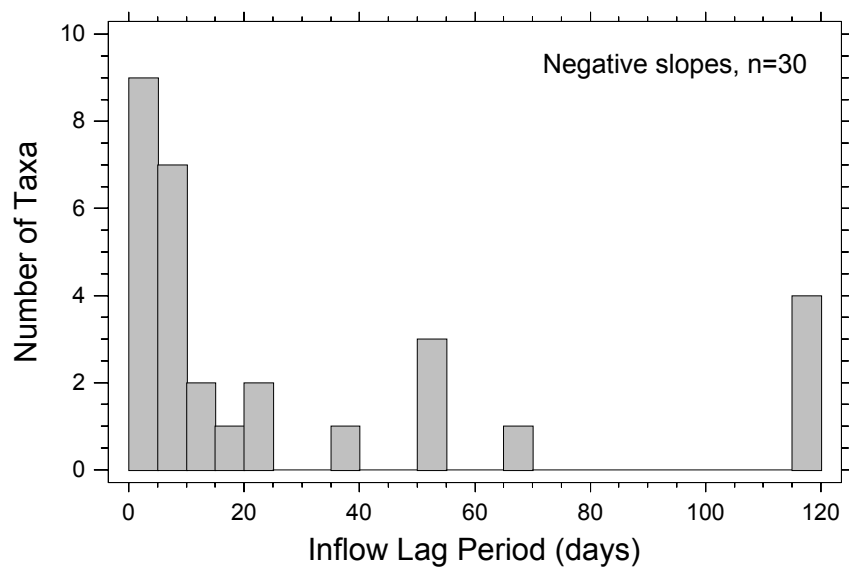
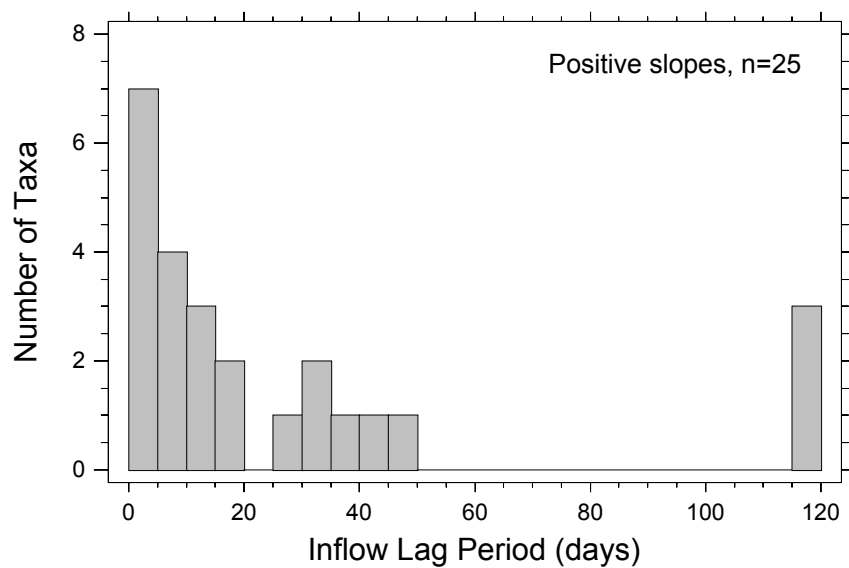


Fig. 3.8.1.2. Distribution of the abundance response lags (D) for taxa with positive and negative response slopes in Table 3.8.1.1.

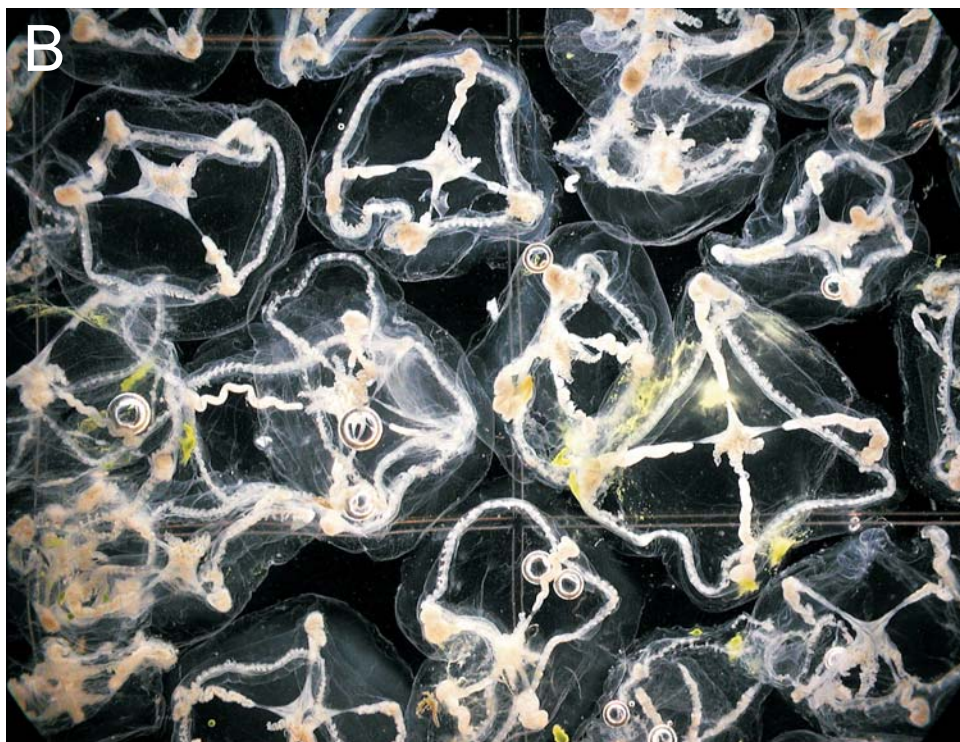


Fig. 3.8.1.3. Photos of Hillsborough River plankton samples when hydromedusae are A) absent, and B) blooming.

3.8.2 Seine and Trawl.

Among the 69 pseudo-species considered in these analyses, abundances of 49% were significantly related to average inflow (Table 3.8.2.1). The greatest proportion of variance was explained by linear models for 21 pseudo-species and by quadratic models for 13 pseudo-species. The most common best models (either linear or quadratic) indicated negative relationships between abundance and inflow, but positive relationships were found among both residents and offshore spawners (Fig. 3.8.2.1). Pseudo-species in the latter two categories also exhibited intermediate relationships in which the best models indicated either maximum or minimum abundance at intermediate levels of inflow. All best models are plotted in Appendix I.

The best models tended to incorporate longer lags for residents and shorter lags for estuarine spawners but were well distributed among lag periods for offshore spawners (Fig. 3.8.2.2). Lag periods ranged from 14 to 360 days, with a peak at 330 days, for residents; 1 to 150 days, with peaks at 30 and 45 days, for estuarine spawners; and 1 to 300 days, with peaks at 1, 180, and 300 days, for offshore spawners.

The strongest abundance-inflow relationships among residents (those with $r^2 > 49\%$) may indicate inflow-related changes in catchability among fishes living along the shoreline (as opposed to actual changes in abundance) (Figs. I16–19, and I29–30). All three taxa involved in these relationships (i.e., tilapias, eastern mosquitofish, and sailfin mollies) have broad salinity tolerances yet their abundances decline precipitously along the shoreline (i.e., in our seine data) at higher levels of inflow. The relationship for tilapias is the least convincing, with much of the trend being based on very high catches during one trip after a period of 60 days with inflows averaging less than 50 cfs. The relationships for eastern mosquitofish and sailfin mollies are, however, very similar and very compelling. In each case, the strongest relationship was with long-term average inflow (lagged 300 or 330 days), and catches were relatively high at inflows less than approximately 90 cfs and relatively low above approximately 330 to 360 cfs. This “low water=high fish abundance” phenomenon is commonly seen among smaller shoreline residents whose populations can spread out into a larger habitat volume (or perhaps

into habitats inaccessible to our sampling gear) during periods of higher inflows (i.e., higher water levels), and thus their abundance per unit area (our CPUE) declines. Simple physical removal from the area by strong currents (“wash out”) could also be involved in these trends, but this effect should be strongest for short-term inflow.

The strongest relationships among estuarine spawners probably indicate avoidance of low salinities by one species, the striped anchovy, that is generally only abundant in the lower portion of tidal rivers (Figs. I5–6). Abundances of both small and large size classes of striped anchovies were very low after periods of approximately 1 to 5 months during which inflows averaged greater than approximately 70 cfs.

The strongest relationships among offshore spawners indicate three very different trends. Small menhadens were rare along the shoreline after periods of one week with inflows greater than approximately 100 cfs (Fig. I4). This trend could be based on wash out such as that observed in the plankton-net data. Small spot, on the other hand, were almost non-existent in the river channel after periods of three months with average inflows less than approximately 365 cfs (Fig. I27). One explanation for this trend is that sustained high levels of inflow stimulate transport of young spot into the tidal river, either passively through density driven circulation or actively due to attraction by factors such as odor or reduced salinity. Another possible explanation is that periods of higher inflow are correlated with larger scale climatic events that favor transport of larvae into Tampa Bay from offshore spawning grounds. Finally, the abundance of young pinfish was greatest after six months with average inflow levels less than approximately 70 cfs but was also relatively high after periods with inflows greater than approximately 490 cfs. This trend is very difficult to explain in terms of inflow and probably indicates the combined influence of opposing forces on recruitment levels in this species.

Association of maximum abundance with intermediate levels of inflow, a relationship that we have commonly observed in other tidal rivers (Greenwood et al. 2004, Matheson et al. 2004), was evident in only a few species in the Hillsborough River. This trend is well illustrated by abundance-inflow plots for Seminole killifish (14-day lagged inflow; Fig. I14) and red drum (30-day lagged inflow; Fig. I28). As in the case of pinfish above, opposing forces are probably affecting abundance. For the

Seminole killifish, low inflows could restrict the area of favorable salinity available to this low-salinity species, and high inflows could lead to washout or changes in catchability as described for eastern mosquitofish and sailfin mollies above. Red drum enter the tidal river as relatively strong-swimming juveniles that are probably attracted by some constituent of water flowing out of the watershed. This attractive signal could be non-existent at low inflows and diluted at very high inflows.

Table 3.8.2.1. Best-fit seine and trawl-based pseudo-species abundance (\bar{N}) response to continuously-lagged mean freshwater inflow [$\ln(\text{cpue})$ vs. $\ln(\text{inflow})$] for the Hillsborough River estuary. The type of response is either quadratic (Q) or linear (L). Degrees of freedom (df), intercept, slope (*Linear coef.*), probability that the slope is significant (*Linear P*), quadratic coefficient (*Quad. coef.*), probability that the quadratic coefficient is significant (*Quad. P*), and fit (r^2) are provided. The number of days in the continuously-lagged mean inflow is represented by D . An “x” in DW indicates that the Durbin-Watson statistic was significant ($p < 0.05$), a possible indication that serial correlation was present

Species	Gear	Size	Months	Response	df	Intercept	Linear coef.	Linear P	Quad. coef.	Quad. P	r^2	DW	D
<i>Palaemonetes pugio</i>	Seines	All	Jan. to Dec.	L	54	6.885	-0.782	<0.0001			0.251	x	60
<i>Callinectes sapidus</i>	Trawls	0 to 49-mm	Nov. to Feb.	Q	15	4.821	-1.875	0.048	0.181	0.044	0.264	x	240
<i>Elops saurus</i>	Seines	0 to 149-mm	May to Jun.	L	18	1.321	-0.161	0.044			0.207	x	1
<i>Brevoortia</i> spp.	Seines	0 to 29-mm	Mar. to Jun.	Q	15	8.610	-2.866	<0.0001	0.233	0.004	0.755		7
<i>Anchoa hepsetus</i>	Seines	0 to 34-mm	Apr. to Jul.	Q	16	9.463	-3.199	0.004	0.269	0.023	0.674	x	30
<i>Anchoa hepsetus</i>	Seines	≥35-mm	Jul. to Aug.	Q	7	6.545	-2.282	<0.0001	0.196	0.001	0.947		150
<i>Anchoa mitchilli</i>	Seines	0 to 24-mm	Jan. to Dec.	L	54	8.172	-1.022	<0.0001			0.310	x	30
<i>Anchoa mitchilli</i>	Seines	25 to 34-mm	Jan. to Dec.	L	54	9.398	-1.221	<0.0001			0.472	x	60
<i>Cyprinodon variegatus</i>	Seines	0 to 29-mm	Jan. to Dec.	Q	53	-6.703	3.732	0.023	-0.415	0.010	0.357	x	360
<i>Fundulus majalis</i>	Seines	0 to 34-mm	Jan. to Jun.	Q	23	-14.888	6.882	0.017	-0.719	0.012	0.361		360
<i>Fundulus majalis</i>	Seines	≥35-mm	Jan. to Jun.	Q	23	5.957	-2.211	0.016	0.208	0.035	0.371	x	90
<i>Fundulus grandis</i>	Seines	0 to 44-mm	Sep. to Jun.	L	44	2.788	-0.361	<0.0001			0.244	x	120
<i>Fundulus grandis</i>	Seines	≥45-mm	Jan. to Dec.	L	54	3.302	-0.455	<0.0001			0.296	x	180
<i>Fundulus seminolis</i>	Seines	0 to 80-mm	Oct. to Dec.	Q	16	-4.469	1.976	0.011	-0.188	0.014	0.361		14
<i>Lucania parva</i>	Seines	0 to 24-mm	May to Jan.	L	42	5.497	-0.847	<0.0001			0.459	x	330
<i>Gambusia holbrooki</i>	Seines	0 to 24-mm	Jan. to Dec.	L	54	7.668	-1.102	<0.0001			0.529	x	330
<i>Gambusia holbrooki</i>	Seines	≥25-mm	Jan. to Dec.	L	54	6.868	-0.962	<0.0001			0.502		300
<i>Poecilia latipinna</i>	Seines	0 to 34-mm	Jan. to Dec.	L	54	6.077	-0.950	<0.0001			0.516		330
<i>Poecilia latipinna</i>	Seines	≥35-mm	Jan. to Dec.	L	54	4.406	-0.666	<0.0001			0.378		210
<i>Lepomis macrochirus</i>	Seines	20 to 69-mm	Jun. to Nov.	L	28	-1.084	0.298	0.001			0.347	x	240
<i>Micropterus salmoides</i>	Seines	0 to 74-mm	Apr. to Jun.	L	17	-0.850	0.298	0.003			0.410		30
<i>Oligoplites saurus</i>	Seines	All	May to Jul.	L	13	2.171	-0.316	0.035			0.299		180
<i>Eucinostomus gula</i>	Seines	All	Feb. to May	L	15	3.679	-0.559	0.012			0.349		300

Table 3.8.2.1 (cont.)

<i>Species</i>	<i>Gear</i>	<i>Size</i>	<i>Months</i>	<i>Response</i>	<i>df</i>	<i>Intercept</i>	<i>Linear coef.</i>	<i>Linear P</i>	<i>Quad. coef.</i>	<i>Quad. P</i>	<i>r</i> ²	<i>DW</i>	<i>D</i>
<i>Lagodon rhomboids</i>	Seines	0 to 34-mm	Jan. to Mar.	Q	9	45.954	-15.965	0.028	1.392	0.039	0.666		180
<i>Lagodon rhomboids</i>	Seines	≥35-mm	Apr. to Oct.	L	32	1.824	-0.200	0.023			0.151	x	14
<i>Leiostomus xanthurus</i>	Seines	≥50-mm	Apr. to Jul.	L	17	2.232	-0.270	0.018			0.289		1
<i>Leiostomus xanthurus</i>	Trawls	0 to 49-mm	Feb. to May	Q	14	5.658	-3.085	0.001	0.397	<0.0001	0.822	x	90
<i>Sciaenops ocellatus</i>	Seines	0 to 49-mm	Oct. to Feb.	Q	20	-9.165	4.595	0.008	-0.471	0.006	0.348		30
<i>Tilapia</i> spp.	Seines	0 to 34-mm	Jun. to Aug.	L	13	2.604	-0.400	0.030			0.312	x	210
<i>Tilapia</i> spp.	Seines	≥35-mm	Oct. to Nov.	Q	7	18.442	-6.017	0.003	0.487	0.005	0.844		60
<i>Mugil cephalus</i>	Seines	0 to 29-mm	Jan. to Mar.	L	10	8.918	-1.223	0.027			0.403		300
<i>Microgobius gulosus</i>	Seines	0 to 29-mm	May to Oct.	L	28	2.280	-0.286	<0.0001			0.413		14
<i>Trinectes maculatus</i>	Seines	0 to 34-mm	Jan. to Dec.	L	54	2.148	-0.142	0.032			0.083	x	1
<i>Trinectes maculatus</i>	Seines	≥35-mm	Jan. to Dec.	Q	53	1.916	-0.547	0.021	0.048	0.046	0.153	x	45

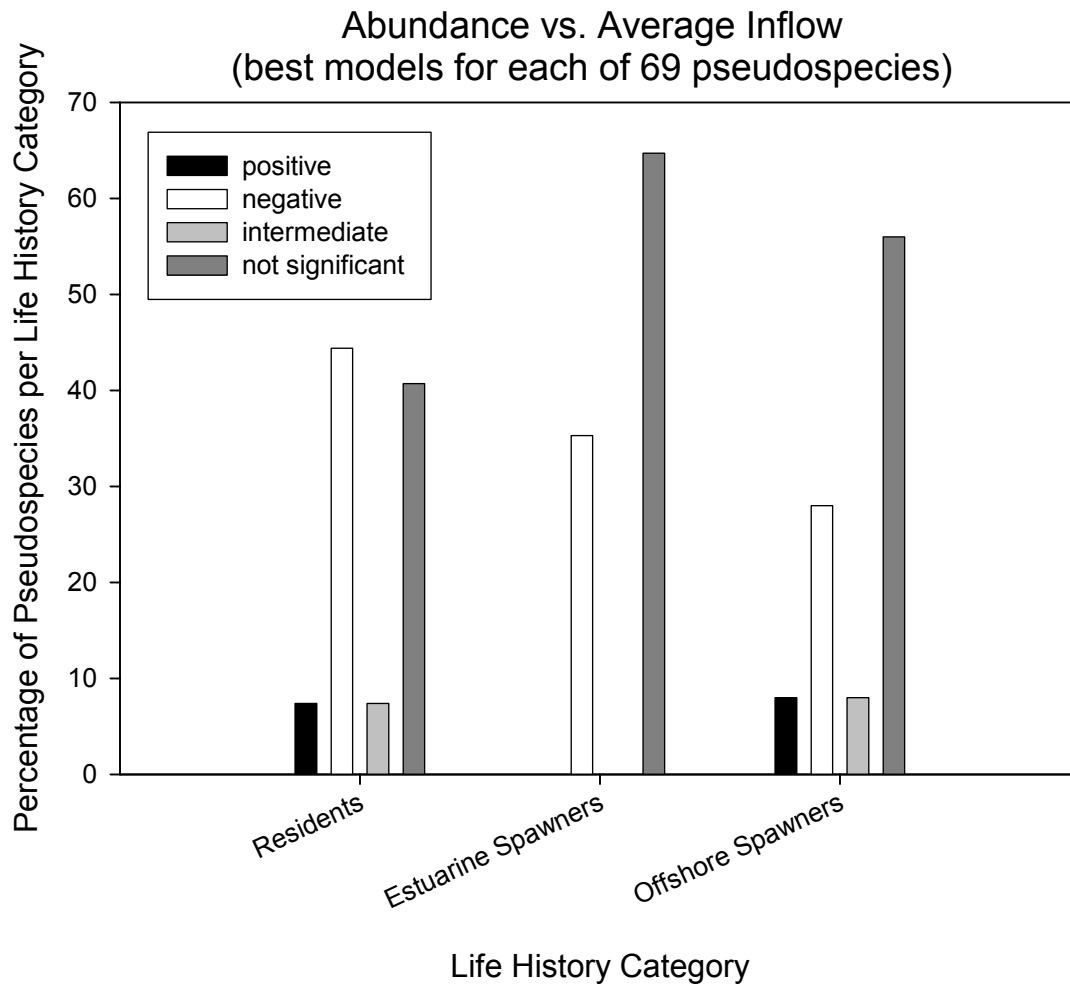


Fig. 3.8.2.1. Summary of regression results assessing abundance (\bar{N}) in relation to inflow. Positive and negative indicate increase and decrease in abundance with increasing inflow, respectively, while intermediate indicates maximum or minimum abundance at intermediate inflows.

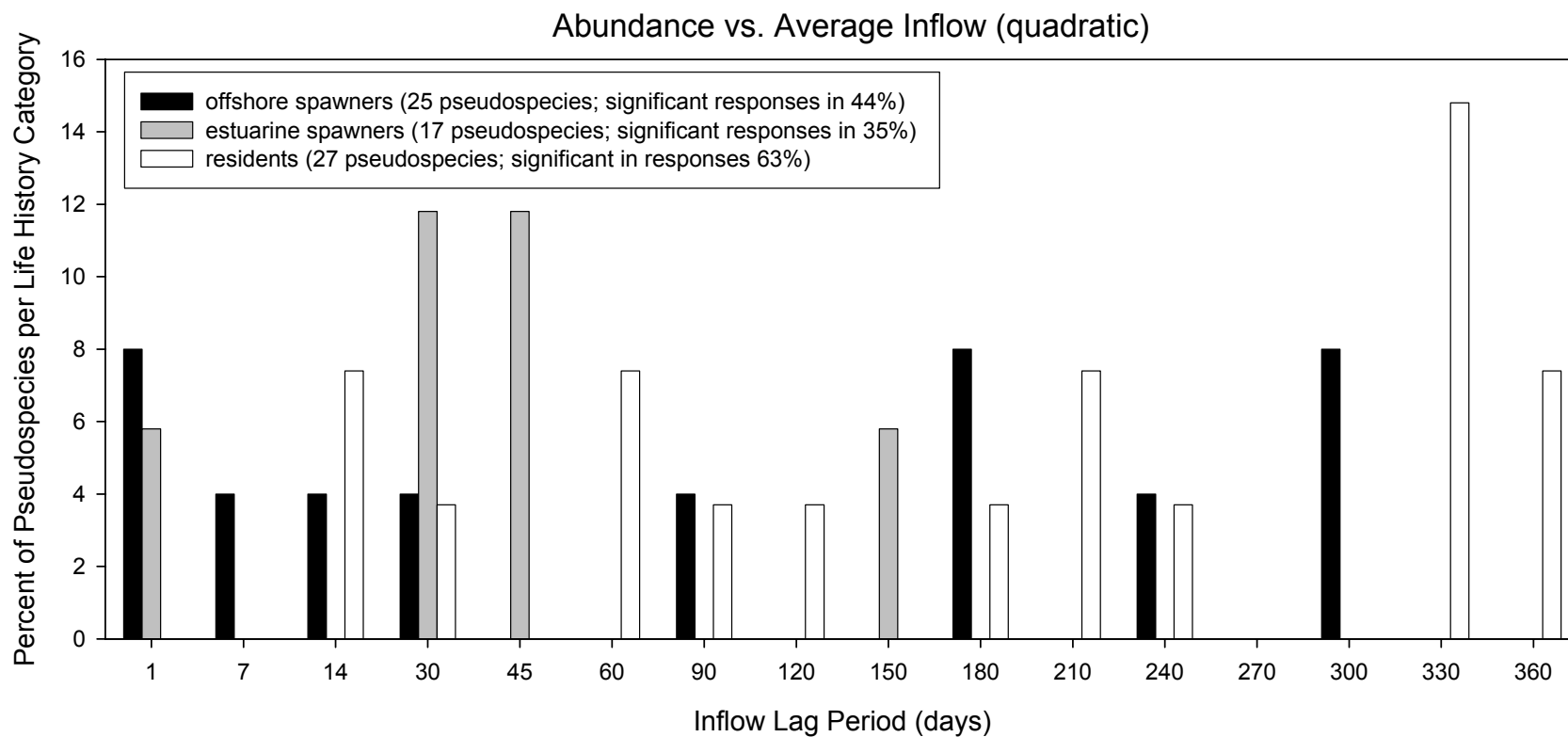


Fig. 3.8.2.2. Summary of regression results assessing abundance (\bar{N}) in relation to inflow and lag period.

3.9 Responses to Low Inflow

3.9.1 Distribution (km_U) and Abundance (\bar{N}) Responses.

The stenohaline and euryhaline freshwater species groups in the upper two geographic strata had significant short- and long-term responses in abundance, distribution, and taxon richness to increases in inflow. Positive relationships between relative abundance and same-day inflow existed for both species groups (Fig. 3.9.1), but inflow that was lagged over longer periods explained more of the variability in the abundance data. Similarly, inflow had a positive relationship with taxon richness (Fig. 3.9.2) and accounted for more than 40% of the variability in taxon richness for both the steno- (360-day lag, $r^2=43.1\%$) and euryhaline (45-day lag, $r^2=48.7\%$) species groups. Centers of abundance were shifted upstream with decreased inflow for both species groups and, although the lags differed (14-day for stenohaline, and 210-day for euryhaline), the regression parameters were remarkably similar (Fig. 3.9.3). The variability explained by the distributional regressions (max of 15%) was relatively small, as were the distributional shifts with increased inflow ($\sim 0.7\text{km}$ shift with an increase from 0 to 20cfs, and a maximum of 1.6km shift with an inflow increase from 0 to 800cfs).

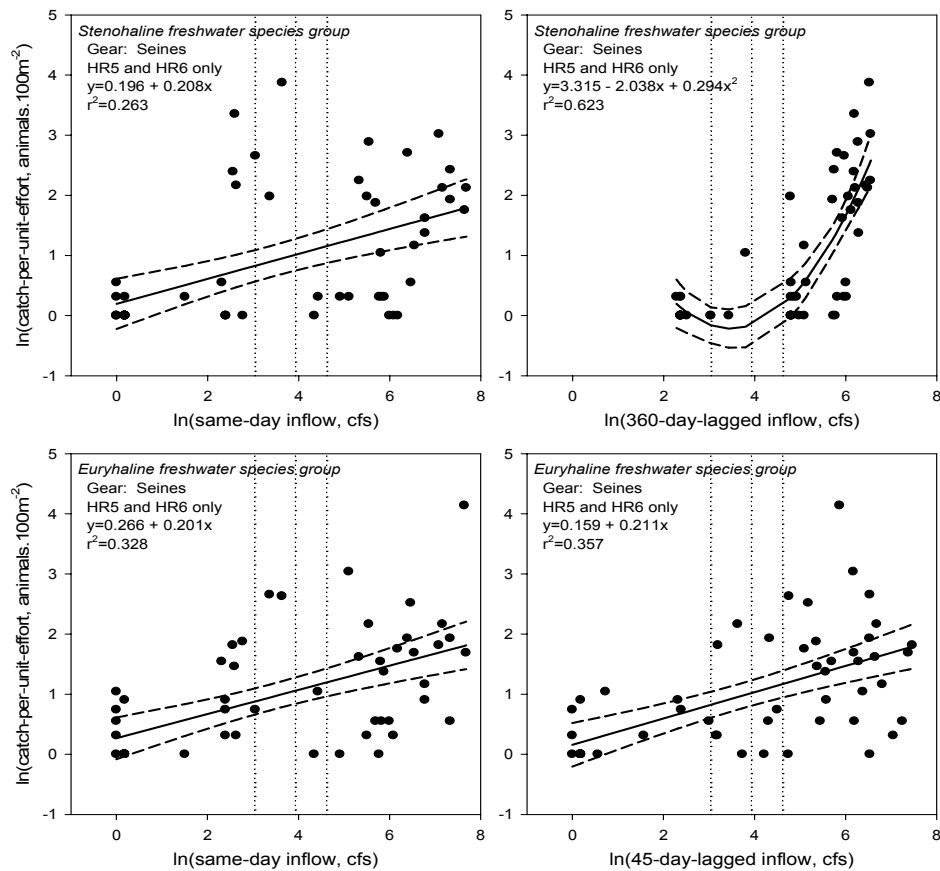


Fig. 3.9.1. Abundance response of two freshwater species groups to inflow. Solid line is the predicted value, while the dashed line represents the upper and lower 95% confidence interval. The vertical dotted lines represent inflows of 20, 50, and 100cfs.

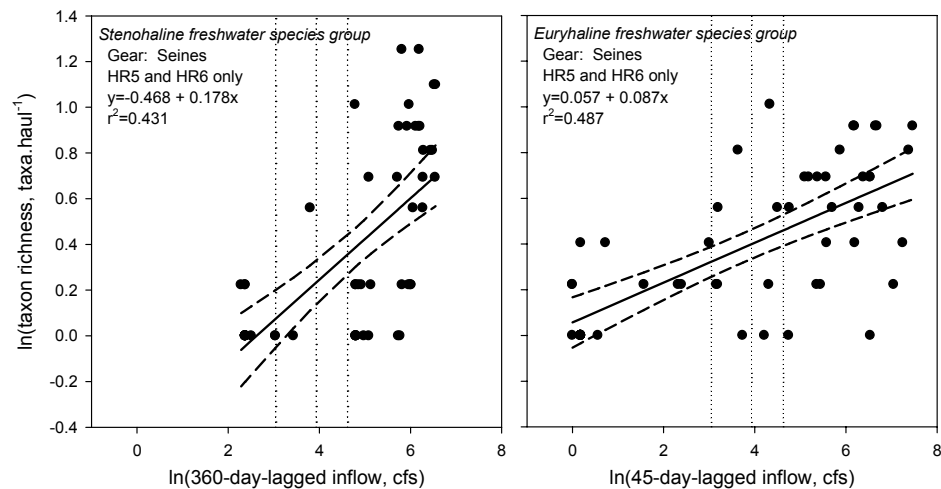


Fig. 3.9.2. Taxon richness response of two freshwater species groups to inflow. Solid line is the predicted value, while the dashed line represents the upper and lower 95% confidence interval. The vertical dotted lines represent inflows of 20, 50, and 100cfs.

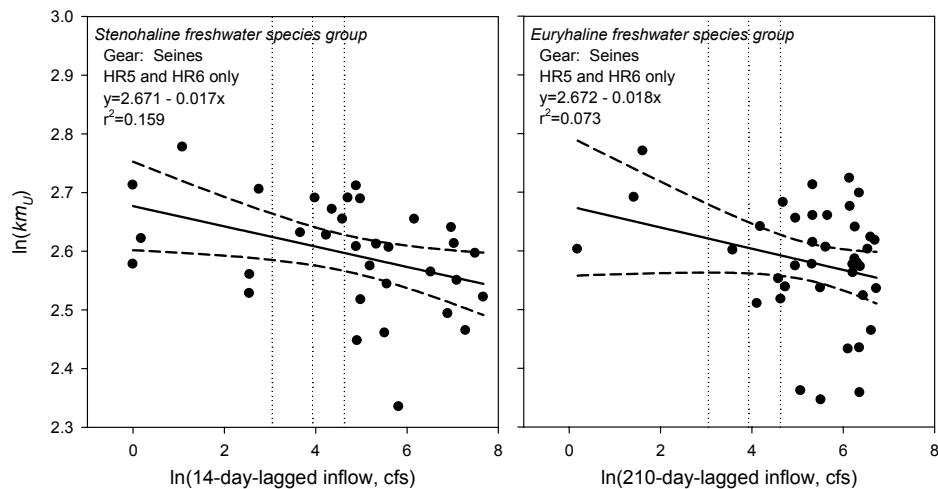


Fig. 3.9.3. Distributional response of two freshwater species groups to inflow. Solid line is the predicted value, while the dashed line represents the upper and lower 95% confidence interval. The vertical dotted lines represent inflows of 20, 50, and 100cfs.

Fish collections made during periods of moderate inflow (10 and 100 cfs) were sparse, but it appears that components of both freshwater species groups might be established below the dam with relatively small, consistent, long-term increases in inflow. During this study, abundance and taxon richness initially increased for both freshwater species groups at relatively low inflows (20 to 30 cfs) and continued to increase with even higher inflows. Inconsistent inflows throughout this study period (coefficient of variation of 166% for same-day inflow) with a high percentage of very low inflows (35.7% were less than 10 cfs) probably allowed freshwater species to colonize below the dam during periods of heightened inflow, only to be removed during subsequent periods of low inflow. Consistently higher minimum inflows might avoid the removal of these freshwater species groups during periods of low inflow.

The creation of a permanent freshwater zone below the dam would be beneficial to estuarine species even if a permanent freshwater community cannot be established below the dam. Many estuarine and marine species recruit to oligohaline waters during their juvenile life-history stages. Even in the highly altered Hillsborough River, economically important species utilize these low salinity habitats when they are available. In the Hillsborough River, for instance, snook and ladyfish both have centers of abundance in oligohaline waters and would benefit if a permanent oligohaline zone were established.

3.9.2 Change in Nearshore Nekton Community Structure with Varying Inflows

Flows through the dam during summer 2000 sampling varied from 0.2 cfs in July, to 3.6 cfs in August, to 81 cfs in September, and back to 0.2 cfs in October. In 2001, flows were 0.2 cfs in July, 532 cfs in August, 419 cfs in September, and 37 cfs in October. Thus both years exhibited low flows followed by enhanced releases, then subsequent decreases in October. There was some evidence that the composition of the nekton community in zones 5 and 6 changed in response to these varying flows (Fig. 3.9.4). In zone 5 (both years) and zone 6 (2000 only) the fauna present in July changed substantially through August and September before returning to a more July-like assemblage in October. The exception to this pattern was in zone 6 (2001), when there was a linear change in community structure from July through October (Fig. 3.9.4).

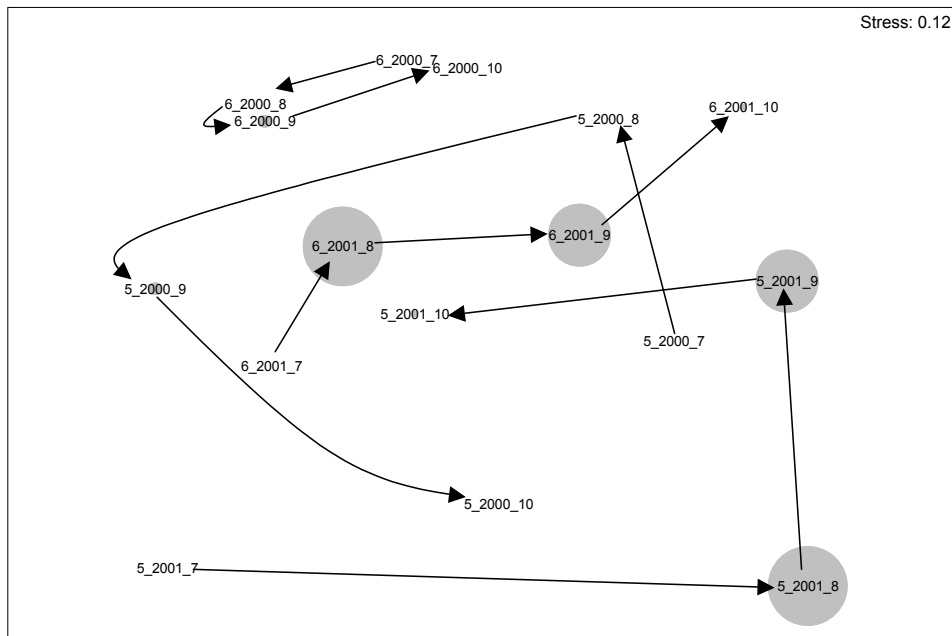


Fig. 3.9.4. Non-metric multidimensional scaling (MDS) ordination of nearshore nekton community structure in zones 5 and 6 of the Hillsborough River, summers of 2000 and 2001. Labels indicate zone_year_month, with arrows joining successive samples within a zone (each sample point is the average of two seine hauls). Bubble plots behind samples indicate magnitude of inflow at Hillsborough Dam, averaged over the day of sampling and the preceding day.

3.10 Hypoxia effects

3.10.1 Hypoxia and Organism Distribution

Limited evidence existed for organisms avoiding low dissolved oxygen in the river channel by moving to the adjacent shallower margins. Very weak, statistically significant declines in abundance and taxon richness were noted in seines with increasing dissolved oxygen levels in the adjacent trawled river channel (Table 3.10.1a, Figs. 3.10.1–3.10.2).

Organisms tended to avoid areas of hypoxia, particularly those regions below 2 mg l⁻¹. Graphical exploration of average animal abundance and taxon richness by river zone for trawl data shows that, in general, very low dissolved oxygen concentration led

to low abundance and low taxon richness. This was true on days when dissolved oxygen was low downstream and increased with movement upstream (Fig. 3.10.3), when dissolved oxygen was high downstream and decreased with movement upstream (Fig. 3.10.4), or when dissolved oxygen was low in the middle reaches of the lower Hillsborough River and increased with movement either upstream or downstream (Fig. 3.10.5).

3.10.2 Hypoxia and Organism Abundance

There was substantial evidence that dissolved oxygen concentration is an important determinant of organism abundance in the river channel. Abundance of organisms collected by trawling increased with increasing concentration of dissolved oxygen, although the initial regression treating all samples individually had heterogeneous variance and so a regression of abundance averaged by dissolved oxygen category was performed (Table 3.10.1b, Fig. 3.10.6). Taxon richness in trawls also increased with increasing dissolved oxygen (Table 3.10.1b, Fig. 3.10.7). There was no significant relationship between abundance of organisms in seines and dissolved oxygen. Taxon richness in seines increased with decreasing dissolved oxygen (Fig. 3.10.8). Note, however, that there were very few sets conducted at dissolved oxygen levels $<2 \text{ mg l}^{-1}$, making pooling of the data within this range necessary (see Breitburg et al. 2001). This complicates interpretation of this result.

Table 3.10.1. Summary of regression results between abundance or richness and dissolved oxygen (DO). (a) Seine data averaged by river zone and compared to average DO level in adjacent trawled area to assess distribution change in the river, (b) trawl data, (c) seine data. Cat. indicates that the DO parameter was based on 0.5 PSU ranges (see text). KS and CV indicate results of normality and constant variance tests respectively (Checks [✓] = pass, cross [×] = fail). Statistically acceptable regressions are highlighted in bold.

Gear/Response	Parameter	Estimate	SE	T-statistic	p	r ²	KS	CV
(a) Seine Ln(Mean abundance+1) (n=282)	Constant	6.135	0.203	30.238	<0.0001	1.5	✓	✓
	Mean trawl DO	-0.0943	0.0454	-2.0767	0.0387			
(a) Seine Mean richness (n=282)	Constant	9.014	0.433	20.823	<0.0001	3.1	✓	×
	Mean trawl DO	-0.290	0.097	-2.993	0.0030			
(a) Seine Ln (Mean richness+1) (n=282)	Constant	2.202	0.053	41.362	<0.0001	1.7	✓	✓
	Mean trawl DO	-0.026	0.012	-2.202	0.0285			
(b) Trawl Ln (Abundance+1) (n=337)	Constant	0.298	0.104	2.864	0.0045	15.6	×	×
	Trawl DO	0.181	0.023	7.860	<0.0001			
(b) Trawl Mean abundance (n=14)	Constant	0.828	0.603	1.374	0.195	64.9	✓	✓
	Trawl DO cat.	0.667	0.142	4.711	0.0005			
(b) Trawl Richness (n=337)	Constant	1.381	0.336	4.106	<0.0001	14.2	×	✓
	Trawl DO	0.554	0.074	7.451	<0.0001			
(b) Trawl Ln (Richness+1) (n=337)	Constant	0.4927	0.081	6.098	<0.0001	24.9	✓	×
	Trawl DO	0.1882	0.018	10.535	<0.0001			
(b) Trawl Mean richness (n=14)	Constant	0.828	0.603	1.374	0.1946	64.9	✓	✓
	Trawl DO cat.	0.667	0.142	4.711	0.0005			

Gear/Response	Parameter	Estimate	SE	T-statistic	p	r ²	KS	CV
(c) Seine	Constant	5.522	0.223	24.727	<0.0001	0.3	✓	×
Ln (Abundance+1)	Seine DO	-0.051	0.039	-1.304	0.1927			
(n=674)								
(c) Seine	Constant	1618.192	401.404	4.031	0.0014	13.6	✓	✓
Mean abundance	Seine DO cat.	-97.083	67.931	-1.429	0.1765			
(n=15)								
(c) Seine	Constant	8.801	0.475	18.515	<0.0001	1.2	×	×
Richness	Seine DO	-0.237	0.083	-2.868	0.0043			
(n=674)								
(c) Seine	Constant	2.143	0.063	34.148	<0.0001	0.7	×	✓
Ln (Richness+1)	Seine DO	-0.024	0.011	-2.229	0.026			
(n=674)								
(c) Seine	Constant	9.354	0.490	19.106	<0.0001	51.6	✓	×
Mean richness	Seine DO cat.	-0.309	0.083	-3.75	0.0025			
(n=15)								
(c) Seine	Constant	2.245	0.058	38.818	<0.0001	55.3	✓	✓
Ln(Mean richness+1)	Seine DO cat.	-0.039	0.010	-4.010	0.0015			
(n=15)								

Hypoxia was most common in the river channel, so it is appropriate to focus on results obtained by trawling in this analysis. Although the results of the regressions gave valid positive linear relationships between mean abundance or mean richness and dissolved oxygen concentration, there was a marked increase in abundance and richness above 2 mg l^{-1} (Figs. 3.10.6, 3.10.7). This suggests that a dissolved oxygen concentration of 2 mg l^{-1} is an important threshold below which abundance and taxon richness of animals in the Hillsborough River significantly decline. A similar increase in species richness above 2 mg l^{-1} was found in the Kattegat (Sweden), but there was a more regular linear increase in richness from $0.5\text{--}6 \text{ mg l}^{-1}$ in Chesapeake Bay (Breitburg et al. 2001). CPUE (kg h^{-1} by bottom trawling) of fish and invertebrates in offshore waters of the northern Gulf Mexico was significantly greater in areas with dissolved oxygen of $2\text{--}5 \text{ mg l}^{-1}$ than in hypoxic areas $<2 \text{ mg l}^{-1}$ (Craig et al. 2001). A positive correlation between fish abundance or species richness and dissolved oxygen has been noted in various estuaries, e.g., Elbe (Thiel et al. 1995) and Zeeschelde (Maes et al. 1998).

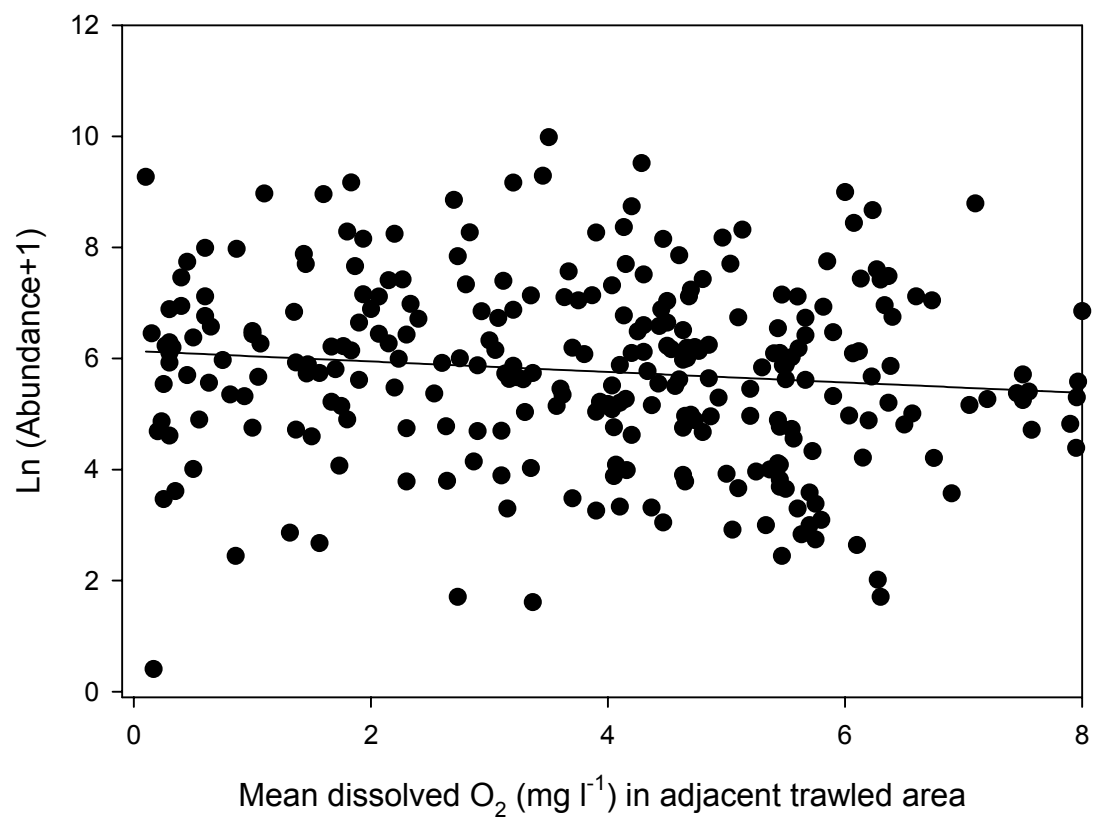


Fig. 3.10.1. Linear relationship between mean animal abundance in seines and dissolved oxygen in the adjacent channel of the Hillsborough River.

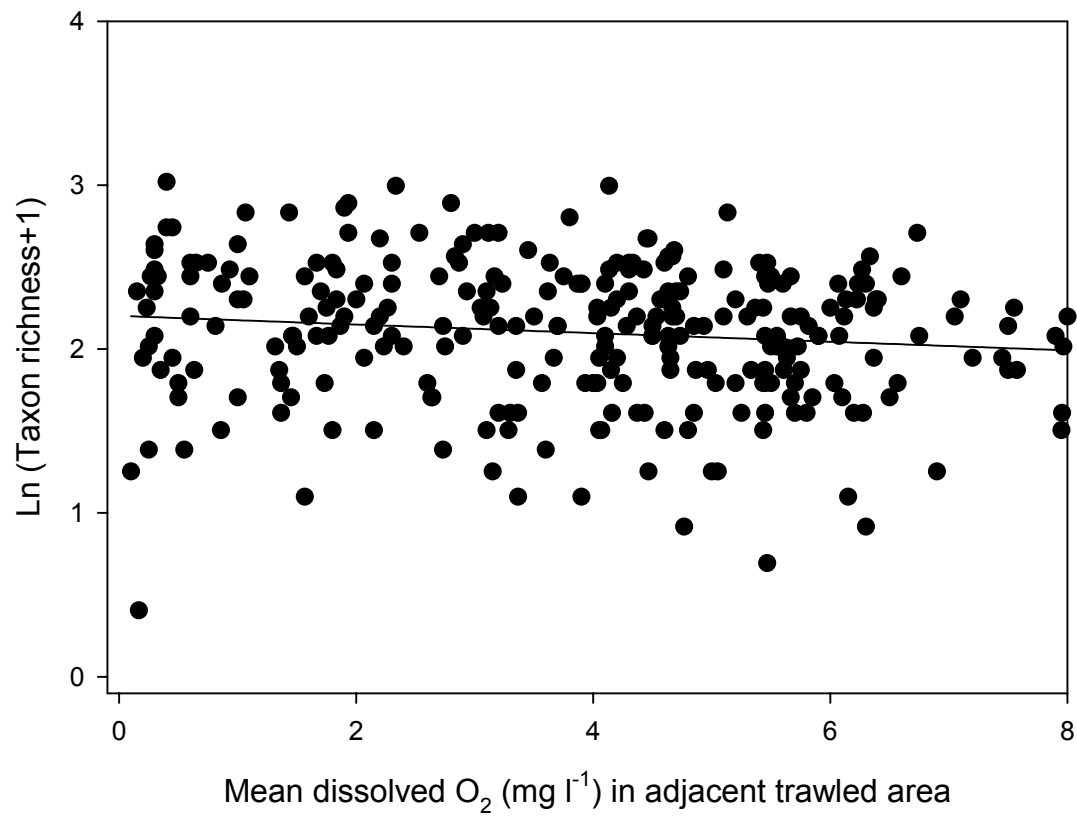


Fig. 3.10.2. Linear relationship between mean taxon richness in seines and dissolved oxygen in the adjacent channel of the Hillsborough River.

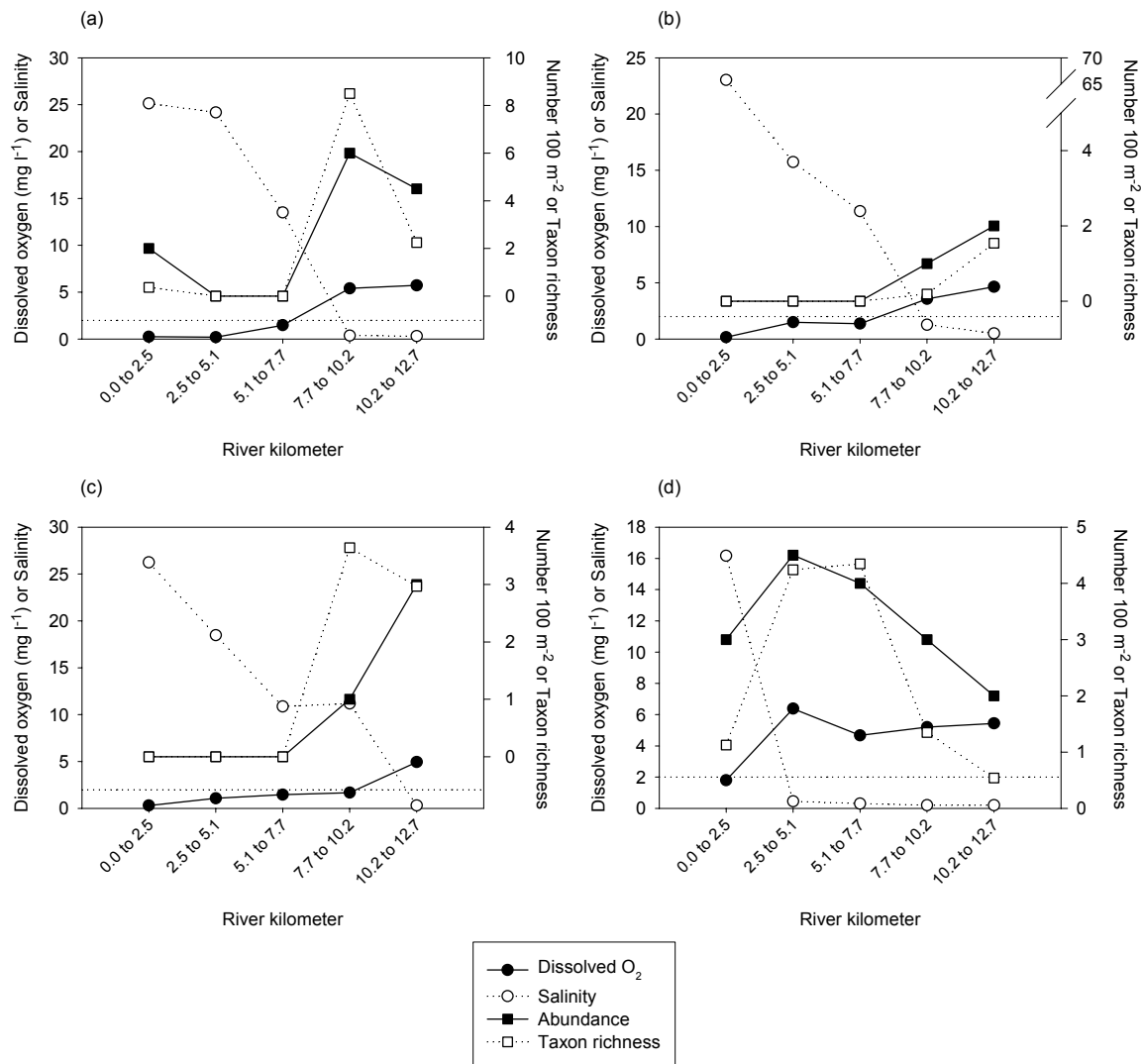


Fig. 3.10.3. Abundance and taxon richness of animals caught in trawls in relation to dissolved oxygen and salinity in (a) August 2001, (b) September 2001, (c) July 2002, and (d) September 2002. Dotted horizontal reference line indicates hypoxia (2 mg l⁻¹).

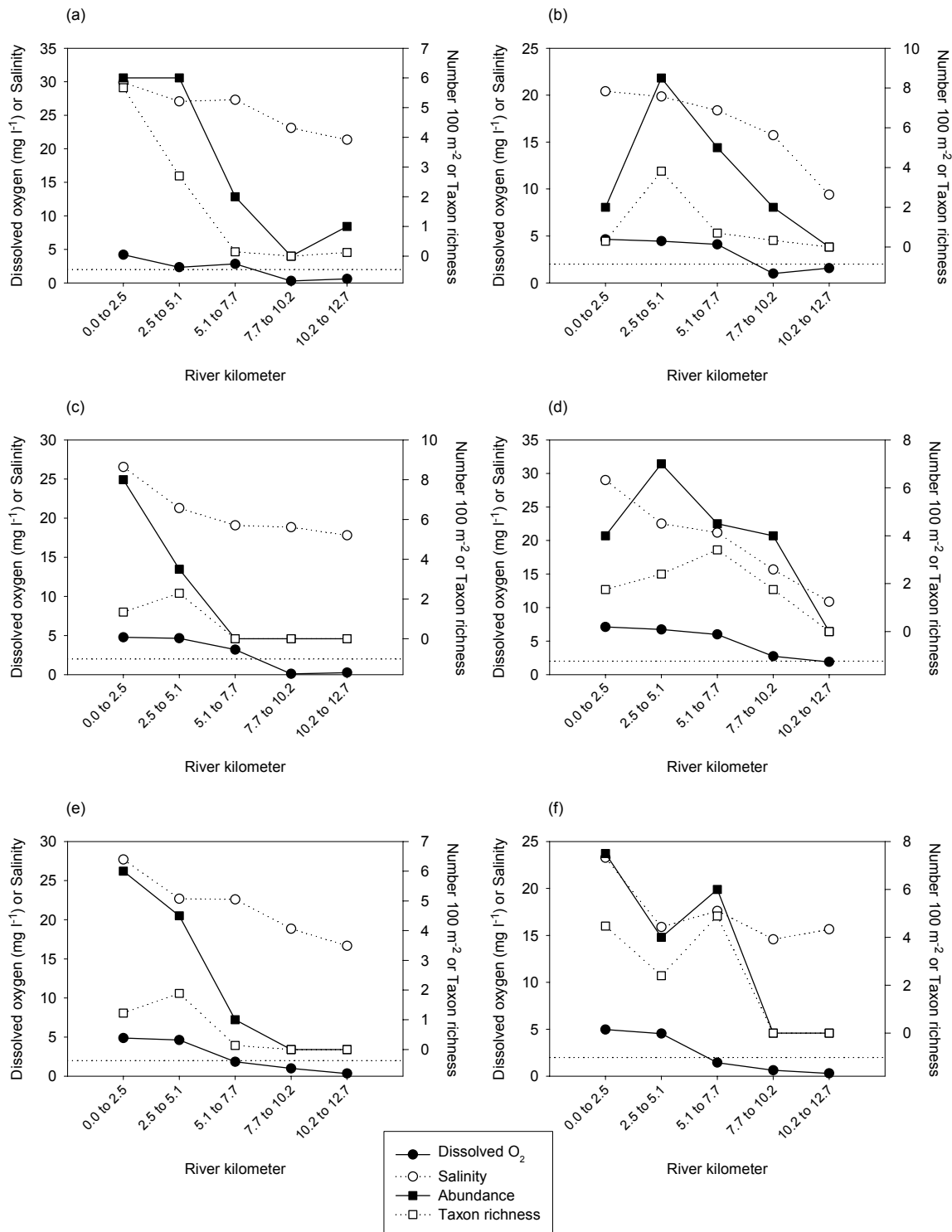


Fig. 3.10.4. Abundance and taxon richness of animals caught in trawls in relation to dissolved oxygen and salinity in (a) June 2000, (b) November 2000, (c) December 2001, (d) January 2000, (e) April 2002, and (f) December 2003. Dotted horizontal reference line indicates hypoxia (2 mg l⁻¹).

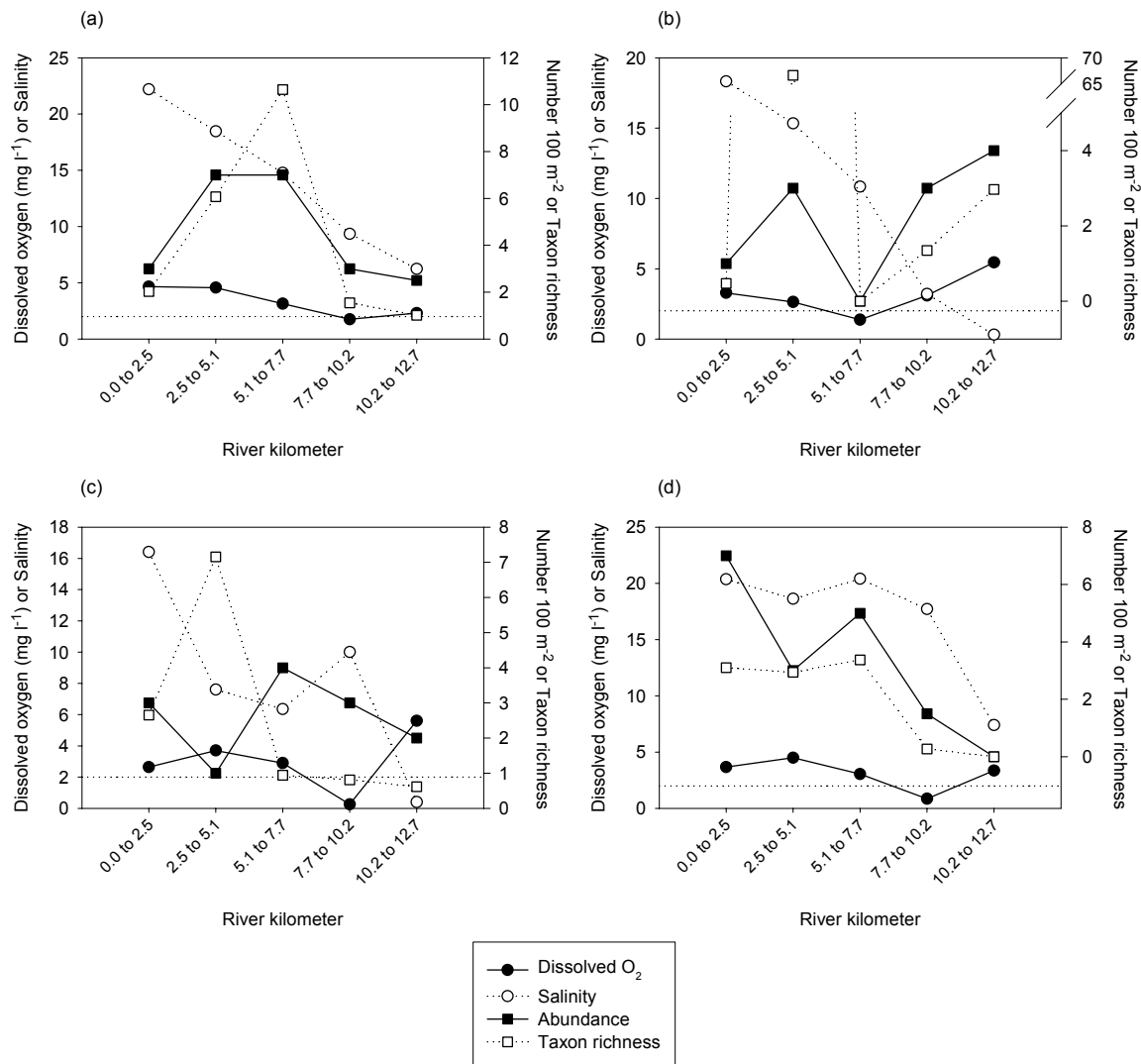


Fig. 3.10.5. Abundance and taxon richness of animals caught in trawls in relation to dissolved oxygen and salinity in (a) April 2003, (b) May 2003, (c) October 2003, and (d) November 2003. Dotted horizontal reference line indicates hypoxia (2 mg l⁻¹).

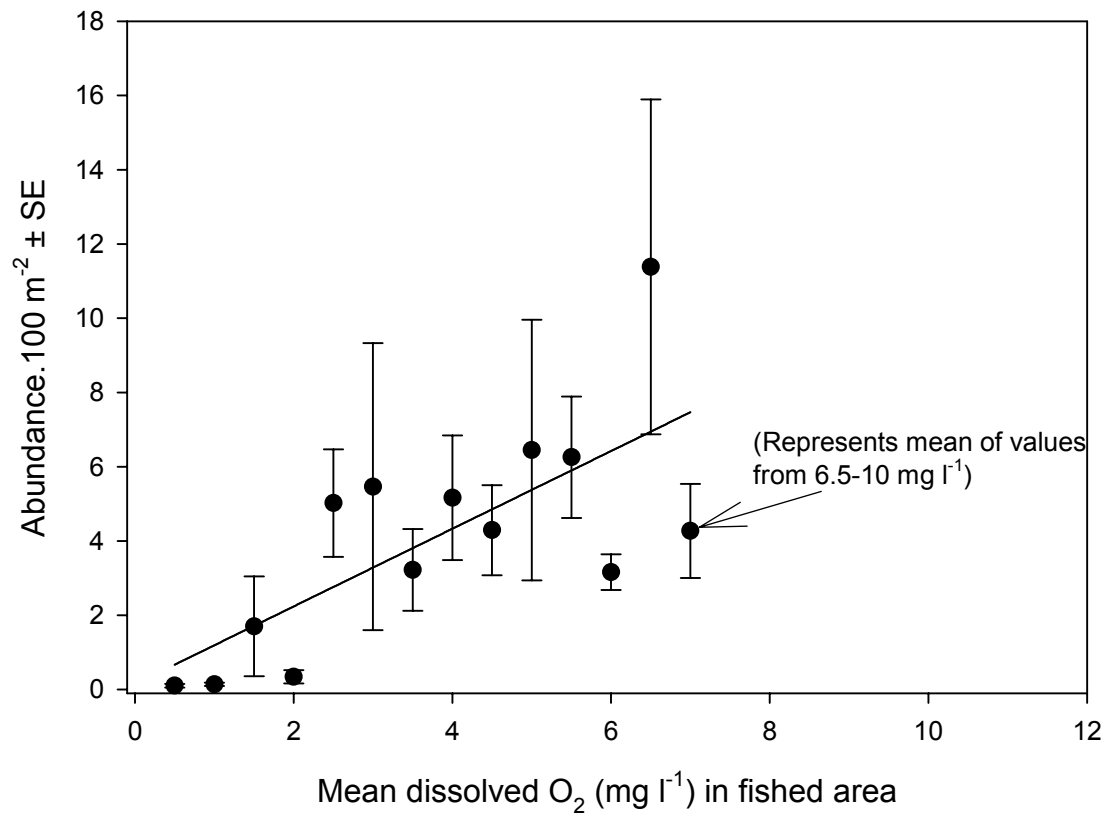


Fig. 3.10.6. Linear relationship between mean animal abundance in trawls and dissolved oxygen in the Hillsborough River.

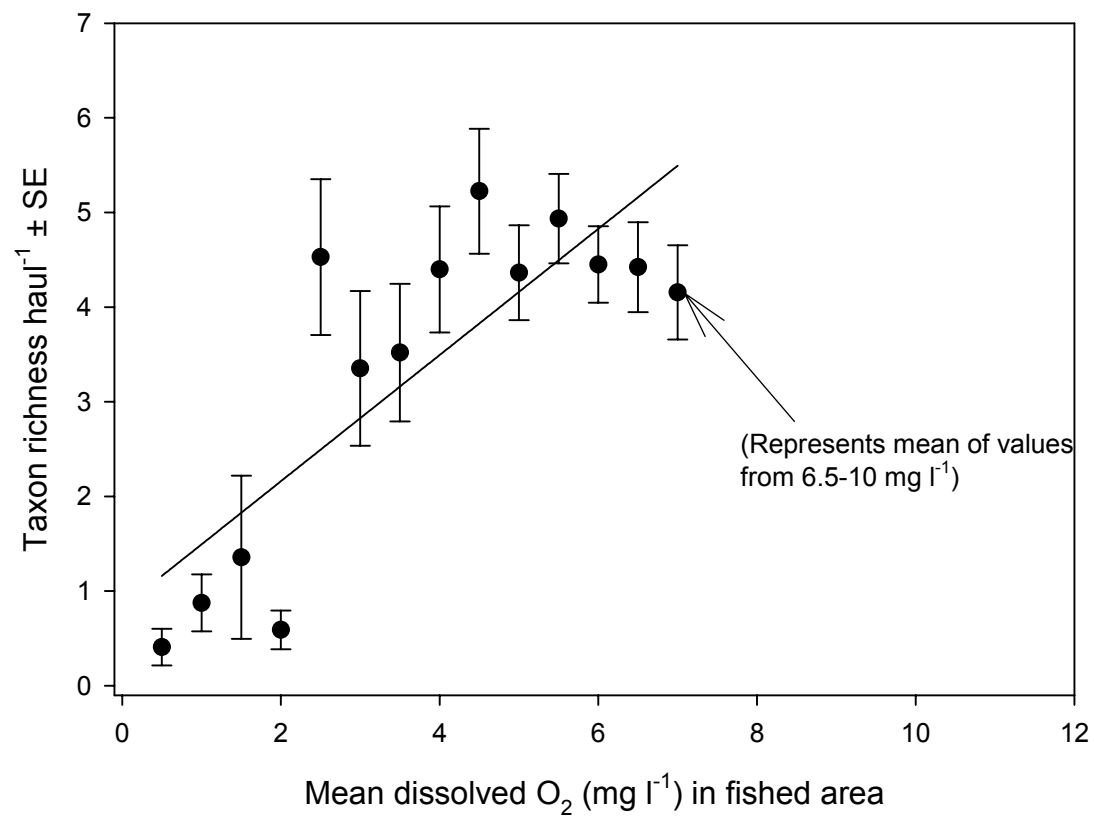


Fig. 3.10.7. Linear relationship between mean taxon richness in trawls and dissolved oxygen in the Hillsborough River.

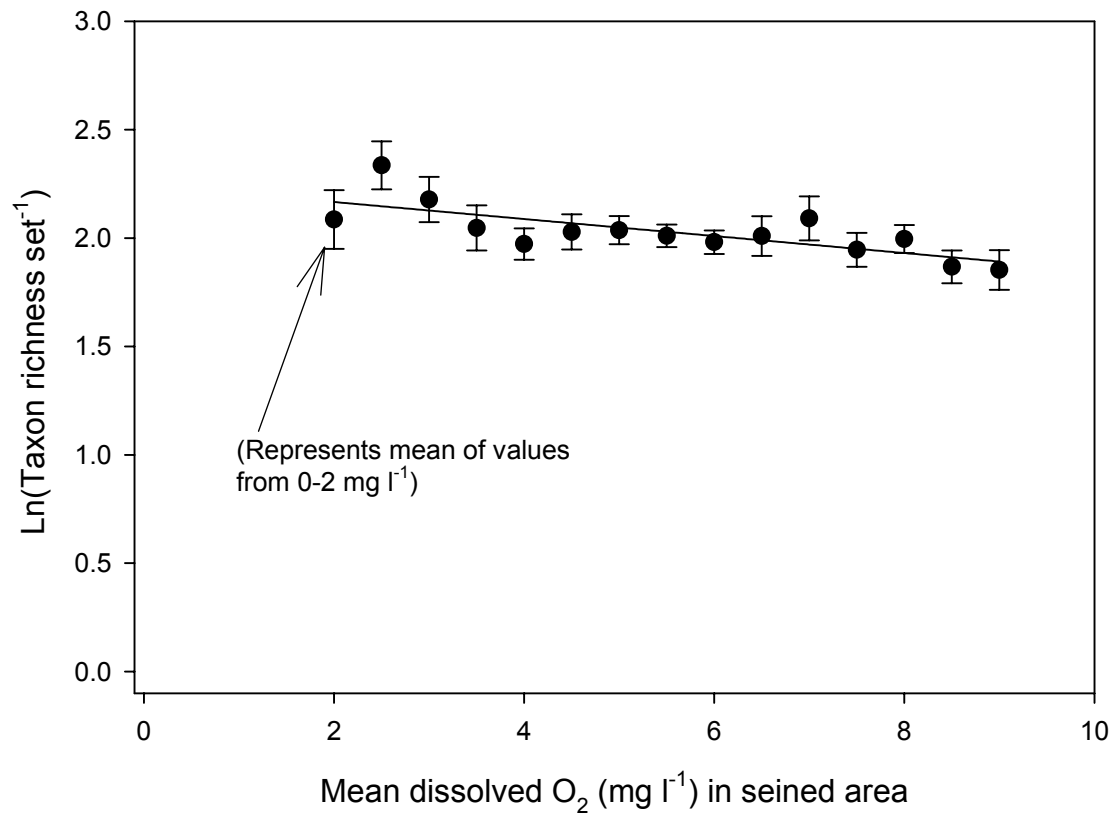


Fig. 3.10.8. Linear relationship between mean taxon richness in seines and dissolved oxygen in the Hillsborough River.

4.0

CONCLUSIONS

4.1

Descriptive Observations.

1.) **Dominant Catch.** The plankton-net fish catch was dominated by bay anchovy juveniles (*Anchoa mitchilli*) and postflexion stage gobies. Gobies of the genus *Gobiosoma* were the dominant gobies in the Hillsborough River, with *Microgobius* spp. being of secondary importance. Other abundant fishes were menhadens (*Brevoortia* spp.), skilletfish (*Gobiesox strumosus*), silversides (*Menidia* spp.), blennies (primarily *Chasmodes saburrae*) and the hogchoker (*Trinectes maculatus*).

The plankton-net invertebrate catch was dominated by larval crabs (decapod zoeae, primarily *Rhithropanopeus harrisi*), hydromedusae (primarily *Clytia* sp.), calanoid copepods (primarily *Acartia tonsa* and *Labidocera aestiva*), mysids (primarily *Americamysis almyra*), chaetognaths (*Sagitta tenuis* and *Ferosagitta hispida*), the freshwater cyclopoid copepod *Mesocyclops edax*, gammaridean amphipods, polychaete worms (primarily nereids), the parasitic isopod *Lironeca* sp., larval shrimps (primarily *Palaemonetes*) and dipteran insect larvae (esp. *Chaoborus punctipennis*).

Shoreline seine fish collections were dominated by bay anchovy, silversides, menhadens, eastern mosquitofish (*Gambusia holbrooki*), spot (*Leiostomus xanthurus*), rainwater killifish (*Lucania parva*), and striped mullet (*Mugil cephalus*). The trawl fish catch from the channel was mostly composed of spot, hogchoker, bay anchovy, sand seatrout (*Cynoscion arenarius*) and southern kingfish (*Menticirrhus americanus*). Invertebrates collected by seines were dominated by daggerblade grass shrimp (*Palaemonetes pugio*); invertebrate trawl catches primarily consisted of blue crab (*Callinectes sapidus*), daggerblade grass shrimp, and pink shrimp (*Farfantepenaeus duorarum*).

2.) **Use of Area as Spawning Habitat.** Fishes that spawned very near or within the tidal Hillsborough River, as indicated by the presence of eggs or early-stage larvae, were the bay anchovy, striped anchovy (*Anchoa hepsetus*), silversides, killifishes (*Fundulus* spp.), Florida blenny (*Chasmodes saburrae*), naked goby (*Gobiosoma bosc*),

code goby (*G. robustum*), green goby (*Microgobius thalassinus*), clown goby (*M. gulosus*) and the frillfin goby (*Bathygobius soporator*).

3.) **Use of Area as Nursery Habitat.** Estuarine-dependent taxa that use the tidal river as a nursery area are the numerical dominants in the Hillsborough River. Overall, seven of the ten most abundant taxa in the river channel and five of the ten most abundant taxa in nearshore habitats are estuarine-dependent. These include both offshore-spawning taxa (i.e., menhadens, spot, striped mullet, red drum [*Sciaenops ocellatus*], blue crab, pink shrimp, pinfish [*Lagodon rhomboides*]), and mojarras and estuarine spawning taxa (i.e., striped mojarra [*Diapterus plumieri*], sand seatrout, hogchoker, and bay anchovy). Using seine and trawl data, the juvenile nursery habitats for selected species were characterized in terms of preference for the shoreline or channel, type of shoreline, physical location (distance from the river mouth), and salinity (Appendices D & E).

4.) **Plankton Catch Seasonality.** Lowest richness in the plankton-net catch was observed from July through February. The abundances of many estuarine organisms decreased with the onset of the summer rainy season. Alteration of inflows would appear to have the lowest potential for estuarine impact during the period from November through February, which is the period when the fewest estuarine taxa are present in Tampa Bay waters. The highest potential for impacting most species would appear to be from April to June, a time of year when naturally low inflows are coupled with increasing use of the estuary as nursery habitat. The potential for impact is species-specific. During fall, winter, and early spring, for example, there could be impact on red drum and menhadens because these fishes recruit to tidal river nursery habitats during these times. Other species, such the bay anchovy, are present year-round.

5.) **Seine and Trawl Catch Seasonality.** The number of taxa collected by seine was generally highest from May through July and lowest in fall/winter (December/January). The pattern was less clear in the trawl data, but taxonomic

richness was generally highest in May. Thus the period from May to July seems to have the greatest potential for negative effects of anthropogenic change to the tidal river inflow. Offshore-spawning species (e.g., economically important species such as red drum, striped mullet, pink shrimp, and blue crab, and ecologically important taxa such as mojarras) generally had peaks in recruitment during late fall and winter, whereas estuarine spawners (e.g., economically important silver perch and sand seatrout, and ecologically important bay anchovy and hogchoker) and residents [e.g., economically important largemouth bass (*Micropterus salmoides*) and ecologically important killifishes] generally recruited from spring to early fall. As in Conclusion 4, there is no time of year when inflow reduction would not affect economically or ecologically important taxa.

6.) **Conditions Associated with Hypoxia.** Negative dissolved oxygen (DO) anomalies were strongest in the upper reaches of the tidal river. In a forward stepwise multiple regression that included depth, location (km from mouth), bottom pH and surface-to-bottom differences in salinity and temperature, pH was the first variable selected, explaining 58% of the variation in DO anomaly at the bottom. Because pH is indicative of CO₂ concentration, these results suggest that the benthic hypoxia in the upper part of the tidal Hillsborough River is primarily caused by high ratios of community respiration to primary production. Physical factors such as density stratification appear to play a secondary role.

7.) **Organism Responses to Hypoxia.** Organisms tended to avoid areas of hypoxia, with evidence - albeit weak evidence - of shoreline seine catches being marginally elevated in association with decreasing oxygen concentration in the adjacent channel habitat. Both relative abundance and taxon richness of organisms in the channel habitat decreased with decreasing oxygen concentration, particularly in hypoxic conditions (i.e., dissolved oxygen $\leq 2 \text{ mg l}^{-1}$). Hypoxia was rare in the nearshore habitat, so that no conclusions on the relationship of seine-caught species to low dissolved oxygen could be drawn.

4.2 Responses to Freshwater Inflow

1.) **Plankton Catch Distribution Responses.** Approximately half (49%) the 108 plankton-net taxa evaluated for distribution responses to freshwater inflow exhibited significant responses. All except two of these were negative responses, indicating that the predominant response to increased inflow was movement downstream. Although response lags ranged from 1 to 120 d, most were 10 d or less, and many were 5 d or less. The taxa with the most predictable distribution responses ($r^2 > 50\%$) were estuarine-dependent and estuarine-resident animals (i.e., they were not freshwater animals). Among the 51 negative relationships, the steeper slopes tended to have higher r^2 values and also tended to have larger intercepts. These results collectively suggest that the estuarine animals that penetrate far into the tidal river during low inflow periods respond to inflow increases in a stronger, more predictable manner than freshwater organisms below the dam or higher-salinity organisms near the river mouth. The planktonic hydromedusa *Clytia* sp. had the strongest distribution response to inflow.

2.) **Seine and Trawl Catch Distribution Responses.** Nearly one-third (32%) of the 69 taxon-size class combinations ('pseudo-species') evaluated for distributional responses to freshwater inflow exhibited significant responses. In all cases, taxa moved downstream with increasing inflow. Taxa resident within the tidal river responded most strongly to inflow averaged over medium to long-term lag periods (90–365 days). Distribution of taxa spawning within Tampa Bay tended to be most strongly associated with short inflow lags (0–14 days), whereas responses of offshore-spawning taxa were relatively evenly distributed over lagged inflow periods from 0–365 days.

3.) **Plankton Catch Abundance Responses.** Approximately half (51%) the 108 plankton-net taxa evaluated for abundance responses to freshwater inflow exhibited significant responses. These were largely split between freshwater taxa that were introduced by inflows (positive responses) and higher-salinity taxa that moved out of the river and into Hillsborough Bay during high inflow periods (negative responses).

The negative distribution responses of most estuarine-dependent juveniles (i.e.,

their movement into Hillsborough Bay during high inflows) reduced abundances in the Hillsborough River even though total numbers of these species in the river and bay may have been responding favorably to inflows. Hogchoker juveniles, on the other hand, remained in the river during relatively high inflow periods and tended to increase in number. As in other tidal rivers, hogchoker juveniles occurred farther upstream than other estuarine-dependent juvenile fishes. Hogchoker juveniles did not exhibit a measurable downstream movement in response to inflow, regardless of the data source used (plankton net, seine, or trawl). The positive abundance response by hogchoker juveniles was lagged by 47-d, which is comparable to the general age of these fish.

Freshwater inflow had a strong distributional effect on the hydromedusa *Clytia* sp. that resulted in a strong reduction in its abundance. Because hydromedusae compete with and consume the early stages of fishes, their rapid displacement downstream and away from tidal river nursery habitats can be considered to be a beneficial effect of increased inflow. When hydromedusa blooms were present, the biomass and diversity of the plankton community was usually strongly reduced. The inflow levels that reduce hydromedusa numbers are generally lower than the inflow levels that reduce fish abundance.

4.) **Seine and Trawl Catch Abundance Responses.** Among the 69 pseudo-species considered in the abundance response regressions for seine and trawl catch, abundances of 49% were significant. The most common response was decreased abundance with increased inflow, typified by a precipitous decline of high-salinity animals (e.g., striped anchovy) with higher inflows, although there were positive relationships to increased inflow in several resident and offshore-spawning taxa. Juvenile spot, for example, were quite rare at lower inflows but greatly increased in abundance with increased inflow, perhaps due to enhanced attraction by substances emanating from the tidal river and its watershed or improved density-driven transport mechanisms. Maximum or minimum abundance at intermediate levels of inflow was also seen in several residents and offshore spawners. The strongest abundance-inflow relationships incorporated longer lags for residents and shorter lags for estuarine spawners but were well distributed among lag periods for offshore spawners.

5.) **Seine and Trawl Catch Responses to Inflows <50 cfs.** Responses of stenohaline and euryhaline freshwater taxa to inflow in the upper reaches of the study area, above the confluence with Sulphur Springs, were similar: decreased inflow tended to lead to movement upstream, decreased abundance, and decreased taxon richness. Components of both freshwater taxon groups might be established below the dam with relatively small, consistent, long-term increases in inflow. In particular, inflows >20–30 cfs appeared important in increasing abundance and taxon richness. The establishment of a permanent freshwater zone below the dam would be beneficial to estuarine species even if a permanent freshwater community does not form. Many estuarine and marine species recruit to oligohaline waters during their juvenile life-history stages. Even in the highly altered Hillsborough River, economically important species (e.g., snook) utilize these low-salinity habitats when they are available. Compression of the oligohaline zone near the base of the dam may lead to crowding of species seeking low-salinity habitats.

Nekton community structure upstream of the confluence with Sulphur Springs underwent considerable change from July to September in 2000 and 2001, coincident with increased inflows caused by dam release. Upon reduction of flows in October, the community generally reverted to a structure more similar to that of July.

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