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**The Biscayne Bay Commercial Fisheries for
Pink Shrimp (*Farfantepenaeus duorarum*), 1986-2005, and
Relationship with Salinity and Freshwater Flow**

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ABSTRACT- The Biscayne Bay bait (1986-2005) and food (1989-2005) shrimp fisheries were examined based on dealer-reported individual vessel-trip landings data. During the 1980's and early 1990's, landings were consistent, the bait shrimp fishery harvesting more than the food shrimp fishery. The number of trips and landings increased during the late 1990's through 2002 in both fisheries, after which levels of both landings decreased. During this time the food fishery harvests reached and exceeded harvest levels of those from the bait fishery. Statistical models were developed for each fishery to explore the relationship of bay salinity or freshwater flow to shrimp catch-per-unit-effort (cpue), assumed to reflect relative abundance over time of the shrimp available to each fishery. Catch/trip and catch/hour from individual trip landings records were used as the dependent variables (i.e., cpue), and month, salinity or freshwater flow, and moon illumination on the night of the trip were used as the independent variables in initial models. In addition, monthly or cumulative bait shrimp landings were used in the food shrimp models to examine the possible influence of the bait shrimp fishery on the food shrimp fishery. Catch/trip and catch/h varied relatively little in the bait shrimp fishery compared to the food shrimp fishery. Within each fishery, catch/trip and catch/h were highly correlated and were similar predictors. Month and salinity were the significant predictors of bait shrimp cpue, while moon illumination was not an important variable. Bait shrimp cpue had a curvilinear relationship with bay salinity. Moon illumination was the most important model variable in the food shrimp model, followed, in order of importance, by salinity, month, and bait shrimp landings. Food shrimp cpue and landings showed a bimodal relationship with salinity. Examination of sizes of shrimp caught confirmed that each fishery exploited a different size group of shrimp. The bait shrimp fishery typically caught shrimp less than 19 mm CL, while the food shrimp fishery harvested shrimp greater than 19 mm CL. An analysis of monthly bait shrimp cpue in relation to shrimp density, as determined from throw-trap sampling over a 3-yr period, indicated a strong statistical relationship with the throw-trap data lagged by 3 months, supporting the use of bait shrimp cpue as an index of abundance. Establishing the validity of bait shrimp cpue as an index of shrimp abundance would extend back in time (to 1986) the time series of relative shrimp abundance for analysis in relation to environmental variables such as salinity that might be affected by changes in water management.

Introduction

Shrimp is the most important seafood item produced in the State of Florida in terms of pounds sold and dollar value (Bureau of Seafood and Aquaculture Marketing 2005). The estimated value of Florida shrimp was \$33,322,548 in 2004. Ninety-five percent of Florida-produced shrimp are caught in Florida estuarine and marine waters and 5% are produced through aquaculture. About 88% of the shrimp sold in the United States is imported, principally from China, India, Viet Nam, Brazil, Ecuador, and Thailand (Salveggi 2005). Both bait and food shrimp are harvested commercially from Biscayne Bay, a shallow subtropical lagoon located on the southeast coast of Florida adjacent to Miami (Fig. 1). The bay is 90 km long and is connected to the continental shelf waters of the Atlantic Ocean through a network of tidal inlets (Criales et al. 2000). The pink shrimp (*Farfantepenaeus duorarum*) is the principal shrimp species harvested (Tabb and Kenny 1968, Campos and Berkley 1986, Browder et al. 2003). Another species, the spotted pink shrimp (*Farfantepenaeus brasiliensis*) also is found in the bay (Criales et al. 2000) but appears inconsequential in trawl catches (Browder et al. 2003) and is not distinguished in landings data of the National Marine Fisheries Service or the State of Florida.

The origin of the postlarvae and juvenile pink shrimp population recruiting to Biscayne Bay is unclear, but it has been presumed that the postlarvae entering the bay originate from the Dry Tortugas population off southwest Florida and are brought to the east coast and Biscayne Bay via the Florida Current and the Tortugas Gyre (Criales et al. 2000). Transport mechanisms have been documented in the Florida Keys for recruitment into Florida Bay (Criales and Lee, 1995; Criales et al. 2003).

Two commercial shrimp fisheries operate in Biscayne Bay: a live bait fishery and a food shrimp fishery. Each shrimp fishery operates under a different set of regulations (Appendix Table 1) that were first established in 1959 by the Florida Fish and Wildlife Conservation Commission (FWC 2004a). Bait shrimp dealers began reporting bait landings in 1986, and statistics on food shrimp landings began being reported in 1989. Annual Biscayne Bay shrimp landings ranged from a low of 48,254 kg in 1993 to a high of 445,378 kg in 2003 (Fig. 2A, Table 1). Bait shrimp annual landings, estimated by converting reported numbers to pounds (numbers $\times$ 0.01), exceeded food shrimp landings in all but 5 years (1997-2000, 2002). Prior to 1997, food shrimp landings were small, $<50,000$ kg/yr. The annual number of bait shrimp trips still greatly exceeds the number of food shrimp trips (Fig. 2B). In contrast, the catch per trip was substantially greater for food shrimpers (87-322 kg/trip) than for bait shrimpers (27-43 kg/trip) (Fig. 2C).

This report describes the two fisheries and provides results of statistical analyses exploring the possible influence of water management on pink shrimp catch per unit of effort (cpue) in each fishery. Catch-per-unit-effort is frequently used in fisheries research as a rough index of stock abundance. Salinity has been shown to influence the behavior and abundance of pink shrimp. Bay salinities result from the interaction of fresh water with salt water.

Previous studies examining pink shrimp in relation to salinity pertain to pink shrimp of Florida Bay and the southwest Florida coast. Laboratory experiments by Hughes (1969a; 1969b) suggested that postlarvae and juvenile pink shrimp use tidal differences in salinity as cues to find their way in and out of nursery grounds. During an ebb tide, postlarvae drop to the bottom of the water column and become inactive in response to decreasing salinity, thus avoiding displacement out of the estuary; and during the flood tide (rising salinities), postlarvae reenter the water column and are carried into the estuary. In contrast, immigrating juvenile pink shrimp, which are positively rheotactic (swim into the current), will switch and swim downstream when they sense salinities are decreasing, thus ensuring that they will be moved out of the estuary by the ebb tide.

Statistical relationships between fishery landings and indices of freshwater flow to the southwest coast have been found. Browder (1985) observed a relationship between pink shrimp landings on the Tortugas grounds and water levels in Shark River Slough, which served as a proxy for freshwater outflow. Sheridan (1996) forecasted Dry Tortugas shrimp landings using models that included indices of fishing activity as well as variables characterizing hydrologic conditions upstream from Florida Bay and the Everglades estuaries, groundwater levels, rainfall, and surface water inflow to the Park.

Laboratory experiments have determined that growth and survival are influenced by salinity in interaction with temperature. Browder et al. (2002) found that optimal pink shrimp growth occurred at 30 psu. The survival response curve was broad and nearly flat between 20 psu and 40 psu, declining abruptly beyond the plateau, and showed a strong salinity-temperature relationship. A simulation model based on the relationships determined from experimental data suggested that juvenile production and potential harvests might differ among years, seasons, and regions of Florida Bay based solely on daily temperature and salinity.

Water management practices that influence salinity patterns may not only influence shrimp abundance through direct effects on survival and growth but also through effects on the quantity and quality of habitat. Various studies suggest that seagrass beds provide optimal habitat for pink shrimp. Water management practices might also influence shrimp abundance through effects on the immigration of postlarvae into Biscayne Bay from offshore grounds and their settlement in the bay. On the other hand, water management practices might change the vulnerability of shrimp to harvest by concentrating them in the areas most accessible to commercial bait shrimp trawlers or by stimulating their emigration from the bay through passes where they become vulnerable to the wing-nets used by food shrimp operators.

This report describes the two pink shrimp fisheries in Biscayne Bay and examines fishery cpue in relation to freshwater inflow from the canals discharging into south Biscayne Bay (Rickenbacker Causeway to Turkey Point) and in relation to average salinities of south Biscayne Bay, which are influenced by the canal discharges. Much of the area of south Biscayne Bay, including areas where the fisheries operate, is within the boundaries of Biscayne National Park (Fig. 1). Changes to the water management system

that controls the flow through the canals are planned as part of the Comprehensive Everglades Restoration Program (USACE and SFWMD 1999), and information about the fishery and the possible influence of freshwater inflow and salinity on fishery stocks is needed in order to evaluate the potential impact of changes and establish a baseline against which to compare results of future monitoring. The present report is part of a larger study that includes fishery-independent sampling of the density of pink shrimp and other epibenthic species in south Biscayne Bay.

Materials and Methods

Monthly Biscayne Bay commercial shrimp landings data for the period 1986 through 1996 were provided by Steve Brown of the Florida Fish and Wildlife Conservation Commission (FWC), and monthly landings for the period 1997 through June 2005 were obtained from Guy Davenport of NOAA Fisheries. Monthly throw-trap (2002-2005) data were provided by Michael Robblee (USGS). Salinity and flow data were obtained from South Florida Water Management District (SFWMD) website (2005) for the Biscayne Bay project, Richard Alleman (SFWMD), and Jiangang Luo (University of Miami). Moon illumination data came from the Astronomy Applications Dept., U.S. Naval Observatory website. Unpublished data sources are at the end of the document.

General linear modeling (GLM) was used to test the effects of month, salinity, freshwater flow, and moon illumination on bait and food shrimp landings. Salinity was tested using linear, 2nd-order ($Y \sim a + bx + cx^2$), and restricted cubic spline (knots=3) functions. Flow and salinity were tested alternately in the models, as they were inversely correlated with each other (i.e., the higher the flow, the lower the salinity) in a linear relationship ($r=0.538$). Both variables were tested because the flow data are known to have errors (Swain et al. 1997), and the salinity data provided was incomplete and variable in its coverage of the southern and southwestern bay (because monitoring stations vary in their coverage in time and space and sometimes are inoperative, causing coverage for periods of days or weeks to be missing). Monthly average salinity data, lagged by 1 to 3 months, and cumulative (i.e., summed) flows for one to three months were used alternatively in models in order to determine the best model. Average monthly salinities were calculated from stations for the entire southern bay (from Rickenbacker causeway to Turkey Point) and for only southwestern stations (sw) that were located on the bay side near the mainland where freshwater flow would be expected to have the greatest influence. Nightly moon illumination was linked to the dealer-reported catches for each date. The cpue was calculated alternatively as catch/trip or catch/hr. The alternative effort measures (i.e., trip and hour) were highly correlated in both fisheries ($r = 0.986$ and 0.995 for the bait and food shrimp fisheries, respectively). Details of the models, which vary somewhat by fishery, are given with the results.

The trip objectives of the two shrimp fisheries in Biscayne Bay vary substantially, which may influence results of these analyses. Bait shrimp operators fish to fill orders, so their catches per trip may be less variable than if they were based solely on the abundance of shrimp on the grounds. The food shrimp fishery operates for a relatively

short period of time each year and, within that time period, focuses effort on only certain nights when the shrimp are running. In other words, food shrimp operators fish to capture as much shrimp as possible while they can. There are other differences between the two fisheries that may be the basis for differences in our results.

The throw-trap gear is a fishery-independent gear that samples an area of 1 m^2 and, because of its high catch efficiency for small organisms such as shrimp, is an exceptionally reliable indicator of abundance. If a relationship were established between monthly shrimp throw-trap samples (1-3 month lagged) and bait shrimp landings, bait shrimp landings might also be used as an indicator of shrimp abundance and make it possible to extend back to 1986 analyses of shrimp abundance in relation to environmental variables. Therefore, we used GLM to examine the relationship of bait shrimp cpue to throw-trap density.

The Bait Shrimp Fishery

Description

The bait shrimp fishery supplies bait to the recreational fisheries of southeast Florida, and nightly catches are kept alive in live wells aboard the shrimp vessels. Bait shrimp harvests are related to the seasonal demands from tourism and levels of recreational fishing. Tabb and Kenny (1968) gave a history of the fishery and a description of the fishing gears and their evolution in the 1950's and 1960's. As of 1968, the otter trawl had virtually disappeared from the fishery and had been replaced with the roller-frame trawl. The roller-frame trawl was described by Tabb and Kenny (1968) as efficient to operate, catching shrimp with minimal trash (algae, sponges, water-logged coconuts and other by-catch) at low operating costs. According to Tabb and Kenny (1968), the trawl was designed to minimize contact with the bottom or vegetation, thus reducing damage to the root structure of seagrasses. Based on the analyses of 22 shrimp boat tows, they reported that the average composition of catch was 82% invertebrates, 9% fish, and 16% plant material. A later study suggested that the roller-frame trawl had a significant impact on sponges and hard and soft corals (Ault et al. 1997). The Ault et al. study estimated that the bait shrimp fishery swept the shallow (1.2-1.8 m) bottom habitats of South Biscayne Bay up to four times per year.

In studies conducted in the 1960's, Tabb and Kenny (1968) reported that bait shrimping was primarily restricted to the bay south of Rickenbacker Causeway. Heaviest shrimping was reported between Rickenbacker Causeway and Black Point Marina, principally over muddy sand bottoms with higher organic content. They reported that shrimping was prohibited near the mainland shoreline because these areas are known to be spotted-seatrout fishing grounds. However, in a recent sociological study by EDAW (2003), vessels were reported to trawl on the western side of the bay in the seagrasses relatively close to the mainland. Vessels are physically unable to operate in extremely shallow water, i.e., inside the 0.9-m depth contour along the shoreline. Tabb and Kenny (1968) reported that only moderate shrimping occurred in the southernmost part of

Biscayne Bay (south of Black Point Marina), which is shallower, with sparse to heavy seagrass, because shrimp found there were often too small for the market.

Bait shrimping is conducted nearly every night year-around, except under extreme weather conditions. The bait shrimp fishery operates on a nightly quota system where dealers place orders to the shrimpers for a certain number of shrimp to be delivered. Thus, when the shrimpers meet their nightly order, they may not necessarily continue fishing. They deliver their catch to dealers that meet them at the dock in trucks with oxygenated salt-water tanks that are used to transport the bait. Markets for the shrimp are bait and tackle stores that range from Key West to well north of Miami, and stores may buy from more than one fishing operation to hedge against a decrease in performance from any one operation (EDAW 2003).

Bait shrimp are usually sold by number rather than by weight. Pounds are approximated from numbers by multiplying by 0.01 (thus assuming 100 shrimp per lb) in the NOAA and FWC databases, and reported along with the original number units. Annual bait shrimp landings fluctuated in the 45,000-91,000 kg range from 1986 through 1995, doubled to around 180,000 kg from 1997 through 2002, then reverted back to the 91,000 range from 2003 into 2004 (landings for the first six months of 2005 were similar to 1993 landings) (Fig. 2A, Table 1). Miami-Dade County landings from 1963 through 1965 were of a similar magnitude (94,000-120,000 kg) as the late 1980's and early 1990's (Tabb 1968 after Joyce and Eldred 1966). Estimated value of landings ranged from \$665,000 in 1995 to \$1,236,000 in 2002 (Fig. 3A). The most recent complete annual landings (2004) were \$1,045,000.

Approximately 2,000 bait trips were conducted annually from 1986 through 1994 (Fig. 2B). Annual trips began increasing in 1995 to a high of 5,828 and 5,000 trips in 2000 and 2001, respectively. However, catch (pounds) per trip has remained relatively constant throughout the last 18 yr, suggesting that abundance has been relatively constant (Fig. 2C). Catch/h (Fig. 3B), rather than catch/trip, may be a more accurate estimate of cpue in this fishery because the length of each trip varies depending upon the magnitude of the order for bait (e.g., a dealer may request 1000 shrimp for delivery the following morning), as well as the catch rate.

Bait shrimp harvests have a seasonal component with highest numbers harvested per hour in the winter months, December-February (~900 shrimp/h), and lowest numbers in the summer months (<500 shrimp/h) (Fig. 4A). Highest harvests coincide with the peak winter tourist season when the demand for bait shrimp to support recreational fishing is greatest. The time series of catch/trip (Fig. 4B) has a similar seasonal and annual pattern.

The number of bait shrimp vessels operating in Biscayne Bay has ranged between 3 and 60 historically. Three bait shrimp boats worked Biscayne Bay during 1952-1953 (Siebenaler 1953), and 12 boats were reported to fish the bay year-around in 1958 (Tabb 1958). Forty-six vessels were fishing the bay in 1966 when bait shrimping was placed under a permit system (Tabb and Kenny 1968). There were still 46 vessels shrimping in

the bay in 1987 (Fig. 5A). The number of vessels increased to a high of 60 in 1988, and then plunged to a low of 23 in 1989. From that time, the annual number of active shrimp vessels has fluctuated between 24 and 40. There were 36 vessels in the Biscayne Bay bait shrimp fishery in 2004.

From 1986 through 1993, the annual number of bait shrimp trips ranged from 1,000 to 2,500 (Fig. 5B). The annual number of trips grew exponentially from 1994 through 2001 to around 6,000 then decreased to around 3,000 trips in 2003 and 2004. The increase in annual trips was due to an increased number of trips per vessel. Each vessel made around 50 trips per year from 1987 through 1989 (Fig. 5C), which suggests that more part-time operators were fishing at that time. The increase to 200 trips/yr between 1994 and 2001 suggests operating vessels were fishing full-time. The subsequent decline in 2003-2004 in number of annual trips per operator suggests that, again, more vessels are shrimping on a part-time basis. This observation differs, however, from EDAW (2003), who reported that most shrimpers were operating full time. Turnover is high in this fishery; only 12 permitted shrimpers that fished in 1997 were fishing in 2003, and only nine shrimpers were still fishing in 2004. The number of bait shrimp dealers has increased over time. During the period 1986 through 1991, there were 3-7 bait shrimp dealers in Miami-Dade County; while, from 1992 through 2004, there were 9-15 dealers (Fig. 6).

There may be several reasons for the recent decline in annual bait shrimp landings. High fuel costs and recently increased dockage fees, which increase the operating cost, may have contributed to the decrease in landings. Dockage fees at Dinner Key marina in Coconut Grove have recently tripled (personal communication, Samuel Quinland). Based on 2004 landings data and dockage/dealer location information (Pamela Eyo, NOAA port agent, personal communication), we determined that 65% of the Biscayne Bay bait shrimp were landed at Dinner Key, 3% at Virginia Key (both in the central bay), and 33% from the south Miami-Dade part of the county, where vessels can be found at Black Point Marina. We determined that 16 vessels landed bait shrimp at the Black Point/South Dade Area, 18 vessels landed at Dinner Key, and two vessels landed on Virginia Key. This differs from EDAW (2003), who reported that the largest concentration of vessels (12-13) worked out of Black Point Marina. Regardless, increased dockage fees at Dinner Key must have heavily impacted the bait shrimp fleet. There may also be less demand for live bait shrimp due to increased use of artificial lures or imported frozen bait shrimp.

Table 2 shows the monthly shrimp/trip from our data, which comes from shrimp dealers, and shrimp/trip estimated for 1984-1985 by Campos and Berkeley (1986). The number of shrimp caught per trip is similar between the two data sets, but the number of trips varies between the dealer-based data and that estimated by Campos and Berkeley. Table 3 shows the annual number of trips for the two data sets. Campos and Berkeley estimated 1984-1985 trips by counting vessels at landing sites. Their trip numbers are much higher than that reported by dealers (which should have all of the trips) in adjacent years (1986-1987), or average years (1988-2004). (Information for 1984-1985 was not available from dealers.) The Campos and Berkeley trip estimates were expanded from

sub-sampling conducted at landing areas; the monthly number of days sampled was 3-14 d/mo at Dinner Key, 2-23 d/mo at Black Point, and 3-14 d/mo at Virginia Key (mean effort for March-July was used to estimate December-February effort). The estimated total landings for 1984-1985 from Campos and Berkley are 1.9 times the dealer-reported landings of 1987 and 2.3 times the average dealer-reported landings for 1986-2004 (Table 4). If the Campos and Berkley landings estimates are inaccurately high, then their Biscayne Bay fishing mortality rates also are overestimated. Campos and Berkeley (1986) estimated that fishing mortality from the bait shrimp fishery during 1984-85 represented 8-9% of the total mortality of the population and considered the impact of the bait shrimp fishery on the local stock relatively small. They estimated annual total mortality (fishing and ecosystem) at 23% for males and 26% for females.

No data were available from the bait fishery for size of shrimp harvested. In a fisheries independent study using a shrimp trawl, we found that 86% of the shrimp were <19 mm CL (Fig. 7) (Browder, unpublished data.). Shrimp caught in the shrimp trawl ranged from 4 to 43 mm CL, although shrimp smaller than 9 mm CL or larger than 24 mm CL were rare. Ninety-three percent were 10-22 mm CL.

Analysis

Two sets of models were developed for the bait shrimp fishery. The first set of models examined individual trip landings and effort as reported from the dealer. The second set of models used compiled monthly landings and effort data. Catch-per-unit-effort models based on individual trip data were developed using either number/trip or number/hour as the dependent variable with month, moon illumination fraction on the day of the landing, and either salinity or freshwater flow as the independent variables. Monthly models were developed using total monthly landings as the dependent variable and total trips or total hours and month and salinity as the independent variables. Both sets of models were developed with and without log transformation of the dependent variables. Alternative models were constructed assuming linearity, a parabolic relationship (2nd order equation), and a cubic spline function.

Fig. 8 shows the 1986-2004 monthly flows for southern Biscayne Bay (Rickenbacker Causeway to Black Point Marina) and the southwestern part of the bay (sw), which is most subject to freshwater influence. Station contributions to annual flow are provided in Appendix Table 2. Average monthly salinity and lagged salinities (1-3 mo) were tested in the models. Table 5 shows a correlation matrix of the salinity and flow variables. The highest correlation was between the monthly southern bay salinity and the monthly southwestern bay salinity and the corresponding one month lag, $r=0.834$ and $r=0.833$, respectively. The highest correlation between salinity and flow was 0.515. Salinity was most closely correlated with the cumulative flow of the same month, rather than with the cumulative flows of previous months. Monthly flow and cumulative flow (1-3 mo) were tested alternatively with salinity.

Fig. 9A shows a density plot of the number of trips associated with the fraction of the moon illumination. Higher effort was associated with the full and new moon phases (1 and 0 respectively). However, mean landings (mean catch per trip) were not significantly higher ($p>0.05$) during these moon phases (Fig. 9B).

Model results are presented in Table 6. Table 7 shows, for the best model, the unique variance explained by each variable, calculated from the change in r^2 resulting from deleting one variable at a time. Monthly models had a higher r^2 than the per trip models. There was little difference in r^2 or p-value among models within types of models. All models were significant with a p-value of 1×10^{-16} . Month, salinity or freshwater flow, were significant in the models ($p<0.0001$). Salinity was a better predictor than flow in the models. Even so, salinity uniquely explained a relatively small proportion of variance in cpue. Month was the most important model variable in the per-trip models, while number of trips was the most important variable in the monthly models. Moon illumination was significant in some of the per-trip models, but it contributed so little that the r^2 of the models containing it was actually lower, so it was removed from the final selected models. The log-transformed model performed better than the untransformed in the catch-per-trip models, but the reverse was true for the monthly models. The best monthly models were the models containing either 3-mo-lagged bay salinity or 3-mo-lagged sw bay salinity with no log transformation. The monthly models had an r^2 between 0.861 and 0.882. The best cpue model was the cubic spline no./h model with 3-mo-lagged salinity (model $r^2=0.1335$). Nearly all log-transformed cpue models had $r^2=0.120-0.134$, whether using salinity or flow (Table 6). Both catch/h and catch/trip were correlated with salinity or freshwater flow, although the models with salinity were better than the models using flow. Neither lagging the independent variables (salinity and flow) nor changing the form of the model (cubic smoothing spline or adding a 2nd-order term) made a significant difference in the model r^2 or changed the model's significance. The majority of models using salinity suggested a bimodal relationship between cpue and salinity, especially those with the 2-3 mo lags with a dip in predicted cpue at around 33 psu. There was an exponential relationship with 1-mo-lagged salinity (previous month's salinity). Models using salinity from the entire southern bay stations gave similar results to those using salinity from only the western bay stations. Fig. 10 shows the predicted cpue in relation to month and 1-3 mo-lagged sw salinity using per-trip data adjusted by hours fished. Catch/trip and catch/h were negatively related to all lagged flows. Highest cpue was in January and February and lowest was in July.

We expected that using reported hourly effort instead of trip effort would improve the models, but little improvement was gained by using hours of effort. Hours of effort, at best, represent the hours of the trip, not the hours actually spent in trawling. Trip time includes time spent running to and from port and between fishing sites and time spent clearing the net, and these periods vary because of several factors, the more important of which may be the distance between the port and the fishing area, the amount of shrimp caught, and the magnitude of the incidental caught. Reported hours of effort are not only imprecise but probably also inaccurate. The average reported trip was 7.9 hr, and 61% of the records had a reported fishing time of 8 hr, suggesting that 8 hrs was a standard

response, regardless of actual time spent on the trip. Reported trips fished and hours fished, summed by year and month, were highly correlated ($r=0.973$), which suggests they are similar indices of effort.

The number of trips was the most important variable in the monthly models. Fig. 11A shows the predicted landings for month, number of trips, and 3-mo-lagged salinity. Like the cpue model, the monthly landings model also predicted a dip at around 33 psu. Monthly models with the 1- and 2-mo-lagged salinity also suggested this relationship although the relationship to salinity from the 1-mo-lag model was flatter.

The higher r^2 of the monthly landings models compared to the individual cpue models was due to inclusion, in the monthly landings models, of effort as an explaining variable rather than as the denominator of the dependent variable. Most of the explained variance in monthly landings (0.5914 of total variance) was explained uniquely by the number of trips (Table 7). The variance in the dependent variable explained by month and salinity was slightly more for month (0.1269 vs. 0.0759) and slightly less for salinity (0.0033 vs. 0.0064) in the landings model compared to the cpue model (Table 7).

An analysis was conducted to compare monthly average bait shrimp cpue to average monthly throw-trap catch per square meter, a fishery-independent index of abundance of younger shrimp in the bay. This analysis was conducted because interviews with bait shrimp fishermen had suggested that the amount of shrimp landed on a trip was fixed in advance by the order placed by the dealer, which raised the question of whether cpue in the bait shrimp fishery was a valid estimate of abundance. Monthly average bait shrimp cpue was significantly related ($r^2=0.38$; $p=0.0108$) to 3-mo-lagged average throw-trap catch per square meter (Fig. 12). Three years of bi-monthly throw-trap data (Oct. 2002-Oct-2005) were paired with 18 months of 3-mo-forward bait shrimp cpue to perform the analysis. No significant relationship was found with current, 1-, or 2-mo-lagged throw-trap catches. The statistically significant relationship between bait shrimp cpue and the fishery-independent abundance index 3-mo-prior suggests that bait shrimp cpue can appropriately be used as an index of abundance. It will be especially useful for application to past years for which there is no throw-trap data. These results also suggest that, contrary to what the fishermen said in interviews, vessel operators continue to fish when catch rates are high and are able to sell the excess catch to dealers.

The Food Shrimp Fishery

Description

Food shrimpers use wing-net gear, collecting shrimp in the upper part of the water column and operating in or near passes, where the tidal current is strong. Effort is highest around the full moon when shrimp are concentrated at the surface. Aaron and Wisby (1964) reported that maximum photo-activation (attraction to light) of pink shrimp occurred during the full moon. EDAW (2003) reported on the fishery based on interviews with Biscayne Bay shrimpers in an ethnographic study of Miami. They

reported that food shrimpers work areas around estuaries, canals, and bridges, and that the best time for shrimping is during strong winds, especially northerners, because shrimp leave the bottom and move up into the water column. They reported that shrimpers use skiffs, 7.6-9.1 m long, which are launched from trailers and powered by outboard motors. Wing-netters do not and cannot net in waters shallower than 1.2-1.8 m, which separates them from the grounds used by bait shrimpers. According to EDAW (2003), most of the food shrimpers operate in the middle and upper portion of Biscayne Bay from the Venetian Causeway to the Rickenbacker Causeway, launching at Crandon Park marina and other places north of Biscayne National Park (BNP). BNP is not fished as it is too far south of their base of operations, although some may use the northern edge. The majority of the catch is sold to wholesale fish houses that ship it to fish markets around the country.

FWC (2004b, 2005) provides a history of Florida regulations governing the shrimp fishery. A "count" law, first initiated in the 1950's, was revised in 1992 to regulate the minimum size for legally harvested food shrimp at 47 shrimp/lb, heads-on, or 70 tails/lb, heads-off. The count law was terminated in 1998 and replaced with seasonal closures and a Saturday harvest restriction. Current regulations (FWC 2005), which were established in December 2000, limit the wing-net fishery to October 15- May 15 and prohibit fishing from 6:00 am Saturday to 6:00 am Sunday (the latter to minimize interactions with the recreational shrimp fishery. See Appendix Table 1 for a summary of State of Florida regulations affecting commercial shrimp fishing in Biscayne Bay.

Landings statistics for Biscayne Bay food shrimp began in 1989 (Fig. 13A, Table 1). Landings were under 50,000 kg/yr from 1989-1995. Landings during the period 1997 through 1999 grew to over 180,000, and 2000 landings jumped to over 250,000 kg. Total landings declined after 2000, fluctuating between 14,000-181,000 kg. Similar trends were found in landings for the high season (December-May) only, except that 2002 was higher and 2003 lower (Fig. 13B). Highest landings were in Jan and Feb (Fig. 14A). The annual value of landings (Fig. 14B) showed a similar trend. The annual number of food shrimp trips increased exponentially from 1994 through 1998, remained high from 1998 through 2002, plunged in 2003, and then increased in 2004 to 1995-1996 levels (Fig. 15A, Table 8). Landings during the first 6 mos of 2005 were high; suggesting 2005 will also be at least a moderately high year. The increase in trips was likely due to an increased number of vessels, as number of trips and number of vessels had similar year-to-year patterns (Fig. 15B). The annual average number of trips per vessel was low (1-8 trips/yr), suggesting either that part-time operators dominate the food shrimp fishery or that the majority of Biscayne Bay food shrimp operators fish for shrimp only sporadically (Fig. 16A). The maximum annual number of trips per vessel was 3 to 84, which indicates that fishing is not a fulltime activity even during the 7 mo that shrimping with the wing-net is allowed (Fig. 16B).

The number of food shrimp dealers rose exponentially from 1989 through 1997 and then slowly declined, although current levels are in the range of 1995 levels (Fig. 17A). EDAW (2003) reported that the Wingnet Shrimpers of Florida, an organization

that was formed around 1998, was attempting to set up a cooperative to distribute the catch (cutting out the middle man).

The price that vessels received for shrimp in 2005 is lower than the price in 2001, despite rising costs of fuel and other operating expenses. The average annual price per pound fluctuated between \$1-2/lb (Fig. 17B). Highest average annual price was in 2001, \$1.85/lb. Average annual prices in 2004-2005 (\$1.12-1.20/lb) were closer to that in 1992 (\$1.05) in spite of rising costs of fuel and operating costs. The value of total U.S. shrimp harvests has decreased more than 50% between 2000 and 2002, mainly due to competition from low-cost imported shrimp that are produced through aquaculture (Salveggi, 2005). The decline in landings is probably related to the reduced number of annual trips. Reduced sales to local seafood dealers and distribution to other sources, that would pay higher prices but may not report landings as coming from Miami-Dade County (i.e. dealers in other counties, roadside selling, etc), may also play a role.

The food shrimp fishery, in terms of effort, has increased dramatically, but the increase in effort has been accompanied by a decrease in cpue. Catch (kg/trip) of food shrimp was highest in 1989 when shrimping effort (number of fishing trips) was lowest (18 trips for the year, Table 8, Fig. 18A, Fig. 14A). The high cpue in February 1989 was largely responsible for the exceptionally high annual catch that year (Table 9). When February was removed from the calculations, the annual catch/trip for 1989 was equal to the annual mean of all of the years. Annual landings/trip were 91-318 kg or 45-272 kg in the high season. Patterns of high season cpue were similar to annual cpue, as the majority of the landings occurred in the high season (Fig. 18 B). The highest monthly kg/trip recorded was not during the high season but in the summertime (July-September); however, this was based on just a few monthly trips that may have skewed the data (Table 8). The general pattern in annual landings/h was similar with the exception that cpue was lowest in August, although July was still high (Fig. 19 A and B). The number of trips and the number of hours fished were highly correlated, $r^2=0.991$. The average trip length was 6.6 h, and 52% of the samples had a reported fishing time of 6-8 h. The majority of years (especially recently) did not have summer landings due to regulations, although total summer landings for years with summer data were low compared to high season landings (Appendix Table 1). Nevertheless, landings/trip was sometimes high in the summer when overall effort was low. Fishing activity is highest on nights near the full moon (Fig. 20), when more wing-net vessels are operating in the bay.

Shrimp count data (no/lb) were used to approximate size of harvest (carapace length) using unpublished tables developed by Victor Restrepo (personal communication, ICCAT, Madrid, Spain). Ninety-six percent of the food shrimp harvested in Biscayne Bay were greater than 19 mm CL (Fig. 21). Harvested sizes were 19-37.8 mm CL. Ninety-three percent were 19-26.9 mm CL.

Analysis

The best per-trip model for the food shrimp was the log (shrimp/h) ~ month + spline (2-mo-lagged salinity, 4 knots) + spline (2-mo-cumulative bait shrimp landings, 4

knots) + spline(moon illumination, 4 knots) (Fig. 22A). All of the model independent variables were significant at $p < 0.0001$. Moon illumination was the most important model variable, followed, in order of importance, by salinity, month, and bait shrimp landings. Salinity for the whole bay was a better predictor than the salinity of the western bay. Flow did not perform as well as salinity in the models. All of the food shrimp models were significant with a p-value of 1×10^{-16} (Table 10), but all of these models had relatively low r^2 values, the best being 0.0864, which suggests that factors other than the model variables are influencing food shrimp landings.

Like the bait shrimp models, both kg/trip and kg/h models showed a bimodal relationship of cpue with salinity (i.e., inverted parabola). Most of the relationships with salinity, regardless of lag, showed this distinct pattern. Both mean and median plots of the raw data in relation to salinity showed this same pattern. The dip in predicted food shrimp cpue occurred around 29 psu (compared to the dip at 33 psu in the relationship of bait shrimp cpue to salinity), and a slight increase in cpue occurred at 33 psu. Monthly Biscayne Bay food shrimp landings were positively correlated with bait shrimp landings. Highest model-predicted catches were in February, and the lowest were in July. Summarized raw data (Table 9) indicated high catch rates in the summer, but this was based on a small number of summer trips, and there was high variance in summer catches (the wing-net fishery has been closed during the summer during the most recent years of the record).

In analyses using only high season data (December-May), the kg/trip model performed better than the kg/h model. The best high season model had a slightly higher r^2 (0.0912 vs. 0.0864) than the all-months model. Predicted relationships from the high season model were similar to that from the all-months model, and salinity showed a similar bimodal pattern (Fig. 22B).

Monthly bait shrimp landings were highly correlated with monthly food shrimp effort (Fig. 23A and B), whether effort was expressed as monthly hours or monthly trips ($r^2 = 0.96$ for both). The relationship between the two fisheries was positive, suggesting that they are not in direct competition with each other. Because of the correlation with food shrimp effort, monthly bait shrimp landings were not included in the monthly landings model. Month was also excluded from the final monthly food shrimp landings model.

The final monthly landings model was $\text{kg/mo} \sim \text{mo effort in hours} + \text{spline}(\text{salinity}, 4 \text{ knots})$ where the best salinity variable was the 2-mo lagged bay salinity (Fig. 24). Monthly models had a high $r^2 = 0.86$ (Table 10). Like in the cpue models, landings showed a bimodal relationship with salinity. The dip was at 30 psu (in contrast to 29 psu in the food cpue models). Fig. 25 shows a plot of the raw data for bait shrimp landings and food shrimp effort.

Summary

Salinity was a significant factor in models describing variation in the catch per unit effort of the Biscayne Bay bait shrimp and food shrimp fisheries. Salinity uniquely explained about 5% of the explained variation in bait shrimp cpue (no./trip) but 47% and 38% of explained variation in food shrimp cpue (kg/h and kg/trip, respectively). On the other hand, only 13.4% of total variance in bait shrimp cpue (no./trip) and 8.6% and 9.1% of total variance in food shrimp cpue (kg/h and kg/trip, respectively) was explained by the full models. Month was another significant explaining factor in the bait shrimp and food shrimp models. Moon illumination fraction was another significant explaining factor in the food shrimp model. Other, unexplored factors appear to be the main determinants of cpue in the Biscayne Bay shrimp fisheries.

The inverse parabola or bimodality evident in all model-predicted relationships of cpue or landings with salinity is peculiar. That this type of relationship was apparent in predictions from all of the models, both for bait shrimp and for food shrimp, both for individual cpue and for monthly landings, suggests that the relationship is not an artifact but a real phenomenon. There are several factors that might explain it: for example, distribution shifts within the bay in relation to large-scale changes in salinity patterns; the movements of shrimp in relation to seasonal or ontogenetic cues; or simultaneous predation pressure from both stenohaline and euryhaline predators, which might occur at medium salinities (e.g., 29-33 psu). That any one or all of these factors is operating here is only conjecture.

Had there been a significant negative relationship between food shrimp and salinity, it might not have been possible to determine whether it reflected a negative influence of salinity on abundance (a positive influence of freshwater inflow on abundance) or indicated that shrimp were being driven out of the bay by reduced salinity, becoming more vulnerable to wing-net fishing at the passes leading out of the bay. The bimodal relationship between food shrimp cpue and salinity does not support the hypothesis that decreased salinity drives food shrimp into the passes where they can be more readily caught in the wing-net fishery.

Catch-per-unit-effort in the two fisheries varies from year to year, possibly reflecting variation in the abundance of shrimp in the bay. Our analysis in which monthly average bait shrimp cpue was significantly ($p=0.0108$) related to a 3-mo-prior fishery-independent index of abundance suggests that bait shrimp cpue is a valid index of juvenile abundance.

The level of exploitation, especially of food shrimp, increased substantially in the latter half of the 1990's, although recent harvests, especially of bait shrimp, have declined to previous levels. Declines in landings in both fisheries in recent years are probably partially caused by economic factors that have stabilized or decreased the price paid for harvests while costs (fuel and operating costs (i.e. dockage fees, cost of nets, etc.) have increased. This has resulted in reduced fishing effort in both fisheries.

The shrimp harvested as food shrimp were larger than those harvested as bait shrimp. Although there was some overlap of size in the shrimp harvested by the two Biscayne Bay shrimp fisheries, 96% percent of the food shrimp harvested were greater than 19 mm CL (based on landings data), whereas 86% of the shrimp caught in a commercial bait shrimp trawl used in a fisheries independent survey (October 2002-February 2004) (Browder, unpublished data) were under 19 mm CL. Therefore, the wing-net fishery is catching shrimp that were not caught in the bait shrimp fishery during an earlier life stage. Nevertheless, according to our model predictions, food shrimp cpue increases with bait shrimp landings of the previous month over most of the range of bait shrimp landings. The shape of the curve suggests some effect of bait shrimp catches on food shrimp cpue in the mid-range of bait shrimp landings.

Due to the economics of fishing, small shrimp may experience less fishing pressure from trawling operations when they occur in low abundance than when they are abundant. On the other hand, when they are exceptionally abundant, available fishing capacity may not be sufficient to take full advantage of the excess. This might explain why food shrimp operations might not experience any effect of bait shrimp catches on their cpue except in the mid-range of bait shrimp landings and small shrimp abundance.

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Table 1. Number of pounds of bait and food shrimp harvested in Florida Bay (bait shrimp numbers converted to pounds using 0.01 conversion). Bait shrimp data are missing for November 1989. 2005 landings are for only the first six months.

Year	Total landings Pounds	Total landings Kg	Bait landings Pounds	Bait landings Kg	Percent bait	Food landings Pounds	Food landings Kg	Percent food
1986			187,875	85,219				
1987			157,159	71,287				
1988			174,596	79,196				
1989	162,463	73,693	149,702	67,904	92.1	12,761	5,788	7.9
1990	106,380	48,253	94,099	42,683	88.5	12,281	5,571	11.5
1991	174,051	78,949	133,060	60,355	76.4	40,991	18,593	23.6
1992	165,644	75,136	129,671	58,818	78.3	35,974	16,318	21.7
1993	188,549	85,525	123,714	56,116	65.6	64,836	29,409	34.4
1994	223,276	101,277	178,865	81,133	80.1	44,411	20,145	19.9
1995	274,919	124,703	212,453	96,368	77.3	62,466	28,334	22.7
1996	419,919	190,474	260,408	118,120	62.0	159,511	72,354	38.0
1997	711,057	322,533	337,863	153,254	47.5	373,194	169,280	52.5
1998	732,453	332,239	351,328	159,362	48.0	381,125	172,877	52.0
1999	732,444	332,234	359,831	163,218	49.1	372,613	169,016	50.9
2000	981,880	445,378	353,940	160,546	36.0	627,940	284,832	64.0
2001	581,172	263,618	353,657	160,418	60.9	227,515	103,200	39.1
2002	720,974	327,032	332,939	151,020	46.2	388,035	176,012	53.8
2003	222,994	101,149	190,343	86,339	85.4	32,651	14,810	14.6
2004	440,116	199,635	240,228	108,967	54.6	199,888	90,669	45.4
2005	558,762	327,032	117,204	53,164	25.5	344,558	154,930	74.5

Table 2. Average number of bait shrimp per trip by month and year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	Average	Source
1984									6385	5936	7162	7476	6740	Campos and Berkeley 1986
1985	9194	8224	7442	6248	5436	5752	5410	6759					6808	Campos and Berkeley 1986
1986	15148	9674	8079	7850	7179	6944	5532	4637	4927	5468	7050	7095	7130	Dealer-reported
1987	7643	8090	8218	9942	8508	5622	5048	5177	6486	7393	9287	10308	7633	Dealer-reported
1988	12290	10734	10107	10441	9972	7018	6182	7911	8655	8539	8146	11039	9387	Dealer-reported
1989	12390	10358	9145	7997	5419	6833	7629	6262	6309	7247		7244	8010	Dealer-reported
1990	7784	9199	8306	8018	7168	7993	4528	6953	7090	9078	9477	12462	7914	Dealer-reported
1991	9728	7563	5979	6634	6020	4041	4953	5075	5798	5818	7268	8512	6577	Dealer-reported
1992	11403	8995	6574	7382	7055	6783	5077	5998	7776	7879	7244	11389	7718	Dealer-reported
1993	9306	8058	7417	8284	7389	5887	6708	6562	6237	5222	6605	10389	7381	Dealer-reported
1994	9309	9722	7949	7289	5877	6219	5790	5588	5400	5349	6836	6415	6717	Dealer-reported
1995	7827	7973	7304	7734	6837	4742	2811	4211	5593	5909	6947	7532	6584	Dealer-reported
1996	8517	9328	7783	7172	5740	5242	2401	4076	5374	5798	6821	8123	6641	Dealer-reported
1997	9735	8823	8009	7175	6990	4440	4867	4013	3915	5665	7367	8348	7035	Dealer-reported
1998	10119	9043	8700	7930	5670	3594	3860	5313	5604	5568	6193	6557	6601	Dealer-reported
1999	8141	9177	8548	7013	6007	5398	4527	4794	4445	5564	6722	7619	6534	Dealer-reported
2000	8679	8973	8282	7151	5660	4584	5160	4320	3751	5073	5575	5656	6066	Dealer-reported
2001	6025	6769	6615	6331	5870	4549	4856	5689	5285	5533	6648	7569	5989	Dealer-reported
2002	9570	8449	8000	6838	5945	4908	2994	3862	4565	4284	4753	5871	5935	Dealer-reported
2003	6181	6321	4984	5804	5785	2639	2478	4316	4297	5159	5772	7331	5329	Dealer-reported
2004	8701	9617	8556	8094	6522	4887	7596	6933	5932	7251	8110	9599	7794	Dealer-reported
2005	10093	8599	8439	7209	5622	4246							7368	Dealer-reported
Average	9418	8747	7830	7549	6508	5349	4920	5422	5691	6187	7052	8327	6995	

Table 3. Number of bait shrimp trips by year and month.

Year	1	2	3	4	5	6	7	8	9	10	11	12	Annual trips	Source
1984												484		Campos and Berkeley 1986
1985	614	577	558	444	549	465	518							Campos and Berkeley 1986
1984-1985													4209	Campos and Berkeley 1986 8-month estimate
1986	132	219	239	215	222	210	264	254	231	233	221	198	2638	Dealer-reported
1987	228	227	174	171	154	169	157	184	146	145	148	156	2059	Dealer-reported
1988	157	185	219	177	145	149	154	146	119	114	130	165	1860	Dealer-reported
1989	218	160	165	170	160	123	151	170	192	116		244	1869	Dealer-reported
1990	164	142	90	136	95	76	123	100	75	51	86	52	1190	Dealer-reported
1991	127	208	141	186	166	135	147	151	158	143	234	227	2023	Dealer-reported
1992	131	214	155	187	113	115	245	84	29	117	151	139	1680	Dealer-reported
1993	171	120	149	138	164	92	112	205	115	127	160	123	1676	Dealer-reported
1994	195	194	212	237	282	255	243	188	240	237	168	212	2663	Dealer-reported
1995	249	216	302	293	315	244	114	162	279	305	355	393	3227	Dealer-reported
1996	334	406	331	318	427	455	159	257	271	257	303	403	3921	Dealer-reported
1997	441	475	608	526	511	341	116	235	311	390	451	396	4801	Dealer-reported
1998	446	465	509	516	539	432	435	437	318	377	434	411	5319	Dealer-reported
1999	466	462	520	521	512	496	522	445	391	343	397	428	5503	Dealer-reported
2000	494	461	426	496	595	481	519	471	410	467	481	527	5828	Dealer-reported
2001	575	532	616	546	547	519	505	500	376	348	404	432	5900	Dealer-reported
2002	525	474	526	485	533	491	472	476	448	406	372	397	5605	Dealer-reported
2003	495	443	476	357	341	306	177	142	129	219	223	260	3568	Dealer-reported
2004	260	397	379	377	319	277	65	251	147	185	209	215	3081	Dealer-reported
2005	242	211	314	362	349	57								Dealer-reported
Average 1986-2005	303	311	328	321	324	271	246	256	231	241	274	283	3390*	

* Average landings 1986-2004.

Table 4. Annual bait shrimp landings (number of shrimp) by year.

Year landed	Annual number of shrimp landed	Source
1984-1985	43,257,537	estimated by Campos and Berkeley 1986
1986	18,787,450	Dealer-reported
1987	15,715,860	Dealer-reported
1988	17,459,552	Dealer-reported
1989	14,970,150	Dealer-reported
1990	9,409,850	Dealer-reported
1991	13,305,970	Dealer-reported
1992	12,967,070	Dealer-reported
1993	12,371,376	Dealer-reported
1994	17,886,520	Dealer-reported
1995	21,245,345	Dealer-reported
1996	26,040,797	Dealer-reported
1997	33,776,375	Dealer-reported
1998	35,111,873	Dealer-reported
1999	35,957,832	Dealer-reported
2000	35,353,643	Dealer-reported
2001	35,334,001	Dealer-reported
2002	33,266,802	Dealer-reported
2003	19,013,470	Dealer-reported
2004	24,014,800	Dealer-reported
mean (1986-2004)	22,736,249	Dealer-reported

Table 5. Correlation matrix for salinity and flow variables.

	South Bay salinity	South Bay salinity 1month lag	South Bay salinity 2 month lag	South Bay salinity 3 month lag	Southwest Bay salinity	Southwest Bay salinity 1 month lag	Southwest Bay salinity 2 month lag	Southwest Bay salinity 3 month lag	Flow 1 month cumulative	Flow 2 month cumulative	Flow 3 month cumulative
South Bay salinity	1.000	0.511	0.359	0.236	0.834	0.440	0.252	0.134	-0.515	-0.350	-0.072
South Bay salinity 1month lag	0.511	1.000	0.508	0.358	0.453	0.833	0.437	0.254	-0.445	-0.515	-0.075
South Bay salinity 2 month lag	0.359	0.508	1.000	0.505	0.290	0.451	0.832	0.436	-0.216	-0.467	-0.100
South Bay salinity 3 month lag	0.236	0.358	0.505	1.000	0.162	0.292	0.448	0.832	-0.141	-0.220	-0.048
Southwest Bay salinity	0.834	0.453	0.290	0.162	1.000	0.494	0.344	0.132	-0.462	-0.290	0.089
Southwest Bay salinity 1 month lag	0.440	0.833	0.451	0.292	0.494	1.000	0.493	0.347	-0.408	-0.457	0.099
Southwest Bay salinity 2 month lag	0.252	0.437	0.832	0.448	0.344	0.493	1.000	0.492	-0.121	-0.426	0.072
Southwest Bay salinity 3 month lag	0.134	0.254	0.436	0.832	0.132	0.347	0.492	1.000	-0.041	-0.135	0.126
flow 1 month cumulative	-0.515	-0.445	-0.216	-0.141	-0.462	-0.408	-0.121	-0.041	1.000	0.524	0.353
flow 2 month cumulative	-0.350	-0.515	-0.467	-0.220	-0.290	-0.457	-0.426	-0.135	0.524	1.000	0.366
flow 3 month cumulative	-0.072	-0.075	-0.100	-0.048	0.089	0.099	0.072	0.126	0.353	0.366	1.000

Table 6. Summary of bait shrimp per-trip models using various salinity lags and transformations. Salinity is for the bay or southwest (sw) bay. Numbers in the salinity variable represent the lag (1-mo, 2-mo, or 3-mo).

Model		Per trip ¹				Monthly landings ²			
Effort	Salinity variable	Log transformation spline fit r ²	Shape	No-transformation spline fit r ²	Shape	Log transformation spline fit r ²	Shape	No-transformation spline fit r ²	Shape
Hour	bay1mo	0.1294	u-shape/ exponential	0.1191	bimodal	0.8673	bimodal	0.8622	bimodal
	bay2mo	0.1279	bimodal	0.1188	bimodal	0.8701	bimodal	0.8634	bimodal
	bay3mo	0.1308	bimodal	0.1191	bimodal	0.8752	bimodal	0.87	bimodal
	swsal1mo	0.129	v-shaped	0.1198	bimodal	0.867	u-shape	0.8614	bimodal
	swsal2mo	0.1296	bimodal	0.1208	bimodal	0.8721	bimodal	0.8649	bimodal
	swsal3mo	0.1335	bimodal	0.1241	bimodal	0.8765	bimodal	0.8661	bimodal
Trip	bay1mo	0.1308	exponential	0.1259	exponential	0.8715	exponential	0.8811	bimodal
	bay2mo	0.1236	exponential	0.1197	bimodal	0.8709	bimodal	0.8794	bimodal
	bay3mo	0.1229	exponential	0.1208	bimodal	0.8734	bimodal	0.8825	bimodal
	swsal1mo	0.1235	exponential	0.1204	exponential	0.8718	exponential	0.8785	bimodal
	swsal2mo	0.122	exponential	0.1197	bimodal	0.8751	bimodal	0.8805	bimodal
	swsal3mo	0.1239	bimodal	0.1215	bimodal	0.8777	bimodal	0.8825	bimodal

¹Number/(hour or trip) = month + spline(salinity,4)

²Monthly number = month + no. trips (or hours) + spline(salinity,4)

Table 7. Bait shrimp model summary of "best" monthly landings model and best per trip models, with calculated unique variance explained by each variable.

Data	Transformation	Dependent variable	Model	Salinity lag	Salinity	R2	P	Explaining variables	Unique explained variance
Per trip	log	number/hour	month + spline(salinity)	3	sw bay	0.1335	1x10-16		
Per trip	log	number/hour	salinity	3	sw bay	0.0576	1x10-16	month	0.0759
Per trip	log	number/hour	month			0.1271	1x10-16	salinity	0.0064
Monthly total	none	number/mo	month + no. trips + spline(salinity)	3	sw bay	0.8825	1x10-16		
Monthly total	none	number/mo	no. trips + spline(salinity)	3	sw bay	0.7556	1x10-16	month	0.1269
Monthly total	none	number/mo	month + spline(salinity)	3	sw bay	0.2911	1x10-16	no. trips	0.5914
Monthly total	none	number/mo	month + no. trips			0.8792	1x10-16	salinity	0.0033

Table 8. Number of trips of year and month for Biscayne Bay food shrimp fishery.

Year	Month												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
1989	5	6	1	3								3	18
1990	18	1	3	7	15	7						13	64
1991	11	26	20	7	20						1	11	96
1992	14	48	41	21	17	9	2			1	6	4	163
1993	44	28	40	19	12	5	2					4	154
1994	47	46	52	47	4	2	1			4	4	14	221
1995	28	43	82	62	26	1					2	54	298
1996	103	85	68	42	8	8				2	16	33	365
1997	100	359	167	101	80	22	18	1		2	3	61	914
1998	173	343	272	119	55	21		2	1	2	5	47	1040
1999	224	295	171	142	41	6					3	55	937
2000	441	168	236	110	64	3					3	81	1106
2001	22	180	199	47	108	7	3			5	4	243	818
2002	362	531	158	92	30							3	1176
2003	13	37	57	9	8	1			1			3	129
2004	49	101	115	69	66	1					5	26	432
2005	355	135	126	66	74	1							757
Total	2009	2432	1808	963	628	94	26	3	2	16	52	655	8688

Table 9. Average kg/trip of food shrimp by year and month

Year	Month												Average
	1	2	3	4	5	6	7	8	9	10	11	12	
1989	93	608	82	292								240	322
1990	15	4	122	49	75	189						165	87
1991	157	258	189	182	196						68	102	194
1992	52	73	104	90	172	185	57			113	132	87	100
1993	189	149	236	218	127	194	400					14	191
1994	82	70	69	102	215	227	91			73	71	191	91
1995	52	64	67	153	129	159					92	102	95
1996	96	221	262	214	234	219				173	120	335	198
1997	165	210	160	205	152	50	326	181		154	176	164	185
1998	123	206	127	148	223	219		227	544	205	172	205	166
1999	146	135	189	271	325	271					4	196	180
2000	349	166	163	328	343	209					7	72	258
2001	46	115	95	114	107	60	112			193	4	181	126
2002	117	166	149	184	159							32	150
2003	48	91	157	73	77	272			23			113	115
2004	108	217	177	215	359	202					98	150	210
2005	239	157	188	213	163	166							206
Average	192	169	151	204	204	163	277	212	283	152	100	165	176

Table 10. Summary of "best" food shrimp models.

Transformation	Dependent variable	Model	Bait shrimp cum.	Salinity lag	Salinity	R ²	P	Explained variable	Variation explained
By-trip all data model									
log	kg/hour	month+spline(salinity,4)+spline(baitshrimp,4)+spline(moonfraction,4)	2	2	bay	0.0864	1x10-16		
log	kg/hour	spline(salinity,4)+spline(baitshrimp,4)+spline(moonfraction,4)	2	2	bay	0.0789	1x10-16	month	0.0075
log	kg/hour	month+spline(baitshrimp,4)+spline(moonfraction,4)	2			0.0462	1x10-16	salinity	0.0402
log	kg/hour	month+spline(salinity,4) +spline(moonfraction,4)		2	bay	0.0834	1x10-16	bait shrimp	0.0030
log	kg/hour	month+spline(salinity,4)+spline(baitshrimp,4)	2	2	bay	0.0541	1x10-16	moon fraction	0.0323
By-trip high season model									
log	kg/trip	month+spline(salinity,4)+spline(baitshrimp,4)+spline(moonfraction,4)	21	2	bay	0.0913	1x10-16		
log	kg/trip	spline(salinity,4)+spline(baitshrimp,4)+spline(moonfraction,4)	2	2	bay	0.0786	1x10-16	month	0.0127
log	kg/trip	month+spline(baitshrimp,4)+spline(moonfraction,4)	2			0.0562	1x10-16	salinity	0.0351
log	kg/trip	month+spline(salinity,4) +spline(moonfraction,4)		2	bay	0.0836	1x10-16	bait shrimp	0.0077
log	kg/trip	month+spline(salinity,4)+spline(baitshrimp,4)	2	2	bay	0.0539	1x10-16	moon fraction	0.0374
Monthly model ¹									
none	kg/month	Hours + spline(salinity,4)		2	bay	0.8581	1x10-16		
none	kg/month	Hours				0.8456		salinity	0.0125
none	kg/month	spline(salinity,4)		2	bay	0.0286	0.0292	hours	0.8295

¹bait shrimp landings was not used as a model variable because it was highly correlated with hours (r=0.96).

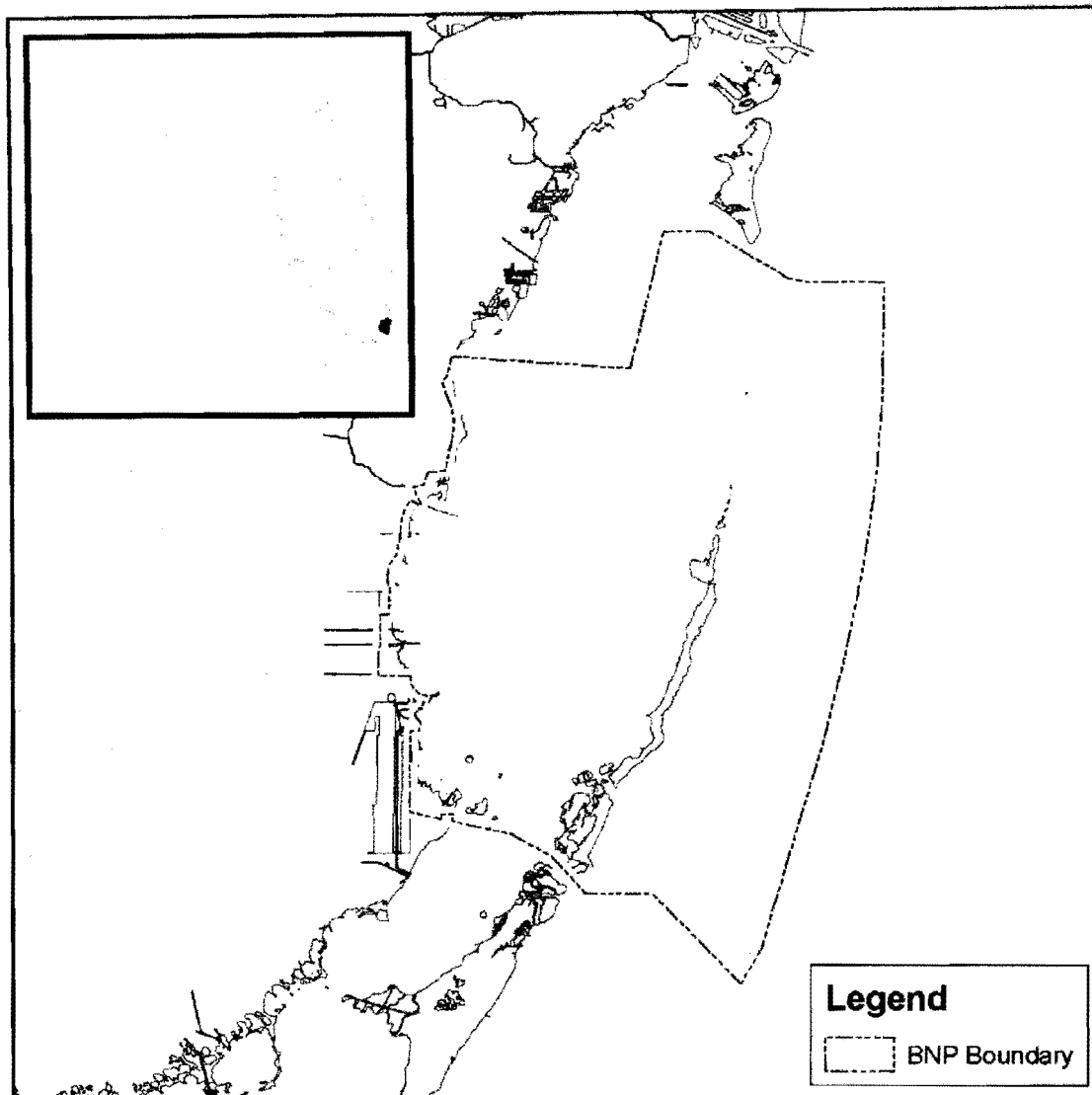


Figure 1. Map of Biscayne Bay showing Biscayne National Park boundaries. Shrimp fishing occurs both within and outside of the Park.

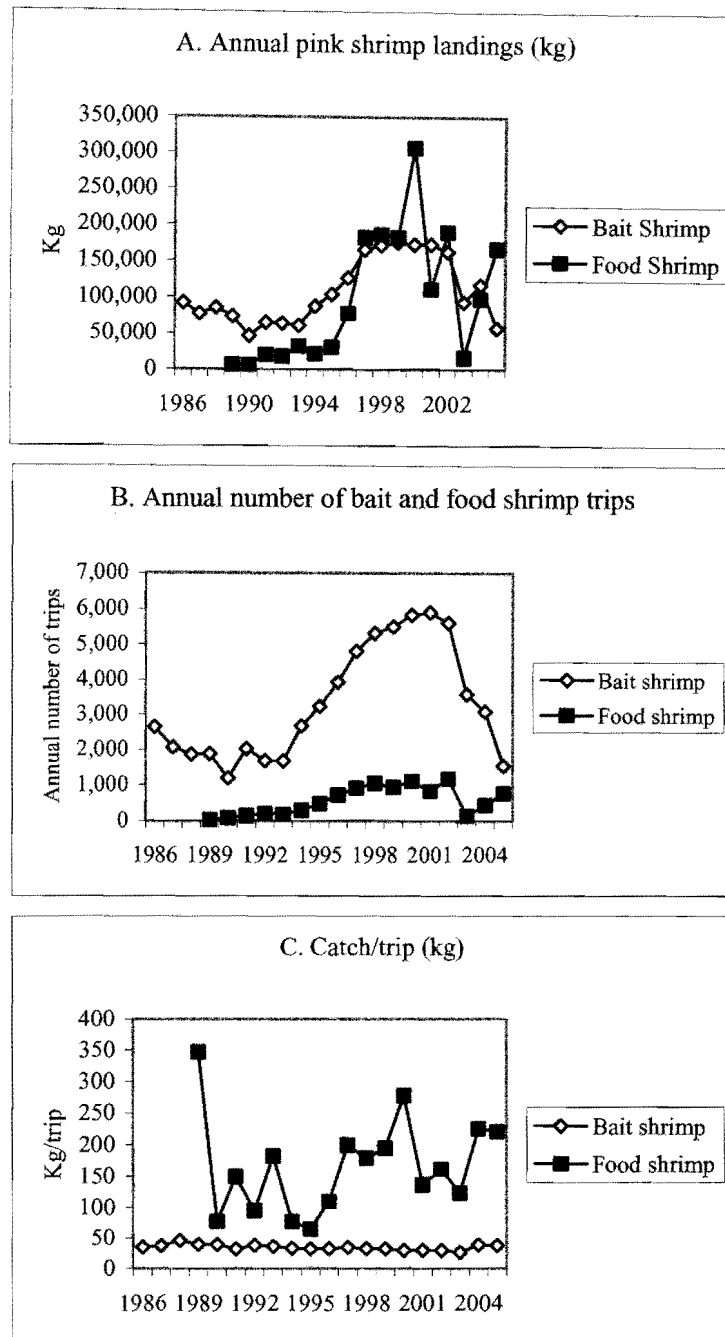


Figure 2. A. Annual landings of Biscayne Bay bait and food pink shrimp. B. Annual number of bait and food shrimp trips. C. Catch/trip of bait and food fisheries. Bait numbers converted to pounds using 0.01 conversion, then converted to kg (Note that 2005 is only for January to June).

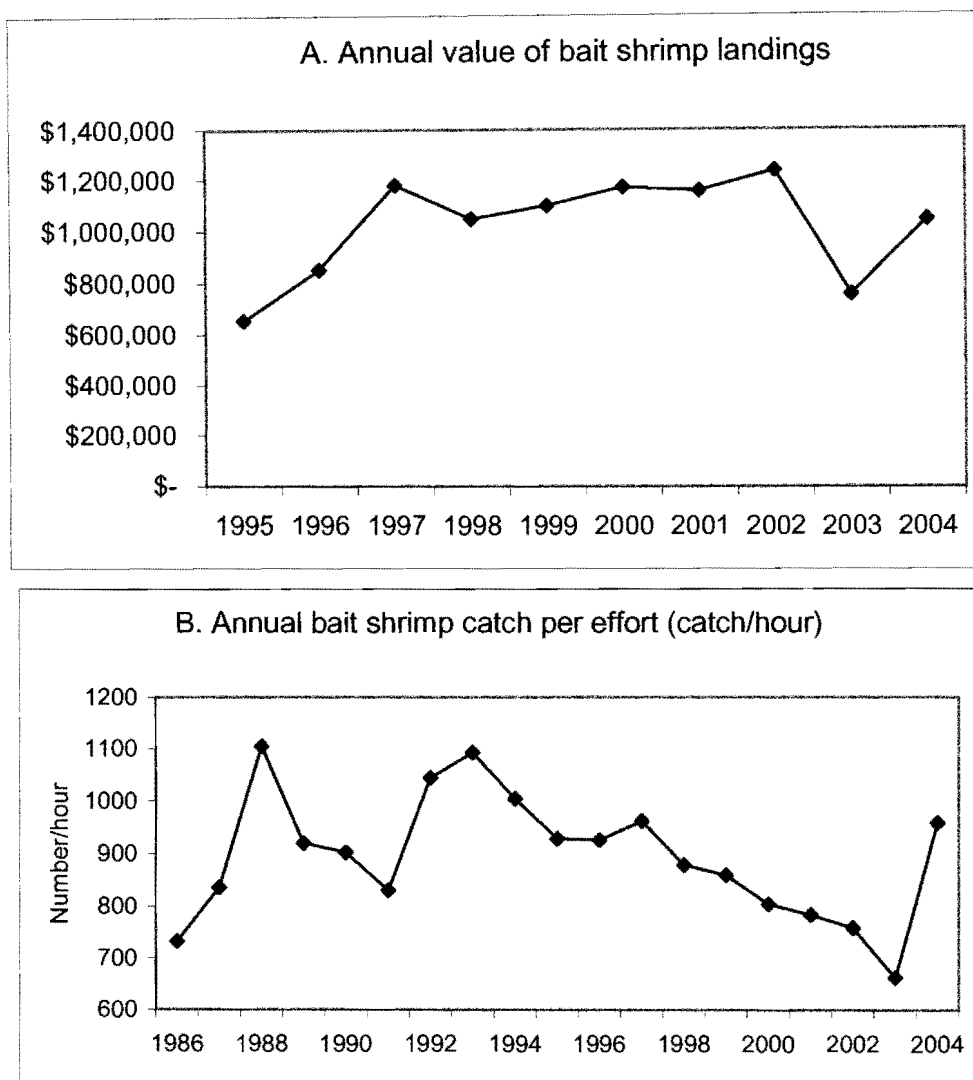


Figure 3 A. Annual value of bait shrimp landings B. Annual catch per effort of bait shrimp (number/hour).

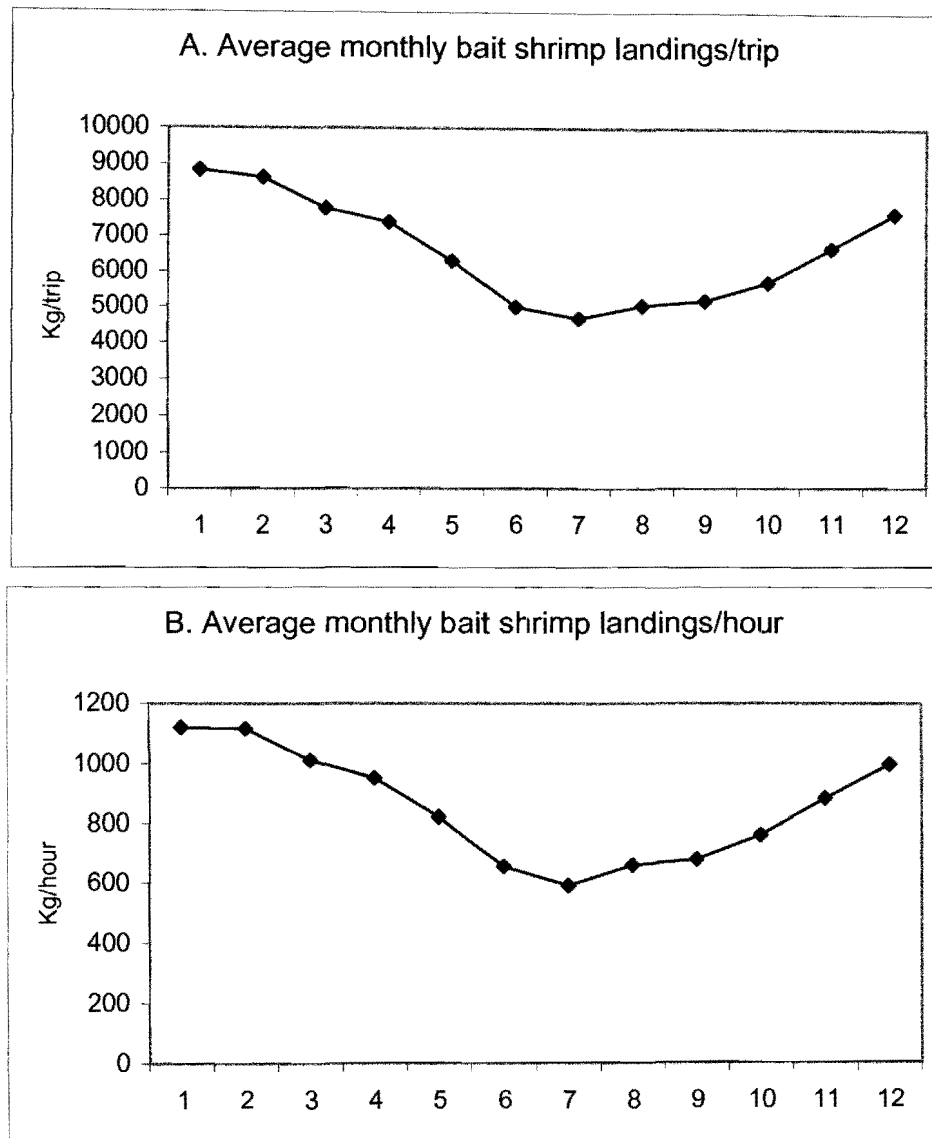


Figure 4. A. Average monthly bait shrimp landings/trip. B. Average bait shrimp landings/hour.

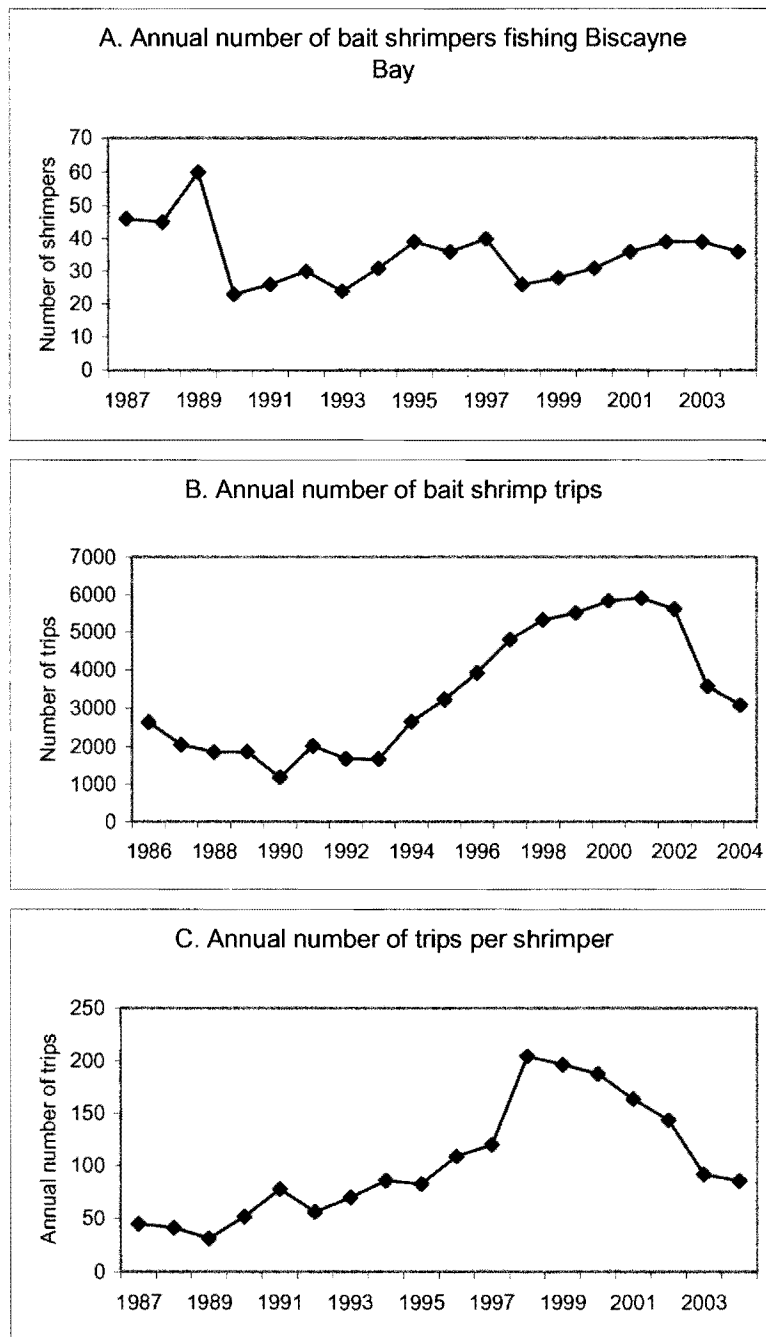


Figure 5. A. Annual number of bait shrimpers fishing Biscayne Bay. B. Annual number of bait shrimp trips. C. Annual number of trips per shrimper (Note: missing data on number of shrimpers for 1986).

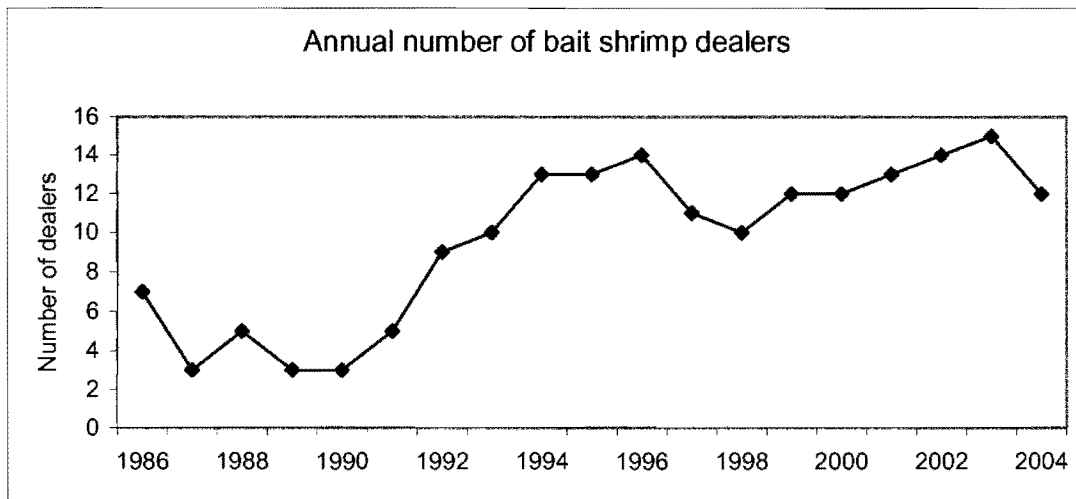


Figure 6. Annual number of bait shrimp dealers buying catch from Biscayne Bay.

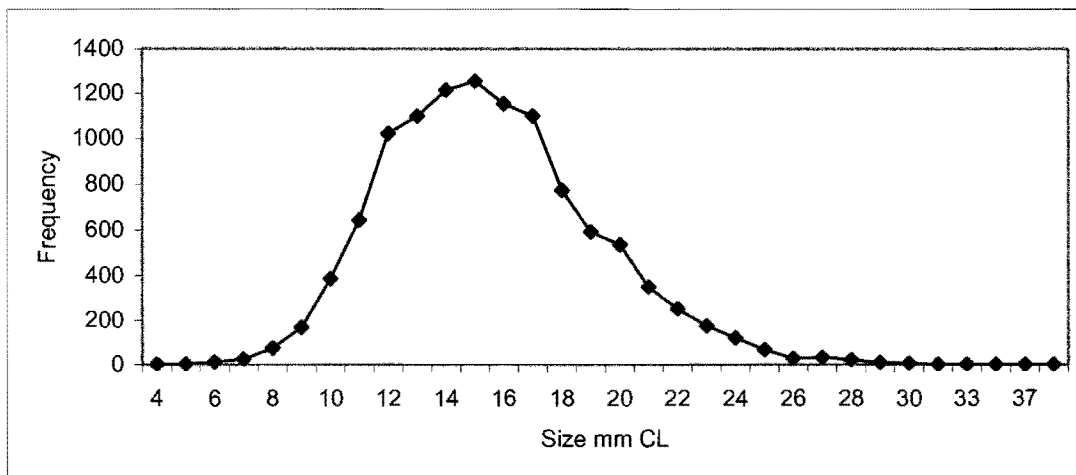


Figure 7. Size-frequency of bait shrimp in fishery-independent shrimp trawl.

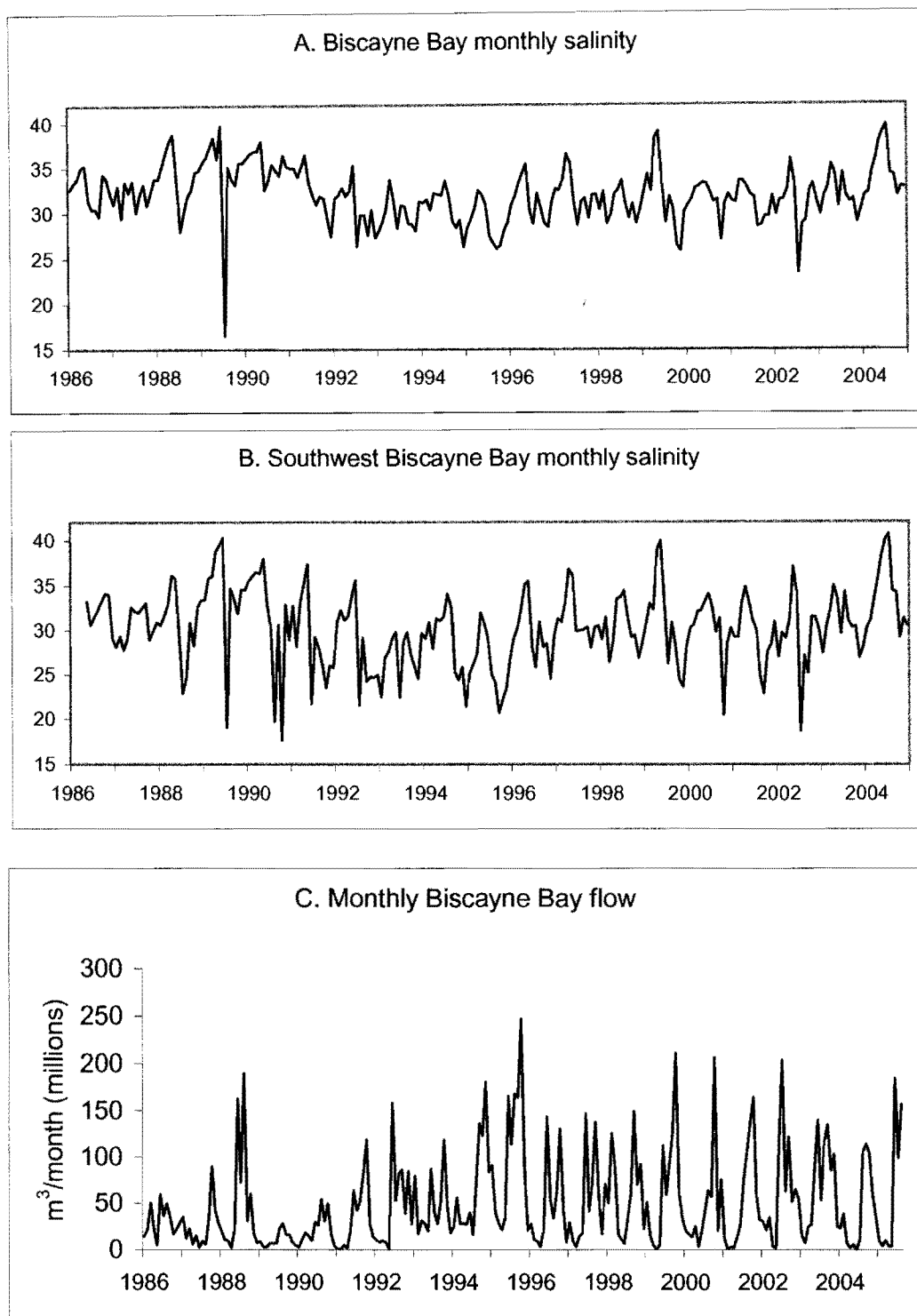


Figure 8. Biscayne Bay salinity (psu) (Rickenbacker Causeway to Blackpoint Marina) and flow (1986-2004). A. Biscayne Bay monthly salinity (psu) B. Southwest Bay monthly salinity C. Monthly flow into Biscayne Bay ($m^3/month$).

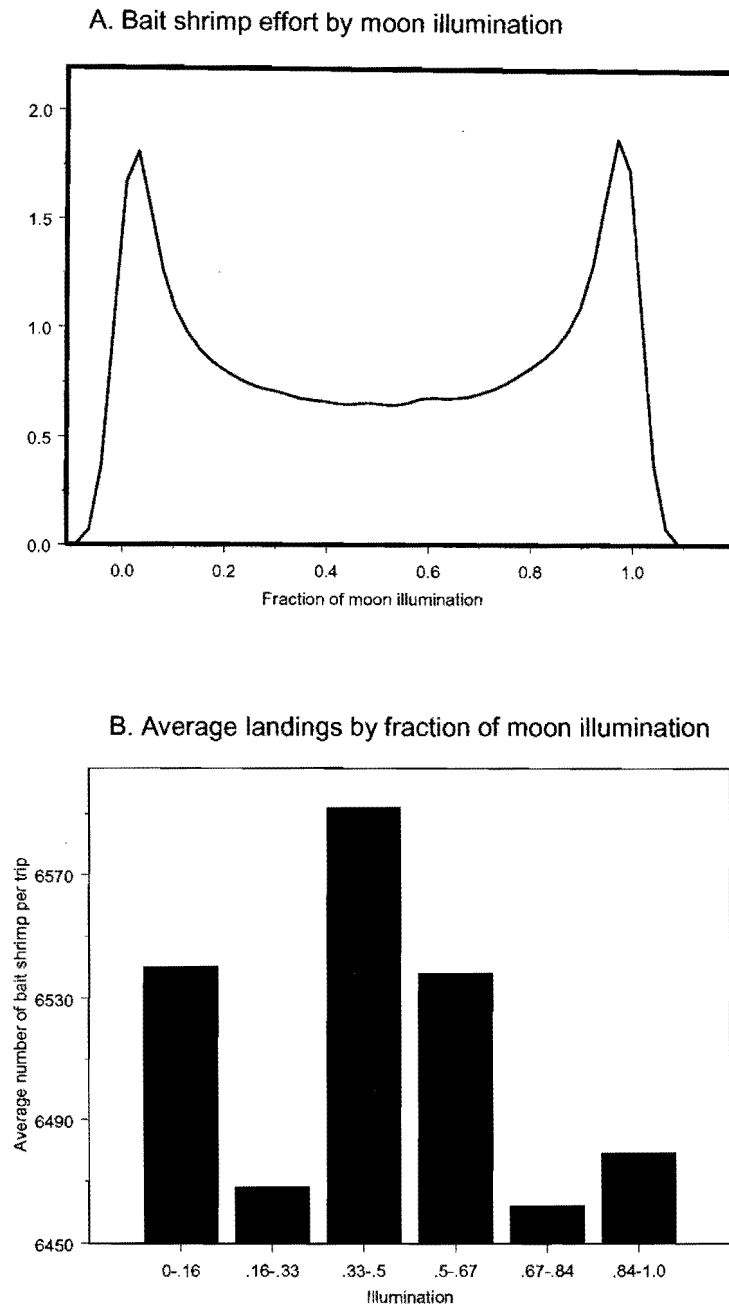


Figure 9. Biscayne Bay bait shrimp and moon illumination. A. Number of trips by fraction of moon illumination B. Average number of shrimp caught per trip, by fraction of moon illumination.

Bait shrimp

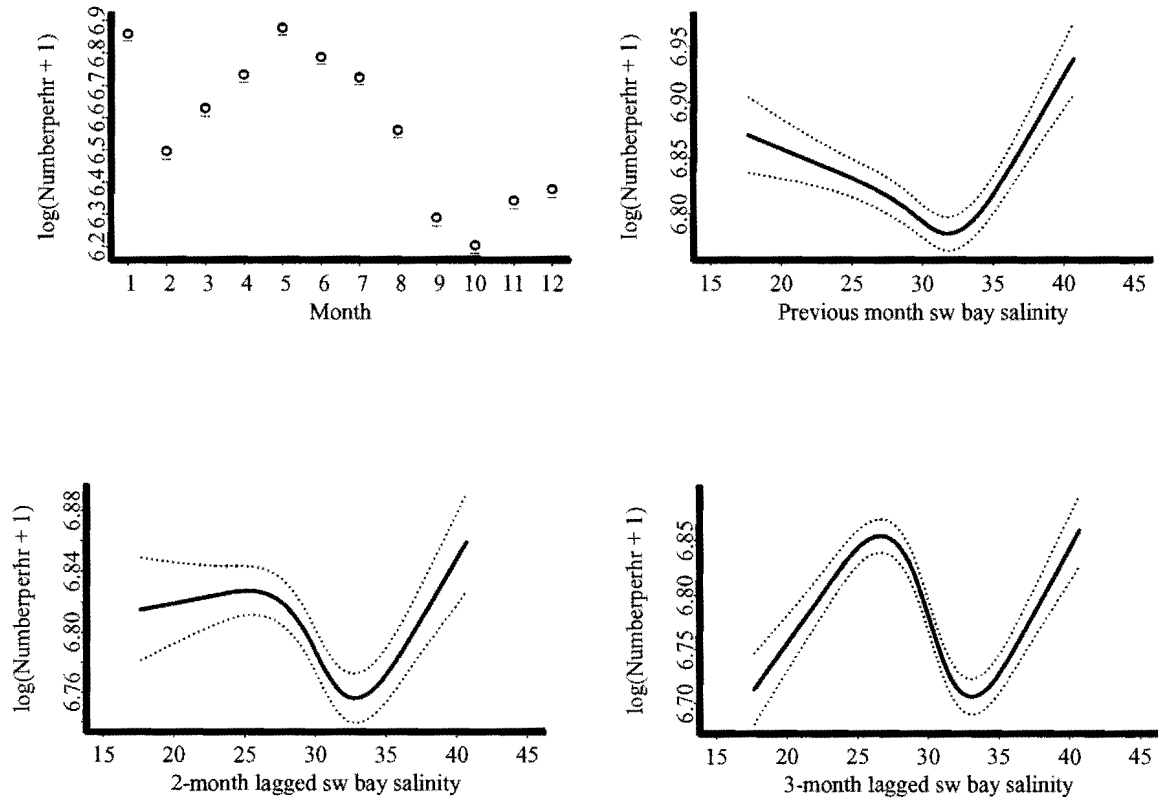
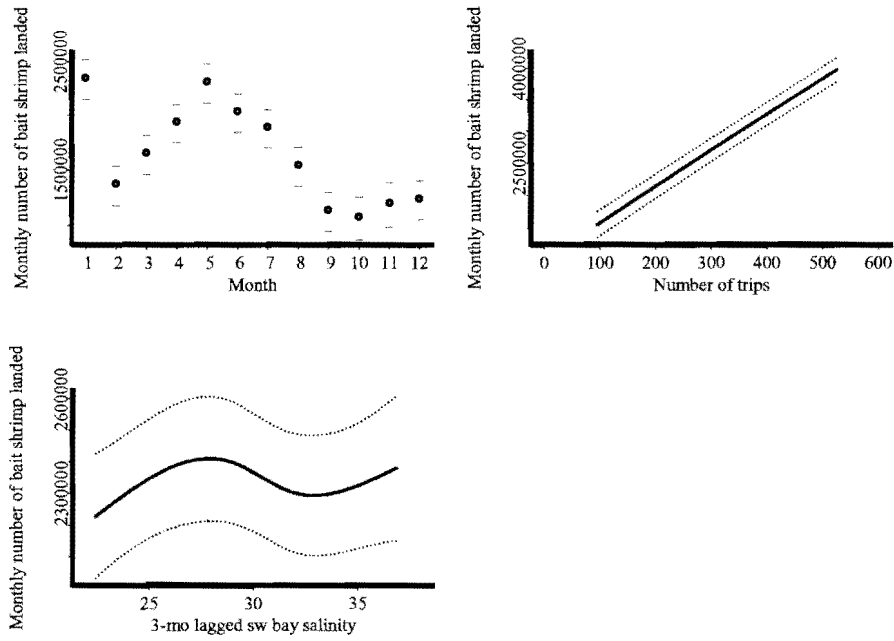


Figure 10. Standardized predicted bait shrimp (log(number/hour)) caught by month and for 1-3 month lagged sw bay salinities (using per-trip data). Dotted lines are 95% confidence intervals.

A. Best bait shrimp model



B. Predictions from 1 and 2 month lagged sw bay salinity models

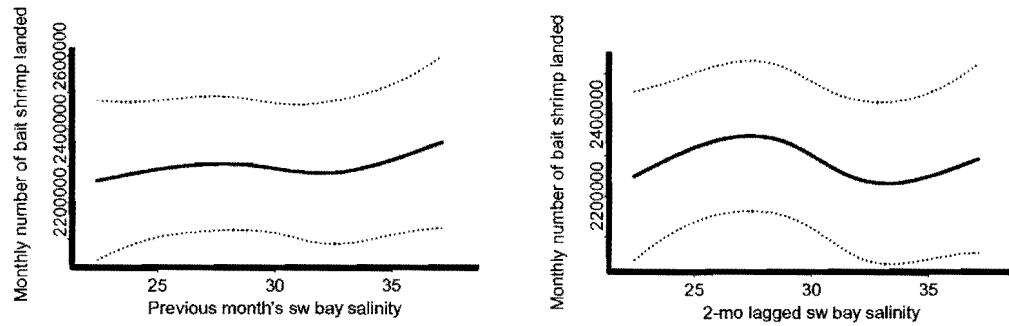


Figure 11. A. Standardized predicted monthly bait shrimp landings (from best monthly landings model) for month, number of trips, and 3-month lagged sw bay salinity. B. Predictions for 1 and 2 month lagged sw bay salinity models. Dotted lines are 95% confidence intervals.

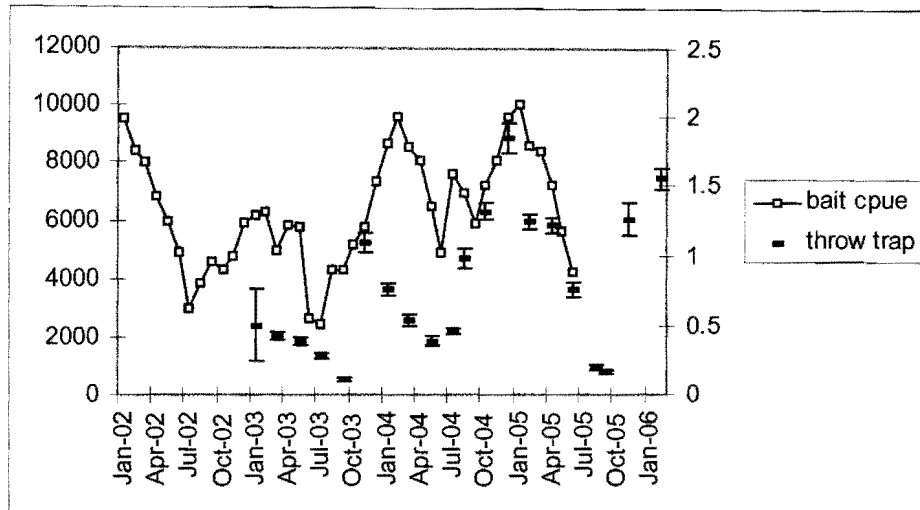


Figure 12. Average monthly number of shrimp caught per trip in the bait shrimp fishery (left ordinate) and average number of shrimp caught per square meter in the throw trap 3 mo previously (right ordinate) (unpubl. data, Robblee).

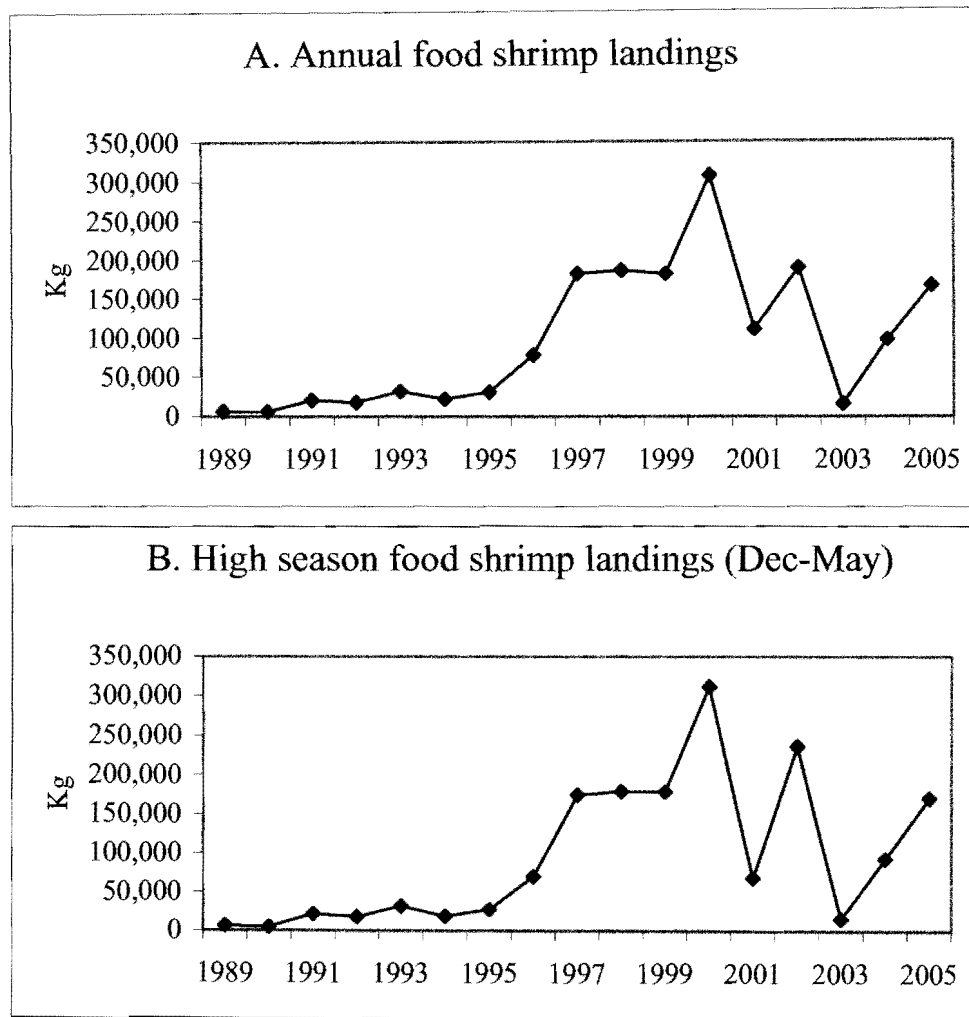


Figure 13. Biscayne Bay food shrimp landings 1989-2005 (Note that 2005 is only for January-June). A. Annual landings B. High season (Dec-May) landings.

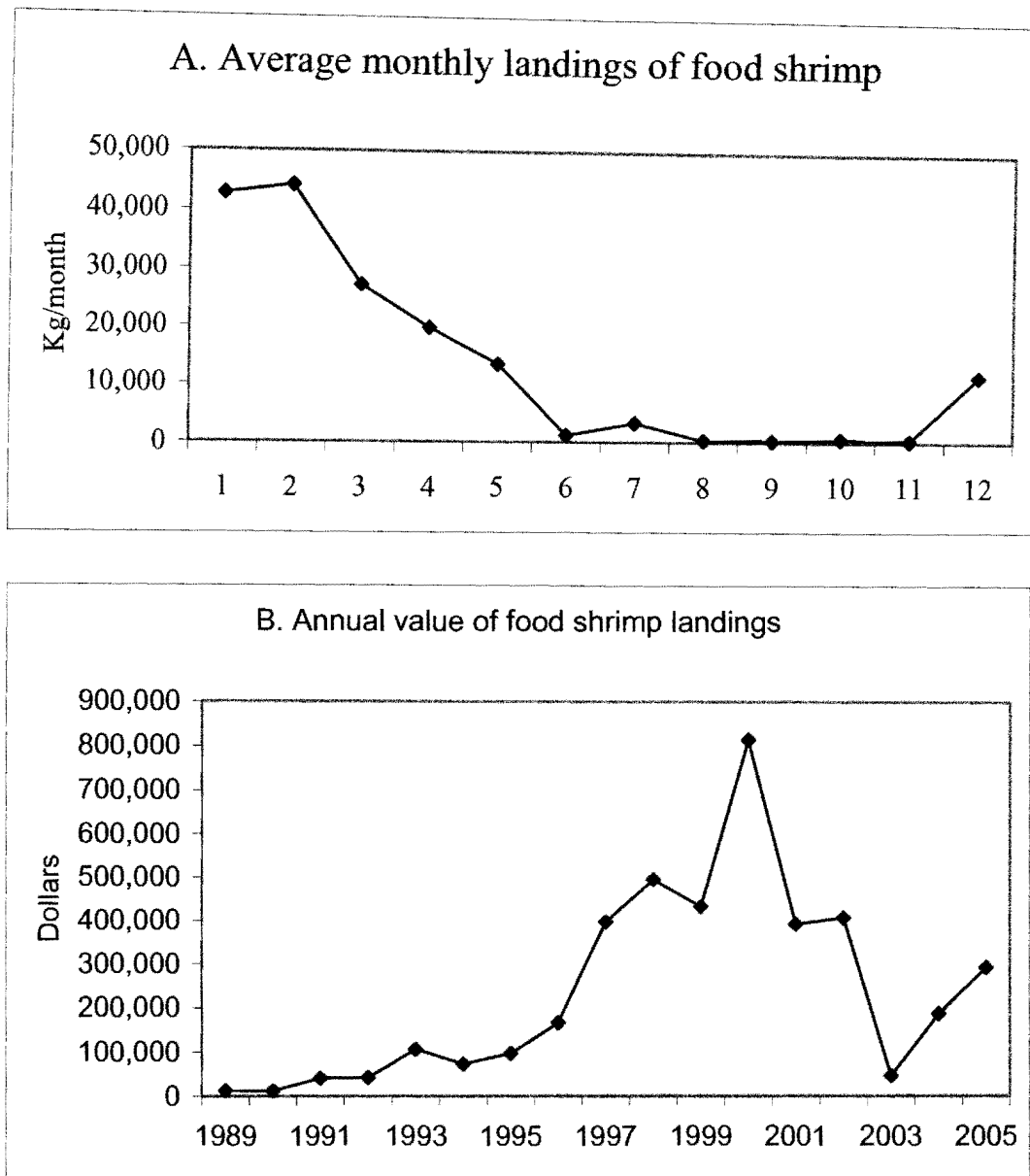


Figure 14. Biscayne Bay food shrimp fishery 1989-2005 (Note that 2005 is only for Jan-June). A. Average monthly landings (Note that there has been a closed season for the wing-net fishery between June and November, the exact months have been variable among years, see Table 7). B. Annual value of landings.

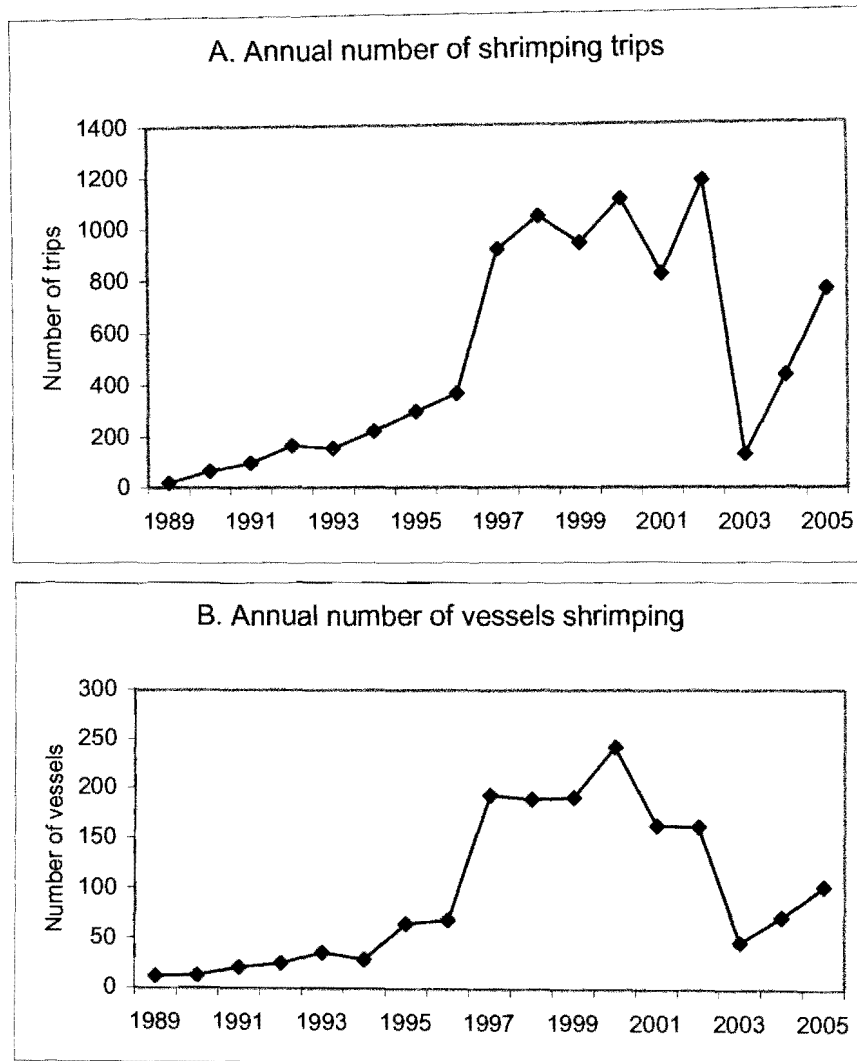


Figure 15. Biscayne Bay food shrimp fishery 1989-2005. A. Annual number of shrimp fishing trips B. Annual number of vessels fishing.

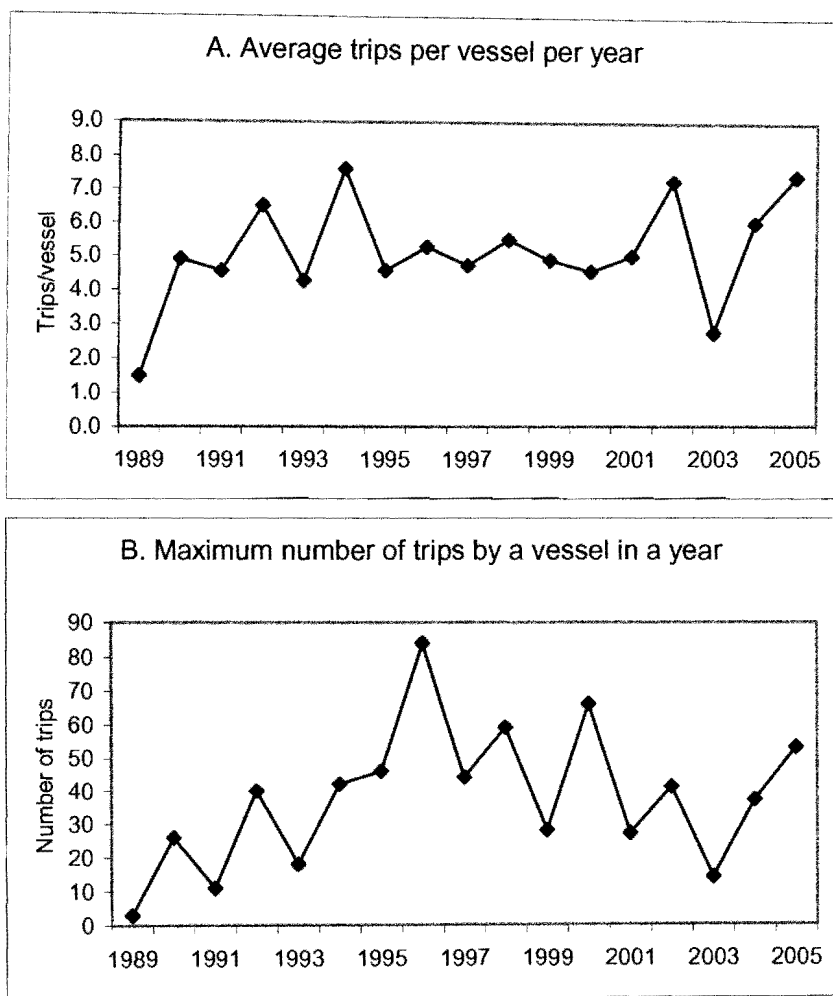


Figure 16. Biscayne Bay food shrimp fishery 1989-2005. A. Annual number of shrimp fishing trips B. Annual number of vessels fishing.

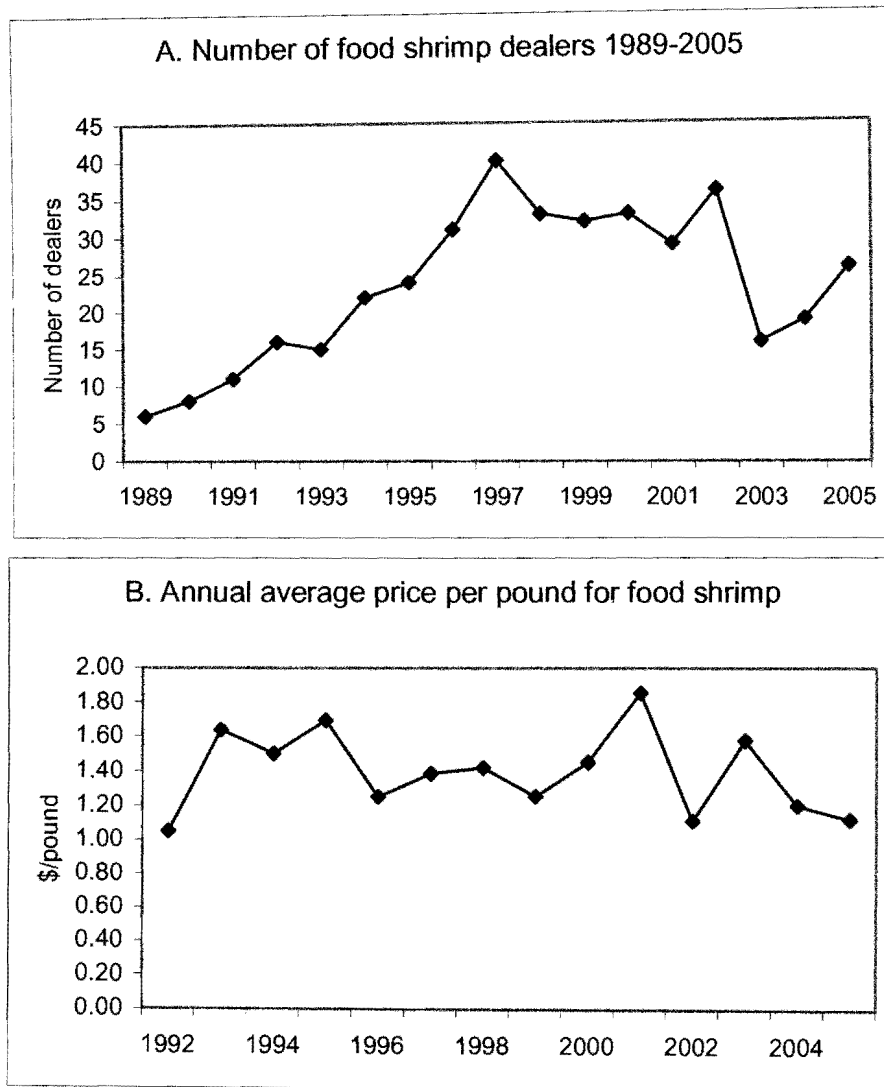


Figure 17. Biscayne Bay food shrimp fishery 1989-2005 A. Number of food shrimp dealers B. Annual average price per pound for food shrimp.

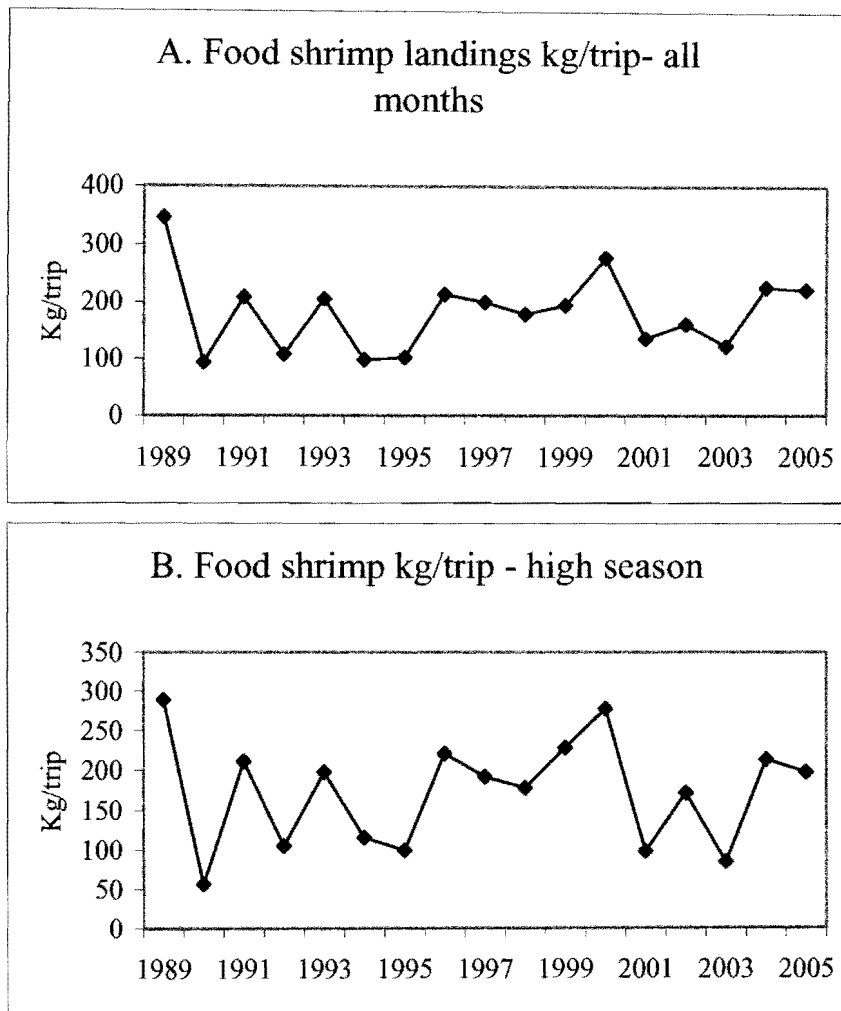


Figure 18. Catch/effort in Biscayne Bay food shrimp fishery (1989-2005) A. Kilograms/trip-all months B. Kilograms/trip- high season.

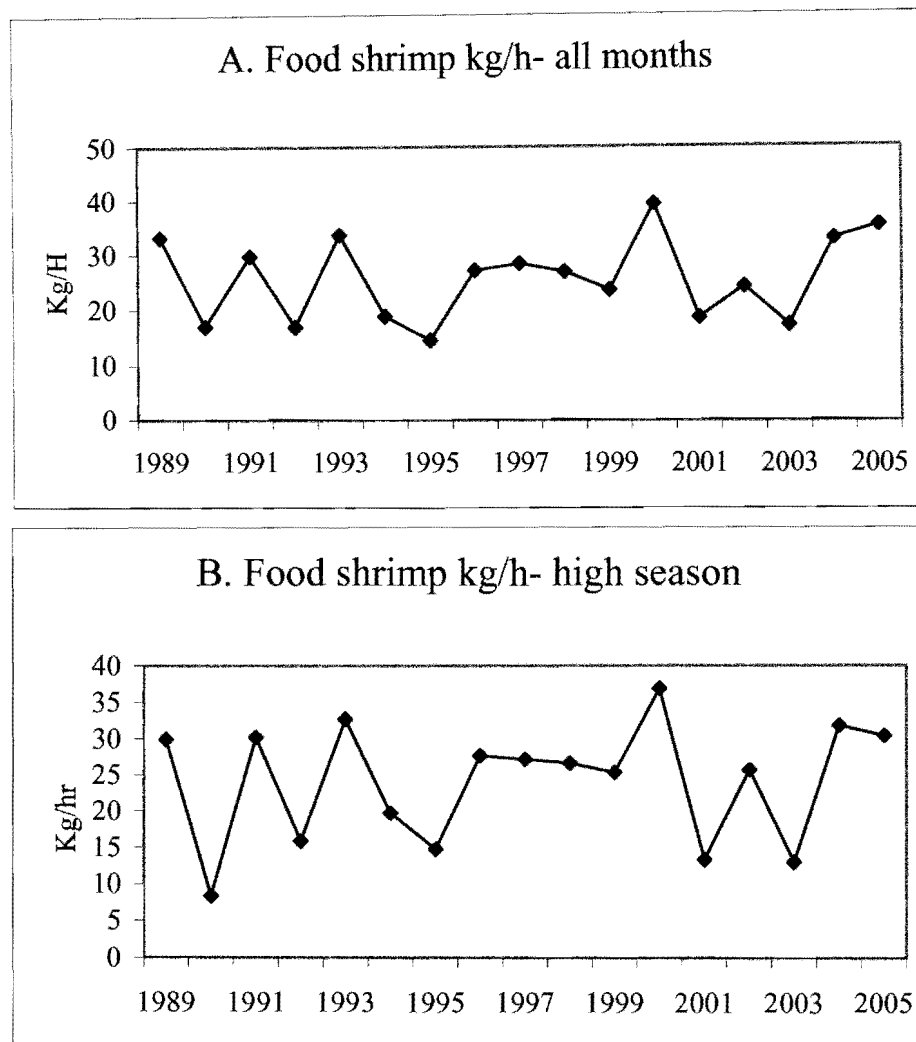


Figure 19. Catch/effort in Biscayne Bay food shrimp fishery (1989-2005). A. Kilograms/hour- all months B. Kilograms/hour- high season (December-May).

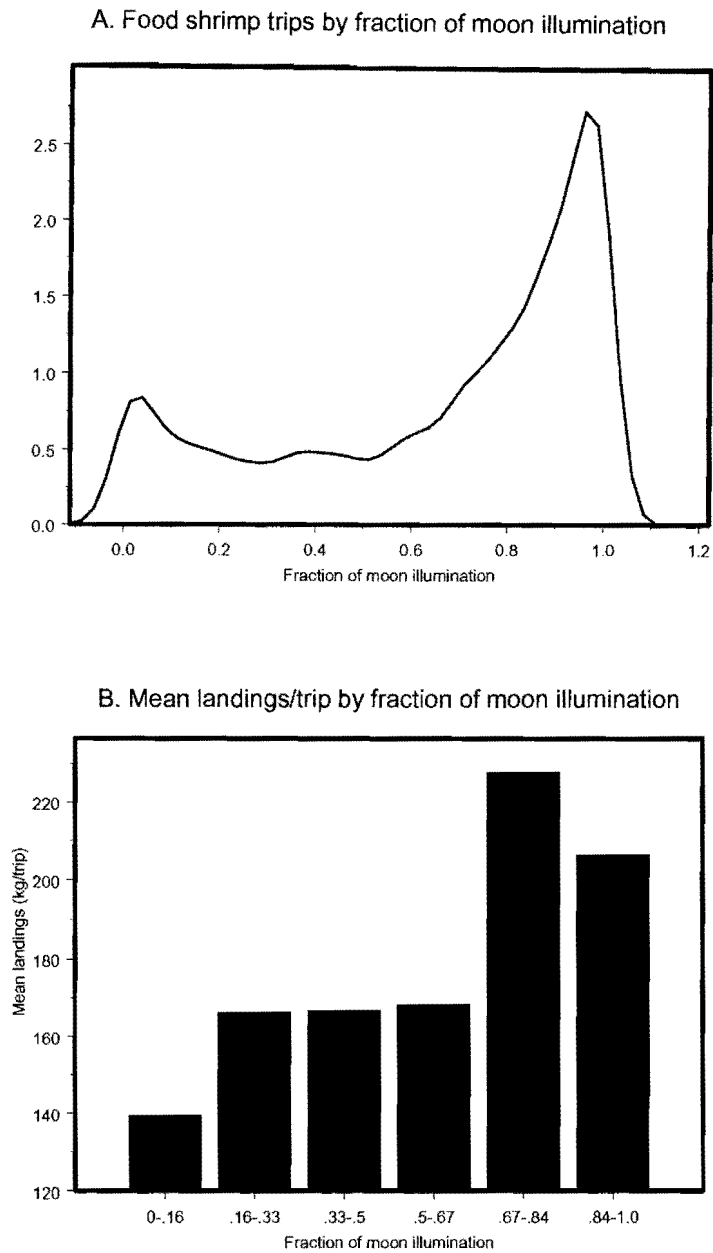


Figure 20. Biscayne Bay food shrimp and moon phase. A. Number of trips by fraction of moon illumination B. Mean landings/trip by fraction of moon illumination.

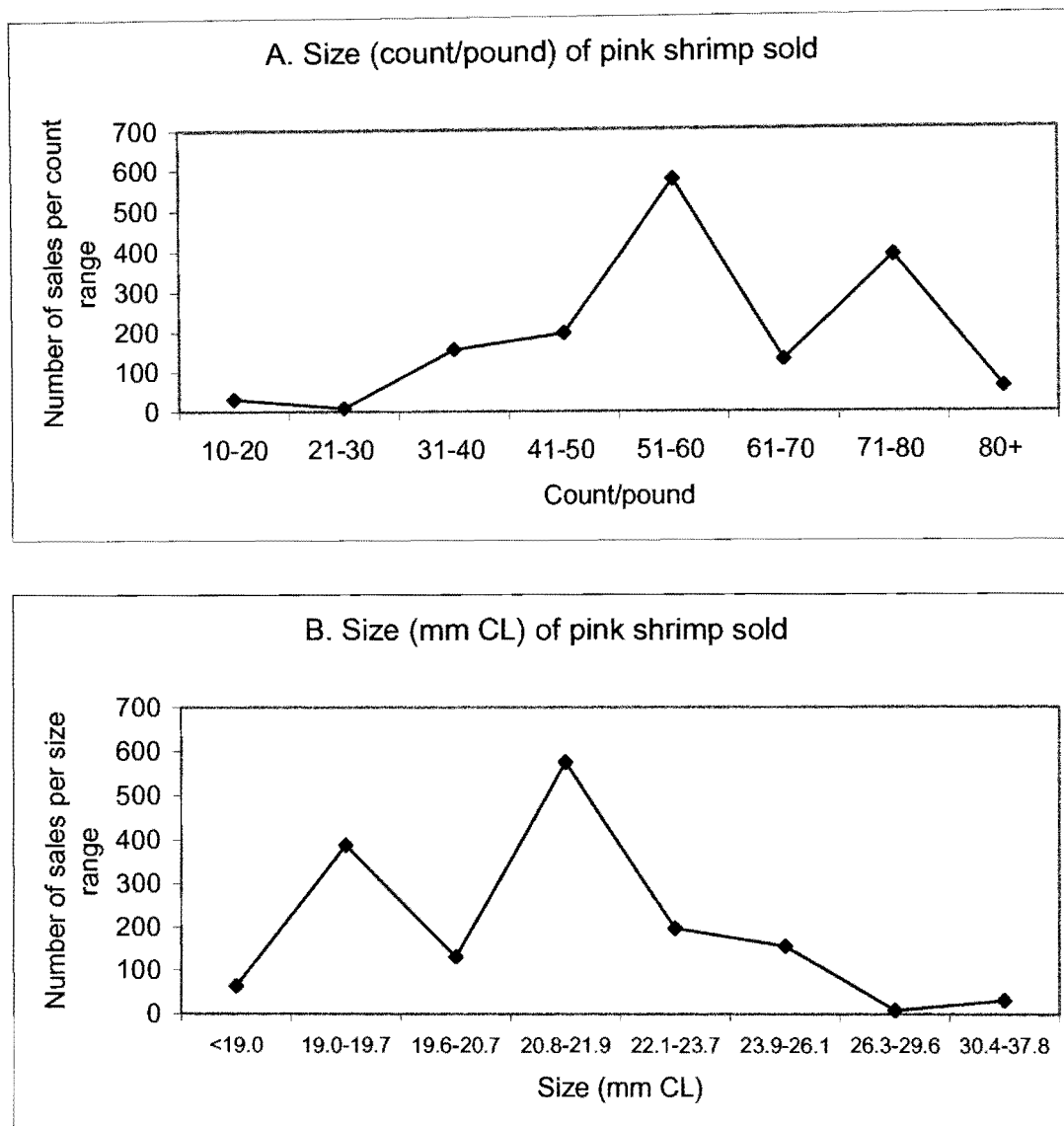
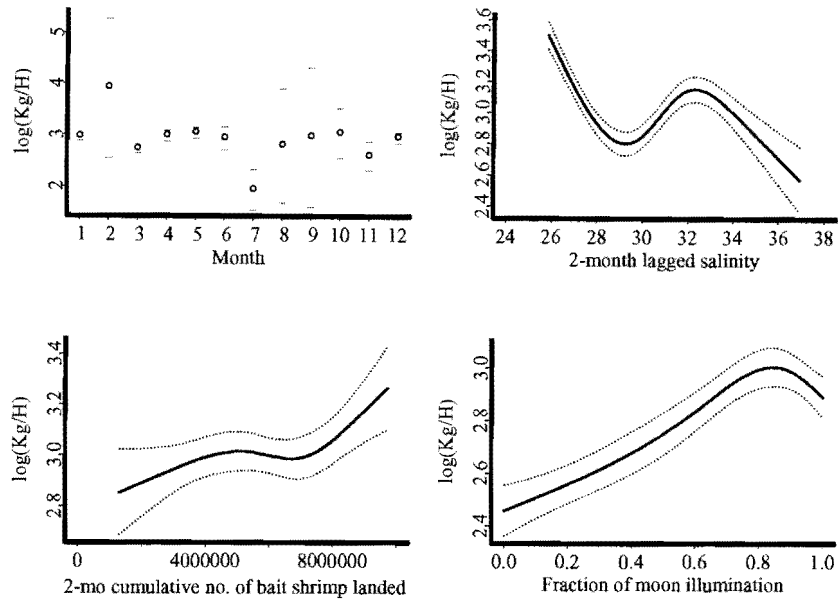


Figure 21. Biscayne Bay food shrimp fishery (1989-2005) A. Size (count/pound) of pink shrimp sold B. Size by mm CL of pink shrimp sold.

A. Food Shrimp - all data



B. Food Shrimp- high season

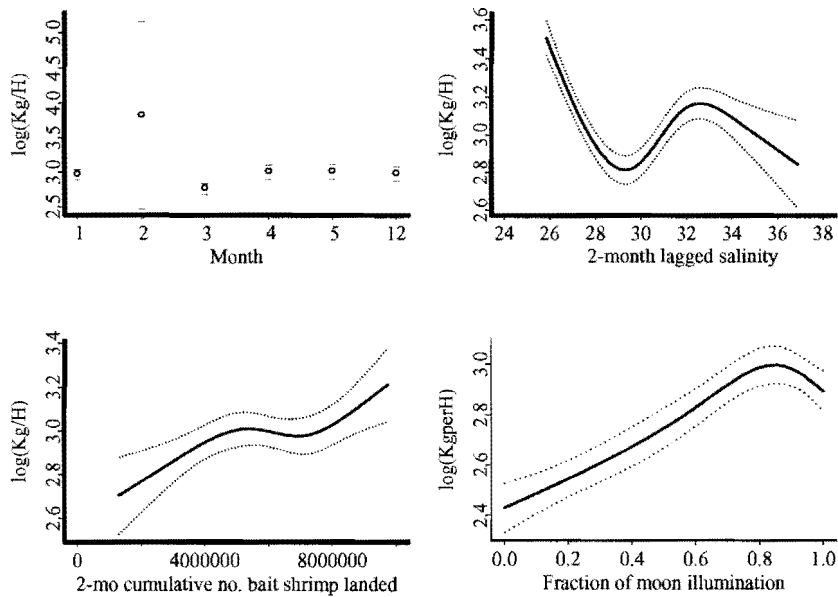


Figure 22. Standardized predicted food shrimp catch per trip for month, 2-month lagged salinity, 2-month cumulative bait shrimp landings, and fraction of moon illumination A. All months B. High season only. Dotted lines are 95% confidence limits.

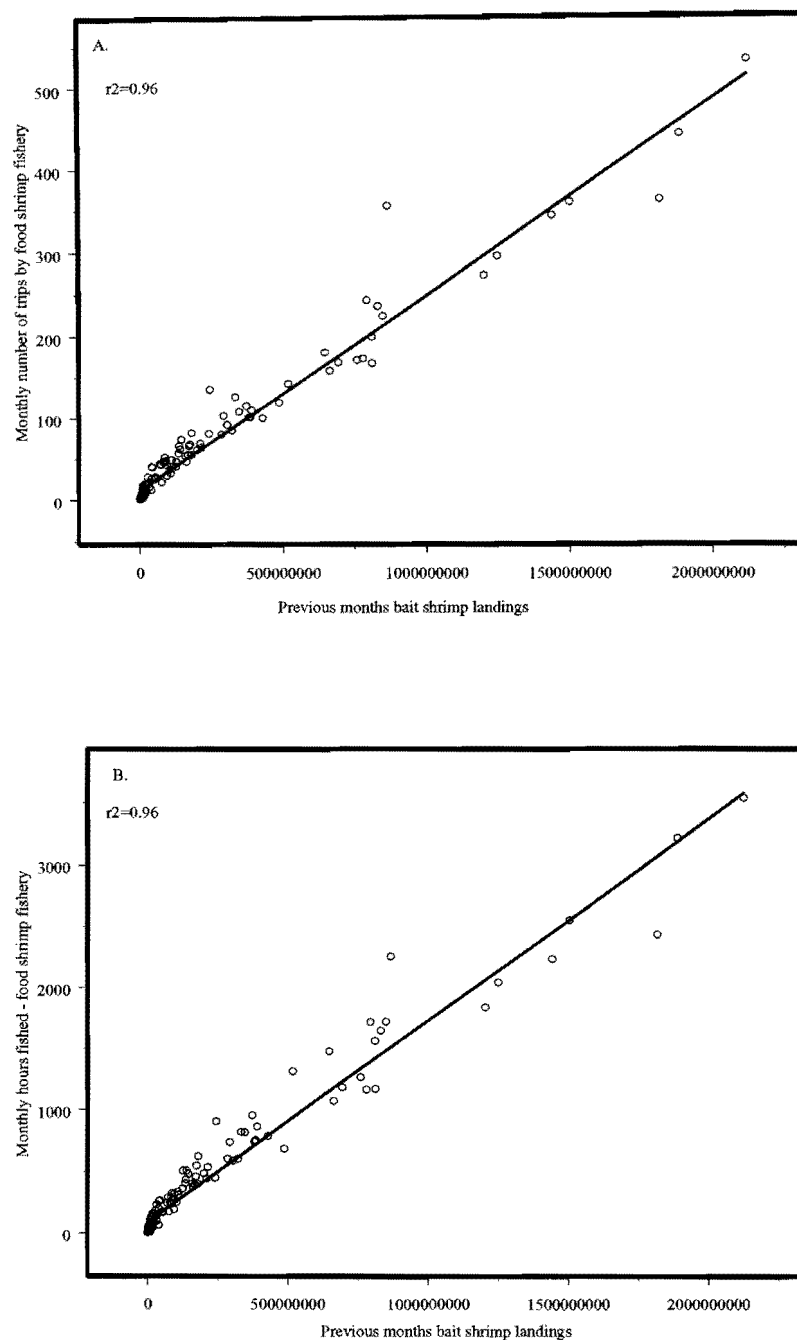


Figure 23. Previous month bait shrimp landings vs. effort. A. Number of food shrimp trips B. Number of reported hours fished for food shrimp.

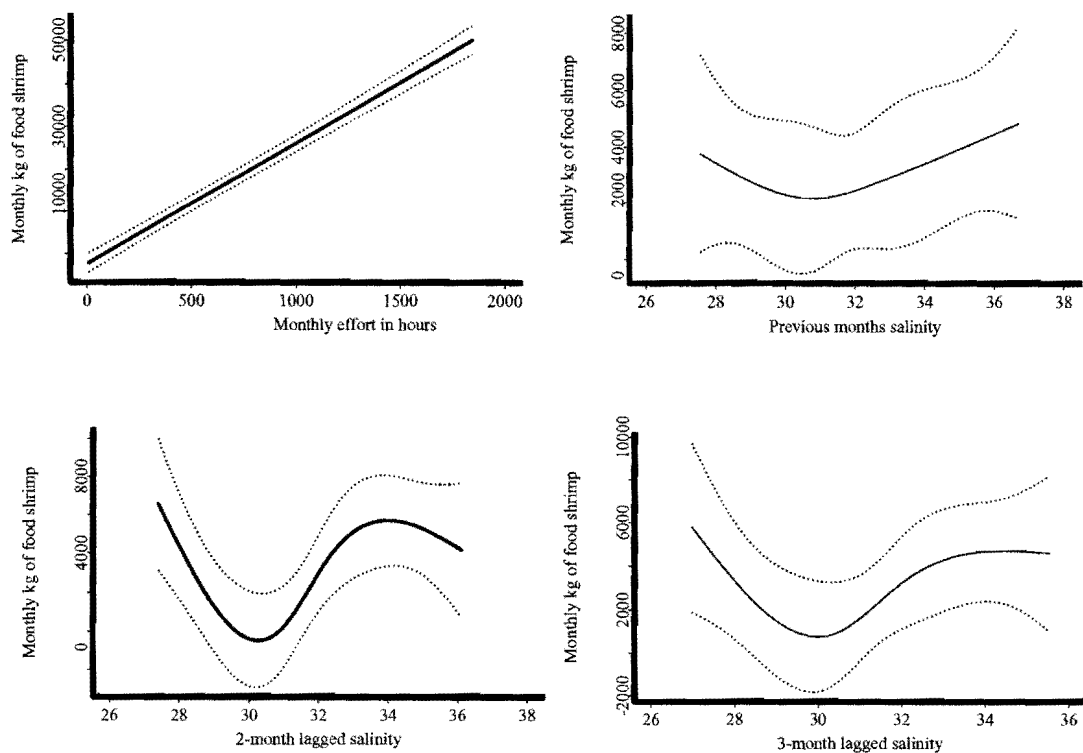


Figure 24. Standardized predicted monthly food shrimp landings (monthly landings model) by month and 1-3 month lagged salinity. Dotted lines are 95% confidence intervals. Note that the salinity predictions are the output from three separate models that used month and salinity as model variables.

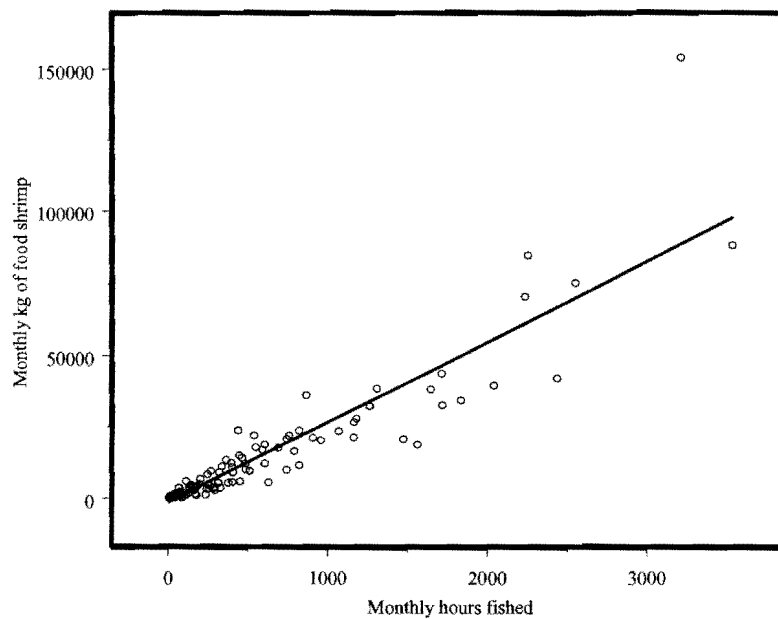
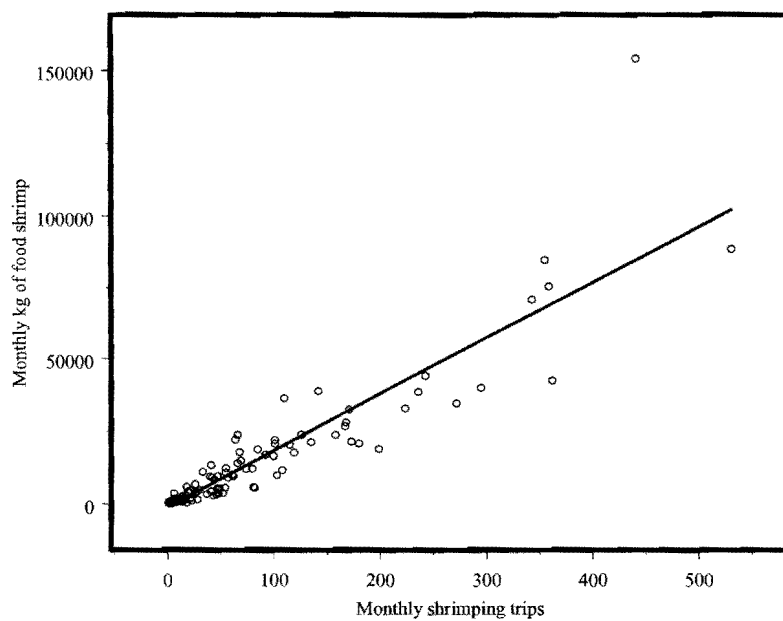


Figure 25. Monthly kg of food shrimp harvested in Biscayne Bay by number of monthly trips and hours harvested.

Appendix Table 1. SHRIMP REGULATIONS THAT AFFECT BISCAYNE BAY

SHRIMP - TURTLE EXCLUDER DEVICES - Emergency Rule, 46ER89-3, F.A.C. (Effective August 9, 1989- November 7, 1989)

Requires the use of a qualified TED in any trawl vessel 25 feet or greater in length in any offshore waters, and prohibits possession of a trawl rigged for fishing that does not have a qualified TED aboard any vessel 25 feet or greater in length in offshore waters. Any person operating a fishing trawl from a vessel less than 25 feet in length in offshore waters will not be required to use a TED as long as each tow time is limited to 90 minutes.

SHRIMP - TURTLE EXCLUDER DEVICES, CH 46-31, F.A.C. (Effective November 8, 1989 until permanent rule becomes effective)

Renews above emergency rule.

SHRIMP - TURTLE EXCLUDER DEVICES, CH 46-31, F.A.C. (Effective June 11, 1990)

Prohibits persons from operating or fishing in any state waters any trawl that is not equipped with a qualified TED, and prohibits possession by any person aboard any vessel in or on state waters of any trawl rigged for fishing that is not equipped with a qualified TED. The altering of any TED in order to render it nonfunctioning is also prohibited. This rule does not apply to:

A single test net having a headrope length of 20 feet or less if it is pulled immediately in front of any other net or trawl or is not connected to another net or trawl in any way

A roller frame trawl with a rectangular rigid frame to keep the mouth of the trawl open while being towed, rollers on the lower horizontal beam of the frame to allow the trawl to roll over the bottom and any obstructions while being towed, a grid of vertical bars spaced no more than 3 inches apart shielding the trawl opening, and no doors attached to keep the mouth of the trawl open (in addition, the trawl must be towed by attaching a line or towing cable to a tongue located above or at the center of the upper beam of the frame)

Trawls used as part of experiments sanctioned by the National Marine Fisheries Management Service

Any trawl operated, fished, or on a vessel and rigged for fishing with a headrope length not greater than 35 feet and a perimeter around the leading edge of the net not greater than 100 feet, while in the inside waters of the state (defined as all waters landward of the Colregs Demarcation Line)

SHRIMP, CH 46-31, F.A.C. (Effective January 1, 1992)

Sets a recreational daily bag limit of 5 gallons of shrimp, heads on, per person or vessel, whichever is less, and requires recreationally harvested shrimp to be landed in a whole condition (heads on)

Allows recreational fishermen to use only landing or dip nets with an opening no larger than 96 inches around the perimeter, cast nets, push nets, one frame net with an opening no larger than 16 feet around the perimeter, legal shrimp traps, beach or haul seines no greater than 100 feet in length, and an otter trawl with a headrope length not greater than 16 feet and a perimeter around the leading edge of the net not greater than 48 feet

Allows recreational fishermen to use a cast net in conjunction with non-metal poles to bait shrimp under certain conditions

Allows harvesters of live bait shrimp to only use a roller frame trawl with neither the upper or lower horizontal beams greater than 16 feet in length, vertical bars shielding the trawl opening spaced no more than 3 inches apart, no more than two such trawls to be towed by a single vessel at any time, and a minimum net mesh size of 5/8 inch bar measurement in the net body and 1/2 inch bar measurement in the net bag (live bait shrimp harvesters in state waters of Brevard through Nassau counties)

Requires harvesters and dealers of live bait shrimp to use live wells of certain specifications on board vessels and during land transport and storage

Prohibits harvesters of live bait shrimp from operating as a food shrimp producer or recreational harvester on the same trip, requires shrimp harvested as bait to be sold as bait, prohibits harvesters of live bait shrimp from transferring such shrimp to another vessel in state waters, and prohibits harvesters of live bait shrimp from possessing more than 5 gallons of heads on dead shrimp aboard vessels at any time

Prohibits food shrimp producers statewide from possessing more than 47 heads on/70 heads off shrimp per pound (except seabobs), from using a brine box to separate shrimp from bycatch, and from operating as a live bait shrimp producer or a recreational harvester on the same trip - persons harvesting shrimp in state waters may use a single try net with a headrope length not greater than 10 feet in inshore waters and 20 feet in offshore waters and a perimeter around the leading edge of the net not greater than 30 feet in inshore waters and 60 feet in offshore waters if such net is pulled immediately in front of another trawl or trawls or is not in any way connected to another trawl (such net shall also have a legal mesh size)

Allows food shrimp producers to only use the following gear:

Monroe through Indian River counties (inshore waters) - a wing net or frame net with an opening no larger than 28 feet around the perimeter (no more than two wing nets may be attached to or fished from a single vessel), and wing nets and frame nets may not be towed or dragged over the bottom

SHRIMP - TRAWL SPECIFICATIONS - Emergency Rule, CH 46ER95-1, F.A.C. (Effective July 3 - September 30, 1995)

Prohibits the use of any trawl in inshore and nearshore state waters that contains more than 500 square feet of mesh area

Prohibits the use of any otter trawl that has a perimeter around its mouth greater than 66 feet

Prohibits the use of more than two unconnected otter trawls, including any try net

SHRIMP, CH 46-31, F.A.C. (Effective January 1, 1996)

Prohibits the use of any trawl in inshore and nearshore state waters with more than 500 square feet of mesh area

Allows the use of otter trawls with a perimeter around the opening no greater than 66 feet in all areas of the state where otter trawls are allowed in inshore and nearshore waters

Prohibits the use of more than two unconnected trawls, including any try net, in inshore and nearshore state waters

Allows the use of a sled in lieu of the inner doors between two otter trawls (with a spread of at least 10 feet between the trawls) where the use of otter trawls is allowed in inshore and nearshore state waters

Allows the use of trawls for the directed harvest of shrimp only

Prohibits the use of otter trawls by recreational fishermen

SHRIMP - RECREATIONAL FRAME NETS, CH 46-31, F.A.C. (Effective June 3, 1996)

Allows recreational fishermen statewide to harvest shrimp with frame nets if such gear is deployed from a vessel, or from a structure other than an operational bridge or causeway, or from a catwalk attached to such bridge or causeway (these frame nets are not allowed to be fished or dragged along the bottom)

Reaffirms that frame nets used by commercial food shrimp producers in the Southeast Region be deployed only from vessels

SHRIMP - BYCATCH REDUCTION DEVICES, CH 46-31, F.A.C. (Effective August 17, 1998)

Requires a legal, functioning bycatch reduction device (BRD) to be installed and used in all otter trawls rigged for fishing by food and live bait shrimp producers in all state waters

Prohibits the rigging or altering of BRDs installed in trawls in a manner that would render the BRD nonfunctioning or ineffective

Provides a process of expedited rulemaking (as provided in the Administrative Procedure Act) to be employed to allow the use of new BRDs that are approved and certified for use by the National Marine Fisheries Management Service

SHRIMP - SUSPENSION OF MINIMUM SIZE LIMIT IN DADE COUNTY - Emergency Rule, CH 46ER99-1, F.A.C. (Effective January 26, 1999 - April 26, 1999)

Suspends the food shrimp minimum size limit (47/70 count law) in state waters of Dade County.

SHRIMP - SOUTHEAST SHRIMP AND STATEWIDE RESTRICTED SPECIES DESIGNATION, CH 68B-31, F.A.C. (Effective December 2, 1999)

Eliminates the count law (minimum size limit) for food shrimp harvested in Dade County

Establishes an Oct. 15 - May 15 allowable harvesting season for food shrimp in Biscayne Bay (with a 6 a.m. Saturday to 6 a.m. Sunday closed period to food shrimp harvest each week during this open season)

Prohibits the use of frame nets by recreational fishermen to harvest shrimp in Dade County

Designates shrimp as a "restricted species" statewide, effective Jan. 1, 2001

SHRIMP - SOUTHEAST SHRIMP, CH 68B-31, F.A.C. (Effective December 21, 2000)

Changes the Oct. 15 - May 15 Biscayne Bay food shrimp production season to
Nov. 1 - May 31.

SHRIMP - LIVE BAIT SHRIMP, CH 68B-31, F.A.C. (Effective February 28, 2002)

Requires persons who sell live bait shrimp to equip their facilities with watertight tanks with at least 32 cubic feet of continuously aerated saline water to store the shrimp (instead of 64 cubic feet previously required in most of Florida).

Appendix Table 2. Annual measured flow (m³/yr) to South Biscayne Bay (Rickenbacker Causeway south to Turkey Point),

Year	s123	Percent	s20f	Percent	s21	Percent	s21a	Percent	s22	Percent	s197	Percent	Total Flow
1986	10,625,535	2.9%	111,807,175	30.7%	54,284,741	14.9%	76,050,818	20.9%	75,453,802	20.7%	35,753,495	9.8%	363,975,566
1987	12,829,912	4.2%	132,348,613	43.4%	55,011,549	18.0%	46,624,153	15.3%	25,187,901	8.3%	33,281,779	10.9%	305,283,907
1988	25,192,525	4.1%	170,444,643	28.0%	100,647,770	16.5%	88,968,269	14.6%	79,897,003	13.1%	144,559,024	23.7%	609,709,233
1989	2,238,629	1.7%	75,105,310	56.5%	23,289,079	17.5%	12,861,032	9.7%	19,501,074	14.7%	0	0.0%	132,995,124
1990	5,091,351	1.9%	80,347,933	29.9%	113,022,739	42.0%	47,146,720	17.5%	23,334,536	8.7%	0	0.0%	268,943,280
1991	24,098,484	5.6%	134,098,193	31.2%	81,937,189	19.1%	75,725,324	17.6%	110,682,992	25.7%	3,492,726	0.8%	430,034,907
1992	26,773,633	4.7%	159,313,006	28.0%	116,727,755	20.5%	111,264,082	19.5%	103,191,391	18.1%	51,943,845	9.1%	569,213,711
1993	17,630,315	3.1%	161,478,482	28.4%	125,956,361	22.2%	89,703,395	15.8%	170,179,383	30.0%	3,183,012	0.6%	568,130,948
1994	19,811,057	2.4%	213,609,784	26.1%	229,503,632	28.0%	114,887,553	14.0%	204,265,014	24.9%	37,513,619	4.6%	819,590,660
1995	-1,823,834	-0.2%	299,399,029	25.3%	312,916,041	26.4%	145,551,947	12.3%	309,796,395	26.2%	118,116,243	10.0%	1,183,955,821
1996	12,726,176	2.3%	168,662,474	30.6%	134,669,691	24.4%	80,686,028	14.6%	121,708,055	22.1%	33,028,092	6.0%	551,480,517
1997	45,348,282	7.3%	176,064,946	28.5%	111,567,532	18.0%	92,745,582	15.0%	148,573,656	24.0%	44,437,343	7.2%	618,737,341
1998	85,589,701	11.7%	180,823,929	24.8%	187,682,059	25.8%	84,846,696	11.6%	153,049,910	21.0%	36,728,338	5.0%	728,720,633
1999	75,130,094	9.7%	200,131,942	25.7%	118,431,486	15.2%	122,348,817	15.7%	210,670,452	27.1%	51,311,597	6.6%	778,024,389
2000	42,122,552	7.4%	185,852,623	32.8%	110,503,608	19.5%	115,367,721	20.4%	80,706,236	14.3%	31,444,538	5.6%	565,997,278
2001	42,271,476	6.6%	183,002,983	28.6%	142,751,728	22.3%	119,375,086	18.7%	125,834,815	19.7%	25,689,916	4.0%	638,926,005
2002	40,742,334	5.2%	206,654,842	26.5%	233,900,887	30.0%	131,057,621	16.8%	146,411,752	18.8%	19,906,132	2.6%	778,673,567
2003	28,357,506	3.4%	225,862,252	27.4%	272,110,340	33.0%	122,673,381	14.9%	170,270,348	20.7%	4,226,286	0.5%	823,500,113
2004	24,284,376	4.8%	130,261,966	25.6%	183,213,512	36.0%	96,815,164	19.0%	71,322,125	14.0%	2,909,850	0.6%	508,806,993
2005	47,609,444	10.0%	136,460,717	28.8%	107,551,334	22.7%	83,367,709	17.6%	90,594,786	19.1%	8,329,216	1.8%	473,913,205
Grand Total	586,649,546	5.0%	3,331,730,840	28.4%	2,815,679,033	24.0%	1,858,067,100	15.9%	2,440,631,625	20.8%	685,855,052	5.9%	11,718,613,197

Appendix 3. Average South Biscayne Bay (Rickenbacker Causeway to Turkey Point) salinity (psu) by month and year.

Year	Month												Average
	1	2	3	4	5	6	7	8	9	10	11	12	
1986					35.3	31.4	30.5	30.5	29.7	34.3	33.8	32.2	32.8
1987	31.0	33.0	29.4	33.4	32.3	33.6	30.1	32.0	33.2	30.9	32.3	33.8	31.9
1988	33.8	35.2	36.6	38.0	38.8	33.4	28.0	30.2	31.9	32.6	34.6	34.8	32.9
1989	35.7	36.2	37.3	38.4	36.0	39.7	37.4	35.1	33.8	33.2	35.4	35.6	34.9
1990	36.1	36.6	36.9	36.9	38.0	32.6	33.7	35.4	34.7	34.2	36.4	35.2	35.7
1991	35.0	35.0	34.0	35.2	36.4	33.3	32.0	30.9	31.9	31.6	29.5	27.4	32.3
1992	31.6	32.0	32.8	31.9	32.4	35.3	26.4	29.8	29.8	27.6	30.3	27.3	30.7
1993	28.0	29.1	30.4	33.7	31.5	28.3	30.8	30.7	28.8	28.7	28.0	31.3	29.9
1994	31.1	31.5	30.3	32.2	32.0	31.9	33.5	31.8	29.1	28.4	29.2	26.3	30.6
1995	28.3	29.3	30.5	32.5	31.9	30.9	27.5	26.8	26.1	26.4	28.0	29.0	28.9
1996	30.8	31.8	33.2	34.4	35.4	30.2	28.8	32.2	30.5	28.9	28.4	31.1	31.4
1997	32.6	32.5	33.7	36.5	35.5	31.3	28.6	31.3	31.6	29.4	32.0	32.0	32.6
1998	30.3	32.3	28.8	29.8	32.1	32.5	33.6	31.2	29.4	31.0	28.8	30.3	31.2
1999	32.3	34.2	32.4	38.3	39.0	33.2	28.9	31.7	30.5	26.4	25.8	30.1	30.3
2000	30.8	31.5	32.7	32.9	33.3	33.2	32.3	31.2	31.4	27.0	31.0	32.0	31.6
2001	31.3	31.1	33.5	33.4	32.9	32.0	31.7	28.5	28.6	29.6	29.6	31.8	31.4
2002	29.8	31.4	31.4	32.6	35.9	33.1	23.4	28.8	29.1	32.3	33.2	31.3	31.0
2003	29.8	31.8	32.8	35.3	34.2	30.6	34.3	31.9	31.2	31.5	28.9	30.3	31.7
2004	31.9	32.2	34.5	35.9	37.9	39.0	39.7	34.3	34.1	31.8	32.8	32.7	34.7
Average	31.2	32.0	32.5	33.7	34.0	32.6	29.9	30.8	30.4	29.2	30.2	30.7	31.5

Appendix 4. SW Biscayne Bay salinity (psu) by month and year.

Year	Month												Average
	1	2	3	4	5	6	7	8	9	10	11	12	
1986					33.3	30.6	31.5	32.3	33.3	34.2	34.1	29.1	32.3
1987	28.1	29.4	27.8	29.0	32.6	32.2	32.0	32.5	33.1	28.9	29.9	30.9	30.6
1988	30.6	31.7	32.9	36.1	35.9	29.4	22.9	24.8	30.9	28.3	32.7	33.4	29.9
1989	33.5	35.8	36.1	38.8	39.5	40.3	37.5	34.7	33.6	31.9	34.0	34.6	34.9
1990	35.5	36.1	36.5	36.4	38.0	33.0	30.1	19.8	30.6	17.7	32.9	29.0	33.5
1991	32.8	28.2	33.2	35.3	37.4	21.7	29.3	28.1	26.1	23.5	26.0	25.8	28.5
1992	31.0	32.3	31.2	31.6	33.9	35.6	21.6	29.2	24.2	24.8	24.7	25.0	28.9
1993	22.5	26.9	27.6	29.1	29.8	22.4	28.7	29.8	27.3	26.0	24.6	29.7	27.0
1994	29.1	30.9	28.0	31.4	31.1	31.7	34.1	32.7	25.3	24.4	25.9	21.4	28.7
1995	25.1	26.2	27.4	32.0	30.8	29.1	25.0	24.2	20.7	22.1	23.5	26.8	26.1
1996	29.1	30.3	32.3	35.1	35.5	28.2	25.8	31.0	28.2	28.5	24.6	29.4	30.1
1997	31.4	31.0	33.2	36.9	36.2	29.9	30.0	30.1	30.4	28.1	30.4	30.5	31.6
1998	29.0	31.6	26.5	28.7	33.6	33.8	34.5	31.6	29.3	29.5	26.9	28.6	30.9
1999	30.8	33.1	32.4	39.0	40.0	32.9	26.3	31.0	28.3	24.5	23.6	28.3	29.1
2000	30.3	30.7	32.1	32.3	33.3	34.2	32.6	29.8	31.4	20.5	28.4	30.3	30.5
2001	29.2	29.3	33.1	34.9	33.2	31.1	30.1	24.9	22.9	27.6	28.4	31.0	29.9
2002	27.0	29.8	29.2	31.5	37.1	34.1	18.7	27.2	25.2	31.6	31.6	30.1	29.5
2003	27.4	30.5	32.4	35.1	33.6	29.7	34.4	31.2	30.4	30.5	27.0	28.3	30.6
2004	30.4	31.3	33.7	36.0	38.4	40.1	40.7	34.5	34.4	29.3	31.5	30.6	34.2
Average	29.0	30.4	31.1	33.2	34.2	32.2	28.5	29.3	27.3	25.8	27.3	28.5	29.8