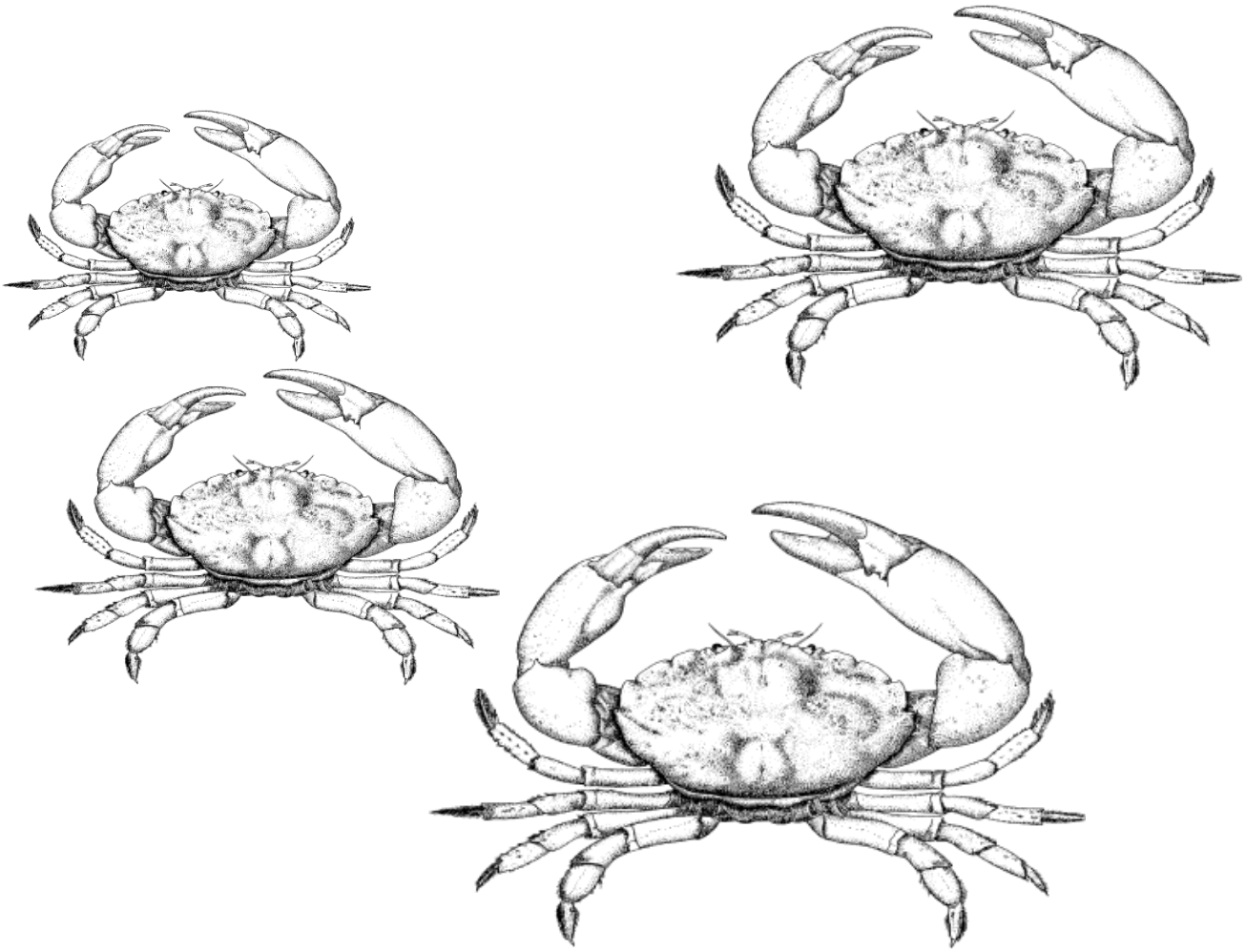

The 2011 Stock Assessment Update for the Stone Crab, *Menippe* spp., Fishery in Florida

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Executive Summary

- The stone crab fishery, which occurs primarily on Florida's west coast, is unique among fisheries in the southeast United States (SE US) because harvesters do not harvest the crabs; but, rather, the harvesters remove the crabs' legal-sized claws at sea and return the declawed crabs to the water alive.

- The stone crab fishery is managed in the SE US with a seven-month fishing season (15 October through 15 May), a minimum harvest claw (propodus) size of 2-3/4 in (70 mm), trap specifications, and a passive trap limitation program. The minimum claw size ensures that most female crabs have already spawned one or more years by the time their claws reach legal size.

- To provide a historical perspective for evaluating more recent landings for which we have information on effort, historical landings, in pounds of claws on a calendar-year basis, were extended back to 1895. The stone crab fishery was a developing fishery until the 1990s.

- This update includes commercial landings through the 2009-10 fishing year. Peak landings were 3.5 million pounds of claws statewide in the 2000-01 fishing year. Statewide landings in 2009-10 were 2.4 million pounds of claws.

- The landings at the beginning of the fishing year in October are good predictors of the landings for the entire year and, since 1985-86, the landings in this half-month have averaged 18% of the fishing year's total.

- An average of 31% of the claws observed by FWC samplers in fish houses statewide (weighted by regional landings) showed evidence of forced breaks, which lowers the crab's likelihood of surviving after being declawed.

- Approximately 13% of the claws observed by FWC samplers in fish houses statewide had the broken stridulatory pattern, indicating that they were regenerated claws and more than half (52%) of these regenerated claws exceeded 80 mm (3.15 in) in length. The presence of these larger regenerated claws indicates that some crabs survive the loss of their claws. Depending upon the size of the crab and when in the intermolt cycle the crab is declawed, it can take 1 to 2 years for a crab to regenerate a claw to legal size.

- Since the 1962-63 fishing year (the first year with an estimate of the number of traps in the fishery), the number of traps in the fishery has increased more than a hundred-fold -- from 15,000 traps in the 1962-63 year to 1.6 million traps in the 2001-02 year. In the

1998-99 fishing year, FWC employees conducted a physical count of the stone crab traps and found a total of 1.4 million traps, which was twice the number that was estimated in 1992-93. As a response to the rapidly increasing number of traps in the fishery, the Florida State Legislature approved a stone crab trap limitation program in 2000 that was implemented in October 2002. Another measure of effort, the number of commercial trips, also increased from 19,000 in the 1985-86 fishing year (the first year with trip information available) to 38,000 trips in the 1996-97 fishing year and then declined afterwards.

- Catch-per-trap-claimed has fluctuated widely over time, but it has shown a generally decreasing trend. Catch rates dropped rapidly from more than 20 pounds per trap in the 1960s to less than 10 pounds per trap by 1971 to less than 5 pounds per trap by 1983. The catch-per-trap-claimed has been so low that, it declined only slightly since 1983, even though the number of traps doubled.

- Catch-per-trip, available only since the 1985-86 fishing year, was standardized using a generalized linear model (GLIM) to remove confounding effects such as differences in numbers of traps, location or time of the year. The catch-per-trip data declined until the 2007-08 fishing year and then began to increase. As would be expected in a fishery with a closed season, the stone crab fishery has a strong pattern of declining catch-per-trip within each season.

- Catch per trap pulled, also available since the 1985-86 fishing year and standardized with a GLIM, decreased until 2000-01 and then has slowly increased.

- We used two models to evaluate the condition of the stock. First, we developed a surplus production model with landings, in pounds of claws, and the estimated numbers of traps claimed by harvesters from the 1962-63 through 2009-10 fishing years. As expected, the model indicated that the fishing mortality rate was too high, i.e., there were more traps in the fishery than were necessary. Because the crabs are released alive after the legal-sized claws have been removed, estimating a biomass-of-claws benchmark is not relevant. The second model was a modified DeLury model in which we estimated the recruitment that would be necessary to account for the removals from the fishery and from natural mortality. Fishing effort in the DeLury model was the monthly number of commercial trips (continuity model) or the monthly number of traps pulled from the 1985-86 through 2009-10 fishing years. Recruitment to the fishery estimated with the DeLury models varied without trend during this period.

- The status of the stone crab stock is best indicated by the lack of an increase in landings when the number of traps more than doubled. The lack of correspondence between landings and effort indicate that the current level of landings represents all that can be harvested under current environmental conditions, regulations, and fishery practices.

The surplus production model concluded that the fishery is overfishing. These conclusions were the same as those from the 1997, 2001, and 2006 assessments. Recruitment into the fishery has varied without trend over this period. Stone crabs may be resilient because most female stone crabs spawn one or more times before their claws reach legal size, some crabs survive declawing, and the fishery is closed during the principal spawning season. However, because of the reproductive behavior of stone crabs, there is concern for adequate numbers of large, mature males.

- The numbers of traps in the fishery will remain high for some time. Specifically, if the decline in the issuance of trap certificates continues at the present rate (2.57% per year), it will take 37 years for the fishery to reach the Commission's goal of 600,000 traps in the fishery.

- A shortcoming of this assessment, and of all the previous stone crab assessments, is the total lack of recreational data. We know that there is a recreational sector that can either fish five traps per person or catch the crabs while diving but we have no idea of the number of participants or the magnitude of their harvest. In spiny lobster, there is a Saltwater Fishing permit which allows scientists to develop a mail survey to identify recreational fishing pressure and harvest. A similar permit for the recreational harvest of stone crabs would provide similar information and remove a major source of uncertainty in the assessment process.

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Background

Initially, stone crabs were landed as by-catch from spiny lobster traps in the Florida Keys (Schroeder 1924); eventually, markets were developed and the harvesting of stone crabs became a fishery in its own right. The stone crab fishery is atypical in that stone crabs are not killed outright but, rather, legal-sized claws are removed and the crabs are returned to the water alive. Because the crabs are released alive instead of being harvested as whole animals, crabs that survive declawing can regenerate their claws through molting. Regenerated claws that attain legal size subsequently can be harvested. Regenerated claws are distinguished by the different stridulatory pattern on the claws (Savage et al. 1975, Savage and Sullivan 1978). Prior to the 1973-74 fishing year, harvesters were allowed to take one claw from male crabs only. However beginning in 1973, the Florida state legislature allowed harvesting both claws from both sexes of stone crabs, provided that both claws were legal-sized and that the female crabs were not carrying eggs. Because female crabs mature at a relatively small size and because their claws are proportionally smaller than those of male crabs, female crabs spawn one or more seasons by the time their claws attain legal size. However because male crabs have a size-related mating hierarchy, probably few males have mated before they attain legal size (Gerhart and Bert 2008). Both male and female stone crabs are also protected from harvesting during the principal part of the spawning season but not during either the spring or fall mating seasons (Gerhart and Bert 2008). The principal stone crab spawning season varies with latitude, extending from April through September in the north of Florida and from March through October in the south (Bert in preparation).

Harvesters in Florida catch two species of stone crabs *(Menippe adina* and *M. mercenaria*) and their hybrids. Based on the extent and pattern of species distributions and hybridization, as well as on patterns of fishing activity and landings (discussed later), Florida waters can be divided into seven stone crab fishing regions (Figure 1). Stone crabs in Florida Panhandle waters are principally *M. adina* and *M. adina*-like hybrids. Both species and all forms of hybrids inhabit Florida Big Bend waters. West-central Florida waters are populated principally by intermediate and *M. mercenaria*-like hybrids and by *M. mercenaria*. Stone crabs comprising the southwest Florida and the Florida Keys population are *M. mercenaria*, with a low percentage of intermediate and *M. mercenaria*-like hybrids and a few *M. adina*-like hybrids.

Most early studies of the stone crab fishery were conducted by either staff working for the precursors to the Florida Fish and Wildlife Conservation Commission (FWC) (e.g., Savage et al. 1975, Sullivan 1979), Florida Sea Grant (Bert et al. 1978), or the National Park Service (Davis et al. 1978, Bert et al. 1986). In 1981, the Gulf of Mexico Fishery Management Council (GMFMC) developed a fishery management plan for the stone crab fishery in the Gulf of Mexico (GMFMC 1981). After that, NOAA Fisheries (then named the National Marine Fisheries Service,

NMFS) staff analyzed the fishery for the GMFMC (Powers 1982; Phares 1985, 1989; Bolden and Harper 1992; Bolden 1993) and staffs in the FWC and its precursors analyzed the fishery within state territorial waters (Muller and Bert 1997, 2001; Muller et al. 2006).

Regulations

Stone crabs are regulated in Florida under Florida Administrative Code, Chapter 68B-13 as well as the GMFMC Stone Crab Fishery Management Plan. The statute covers *Menippe mercenaria, M. adina* and their hybrid forms. Only claws 2-3/4 inches (or 70 mm) propodus length can be removed. Propodus length is measured as a straight line from the junction of the elbow and "hand" (the crushing part of the claw) to the tip of the lower immovable finger of the hand (F.A.C. 68B-13.007(1). Not only is it unlawful to remove claws from egg-bearing female stone crabs, but it is illegal to have any egg-bearing female stone crabs on board a vessel. The open season is from 15 October through 15 May. Additional regulations include specific requirements for the of design and construction of traps, a date when the traps can be initially deployed at the beginning of the fishing season, descriptions of how the harvested crabs are to be treated onboard crabbers' vessels, notification requirements of the Division of Law Enforcement for post-season trap retrieval, prohibition on the use of spears or hooks to capture stone crabs, requirements for marking buoys and vessels , and the requirement to possess a Saltwater Products License (SPL) with a stone crab (X) endorsement and a restricted species (RS) endorsement. The recreational harvest of stone crabs is restricted to a daily bag limit of one gallon of claws per person or two gallons of claws per vessel and using a maximum of five traps per person. Recreational traps must meet all commercial trap design criteria and be marked with, a buoy bearing the letter "R" together with the name and address of the recreational crabber (unless the trap is fished from a dock). Recreational traps must be pulled manually during daylight hours only.

The passive-reduction stone crab Trap Limitation Program (TLP) implemented in 2002-03 reduces the numbers of traps in the fishery when the ownership of trap certificates is transferred. When stone crab trap certificates are transferred, the number of certificates received by the purchaser is reduced by a percentage that depends upon the statewide total number of trap certificates available to harvesters. This provision is in effect until the total number of available trap certificates per fishing year is reduced to the commission's goal of 600,000 certificates.

The GMFMC voted in October 2010 to repeal the stone crab FMP in the Gulf of Mexico, transferring the management of stone crabs to the State of Florida. State regulations would be extended to cover federal waters. This change takes effect October 24, 2011.

Landings

Although some people capture stone crabs for recreation by diving or trapping, stone crab landings data are available only from the commercial sector of the fishery. In the absence

of data on recreational landings, we assume that recreational landings follow similar trends as commercial landings.

Historical landings

To provide a context for understanding today's fishery, we retrieved historical commercial landings by calendar year, beginning in 1895 from various sources (Reports of U.S. Commissioner of Fisheries from various years 1896-1924; U. S. Bureau of Fisheries, 1925-37; State Board of Conservation Biennial Reports, 1941-50; NOAA Fisheries' website: http://www.st.nmfs.gov/st1/, 1950-2009; and FWC trip tickets, 1986- May 2010 including all trip tickets that had been received by FWC through 14 April 2011 (Batch 1095)). The landings data are considered final even though a few trip tickets inevitably show up later.

On a calendar year basis, the landings of stone crab claws increased until they reached a plateau around 3.2 million pounds from 1992 to 2001 after which landings decreased until 2005 and, more recently, have averaged 2.6 million pounds (Figure 2). Savage et al. (1975) said that the Florida stone crab landings in 1973 came from the coastal region starting in Franklin county in Northwest Florida extending around the peninsula to Brevard county in Northeast Florida (Figure 1); and of those landings, most (73%) came from Collier and Monroe counties. Since the implementation of the TLP in 2002-03, essentially all statewide landings have continued to come from the counties along the gulf coast (99%, coefficient of variation (CV) = 0.3%). Landings from Collier and Monroe counties have declined to an average of 53% of the statewide landings. This assessment focuses only on landings from the gulf coast fishery which represent 99% of the state wide landings of this fishery.

To assess the fishery over time within fishing years, we used monthly landings of stone crab claws by county from the NOAA Fisheries' General Canvass and Florida's Marine Resources Information System (trip ticket) program. Port samplers from NOAA Fisheries collected monthly landings and value from wholesale seafood dealers during the fishing season for the General Canvass program. These monthly data are available in digital form since January 1978. Fishery dependent data (catch and effort) for the 1985-86 through 2009-10 fishing years came from FWC's trip ticket program. Landings by fishing year (October through May) prior to 1978-79 were taken from the GMFMC Stone Crab Fishery Management Plan, which presented revised landings from Florida's gulf coast from 1962-63 through 1977-78 (Table 5-2, GMFMC 1981). Thus, we were able to piece together a time series of landings of claws and numbers of traps claimed by harvesters by fishing year from 1962-63 through 2009-10.

Landings of stone crab claws by fishing year show the typical pattern of fishery development – increasing until reaching a peak and then declining (Tables 1, Figure 3a). We used a Loess regression (SAS 2008, bandwidth = 0.281) to smooth the landings (Figure 3b). Landings were less than 0.5 million lb per fishing year on the gulf coast until 1967-68. Landings reached 1.0 million lb by 1973-74 and continued to increase until reaching a plateau of 3.2 million lb of claws from 94-95 through 1999-2000, and then they declined through 2009-10. In 2009-10, the gulf coast landings of stone crab claws were 2.4 million lb and the Atlantic coast

landings were 38,000 lb.

When landings are compared to the number of traps claimed by the harvesters (Figure 4), it is apparent that landings from the developing fishery tracked the increasing number of traps quite closely up to 3.1 million lb in the 1992-93 fishing year taken with 777,000 traps (Table 1). A piecewise regression on these data estimated the pivot point at 737,000 traps (landings = 3.3 million lb of claws; $F = 97.06$; $df = 3,44$; $P < 0.05$) which would have occurred between 1991-92 and 1992-93. Although the number of traps has more than doubled since then, landings have only increased 0.4 million lb, reaching a peak of 3.5 million lb in 2000-01 and then declining afterward. A feasible explanation for the lack of relationship between the number of traps and landings at high numbers of traps is that the crabbing grounds can support a certain number of stone crabs and additional traps only compete with each other for those crabs. The lack of a corresponding increase in landings with increased numbers of traps was the genesis of the TLP.

As with the spiny lobster fishery, gulf coast landings at the beginning of the fishing year in October serve as a good predictor of the season's total landings. The equation for stone crabs is:

$$\text{Landings}_{FY} = 3.00\ \text{Landings}_{October} + 1{,}350{,}000 \qquad (1)$$

where Landings_{FY} is pounds of claws landed for the fishing year and $\text{Landings}_{October}$ are the pounds landed between October 15 and October 31 of the fishing year (Figure 5). The regression of the season's landings on October landings was significant when tested with an F-test of the variance explained by the model versus the variance not explained by the model (Zar 1996; $F = 137.0$, $df = 1, 30$, $P < 0.05$). The regression explained 82% of the variance ($R^2 = 0.82$) of the predicted season's landings.

The Trip Interview Program (TIP), expanded in 1996, record morphological data from stone crab claws in commercial fish houses. In addition to recording claw lengths, the program also records the claw break quality (clean or forced), the type of claw (crusher or pincher) and if the claw was regenerated. On the gulf coast, an average of 31% of the claws, weighted by the regional landings, had forced or bad breaks and that percentage was similar over the time period (t-test that the slope of the line fitted to the points differed significantly from zero, $t = -0.90$, $df = 12$, $P = 0.39$). Simonson and Hochberg (1992) observed a similar percentage (30%) in the 1983-84 and 1984-85 fishing years. Improper breakage of claws frequently causes death or severely disrupts growth (Savage and Sullivan 1978). Samplers also noted that approximately 13% of the claws that they observed in fish houses had the broken stridulatory pattern indicative of claws that were regenerated. The presence of regenerated claws, especially those with claw lengths exceeding 80 mm (Figure 6), indicates that some crabs survive the 1-2 years that it takes for a crab to regenerate a claw to legal size after fishery harvest.

Geographical Distribution

In contrast to our previous stock assessments (Muller and Bert 2001, Muller et al. 2006) we separated Monroe County (Florida Keys) from the Southwest Region to refine the spatial resolution in this stock assessment.

Landings by region are shown in Table 2a and Figure 7. The majority of Florida gulf landings have consistently come from the Florida Keys and Southwest regions; but the proportional contributions of those regions, particularly that from the Florida Keys Region, have decreased from the high levels of the 1990's. The Tampa Bay Region contributes a low and variable proportion of the total fishing-year landings; and, generally, higher proportions of statewide landings come from that region in years when overall landings are high. The Crystal River Region generally ranks as third-highest in production, vacillating around 20% of the total yearly production. The Big Bend Region has consistently produced about 5-10% of the yearly landings.

The average depth of trap placement also differed among regions (Figure 8). The mean depth of traps set by harvesters in the Southwest Region was the deepest (16 m or 34 ft), followed by the Florida Keys (12 m or 25 ft), Tampa Bay (11 m or 24 ft), and Crystal River (10 m or 22 ft) regions; and the shallowest mean depths fished were in the Panhandle (6 m or 13 ft) and the Atlantic coast (7 m or 14 ft) regions. This variation in mean depth is due to a combination of differences in age and intensity of the regional fisheries and submarine topography. The Southwest and Florida Keys regions have been fished the most intensely for the longest time periods as compared to the peripheral fisheries in and the Panhandle and Atlantic-region fisheries.

Effort

The measures of effort available in the stone crab fishery for each fishing year are the numbers of harvesters with reported landings, the number of traps claimed by an individual harvester, the number of commercial trips reporting stone crab landings, and the estimated numbers of traps pulled per fishing year.

Numbers of Participants

The most straight-forward way to count the number of commercial participants is to tally the Saltwater Products License (SPL) numbers from trip tickets with reported landings of stone crab claws by fishing year. During the 1986 session, the Florida legislature allowed the SPLs to be retained and by the 1987-88 fishing year, very few trip tickets with stone crabs landings did not have accompanying SPL numbers.

Statewide, the total number of SPL holders who landed stone crabs in a given fishing year increased to more than 1,900 by 1993-94, varied around that level until 1996-97 and then declined afterward (Table 2c, Figure 9). The number of SPL holders statewide with landings of

stone crabs in the 2009-10 fishing year was 865 harvesters. Similar to the numbers of stone crab harvesters statewide, the numbers of SPL holders within regions have been decreasing in recent fishing years, especially after the mid-1990s (Table 2c; Figure 9). The Big Bend to Florida Keys regions accounted for 90% of the harvesters in 2009-10. By far, the greatest reduction in stone crab harvesters has been in the Florida Keys Region, which now has less than half of the stone crab harvesters that were licensed in the 1990's. In contrast, the numbers of licensee reductions in the Tampa Bay, Crystal River, and Big Bend regions have been far fewer, but proportional changes have been similar to that of the Florida Keys Region.

Numbers of Traps and Catch-per-Trap

We obtained estimates of annual total number of traps from various sources. Before the TLP was implemented in 2002-03, the measure of annual effort typically used in this fishery came from the NOAA Fisheries General Canvass and was the estimated number of traps reported by wholesale dealers who had stone crab harvesters as suppliers to their fish houses. After implementation of the TLP, the estimated annual number of traps was the number of stone crab trap tags that harvesters purchased from the FWC each fishing year. For those fishing years prior to 2002-03 that lacked the numbers of traps, the estimates are as reported in the 2001 assessment (Muller and Bert 2001).

Over forty years, the number of traps in the stone crab fishery increased a hundred-fold from less than 15,000 in the 1962-63 fishing year to approximately 1.57 million in the 2002-03 fishing year (Table 1, Figure 3a). The number of traps doubled during the 1990s, partly in anticipation of the TLP that was being discussed (Tom Matthews, FWC; personal communication). A physical count of stone crab traps, conducted by FWC staff in September and early October 1998, yielded an estimate of 1.4 million stone crab traps statewide (Matthews and Larkin 2002).

Although the historical fishing-year measure of pounds-per-trap as total landings divided by total estimated number of traps is rough, it reflects the historical development of the fishery (Figure 10a). As is typical for fisheries in the initial stages of development, the catch-per-trap was high but fluctuated markedly in the early years, possibly reflecting inter-annual differences among harvesters or in effort. Except for two anomalous years (1981-82 and 1982-83), the catch-per-trap continued to decline through 2005-06 (when catch-per-trap was only 1.4 lb per trap). Although the low catch-per-trap in that fishing-year was partially due to interruption of the fishery by Hurricane Wilma in late October, catch-per-trap had been low and generally declining for a decade.

When annual pounds-per-trap were plotted against number of traps in the fishery (Figure 10b), the pattern was similar. Considering the potential effects of fluctuations in juvenile survival, predation, and other environmental perturbations, the catch-per-trap should have varied more among years. The stability may be an artifact as harvesters compensated with better navigation equipment, such as GPS coupled to bottom plotters, graphical displays of previous catches by position, and exploration of alternative fishing areas.

Numbers of Trips and Catch-per-Trip

The number of commercial stone crab trips peaked statewide in 1996-97, when 38,442 trips were recorded, and then generally declined (Table 2b).

To evaluate standardized catch-per-trip by fishing year, the pounds on each trip from the gulf coast (Panhandle through the Florida Keys regions) trip tickets were analyzed with a generalized linear model (GLIM) using a gamma distribution and a log link. As in the earlier 2001 and 2006 stock assessments (Muller and Bert 2001, Muller et al. 2006), we only used directed trips, which were defined as one-day trips where stone crab landings accounted for at least half of the total landings on the trip. Any trip that occurred outside of the open stone crab fishing season and trips lacking complete data were also excluded. Goodness-of-fit of the predicted to the observed landings in pounds of claws for the generalized linear model was evaluated with the deviance. The deviance is twice the difference between the likelihood of a particular model and the maximum likelihood with an exact fit of the fitted values to the observations (McCullagh and Nelder 1989). Potential explanatory variables for inclusion in the model were: 1) fishing year; 2) month; 3) geography (six regions); 4) depth category by 25-ft depths, with any depths greater than 175 ft grouped into the "175" category; 5) soak time in five-day increments and any soak times greater than 35 d grouped into the 35-day category; 6) the number of traps by 100-trap categories, with trips using more than 900 traps grouped into the 900-trap category; and 7) the pounds of octopus landed on the trip. By using "greater than" groupings for deep depths and high trap numbers, we are able to include trips that otherwise would be considered outliers. We used a stepwise approach to identify which variables to include in the final model and only included variables that were statistically significant and that reduced the mean deviance (deviance/df) by at least 0.5% (R.I.C.C. Francis, New Zealand National Institute of Water and Atmospheric Research, Ltd., personal communication).

In the final model, the number of traps pulled on the trip explained most of the variability (35.0%) in catch-per-trip; month explained 3.5%, fishing year explained 1.7%, region explained 1.5%, and soak time explained 0.7%; for a total reduction in mean deviance of 42.4%. The depth category and the pounds of octopus landed on the trip did not meet the criteria for inclusion and were excluded from the final model. We estimated the variability in the catch-per-trip estimates using the same method that was used in the 2006 stock assessment (Muller et al. 2006), i.e. a Monte Carlo approach (Poole 1974). In this approach, we used the number of trips per fishing year, least-squares mean catch rates, and their standard errors calculated from the GLIM to generate possible outcomes from the log-linear distribution, which then were back-transformed to an arithmetic scale.

The catch-per-trip on the gulf coast generally decreased over the 25-yr period except for 2007-08 and 2008-09 (Figure 11a); and the change in catch rate was significant (t-test that the slope of the line fitted to the points differed significantly from zero, $t = -3.51$, $df = 23$, $P < 0.05$). A second GLIM was calculated using trip tickets from the Atlantic coast. The standardized catch-

per-trip varied without trend (t-test that the slope of the line fitted to the points differed significantly from zero, t = -1.47, df = 22, P = 0.15; Figure 11b). The high catch rate in 1989-90 may have been due to landings in Florida of claws obtained in the Bahamas. Florida Keys stone crab harvesters participated in exploratory fishing there during that time (T.M. Bert, personal observation).

Traps pulled per year

Powers (1982) and Phares (1985, 1989) noted that the number of traps in the fishery would provide a useful measure of effort if all of the traps were fished the same way and were pulled the same number of times during a fishing year. However, harvesters deploy traps in different areas and vary the length of time they leave traps in the water (soak time), the baits, and the number of times they pull the traps over the fishing season. Therefore our measure of effort is based on the total number of times that traps were pulled per fishing year, accounting for differences among harvesters, months, and regions. The data needed for our calculations were the numbers of traps pulled per fishing trip; but not all stone crab harvesters reported the number of traps pulled on their trip tickets. Since the 1992-93 season, the percentages of trip tickets that included numbers of traps pulled ranged from 34% in the Crystal River region to 83% in the Southwest region; overall, the statewide percentage with the number of traps was 75%. Using the data available, we calculated the numbers of traps pulled for each month and region by dividing the total landings of claws in pounds by the average pounds of claws landed per trap pulled.

The estimated number of traps pulled per fishing year generally increased from the 1985-86 through 1995-96 seasons, remained essentially stable between the 1996-97 and 2004-05 seasons, and then declined until 2008-09 (Table 2d, Figure 12). The recent reduction in effort from that maximum period is principally due to a decline in the number of trap pulls in the Florida Keys and, to a lesser degree, in the northwest regions.

Comparing statewide yearly number of trap-pulls and number of trips, the overall number of trips has declined but the number of traps pulled declined less (Figure 13). After implementation of the TLP, fewer crabbers are pulling more traps per trip; thus, overall effort, as measured by number of traps pulled, has not decreased. Although catch per trap pulled was elevated in 2000-01 and 2001-02, compared with previous and following years (Figure 14a), the smoothed catch rate in pounds of claws per trap pulled by fishing year declined until bottoming out in 2000-01, and then increased (Figure 14b).

Octopus catch rates

The presence of octopi in traps affects catches because octopi are voracious predators on stone crabs, octopi use stone crab traps as dens, and stone crabs avoid traps inhabited by octopi. According to Lindberg et al. (1989), harvesters claim that increases in octopus abundance can depress stone crab landings; but Lindberg and his co-workers were unable to

verify the harvesters' belief. To test whether stone crab catch rates were low when octopus catch rates were high, we calculated (GLIM) standardized octopus catch rates (pounds of octopus per trip) on the gulf coast using trip tickets that reported octopus landings from the gulf coast. The model was configured similar to the stone crab GLIMs. The variables included in the final model and the percentage of the percentage of reduction in the mean deviance that they accounted for were as follows: fishing year (8.5%), region (7.1%), month (4.5%), the number of traps pulled on the trip (3.2%), depth category (2.9%), trip length (0.9%), and soak time (0.5%); for a total reduction in mean deviance of 27.6%. Octopus catch rates demonstrate variability in octopus' relative abundance among years; for example, catch rates were notably higher in the 1985-86 and 1996-97 fishing years (Figure 15a). However, stone crab catch rates were not correlated with octopus catch rates ($r = 0.17$, $df = 22$, $P = 0.41$; Figure 15b). In addition, octopi are caught on only a few hundred trips a year, which is about 1% of the total number of stone crab trips. Octopus can markedly decrease the mean number of stone crabs per trap (FWC/FWRI unpublished data; T.M. Bert personal communication), but the decrease continues over only part of a fishing season and typically occurs only locally or regionally, and not statewide. In addition, octopus outbreaks sweep across an area, generally from offshore to inshore; and stone crabs move to remain ahead of the outbreak, forming high-density "waves" of individuals. Harvesters take advantage of this movement and place their traps in locations where these waves are known or anticipated to occur. High stone crab catch rates in wave areas can compensate for low stone crab catch rates within the area of high octopus abundance.

Population Analyses

Models are used to synthesize information and to identify and summarize patterns. Many fishery models attempt to estimate fishing mortality rates by age and fishing year; however, neither the size-at-age nor length-based models used for finfish and other invertebrate fisheries are appropriate for the stone crab fishery because claw size is not tightly correlated with crab age or crab size for several reasons. Some surviving crabs regenerate claws that can be harvested again; but those claws may be small compared with the size that their original claws would be. Also, claws less than 70 mm that appear as regenerated in TIP surveys may have been lost prior to entering the fishery due to injury. In addition, growth rates in stone crabs are highly variable and females have proportionally smaller claws than do males (Gerhart and Bert 2008). Therefore, we chose two empirical models to apply to Florida's gulf coast data to identify 1) whether landings will continue to increase with increasing effort (surplus production model) and 2) whether there is a trend in recruitment based on monthly landings (DeLury Depletion Model, for examples see Rosenberg et al. 1990, Basson et al. 1996, Sosa-Cordero 2003, González-Yáñez et al. 2006).

Surplus Production Model Catch versus Effort

Surplus production models require only landings in biomass and effort. Two implementations of the surplus production model were developed for the stone crab fishery. In the first surplus production model, we used the longer time series -- stone crab landings from the 1962-63 fishing year through the 2009-10 fishing year and the number of traps claimed by harvesters (Table 1, Figure 4). In the second model, we used the more recent measure of effort (beginning with the 1985-86 fishing year)--numbers of traps pulled per fishing year (Table 3). We did not assume equilibrium in either model because fisheries rarely attain equilibrium (Hilborn and Walters 1992).

A surplus production model is very straight-forward. The biomass next year is a function of the biomass this year plus production from a combination of growth and recruitment decremented for natural mortality less the deaths due to fishing or:

$$B_{t+1} = B_t + rB_t(1 - \frac{B_t}{K}) - C_t \qquad (2)$$

where B_{t+1} is the biomass of claws at time, *t+1*; B_t is the biomass of claws at the beginning of time, *t*; *r* is the intrinsic rate of increase combining growth, recruitment, and natural mortality; *K* is the population carrying capacity or the population size in the absence of fishing; and C_t is the catch in time, *t*. If production, ($rB_t(1 - \frac{B_t}{K})$, is greater than landings then the population biomass increases. The predicted catch-per-unit-effort at time, *t*, $\frac{C}{E}t$, is

$$\frac{C}{E}t = qB_t \qquad (3)$$

and the predicted catch, $\hat{C}_t$ is

$$\hat{C}_t = qE_tB_t \qquad (4)$$

where *q* is the catchability coefficient and E_t is the effort at time, *t*. Fishing mortality during time *t*, is $F_t = qE_t$.

To run the model, we used the surplus production program, ASPIC 5.34 (Prager 1994), from the NMFS Stock Assessment Toolbox. This version of ASPIC uses catch and effort to solve for the fishery benchmark maximum sustainable yield (*MSY*) instead of *r*, the carrying capacity of the environment to support stone crabs (*K*), the catchability coefficient relating the average population size to the catch or indices (*q)*, and the ratio of the initial biomass to the carrying capacity (B_1/K).

For the longer time-series data (Table 1), we used three catchability values: (*q1*) for the

1962-63 through 1972-73 fishing years, (*q2*) for 1973-74 through 1984-85, and q3 for 1985-86 through 2009-10. The change in 1973 was due to the regulatory change that allowed harvesting claws from females as well as males and the removal of both claws if both were legal-sized and the change in catchability beginning in 1985-86 was due to the implementation of the mandatory reporting of landings on trip tickets. Thus, the longer time-series model solved for six parameters (*MSY*, *K*, *q1*, *q2*, q3 and B_1/K).

Uncertainties of the six parameter estimates in the model were evaluated using the bootstrapping option to generate 1000 sets of parameter estimates. In each of the 1000 iterations, the predicted yields for each fishing year were assigned randomly-chosen residuals to arrive at pseudo-yield values which the model used to refit the parameters.

For evaluating stock status, ASPIC produces two benchmarks both of which are based on the maximum sustainable yield (MSY). The first benchmark is the fishing mortality rate that yields MSY (F_{msy}) and $F_{msy} = 2*MSY/K$. The second benchmark is the equilibrium biomass if the stock were fished at F_{msy} (B_{msy}). Because the crabs are returned to the water alive, we have no direct link between landings and stone crab biomass and so the biomass benchmark is not applicable in this fishery which leaves us with only the fishing mortality rate benchmark. Prager (1994) noted that the ratio of fishing mortality to the fishing benchmark was more robust than the actual values because in the ratio the uncertainty due to catchability canceled out. The criterion for evaluating whether the fishery is overfishing the stock is a fishing mortality ratio (F/F_{msy}) greater than 1.0.

The surplus production model using the longer time series data fit the pounds of claws-per-trap-claimed reasonably well, especially after the 1985-86 fishing year (Figure 16a). The catch-per-trap residuals (observed values - predicted values) were mostly balanced but larger in the earlier years (Figure 16b). According to the model, the F-ratio has been above 1.0 since 1996-97 except for one fishing year (Figure 17a) and the surplus production topped out in the mid to late 1990s (Figure 17b). The median fishing mortality ratio of F_{2009}/F_{msy} from the bootstrap outcomes was 1.03 and 558 of the 1,000 outcomes exceeded 1.0 (Figure 18) indicating that the fishing mortality rate in the most recent year, 2009-10, was too high (more traps were deployed than were needed to catch the available crabs).

The fit of the shorter time series data to the model also was good. Residuals were balanced (Figure 19) and the fit of years where the two series overlapped was slightly better (less variation in the residuals) than fit of the model with the longer data series. The fishing mortality ratio generally increased over time until 2000-01 and then has been quite variable (Figure 20a) and the surplus production has declined slowly since 1989-90 (Figure 20b). As did the model with the longer time series, this model also demonstrated that the fishery was overfishing in 2009-10 (median fishing mortality ratio of F_{2009}/F_{msy} = 1.11 and 685 outcomes out of 1,000 outcomes exceeded 1.0, Figure 21). The intrinsic rate of increase, *r*, is a measure of a stock's net productivity and $r = 2\ F_{msy}$. While both versions of the model estimated similar levels of surplus production (Figure 22), the model with the shorter time series estimated far lower stock productivity (r = 0.19) than the model with more years of data (r = 1.99). However with either version of the surplus production model, the conclusion is that the fishery was

overfishing in 2009-10 and had been for more than a decade.

DeLury Model Recruitment Trends

Because the surplus production model indicated that the fishery is overfishing, we wanted to explore whether recruitment to the fishery is decreasing because of the overfishing (i.e., the stock is recruitment overfished). Estimates of recruitment into the stone crab fishery are not as straightforward as in other fisheries because recruits come from two sources: 1) crabs with original claws that have reached legal size and 2) crabs that have been declawed in the fishery or due to natural causes, have survived, and undergone sufficient molts for their regenerated claws to attain legal size.

For continuity with previous assessments (Muller and Bert 2001; Muller et al. 2006), we used the same DeLury Depletion model that was developed in the previous stone crab assessments and updated with data through the 2009-10 fishing year. Using this model, we estimated the number of legal-sized claws needed in the fishery each October to account for the monthly dynamics of landings, effort, natural mortality, and catch rates each fishing year. Model requirements (catches expressed in number of claws) were such that we could only use the shorter time series. To convert monthly landings in pounds of claws to the number of claws that were harvested, we used the average claw weight by size class and two periods (Oct-Nov and Dec-May) from the Trip Interview Program (TIP) fish house sampling (Table 3). Additionally, we used monthly landings in number of claws, number of trips, and standardized catch rates from the shorter time series (85-86 through 2009-10).

The relevant equations in the DeLury Depletion model are:

The number of claws at the beginning of time, t+1, N_{t+1}, is

$$N_{t+1} = (N_t + R_t)e^{-Z_t} \qquad (5)$$

where N_t *is* the number of claws at the beginning of time, *t*; R_t is the recruitment in number of claws at time, *t,* and Z_t is the total mortality per year in time, *t.*

The average number of claws during time t, $\overline{N}_t$, is

$$\overline{N}_t = (N_t + R_t)e^{-\frac{M}{2}} - \frac{C_t}{2} \qquad (6)$$

where R_t and N_t are as before; *M* is the natural mortality rate; and C_t is the landed catch expressed in number of claws.

The predicted catch in numbers during time *t,* $\hat{C}_t$, is

$$\hat{C}_t = qE_t\overline{N}_t \qquad (7)$$

where q is the catchability coefficient that estimates the fishing mortality from one unit of effort; and E_t is the effort expended during time, *t; and* $\overline{N}_t$ is as before. The predicted catch-per-unit-effort is obtained by dividing equation (7) by effort, E_t and the fishing mortality during time, t, F_t, is calculated as $F_t = qE_t$.

In the DeLury model, we used the same natural mortality rate (0.35 per year that was used in the previous assessments based on the maximum age estimates for stone crabs of eight years; Restrepo 1989, Gerhart and Bert 2008). We made a sensitivity run using an alternative value of 0.55 per year from Hoenig's regression (1983) to explore the effect of natural mortality rates on the model and we made a third run using the numbers of traps pulled per month instead of trips as the measure of effort.

The DeLury continuity model fit the monthly pounds per trip data well (Figure 23a). Residuals were balanced (Figure 23b) and the standard deviation of the normalized residuals were all near 1.0 (Francis 2010). Fishing mortality rates paralleled the number of commercial trips (Figure 24a and compare with Figure 13) and the recruitment pattern derived from the model was quite similar to that from the previous stock assessments -- variable but without a trend (Figure 24b, ; t-test for the slope being equal to zero, t = -0.15, df = 23, P = 0.88). Recruitment levels in 2007-08 and 2008-09 were high. When the DeLury model was rerun with a natural mortality rate of 0.55 per year (Figure 25), the fit of the model was slightly better (negative log likelihood = 116.63 vs. 113.92) and recruitment still varied without trend (t-test for the slope being equal to zero, t = 1.57, df = 22, P = 0.13). As expected the recruitment level was higher with the higher natural mortality rate because the model was accounting for the higher number of natural deaths and the fishing mortality rates were correspondingly lower. The DeLury model using the number of traps pulled per month instead of commercial trips (Figure 25) also showed no trend in recruitment (t-test for the slope being equal to zero, t = 0.17, df = 22, P = 0.87). When the three DeLury models were compared by scaling the annual values by their means, the recruitment was consistent across model configurations (Figure 25b, all of the cross-correlations among the models were significant at P = 0.01).

Condition of the Stock

The key indicator of stock condition in this fishery is that landings reached a plateau around 3.2 million pounds (1990-91 through 2000-01 mean) and landings did not continue to increase when the number of traps in the fishery doubled; however, recently landings have decreased with decreasing effort. The surplus production model demonstrated that the fishery is undergoing overfishing. Although there are too many traps in the fishery, the lack of recruitment trends from the DeLury models indicates that the compensation by the stock is adequate to maintain current recruitment levels. A possible scenario is that, given the current fishing practices, there are only so many claws that can be harvested each fishing year from the nearshore crabbing grounds and harvesters compete with each other for those claws. During the season, the depletion rate is partially mitigated because crabs molt and some of those crabs have claws that attain legal size and because some crabs move into the fishing areas from more

widely distributed low density areas. While stone crabs do not exhibit a strict migration pattern, they move extensively (Sullivan 1979) and their movements tend to replenish the nearshore crabbing grounds during the closed season such that crabs with legal-sized claws are once again available when the season opens in mid-October (Figure 23a) even though most crabs with legal-sized claws do not molt during the closed season (Gerhart and Bert 2008).

The number of harvesters and the number of trips have declined in recent years, probably because of the TLP. The number of traps is still excessive and, even with the TLP in place, the passive reduction in numbers of traps means that the numbers of traps in the fishery will remain high for some time. Specifically, when the TLP began eight years ago, FWC issued 1.57 million traps certificates; and in 2009-10, FWC issued 1.31 million certificates. If that rate of decline in the issuance of trap certificates (2.57% per year) continues, it will take 37 years for the fishery to reach the Commission's goal of 600,000 traps in the fishery.

Research Needs

The principal research need for stone crab management and assessment is to continue the fishery-independent monitoring projects; this sampling provides essential information on recruitment, sex ratios of the crabs, detailed catch-per-trap, carapace width, claw size, and numbers of legal-sized claws per crab. These programs are much less expensive than the alternative method for collecting these data -- observer programs.

As mentioned in the assessment, this stock assessment does not contain any information on the recreational fishery. A mail survey similar to that conducted for spiny lobster could be developed if there were some licensing requirement such that FWC could identify participants and then query these individuals regarding their participation and catches which would fill a major data gap.

Research into the spatial and temporal mortality rates of declawed crabs (FWRI research in progress Gandy pers. comm.); habitat usage by sex and different life stages; effects of soak time (some research has been done on this topic; T.M. Bert, unpublished data); stone crab movement patterns; and effects of red tide on stone crabs could provide information to improve future assessments. Funding to support this basic fishery-related research on stone crabs comes from the stone crab endorsement fees. This annual funding initially was solely for the monitoring program and the amount has not been increased since the initial funding was established in 2004.

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LIST OF TABLES

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2	Stone crab landings in pounds of claws (a), number of commercial trips (b), number of Saltwater Products Licenses (c), and number of traps pulled (d) by region and fishing year.
3	Mean weight (lb) of claw size categories by period within fishing years.

Table 1. Historical landings, number of traps, and pounds per trap for the stone crab fishery on the Gulf of Mexico coast of Florida by fishing year.

Fishing Season	Landings Claw Weight (1000 Lbs)	Number of traps Thousands	Pounds per trap
62-63	300	14.6	20.5
63-64	350	15.0	23.3
64-65	310	21.0	14.8
65-66	450	19.7	22.8
66-67	390	43.2	9.0
67-68	560	39.3	14.2
68-69	610	55.9	10.9
69-70	700	36.0	19.4
70-71	870	60.8	14.3
71-72	960	73.7	13.0
72-73	920	113.3	8.1
73-74	1,260	143.0	8.8
74-75	990	159.1	6.2
75-76	1,140	193.2	5.9
76-77	1,430	224.4	6.4
77-78	1,870	267.0	7.0
78-79	1,895	312.2	6.1
79-80	2,011	294.7	6.8
80-81	1,696	275.7	6.2
81-82	2,668	277.6	9.6
82-83	2,698	353.5	7.6
83-84	1,952	432.8	4.5
84-85	1,761	421.4	4.2
85-86	2,166	567.1	3.8
86-87	2,185	577.6	3.8
87-88	2,207	624.0	3.5
88-89	2,591	567.1	4.6
89-90	2,688	565.6	4.8
90-91	3,124	611.3	5.1
91-92	3,166	617.3	5.1
92-93	3,113	777.0	4.0
93-94	3,364	918.2	3.7
94-95	3,274	1107.3	3.0
95-96	2,831	1075.4	2.6
96-97	3,184	1188.3	2.7
97-98	3,475	1246.8	2.8
98-99	3,214	1385.8	2.3
99-00	2,859	1324.6	2.2
00-01	3,534	1370.6	2.6
01-02	3,446	1568.5	2.2
02-03	2,673	1568.5	1.7
03-04	2,592	1534.4	1.7
04-05	3,029	1458.7	2.1
05-06	2,015	1441.9	1.4
06-07	2,646	1410.8	1.9
07-08	3,116	1369.7	2.3
08-09	2,955	1324.2	2.2
09-10	2,408	1307.5	1.8

Table 2. Stone crab landings in pounds of claws (a), number of commercial trips (b), number of Saltwater Products Licenses (c), and number of traps pulled (d) by region and fishing year. These landings are a composite of *Menippe mercenaria*, *M. adina*, and their hybrids.

a. Pounds of claws

Fishing Year	PH -Escambia-Gulf Pounds	BB - Franklin-Levy Pounds	CR - Citrus-Pasco Pounds	TB - Pinellas-Sarasota Pounds	SW - Charlotte-Collier Pounds	KY - Florida Keys Pounds	AT - Atlantic Coast Pounds	Statewide Pounds
85-86	3,857	110,896	384,657	35,420	682,892	948,363	2,919	2,169,004
86-87	114	138,325	459,517	40,447	783,574	762,897	8,149	2,193,023
87-88	249	229,565	381,795	63,161	707,438	824,767	34,096	2,241,071
88-89	1,461	147,674	334,071	98,670	881,767	1,126,941	19,695	2,610,279
89-90	264	99,133	395,459	115,267	758,776	1,318,807	27,135	2,714,841
90-91	407	186,587	612,424	138,782	937,542	1,245,483	30,480	3,151,705
91-92	123	237,036	620,105	131,859	786,540	1,390,022	40,557	3,206,242
92-93	228	137,713	559,068	219,471	833,517	1,362,578	29,033	3,141,608
93-94	342	202,979	534,957	315,159	976,140	1,334,692	57,101	3,421,370
94-95	312	223,376	430,317	192,178	1,126,180	1,301,692	54,008	3,328,063
95-96	403	182,054	403,659	136,551	948,812	1,159,851	38,754	2,870,084
96-97	46	248,818	485,894	399,898	812,917	1,236,165	44,739	3,228,477
97-98	80	261,801	616,652	173,275	910,824	1,512,024	78,038	3,552,694
98-99	39	256,027	691,453	243,079	653,069	1,369,873	37,125	3,250,665
99-00	120	214,644	422,013	151,199	822,609	1,248,435	45,265	2,904,285
00-01	255	183,560	712,130	355,696	1,096,095	1,186,216	53,135	3,587,086
01-02	698	261,417	702,357	193,761	1,065,897	1,221,744	39,338	3,485,212
02-03	561	283,453	628,462	259,719	578,447	922,145	45,990	2,718,776
03-04	77	196,825	427,756	143,113	781,683	1,042,877	28,430	2,620,762
04-05	353	233,321	479,121	274,400	882,634	1,159,010	35,400	3,064,239
05-06	124	210,257	407,547	99,858	592,745	704,195	34,380	2,049,106
06-07	52	337,555	609,533	182,610	558,143	958,510	37,542	2,683,945
07-08	322	482,230	808,575	269,471	724,274	858,169	37,169	3,180,210
08-09	391	451,475	861,076	259,869	827,156	555,430	28,334	2,983,731
09-10	615	261,600	537,409	209,259	736,687	662,380	37,956	2,445,906

Table 2 continued. Stone crab landings in pounds of claws (a), number of commercial trips (b), number of Saltwater Products Licenses (c), and number of traps pulled (d) by region and fishing year. These landings are a composite of *Menippe mercenaria*, *M. adina*, and their hybrids.

b. Numbers of commercial trips

Fishing Year	PH -Escambia-Gulf	BB - Franklin-Levy	CR - Citrus-Pasco	TB - Pinellas-Sarasota	SW - Charlotte-Collier	KY - Florida Keys	AT - Atlantic Coast	Statewide
85-86	20	1,852	2,637	568	3,142	10,795	54	19,068
86-87	4	2,116	3,011	555	4,982	10,727	196	21,591
87-88	8	3,108	3,400	930	5,876	12,431	391	26,144
88-89	26	2,309	2,618	1,125	4,772	13,968	473	25,291
89-90	9	2,192	3,021	1,287	4,258	16,958	713	28,438
90-91	14	2,392	3,370	1,825	4,774	14,931	1,269	28,575
91-92	7	2,400	4,072	1,595	5,966	14,788	1,063	29,891
92-93	3	1,911	3,962	2,272	6,935	14,310	972	30,365
93-94	25	3,060	3,381	2,954	6,979	13,536	1,618	31,553
94-95	24	2,465	2,950	2,628	8,439	14,314	1,763	32,583
95-96	12	2,120	3,408	2,121	9,611	15,167	1,541	33,980
96-97	6	3,014	3,853	3,590	10,826	15,833	1,320	38,442
97-98	7	2,455	4,126	2,450	9,025	16,446	1,521	36,030
98-99	*	2,802	5,101	2,496	7,383	14,956	1,221	**
99-00	3	2,714	4,343	2,348	7,834	16,166	1,378	34,786
00-01	16	2,057	4,233	2,848	8,295	12,105	1,638	31,192
01-02	77	2,093	4,053	2,197	8,724	10,082	1,517	28,743
02-03	81	2,983	4,255	3,052	7,094	11,194	1,622	30,281
03-04	11	2,781	3,585	2,369	7,191	11,284	1,156	28,377
04-05	14	2,447	3,273	2,520	7,012	10,991	1,074	27,331
05-06	8	2,130	3,014	1,717	6,248	8,764	922	22,803
06-07	5	2,243	3,216	3,008	5,469	9,738	804	24,483
07-08	41	2,179	2,823	2,800	4,344	7,992	954	21,133
08-09	61	2,019	2,756	2,282	4,524	4,208	919	16,769
09-10	38	2,033	2,530	2,351	5,174	5,822	999	18,947

* Less than three commercial trips.

** This fishing year had a region with less than three commercial trips.

Table 2 continued. Stone crab landings in pounds of claws (a), number of commercial trips (b), number of Saltwater Products Licenses (c), and number of traps pulled (d) by region and fishing year. These landings are a composite of *Menippe mercenaria*, *M. adina*, and their hybrids.

c. Numbers of Saltwater Products licenses

Fishing Year	PH -Escambia-Gulf	BB - Franklin-Levy	CR - Citrus-Pasco	TB - Pinellas-Sarasota	SW - Charlotte-Collier	KY - Florida Keys	AT - Atlantic Coast	Statewide
85-86	Saltwater Products license numbers were not retained initially							
86-87								
87-88	3	166	148	89	155	855	75	1,491
88-89	13	170	145	114	163	976	86	1,667
89-90	6	156	169	165	160	1,108	99	1,863
90-91	12	133	171	196	150	1,051	129	1,842
91-92	6	152	176	150	193	829	118	1,624
92-93	3	139	154	174	189	727	115	1,501
93-94	5	190	191	267	240	811	196	1,900
94-95	5	176	197	244	280	771	206	1,879
95-96	7	175	171	174	296	772	135	1,730
96-97	4	166	210	266	352	751	124	1,873
97-98	3	148	192	202	273	725	141	1,684
98-99	*	163	207	205	241	673	121	**
99-00	*	154	181	170	229	697	114	**
00-01	*	140	172	208	235	631	130	**
01-02	15	120	155	159	222	551	115	1,337
02-03	16	130	151	172	192	526	126	1,313
03-04	6	114	138	153	181	480	97	1,169
04-05	5	118	127	161	185	459	90	1,145
05-06	3	100	110	103	158	411	94	979
06-07	*	102	117	138	151	436	83	**
07-08	6	108	112	135	130	425	112	1,028
08-09	6	92	98	136	130	267	107	836
09-10	4	112	98	143	131	289	89	866

* Less than three Saltwater Products licenses.

** This fishing year had a region with less than three Saltwater Products licenses.

Table 2 continued. Stone crab landings in pounds of claws (a), number of commercial trips (b), number of Saltwater Products Licenses (c), and number of traps pulled (d) by region and fishing year. These landings are a composite of *Menippe mercenaria*, *M. adina*, and their hybrids.

d. Numbers of traps pulled

Fishing Year	PH -Escambia-Gulf	BB - Franklin-Levy	CR - Citrus-Pasco	TB - Pinellas-Sarasota	SW - Charlotte-Collier	KY - Florida Keys	AT - Atlantic Coast	Statewide
85-86	11,020	298,358	833,171	64,688	1,906,327	3,044,406	20,018	6,177,988
86-87	479	304,013	800,631	85,637	2,765,361	3,395,072	26,869	7,378,062
87-88	1,046	573,883	914,827	197,916	2,796,947	2,093,964	139,535	6,718,118
88-89	2,828	469,335	801,063	181,696	3,792,647	2,726,867	118,551	8,092,987
89-90	220	391,326	892,831	312,853	4,951,800	3,968,589	95,277	10,612,896
90-91	1,589	2,201,086	833,153	295,180	2,241,770	2,315,227	212,256	8,100,261
91-92	517	636,427	1,384,666	356,284	2,667,515	4,611,329	141,549	9,798,287
92-93	1,382	447,406	1,356,012	438,828	2,875,957	4,033,803	133,535	9,286,923
93-94	6,596	697,554	960,811	511,251	2,829,844	3,696,725	293,426	8,996,207
94-95	5,019	565,503	1,182,831	584,865	3,654,462	3,926,496	275,928	10,195,104
95-96	2,105	466,864	1,436,405	418,773	3,723,813	4,109,182	250,886	10,408,028
96-97	193	654,281	1,268,141	635,402	3,855,558	4,240,131	210,995	10,864,701
97-98	1,235	561,663	1,740,020	468,701	3,339,933	4,398,688	295,593	10,805,833
98-99	25	657,880	2,054,238	533,472	2,802,630	4,214,154	233,708	10,496,107
99-00	254	664,229	2,168,438	626,981	2,923,963	4,201,349	227,112	10,812,326
00-01	286	464,109	2,387,897	795,153	3,456,588	3,497,990	322,074	10,924,097
01-02	7,068	540,716	1,608,145	684,530	4,054,210	3,168,972	263,812	10,327,453
02-03	8,220	790,443	1,634,731	916,504	3,158,319	3,485,630	243,110	10,236,957
03-04	1,322	758,771	1,819,144	857,493	5,591,254	3,681,957	170,348	12,880,289
04-05	1,949	708,679	1,905,140	1,048,003	4,833,572	3,678,544	183,664	12,359,551
05-06	727	645,729	2,371,727	583,213	4,920,610	2,179,443	175,065	10,876,514
06-07	450	738,846	2,710,417	1,275,180	4,719,517	3,257,565	122,765	12,824,740
07-08	2,671	838,954	1,539,765	1,377,782	3,844,608	2,695,006	146,829	10,445,615
08-09	3,518	752,243	1,536,091	1,251,140	4,242,209	1,558,981	162,467	9,506,649
09-10	2,610	688,498	1,565,291	1,244,081	4,337,463	2,184,294	173,588	10,195,825

Table 3. Mean weight (lb) of claw size categories by period within fishing years. The periods were identified with Tukey's Studentized range.

Period	Months	Market category	N	Mean (lb)	CV
1	Oct-Nov	Jumbo	865	0.268	0.349
		Large	1346	0.231	0.372
		Medium	468	0.192	0.389
		Small	331	0.147	0.174
		Ungraded	1956	0.244	0.433
2	Dec-May	Jumbo	246	0.346	0.261
		Large	2734	0.201	0.397
		Medium	468	0.192	0.389
		Small	402	0.143	0.177
		Ungraded	601	0.192	0.349

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3	Gulf coast stone crab landings, in pounds of claws, and the numbers of traps by fishing year (a) and gulf coast landings with a loess regression line to smooth the variability in reported landings (b).
4	Relationship between landings of stone crab claws by fishing year and the number of traps claimed by the harvesters.
5	October landings and the total landings by fishing year, in pounds of claws.
6	Sizes, by 5-mm length category, of regenerated claws from fish house sampling, with lengths from combined fishing years and regions.
7	Landings of claws, in pounds, by region and fishing year.
8	Distribution of depths fished by region based on trip tickets.
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15	Standardized octopus catch rates using all gears by stone crab fishing year on the gulf coast (a) and a comparison of the stone crab catch rates with the octopus catch rates by fishing year (b).
16	Fit of the surplus production model using the ASPIC statistical program to catch-per-trap claimed per fishing year (a,~~,~~ observed values – points and estimated values – lines) and catch-per-trap residuals (b).
17	Annual fishing mortality ratio of estimated fishing mortality rate (F) to fishing mortality rate at maximum sustainable yield (Fmsy, a) and annual surplus production with landings in pounds superimposed (b).
18	Distribution of fishery mortality benchmark ratios, F2009/Fmsy, from surplus production model (ASPIC) based on 1000 bootstrap/Monte Carlo outcomes using catch-per-trap data.

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Figure Number	Description
19	Fit of surplus production model (ASPIC) to traps pulled data (a) and traps pulled residuals (b).
20	The ratio of the fishing mortality rate in a given fishing year (F) to the fishing mortality rate at maximum sustainable yield (F_{msy}) (a) and the surplus production together with landings in pounds of claws (b) using the number of trap pulls per fishing year.
21	Distribution of fishery mortality benchmark ratios, F2009/Fmsy, from surplus production model (ASPIC) based on 1000 bootstrap/Monte Carlo outcomes using traps pulled data.
22	Estimated surplus production in pounds of claws from the long and short time series.
23	Observed (Obs, points) and predicted (Pred, lines) monthly landings, in numbers of claws, from the DeLury continuity model (a) and the standardized landings residuals ((observed minus predicted)/σ, b).
24	Fishing mortality rates (a) and recruitment estimates (b) from the DeLury continuity model by fishing year together with recruitment estimates from the 1997, 2001, and 2006 assessments.
25	Estimated recruitment by fishing year from the DeLury model for the continuity model (solid line), natural mortality = 0.55 per year (dashed line), and with effort in monthly numbers of traps pulled (dotted line, a) and the same recruitment estimates scaled to their means (b).

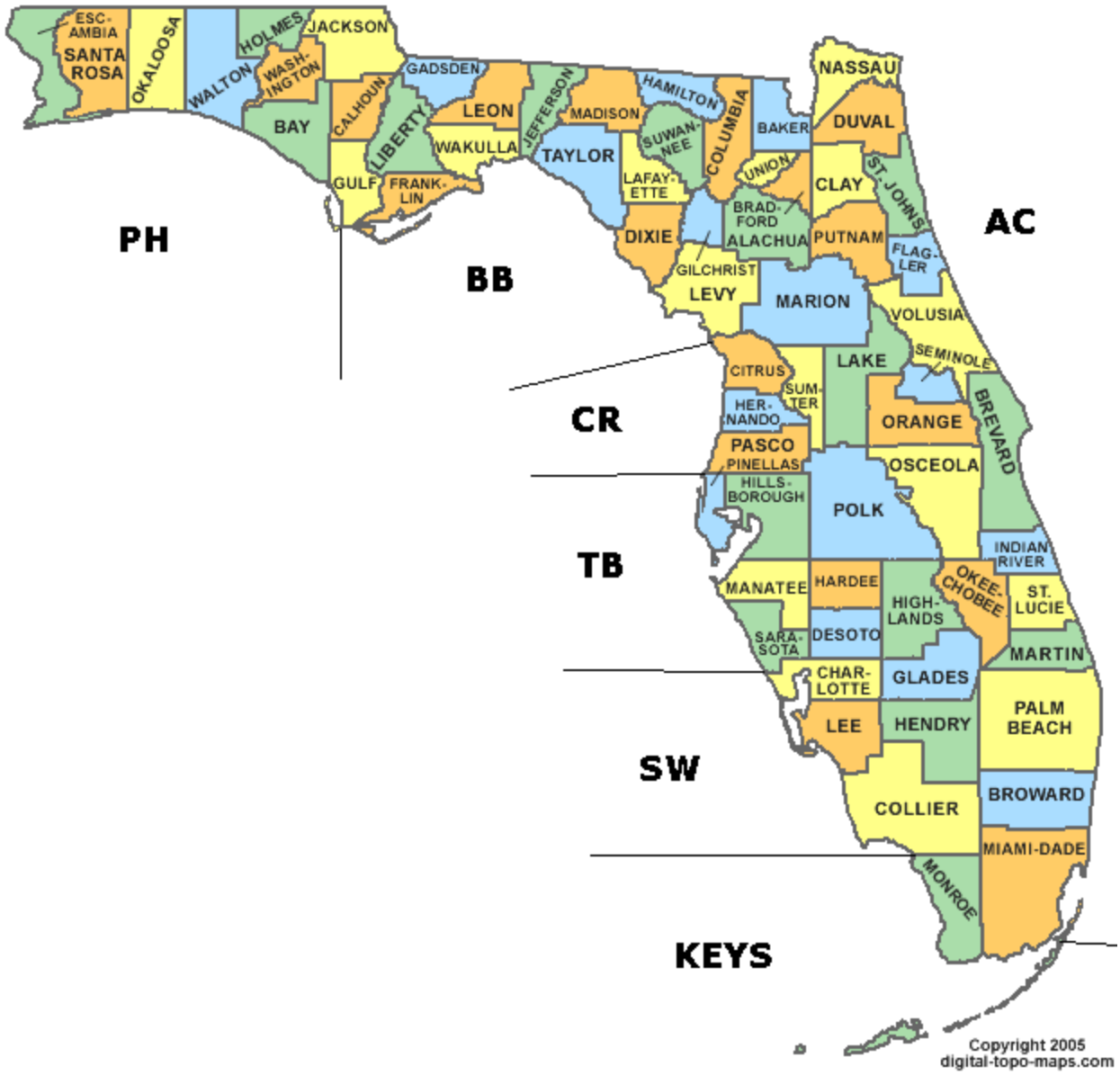


Figure 1. Geographic regions for stone crab landings and effort. PH - Panhandle (Escambia - Gulf counties), BB - Big Bend (Franklin - Levy counties, CR - Crystal River (Citrus - Pasco counties), TB - Tampa Bay (Pinellas - Sarasota counties). SW - Southwest (Charlotte - Collier counties), KEYS – Monroe county (Florida Keys), and AC - Atlantic Coast (Nassau - Miami-Dade counties).

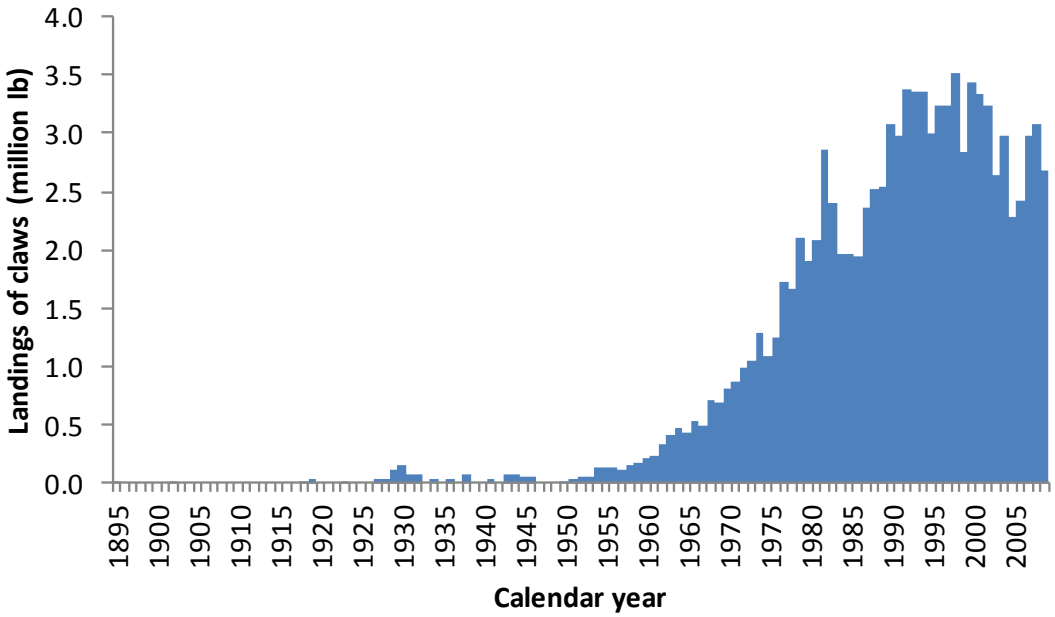
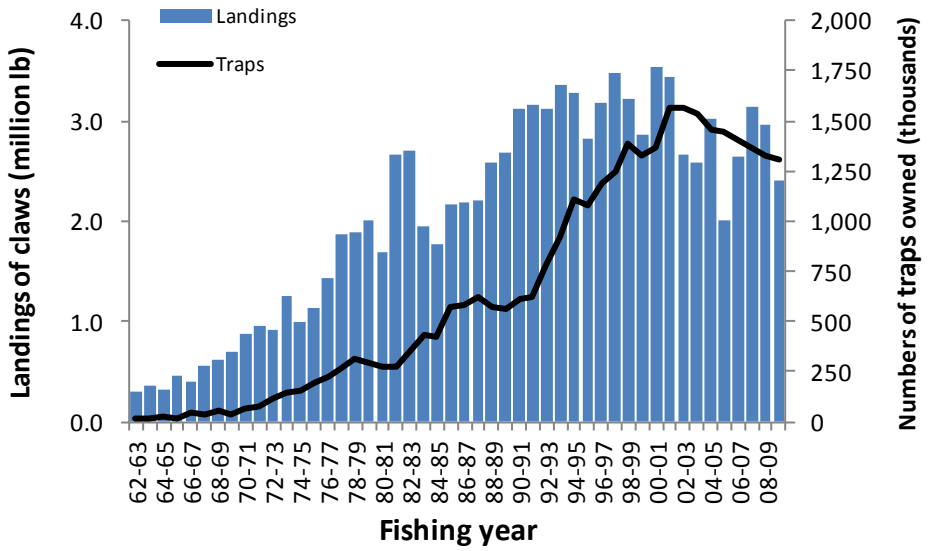


Figure 2. Historical landings of stone crabs statewide, in pounds of claws, on a calendar-year basis.

a.



b.

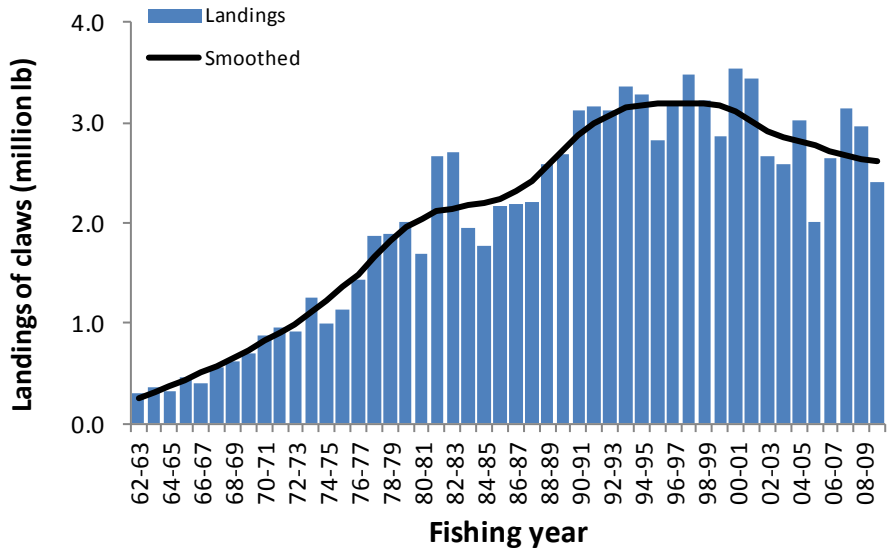


Figure 3. Gulf coast stone crab landings, in pounds of claws, and the numbers of traps by fishing year (a) and gulf coast landings with a loess regression line to smooth the variability in reported landings (b).

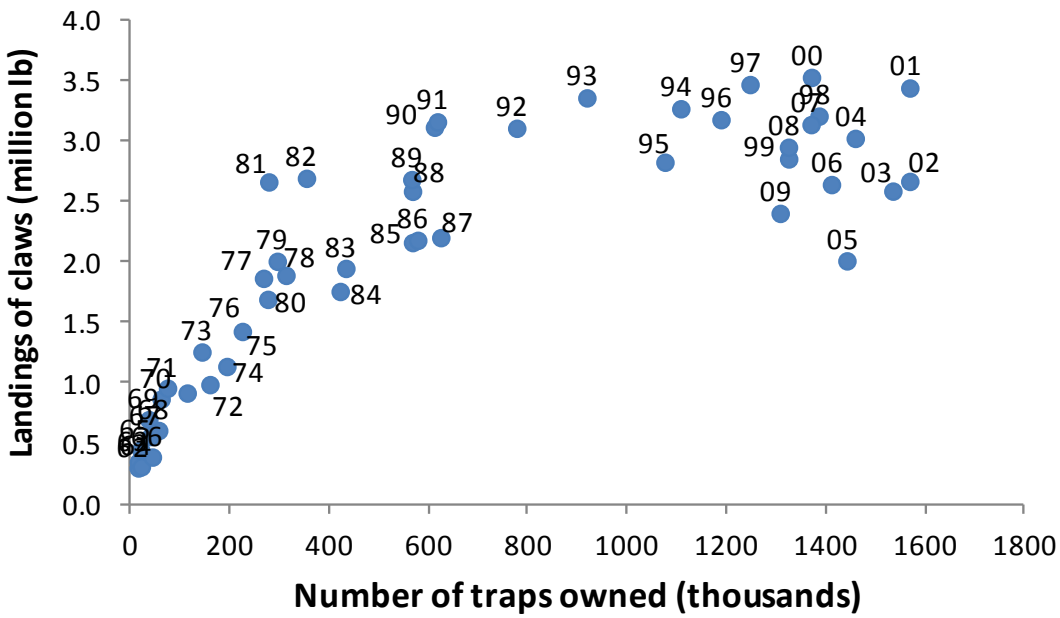


Figure 4. Relationship between landings of stone crab claws by fishing year and the number of traps claimed by the harvesters. The numbers above the symbols are the beginning year of the fishing year.

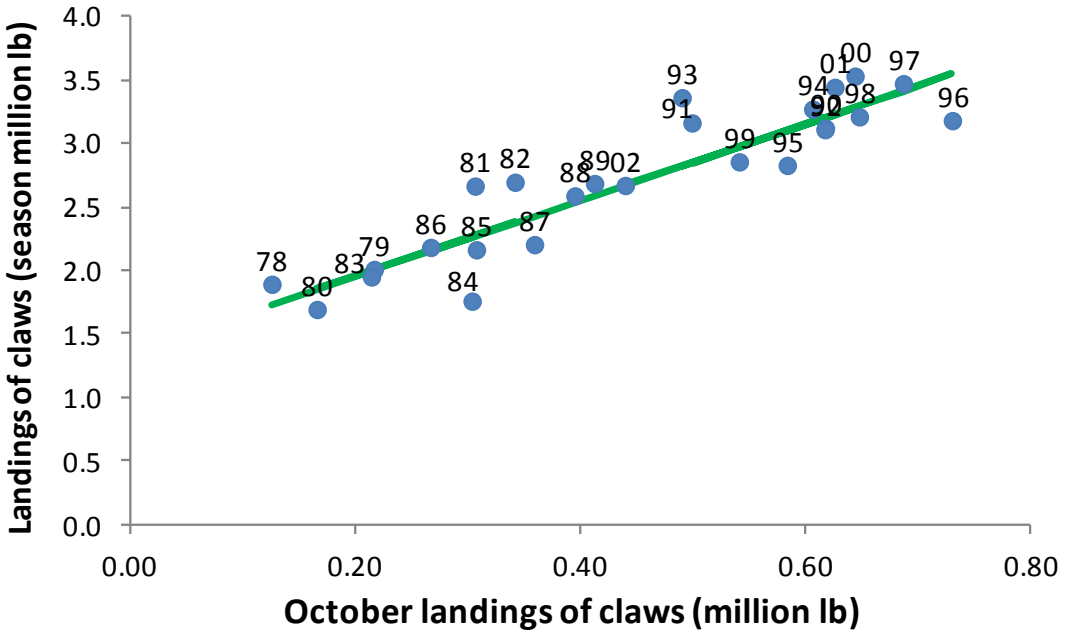


Figure 5. October landings and the gulf landings by fishing year, in pounds of claws. The regression equation for the whole fishing year is:

FY = 3.00 $\text{Landings}_{\text{October}}$ + 1,350,000, (F = 143, df = 1, 30, P < 0.05).

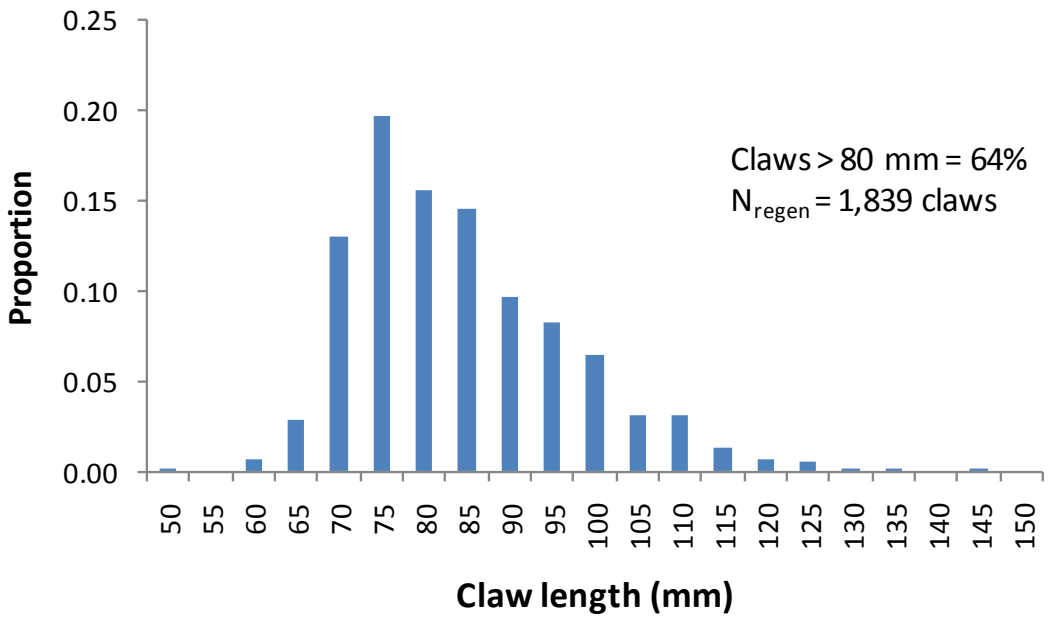


Figure 6. Sizes, by 5-mm length category, of regenerated claws from fish house sampling with lengths from combined fishing years and regions.

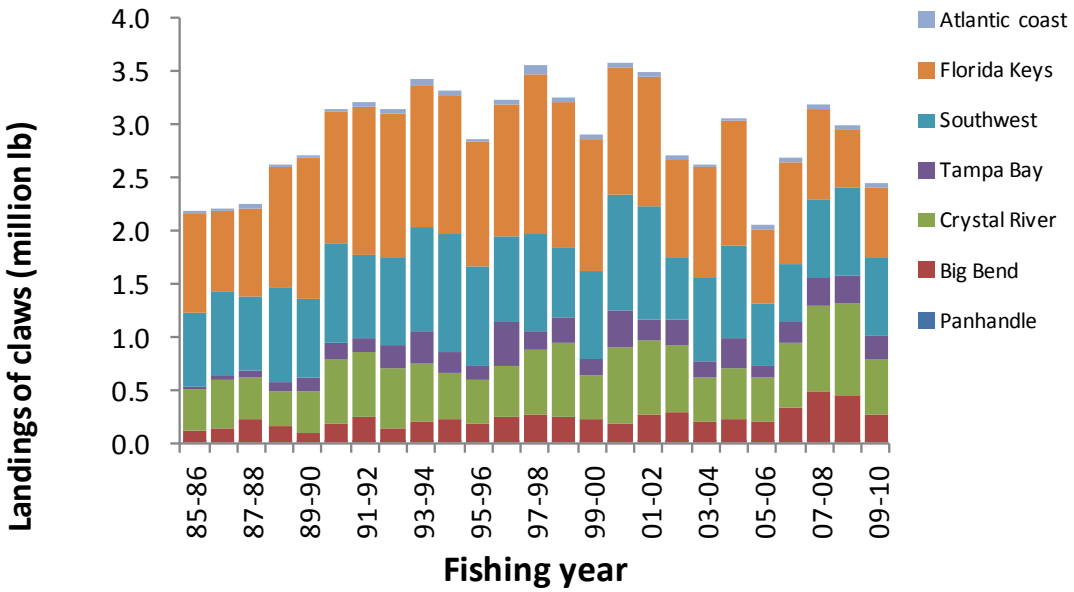


Figure 7. Landings of claws, in pounds, by region and fishing year.

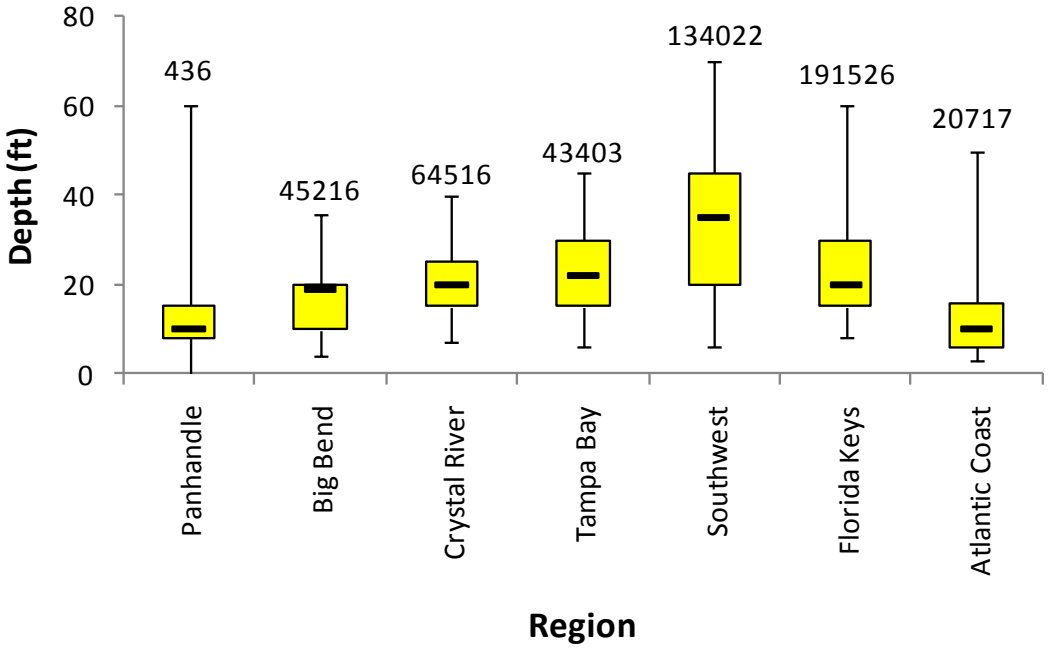


Figure 8. Distribution of depths fished by region based on trip tickets. For each plot, number above the plot - number of trips, vertical bar - 95% confidence interval, box - inter-quartile range, and horizontal line - median.

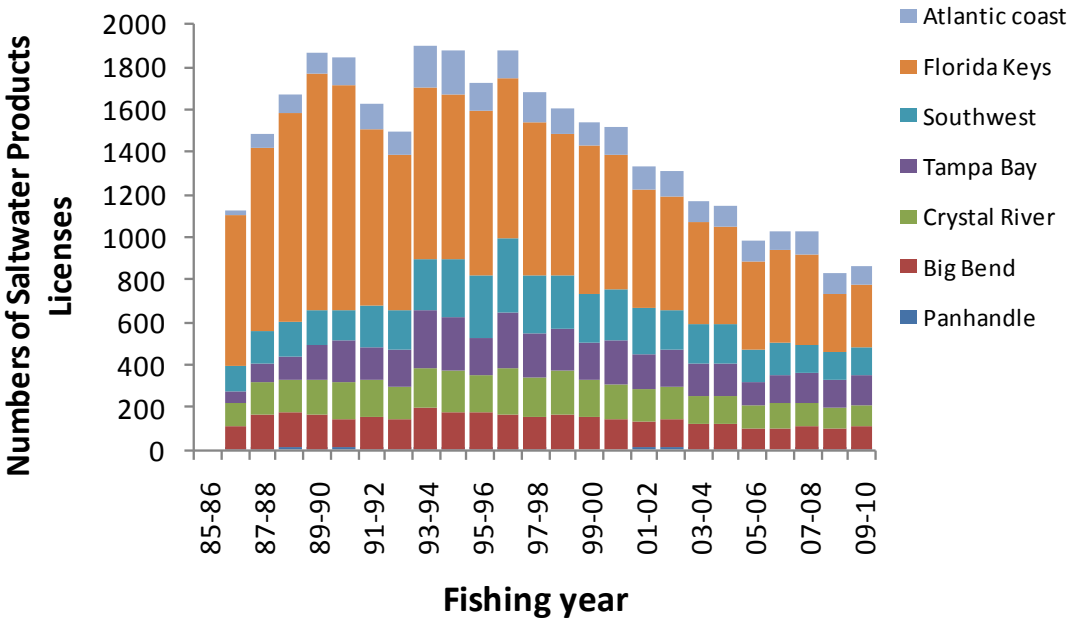
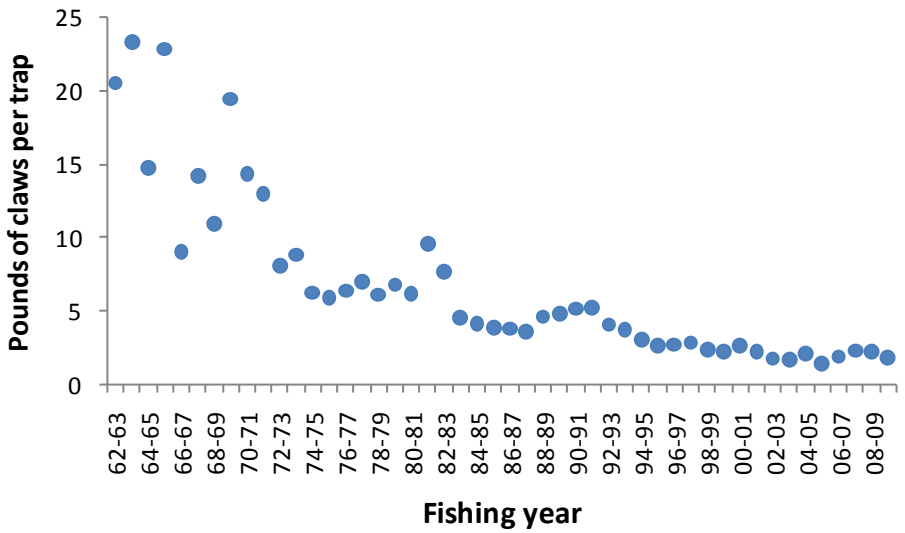


Figure 9. Regional participation (numbers of Saltwater Products licenses with landings) by fishing year.

a.



b.

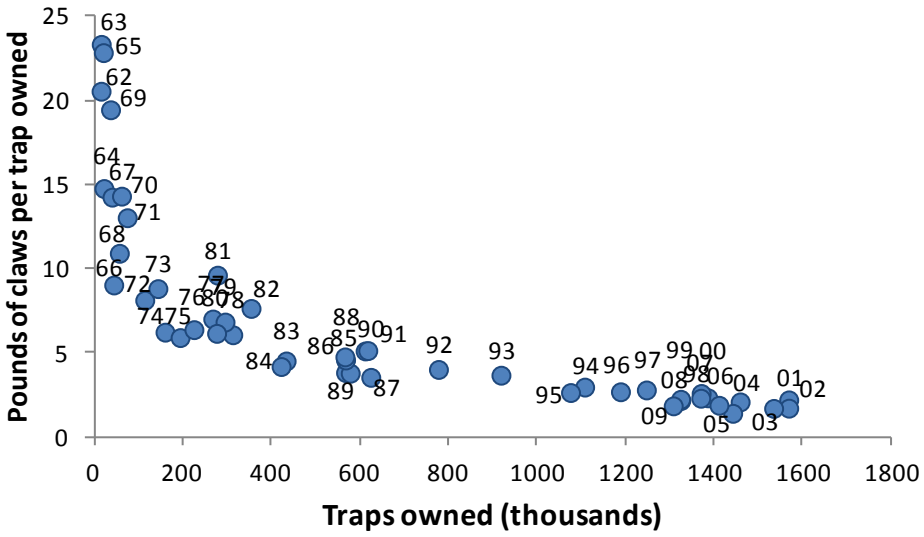
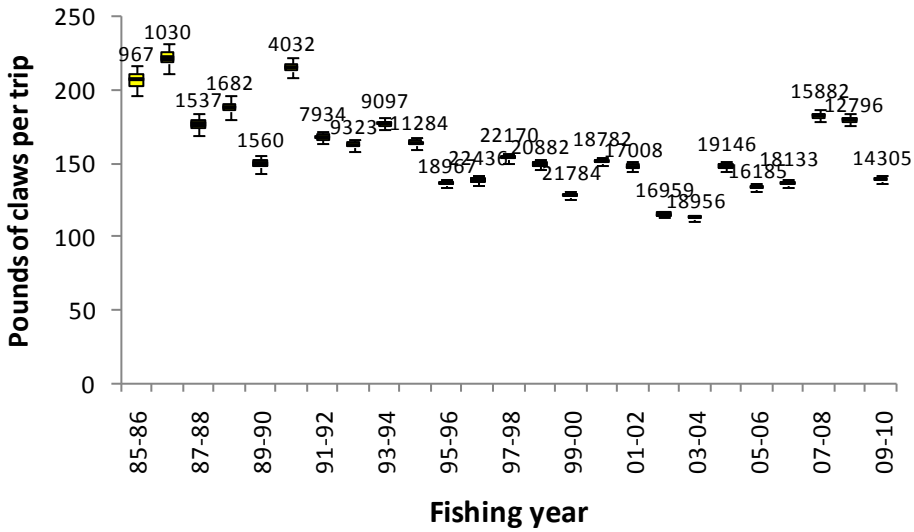


Figure 10. Historical pounds of claws per trap by fishing year (a) and by the number of traps claimed (b, fishing year is indicated above each symbol).

a.



b.

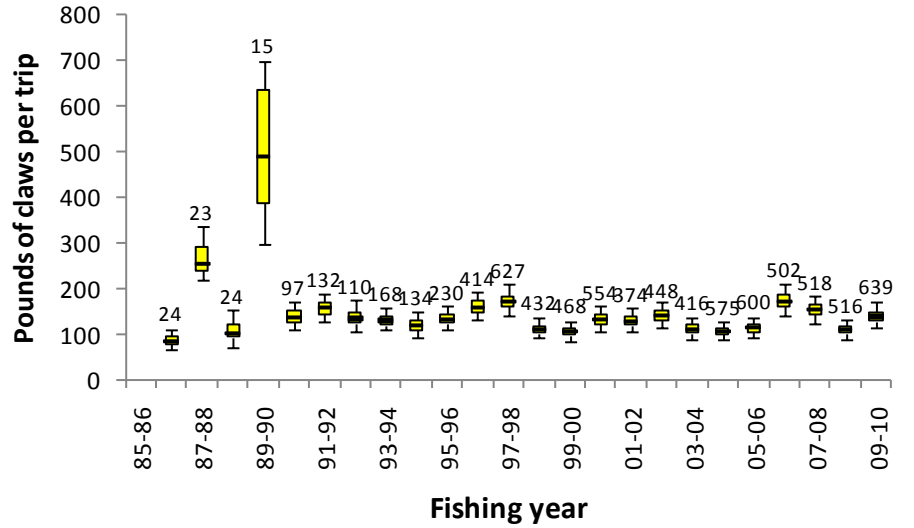


Figure 11. Standardized catch-per-trip for the gulf (a) and Atlantic (b) coasts. For each plot, number above the plot - number of trips, vertical bar - 95% confidence interval, box - inter-quartile range, and horizontal line - median.

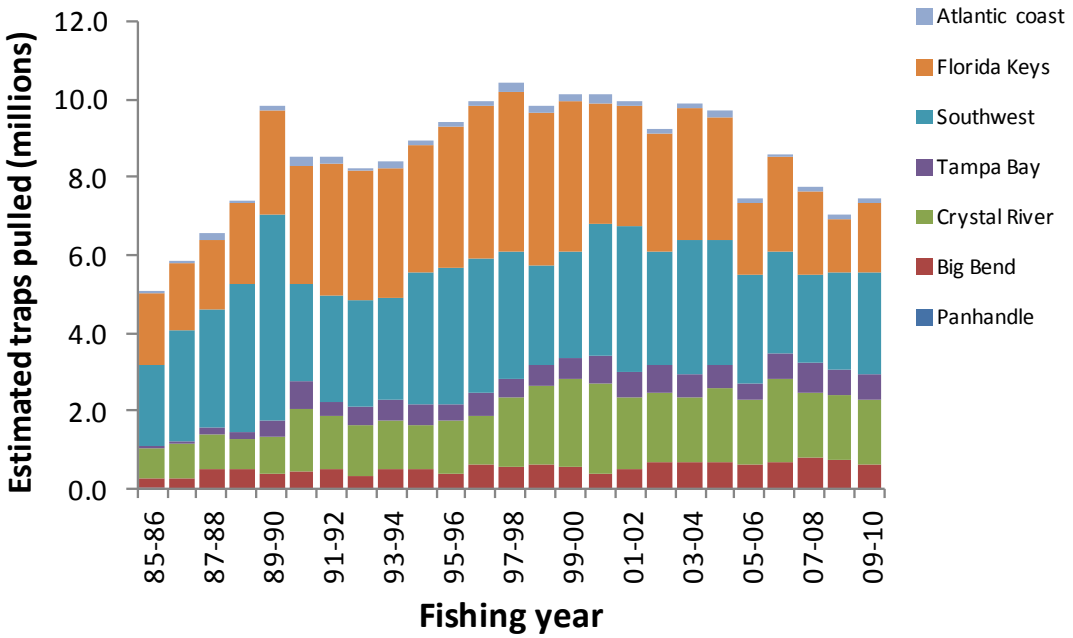


Figure 12. Estimated number of traps pulled per fishing year, by region.

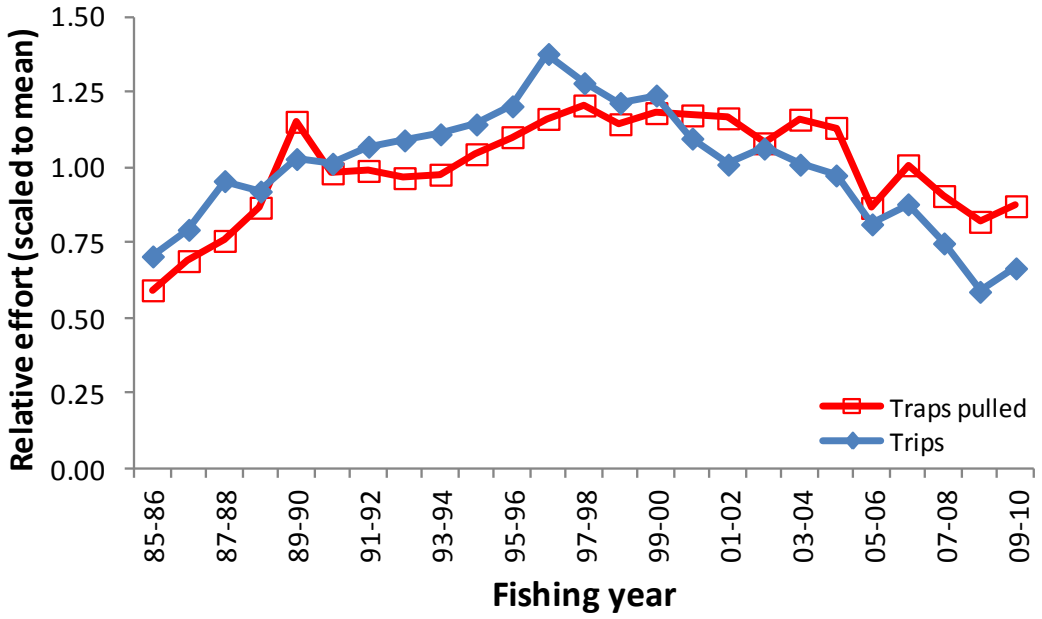
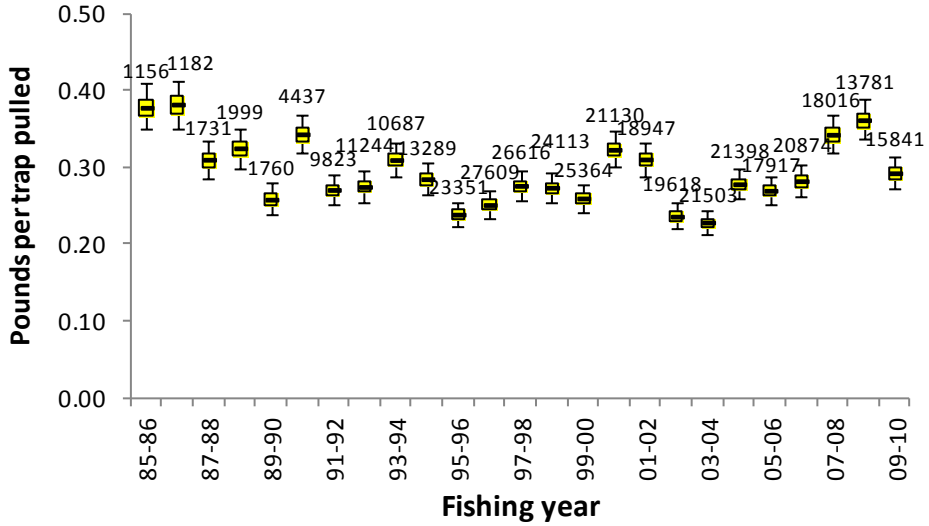


Figure 13. Comparison of the number of traps pulled per fishing year with the number of trips. Both effort series have been scaled to their means to facilitate comparison.

a.



b.

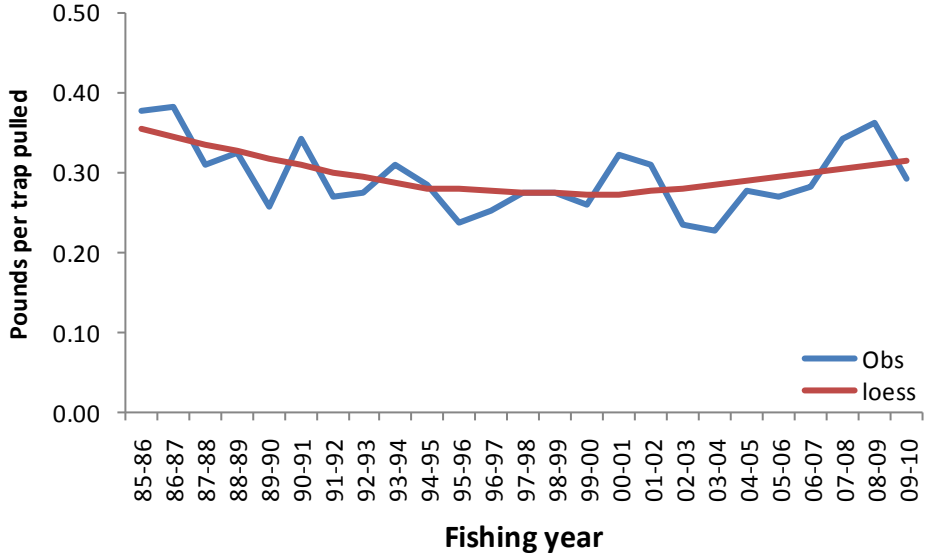
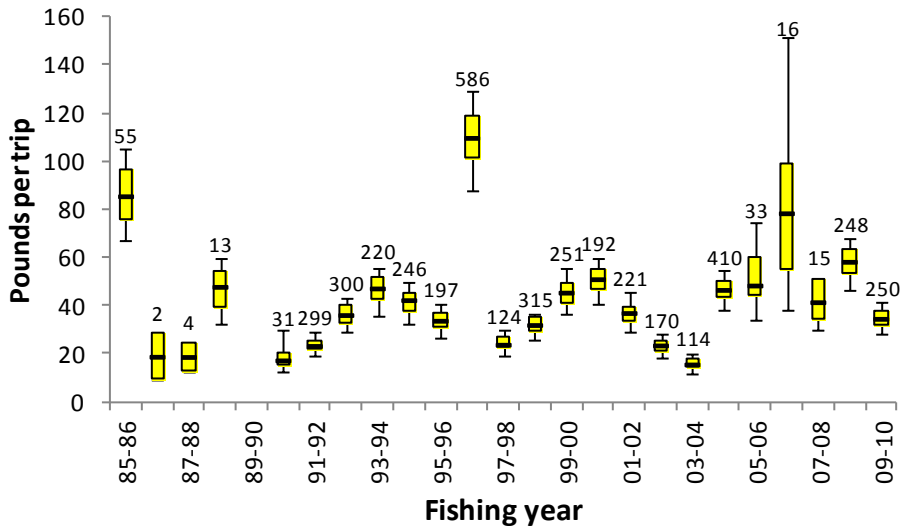


Figure 14. Pounds of claws per trap pulled by fishing year (a) and mean pounds of claws per trap pulled and smoothed pounds of claws per trap pulled from loess regression (b). For each plot, number above the plot - number of trips, vertical bar - 95% confidence interval, box - inter-quartile range, and horizontal line - median.

a.



b.

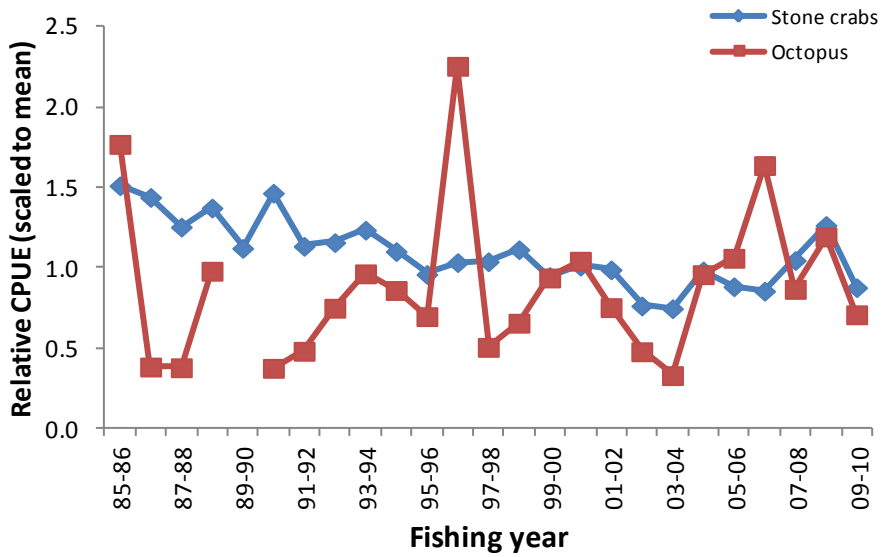
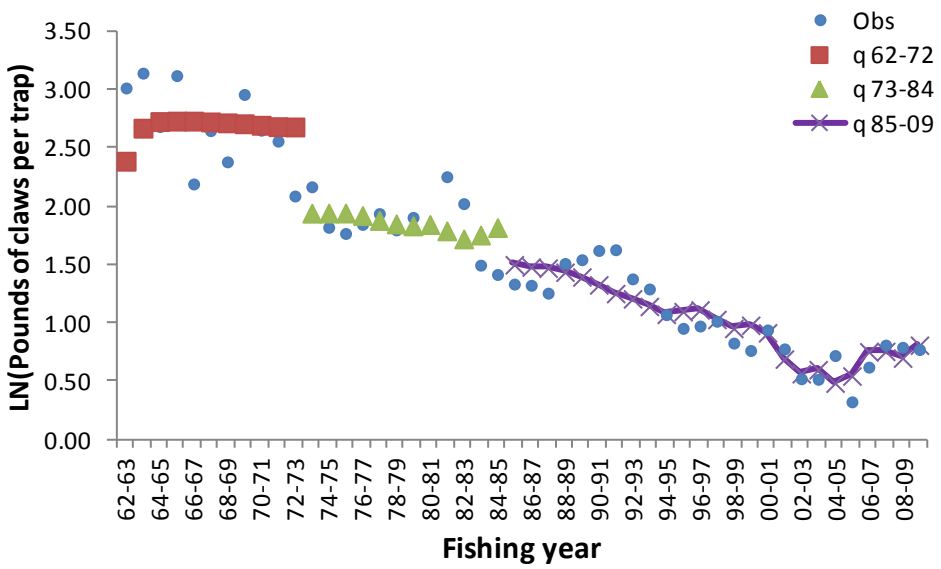


Figure 15. Standardized octopus catch rates using all gears by stone crab fishing year on the gulf coast (a) and a comparison of the stone crab catch rates with the octopus catch rates by fishing year (b). The catch rates were scaled to their means to facilitate comparison. For each plot, number above the plot - number of trips, vertical bar - 95% confidence interval, box - inter-quartile range, and horizontal line - median.

a.



b.

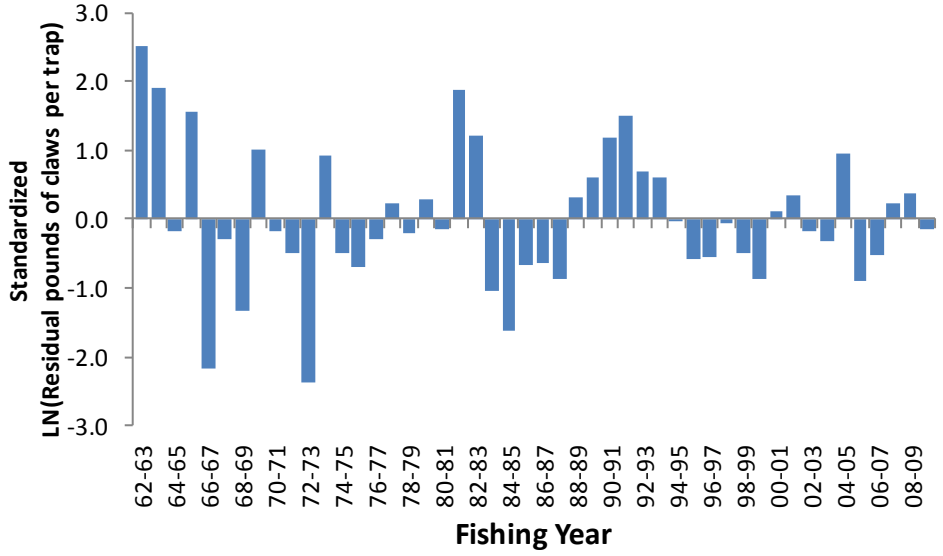
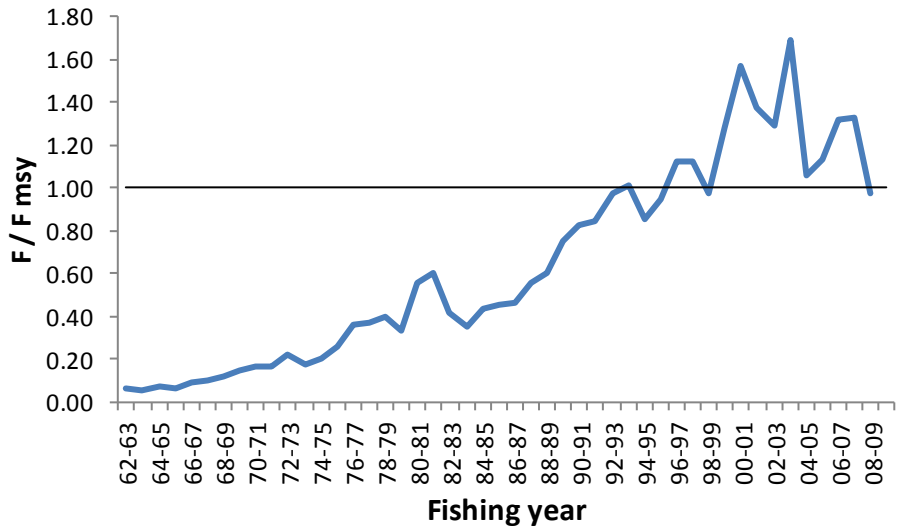


Figure 16. Fit of the surplus production model using the ASPIC statistical program to catch-per-trap claimed per fishing year (a, observed values – points and estimated values – lines) and standardized catch-per-trap residuals (b). The model was calculated using the longer landings time-series (defined in the text) and two catchability coefficients, q1, for the 62-72 through 1972-73 fishing years, and q2, for the 1973-84 fishing years, and q3 for later fishing years.

a.



b.

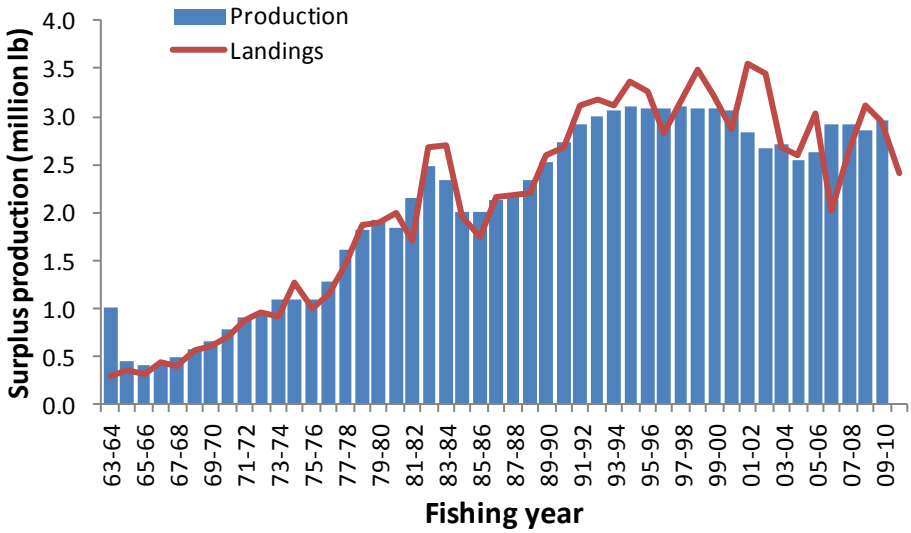


Figure 17. Annual fishing mortality ratio of estimated fishing mortality rate (F) to fishing mortality rate at maximum sustainable yield (F_{msy}, a) and annual surplus production with landings in pounds of claws superimposed (b).

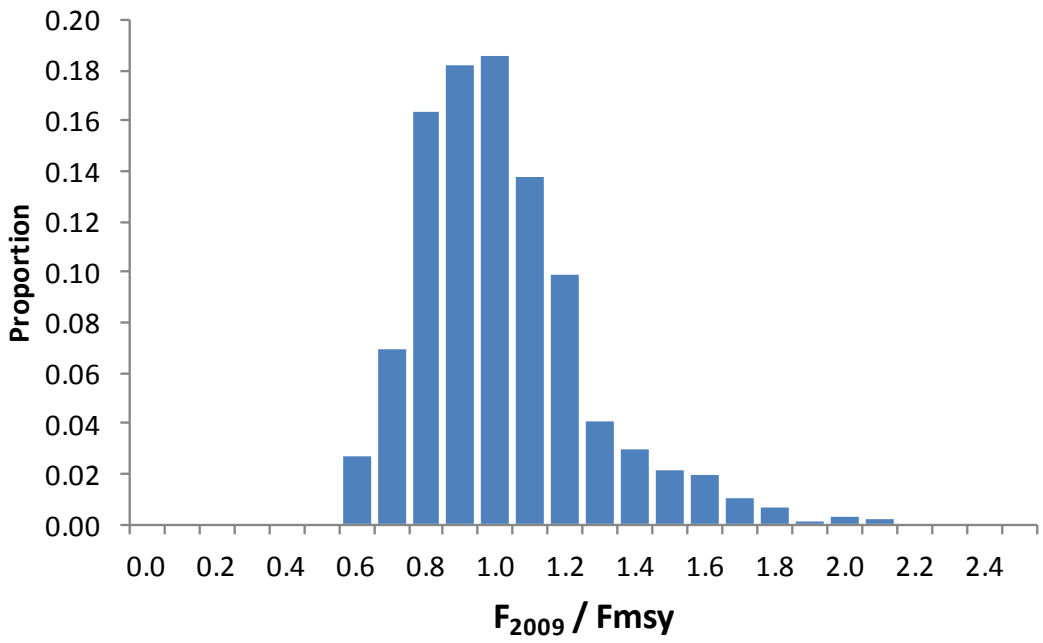
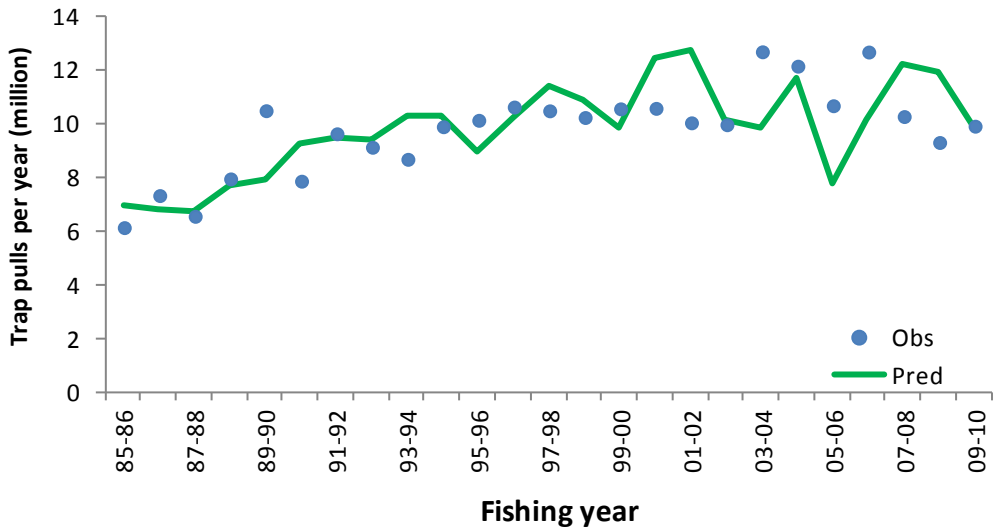


Figure 18. Distribution of fishery mortality benchmark ratios, F_{2009}/F_{msy}, from surplus production model (ASPIC) based on 1000 bootstrap/Monte Carlo outcomes using catch-per-trap data.

a.



b.

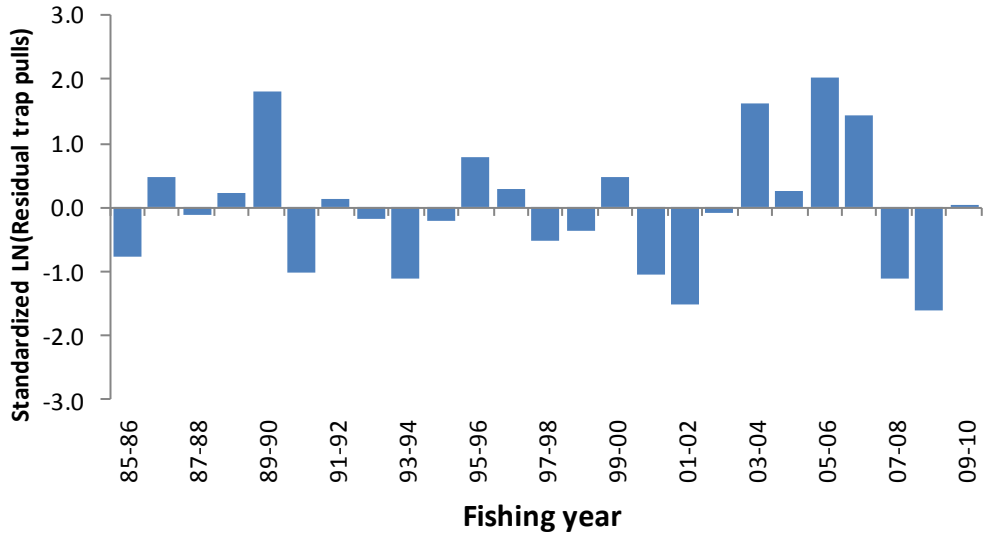
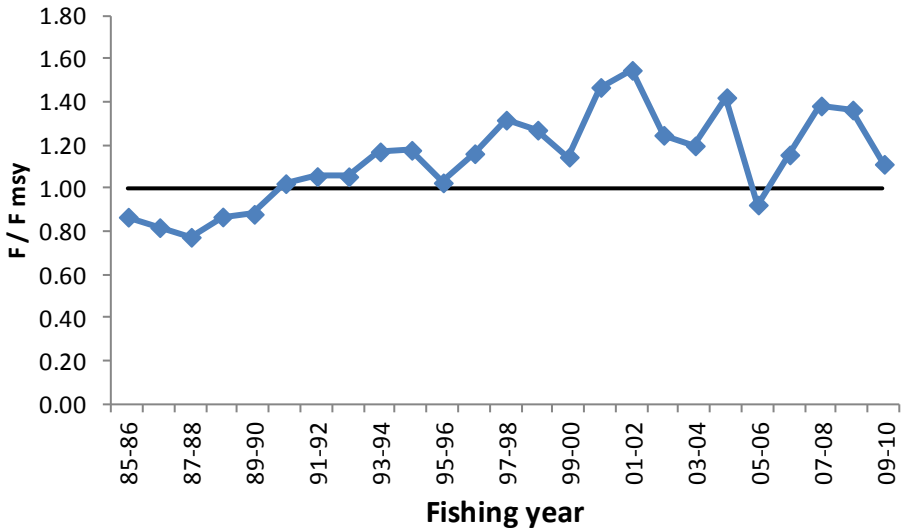


Figure 19. Fit of surplus production model (ASPIC) to traps pulled data (a) and traps pulled residuals (b). The model used a single catchability coefficient for the 1985-86 through 2009-10 fishing years.

a.



b.

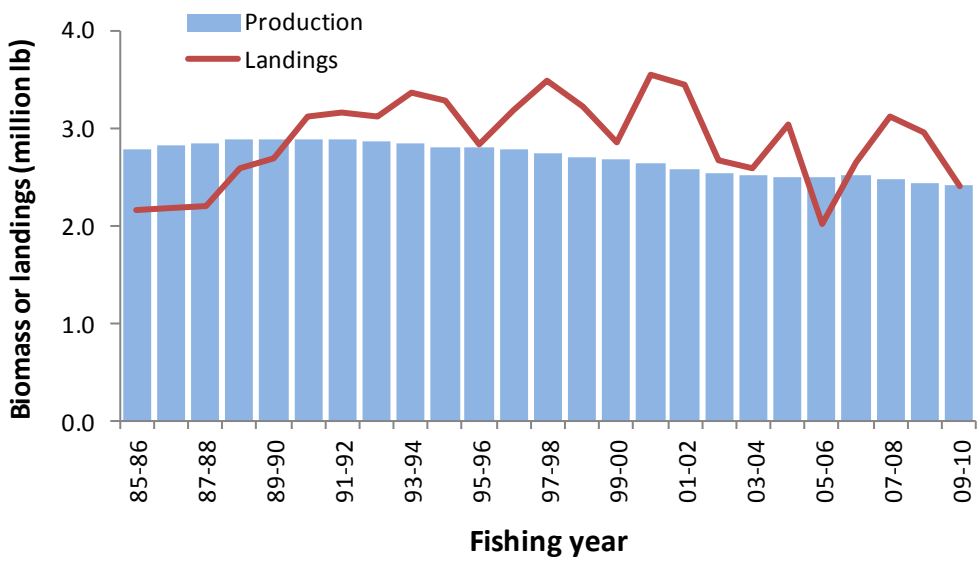


Figure 20. The ratio of the fishing mortality rate in a given fishing year (F) to the fishing mortality rate at maximum sustainable yield (F_{msy}) (a) and the surplus production together with landings in pounds of claws (b) using the number of trap pulls per fishing year.

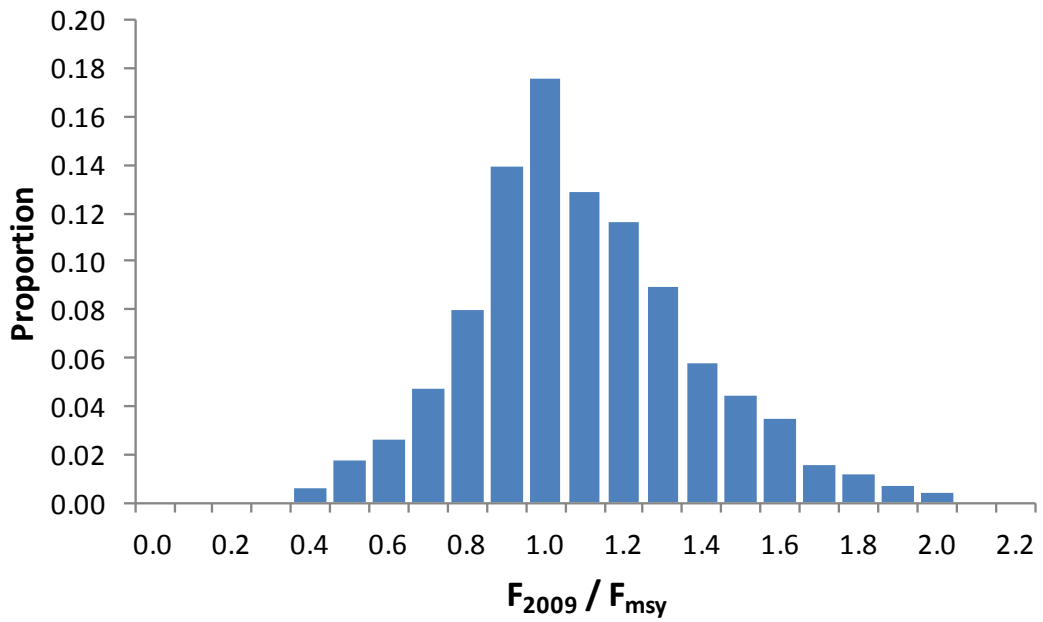


Figure 21. Distribution of fishery mortality benchmark ratios, F_{2009}/F_{msy}, from surplus production model (ASPIC) based on 1000 bootstrap/Monte Carlo outcomes using traps pulled data.

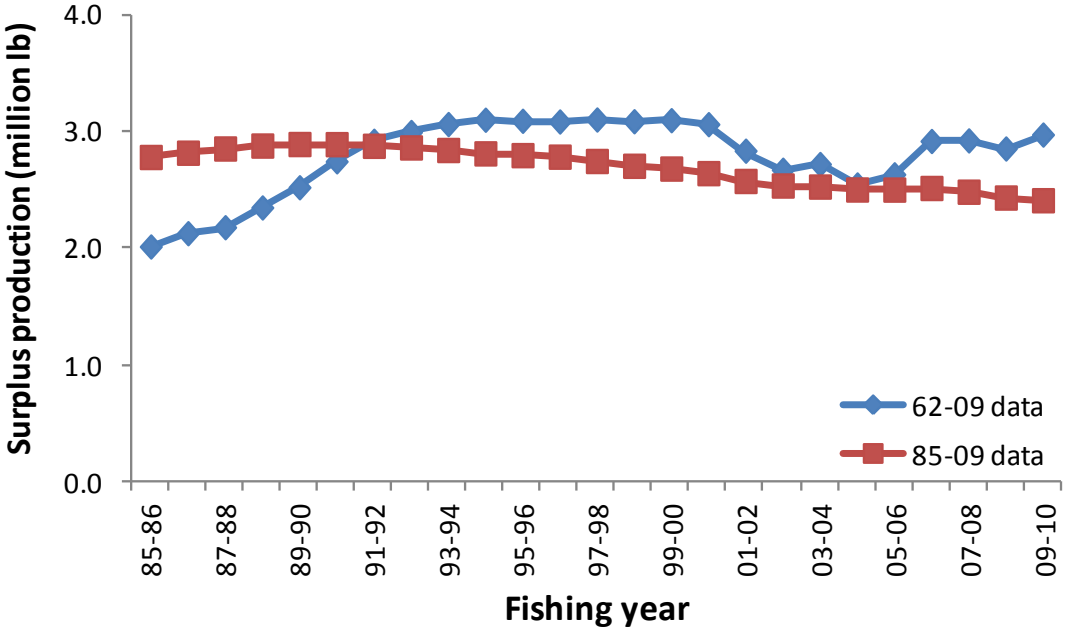
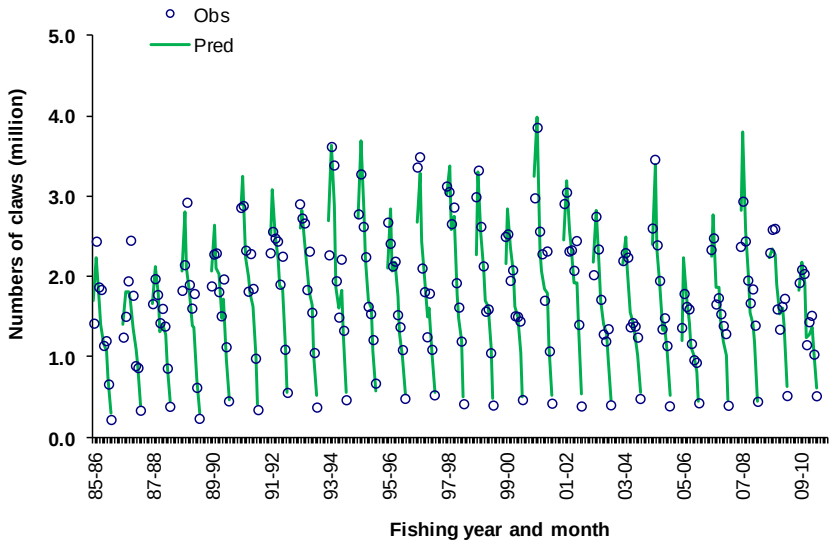


Figure 22. Estimated surplus production in pounds of claws from the long and short time series.

a.



b.

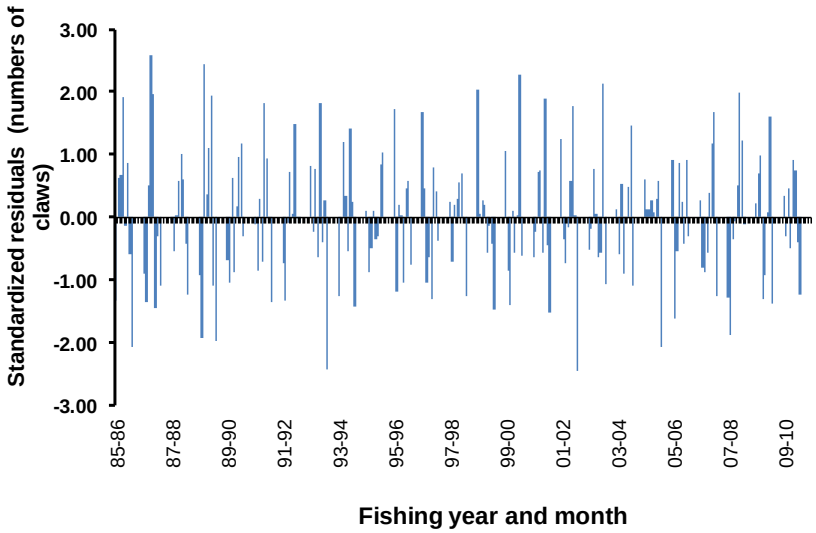
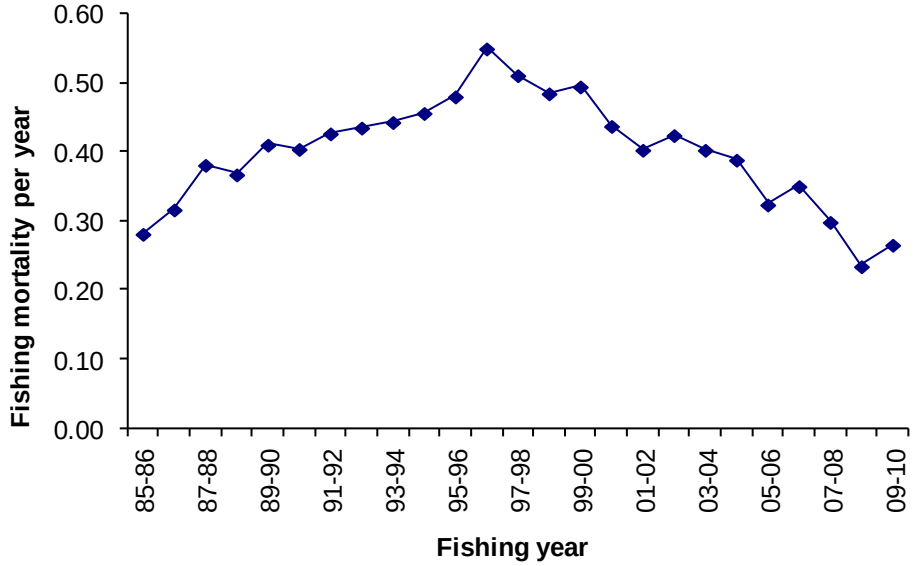


Figure 23. Observed (Obs, points) and predicted (Pred, lines) monthly landings, in numbers of claws, from the DeLury continuity model (a) and the standardized landings residuals ((observed minus predicted)/σ, b).

a.



b.

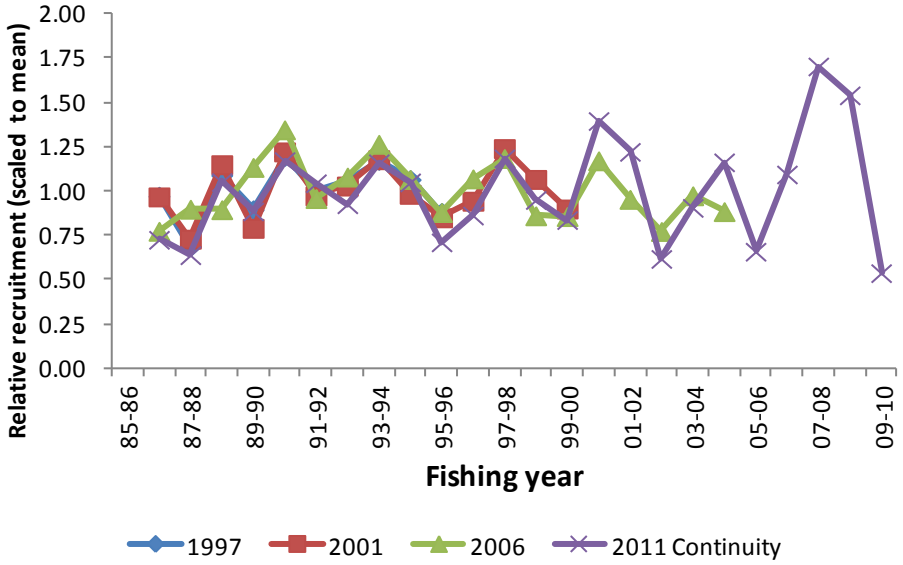
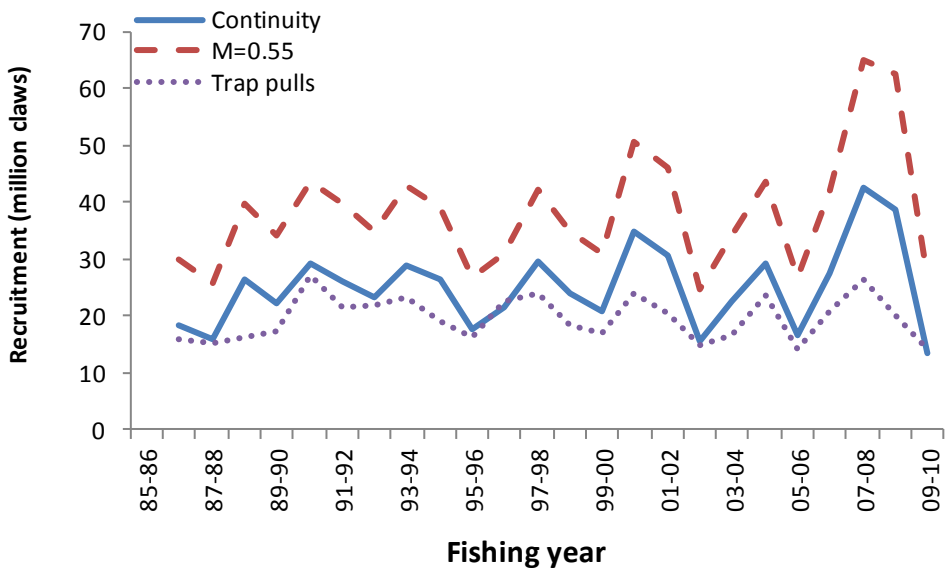


Figure 24. Fishing mortality rates (a) and recruitment estimates (b) from the DeLury continuity model by fishing year together with recruitment estimates from the 1997, 2001, and 2006 assessments. The recruitment series have been scaled to their means to facilitate comparison.

a.



b.

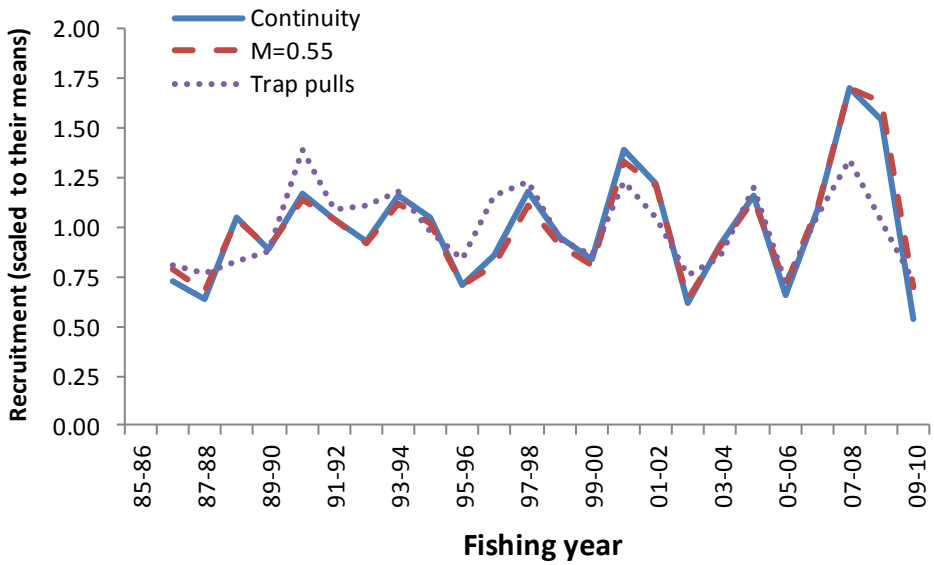


Figure 25. Estimated recruitment by fishing year from the DeLury model for the continuity model (solid line), natural mortality = 0.55 per year (dashed line), and with effort in monthly numbers of traps pulled (dotted line, a) and the same recruitment estimates scaled to their means (b).