Standardized Catch Rates and Preliminary Assessment Scenarios for Queen Conch (*Strombus* gigas) in the U.S. Caribbean

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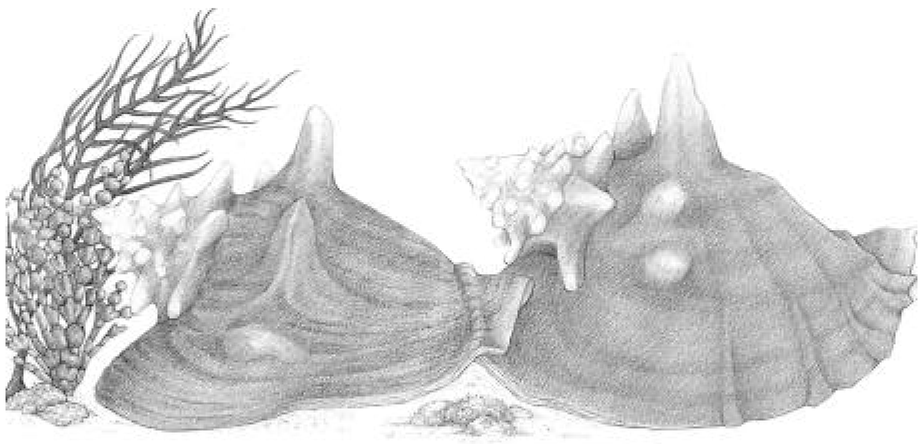

Taken from CMRC Queen Conch *Strombus* gigas
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SUMMARY

Queen conch (*Strombus gigas*) catch and effort data from the U.S. Caribbean commercial fisheries were used to develop relative indices of abundance for the stocks of Puerto Rico and St. Croix, U.S.Virgin Islands. Standardized catch rates were estimated using a Generalized Linear Mixed Modeling (GLMM) approach under two different assumptions: a delta-lognormal error distribution and a lognormal error distribution.

A non-equilibrium surplus production model (ASPIC) was fit to a time series of commercial queen conch landings (1983-2001) from Puerto Rico. Standardized catch-rates were used to tune the model. Two separate assessments were conducted: one for the whole conch fishery and a second one for the fishery of the southwest coast of Puerto Rico, where conch productivity is higher. Due to insufficient data, it was not possible to conduct an assessment of the St. Croix fishery.

Contradicting trends between the catch rates and the landings data complicated model fit and parameter estimation. A variety of sensitivity trials were performed to test different assumptions about the population and the fishery. Assessment results were highly dependent on constraints imposed on initial parameter values, and are thus presented as possible scenarios and not as unique values. Other assessment methods and more informative priors for biological parameters are needed to elucidate the actual condition of these stocks.

INTRODUCTION

Queen conch (*Strombus gigas*) is a marine gastropod, widely distributed in sea grass beds and sandy bottoms across the Caribbean Sea, ranging from Bermuda to northern Brazil. The species has traditionally been used as a source of food and is characterized by a large, pink shell, of high ornamental value. Although the resource still holds commercial importance, it has been depleted in many regions by overfishing (Appeldoorn and Rodriguez 1994).

In the U. S. Caribbean, queen conch is an important component of the commercial and recreational fisheries, representing approximately 7.2 % of the total commercial landings in Puerto Rico, 5 % in St. Croix, and only about 0.4% in St. Thomas-St. John, U.S. Virgin Islands. The recreational fishery may represent up to 50% of the commercial conch landings, based on the proportion of finfish estimated from Marine Recreational Fishery Statistics Survey (MRFSS) from Puerto Rico for years 2000-2001 (Caribbean Council's Sustainable Fisheries Act Amendment, in prep.).

In Puerto Rico, the conch fishery is concentrated around the southwest shelf, and around St. Croix in the U.S. Virgin Islands. Historical records for Puerto Rico indicate large fluctuations in the conch landings since the 1970's. The initial phase was characterized by a rapid increase in landings, from 60,000 pounds in 1970 to a peak of 440,000 pounds in 1983. A sharp decline occurred from 1984 into the early 90's, when levels under 100,000 pounds were again reported (91,000 pounds in 1992). Since then, conch landings have increased again, to a level of 290,000 pounds in year 2001. In St.

Croix, conch landings have changed dramatically since the late sixties, increasing toward a maximum of 60,000 lb in 1979, and showing fluctuating levels centered around 20-30,000 lb since then (Figure 1).

Fishery-independent surveys conducted in the U.S.V.I. in 1981, 1985, 1990, and 1996, showed a decline in conch densities, from 40.87 to 14.71 conch/ha (Friedlander et al. 1994, Friedlander 1997). In the West coast of Puerto Rico, densities have also declined, from 8.11 conch/ha in 1987 (Torres-Rosado 1987) to 5.68 conch/ha in 1996 (Appeldoorn 1996). These indices of relative abundance are illustrated in Figure 2.

Analyses of the nominal catch per unit effort have shown that in Puerto Rico conch trips in the mid-eighties landed over 160 pounds of conch meat, whereas during the period 1988-2001 the average was below 72 pounds. In St. Croix, catch-rates averaged 83 lb/trip during the 1980's, and declined to 57 lb/ trip in the1990's, while the amount of effort exerted nearly quadrupled (Valle-Esquivel 2002).

In addition to fluctuating catches, increasing effort, low densities, and declines in abundance, there has been sufficient anecdotal and scientific evidence indicating that since the late 1970's conch stocks in the U.S. Caribbean have been seriously depleted (Friedlander et al. 1994, Wood and Olsen 1983). For example, fishermen perceive that search-time for conch has increased significantly, that fishing occurs further offshore and in deeper waters, that the size of individuals has decreased, and that they spend more time to harvest less conch (Appeldoorn 1991). Biological surveys have shown that the majority of the shells measured from commercial landings are sub-legal in size (Garcia-Moliner 1997).

Two previous assessments have been made of the queen conch stocks of the U.S. Caribbean. Wood and Olsen (1983) used transect survey data and yield-per-recruit (YPR) analysis to estimate MSY at 60,000 lb in St. Croix and 364,000 lb in St. Thomas/St. John, U.S.Virgin Islands. Appeldoorn (1991, 1992a) performed YPR and production model analyses using data from 1970 to1986, and estimated MSY values of 227 mt (500,000 lb) for Puerto Rico, 86 mt (190,000 lb) for the west coast of Puerto Rico, 12 mt (42,000 lb) for St. Croix, and 91 mt (200,000 lb) for St. Thomas/St. John.

Territorial and federal management regulations for queen conch in the U.S.V.I. include size limits, catch quotas, a closed season (July 1^{st} –September 30^{th}), and a landing restriction requiring that the conchs be landed whole and in the shell. No regulations are in place for Puerto Rico. Protection of a significant proportion of deep-water spawners may be accomplished by implementing a closure of the EEZ (CFMC, 2001). However, much of the habitat essential to growth and development of queen conch occurs in State waters. Thus, the cooperation of State governments is essential to effective management of this species. The U.S. Caribbean queen conch stock is considered to be overfished and is undergoing overfishing (Powers 2001). A fifteen-year rebuilding schedule has been proposed in the Caribbean Council's Sustainable Fisheries Act Amendment (CFMC, 2002, in prep.).

The goal of this study is to estimate relative indices of abundance, to conduct formal queen conch stock assessments, and to provide scenarios that can help to guide management of the species in the U.S. Caribbean. Even when the best information available to date was used in this study, some inconsistencies and contradictions were encountered in the data that limited the use of production models. As such, the stock assessment results presented here include a range of possible scenarios that need verification with alternative methods.

BIOLOGICAL INFORMATION

DISTRIBUTION – The strombid snails, including queen conch, are found in the Western north Atlantic, ranging from northern South America, through the Caribbean, Gulf of Mexico and the Bahamas, to south Florida and Bermuda (CFMC 1996).

HABITAT – Conch generally occur on shallow shelf areas in tropical or subtropical waters from a few inches in depth to a maximum of 250 feet. Being benthic grazers, conch habitat and depth is limited to areas where clear water and sandy substrate support algae and seagrass production, so preferred habitats for conch are shallower than 60-80 ft. and include seagrass and sandy algal beds, gravel, coral rubble, smooth hard coral and beach rock bottoms (CFMC 1996).

MOVEMENT AND MIGRATION – After a planktonic stage that lasts two or three weeks, conch settle in areas of soft sand and remain buried during the first year. At shell lengths ranging from 50 to 100 mm young juveniles begin to emerge and take up an epibenthic existence into nearby seagrass beds (Appeldoorn and Ballantine 1983). Conchs are benthic and slow moving, with the degree of movement related to size. They exhibit two types of migration: the first is an ontogenetic migration, characterized by the juveniles leaving the nursery areas to move gradually into deeper waters as they age. The second migration is seasonal and related to spawning. Adults move to into shallower waters for reproduction during the summer months, and move back to deeper waters during the winter (Stoner *et al.* 1988, Stoner and Waite 1990, CFMC/CFRAMP 1999).

GROWTH – Growth in queen conch is deterministic. Conch grow in length only as juveniles; at the time of sexual maturity conch cease growing in a spiral fashion and start building the flared shell lip characteristic of the species. Further shell growth occurs only as thickening of the shell, especially the lip. Meat weight increases markedly during juvenile growth, but ceases to increase within about a year of maturation, as the energy is channeled into reproduction (CFMC 1996, CFMC/CFRAMP 1999). The following equations characterize conch growth in the La Parguera, Puerto Rico population:

Juvenile growth, from length-frequency analysis (1) and growth-increment data (2). Length is in millimeters, age (t) is in years (Appeldoorn 1990).

(1) $$L_t = 340\,(1 - e^{-0.437(t-0.462)})$$

(2) $$L_t = 460\,(1 - e^{-0.25(t-0.244)})$$

Adult growth, from shell lip-thickness increment information. Lip-thickness is in millimeters, age (t) is in years from maturation (Appeldoorn 1988a).

(3) $LT_t = 54.9\,(1 - e^{-0.3706\,t})$

Combined growth in weight for juveniles and adults for an average size individual (245mm in length); weight is in grams, age (t) is in years (Appeldoorn 1992b).

(4) $MW = 4.394X10^{-07}\ e^{20.12(1-e^{-1.275t})}$ Meat Weight

(5) $TW = 1.263X10^{-5}\ e^{17.44(1-e^{-1.126t})}$ Tissue Weight

REPRODUCTION – Conch mature at about 2.5-3 years of age, with the first reproduction at age 3 to 4. First reproduction occurs after the shell lip has completely formed and is at least 5mm thick. In Puerto Rico, age at maturation was estimated at 3.6 years and at 3 years in St. John, U.S.V.I. (Appeldoorn 1988b, Berg 1976). Conch is a dioic species and the ratio of males:females approximates 1. Conchs mate by copulation. The spawning season varies by location, and spans about 6 months, peaking in July. Females lay an average of 10 million demersal eggs per year (13-14 egg masses/ spawning season * 750,000 eggs/egg mass) that hatch in about 5 days, releasing planktonic (veliger) larvae. Larvae remain in the water column for two to four weeks (Appeldoorn 1993, CFMC 1997).

MORTALITY – Conch have a maximum longevity of 20-30 years. Estimates of mortality on juveniles have shown that mortality decreases significantly with increasing size and shell-thickness (Appeldoorn 1988b, Ray *et al.* 1994). Appeldoorn (1988b) derived the following relationship between natural mortality (M) and age (t):

(6) $M_t = -0.242 + 4.33/t$

Another approximation of natural mortality in conch has been obtained from the empirical equation of Hoenig (1983) that predicts total mortality from the maximum age in the population.

(7) $\mathrm{Ln}(Z) = 1.23 - 0.832\ \mathrm{Ln}\ (t_{max})$

For a longevity of 20 to 30 years and in the absence of fishing, estimates of M are 0.28 and 0.20, respectively (Appeldoorn 1988b). This equation assumes that mortality is constant over the life span, and because the adult stage covers the vast majority of the life span, these estimates correspond to the expected mortality for adult conch (CFMC/CFRAMP 1999).

DATA SOURCES

1. PUERTO RICO

The Fisheries Research Laboratory (FRL) of the Puerto Rico Department of Natural and Environmental Resources (DNER) monitors the commercial landings of fish and shellfish in Puerto Rico since the implementation of the Fisheries Statistics Program (FSP) in 1967. Currently, this project is supported by NOAA/National Marine Fisheries

Service (NMFS) through the State/Federal Cooperative Fisheries Statistics Program (S/F), Interjurisdictional Fisheries Programs (IJ) and the DNER.

The main goals of the S/F program are: 1) to collect landings data from the island of Puerto Rico ensuring coverage of all coastal municipalities and their major fishing centers; 2) to determine the total weight and ex-vessel value of the principal finfish and shellfish landed in PR each month; 3) to manage, correct, evaluate, summarize data and prepare reports; 4) to collect biostatistical data; and 5) to collect data to estimate catch per unit effort (CPUE) from landings and from biostatistical data (Matos-Caraballo 2001).

Landings data of the multi-species and multi-gear fisheries of Puerto Rico are collected using a landing trip ticket system, which has been consistent since the program's inception. Trip tickets contain the following information: fishing date, name of fish buyer, fisherman and/or helper, fishing license number, municipality, fishing center (landing area), number of trips reported, gear type, fishing effort (hours fishing), weight in pounds by species or taxonomic family, market value, depth, and fishing area. Tickets use common names and species identification is possible using Erdman's (1985) numeric codes. Fishermen usually land fishes, lobster, oyster and octopus in the round (not eviscerated); conch weights include (dressed) meat only (Matos-Caraballo 2001).

Frequently, fishers report more than one trip in a single ticket, which complicates analysis. For estimation of CPUE, the DNER uses only those tickets that clearly indicate a single trip. In addition, the DNER has traditionally used a correction factor in the calculations to correct for under-reporting. This factor is expressed as the percentage of fishers that regularly cooperated with statistics, divided by the total number of active fishers in the island.

The commercial landings have only been computerized from year 1983 on. This study used the data for years 1983-2001, updated in August, 2002. Queen conch landings for Puerto Rico are provided in Table 1 and Figure 3 .

Recreational landings statistics for queen conch were not collected in Puerto Rico until January 2000, when the MRFSS initiated the collection of participation data for the recreational sector of the fishery. This telephone survey has shown that tens of thousands of recreational fishers participate in the fishery, and could account for a significant proportion of the total catch (C. Lilyestrom, pers. comm.). The recreational queen conch landings were not available for this study.

CPUE information was extracted from the commercial landings statistics (1983-2001). No other recreational or commercial data is currently available to develop other indices of abundance. Two fishery-independent abundance indices are available for the west coast of Puerto Rico, for years 1987 and 1996, and one estimate for the east coast for 1996 (Torres-Rosado 1987, Appeldoorn 1996, Friedlander et al. 1994) (Figure 2). These indices were considered insufficient for use in tuning the assessment models.

1.A. PUERTO RICO SOUTHWEST COAST

Major areas for conch fishing in Puerto Rico are on the southwest coast, the south coast, and the east coast, with the southwest corner of the island representing the most productive area (Appeldoorn 1991, Valle-Esquivel 2002, Garcia-Moliner, pers. com.). The coastal municipalities of Lajas (36), Cabo Rojo (37), and Mayaguez (38) contributed with 58% of the total conch landings between 1983 and 2000 (Figure 4). The commercial landings for this area are included in Table 1 and Figure 3.

The western offshore banks are fished mainly by fishermen from el Combate, in Cabo Rojo, where a 34% of the total conch landings were reported during those years (Figure 5).

Most of the biological and stock assessment studies for queen conch in Puerto Rico have been conducted in the southwest coast, particularly around La Parguera in Lajas (Appeldoorn 1988, 1990, 1991, 1992a, 1992b). Appeldoorn (1991) considered this area as representative of commercially important areas with respect to habitat and fishing activities.

A separate analysis of the queen conch fishery of Puerto Rico's southwest coast was conducted because, as noted above, this area represents the vast majority of Puerto Rico's conch landings, the data are thought to be the most reliable, and results may be comparable to previous assessments (Appeldoorn 1992a). CPUE information was extracted from the commercial landings statistics (1983-2001) for the southwest municipalities of Lajas, Mayaguez, and Cabo Rojo.

2. UNITED STATES VIRGIN ISLANDS

In 1974, U.S. Virgin Islands Legislative Act 3330 established a mandatory reporting system for fisheries data. To improve the information (total landings by gear type), the U.S. Virgin Islands Division of Fish and Wildlife, Bureau of Fisheries (DPNR/DFW) and NMFS entered into a cooperative agreement in 1983.

Commercial landings data in the U.S. Virgin Islands are obtained from catch records submitted by commercial fishermen on a monthly basis to the DFW. All reports for the 12-month period beginning in July must be received before a commercial fishing license is renewed. DFW is responsible for entering the data and verifying it prior to submission, once a year, to the Southeast Fisheries Science Center/ NMFS. Separate data sets are maintained for the landings made in St. Croix and the landings made in St. Thomas and St. John combined. (Poffenberger 2000a, 2000b).

Since the beginning of the fisheries statistics program, the DFW changed the monthly reporting form at least three times to accommodate the level of detail necessary to assess and manage their complex multi-species and multi-gear fishery. Prior to 1995, commercial landings data were recorded per trip by gear type (e.g., potfish, netfish, hookfish, conch, lobster, etc.); the new catch record form includes gear type, amount of gear used, area fished, effort (hours) and catch by family group. Added to these changes, inconsistencies in the data entry and data transfer systems, and an overlap in use of different forms with incompatible formats have complicated the accumulation of landings data.

A method similar to that outlined in Valle-Esquivel (2002) was used to reconstruct and update a time series of the landings statistics from the U.S.V.I. Various annual data files were combined into a single dataset, which contained basic information about the fishing trips (id, date, area fished) and the queen conch and aggregated species landings in weight. An island field was added based on the area fished and the (known) origin of files, which helped in the extraction of a subset for St. Croix. Finally another subset with only successful (positive) queen conch trips was created. Even when a similar procedure was applied to build a single dataset for St. Thomas/ St. John, the data was inconsistent and limited (as shown in Valle-Esquivel, 2002), and could not be analyzed further in the present study.

Recreational fisheries data are not collected in the Virgin Islands at the present time, but recreational effort is known to occur in shallow seagrass backreef areas, with juveniles constituting the majority of the conch harvested (CFMC/CFRAMP 1999).

The commercial landings statistics for St. Croix used in this study were last updated in August 2002, and include data from July 1986 through December 2001. They are presented in Table 2 and Figure 6. CPUE analysis was based on this commercial dataset.

CPUE ANALYSIS

A Generalized Linear Mixed Model Approach (GLMM) was used to estimate relative indices of abundance for queen conch. Two different methods were tested, a conventional GLM model and a delta-lognormal model. The GLM model uses only the positive CPUE observations of the target species (or the trips where at least one pound of conch was caught) to standardize the catch rates. The estimated CPUE is assumed to follow a lognormal error distribution of a linear function of fixed factors and fixed and random interactions. The delta-lognormal model estimates separately: 1) the probability that a given trip is successful in catching the target species (proportion of positive trips), assuming a binomial error distribution, and, 2) the mean catch rate of positive trips, assuming a lognormal error distribution. Both, the estimated proportion and the catch rates are assumed to be linear functions of fixed effects and random interactions. CPUE is modeled as the product of these two components (Lo et al., 1992).

A step-wise regression procedure was used to determine the set of factors and interactions that significantly explained the observed variability. Factors were added sequentially to the model based on the percentage of deviance explained (>5%), using a **?**^{2} (Chi-square) statistic (McCullagh and Nelder, 1989). Deviance analysis tables for catch rates in pounds are presented for each index developed.

Once a set of fixed factors was selected, possible interactions were evaluated, in particular interactions between the *year* effect and other factors. Selection of the final mixed model was based on the Akaike's Information Criterion (AIC), the Bayes Information Criterion (BIC), and a likelihood-ratio test, based on a **?**^{2} test. Relative indices for the delta model formulation were calculated as the product of the year effect least square means (LSMeans) from the binomial and the lognormal model components. Analysis were done using programs developed by Ortiz et al. (Ortiz et al. 2000, Ortiz and Scott 2001, Legault and Ortiz 1998), that incorporate the GLIMMIX and MIXED procedures from the SAS® statistical computer software (SAS Institute Inc. 1999-2001). The data and the CPUE indices developed are described below.

1. Puerto Rico.

The commercial landings statistics from 1983 through 2001 were used to estimate relative indices of abundance for queen conch in Puerto Rico. Commercial trip-ticket data include landings in weight by species or taxonomic family, information about the crew, the area and depth fished, the gear type and number, the hours spent fishing, and the number of trips reported. Only records corresponding to single trips were used for CPUE analysis. The fishing effort unit considered was a fishing trip, as finer effort categories (e.g., hours fishing, number of gear used, etc.) were generally not available. Nominal catch rates were estimated as the total conch landings (in pounds of dressed meat) per fishing trip.

Municipality and coast fields were added to group the data from fishing centers into broader area categories deemed more useful for CPUE analyses. The municipalities were coded (1-42) as in the FRL annual reports (Matos 2001), and these were reassigned a coast code (1-7) as follows: 1) Northwest, 2) Northeast, 3) East, 4) Southeast, 5) Southwest, 6) West-Southwest, and 7) West-Northwest (see Table 3). These finer coast subdivisions were made to be able to assess differences in relative conch abundance, particularly between the areas known to be most productive (i.e., the south and southwest coasts).

Three commercial CPUE indices were estimated for Puerto Rico: two for the whole island, applying a delta-lognormal model and a conventional generalized linear model (GLM), and one for the southwest coast, using only a GLM model. Deviance analysis and mixed model evaluation tables, diagnostic plots for model fitting, and plots of the nominal and standardized catch rates are shown for each index developed. The specific assumptions used in each case and the results are described below.

1.A. Puerto Rico. Delta-Lognormal Model.

Queen conch is a component of a complex multi-gear and multi-species fishery in Puerto Rico. Reports from interviews with conch fishers (Rosario 1996, Rivera 1999) indicate that only a small proportion (11 %) target conch exclusively. Analyses of the catch composition (Valle-Esquivel 2002) suggested that almost 75% of the conch trips harvested other fish or shellfish species.

In attempt to account for the total effort exerted to harvest conch, both successful and unsuccessful trips were analyzed using the delta-lognormal approach. Successful trips were considered those where at least one pound of conch was harvested, whereas unsuccessful trips were those where no conch was fished, but other species were. The main assumption was that all the trips that used scuba, skin diving, and/or spear fishing as the primary fishing methods were potential conch trips. These three gears were selected because they represented 95% of the total conch observations between 1993 and 2001 (see Figure 7). Also, these gears were used in 20% of the total number of trips, from which a significant proportion (59%) harvested to queen conch:

	Code	Total Num Trips	% Use of gear	Conch Trips	% Conch
All Records		1076052		39827	4%
Spear Fishing	110	10306	1%	3062	30%
Skin Diving	114	17166	2%	2030	12%
Scuba Diving	116	184023	17%	32897	18%
TOTAL			**20%**		**59%**

The restrictions imposed to the data to develop this index were:

1. Years included: 1983-2001.
2. Only single-trip records were used; the data was rearranged so that one record corresponded to one trip.
3. Gears included: 110 (spear fishing), 114 (skin diving), and 116 (scuba diving).
4. The data was restricted to observations with (positive) catch of any species, i.e., absolute "zero" trips were discarded.
5. Trips with successful and unsuccessful queen conch catch were considered; catch of all other species was aggregated into the unsuccessful catch.
6. The data was limited to the upper 99.5% of the combined multispecies cumulative distribution (Total Wt = 420 lb/trip) and to the lower 1% of the conch distribution (CPUE = 5 lb).

The explanatory variables considered were: year, season (quarterly months), wave (two-month periods), month, coast, gear, and fishing target, where Target= 1 were the trips where only conch was harvested. The levels included in each factor were:

FACTORS	# LEVELS	LEVELS
YEAR	19	1983-2001
MONTH	12	1-12
WAVE	6	1-6
SEASON	4	1-4
COAST	7	1-7
GEAR	3	110,114,116
TARGET	2	0,1

Table 4 contains the deviance analysis for this index, including the positive catch rate and the proportion of positive components. The positive catch rates were explained by the fixed year, gear, and coast factors and the year*month, year*coast interactions. Normally, if a factor was present in an interaction, it was included in the model even if it was not significant by itself (e.g., month). The probability of capture of at least one pound of queen conch (proportion of positive trips), and was explained by the year and coast fixed effects, and the year*month, year*coast interactions.

Once these fixed factors were selected, the first level random interactions were evaluated. Table 5 shows the results from the random test analyses; all criteria (AIC, AICC, BIC, and -2 res LL) showed agreement for the best model selection.

Other tests were performed that replaced the month factor by either season or wave. Neither factor was significant by itself, but they were all significant in the fixed interaction term. The month factor was selected because it provides better resolution and because the reduction in deviance was larger when it was included in the interaction term. The target factor was also tested in the positive catch rate model, but it did not improve model fit.

Standardized catch rates using the delta-lognormal approach are shown in Table 9 and Figure 9. Diagnostic plots used for model fitting are also included. The lognormal assumption was met, even when the log CPUE distribution appears somewhat skewed. Chi-square residuals for the positive trips and the proportion of positive trips by year show symmetric distribution patterns, except for a few outliers in the latter.

In general, the standardized and nominal rates followed similar trajectories, but the nominal were usually larger. The average proportion of positive trips was 19%. The index increased at the beginning of the time series, reaching a peak in 1988, decreased in 1989 and stabilized since then. The initial increase appears to be driven by an increase in the proportion of positive trips (see separate plots for each component), which may be explained by changes in targeting, rather than by increased abundance, since the mean positive rate remained fairly stable during this period. If a straight line is fitted along the estimated time-series (not shown), a negative slope is observed, indicating an overall declining trend in relative abundance. The amount of unexplained variability averaged 30%.

1.B. Puerto Rico. GLM- Model.

To avoid making additional assumptions regarding what constitutes a potential conch trip and whether the species is targeted exclusively or not, only the successful (or positive) queen conch trips were considered in this analysis. However, it is important to note that the unsuccessful trips, which targeted conch and did not harvest any, will not be accounted for. Thus, the amount of effort may be underestimated and the catch rates overestimated. The explanatory variables considered were: year, month, coast, and gear. The data was constrained as follows:

- **a)** Years included: 1983-2001.
- **b)** Only single-trip records.
- **c)** Gears: 110 (spear fishing), 114 (skin diving), and 116 (scuba diving).
- **d)** Only observations with positive queen conch catch (= successful trips).
- **e)** Data restricted to the 1% and 99% of the cumulative distribution (5 lb= CPUE = 253 lb).

The deviance analysis and random test evaluation for this index are shown in Table 6. These results are equivalent to the positive component of the delta-lognormal index, so the final model included the year, month, coast, and gear factors and the year*month year*coast interactions as before.

Standardized catch rates and diagnostic plots using the GLM approach are shown in Table 10 and Figure 10. The nominal and standard indices seem very similar, except at the end of the time series, when the observed indices were increasing and the standardized, decreasing. The standard catch rates showed small fluctuations at the beginning of the fishery, a small decline between 1988-1990, and a fairly constant trend since then. The overall trend suggests a smooth, but consistent decline in relative abundance. The variability not explained by the model was relatively small (average CV of approximately 13%).

2. Puerto Rico Southwest Coast- GLM Model.

A subset of data including the municipalities of Lajas (36), Cabo Rojo (37), and Mayaguez (38) in the southwest coast of Puerto Rico was used for this analysis. Only a GLM model was applied, using the same restrictions as in model 1.B. (above). The explanatory variables tested were year, month, gear, municipality (county), and target, with the following values:

FACTORS	# LEVELS	VALUES
YEAR	19	1983-2001
MONTH	12	1-12
GEAR	3	110,114,116
COUNTY	3	36, 37, 38
TARGET	2	0,1

The deviance analysis and mixed model evaluation for this index are shown in Table 7. The fixed year, county, and target factors, and their first level interactions significantly reduced the deviance. Since the year*month interaction was significant, the month factor was also included in the model. After performing the tests for random interactions, the mixed model selected did not include the target factor nor the year*county interaction, since these added a large amount of variability to the final fit. Therefore, the final model configuration was ln(CPUE)= year + month + county + year*month + year*county, plus the year*month random interaction.

Standardized catch rates and diagnostic plots for queen conch in the southwest coast of Puerto Rico are presented in Table 11 and Figure 11. A good agreement between the nominal and standard catch rates was observed, and the variability around the estimates was very small (less that 7% CVs), except for the first three years (1983-1985), where larger coefficients of variation are explained by a low number of observations during that period. In general, this index showed a decline in relative abundance over the period evaluated.

3. St. Croix, U.S. Virgin Islands- GLM Model.

The commercial landings statistics from 1986 through 2001 were used to estimate relative indices of abundance for queen conch in St. Croix. The data set built for this analysis does not contain very detailed information about each fishing trip, as it was created from multiple, relatively incompatible, annual data files. The data includes basic information about the trips (id or vessel number, date, island, area fished) and the landings in weight (pounds) for queen conch, all other species combined, and the total aggregated weight. A subset with only successful (positive) queen conch trips was used to conduct all analyses.

Fishing areas for St. Croix were made compatible by using a combination of the area designations from the old and the new catch report forms, dividing the island and adjacent waters into 6 sections: XE, XNE, XNW, XSE, XSW, and XW (Figure 8). More detailed information, such as the type and number of gear, the distance from shore, and the hours fishing was incomplete and was discarded. Given that the new database configuration consisted of one record per trip, all the commercial landings from St. Croix were used for CPUE analysis. The fishing effort unit considered was a fishing trip, and nominal catch rates were estimated as the total conch landings (in pounds) per trip.

One commercial CPUE index was developed for St. Croix using a conventional GLM approach. The following restrictions were imposed:

a) Years included: 1989-2001. (Note: year 1986 contained only 6 months of data; 1988 had only 20 observations, and there were no observations for years 1987 and 1998, so these years were eliminated).

b) Only observations with positive queen conch catch (= successful trips).
c) Data restricted to the 1% and 99% of the distribution (6 lb= CPUE = 253 lb).

The explanatory variables tested were: year, month, area, and target, with the following levels and values:

Class	Levels	Values
YEAR	12	1989 1990 1991 1992 1993 1994 1995 1996 1997 1999 2000 2001
MONTH	12	1 2 3 4 5 6 7 8 9 10 11 12
AREA	6	XE XNE XNW XSE XSW XW

The deviance analysis and the mixed model evaluation for the St. Croix CPUE index are shown in Table 8. The main effects of year and month and year*month, year*area, and month*area best explained the mean catch rates of queen conch. Significant first-level random interactions were year*month and year*area.

Standardized catch rates and diagnostic plots for this index are provided in Table 12 and Figure 12. The trends in the nominal and standardized indices were similar, but there were years where clear mismatches were observed, particularly at the beginning of the series. Despite a few small fluctuations and a gap in 1998, this index did not show a clear trend, appearing mostly constant across the period evaluated. The coefficients of variation were small, ranging around 15%.

CPUE DISCUSSION

For Caribbean queen conch, the only time series of relative abundance that are long enough for stock assessment analysis are fishery-derived CPUE indices; thus large correlations between the landings and the catch rates are expected. Unfortunately, indices from independent conch surveys (conducted at the same locations) are only available for 2-3 years, so some of them are still rather uninformative (see Figure 2). Only the SEAMAP index for the west coast of Puerto Rico (Appeldoorn 1996) is comparable to the PR-southwest coast index developed here; both show an overall decline between 1985 and 1996 (Figure 13).

In general, the explanatory variables used to develop most indices were year, month and area (coast, municipality or geographic grid), although when gear information was available, it was also significant. Tests to include the target factor in the positive catch rate models generally showed that it deteriorated model fit, even when it appeared to reduce the total deviance. For this reason, and because it was an artificial variable based on an arbitrary threshold, it was excluded from the models. Perhaps, the definition of what constituted a conch trip (Target=1) was set too low (CPUE = 5lb/trip); larger threshold levels (CPUE = 20-40 lb) should probably be tested to evaluate target effects more precisely.

Other characteristics of the indices developed deserve further examination. First, the delta-lognormal index for Puerto Rico increased during the early part of the time series, even when the landings were consistently declining at that time. The “learning period” of a fishery, is commonly characterized by increases in CPUE in the early stages, followed by a decreasing trend or “one-way trip”. The initial increase may be attributed to a variety of factors, including an actual increase in abundance caused by environmental variation; increasing catchability (q) caused by improvements in fishing power (i.e, more efficient technology); and shifts in the target species in multi-species fisheries.

In the case of Puerto Rico, several factors may have concurred to produce this pattern. Diving operations for the harvesting of underwater species in the inshore areas increased significantly as an economic activity since 1984 (Valdez-Pizzini 1987), and increased revenue from diving activities created shifts in the target species, so harvesting lobsters, conchs, octopuses, and spear-gun fishes became more popular. Finally, the number of port agents that collected fisheries statistics increased substantially between 1985 and 1988, resulting in a much greater coverage and promotion of fisheries data collection (Garcia-Moliner, pers. comm.). Later on, the program dwindled, which may be reflected in the markedly reduced landings reported between 1990 and 1992.

Besides the conflicting trends between landings and CPUE, the criterion used to separate conch trips from the complex multi-gear and multi-species fishery of Puerto Rico was rather subjective. The main assumption, that all scuba, skin diving, and/or spear fishing trips were potential conch trips, may not be completely appropriate. Indeed, a large percentage of the trips utilizing these gears harvested conch in some amount (the average proportion of positive trips between 1983-2001 was 19%), but clearly, “some amount” includes incidental catch and does not imply that conch was the target species. Consequently, the number of potential conch trips may have been overestimated in this analysis, resulting in very small CPUE values. Fishers argue that whenever conch is the target species, it is harvested in amounts exceeding 20-40 lb (CFMC meeting, St. Croix, 2002). Other criteria could be used to define conch trips, such as fishing license information to identify part-time and full-time conch fishermen, selection of trips based on species associations or setting different target levels.

The CPUE estimates obtained with the delta-lognormal method (ranging between 3.2 and 17.7 lb/trip), compared to 44- 86.4 lb/trip with the GLM method, are low because they are the product of the probability of success times the catch rate of positive trips. Given the uncertainties in the definition of a (potential) conch trip described above, and that the positive conch trips can be easily separated and analyzed, the GLM catch rates seem more appropriate, and they are comparable to observed values. To avoid replication of uncertain assumptions, only the GLM method was used to standardize the catch rates for the southwest coast of Puerto Rico and for St. Croix, U.S.V.I.

Another limitation inherent to the data was that precise information regarding the amount of effort applied to harvest conch was not available. Being part of a multi-species fishery, and given that 75% of the positive conch trips harvested other species as well, the time spent fishing for conch is generally not the entire trip. Since such information (in hours fishing) is incomplete in the database, the exact proportion of each fishing trip directed exclusively to conch remains unknown, and was not accounted for in the present analyses.

The conch fishery in Puerto Rico is divided according to effort allocation (Garcia-Moliner, pers. com.). The southwest region, where the conch fishery is most productive, includes the municipalities of Lajas, Cabo Rojo and Mayaguez. The neighboring southern region, that goes from Guanica to Guayama is also very productive, and is perhaps followed by the municipalities in the east coast, from Yabucoa to Fajardo, and the islands of Culebra and Vieques. This study concentrated on the southwest region because it is considered the most representative of the conch fishery in Puerto Rico. Nevertheless, analyses of other areas are possible with the existing information.

The limited information available for the queen conch fishery of St. Croix, U.S. Virgin Islands precluded the use of other explanatory variables to develop a commercial CPUE index. Actually, the only significant factors were year and month, and area was only added to the model because it was present in the interaction term, so the estimated index may not be more informative than the nominal CPUE series. We know that most conch fishing activity occurs in the eastern part of the island (Rivera 1999, Valle 2002), but the precise locations are rarely included in the catch reports. Given the incomplete coverage of this index in time and space and its lack of contrast, it may have limited use for tuning a stock assessment model.

Consistent collection of detailed information regarding fishing effort (i.e., number of hours fishing, number of divers, number of scuba tanks used, engine HP, size of boat, etc.) and the area fished (coordinates, depth, type of substrate, distance from shore, etc.) would help to better understand the sources of variation present in the observed queen conch catch rates. However, it is important to note that the best information available to date was used in this study, and that there is potential for improvement if the catch reports are filled out completely.

Finally, it is important to note that commercial CPUE indices for Caribbean queen conch had not been analyzed before. The present analysis provided some insight into the variables that may have some influence in the relative abundance patterns observed. Longer time-series of fishery-independent and recreational indices of abundance will help to corroborate these findings.

STOCK ASSESSMENT ANALYSES

NON-EQUILIBRIUM PRODUCTION MODEL (ASPIC)

A beta-version of ASPIC4.x (Prager 1994, 2000) was used to fit the generalized (Pella-Tomlinson) production model to queen conch data. ASPIC incorporates various extensions to classical stock-production models, such as the possibility of including several simultaneous or sequential fisheries on the same stock, "tuning" the model to one or more biomass indices, estimating missing values of fishing effort, constructing bias-corrected confidence intervals of parameter values via bootstrapping, and estimating projected trajectories of population biomass and fishing mortality rates.

Input for this software includes a time series of total removals, a corresponding effort or an index of relative abundance (CPUE), and starting guesses for its estimated parameters: K, the carrying capacity of the population; B_1/K, the starting biomass ratio; MSY, the maximum sustainable yield; and q, the catchability coefficient. Initial guesses were loosely based on preliminary equilibrium-production model analyses (not included), and on the observed landings and trends in the fisheries. Model outputs include maximum-likelihood estimates for these parameters, and derived management benchmarks: B_{msy}, F_{msy}, f_{msy}, $B./B_{msy}$, $F./F_{msy}$, $Y.(F_{msy})$, and Ye.

Initial ASPIC runs failed to converge when no constraints were placed on parameters using the original data for Puerto Rico (including 1983-2001, and using the delta-lognormal CPUE). Thus, a number of trials and sensitivity tests were conducted and the model was fitted to alternative sets of data; results from each run guided each subsequent analysis. Bootstrap runs and projections were performed with the models that provided the best fits. Model choice was based both on statistical criteria and common sense; the "best" model was that which used the least constraints, that gave the best fit, and provided the most realistic estimates (from knowledge of the biology of the species, the fishery, the data, or information from other studies). All the steps involved in the model selection process (including several unsuccessful trials), model results and selected assessment scenarios are described in the following section. Separate analyses were made for Puerto Rico, the southwest Coast of Puerto Rico, and St. Croix, U.S.Virgin Islands.

I. Puerto Rico.

1) Years 1983-2001/ Delta-Lognormal catch rates.
2) Years 1985-2001/ Delta-Lognormal catch rates.
3) Years 1983-2001/ GLM catch rates.

The landings and catch rate series used in this section are illustrated in Figure 14.

II. Puerto Rico Southwest Coast.

1) Years 1983-2001/ GLM catch rates. The landings and catch rate series used in this section are illustrated in Figure 15 .

III. St. Croix, U.S. Virgin Islands.

Due to the short time series, the lack of contrast in the CPUE series, and that the data in general did not seem to meet the basic assumptions needed to fit a surplus production model, no stock assessment analyses of this fishery were made. The data are shown in Figure 16.

METHODS AND RESULTS

I. PUERTO RICO

1) Years 1983-2001/ Delta-Lognormal Catch Rates.

Conditions:

- Used **Delta-Lognormal CPUE** estimates, that included trips with zero-catch (no conch), where scuba, skin-diving and spear-fishing gears were used.
- Landings data updated in August 2002.

- Initial guesses and parameter constraints were loosely based on equilibrium-production model analysis (PRODFIT, not shown) and on historical landings. Trials included:

a) Free ASPIC runs: no constraints or fixed parameters. No solution was encountered.

In an effort to search for parameter ranges that could allow the model to converge, other trials were conducted, fixing one or two parameters. Solutions were only found by fixing two parameters.

b) Fixed catchability coefficient. Values tested: q =[1e-8,5e-7,1e-7, 5e-6,1e-6...1e-5]. No solution.

c) Fixed MSY within the range given by historical landings: No solution was found for fixed values ranging between MSY=[50,000-500,000 lb].

d) Fixed B1/K ratios in the range [0.1-1.0]: No solution.

e) Fixed MSY and B_1/K. Sensitivity trials included all combinations of (non-informative) MSY=[10,000-500,000 lb] and B_1/K =[0.1-1.0], and were performed to narrow down the search for initial parameter values. Results are illustrated in Figure 17 and are summarized as follows:

- The model converged for all combinations of MSY and B_1/K with MSY between the range of MSY= [$1.0e^4$-$2.0e^5$], and only for low B_1/K=[0.1, 0.2] at large MSY=[$2.5e^5$-$3.5e^5$]. No convergence was attained for larger MSY values [>350,000lb] at any biomass level.
- From all the solutions, the largest R^2 (that measures observed *vs*. estimated CPUE) was 0.269, which already constitutes a poor fit.
- In general, CPUE fit (R^2) was better for low MSY and biomass levels. However, at low B_1/K, biomass ratios were too small (B/B_{msy}<1.0) and F ratios too large (F/F_{msy}>1.0) for any MSY level.
- As MSY increased, R^2 declined (poorer fits), F ratios decreased, and B ratios increased.
- As B_1/K increased, R^2 and F ratios declined, but B ratios increased.
- In general, as CPUE fits improved, F ratios grew disproportionately large and B ratios became flat and smaller than 1.0.
- The most optimistic scenarios (in terms of B and F ratios) were obtained with the largest B_1/K levels, at the cost of obtaining poorer fits.

The most optimistic results were obtained with MSY levels between [$1e^5$ -$1.5e^5$] and B_1/K=1.0, where overfishing/overfished conditions occurred only at the end of the time series (Figure 18). Under all other assumptions of B_1/K (<1.0), the fishery remained in an overfished/overfishing condition (B/Bmsy<1.0 and F/Fmsy>1.0) throughout the time series. Although this scenario reflected realistic MSY estimates, CPUE fit was very poor (R^2<0.1), particularly at the beginning of the time-series, when CPUE (and possibly q's) were increasing. The lack of convergence when the program was allowed to estimate all parameters suggested that the input data should be revised. The first couple of years where CPUE increased were assumed to correspond to a phase in the fishery when dramatic changes in technology and/or in data recording occurred, so years 1983-84 were eliminated from further trials (see CPUE Discussion section).

f) Fixed MSY, allow estimation of all other parameters. Trials used a more informative MSY range ($MSY=1.5e^5-2.0e^5$), guided by the previous tests, and initial guesses for B_1/K=[0.2, 0.5, 1.0]. No convergence was attained.

g) Fixed $MSY=1.5e^5$, allow estimation of other parameters by changing initial guesses for B_1/K =[0.2-1.0]. The model only converged to realistic values with initial B_1/K =0.2. The ASPIC output is provided in Figure 19. These results were used as inputs in additional constraint-free trials, without success.

2) Years 1985-2001/ Delta-Lognormal CPUE estimates. Initial guesses and parameter constraints were based on the previous trials and sensitivity tests. Trials included:

a) Free ASPIC runs. No parameters were fixed and ASPIC was allowed to estimate all the parameters. The model always converged to similar solutions with different guesses between the ranges: B_1/K=[0.5-1.0], MSY=[$1.0e^5$-$3.0e^5$], $K=1.0e^7$, and $q=1e^{-6}$. The best fits were obtained with larger B_1/K values. Main ASPIC results are provided in Figure 20.

Under these assumptions, model fit was greatly improved (R^2=0.657) by removing the years where CPUE appeared to be increasing (1983-84). However, to find a solution, the program forced some parameters to unlikely values, such as a low $MSY=5.23e^4$, very small fishing mortality rates, and a large initial B_1/K=2.7. Overfishing was observed since 1993 and the biomass ratio levels persisted above B_{msy} throughout the whole period.

Large B_1/K values are unrealistic when biomass is known to be below its virgin state at the beginning of the data series. To force B_1/K to smaller values, a penalty term (an option in ASPIC) was added to the model. In this case, $MSY=7.17e^4$, biomass levels were smaller and dropped below B_{msy} since 1998, and F ratios concurred with the previous run. Even when either of these solutions may represent the global minimum, other trials were conducted to force the parameters to more realistic values.

b) Fixed MSY=[$1.0e^5$-$2.0e^5$]. ASPIC converged with fixed MSY in the interval MSY=[$1.0e^5$-$1.7e^5$] and initial guesses of B_1/K=1.0, $K=1.0e^7$, and $q=1e^{-6}$. Results for this range of MSY values are illustrated in Figure 21.

A comparison among the model fits and parameter values obtained, suggested that whereas the fit in CPUE was best for lower MSY values, the likelihood values were best for MSY models with larger MSY. Population trajectories indicated that initial biomass declined steadily from a median of 4 million pounds in 1985 to approximately 769,000 pounds in 2002. Initial biomass became smaller with the larger MSY values assumed. Fishing mortality rates (Fs) remained fairly stable between 1985-92 (under F=0.1 for most models), and increased subsequently to a median of F=0.29 in year 2001. Larger Fs were estimated for models with larger MSYs.

The trends in biomass and fishing mortality ratios were very consistent for all trials, with B/B_{msy} above the threshold until year 2000 and F/F_{msy} crossing it since 1995. The variability around these ratios was greater during the first half of the time series for B ratios and during the second half for F ratios. B/B_{msy} declined as MSY values increased and F/F_{msy} increased with increasing MSY. The most optimistic scenarios in terms of stock status were provided by the largest MSY models (MSY=1.6-1.7). It is important to note that that the penalty term to constrain $B_1/K<1.0$ was not used in the results shown. If added, biomass levels were smaller and dropped faster, and overfishing and overfished conditions occurred earlier. Therefore, not using the penalty to reduce initial biomass clearly gives more hopeful results.

The consistency of these models and the feasibility of their parameter values made them the best candidates among all the previous models discussed to estimate bootstrap confidence intervals and to perform projections. As an alternative, all these non-bootstrapped estimates can be used as proxies of the variability.

c) **Bootstrap run with fixed MSY= $1.4e^5$.** Given that good fits were obtained with values between MSY= [$1.0e^5$-$1.7e^5$], this can be considered as a feasible confidence range for MSY. A median value of MSY=$1.4e^5$ was thus selected for further analysis.

Confidence limits around the other parameters were constructed by running 1,000 bootstrap trials with fixed MSY=$1.4e^5$ and the same model inputs as above (2b). Bootstrap estimates are provided in Figure 22.

3) Years 1983-2001/ GLM-Lognormal CPUE.

These trials used **GLM (Generalized Linear Model)** CPUE estimates, that included only the positive queen-conch trips. Landings records were updated with files provided in August, 2002.

ASPIC did not find a solution when allowed to estimate all the parameters, so constraints had to be imposed, and sensitivity trials similar to those described before were performed. Initial trials used relatively uninformative limits to find a range of possible parameter values. These were used in subsequent trials as 'informative' ranges.

The program did not converge by changing initial q=[$1e^{-4}$-$5e^{-7}$], fixing B_1/K=[0.5-0.7], or fixing MSY=[$5e^4$-$4e^5$]. However, solutions were found with the following constraints:

a) **Fixed q=[$2.0e^{-7}$-$6.0e^{-7}$].** Fits in CPUE deteriorated from smaller to larger q values, ranging from R^2= [0.464-0.01]. Trends in biomass and fishing mortality rates were consistent for all the trials, and parameter estimates were realistic. ASPIC estimates for the best fit (q=$2.e^{-7}$) are provided in Figure 23.

Under these assumptions, CPUE fit was moderately good (R^2=0.464), and the parameter ranges obtained were fairly reasonable, particularly for MSY=$1.88e^5$, with an 80% CI =[1.14-3.27], which fall well within the array of observed catches. Given the unknown status of the stock at the beginning of the time series, estimates of B_1/K are very uncertain. Not imposing the B_1 ratio penalty automatically forced the B and F ratios into positive scenarios, with biomass continuously declining but remaining above B_{msy} for the whole period and F below the threshold until 1999. Since year 2000 only 'mild' overfishing was detected. However, when the penalty was applied, MSY declined to MSY=$1.41e^5$ (80%CI=$1.12e^5$-$2.45e^5$), sharper increases in F ratios were observed, overfishing occurred since 1995, and biomass ratios were smaller and closer to the threshold (B_{2001}/B_{msy}=1.089). In both cases, the results suggested that current fishing mortality rates are not sustainable and that biomass levels are very near the limit.

Other sensitivity trials were conducted with fixed MSY and B_1/K values, but none of the solutions improved model performance.

b) Model Projections. This model configuration, with q=$2.e^{-7}$ and a B_1 ratio constraint was selected to run ASPIC projections for two reasons:

- A GLM catch rate approach may be more appropriate for this fishery than the Delta-Lognormal because "zero" conch trips are unlikely when this species is targeted. Therefore, using only positive conch trips to estimate CPUE may be a better assumption to assess stock status and to model fishery control rules. However, a threshold level for targeted trips needs to be established. Here, trips with more than 5 pounds were considered.
- From all the trials performed, this one used the least constraints on parameters (only fixed q), and most solutions were reasonable.

Six management policies were projected for a ten-year period:

1. Constant catch (2001).
2. Constant fishing effort (2001).
3. Gradual reduction in fishing effort to attain F_{msy}.
4. Gradual reduction in yield to attain MSY.
5. Constant catch at MSY.
6. Constant fishing effort at F_{msy}.

1. Constant catch.

The 2001 catch (248,000 pounds) was repeated for ten years (2002-2011). The biomass ratio point estimates obtained suggest that the stock would be overfished by year 2004 and that the rate of overfishing would increase exponentially until the end of the management period (year 2011) (Figure 24a).

Projection results are also presented together with a default limit control rule, using a natural mortality of M=0.3 (CFMC/CFRAMP 1999). The trajectory of the stock has fluctuated since the beginning of the time series. Overfishing was occurring in 1983-85, then there was a brief period between 1986 and 1994 where the fishery was in good condition, and then overfishing recurred since 1995. Under this scenario, the fishing mortality ratios would increase exponentially and the stock would be well past the maximum fishing mortality threshold during the whole period. Biomass ratios would soon drop below MSY and by 2010 the stock would cross the minimum stock size threshold (MSST). The current catch levels are clearly not sustainable.

2. Constant fishing effort.

The 2001 fishing effort (F= 0.1068) was repeated for ten years (2002-2011). At this fishing mortality rate, overfishing would continue to occur and the stock would rapidly approach an overfished condition; therefore current effort levels are not sustainable (Figure 24b).

3. Gradual reduction in fishing effort.

The current fishing mortality is greater than the fishing mortality at MSY (F_{2001}/F_{msy}= 1.57), or conversely Fmsy/F_{2001}=0.64. The previous projection showed that the fishing mortality rate should be reduced to prevent overfishing. A 36.48% reduction in effort is needed to bring the fishing mortality rate back to F_{msy} =0.0678 (with effort, f=339,000 trips/yr). To avoid drastic measures, a 3.6% reduction was applied each year for the ten years of the projection . Results are illustrated in Figure 25a. Even when this policy returns F to F_{msy}, the population remains near the threshold level, and the biomass slightly below B_{msy}.

4. Gradual reduction in yield.

The current catch is 76% in excess of MSY (Y_{2001}=2.5e^5 lb, MSY=1.4e^5 lb). This projection used a 7.6% reduction in catch (10,680 lb) each year over the ten-year management period. This policy implies a smoother transition to attain MSY; however, despite the reduction, catches were still too large during the first projection years, causing biomass levels to drop below B_{msy} in 2005 (but not below MSST), and overfishing to persist (Figure 25b). Then, an alternative policy that maintains biomass at or above B_{msy} may be a better strategy. The simplest way to implement such policy is to set a constant quota at MSY.

5. Constant catch at MSY.

The MSY level (141,000 pounds) was fixed for the ten-year projection period, which implied a 43% reduction from the 2001 to the 2002 catch. This may be a rather drastic measure, but, from all the alternatives presented, it is the only option that would prevent the imminent decline in stock biomass, stop overfishing at once, and maintain the stock at safe levels (Figure 26a). A constant effort policy at F_{msy} would produce very similar results (not shown), with yields slightly larger than MSY.

6. No fishing.

A ten year closure of the fishery would produce a smooth recovery to more sustainable biomass levels. Such a stringent measure may not be necessary at this point, since under the assumptions of this model the stock did not yet appear to be overfished (Figure 26b). Strategies that eliminate overfihing and prevent the stock from becoming overfished may be more appropriate under the (modeled) current conditions.

II. PUERTO RICO SOUTHWEST COAST

1) Years 1983-2001/ GLM Catch Rates.

These trials used **GLM (Generalized Linear Model)** CPUE estimates for the southwest coast of Puerto Rico, that includes the municipalities of Mayaguez, Cabo Rojo, and Lajas. Landings for this area were obtained from the total landings updated in August, 2002.

Initially, ASPIC did not find a solution when allowed to estimate all the parameters, so constraints had to be imposed, and sensitivity trials were again performed to identify a range of possible parameter values.

a) Fixed q=[1.0e^{-4}- 1.0e^{-7}]. ASPIC converged with q values in the interval q=[1.0e^{-6}-1.0e^{-7}]. MSY estimates ranged between 1.0e^{5} and 1.9e^{5} pounds, but B_1/K estimates were too large (>2.3), so a penalty on initial biomass was imposed on all subsequent trials. Using this constraint the model converged with the same range of q values, with intermediate q's (4.0e^{-7} – 5.0 e^{-7}) giving the best fits. These results are not shown here.

b) Free ASPIC runs.

The output from a selected model (q=0.5e^{-7}) was used as input in a new trial without fixed parameters, except the penalty imposed on B_1/K. ASPIC always converged to the same solution, even with different initial guesses and random number seeds. This solution was used for bootstrap runs and projections. Model results are provided in Figure 27**.**

c) Model Projections.

Ten-year projections of the bootstrapped results were carried out to assess the effect of different management policies. The following were tested:

1. Constant catch (2001)
2. Constant fishing effort (2001)
3. Constant catch at MSY
4. No fishing

1. Constant catch.

The 2001 catch (115,500 pounds) was repeated for ten years (2002-2011). The biomass ratio trajectory indicates that the stock would be overfished by year 2003 and the relative fishing mortality ratios indicate that the rate of overfishing would increase exponentially until the end of the management period (year 2011) (Figure 28a). The phase plot suggests some fluctuations in stock status in the historical period, with clear overfishing starting in 1994 and continuing into the projected period. With the current catch levels, the stock would approach an overfished condition by year 2008.

2. Constant fishing effort.

The 2001 fishing effort (or fishing mortality, F=0.113) was repeated for ten years (2002-2011). At this rate, overfishing would continue to occur and the stock would eventually become overfished, although not within the ten-year frame. Current effort levels do not appear to be sustainable (Figure 28b).

3. Constant catch at MSY.

The MSY level (69,380 pounds) was fixed for the ten-year projection period, which implied a 40% reduction in catch between 2001 and 2002. This measure would stop the imminent decline in biomass, would stop overfishing at once, and would maintain the stock at MSY levels, as illustrated in Figure 29a. Any increase in fishing effort would soon result in overfishing. A constant effort policy at F_{msy} would produce very similar results (not shown), with yields slightly larger than MSY.

4. No fishing.

A ten year closure of the fishery would produce a smooth recovery to more sustainable biomass levels. Such a severe measure may not be necessary at this point, since under the assumptions of this model the stock did not yet appear as overfished (Figure 29b). Preemptive strategies may be more appropriate.

III. ST. CROIX, U.S. VIRGIN ISLANDS

From looking only at the queen conch landings for which there is a continuous series of data, 1986-2001, the number of trips and the CPUE series from St. Croix (Figure 16), we could speculate the following:

1. Catch and effort have an increasing trend, with some fluctuations.
2. CPUEs have remained fairly stable.
3. Fishing does not appear to be affecting the stock.
4. The fishery is in the initial stages.
5. The stock is either very large or recruitment comes from external sources.

Some of these observations could be disputed based on findings from past studies. First, Wood and Olsen (1983) analyzed landings from 1967-1981 (included in Fig. 1), where increasing levels were observed, probably characterizing the true initial stages of the fishery. After that, landings fluctuated at low levels until a new peak became apparent in 1999-2000. The significance of these recent landings in the latest part of the series is uncertain.

Surveys conducted in the U.S.V.I. in 1981, 1985, and 1990 showed a decline in conch densities from 37 to 11 conch/ha in St. Thomas/ St. John, and the only estimate available for St. Croix, of 7.6 conch/ha, is among the lowest (see Figure 2) (Wood and Olsen 1983; Friedlander et al., 1994; Friedlander 1997).

The general perception that conch populations in the Virgin Islands are overfished, suggest that the data available for this study is incomplete, so it should not be used alone to assess the status of the stocks of the U.S.V.I. as a whole. New assessments should be conducted when a longer and more consistent time-series of fishery data becomes available.

DISCUSSION STOCK ASSESSMENT ANALYSES

An array of stock assessment scenarios was presented in this study, instead of the results from single (optimum) assessment because, from the start, it was clear that the uncertainty in the data and the contradicting trends between the landings and the catch rates from Puerto Rico would not allow a straightforward application of a production model. The delta-lognormal CPUE index estimated here, suggested an increase in relative abundance during the early part of the fishery. The GLM index did not increase substantially, but was also high between 1983-1986 (see Figure 14). After the early peaks, both CPUE series declined in a “one-way trip”, to attain fairly stable levels thereafter. This lack of contrast does not allow simple estimation of the basic population parameters r and K. A recent study on white marlin by Babcock and McAllister (in prep.) showed that it is difficult to fit a conventional surplus production model to high catches that are followed by stable or increasing CPUEs because there is no combination of r and K which, combined with the time series, will cause the predicted biomass trajectory to follow the trend of the CPUE indices.

The CPUE series have been fairly steady over the last 15 years, so if they truly reflect abundance, the stock would appear stable with small fluctuations probably caused by variable recruitment. Since landings do not seem to have a marked effect on abundance, the population would either be very large or would have a very fast growth rate. But, for production modeling purposes, the indices did not convey much information about the stock. Being fishery-derived indices, it is possible that fishers have historically set out on conch trips to harvest a certain amount needed to break even or to obtain a certain profit. This could result in flat CPUEs that would be independent from stock abundance.

On the other hand, landings fluctuated significantly across the time series, declining during the first half, and increasing during the second half. Apparently, catch levels were not driven by the abundance levels, but to some extent by the amount of effort exerted, particularly in the directed sector of the fishery (please refer to Figures 25, 33, and 34 in Valle-Esquivel, 2002). The number of conch fishermen has remained relatively constant since the 1980’s, at around 200 fishermen (Matos-Caraballo 1996, Rivera 1999, Valle-Esquivel 2002), so changes in effort may be more related to the number of trips (depending on economic incentives), or improvements in the fishing gear (scuba vs. free diving). Unfortunately, the large fluctuations observed in the landings may also have to do with episodes of over or underreporting. All ASPIC runs were conditioned on yield, assuming catch was known precisely, but if this was not the case, an important assumption may have been broken. Additional runs used conditioning in effort, estimated from CPUE, to fit the model. A large number of and trials and parameter constraints were also needed to reach a solution, and the results were not very consistent or realistic, so this approach was discarded.

The conch fishery from the southwest coast of Puerto Rico is clearly representative of the fishery of the whole territory, and from the trends observed here, it is likely to guide its behavior. Thus, all the observations noted above apply similarly to this sector.

Fitting ASPIC to data with these characteristics was expected to be complicated considering the problems, inconsistencies, and contradictions mentioned above, that would likely result in breaking some production model assumptions. Tight constraints had to be placed on the parameters to achieve convergence and to obtain reasonable results. In some cases, it was necessary to perform trials with many combinations of parameter values to find a minimum. The model was extremely sensitive to initial values, so these had to be chosen carefully. Even when some degree of subjectivity was used along the process, the models underwent serious statistical scrutiny to be selected.

It is very important to note that the final models generally converged only with large initial biomass values (B_1/K) and that a penalty term had to be added to prevent them from getting much larger than the carrying capacity. Either way, the estimated ratios were larger than one in all cases, which placed the stocks in a very optimistic situation, when it is known that they are largely overfished. One solid argument to interpret these results is that the time series used was constrained by the available data, that includes only the last 19 years. So the first years of the assessment do not represent, by any means, the early part of the fishery, when indeed, population levels relative to the virgin biomass must have been high. This may have been in the 1950s or early 1960s. Then, it is important to keep in mind that the actual initial biomass ratios in the early 1980s may have been much smaller than those estimated by ASPIC, and that in consequence, all the scenarios shown here may be too optimistic. With more realistic (low) B_1/K ratios, the stocks would likely appear as overfished.

Appeldoorn (1991, 1992a) estimates of MSY for Puerto Rico were 226,800 kg (499,559lb), 190,102 lb for the west coast, and 19,504 kg (42,960 lb) for St. Croix. Compared to the estimates obtained in this study, of 140,000 to 188,000 lb for the whole island, and 69,380lb, for the southwest coast, Appeldoorn's seem quite large. These differences may be attributed to the fact that he used data from 1971-1986, that only overlap with the first three years of this study, and that his calculations were based on yield-per-recruit and equilibrium production models, that tend to overestimate MSY. On the other hand, the present estimates are fairly low, compared to the observed and historical landings and to those previous MSY estimates.

Considering the uncertainties about the data and the circumstances under which the ASPIC model was fitted, some of the calculations may be imprecise and should not be applied blindly to guide management decisions. Alternative assessment methods, such as Bayesian production models, should be applied to corroborate these results. However, the scenarios presented are likely to be representative of the general trends, patterns, and the overall status of the Puerto Rican conch fishery, provided we only use data since the early 1980s.

Finally, it should be emphasized that continuation of survey programs to estimate fishery-independent indices of abundance and collection of recreational fisheries information and biological data are of utmost importance to improve stock assessment analyses of the Caribbean queen conch fisheries.

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Gerry Scott helped in the interpretation of results and suggested ideas for alternative analyses and future work; David Die gave excellent recommendations for the analyses and interpretation of results, Graciela Garcia-Moliner shared her long-time experience with Caribbean fisheries; the Caribbean Council provided all the pertinent documentation; John Poffenberger, Daniel Matos, and Josh Bennett provided the data, Mauricio Ortiz provided the SAS code for CPUE standardization; and Chris Legault kindly reviewed this manuscript.

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TABLES

Table 1. Estimated commercial queen conch landings (in pounds) for Puerto Rico and for the southwest coast of Puerto Rico, years 1983-2001.

PR CONCH LANDINGS		
Year	**Total**	**SW Coast**
1983	399880	276919
1984	294773	217614
1985	260825	160412
1986	188360	117200
1987	142994	94911
1988	230702	127453
1989	160247	82083
1990	107964	75244
1991	108084	58564
1992	90947	43619
1993	164590	104142
1994	170802	113062
1995	214231	100713
1996	239817	105757
1997	238619	114831
1998	260905	145434
1999	214044	126609
2000	281265	145144
2001	248169	115547
Total	**4017218**	**2325257**
Percent		**57.9%**

Table 2. Estimated commercial queen conch landings (in pounds) for St. Croix, U.S. Virgin Islands, years 1986-2001.

Year	Conch Landings
1986	4935
1987	5750
1988	17900
1989	13041
1990	10283
1991	36192
1992	19783
1993	22644
1994	33876
1995	23918
1996	13670
1997	38409
1998	44115
1999	19599
2000	77612
2001	62638
Total	444364

Table 3. **a)** Coastal municipalities in Puerto Rico and coasts assigned for CPUE analysis. **b)** Fishing centers in the southwest municipalities of Lajas, Cabo Rojo,and Mayaguez.

(a)

CODE	Municipality
1. NORTHWEST	
1	ISABELA
2	QUEBRADILLAS
3	CAMUY
4	HATILLO
5	ARECIBO
6	BARCELONETA
7	MANATI
2. NORTHEAST	
8	VEGA BAJA
9	VEGA ALTA
10	DORADO
11	TOA BAJA
12	CATAÑO
13	SAN JUAN
14	CAROLINA
15	LOIZA
16	RIO GRANDE
17	LUQUILLO
3. EAST	
18	FAJARDO
19	CEIBA
20	NAGUABO
21	HUMACAO
22	YABUCOA
23	MAUNABO
24	CULEBRA
25	VIEQUES
4. SOUTHEAST	
26	PATILLAS
27	ARROYO
28	GUAYAMA
29	SALINAS
30	SANTA ISABEL
5. SOUTHWEST	
31	JUANA DIAZ
32	PONCE
33	PEÑUELAS
34	GUAYNILLA
35	GUANICA
36	LAJAS
6. WEST-SOUTHWEST	
37	CABO ROJO
38	MAYAGUEZ
7. WEST-NORTHWEST	
39	AÑASCO
40	RINCON
41	AGUADA
42	AGUADILLA

(b)

CODE	FISHING CENTER
36. LAJAS	
360	LA PARGUERA
361	PAPAYO
362	SALINAS
37. CABO ROJO	
370	PITAHAYA
371	BAHIA SUCIA
372	EL COMBATE
373	BOQUERON
374	PUERTO REAL
375	JOYUDA
376	GUANAJIBO
377	GUANIQUILLA
38. MAYAGUEZ	
380	EL SECO
381	EL MANI
382	MARINA MERIDIONAL
383	RASQUETA
384	BOQUILLA

Table 4. Puerto Rico Queen Conch Commercial CPUE (1983-2001) - Delta-Lognormal Model. Deviance analysis table of explanatory variables for the positve catch rates (in lb/trip) and the proportion of positive observations/total. Percent of total deviance refers to the deviance explained by the full model; *p* refers to the 5% Chi-square probability between consecutive models. Factors and interactions with total deviance = 5% were included in the model and are shown in shaded areas.

FIXED FACTORS

PUERTO RICO Queen Conch
Delta-Lognormal Model

Model factors positive catch rates	d. f.	Residual deviance	Change in deviance	% of total deviance	p
NULL	0	33650.38			
year	18	31958.81	1691.6	27.8%	< 0.001
... + month	11	31876.52	82.3	1.4%	< 0.001
... + GEAR	2	31137.93	738.6	12.1%	< 0.001
... + COAST	6	29211.20	1926.7	31.7%	< 0.001
... + year:month	198	28679.41	531.8	8.7%	< 0.001
... + year:GEAR	19	28587.34	92.1	1.5%	< 0.001
... + year:COAST	94	27724.77	862.6	14.2%	< 0.001
... + month:GEAR	22	27665.97	58.8	1.0%	< 0.001
... + month:COAST	66	27574.53	91.4	1.5%	0.021
... + GEAR:COAST	10	27564.94	9.6	0.2%	0.477

Model factors proportion positive catch rates	d. f.	Residual deviance	Change in deviance	% of total deviance	p
NULL	0	639.81			
year	18	603.72	36.1	10.3%	0.007
... + month	11	595.39	8.3	2.4%	0.684
... + COAST	7	496.90	98.5	28.1%	< 0.001
... + GEAR	2	486.55	10.4	3.0%	0.006
... + year:month	198	429.69	56.9	16.2%	1.000
... + year:COAST	108	340.61	89.1	25.4%	0.907
... + year:GEAR	29	324.79	15.8	4.5%	0.978
... + month:COAST	66	309.55	15.2	4.4%	< 0.001
... + month:GEAR	22	300.12	9.4	2.7%	0.492
... + COAST:GEAR	12	289.73	10.4	3.0%	< 0.001

Table 5. Puerto Rico Queen Conch Commercial CPUE (1983-2001) - Delta-Lognormal Model. Random effects evaluation for the mixed model formulation for the positive catch rates and the proportion of positive observations. Likelihood ratios test the difference of the log likelihhod (-2 RES LL) between two nested models. Shaded areas indicate the selected model for each component of the final delta mixed model.

RANDOM TESTS Mixed Model	-2 RES LL	AIC	AICC	BIC	Likelihood Ratio Test	
Positive Catch Rates						p
Year Month Coast Gear	75430.30	75432.3	75432.3	75440.6		
Year Month Coast Gear *Year*Month*	75259.9	75263.9	75263.9	75270.8	170.40	0.0000
Year Month Coast Gear *Year*Month Year*Coast*	74547.7	74553.7	74553.7	74564	712.2	0.0000

RANDOM TESTS Mixed Model	-2 RES LL	AIC	AICC	BIC	Likelihood Ratio Test	
Proportion Positives						p
Year Month Coast	4665.9	4667.9	4667.9	4673.2		
Year Month Coast *Year*Month*	4451.1	4455.1	4455.1	4460.8	214.8	0.0000
Year Month Coast *Year*Month Year*Coast*	4155.9	4161.9	4161.9	4170.6	295.2	0.0000

Table 6. **Puerto Rico Queen Conch Commercial CPUE (1983-2001) – Generalizad Linear Model.** Deviance analysis table of explanatory variables for the positive catch rates (in lb/trip) (top) and; random effects evaluation for the mixed model formulation (bottom). These tables are equivalent to the positive catch rate component from the delta-lognormal model shown in Tables 4-5 .

FIXED FACTORS — **PUERTO RICO Queen Conch Generalized Linear Model**

Model factors positive catch rates	d. f.	Residual deviance	Change in deviance	% of total deviance	*p*
NULL	0	33650.38			
year	18	31958.81	1691.6	27.8%	< 0.001
… + month	11	31876.52	82.3	1.4%	< 0.001
… + GEAR	2	31137.93	738.6	12.1%	< 0.001
… + COAST	6	29211.20	1926.7	31.7%	< 0.001
… + year:month	198	28679.41	531.8	8.7%	< 0.001
… + year:GEAR	19	28587.34	92.1	1.5%	< 0.001
… + year:COAST	94	27724.77	862.6	14.2%	< 0.001
… + month:GEAR	22	27665.97	58.8	1.0%	< 0.001
… + month:COAST	66	27574.53	91.4	1.5%	0.021
… + GEAR:COAST	10	27564.94	9.6	0.2%	0.477

RANDOM TESTS Mixed Model	-2 RES LL	AIC	AICC	BIC	Likelihood Ratio Test	
Positive Catch Rates						*p*
Year Month Coast Gear	75430.30	75432.3	75432.3	75440.6		
Year Month Coast Gear *Year*Month*	75259.9	75263.9	75263.9	75270.8	170.40	0.0000
Year Month Coast Gear *Year*Month Year*Coast*	74547.7	74553.7	74553.7	74564	712.2	0.0000

Table 7. **Puerto Rico Southwest Coast Queen Conch Commercial CPUE (1983-2001) – Generalizad Linear Model.** Deviance analysis table of explanatory variables for the positve catch rates (in lb/trip) (top) and; random effects evaluation for the mixed model formulation (bottom).

FIXED FACTORS — **PUERTO RICO SOUTHWEST COAST Queen Conch**

Model factors positive catch rates values	d. f.	Residual deviance	Change in deviance	% of total deviance	Pr (Chi)
NULL	0	8511.01			
year	18	7483.06	1027.9	38.687%	< 0.001
… + month	11	7449.36	33.7	1.268%	< 0.001
… + COUNTY	2	7266.36	183.0	6.887%	< 0.001
… + GEAR	2	7177.64	88.7	3.339%	< 0.001
… + Target	1	6676.06	501.6	18.877%	< 0.001
… + year:month	188	6369.11	306.9	11.552%	< 0.001
… + year:COUNTY	34	6217.30	151.8	5.713%	< 0.001
… + year:GEAR	15	6203.84	13.5	0.507%	0.567
… + year:Target	17	5853.89	349.9	13.170%	< 0.001

RANDOM TESTS Mixed Model	-2 Res LL	AIC	AICC	BIC	LRT	*p*
Positive Catch Rates						
Year Month County	27738.9	27740.9	27740.9	27748.2		
Year Month County *Year*Month*	27541.9	27545.9	27545.9	27552.7	197	0.0000
Year Month County *Year*Month Year*County*	27413.6	27419.6	27419.6	27429.7	128.3	0.0000

Table 8. **St. Croix, U.S.V.I. Queen Conch Commercial CPUE (1989-2001) – Generalizad Linear Model.** Deviance analysis table of explanatory variables for the positive catch rates (in lb/trip) (top) and; random effects evaluation for the mixed model formulation (bottom).

Model factors positive catch rates	d. f.	Residual deviance	Change in deviance	% of total deviance	*p*
NULL	0	1835.47			
YEAR	11	1760.73	74.7	18.2%	< 0.001
... + MONTH	11	1725.50	35.2	8.6%	< 0.001
... + AREA	5	1713.01	12.5	3.0%	0.029
... + TARGET	1	1692.75	20.3	4.9%	< 0.001
... + YEAR:MONTH	83	1588.89	103.9	25.3%	0.060
... + YEAR:AREA	40	1499.86	89.0	21.7%	< 0.001
... + YEAR:TARGET	8	1489.42	10.4	2.5%	0.235
... + MONTH:AREA	54	1447.14	42.3	10.3%	0.876
... + MONTH:TARGET	10	1437.39	9.8	2.4%	0.463
... + AREA:TARGET	5	1425.58	11.8	2.9%	0.038

RANDOM TESTS Mixed Model	-2 Res LL	AIC	AICC	BIC	Likelihood Ratio Test	
Positive Catch						*p*
Year Month Area	8878.8	8880.8	8880.8	8887.3		
Year Month Area *Year*Month*	8788.2	8792.2	8792.2	8797.5	90.60	0.0000
Year Month Area *Year*Month Year*Area*	8603.3	8609.3	8609.3	8617.3	184.90	0.0000

Table 9. **Puerto Rico Queen Conch Commercial CPUE (1983-2001) - Delta-Lognormal Model.** Nominal and standard catch rate series (lb/trip). The standard index column is scaled to the maximum value of the CPUE series.

	Nominal	Standard			Scaled		95% confidence intervals	
Year	CPUE	CPUE	Coeff Var	Std Error	Obs. Index	Std Index	Upp 95%CI	Low 95%CI
1983	7.01	5.00	30.9%	1.54	0.25	0.28	0.52	0.15
1984	9.14	6.45	33.9%	2.19	0.32	0.36	0.70	0.19
1985	14.70	11.91	30.3%	3.61	0.52	0.67	1.22	0.37
1986	26.39	13.40	27.2%	3.64	0.93	0.76	1.29	0.44
1987	24.14	10.63	27.6%	2.93	0.85	0.60	1.03	0.35
1988	28.53	17.71	26.9%	4.77	1.00	1.00	1.70	0.59
1989	12.84	8.30	29.5%	2.45	0.45	0.47	0.84	0.26
1990	7.56	6.73	29.0%	1.95	0.26	0.38	0.67	0.22
1991	8.79	6.50	28.7%	1.86	0.31	0.37	0.64	0.21
1992	9.59	5.77	29.4%	1.70	0.34	0.33	0.58	0.18
1993	9.95	6.78	28.2%	1.91	0.35	0.38	0.67	0.22
1994	7.53	7.17	27.2%	1.95	0.26	0.40	0.69	0.24
1995	8.78	6.77	27.0%	1.83	0.31	0.38	0.65	0.22
1996	9.15	6.01	28.0%	1.68	0.32	0.34	0.59	0.20
1997	8.59	5.74	27.1%	1.55	0.30	0.32	0.55	0.19
1998	9.37	5.33	27.9%	1.48	0.33	0.30	0.52	0.17
1999	9.44	4.26	29.1%	1.24	0.33	0.24	0.43	0.14
2000	9.86	4.41	28.0%	1.24	0.35	0.25	0.43	0.14
2001	8.03	3.15	29.1%	0.91	0.28	0.18	0.31	0.10

Table 10. **Puerto Rico Queen Conch Commercial CPUE (1983-2001) – Generalizad Linear Model.** Nominal and standard catch rate series (lb/trip). The standard index column is scaled to the maximum value of the CPUE series.

Year	Nominal CPUE	Standard CPUE	Coeff Var	Std Error	Scaled Obs Index	Scaled Std Index	95% confidence intervals Upp 95%CI	95% confidence intervals Low 95%CI
1983	78.38	71.52	13.1%	9.35	0.88	0.83	1.07	0.64
1984	79.26	68.93	15.5%	10.70	0.89	0.80	1.09	0.59
1985	68.78	61.55	14.6%	9.00	0.77	0.71	0.95	0.53
1986	83.75	65.95	12.9%	8.54	0.94	0.76	0.99	0.59
1987	71.92	58.05	13.2%	7.64	0.81	0.67	0.87	0.52
1988	88.83	86.38	13.2%	11.38	1.00	1.00	1.30	0.77
1989	58.95	64.33	13.3%	8.59	0.66	0.74	0.97	0.57
1990	48.72	50.84	13.2%	6.69	0.55	0.59	0.76	0.45
1991	46.75	48.55	13.0%	6.30	0.53	0.56	0.73	0.43
1992	47.54	44.09	13.4%	5.91	0.54	0.51	0.67	0.39
1993	50.17	47.49	13.0%	6.16	0.56	0.55	0.71	0.42
1994	44.55	45.93	12.4%	5.71	0.50	0.53	0.68	0.42
1995	47.46	47.62	12.5%	5.97	0.53	0.55	0.71	0.43
1996	45.07	45.15	13.0%	5.89	0.51	0.52	0.68	0.40
1997	46.56	44.07	12.3%	5.43	0.52	0.51	0.65	0.40
1998	55.09	53.21	12.3%	6.54	0.62	0.62	0.79	0.48
1999	60.15	48.02	12.7%	6.10	0.68	0.56	0.72	0.43
2000	58.34	43.99	12.6%	5.53	0.66	0.51	0.65	0.40
2001	52.12	44.19	12.6%	5.57	0.59	0.51	0.66	0.40

Table 11. **Puerto Rico Southwest Coast Queen Conch Commercial CPUE (1983-2001) – GLM.** Nominal and standard catch rate series (lb/trip). The standard index column is scaled to the maximum value of the CPUE series.

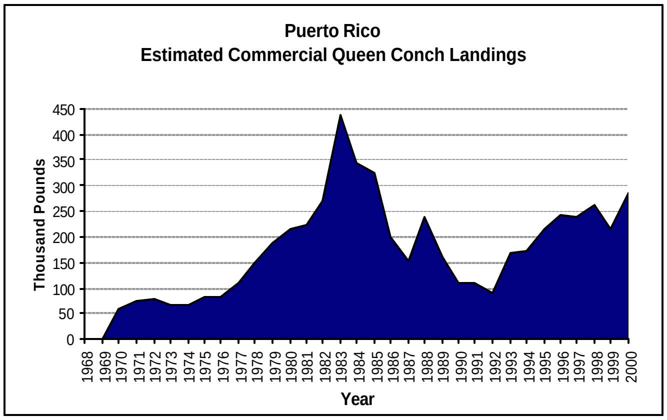
Year	Nominal CPUE	Standard CPUE	Coeff Var	Std Err	Scaled Index Obs Index	Scaled Index Std Index	95% confidence intervals Upp 95% CI	95% confidence intervals Low 95% CI
1983	119.03	100.29	16.0%	16.07	1.00	1.00	1.38	0.73
1984	97.88	93.99	17.6%	16.57	0.82	0.94	1.33	0.66
1985	82.87	80.23	12.8%	10.23	0.70	0.80	1.03	0.62
1986	84.33	80.71	6.6%	5.31	0.71	0.80	0.92	0.71
1987	71.86	65.84	6.2%	4.11	0.60	0.66	0.74	0.58
1988	76.76	73.20	6.2%	4.55	0.64	0.73	0.83	0.64
1989	53.09	47.83	6.7%	3.21	0.45	0.48	0.55	0.42
1990	42.94	36.96	7.0%	2.58	0.36	0.37	0.42	0.32
1991	44.62	40.53	6.6%	2.66	0.37	0.40	0.46	0.35
1992	50.91	52.85	7.1%	3.73	0.43	0.53	0.61	0.46
1993	48.87	53.05	6.7%	3.55	0.41	0.53	0.60	0.46
1994	42.98	43.13	6.7%	2.90	0.36	0.43	0.49	0.38
1995	42.88	43.92	7.2%	3.15	0.36	0.44	0.51	0.38
1996	32.42	33.81	6.6%	2.25	0.27	0.34	0.38	0.30
1997	34.35	36.48	7.1%	2.59	0.29	0.36	0.42	0.32
1998	43.51	44.58	7.6%	3.38	0.37	0.44	0.52	0.38
1999	48.33	50.54	7.2%	3.64	0.41	0.50	0.58	0.44
2000	40.70	45.57	7.0%	3.21	0.34	0.45	0.52	0.39
2001	37.96	42.93	7.0%	3.01	0.32	0.43	0.49	0.37

Table 12. **St. Croix, U.S.V.I. Queen Conch Commercial CPUE (1989-2001) – GLM.** Nominal and standard catch rate series (lb/trip). The standard index column is scaled to the maximum value of the CPUE series.

	Nominal	Standard			Scaled Index		95% confidence intervals	
Year	CPUE	CPUE	Coeff Var	Std Err	Obs Index	Std Index	Upp 95% CI	Low 95% CI
1989	66.64	58.82	19.8%	11.66	0.90	0.83	1.22	0.56
1990	68.26	71.15	15.7%	11.17	0.92	1.00	1.37	0.73
1991	74.03	53.10	16.4%	8.69	1.00	0.75	1.03	0.54
1992	45.10	40.67	17.0%	6.90	0.61	0.57	0.80	0.41
1993	55.45	54.67	14.9%	8.13	0.75	0.77	1.03	0.57
1994	49.52	47.52	12.9%	6.13	0.67	0.67	0.86	0.52
1995	52.76	53.83	13.4%	7.20	0.71	0.76	0.99	0.58
1996	50.77	39.65	15.6%	6.20	0.69	0.56	0.76	0.41
1997	42.76	41.61	14.7%	6.10	0.58	0.58	0.78	0.44
1998								
1999	47.93	46.13	15.4%	7.10	0.65	0.65	0.88	0.48
2000	51.10	50.51	12.0%	6.07	0.69	0.71	0.90	0.56
2001	58.52	67.60	13.0%	8.76	0.79	0.95	1.23	0.73

FIGURES

Figure 1. Reported commercial landings of queen conch for Puerto Rico and St. Croix, U.S.Virgin Islands. (a) Puerto Rico. Sources: Appeldoorn (1991), Garcia-Moliner (1996), DNER/NMFS Annual Cooperative Statistics Reports (1993-2001). (b) St. Croix, U.S.V.I. Wood and Olsen (1983), DFNR Annual Cooperative Statistics Reports (1984-1999), Garcia-Moliner (1996); DPNR Annual Cooperative Statistics Reports (1984-2001).



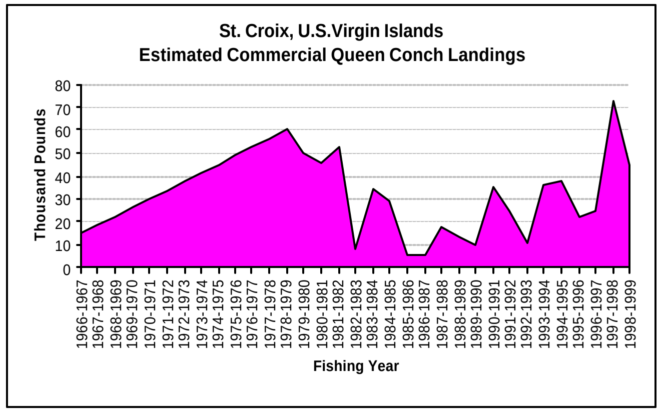
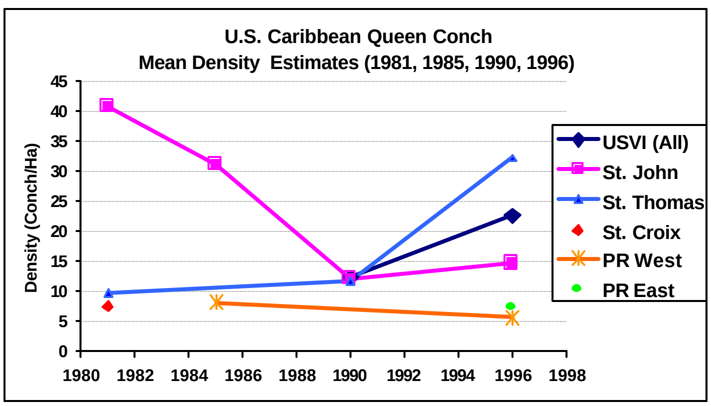


Figure 2. Fishery-independent indices of abundance for Caribbean queen conch. The sources and years of the surveys are provided in the table. Taken from Valle-Esquivel (2002).



Density Estimates (Conch/Ha)		U.S. Virgin Islands				Puerto Rico	
Year	Source	USVI (All)	St. John	St. Thomas	St. Croix	PR West	PR East
1981	Wood and Olsen (1983)		40.87 (52.08)	9.7	7.6		
1985	Boulon (1987)		31.29 (30.83)				
	Torres-Rosado (1987)					8.11	
1990	Appeldoorn (1991) and Friedlander et al. (1994)	12.35 (18.42)	12.10 (20.35)	11.79 (15.01)			
1996	Appeldoorn (1996) and Friedlander (1997)	22.66	14.71 (35.33)	32.19		5.68	7.28

Figure 3. Estimated commercial queen conch landings in Puerto Rico for years 1983-2001. Landings from the southwest coast (in green) represented a 58% of the total landings (in blue) during those years.

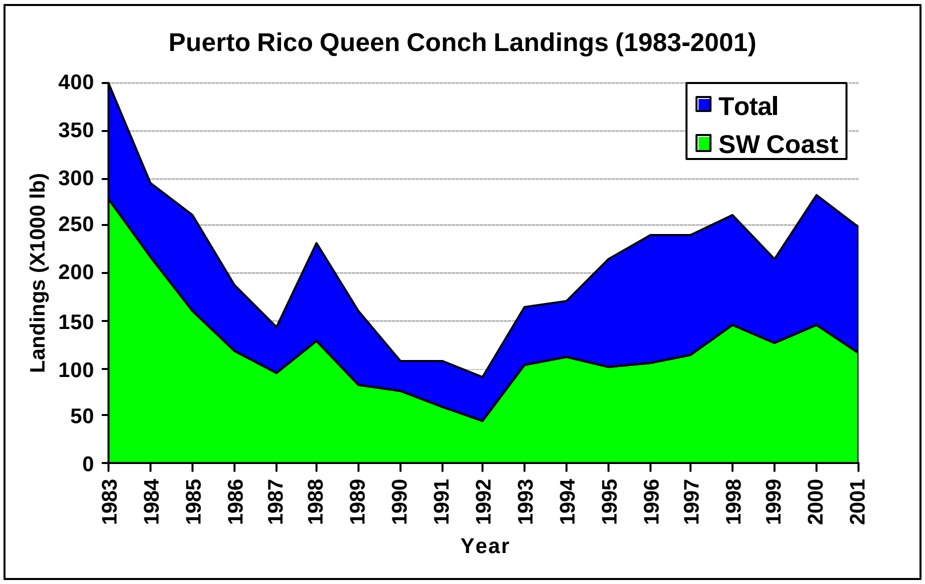


Figure 4. Puerto Rico. Total queen conch landings by coast and municipality for years 1983-2000. The municipalities shown in purple correspond to Lajas (36), Cabo Rojo (37), and Mayaguez (38), and were selected to represent the southwest coast of Puerto Rico in CPUE and stock assessment analyses for that area.

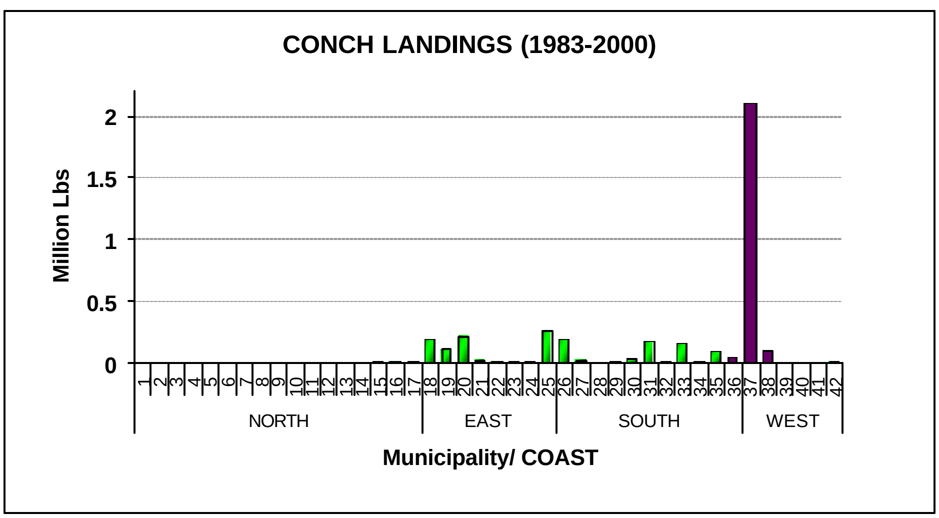


Figure 5. Puerto Rico Southwest Coast. Percent of total queen conch landings by municipality and fishing center for years 1983-2000.

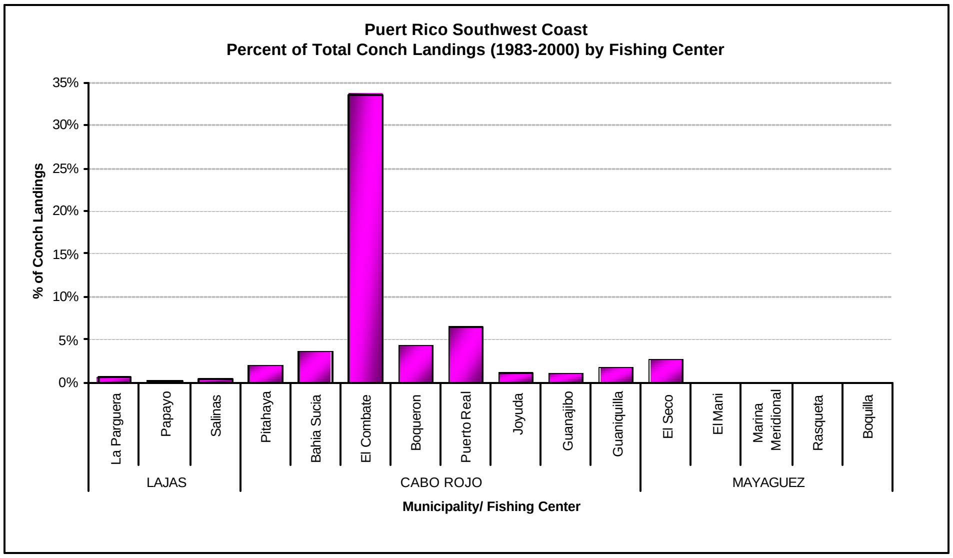


Figure 6. Estimated commercial queen conch landings for St. Croix, U.S. Virgin Islands, years 1986-2001.

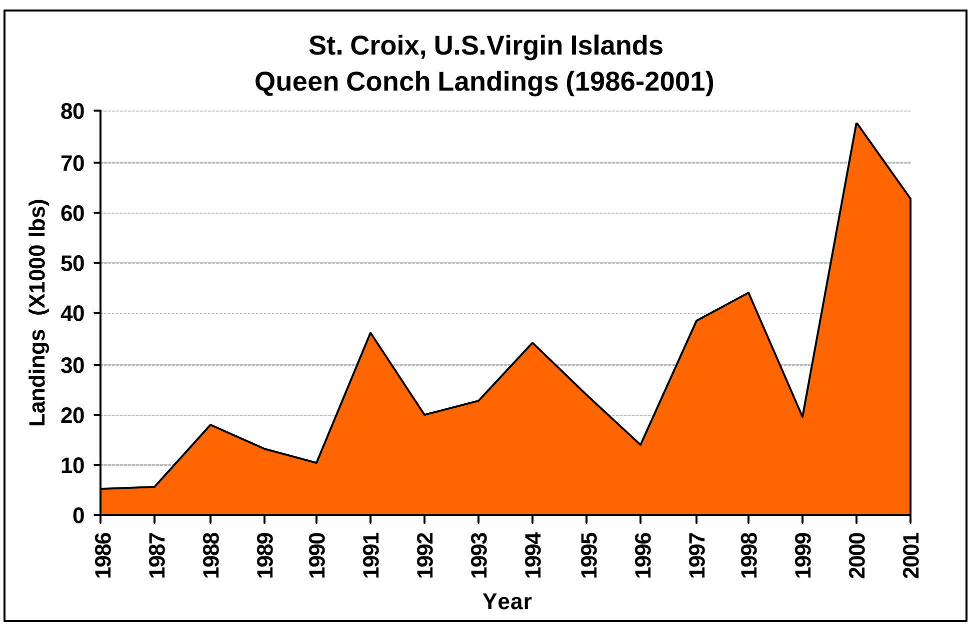
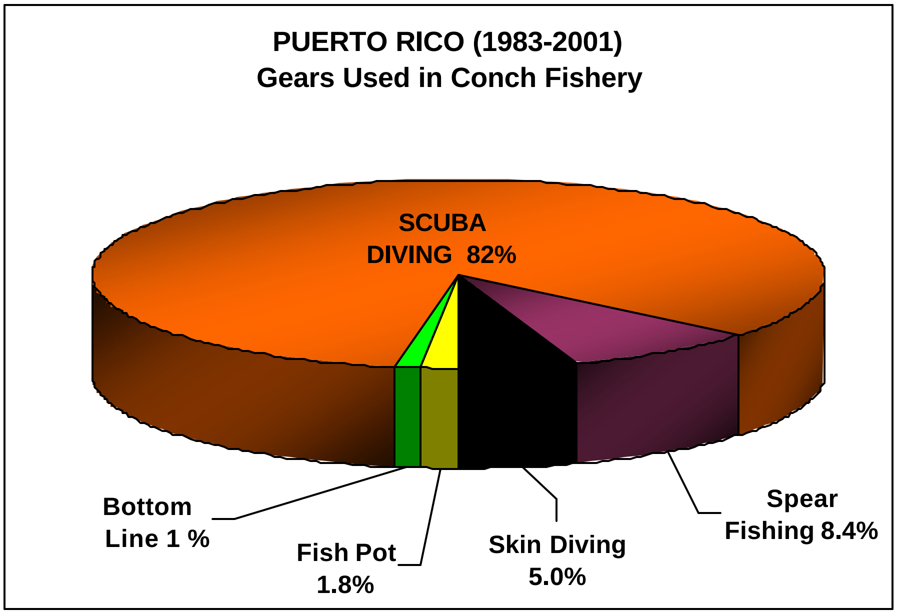


Figure 7. Gears used in the Puerto Rican conch fishery. Percentages were calculated as the proportion of the total positive queen conch trips that used each gear . The name, code, % frequency and cumulative probability are shown in the table.



Gear Name	Gear Code	Frequency	Cum Prob
Scuba Diving	116	82.04%	82.04%
Spear Fishing	110	8.42%	90.46%
Skin Diving	114	5.00%	95.46%
Fish Pot	101	1.85%	97.31%
Bottom Line	104	1.01%	98.31%
Other	111	0.55%	98.86%
Gill Net	103	0.36%	99.22%
Trammel Net	118	0.31%	99.53%
By Hand	115	0.11%	99.64%
Troll Line	105	0.11%	99.75%

Figure 8. Chart of the U.S. Virgin Islands fishing areas provided in the revised catch report forms, with the equivalent areas from the old forms (shown in red for St. Croix).

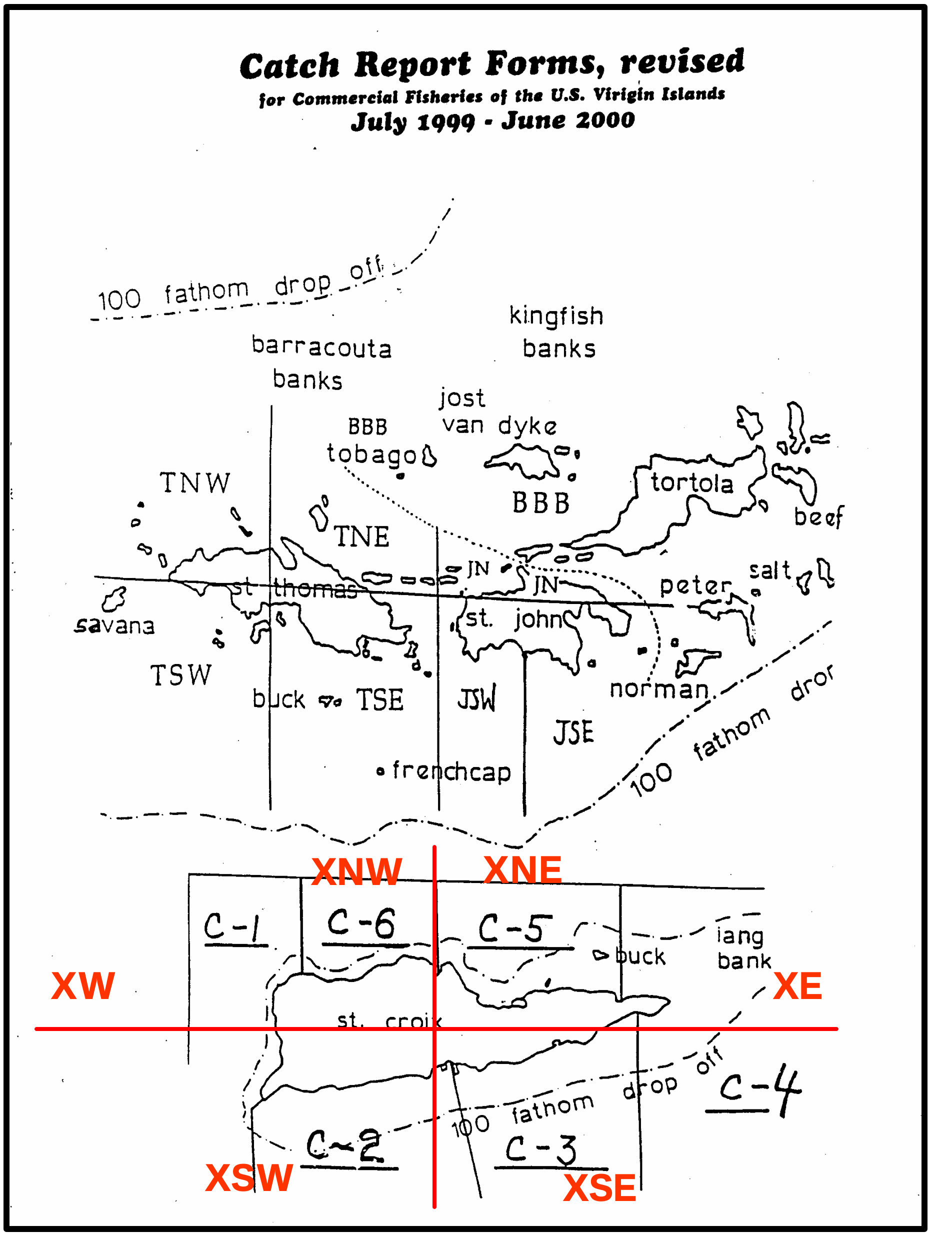


Figure 9. **Puerto Rico Queen Conch Commercial CPUE (1983-2001) - Delta-Lognormal Model. a)** Nominal CPUE (lb/trip); **b)** Nominal and predicted CPUE for the positive trips only; **c)** Observed and predicted proportion of positive/total trips, **d)** Frequency distribution of Log CPUE of positive trips.

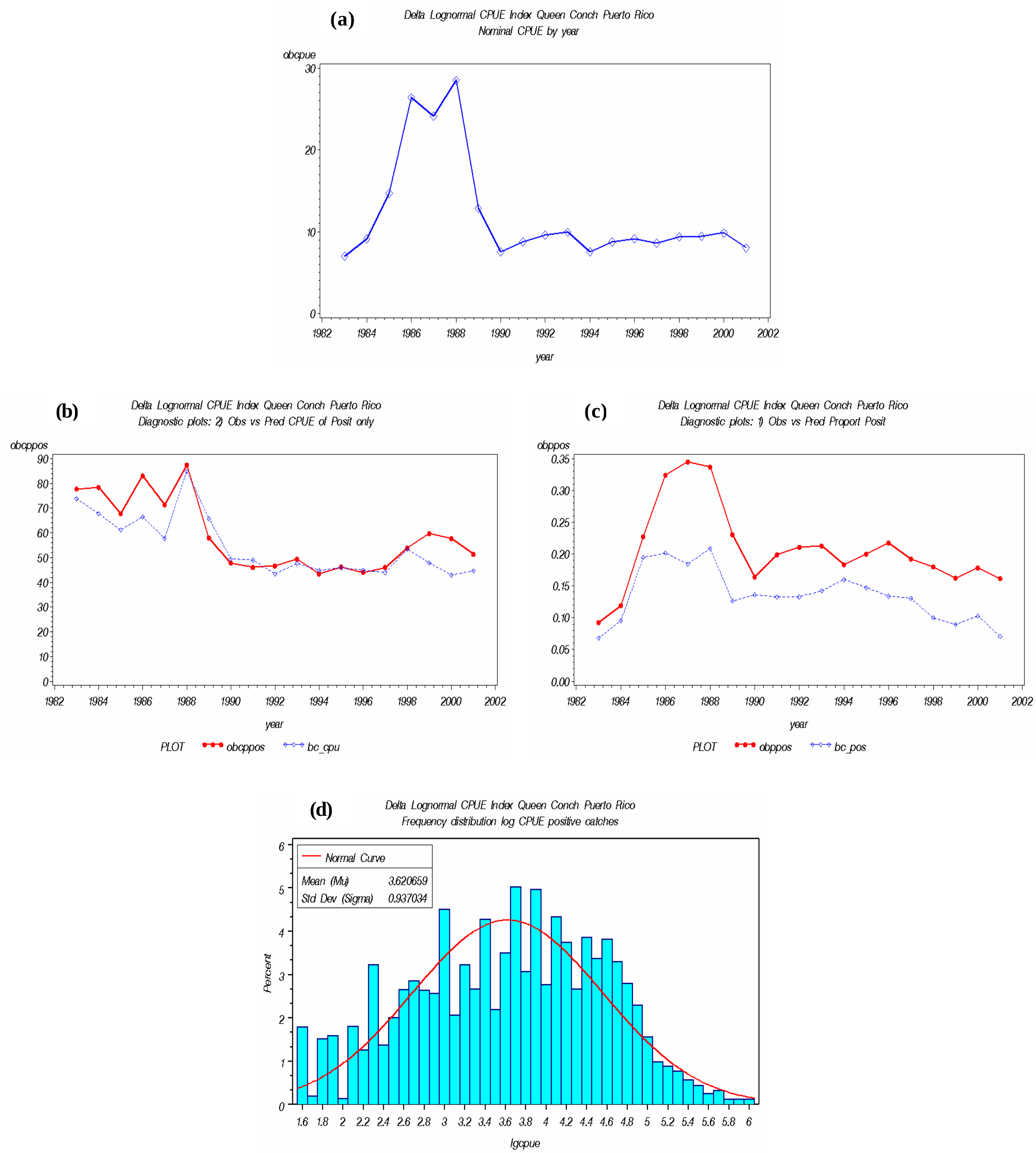


Figure 9. **(Cont.) Puerto Rico Queen Conch Commercial CPUE (1983-2001) - Delta-Lognormal Model. e)** Residuals of the assumed lognormal error distribution for the positive trips; **f)** Chi-square residuals of the assumed binomial error distribution for the proportion of positive trips; **g)** Frequency distribution of the residuals from the positive trips; **h)** Nominal and standardized (scaled) Delta-Lognormal CPUE index for queen conch from the commercial fishery 1983-2001. Bars represent 95% confidence intervals, values are scaled to the maximum CPUE.

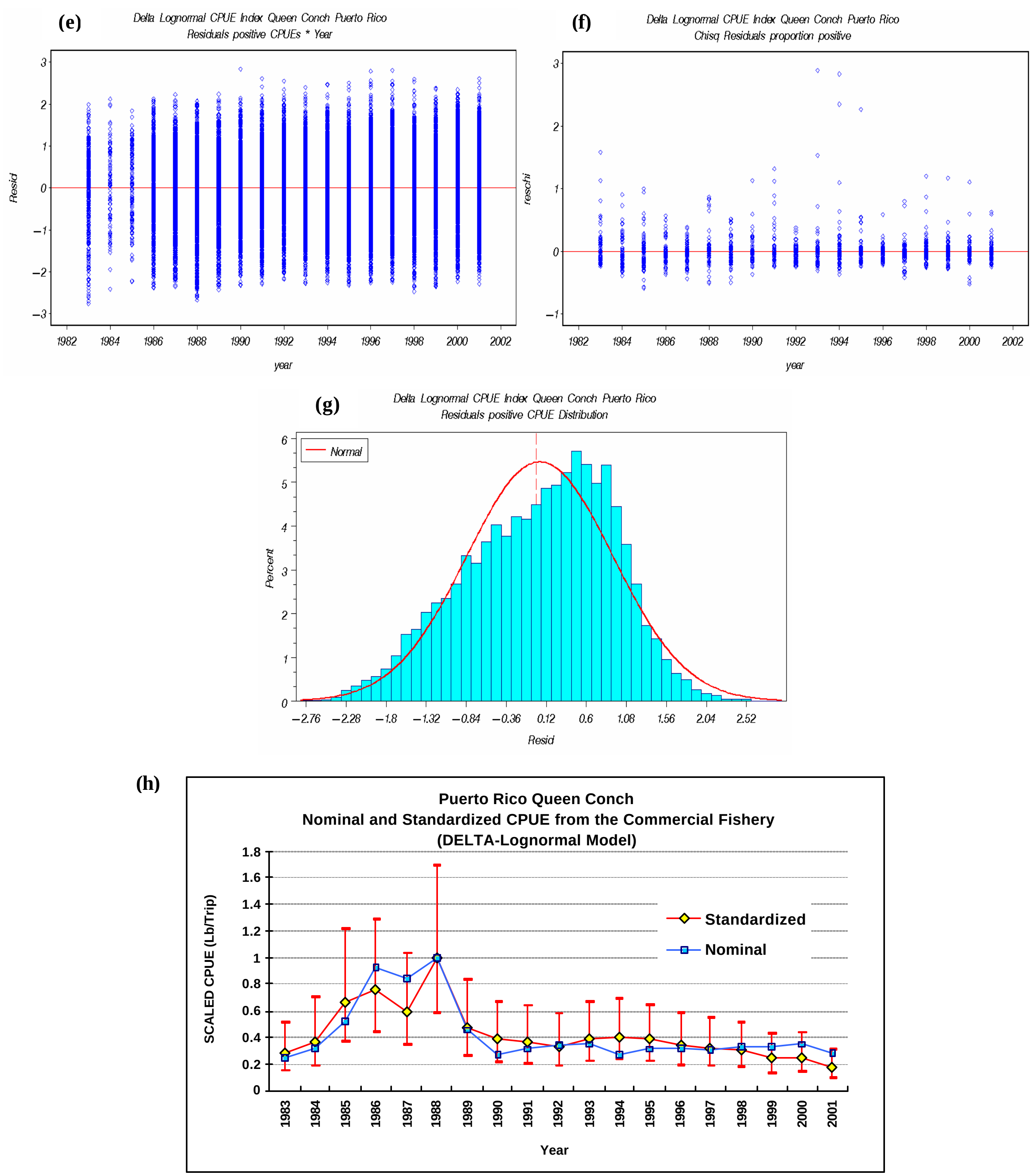


Figure 10. Puerto Rico Queen Conch Commercial CPUE (1983-2001) – General Linear Model (GLM). a) Nominal CPUE (lb/trip); **b)** Frequency distribution of Log CPUE; **c)** Residuals of the assumed lognormal error distribution; **d)** Frequency distribution of the residuals; **e)** Nominal and standardized (scaled) GLM- CPUE index. Bars represent 95% confidence intervals, values are scaled to the maximum CPUE.

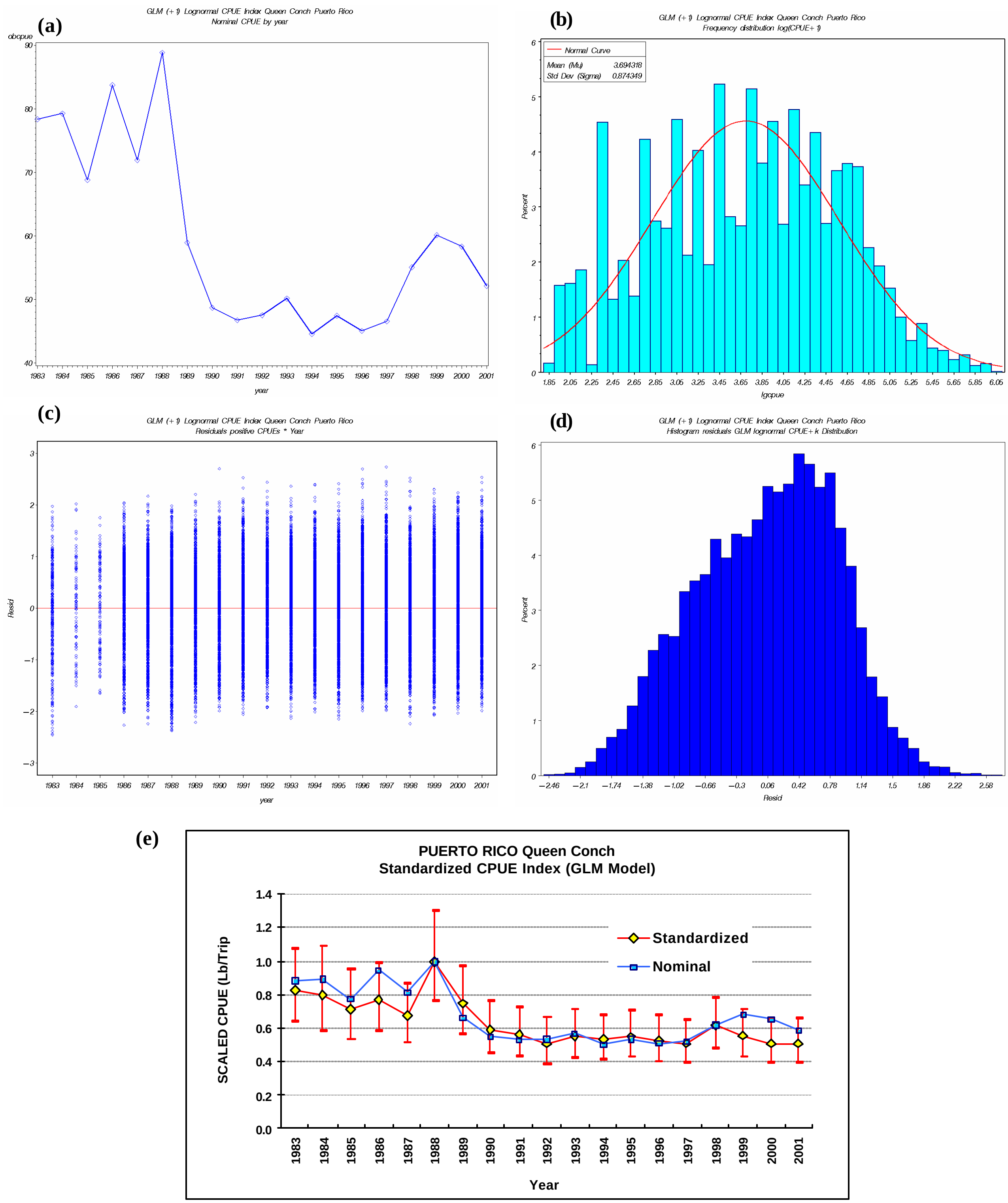


Figure 11. Puerto Rico Southwest Coast. Queen Conch Commercial CPUE (1983-2001) – GLM. **a)** Nominal CPUE (lb/trip); **b)** Frequency distribution of Log CPUE; **c)** Residuals of the assumed lognormal error distribution; **d)** Frequency distribution of the residuals; **e)** Nominal and standardized (scaled) GLM- CPUE index. Bars represent 95% confidence intervals, values are scaled to the maximum CPUE.

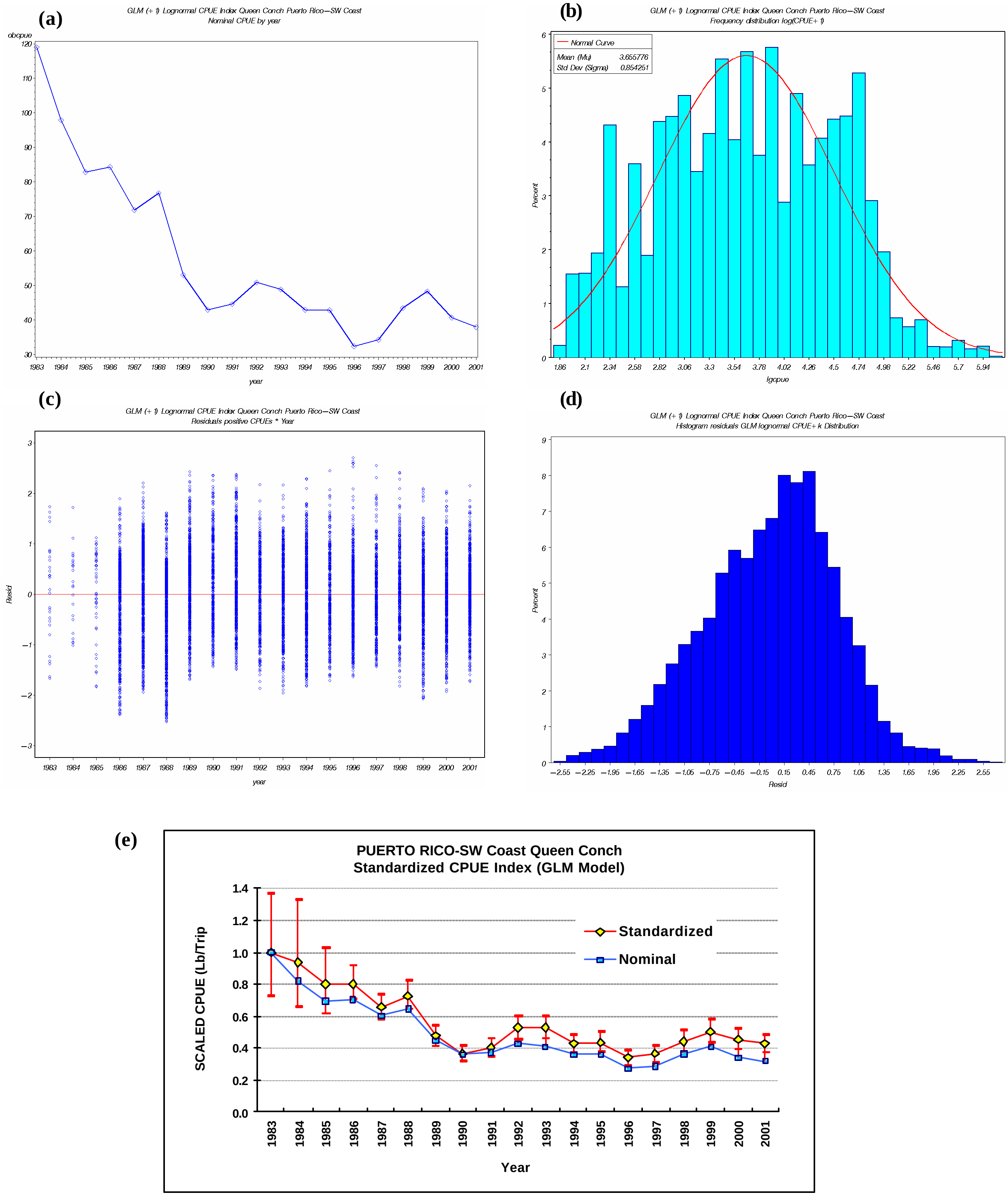
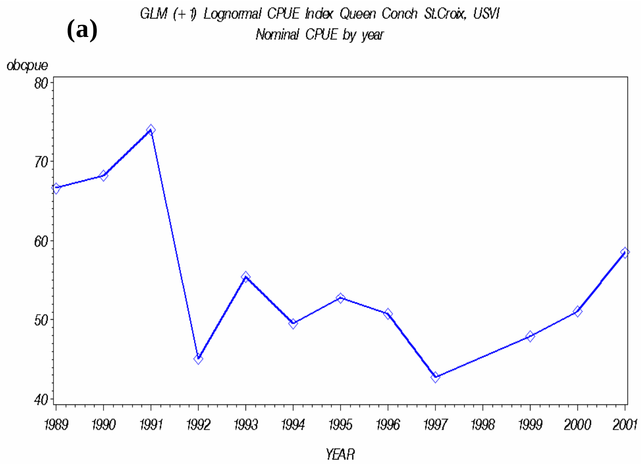
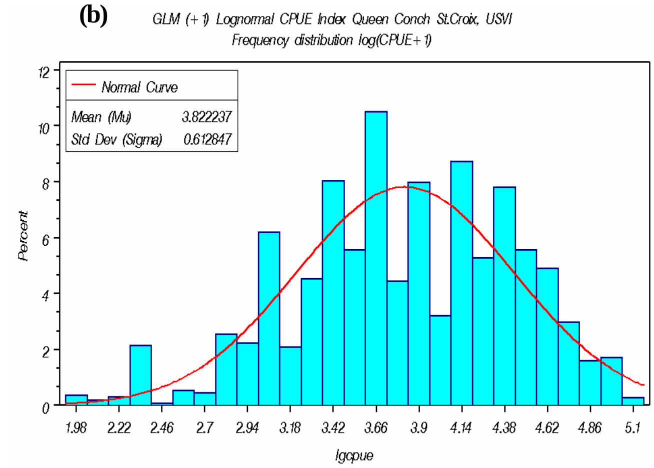


Figure 12. St. Croix, U.S.Virgin Islands. Queen Conch Commercial CPUE (1989-2001) – GLM. **a)** Nominal CPUE (lb/trip); **b)** Frequency distribution of Log CPUE; **c)** Residuals of the assumed lognormal error distribution; **d)** Frequency distribution of the residuals; **e)** Nominal and standardized (scaled) GLM- CPUE index. Bars represent 95% confidence intervals, values are scaled to the maximum CPUE.

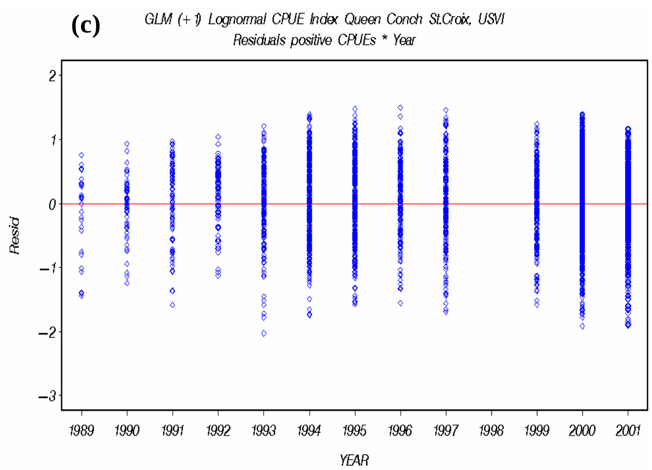
(a)



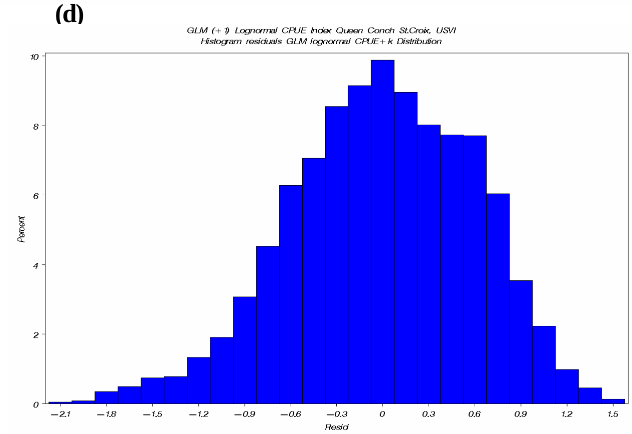
(b)



(c)



(d)



(e)

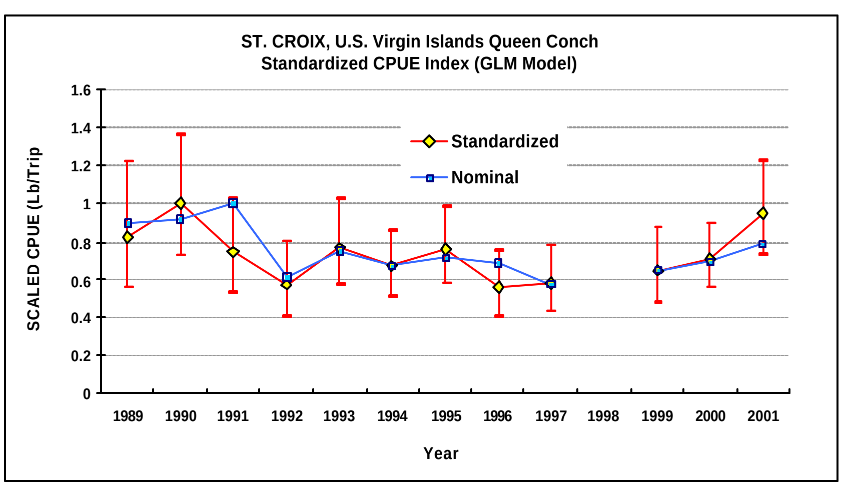


Figure 13. Comparison of the standardized CPUE index and the SEAMAP index (Torres-Rosado 1987, Appeldoorn 1996) for the southwest coast of Puerto Rico. A line was superimposed on both indices to illustrate the overall trends.

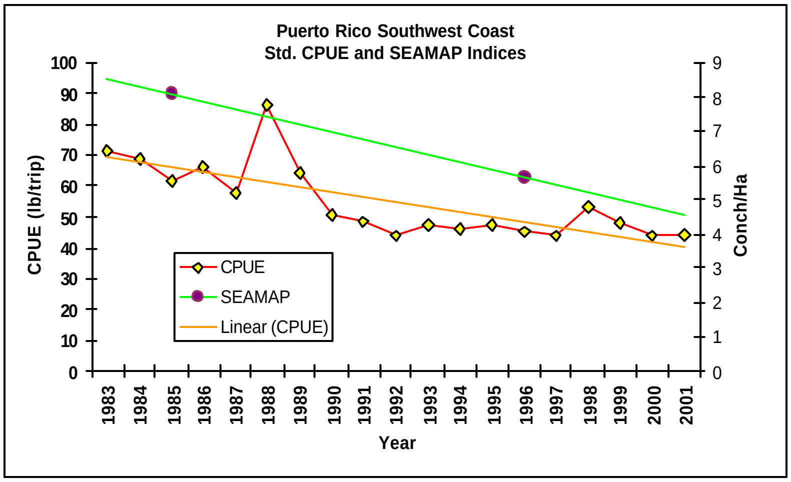


Figure 14. Puerto Rico commercial queen conch landings and standardized CPUE indices used in ASPIC analyses.

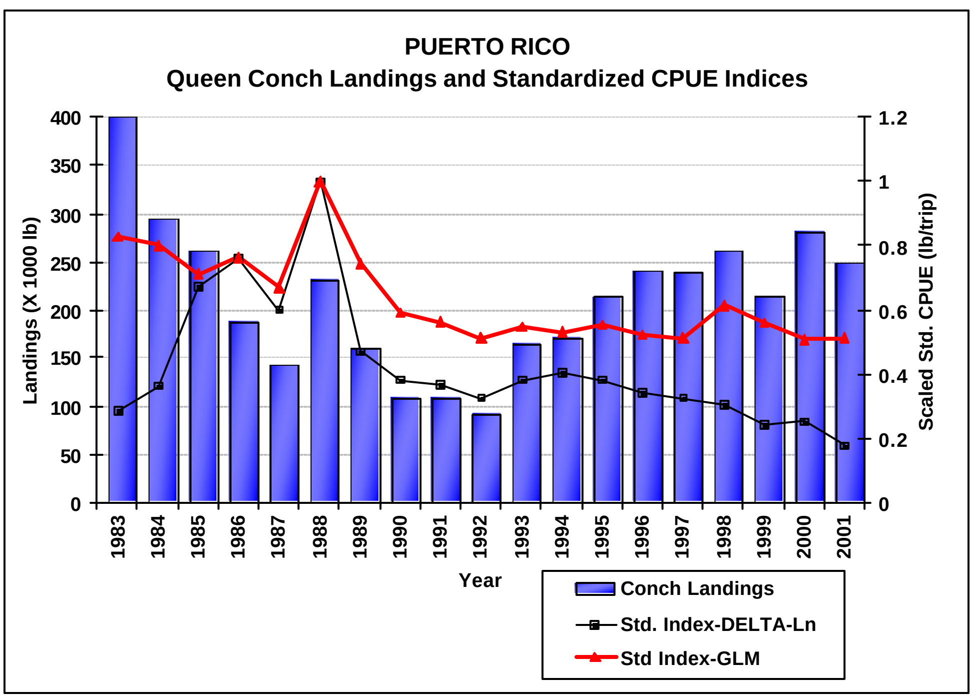


Figure 15. Puerto Rico Southwest Coast. Commercial queen conch landings and standardized CPUE index used in ASPIC analyses.

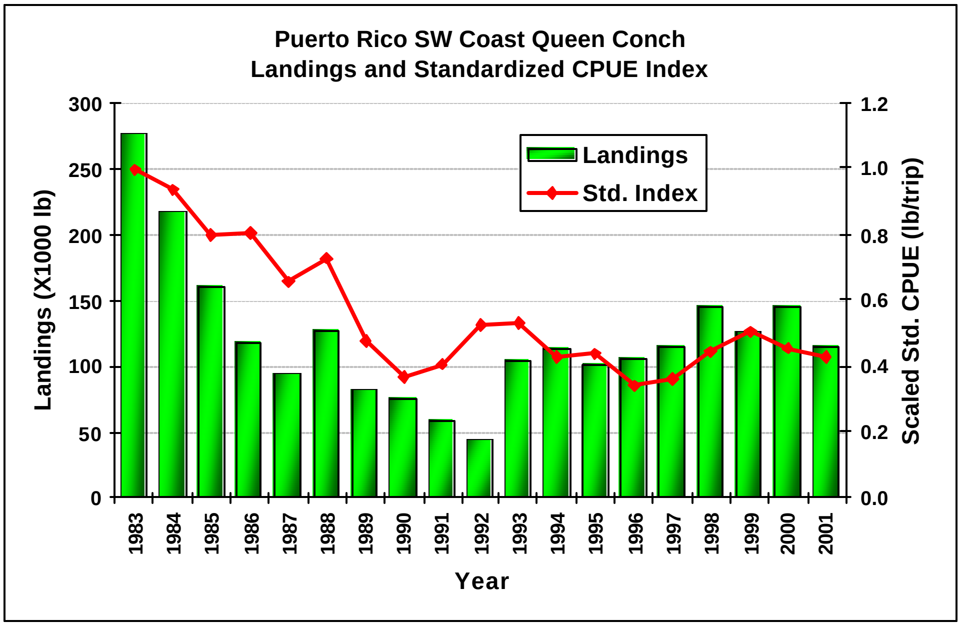


Figure 16. **(a)** St. Croix, U.S.Virgin Islands. Estimated commercial queen conch landings and standardized CPUE index.

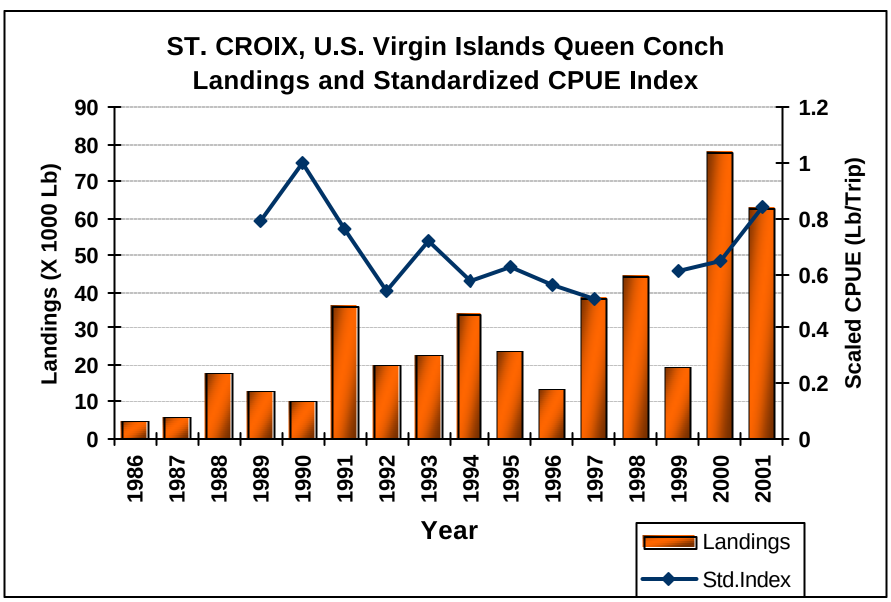
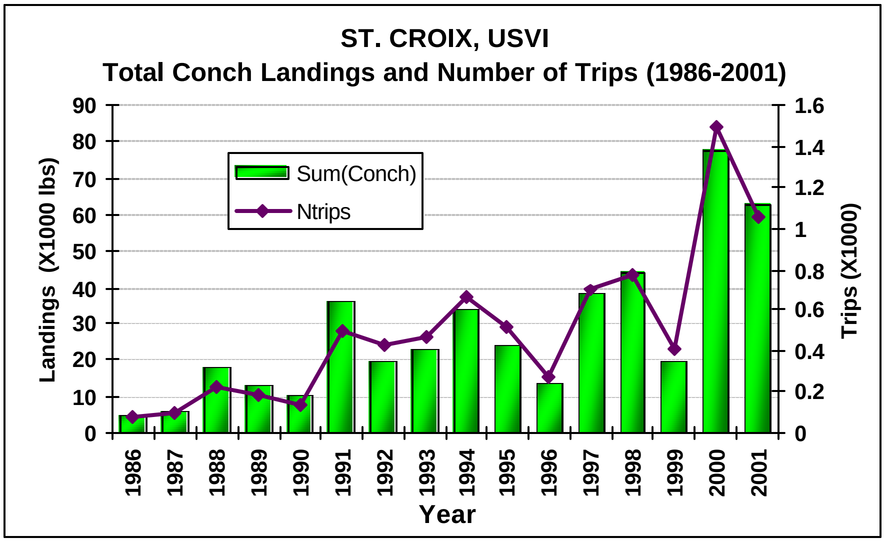


Figure 16. (Cont.) **(b)** St. Croix, U.S.Virgin Islands. Estimated commercial queen conch landings and number of trips (1986-2001).



ASPIC TABLES/FIGURES

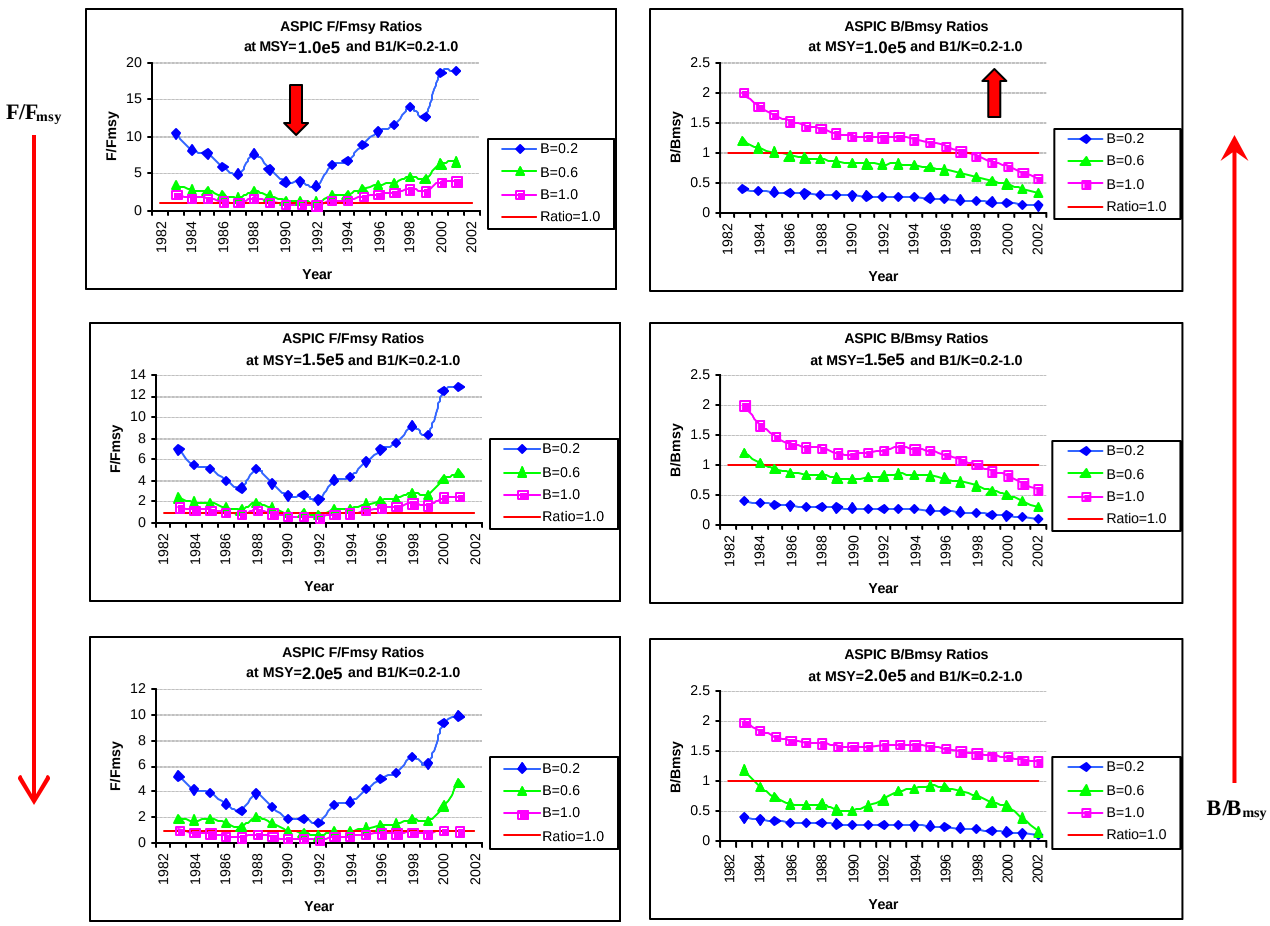


Figure 17. Delta-Ln-CPUE Trials. ASPIC sensitivity trials with fixed MSY=[1.0e5, 1.5e5, 2.0e5] and B1/K=[0.2,0.6,1.0]. F/F_{msy} rates decrease with increasing B1/K for the same MSY value, and decrease as MSY values increase. The opposite trend is observed for B/B_{msy} rates.

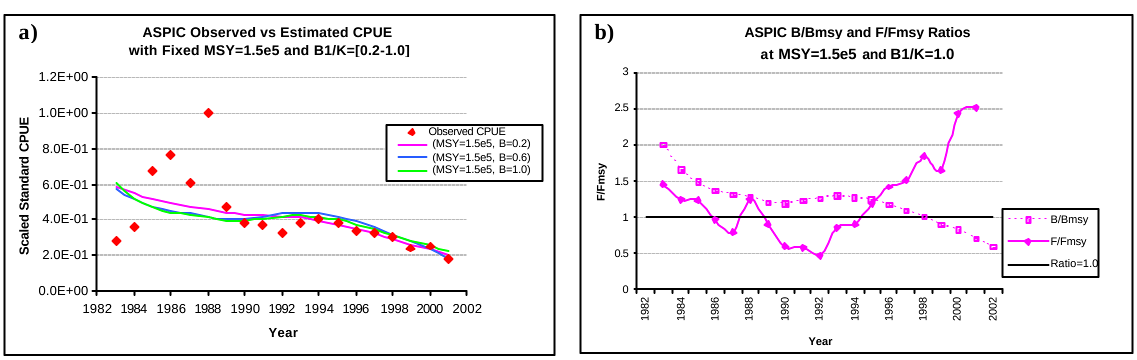


Figure 18. Puerto Rico. ASPIC Trials with Delta-Ln-CPUE. a) ASPIC observed vs. estimated CPUE with fixed MSY=1.5e5 and B1/K= [0.2,0.6,1.0]. **b)** B/Bmsy and F/Fmsy estimates at fixed MSY=1.5e5 and B1/K=1.0.

Figure 19. Puerto Rico. Delta-Ln-CPUE Trials. ASPIC output with fixed MSY=$1.5e^5$ and free estimation of other parameters (Years 1983-2001).

Puerto Rico QUEEN CONCH Assessment **Page 1**
CONTROL PARAMETERS USED (FROM INPUT FILE) **Input file: b-k02.inp**

Operation of ASPIC: Fit logistic model by direct optimization.

Number of years analyzed:	19	Number of bootstrap trials:	0
Number of data series:	1	Lower bound on MSY:	5.000E+04
Objective function:	Least squares	Upper bound on MSY:	5.000E+05
Relative conv. criterion (simplex):	1.000E-08	Lower bound on K:	1.000E+06
Relative conv. criterion (restart):	3.000E-08	Upper bound on K:	1.000E+12
Relative conv. criterion (effort):	1.000E-04	Random number seed:	3941285
Maximum F allowed in fitting:	6.000	Monte Carlo search mode, trials:	0 0
Identical convergences required in fitting:	6		

PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS) **error code 0**

Normal convergence.
Number of restarts required for convergence: 6

GOODNESS-OF-FIT AND WEIGHTING FOR NON-BOOTSTRAPPED ANALYSIS

Loss component number and title	Weighted SSE	N	Weighted MSE	Current weight	Suggested weight	R-squared in CPUE
Loss(-1) SSE in yield	0.00E+00					
Loss(0) Penalty for B1 > K	0.00E+00	1	N/A	0.00E+00	N/A	
Loss(1) CPUE and Yield from Commercial Fishery	2.24E+00	19	1.32E-01	1.00E+00	1.00E+00	0.096
....						
TOTAL OBJECTIVE FUNCTION, MSE, RMSE:		2.24E+00	1.40E-01	3.74E-01		

Log likelihood:	-6.7675	
Estimated contrast index (ideal = 1.0):	0.7395	C* = (Bmax-Bmin)/K
Estimated nearness index (ideal = 1.0):	1	N* = 1 - (min|B-Bmsy|c/K)

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter		Estimate	User/pgm (	2nd guess	Estimated	User guess
B1/K	Starting biomass ratio (year 1983)	1.09E+00	2.00E-01	3.98E-01	1	1
MSY	Maximum sustainable yield	1.50E+05	1.50E+05	1.81E+05	0	1
K	Maximum population size	2.23E+06	1.00E+07	1.08E+06	1	1
phi	Position of Bmsy relative to K	5.00E-01	----	----	0	0
--------- Catchability Coefficients by Fishery ---------------						
q(1)	CPUE and Yield from Commercial Fishery	2.75E-07	1.00E-05	9.50E-04	1	1

MANAGEMENT and DERIVED PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter		Estimate	Logistic formula	General formula
MSY	Maximum sustainable yield	1.50E+05	----	----
Bmsy	Stock biomass giving MSY	1.12E+06	K/2	K*n**(1/(1-n))
Fmsy	Fishing mortality rate at MSY	1.34E-01	MSY/Bmsy	MSY/Bmsy
n	Exponent in production function	2.00E+00	----	----
g	Fletcher's gamma	4.00E+00	----	[n**(n/(n-1))]/[n-1]
B./Bmsy	Ratio: B(2002)/Bmsy	6.94E-01	----	----
F./Fmsy	Ratio: F(2001)/Fmsy	2.21E+00	----	----
Fmsy/F.	Ratio: Fmsy/F(2001)	4.52E-01	----	----
Y.(Fmsy)	Yield available at Fmsy in 2002	1.04E+05	MSY*B./Bmsy	MSY*B./Bmsy
	...as proportion of MSY	6.94E-01	----	----
Ye.	Equilibrium yield available in 2002	1.36E+05	4*MSY*(B/K-(B/K)**2)	g*MSY*(B/K-(B/K)**n)
	...as proportion of MSY	9.06E-01	----	----

--------- Fishing Effort at MSY in Units of each Fishery -----

fmsy(1) CPUE and Yield from Commercial Fishery	4.88E+05	Fmsy/q(1)	Fmsy/q(1)

Figure 19 (cont.). ASPIC output with fixed MSY=1.5e^5 and free estimation of other parameters. Population trajectories and CPUE series for years 1983-2001.

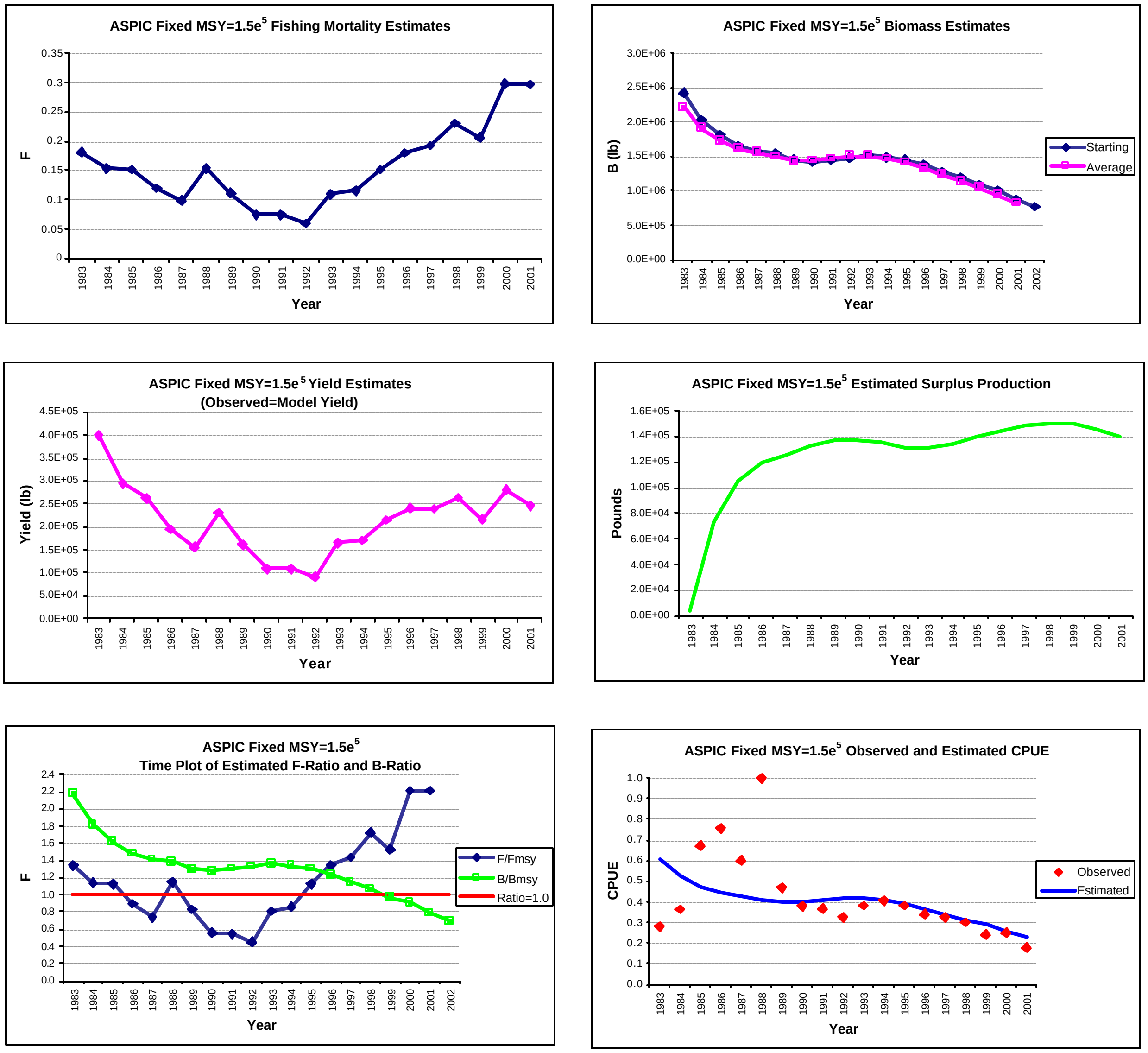


Figure 20. Puerto Rico. Delta-Ln-CPUE Trials. Selected ASPIC output for free model runs (Years 1985-2001) with a penalty imposed on B1/K (indicated by an asterisk *) and without.

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

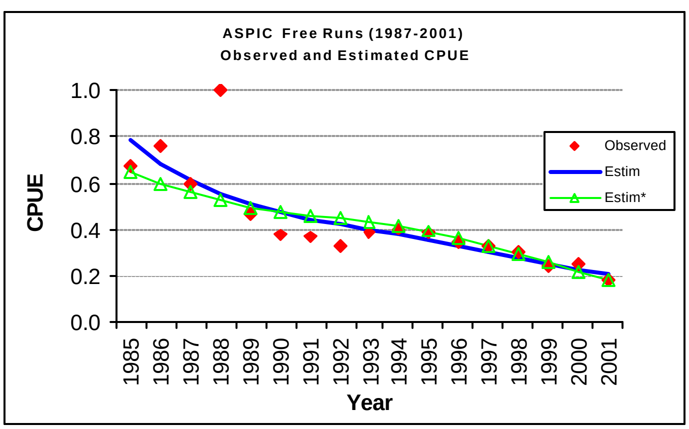
Parameter		Estimate No Penalty	Estimate W/ Penalty on B1/K
B1/K	Starting biomass ratio (year 1985)	2.69E+00	1.17E+00
MSY	Maximum sustainable yield	5.24E+04	7.17E+04
K	Maximum population size	2.87E+06	2.91E+06
phi	Position of Bmsy relative to K	5.00E-01	5.00E-01
q(1)	CPUE and Yield from Commercial Fishe	1.10E-07	2.00E-07

MANAGEMENT and DERIVED PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

		No Penalty	W/ Penalty on B1/K
MSY	Maximum sustainable yield	5.24E+04	7.17E+04
Bmsy	Stock biomass giving MSY	1.43E+06	1.46E+06
Fmsy	Fishing mortality rate at MSY	3.65E-02	4.93E-02
n	Exponent in production function	2.00E+00	2.00E+00
g	Fletcher's gamma	4.00E+00	4.00E+00
B./Bmsy	Ratio: B(2002)/Bmsy	1.22E+00	5.49E-01
F./Fmsy	Ratio: F(2001)/Fmsy	3.65E+00	5.61E+00
Fmsy/F.	Ratio: Fmsy/F(2001)	2.74E-01	1.78E-01
Y.(Fmsy)	Yield available at Fmsy in 2002	6.38E+04	3.94E+04
	...as proportion of MSY	1.22E+00	5.49E-01
Ye.	Equilibrium yield available in 2002	4.98E+04	5.71E+04
	...as proportion of MSY	9.52E-01	7.97E-01
fmsy(1)	CPUE and Yield from Commercial Fishe	3.33E+05	2.46E+05

FIT STATISTICS

		No Penalty	W/ Penalty on B1/K
OF	Total Objective Function	6.01E-01	7.56E-01
R^2	R-Squared in CPUE	0.657	0.593



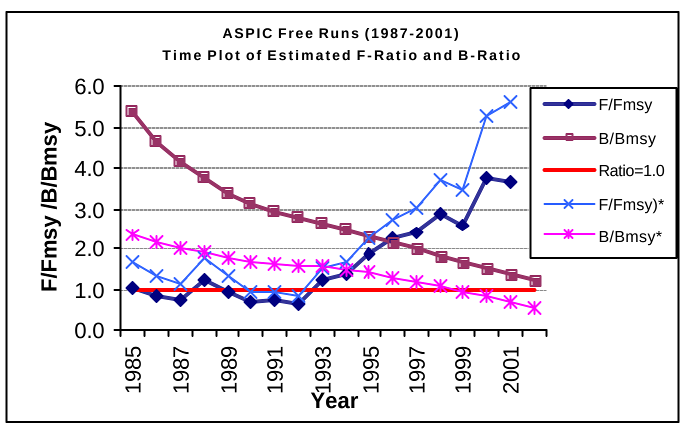
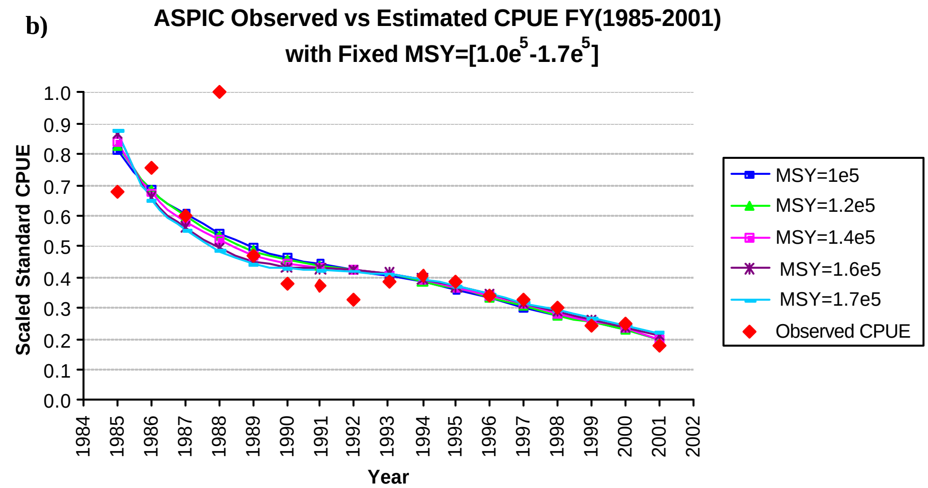


Figure 21. Puerto Rico. Delta-Ln-CPUE Trials. a) ASPIC parameter estimates for non-bootstrapped analysis with fixed MSY=[1.0e^5- 1.7e^5], for years 1985-2001; **b)** Observed vs estimated CPUE; **c)** Time plot of estimated F-Ratio and B-Ratio; **d)** Population trajectories.

a)

	Fixed Model	MSY=1e^5	MSY=1.2e^5	MSY=1.4e^5	MSY=1.5e^5	MSY=1.6e^5	MSY=1.7e^5
Goodness-of-fit	R^2 on CPUE	0.636	0.619	0.593	0.575	0.552	0.527
	Obj. Function	6.10E-01	6.26E-01	6.58E-01	6.86E-01	7.25E-01	7.78E-01
	Log Likelihood	4.00587	3.79423	3.36243	3.0137432	2.5448	1.94277
Model Parameters	B1/K	2.084	1.998	1.986	2.011	2.063	2.159
	MSY	1.00E+05	1.20E+05	1.40E+05	1.50E+05	1.60E+05	1.70E+05
	K	2.57E+06	2.31E+06	2.01E+06	1.87E+06	1.74E+06	1.66E+06
	q	1.67E-07	2.01E-07	2.44E-07	2.68E-07	2.91E-07	3.02E-07
Management Parameters	Bmsy	1.28E+06	1.15E+06	1.01E+06	9.34E+05	8.68E+05	8.31E+05
	Fmsy	7.79E-02	1.04E-01	1.39E-01	1.61E-01	1.84E-01	2.05E-01

b)



c)

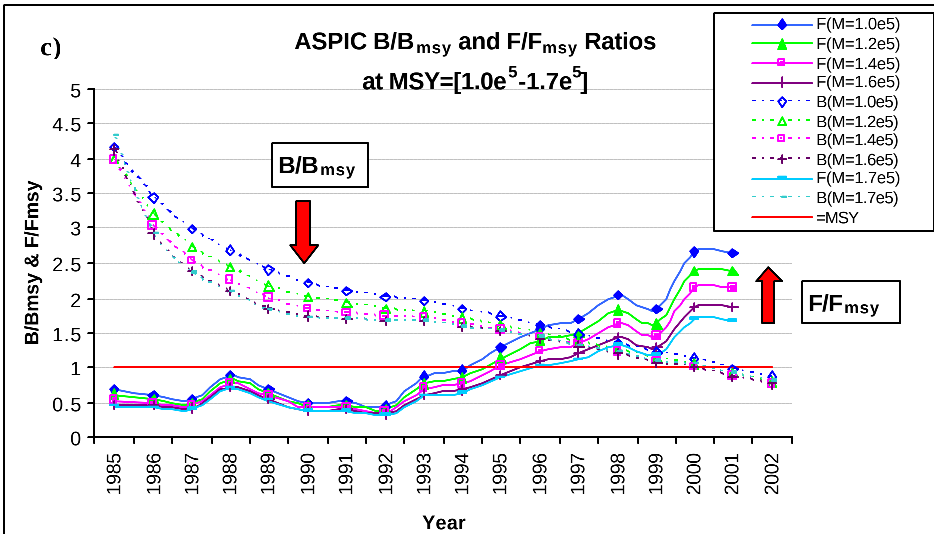


Figure 21. (Cont.) d) ASPIC population trajectories for non-bootstrapped analysis with fixed MSY=[1.0e^5- 1.7e^5], years 1985-2001.

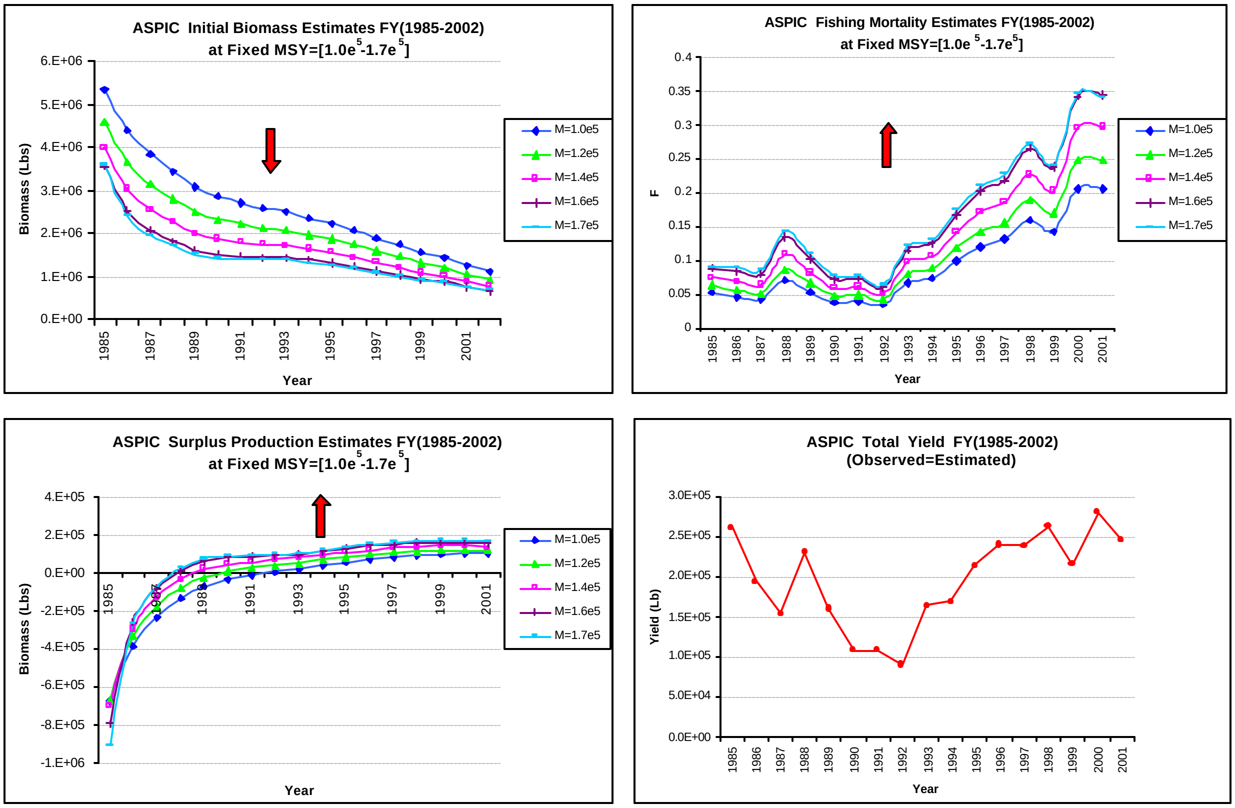


Figure 22. Puerto Rico. Delta-Ln-CPUE Trials. ASPIC estimates from bootstrapped analysis with fixed MSY=1.4e^5, years 1985-2001.

ESTIMATES FROM BOOTSTRAP ANALYSIS

Param name	Point estimate	Bias in estimate	Relative bias	Approx 80% lower CL	Approx 80% upper CL	Approx 50% lower CL	Approx 50% upper CL	Inter-quartile range	Relative IQ range
Model Parameters									
B1/K	1.99E+00	2.11E-01	10.61%	1.40E+00	3.20E+00	1.65E+00	2.34E+00	6.93E-01	0.349
K	2.01E+06	3.01E+05	14.93%	1.75E+06	3.73E+06	1.86E+06	2.41E+06	5.44E+05	0.27
q(1)	2.44E-07	6.44E-10	0.26%	1.28E-07	3.34E-07	1.90E-07	2.87E-07	9.75E-08	0.4
Management Benchmarcks									
MSY	1.40E+05	0.00E+00	0.00%	1.40E+05	1.40E+05	1.40E+05	1.40E+05	0.00E+00	0
Ye(2002)	1.32E+05	-1.53E+04	-11.54%	1.16E+05	1.40E+05	1.27E+05	1.39E+05	1.23E+04	0.093
Y.@Fmsy	1.07E+05	5.86E+03	5.48%	7.72E+04	1.86E+05	9.22E+04	1.35E+05	4.27E+04	0.399
Bmsy	1.01E+06	1.50E+05	14.93%	8.74E+05	1.86E+06	9.32E+05	1.20E+06	2.72E+05	0.27
Fmsy	1.39E-01	-3.56E-03	-2.56%	7.51E-02	1.60E-01	1.16E-01	1.50E-01	3.39E-02	0.244
fmsy(1)	5.71E+05	2.63E+04	4.61%	4.66E+05	6.93E+05	5.13E+05	6.24E+05	1.11E+05	0.194
B./Bmsy	7.64E-01	4.18E-02	5.48%	5.52E-01	1.33E+00	6.59E-01	9.64E-01	3.05E-01	0.399
F./Fmsy	2.15E+00	1.01E-01	4.68%	1.31E+00	2.83E+00	1.75E+00	2.45E+00	7.03E-01	0.327
Ye./MSY	9.44E-01	-1.09E-01	-11.54%	8.26E-01	1.00E+00	9.07E-01	9.95E-01	8.75E-02	0.093

NOTES ON BOOTSTRAPPED ESTIMATES:

- Bootstrap results were computed from 1000 trials.
-Results are conditional on constraints set on MSY and K by the user.
- All bootstrapped intervals are approximate. The statistical literature recommends using at least 1000 trials for accurate 95% intervals. The 80% intervals used by ASPIC should require fewer trials for equivalent accuracy.
- Bias estimates are known to have high variance and so may be misleading.

Figure 23. Puerto Rico. ASPIC trials with GLM-CPUE. a) ASPIC estimates from bootstrapped analysis with fixed q=2.0e^{-7}, years 1983-2001. **b)** Comparison of non-bootstrapped population trajectories and CPUEs for model fits with (*) and without a B_1/K constraint.

a)

ESTIMATES FROM BOOTSTRAP ANALYSIS

Param name	Point estimate	Bias in estimate	Relative bias	Approx 80% lower CL	Approx 80% upper CL	Approx 50% lower CL	Approx 50% upper CL	IQ range	Relative IQ range
B1/K	1.32E+00	5.80E-02	4.41%	9.28E-01	1.76E+00	1.13E+00	1.50E+00	3.70E-01	0.281
K	3.70E+06	4.95E+05	13.39%	3.37E+06	5.00E+06	3.52E+06	4.09E+06	5.71E+05	0.154
q(1)	2.00E-07	3.18E-21	0.00%	2.00E-07	2.00E-07	2.00E-07	2.00E-07	0.00E+00	0
MSY	1.88E+05	1.64E+04	8.72%	1.14E+05	3.27E+05	1.48E+05	2.48E+05	1.00E+05	0.532
Ye(2002)	1.74E+05	-3.88E+03	-2.23%	1.09E+05	2.26E+05	1.44E+05	2.04E+05	5.95E+04	0.342
Y.@Fmsy	2.39E+05	2.84E+04	11.87%	1.04E+05	5.10E+05	1.68E+05	3.55E+05	1.88E+05	0.784
Bmsy	1.85E+06	2.48E+05	13.39%	1.68E+06	2.50E+06	1.76E+06	2.05E+06	2.85E+05	0.154
Fmsy	1.02E-01	9.01E-03	8.87%	4.80E-02	1.87E-01	7.42E-02	1.40E-01	6.62E-02	0.651
fmsy(1)	5.08E+05	4.51E+04	8.87%	2.40E+05	9.34E+05	3.71E+05	7.02E+05	3.31E+05	0.651
B./Bmsy	1.27E+00	-3.66E-02	-2.87%	9.75E-01	1.56E+00	1.14E+00	1.43E+00	2.89E-01	0.227
F./Fmsy	1.02E+00	2.81E-01	27.53%	4.85E-01	2.30E+00	6.95E-01	1.45E+00	7.59E-01	0.743
Ye./MSY	9.26E-01	-4.89E-02	-5.28%	7.19E-01	9.96E-01	8.43E-01	9.80E-01	1.38E-01	0.149

ESTIMATES FROM BOOTSTRAP ANALYSIS (with B_1/K Constraint)*

Param name	Point estimate	Bias in estimate	Relative bias	Approx 80% lower CL	Approx 80% upper CL	Approx 50% lower CL	Approx 50% upper CL	quartile range	Relative IQ range
B1/K	1.06E+00	-1.29E-01	-12.11%	1.05E+00	1.28E+00	1.08E+00	1.22E+00	1.38E-01	0.129
K	4.17E+06	1.26E+06	30.11%	3.68E+06	4.42E+06	3.85E+06	4.21E+06	3.64E+05	0.087
q(1)	2.00E-07	3.18E-21	0.00%	2.00E-07	2.00E-07	2.00E-07	2.00E-07	0.00E+00	0
MSY	1.41E+05	-1.17E+03	-0.83%	1.12E+05	2.45E+05	1.29E+05	1.95E+05	6.60E+04	0.467
Ye(2002)	1.40E+05	-1.26E+04	-8.95%	1.12E+05	2.04E+05	1.31E+05	1.83E+05	5.17E+04	0.369
Y.@Fmsy	1.54E+05	-1.44E+04	-9.37%	1.08E+05	3.81E+05	1.41E+05	2.70E+05	1.29E+05	0.836
Bmsy	2.09E+06	6.28E+05	30.11%	1.84E+06	2.21E+06	1.92E+06	2.11E+06	1.82E+05	0.087
Fmsy	6.78E-02	-7.06E-03	-10.41%	5.11E-02	1.41E-01	6.34E-02	1.05E-01	4.18E-02	0.616
fmsy(1)	3.39E+05	-3.53E+04	-10.41%	2.56E+05	7.02E+05	3.17E+05	5.26E+05	2.09E+05	0.616
B./Bmsy	1.09E+00	-1.23E-01	-11.27%	9.53E-01	1.46E+00	1.06E+00	1.33E+00	2.73E-01	0.251
F./Fmsy	1.57E+00	6.98E-01	44.36%	6.47E-01	2.23E+00	9.04E-01	1.72E+00	8.18E-01	0.519
Ye./MSY	9.92E-01	-6.10E-02	-6.15%	9.33E-01	1.00E+00	9.80E-01	1.00E+00	1.95E-02	0.02

b)

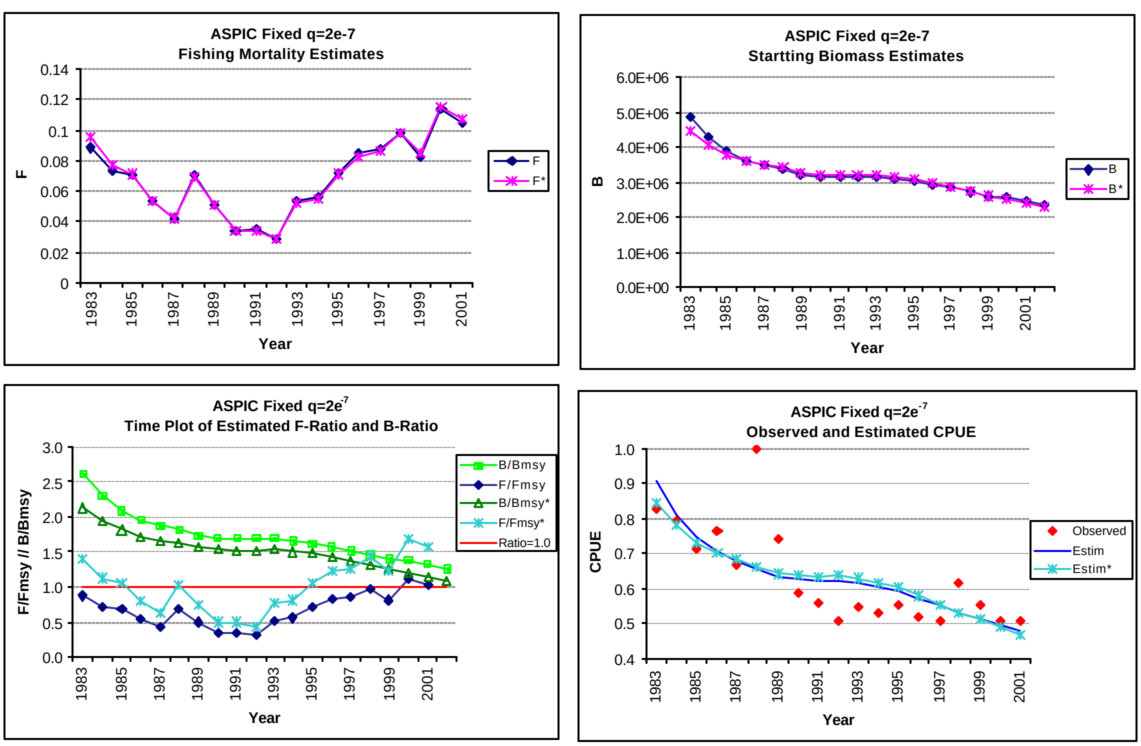


Figure 24. Puerto Rico. Model Projections. Relative biomass, relative fishing mortality and phase plots assuming a natural of mortality of M=0.3. **a)** Constant catch (2001) policy (Y=2.48E+05 lb). **b)** Constant effort (2001) policy (F=0.1068).

(a) **(b)**

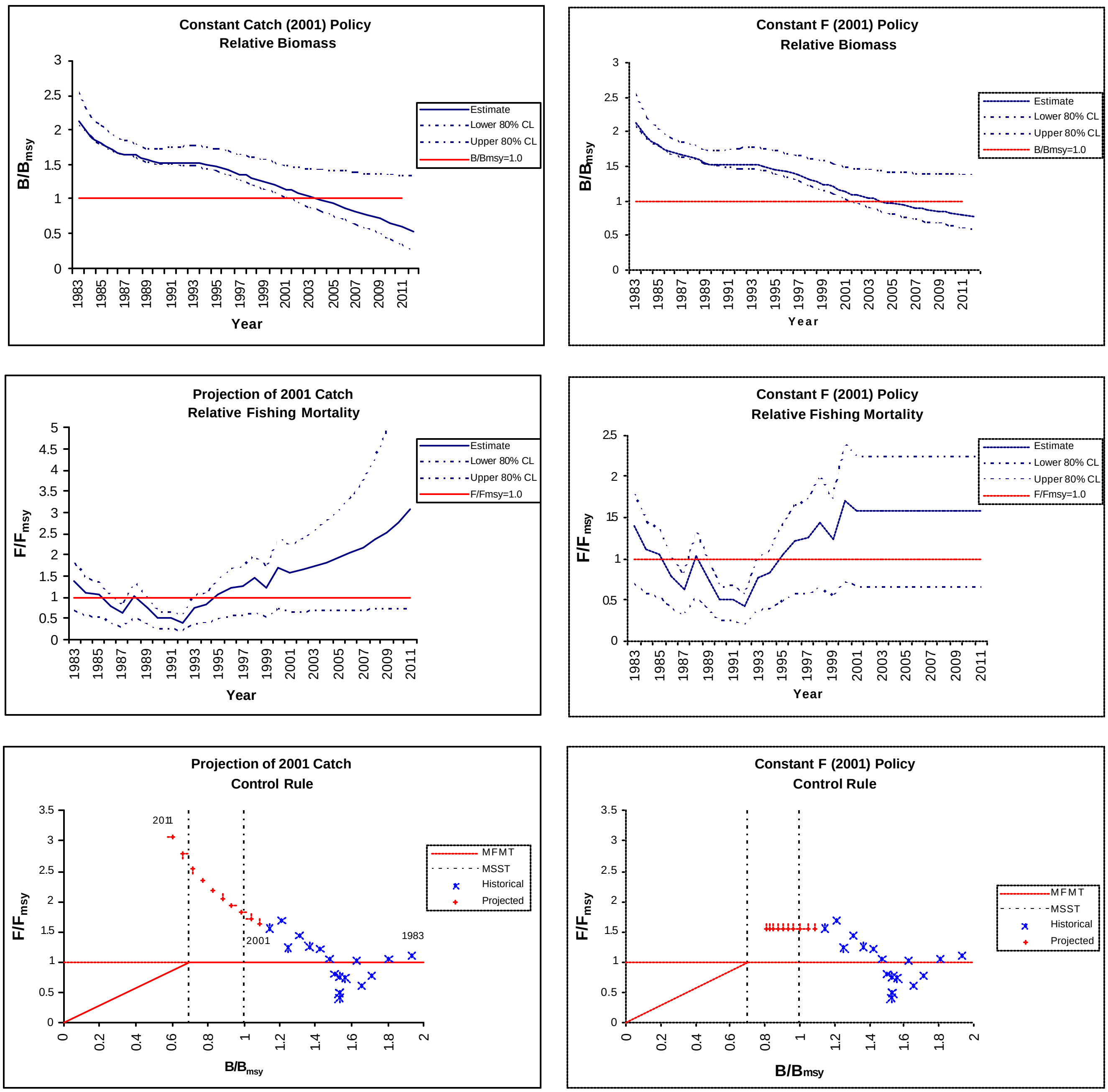


Figure 25. Puerto Rico. Model Projections. Relative biomass, relative fishing mortality and phase plots assuming a natural mortality of M=0.3. Strategies with gradual reductions in: **a)** Fishing Effort and, **b)** Yield, to achieve F_{msy} and MSY, respectively, in 10 years.

(a) **(b)**

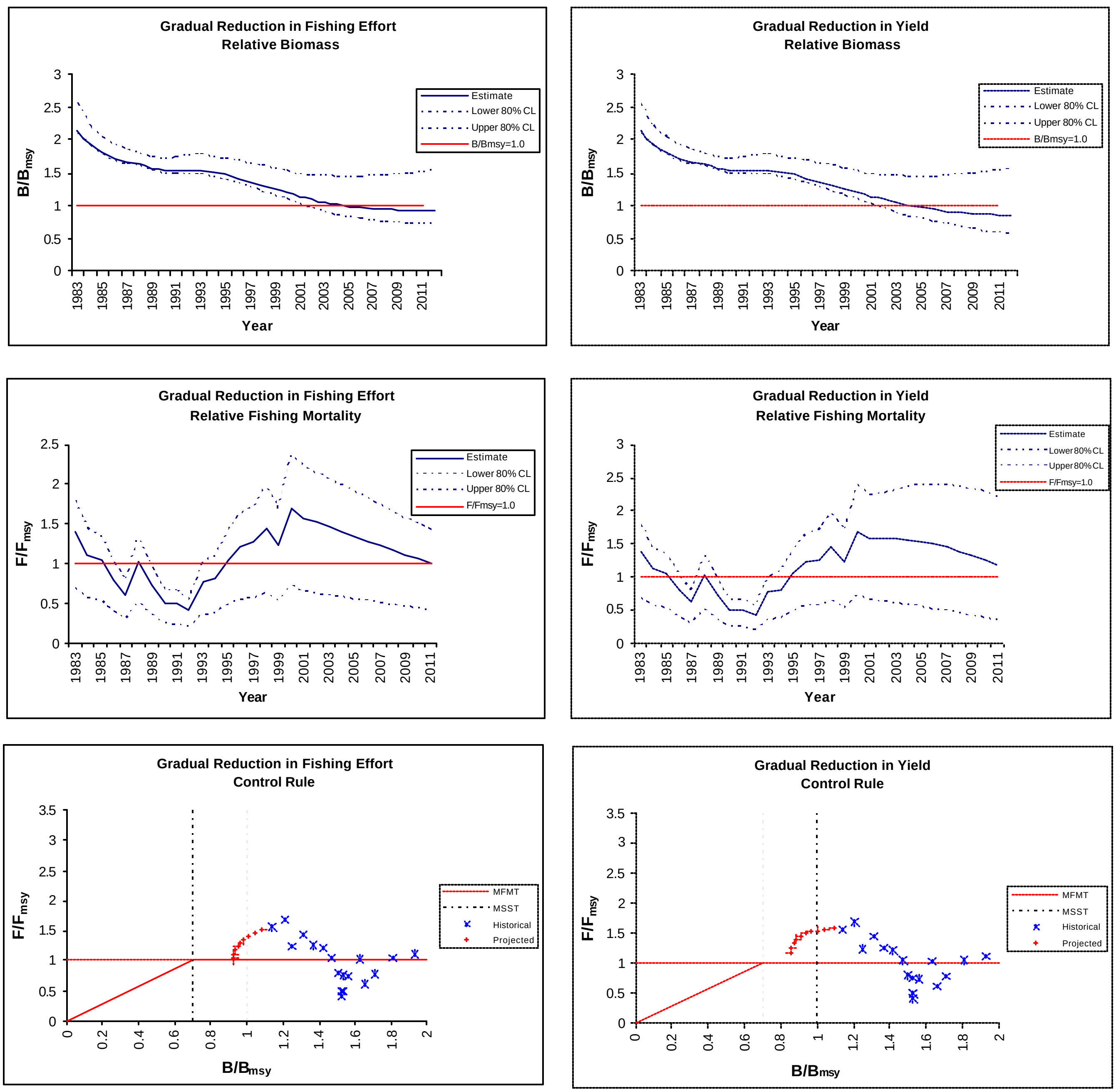


Figure 26. Puerto Rico. Model Projections. Relative biomass, relative fishing mortality and phase plots assuming a natural mortality of M=0.3. **a)** Constant catch at MSY=1.41E+05 lb. **b)** No fishing strategy.

(a) **(b)**

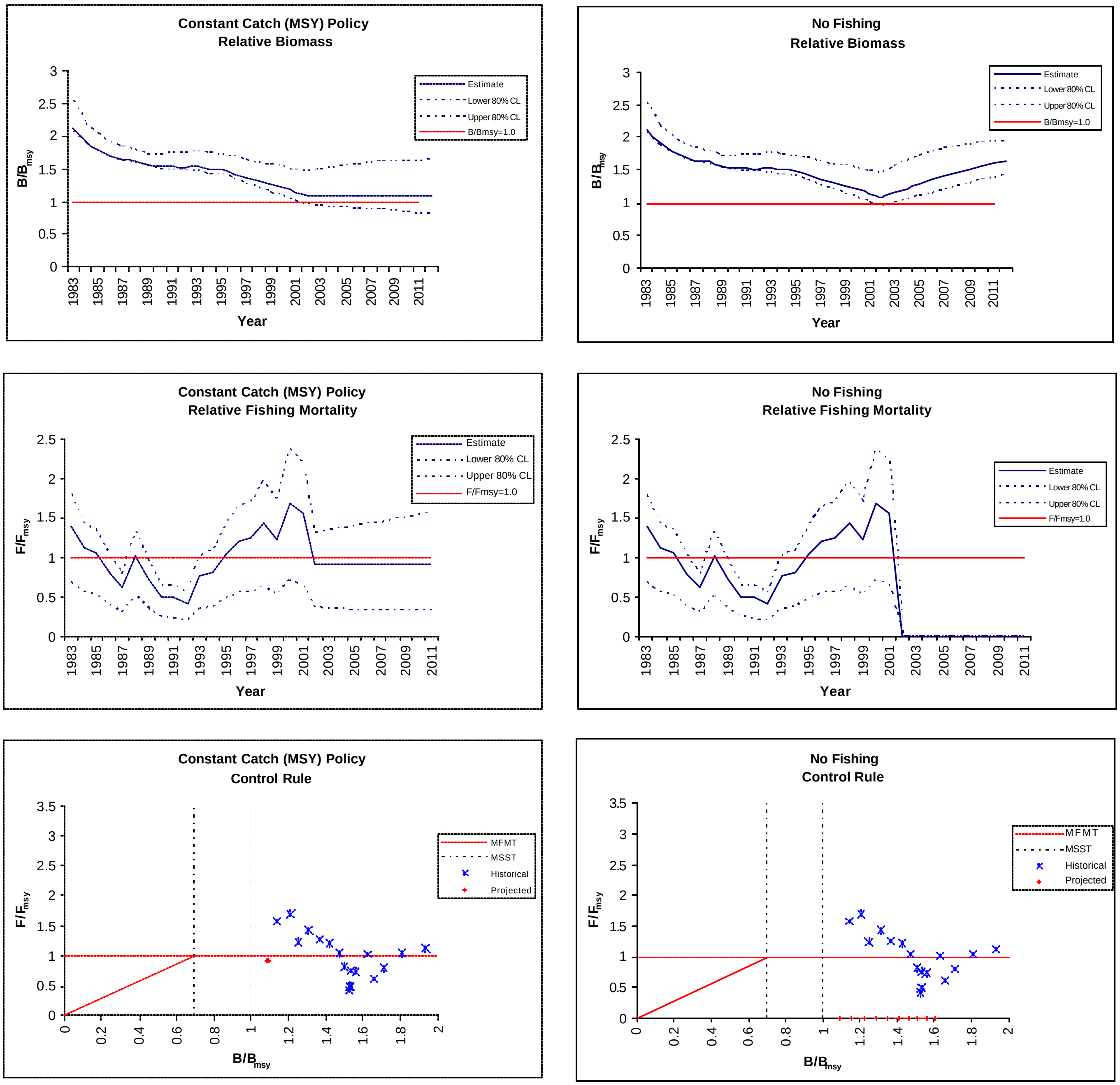


Figure 27. Puerto Rico Southwest Coast. Free ASPIC runs, years 1983-2001. **a)** Results from bootstrapped analysis with a constraint on B_1/K.

a)

SW Coast Puerto Rico QUEEN CONCH Assessment

CONTROL PARAMETERS USED (FROM INPUT FILE) Input file: aspic.inp

Operation of ASPIC: Fit logistic model by direct optimization with bootstrap.

Number of years analyzed:	19	Number of bootstrap trials:	1000
Number of data series:	1	Lower bound on MSY:	1.00E+04
Objective function:	Least squares	Upper bound on MSY:	3.00E+05
Relative conv. criterion (simplex):	1.00E-08	Lower bound on K:	1.00E+05
Relative conv. criterion (restart):	3.00E-08	Upper bound on K:	1.00E+07
Relative conv. criterion (effort):	1.00E-04	Random number seed:	474747474
Maximum F allowed in fitting:	6	Monte Carlo search mode, tri	0
Identical convergences required in fitting:			6.00E+00

PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS) error code 0

Normal convergence.

GOODNESS-OF-FIT AND WEIGHTING FOR NON-BOOTSTRAPPED ANALYSIS

Loss component number and title	**Weighted SSE**	**N**	**Weighted MSE**	**Current weight**	**Suggested weight**	**R-squared in CPUE**
Loss(-1) SSE in yield	0.00E+00					
Loss(0) Penalty for B1 > K	7.99E-02	1	N/A	1.00E+00	N/A	
Loss(1) CPUE and Yield from Commerc	7.87E-01	19	4.63E-02	1.00E+00	1.00E+00	0.673

....

TOTAL OBJECTIVE FUNCTION	**MSE**	**RMSE**
8.67E-01	5.78E-02	2.40E-01
Log likelihood:	2.13E+00	

NOTE: B1-ratio constraint term contributing to loss. Sensitivity analysis advised.

Estimated contrast index (ideal = 1.0):	0.8155	C* = (Bmax-Bmin)/K
Estimated nearness index (ideal = 1.0):	0.9886	N* = 1 - (min|B-Bmsy|c/K)

ESTIMATES FROM BOOTSTRAP ANALYSIS (with Constraint on B_1/K)

Param name	**Point estimate**	**Bias in estimate**	**Relative bias**	**Approx 80% lower CL**	**Approx 80% upper CL**	**Approx 50% lower CL**	**Approx 50% upper CL**	**IQ range**	**Relative IQ range**
B1/K	1.33E+00	-2.86E-01	-21.57%	1.39E+00	1.39E+00	1.39E+00	1.39E+00	0.00E+00	0
K	1.95E+06	1.06E+05	5.44%	1.27E+06	3.65E+06	1.57E+06	2.69E+06	1.12E+06	0.573
q(1)	3.54E-07	1.68E-07	47.37%	1.47E-07	4.76E-07	1.85E-07	3.66E-07	1.82E-07	0.513
MSY	6.94E+04	-1.53E+03	-2.21%	3.25E+04	8.92E+04	4.86E+04	8.09E+04	3.24E+04	0.466
Ye(2002)	6.93E+04	-9.64E+03	-13.91%	5.14E+04	9.45E+04	6.43E+04	8.80E+04	2.37E+04	0.342
Y.@Fmsy	7.10E+04	-2.00E+04	-28.19%	6.16E+04	1.58E+05	7.84E+04	1.30E+05	5.13E+04	0.723
Bmsy	9.76E+05	5.31E+04	5.44%	6.33E+05	1.82E+06	7.87E+05	1.35E+06	5.59E+05	0.573
Fmsy	7.11E-02	1.17E-02	16.50%	1.92E-02	1.40E-01	3.79E-02	1.04E-01	6.56E-02	0.924
fmsy(1)	2.01E+05	-4.82E+04	-24.05%	1.87E+05	3.54E+05	2.18E+05	3.09E+05	9.15E+04	0.456
B./Bmsy	1.02E+00	-2.56E-01	-25.06%	9.97E-01	1.41E+00	1.14E+00	1.41E+00	2.64E-01	0.258
F./Fmsy	1.59E+00	1.13E+00	70.96%	7.27E-01	1.84E+00	8.85E-01	1.46E+00	5.71E-01	0.359
Ye./MSY	1.00E+00	-1.03E-01	-10.29%	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.07E-06	0

Figure 27. (Cont.) Puerto Rico SW. Free ASPIC runs, years 1983-2001. **b)** Non-bootstrapped population and CPUE trajectories. The asterisk (*) indicates a constraint on B_1/K was imposed to the model.

b)

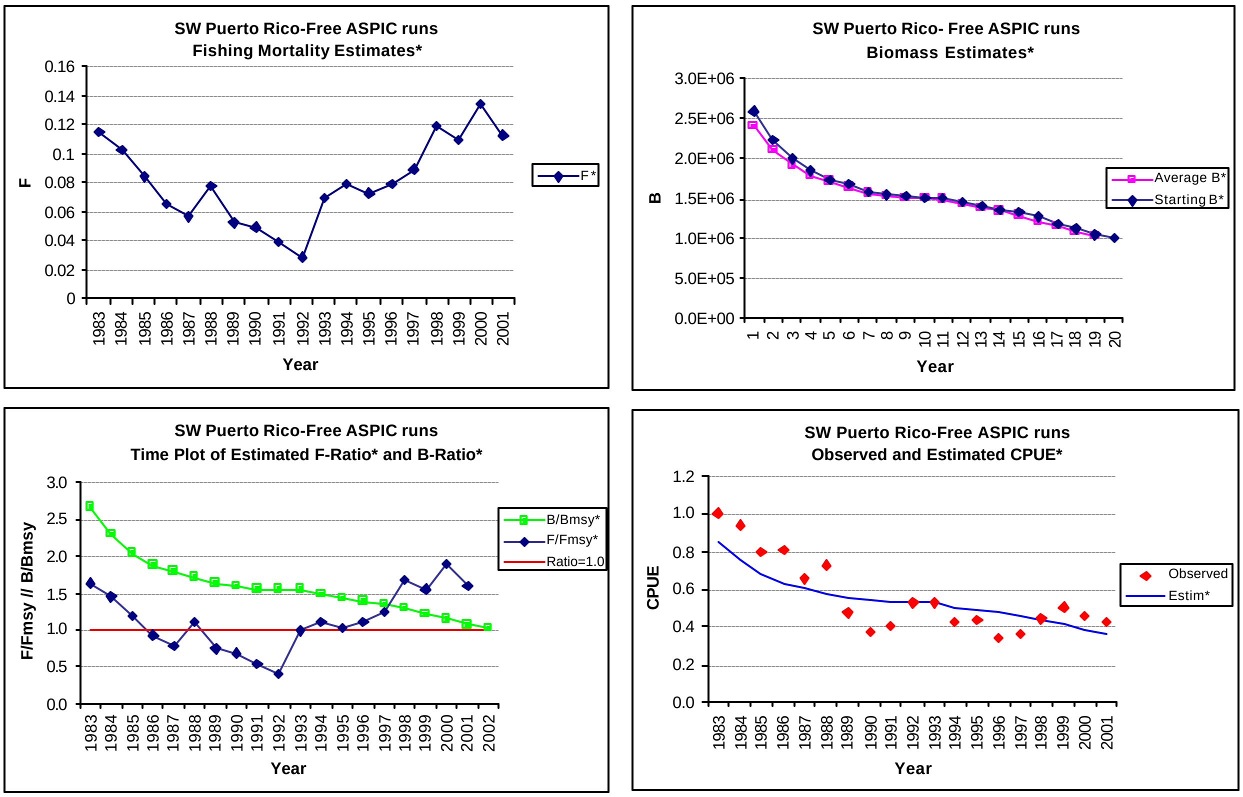


Figure 28. Puerto Rico SW. Model Projections. Relative biomass, relative fishing mortality and phase plots assuming a natural of mortality of M=0.3. **a)** Constant catch (2001) policy (Y=1.155E+05 lb). **b)** Constant effort (2001) policy (F=0.1131).

(a) **(b)**

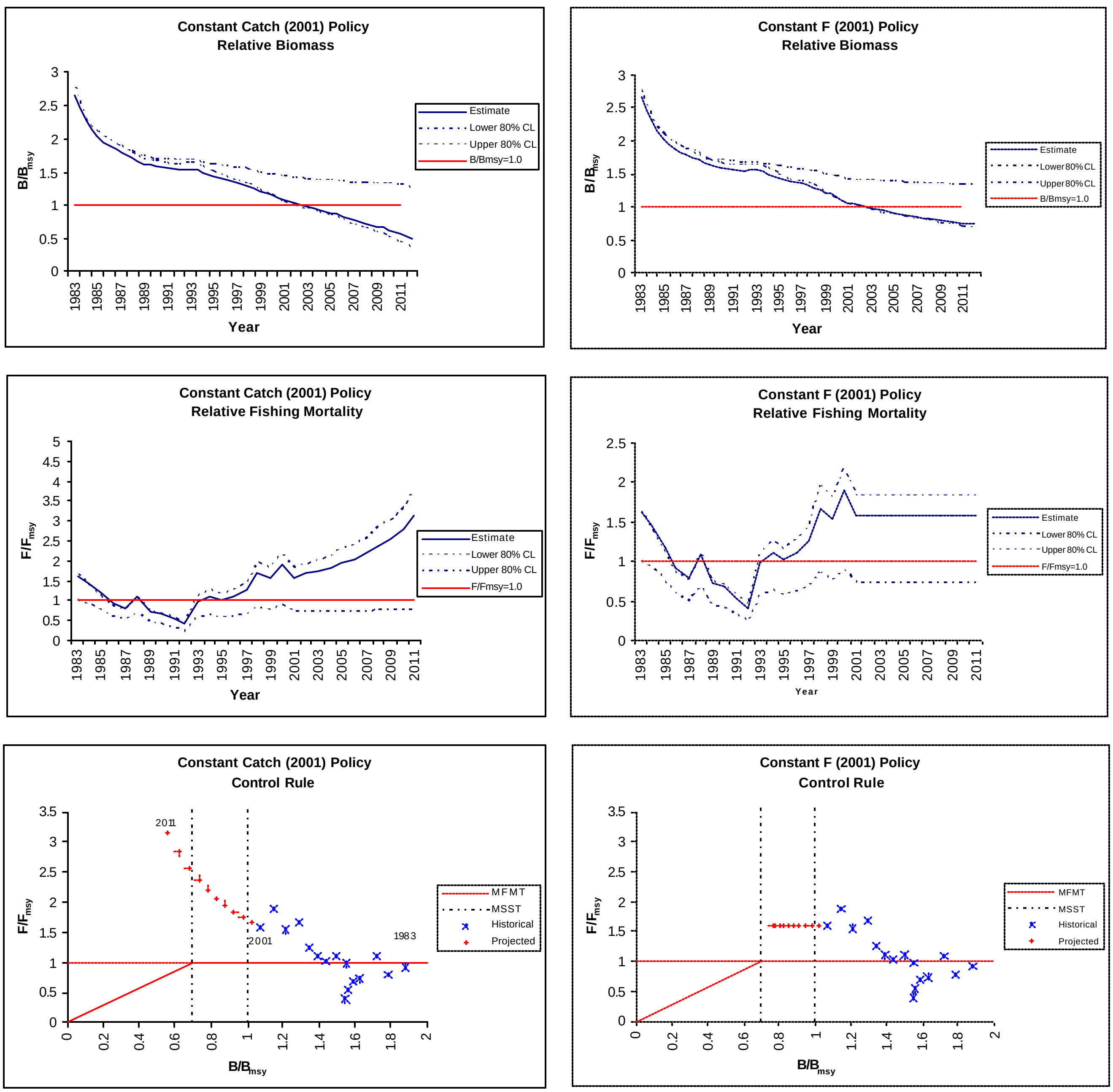


Figure 29. Puerto Rico SW. Model Projections. Relative biomass, relative fishing mortality and phase plots assuming a natural mortality of M=0.3. **a)** Constant catch at MSY=6.938E+04 lb. **b)** No fishing strategy.

(a) **(b)**