A Stock Assessment for Gray Triggerfish, *Balistes capriscus*, in the Gulf of Mexico

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SUMMARY

Standardized indices of abundance were estimated for gray triggerfish (*Balistes capriscus*) in the Gulf of Mexico from five recreational and commercial fisheries data sets: the Marine Recreational Fishery Statistics Survey (MRFSS), the Southeast Fisheries Science Center, National Marine Fisheries Service (SEFSC-NMFS) Headboat Survey, the Alabama Charterboat Survey, the Panama City Charterboat Survey, and the commercial Florida Logbook System Program. A sixth data set from the Texas Park and Wildlife Department (TPWD) Recreational Creel Survey was examined but the indices developed were not considered for subsequent analyses. The standardized indices were estimated using Generalized Linear Mixed Models under a delta lognormal model approach.

Catch-effort statistics from the recreational and commercial sectors for years 1986 to 1998 were used for stock assessment. The standardized catch rates developed here were used to tune a non-equilibrium production model (ASPIC).

INTRODUCTION

The gray triggerfish, *Balistes capriscus* (Gmelin, 1788), is an important component of the Gulf of Mexico reef fishery, particularly for the recreational fishing sector (Goodyear and Thompson, 1993). The species is widely distributed in tropical and temperate waters throughout the Atlantic; in the Western Atlantic it ranges from Nova Scotia through Bermuda and the Gulf of Mexico to Argentina (Harper and McClellan 1997).

Until recently, gray triggerfish were not considered a desirable catch by most fishers, however, the decline in other reef fish stocks (e.g., red snapper and groupers) has probably caused an increased targeting of this and other “under-utilized” species. This has resulted in an initial increase in average annual landings from 1.46 million pounds (1986) to 2.88 million pounds (1990) followed by a steady decline since then (0.85 million pounds in 1998). The cause of this decline has not been determined, but it could be attributed to a consistent increase in fishing effort and a possible consequent decrease in stock size. A thorough stock assessment is required to test this hypothesis.

The gray triggerfish (*Balistes capriscus)* in the Gulf of Mexico EEZ is managed under the 1981 Reef Fish Fishery Management Plan (FMP) and subsequent amendments. It was first added to the list of species included in the FMP in Amendment 1 (8/1989). Amendment 12 to the Reef Fish FMP (12/1995) established an EEZ aggregate daily bag (possession) limit for all reef fish species not having a bag limit. The aggregate bag limit was established to improve enforceability of commercial reef fish harvest regulations by preventing non-permitted fishermen from harvesting commercial quantities of those species under pretense of recreational fishing, which might subsequently be sold. It also served as a pro-active conservation measure to prevent uncontrolled increase in harvest of species for which no regulations or stock assessment existed. This aggregate bag limit applied to reef fish, including gray triggerfish. Species not in the reef fish fishery which did not have a bag limit could continue to be caught in unlimited quantities. Amendment

15 (6/1997) to the Reef Fish FMP continued to include gray triggerfish in the 20 fish aggregate bag limit.

Amendment 16b (1/1999) established compatible bag limits and size limits for several species of reef fish regulated under Florida statutes, for which there previously were either no corresponding limits in federal waters, or for which federal limits differed from the state limits. For consistency of regulations and improvement of enforceability, Florida requested that compatible limits be adopted in federal waters. As part of these changes, a minimum size limit of 12 inches (TL) was adopted for gray triggerfish.

As a result of these amendments, current regulations for gray triggerfish in the Gulf of Mexico are:

1) Recreational regulations: Minimum Size = 12 in. TL, no closed season, with a 5 fish/person bag limit, included in the 20 reef fish aggregate limit.

2) Commercial regulations: Minimum Size= 12 in. TL, no closed season, no trip limit.

The increase in economic value and the steady decline in total landings since 1990 have raised concern regarding the status of gray triggerfish stocks and the effectiveness of the existing management regulations in the Gulf of Mexico. Due to this concern, the SEFSC initiated a thorough examination of the existing information for the species in 1993, with an evaluation of data on size and catch limits conducted by Goodyear and Thompson (1993). They showed catch trends by sector, state, mode, area, and depth strata for the period 1986 to 1991, and estimated various morphometric relationships for the Gulf of Mexico stock. They concluded that there could be significant reductions in landings by size if length and trip limits were implemented.

As a continuation of these efforts to evaluate the Gulf of Mexico fishery for gray triggerfish, Harper and McClellan (1997) conducted a thorough review of the biology and the fishery, and updated the estimates from the previous study. They suggested that several factors could be involved in the initial increase and recent decline in gray triggerfish landings, such as an increased targeting of this species by both recreational and commercial fishers, the reduction in other reef fish stocks, and more restrictive regulations on other reef fish stocks.

Based on this background information, and given that more complete information on landings statistics, CPUE and size-weight relationships is available since 1986, it is now possible to conduct a formal stock assessment. The objective of this study is to evaluate the current status of the fishery and the gray triggerfish population in the Gulf of Mexico.

DATA SOURCES AND METHODS

Commercial landings statistics for gray triggerfish in the Gulf of Mexico exist since 1962. For the recreational sector, landings statistics date back to 1981. For the purpose of this study, only data for the period 1986 to 1998 for both sectors was considered complete and useful for stock assessment. Survey data on catch rates and biological information exists for the recreational sector since 1979 from various sources, including NMFS/SEFSC surveys and state-based fishery statistical programs. Additional information on landings by size from both sectors is available from the SEFSC Trip Interview Program (TIP) for the period 1989-1999, but this last year is still incomplete. Only size information for the period 1986-1998 was included in the present analysis.

Five recreational fisheries survey data were included in the analyses: 1) the NMFS, Marine Recreational Fishery Statistics Survey (MRFSS) (1981-1999) for landings estimates from charterboat, shore, and private/rental modes, for CPUE information, and for samples of landings at size; 2) the NMFS/SEFSC Beaufort Laboratory Headboat Survey (1986-1998) for landings estimates, CPUE and size samples; 3) the Texas Parks and Wildlife Department Recreational Creel Survey (1983-1998) for landings estimates from all modes for Texas, for CPUE, and for size samples; 4) the Alabama Department of Conservation, Marine Resources Division, Charterboat Logbook Survey (1991-1995) for CPUE and landings by size; and 5) the SEFSC Panama City Charterboat Survey (1989-1996) for CPUE estimates.

For analyses of the commercial sector, data were obtained from the SEFSC General Canvass Program for landings in weight. Trip specific landings information from the SEFSC Logbook Program was used for commercial CPUE standardization.

CPUE ANALYSES

Recreational Sector

All the recreational survey data-bases were used to estimate relative indices of abundance for gray triggerfish in the Gulf of Mexico. Recreational logbooks generally record the numbers of fish caught (kept and released) by fishing trip, the number of anglers on the trip, the hours spent fishing, the fishing mode(s), the gear(s) used, the area fished, the target species, and occasionally other, more specific information, such as the number of hooks, the number of trips in the day, and finer categories of the hours spent fishing and the catch. Each data set was analyzed separately, but the estimation of nominal fishing effort, total catch, and nominal catch rates was performed in a similar manner. The fishing effort unit considered was angler hour, estimated as the total hours spent fishing times the total number of anglers in the trip. Catch was summed over all types (kept and released, dead or alive, caught while trolling or not). Nominal catch rates (CPUEs) were estimated as the total catch per angler hour, and were used for abundance index standardization. The peculiarities of each data set will not be described, but the main features, useful for the analyses, will be outlined.

MRFSS. For this data set, CPUE analysis used data from 1981 through 1999. All trips with successful and unsuccessful gray triggerfish catch were considered, whether this species was the primary target or not. The index is the standardized number of fish caught (landed + discarded) per angler hour adjusted to non-interviewed anglers assuming similar catch to those anglers interviewed for a given trip. Only hook and line catches were included, as they accounted for over 99% of the data. The other fishing gear reported in this data set (dip net, gill net, seine, trawl, spear, other) were therefore excluded. Texas data was also removed from the analysis, since this state is covered by the Texas Parks and Wildlife Department Survey, and the catches reported for Texas in MRFSS are negligible. The explanatory variables considered for the MRFSS Gulf of

Mexico analysis included: year, state, fishing mode (shore, headboats, charter, private/rental boats), area (distance from shore: ocean<3 miles, ocean>3 miles, ocean <10 miles, ocean>10 miles), season (Jan-Apr, May-August, September-December), and fishing target, where target 1 specifically included gray triggerfish as a target species.

Headboats. Data for years 1986 through 1998 were available for CPUE analysis. All trips were considered and the index is the standardized number of fish caught (landed + discarded) per angler hour. The explanatory variables analyzed included year, state, and season. Fishing areas (defined here as a subdivisions within each state) were not included in the analysis since their effect was nested within the state variable.

Texas Parks and Wildlife. For the Texas Parks and Wildlife Department Recreational Angler Creel Survey (TPWD) data set, CPUE analysis used data from 1983 through 1990. The index is the standardized number of fish caught (landed + discarded) per angler hour. The explanatory variables included were year, area (distance from shore: ocean<10 miles, ocean>10 miles, and inshore bays and passes), and season of the year.

Alabama Logbook Survey. Data for years 1991 to 1995 was used for CPUE analysis. Fishing effort was estimated as the total number of hours spent trolling and not trolling in estuarine and ocean waters (targeting or not targeting gray triggerfish), times the number of anglers. Catch was calculated as the sum of gray triggerfish kept and released while trolling and not trolling. Therefore the index is defined as the standardized number of fish (landed + discarded) per angler hour. This data set contains catch information for other species, so positive catches of these and/or zero gray triggerfish catch were defined as unsuccessful gray triggerfish trips, and were included in the analysis. Unreported fishing modes were excluded from the analyses, as they accounted for a very small proportion of the catches. The explanatory variables included were only year and season.

Panama City Charterboat Survey. This data base spans years 1989 to 1996 and includes fishing area (state subdivisions) and target species information. Only years 1989 through 1995 were included in the analysis because 1996 was incomplete. The explanatory variables considered were only year, season, and fishing area. State was not included since its effect is confounded with the area effect. The index is defined as the standardized number of fish caught (landed + discarded) per angler hour.

Commercial Sector

The Florida Logbook System (FLS) data-base (1990-1999) was used to estimate relative indices of abundance for the commercial sector of the gray triggerfish fishery in the Gulf of Mexico. The commercial logbook program for the Gulf of Mexico records trip-specific information for various fisheries (reef fish, swordfish, tuna/bluefin, sharks, king mackerel, dolphin, etc.). Trip-specific data include landings in weight by species, information about the vessel, the crew, the location fished (state, county, area), the type of gear used (traps, longlines, gill nets, handlines, trolls, divers), and the amount of fishing effort exerted (days/hours fishing, number of lines/hooks/traps/divers/nets, size of lines/nets). In order to perform the CPUE standardization for gray triggerfish, this data-set was filtered according to the following criteria (see Figures 3, 4, 5, 6, and 7):

1. Use only Gulf of Mexico data-base.
2. Extract only Gulf of Mexico reef fish (based on Gulf of Mexico Fisheries Management Plan).
3. Select vessels that caught at least one pound of gray triggerfish in their catch history.
4. Extract handlines only (they make up for 86% of gray triggerfish catch).
5. Select vessels that caught gray triggerfish for five years or more (5-10) during the period 1990-1999.

Four fishing effort units were considered for analysis: Effort1= angler hours (estimated as the number of crew times hours fished), Effort2= number of hooks (number of lines times number of hooks per line), Effort3=hooks hour (number of hooks times hours fished) , and Effort 4 = hours fished. Nominal catch rates were estimated as the total catch in pounds divided by each effort unit.

CPUE analyses only used data from 1993 to 1999, as there were insufficient data in years 1990-1992. This explains the large standard errors observed for those three years (Figure 5). Nominal CPUE trajectories showed highly fluctuating and dissimilar trends for vessels that caught gray triggerfish for less than 5 years (Figures 5, 6, 7). Conversely, nominal catch rates were comparable among vessels that harvested this species for 5 years or more, and standard errors were smaller as the as the number of years with gray triggerfish catch decreased (Figure 5). Hence, these vessels (>= 5 years) were selected for analyses, even when they constituted only 30 % of the total number harvesting the species.

All trips with successful and unsuccessful gray triggerfish catch were considered; catch of all other species was aggregated into the "not successful" catch. Only handline catches were included as the other fishing gear reported in the FLS data-base accounted for a small proportion of the catch (less than 14 %) (Figure 3). Crew size information was insufficient to use angler hour as an effort unit for CPUE standardization, therefore it was dropped from subsequent analyses.

The commercial indices developed are: CPUE2= standardized catch in weight (pounds) per hook; CPUE3= pounds per hook hour; CPUE4= pounds per hour. The explanatory variables considered were year, state, county, area (Gulf of Mexico grids), and season (Jan-Apr, May-August, September-December).

THE DELTA LOGNORMAL MODEL FOR CPUE STANDARDIZATION

Relative indices of abundance for gray triggerfish were estimated by a Generalized Linear Mixed Model Approach (GLMM) assuming a delta lognormal model distribution. The delta model estimates separately the proportion of positive trips/stratum (in the GLM matrix), assuming a binomial error distribution, and the mean catch rate of trips where at least one fish was caught assuming a lognormal error distribution. The logtransformed frequency distributions of catch rates in numbers for gray triggerfish are shown in Figure 1. The estimated proportion of successful trips per stratum is assumed to be the result of *r* positive trips of a total *n* number of trips, and each one is an independent Bernoulli-type realization. The estimated proportion is a linear function of fixed effects and interactions. The logit function was used as a link between the linear factor component and the binomial error. For trip/days that caught at least one fish (positive observations), estimated catch rates were assumed to follow a lognormal error distribution of a linear function of fixed factors and random effect interactions, particularly when the *year* effect was within the interaction. In some cases other interactions were tested.

A step-wise regression procedure was used to determine the set of systematic factors and interactions that significantly explained the observed variability. The difference of deviance between two consecutive models follows a χ^2 (Chi-square) distribution; this statistic was used to test for the significance of an additional factor in the model. The number of additional parameters associated with the added factor minus one corresponds to the number of degrees of freedom in the χ^2 test (McCullagh and Nelder, 1989). Deviance analysis tables for catch rates in numbers are presented for each index developed. Each table contains the deviance for the proportion of positive observations (i.e. positive trips/total trips), and the deviance for the positive catch rates. Final selection of explanatory factors was conditional to: a) the relative percent of deviance explained by adding the factor in evaluation; normally factors that explained more than 5 % were selected. The *year* term was always included regardless of statistical significance because a time series is desired. b) The χ^2 test significance, and c) the type III test significance within the final specified model.

Once a set of fixed factors was specified, 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 Schwarz's Bayesian Criterion (SBC), and a likelihood-ratio test for successive model formulations, based on a chi-square test (Littell et al. 1996). 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. The LSMeans estimates use a weighted factor of the proportional observed margins in the input data to account for the unbalanced characteristics of the data. LSMeans of lognormal positive trips were bias corrected using Lo et al. (1992) algorithms. Analyses were done using a computer program developed by Ortiz et al. that incorporates the GLIMMIX and MIXED procedures from the SAS statistical computer software (SAS Institute Inc. 1997). This methodology has been applied and refined by Legault and Ortiz (1998), by Ortiz et al. (2000), and Ortiz and Farber (2000), to standardize catch rates of Spanish mackerel, king mackerel, and marlins, respectively.

HARVEST

Recreational landings in numbers of fish by state and fishing mode were estimated for the period 1986-1998 (Table 9, Figure 12). Recreational landings peaked in 1990, followed by a steady decline ever since. The majority of annual landings since

1986 have been reported from the West Coast of Florida, followed by Louisiana. The other states account for a very small proportion of the catch.

Landings from the charterboat mode have dominated recreational landings for most of the period studied. Private and rental boats have also accounted for a significant proportion of the landings, whereas the headboat mode has generally contributed with a small proportion. The shore mode has scarcely been represented during this period.

Landings in weight by year and state were estimated for the commercial sector for the period 1986-1998 (Table 10, Figure 13). The trend throughout this period is similar to that of the recreational sector, but with a peak in 1993 and a steady decline since then. The greatest proportion of commercial landings has been reported for the west coast of Florida, followed only by Louisiana. The other states have generally reported very small proportions of the total commercial catch.

Total landings in weight were estimated for both the recreational and the commercial sectors (Table 11, Figure 14). To evaluate landings in weight from the recreational sector, landings in numbers of fish were converted to total weight. To accomplish this conversion, size and weight samples from each recreational survey (MRFSS, Headboat, and TPWD) were analyzed separately using the information presented in Tables 7 and Figures 10 and 11. Within each data set, when fish weight was not provided, it was estimated from fork length or total length using the morphometric relationships given in Goodyear and Thompson (1993):

Fork length to whole weight: $Wt= (8.975E\text{-}4)\ FL^{2.96}$

Total length to whole weight: $Wt=(9.953E\text{-}4)\ TL^{2.773}$

These weight samples were used to estimate mean fish weight by year, state and fishing mode strata. In cases where the sample size by stratum exceeded 25 individuals, the mean weight estimate corresponded to the average by stratum; if the sample size by stratum was less than 25, the state annual mean was substituted (if $n>25$ individuals), else the gulfwide annual mean was used (Table 8). The three data sets were combined and mean weights were multiplied by numbers of fish stratified in the same manner (year, state, mode) to derive total recreational landings in weight (Table 9). Comparison of these estimates with those from previous studies (Goodyear and Thompson 1993, Harper and McClellan 1997) was made. The stratified landings in weight could not be matched up. The source of the discrepancy was associated with the estimate of mean fish weight per stratum, rather than with the estimate of landings in numbers per stratum. The differences among the estimates from the three studies did not indicate bias in any direction, and, unfortunately, the detailed procedure and assumptions used in those other studies could not be established. Thus, the exact reason of the mismatch could not be determined. However, after a careful review of our method, we believe that our estimates are reasonable as they fall within the range of the previous studies.

Estimated total landings over the period 1986 through 1998 have been dominated by the recreational sector. Total landings increased each year for the first few years, reaching a peak in 1990, and then declined steadily through 1998, to an estimated 854,000 pounds. Both sectors have showed a proportional decline in landings throughout the period.

STOCK ASSESSMENT MODEL AND APPLICATION TO DATA

No previous assessments have been made of the gray triggerfish fishery of the Gulf of Mexico. Given the characteristics of the data available (annual yields in weight and standardized catch rates) and that a simple, straight-forward, and flexible method may be desired as a first approach, a non-equilibrium surplus-production model was selected to conduct this stock assessment. The ASPIC computer program of Prager (1994, 2000) was used for model fitting. This method 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 a biomass index, estimating missing values of fishing effort, and constructing confidence intervals of parameter values via bootstrapping (Prager 1994).

Data needed for parameter estimation under ASPIC are a series of observations on catch (yield in biomass) and corresponding effort or CPUE. The program can fit data from up to 10 data series. In addition to data, ASPIC requires starting guesses and the ranges for its estimated parameters: r, the intrinsic rate of increase; MSY, maximum sustainable yield; the ratio B_1/B_{MSY}, the ratio of the biomass at the beginning of the first year to the biomass at which MSY can be attained; and q, the catchability coefficient. A separate estimate of q is made for each data series (Prager 2000). Initial parameter estimates and their ranges were based on biological knowledge of the species and of the fishery in question.

Initial runs of the model used all the recreational standardized catch rates obtained in this study and the commercial CPUE 4 (lb/hr) as tuning indices (Figure 15 (B)), parameters were not constrained, and the program was allowed to estimate all the parameters. Under these circumstances, the minimization routine wandered off to unrealistic scenarios and rarely attained convergence. It was thus necessary to select fewer and more representative catch rates, along with the yield corresponding to each user group. For the recreational sector, the MRFSS and Headboat indices were selected, and the Logbook-Handline index (in lb/hour) was used to represent the commercial sector (Table 12, Fig. 15). In addition, it was necessary to constrain parameters within reasonable bounds, by fixing some parameters to estimate the others.

Trials to narrow down the search for an absolute minimum included: 1) eliminating some tuning indices; 2) setting r to fixed values to estimate B_1/B_{MSY}, MSY, and q; 3)fixing the B_1/B_{MSY} ratio and r at different levels to estimate MSY and q; 4) fixing MSY, r, and B_1/B_{MSY} to estimate q; 5) fixing B_1/B_{MSY} and MSY to estimate r and q; 6) further limiting the bounds for MSY and r and fixing only B_1/B_{MSY} at different levels to estimate MSY, r, and q, and 7) using a first run's results (with constrained parameters) as starting guesses for subsequent runs. The specifics of these sensitivity trials are provided in the Stock Assessment Results section below. Each of these tests resulted in a number of combinations of fixed parameter values and estimates of others, which guided subsequent searches for more reasonable parameter bounds.

RESULTS AND DISCUSSION

STANDARDIZED CATCH RATES

Recreational Sector

Figure 1 shows the frequency distributions of log CPUE of successful trips, where an approximate normal trend is observed in most cases. Table 1 shows the deviance analysis for each index developed. In each case, the main factors and interactions that exceeded 5% of the total deviance were considered significant and were selected as the explanatory variables for the positive catch rates and the proportion of positive catch. These variables are highlighted in the tables.

Table 2 shows the results from the random test analyses for each index, and the three criteria statistics used for model selection. The selected model is highlighted.

Standardized CPUE series for each index are presented in Table 3 and Figure 2.

MRFSS Index. The mean catch rate for positive observations was explained by the year*state, year*mode, and year*area fixed factor interactions, even when the area factor by itself was not significant. The major fixed factors determining the proportion of positive catches were year, state, mode, and area, with no significant interactions among them.

Once these sets of fixed factors were selected, we evaluated the first level random interactions between the year and other effects, only for the positive catch rates, since no fixed interactions were observed for the proportion of positives. All the random interactions between year and state, area, mode, and season proved significant and were included in the final run of the model.

The standardized catch rate series follows the same general trend of the nominal series, particularly from 1987 on. The variability observed and the occasional lack of agreement between the standardized and nominal indices may be partially attributed to the very low proportion (~ 2 %) of positive catches observed in the database.

Headboat Index. Both the mean catch rate for positive observations and the proportion of positive observations were explained by the year, state, season fixed factors and by the year*state interaction. The significant random interactions for positive observations were year*state and year*season. In this case, the area factor was completely eliminated, since its effect was confounded with the state effect and did not provide any additional information.

Positive observations accounted for a higher proportion in the data (~ 40 %) compared to MRFSS. This is reflected in the good agreement between the observed and standardized indices depicted in the second panel of Figure 2. The peak observed in 1990 corresponds to that observed for the MRFSS catch rates. A large variability, not explained by the model, was observed.

Panama City Index. The mean catch rate for positive observations was explained by year, area, season and year*area interaction. The significant factors and interactions for the proportion of positive catch values were year, state, area, year*state and year*area. The random tests showed significant interactions between year*state, year*area, year* season and area*season for the positive catch.

The standardized index shows a somewhat flat trend and a lack of correspondence with the observed catch rates. This is a portrait of the year factor not being the most important one. In this case, state and area are by far (~60%) the most influential, as well as the interactions state*year and area*year, so these factors determine the yearly predicted trend. The proportion of positive catches was generally large (~ 40 %), except for 1989 and 1995, where lower values were observed. The amount of variability not explained by the model was relatively small; the coefficients of variation of the standardized index ranged around 30%.

Alabama Index. Both the mean catch rate for positive observations and the proportion of positive observations were explained by the year and season fixed factors and by the year*season interaction. This interaction was also significant in the random test for positive observations. A good agreement between the nominal and standard catch rates was observed, even when only four years of data were used. The proportion of positive catches constituted approximately 16 % of the data. The proportion of unexplained variability was fairly reasonable (CVs ~ 30%).

Texas Index. As a result of a highly unbalanced design, it was not possible to standardize catch rates for this data set. The proportion of positive catches accounted for a very small fraction of the data (~ 0.4 %), which is problematic for CPUE standardization. Even when fixed and random factors and interactions were carefully evaluated, the model fits were generally poor and the amount of unexplained variability remained extremely high for most model configurations (CV>200%). Therefore the results presented here for TPWD were excluded from all further analyses.

Commercial Sector

Figure 8 shows the frequency distributions of log CPUE of successful commercial trips (gray triggerfish catch present). Approximate normal distributions are observed in all cases. Table 4 shows the deviance analysis for each commercial index developed. In each case, the main factors and interactions that explained the positive catch rates and the proportion of positive catch are highlighted.

Table 5 shows the results from the random test analyses for each index, and the three criteria statistics used for model selection. The selected model is highlighted.

Standardized CPUE series for each index are presented in Table 6 and Figure 9.

The area factor was found to be nested within state, so the latter was removed as an explanatory variable because area provides more detailed information. The county factor was also removed because the same county identifiers are used in different states in the FLS database, which created confounding effects.

In all CPUEs, the mean catch rate for positive observations was explained by the year and area fixed factors, and the year*area interaction. The same factors and interaction were significant in the proportion of positive catches. It is important to note that deviance values for positive catches vary across indices because different effort units are used and thus the number of observations may also vary if all the effort information is not present for a particular fishing trip. In cases with missing values (effort estimates), observations are omitted from the delta lognormal analysis. On the other hand, the deviance tables for the proportion of positive observations are equal for all the indices because this proportion is a constant in the data base, regardless of the units used to measure effort.

Once these sets of fixed factors were selected, the first level random interaction between the year and area effect were evaluated, both for the positive and the proportion of positive catch rates for each index. The season effect was not considered because it was not significant in the fixed factor evaluation. The random year*area interaction proved significant in all cases and was included in the final run of each model. The random effects evaluation is presented in Table 5.

The nominal and standardized commercial CPUEs are presented in Table 6 and Figure 9. All catch rate estimates follow closely the trend of the nominal series, which may be partially attributed to the large proportion of positive catches observed (~ 65%) once the FLS database was filtered (see page 5). In CPUE2 (lb/hooks), there is a certain mismatch between observed and expected values in the first three years (1993-1995) and the variability is relatively low (18%). Model fit is good for CPUE3 (lb/hook*hr), but the coefficients of variation were the largest observed (27%-33%). The best fit and smallest variability (CVs~16%) was observed for CPUE4 (lb/hr). This standardized index was thus selected for use in the production model analysis.

STOCK ASSESSMENT

Initial runs of the production model analysis (ASPIC) failed to converge when no constraints were placed on parameters using the original data set (Table 12). After a number of trials and sensitivity analyses, model fits were slightly improved by fixing parameters at different levels (B_1/B_{MSY} = 0.2; r=0.75-1.0-1.2), and constraining the bounds for r and MSY (r=0.5-1.5, MSY= 1–5 million pounds). Despite the number and variety of trials attempted, ASPIC was still unable to provide reasonable parameter estimates with this data set (1986-1998). It was thus necessary to make additional assumptions regarding the catch-rate time-series. The discrepancies and fluctuations in the catch rates between 1986-1989 may have introduced extra noise to the assessment, so those years were truncated from all further analyses (Figure 15). Year 1993 in the commercial index was also dropped because its opposing trend with the rest of the data made model convergence difficult, so this CPUE included only years 1994-1998.

A similar procedure to that described before (fixing parameters, constraining bounds and conducting various sensitivity runs) was needed to fit the model with the reduced (1990-1998) data set, as ASPIC was again unable, without constraints, to provide reasonable estimates of all parameters. The best fits were obtained by: fixing r, fixing

B_1/B_{MSY}, fixing B_1/B_{MSY} and *r*, and fixing B_1/B_{MSY} and *r* at different levels. Results of these sensitivity trials are presented in Figure 16.

Fixed *r*.

The range of *r* values examined was *r*= 0.5-2.0. Convergence was limited to a reduced *r*- range (*r*=0.95-1.4) and the best fits were obtained with *r*=1.0-1.2. Over this *r*-range, MSY estimates were between 2.65 and 2.91 million pounds (Figure 16 (A)). These estimates were used as initial guesses for the final bootstrap runs, where no parameters were held constant. Fishing mortality rates were high, between *F*=0.8-1.6, with low stock biomass values.

Fixed B_1/B_{MSY}

Initial biomass ratio levels tested ranged from B_1/B_{MSY} =0.5 to 2.0. Convergence was only attained with B_1/B_{MSY} =0.5 –0.65, as shown in Figure 16 (B). *MSY* and *r* estimates decreased with increasing biomass ratio, and the objective function values increased with increasing B_1/B_{MSY}. *MSY* and *r* estimates are relatively low (*MSY*= 1.36-1.86 million pounds; *r*=0.14-0.16). Fishing mortality estimates were also relatively low (F=0.2-0.3) compared to all other sensitivity trials.

Fixed B_1/B_{MSY} and *r*

ASPIC converged with most combinations of *r*=0.1 - 2.0 and B_1/B_{MSY} =0.5 – 1.0 as seen in Figure 16 (C). For all initial biomass ratio levels, *MSY* and fishing mortality estimates (F) increased with increasing *r* levels. However, the largest *MSY* estimates were obtained with combinations of the smallest B_1/B_{MSY} =0.5 and the largest *r* values. As biomass increased, F estimates decreased, which demonstrates the expected opposing trend between current stock size and fishing mortality. Objective function values show that the model fits best to the low *B*, low *r* combination. The wide range of parameter values obtained (as seen clearly in the plots presented here) may indicate the range of uncertainty present in the data.

Fixed B_1/B_{MSY} and *MSY*

The range of biomass ratio levels examined was from B_1/B_{MSY} =0.5 - 1.5, and *MSY*=1.5 – 3.5 million pounds. Model convergence was attained with only a few combinations of these fixed parameters, as shown in Figure 16 (D). As biomass values increased, *MSY* declined. For all *B* levels, *r* estimates declined as *MSY* increased. In general, *r* also increased with increasing levels of *B* (as seen in Figure 16 (A)). Objective function values were smallest at large *MSY*, small *B*, and small *r* values, which is similar to the previous model runs.

Sensitivity Trials

All the sensitivity trial results discussed above show a range of parameter estimates that could describe the status of the stock. This range might also represent the range of uncertainty present in the data and thus the range of uncertainty in parameter values. Different parameter combinations give different stock size and fishing mortality rates, however, all sensitivities demonstrate that estimates of current stock level are inversely correlated with fishing mortality rate.

ASPIC was very sensitive to starting values and constraints placed on parameters, particularly of MSY. Model convergence or the lack thereof often depended on the initial values used, even when the rest of the input data remained unchanged. It is possible that local minima were often encountered because the response surface may be too flat, resulting from the limited time-series and the tendency in the catch and effort data used. A single reasonable solution does not appear to exist for this data set, so several scenarios need to be tested and explored.

Model Projections

In order to show possible scenarios, that include population trajectories and confidence intervals for the parameters, two additional ASPIC runs were performed. These final runs were based on one fit from the fixed *r* sensitivity analyses (*r*=1.0). This intrinsic rate of population growth was based on individual growth rate and longevity considerations. One thousand bootstrap trials were used in each case in order to characterize the error associated with population parameter estimates.

The first model (Model 1) assumed fixed *r*=1.0. Resulting parameter estimates from this model were used as initial guess values in the second model (Model 2), where the program was allowed to freely estimate all parameters. The two models thus differ in initial guess values and the number of parameters estimated by ASPIC. Results for both model runs are presented in Table 13 and Figures 17, 18, and 19.

The ASPIC model fits for the observed catch to the indices of abundance resulted in a relatively high R-squared values for both models and the three user groups (Figure 18). In Model 1, R-squared in CPUEs were: R^2= 0.97 (MRFSS), R^2= 0.58 (HEADBOAT), and R^2= 0.75 (Commercial-Handlines). In Model 2, R-squared values were: R^2= 0.96, R^2=0.62, and R^2= 0.7, respectively. Both models appear to capture the major dynamics in CPUEs by fishery.

Population and fishing mortality trajectories for both models (Figure 17) follow similar trends, but a difference in scales is observed, attributed to fixing *r*=1.0 in Model 1. The estimates of the biomass-ratio obtained with both models (B/B_{MSY}(1)=0.208, B/B_{MSY}(2)= 0.164) denote that the initial biomass in 1999 is estimated to be approximately 20 percent of the biomass the stock would be at if fished at MSY. The F-ratio estimates (F/F_{MSY}(1)=1.62, F/F_{MSY}(2)=1.65) indicate that the 1998 fishing mortality is about 65 percent higher than that estimated for F_{MSY}.

Results from these analyses suggest that throughout the period 1990-1998, biomass levels have been below B_{MSY}, being the lowest in recent years. Accordingly, fishing mortality rates have exceeded F_{MSY} throughout the whole period. Therefore, the declining stock size seems consistent with the pattern of exploitation. The MSY estimate obtained with Model 1 (MSY(1)=2.65 million pounds) is very similar to the largest recorded catch of 2.88 million pounds in 1990. The MSY estimate from Model 2 was somewhat larger (MSY(2)=3.37 million pounds). This estimate is above the maximum observed catch since 1986 and the results would imply that historical removals were somewhat larger than this.

Confidence limits around these estimates were constructed by running a bootstrap analysis with the same model inputs. A total of 1,000 trials were run in each case. Associated with the ordinary ASPIC parameter estimates, are bias-corrected estimates, percent bias, and upper and lower 80% confidence intervals. These estimates are also given in Table 13. Time series of relative biomass and fishing mortality with 80 percent confidence intervals are shown in Figure 19. Diagrams of generic default limit control rules with M assumed equal to 0.2 are included. For both models, the stock appears as overfished since 1990. Fishing mortality rates indicate that overfishing is still occurring. Biomass levels have declined steadily, attaining the lowest levels in 1998. Fishing mortality was estimated as greater that F_{MSY} throughout the whole period.

Up to this point in the analysis, there is reasonable evidence that the current rate of removal is not sustainable: a steady decline in landings since the peak in 1990, current landings (850,000 pounds in 1998) are below the MSY range, estimated biomass levels are low, and estimated exploitation rates are high. This evidence suggests that the stock is overfished and that catches should at least be held constant if not reduced to bring the population back to sustainable levels. In order to test this hypothesis, projections of the possible future condition of the stock under different fishing scenarios were made using the parameter outputs from the ASPIC models 1 and 2. Even when some data are available for years 1999 and 2000, it has not been processed for this study, so all projections were made using 1998 as the last year in the assessment and 1999 as the first year of management. To determine whether or not the stock could be rebuilt (B/B_{MSY} = 1.0) within a ten year time frame, projections were carried out to the years 1999-2008.

Three fishing scenarios were projected for Models 1 and 2: 1) no fishing for a ten-year period, 2) the 1998 catch repeated for ten years, and 3) the 1998 F value repeated for 10 years. In each case, diagrams of a generic default limit control rule with M assumed equal to 0.2 were constructed.

The first projection assumed that all fishing would completely cease for ten years. Under these circumstances, the stock was estimated to be rebuilt to a level of B/B_{MSY}=1.0 in approximately 3 years (2001) in both Models 1 and 2 (Figure 20).

The second projection assumed a constant catch scenario, whereby the 1998 catch value (854,000 pounds) is repeated over the ten-year management period. In Model 1, the stock was estimated to be rebuilt to a level of B/B_{MSY}=1.0 in approximately 6 years (2004) (Figure 21, panels A, B, C). There is a large uncertainty around this estimate (Figure 21, panel A), which doesn't stabilize until approximately 2006, meaning that it could take the stock up to 8 years to recuperate. Under this scenario, fishing mortality rates are reduced to sustainable levels (F/F_{MSY}=1.0) within a 3 year period (2001), but uncertainty around these estimates is also rather high (Figure 21, panel B). In Model 2, the stock was estimated to be rebuilt in approximately 4 years (2003), which is faster than in Model 1 (Figure 21 D, E, F). Fishing mortality rate is reduced to F/F_{MSY}=1.0 in approximately 2 years (2000).

The third projection assumed the 1998 fishing mortality rates repeated for ten years (F= 0.81 in Model 1, F=1.052 in Model 2). In this projection, estimates of B/B_{MSY}

increased slowly during the management period, but did not attain sustainable levels within the ten-year frame (Figure 22). In Model 1, the estimated mean B/B_{MSY} in ten years was 0.59, and in Model 2, B/B_{MSY} =0.22, which indicates that if the fishery continued to operate at either of these fishing mortality rates, the stock would not recover (ie. $B/B_{MSY} \geq 1$) within the ten-year modeling projection. With Model 1, yield would increase even at this low biomass level, and with Model 2, yield would remain relatively low, near the current (1998) level, or even decline.

These projections indicate that, indeed, as was suggested before, the stock may be overfished, that overfishing is still occurring, and that catches should at least be held constant or preferably reduced to bring the stock back to healthy levels.

In conclusion, the production model analyses utilized here to project the stock trajectory indicate that current fishing mortality rates are not sustainable.

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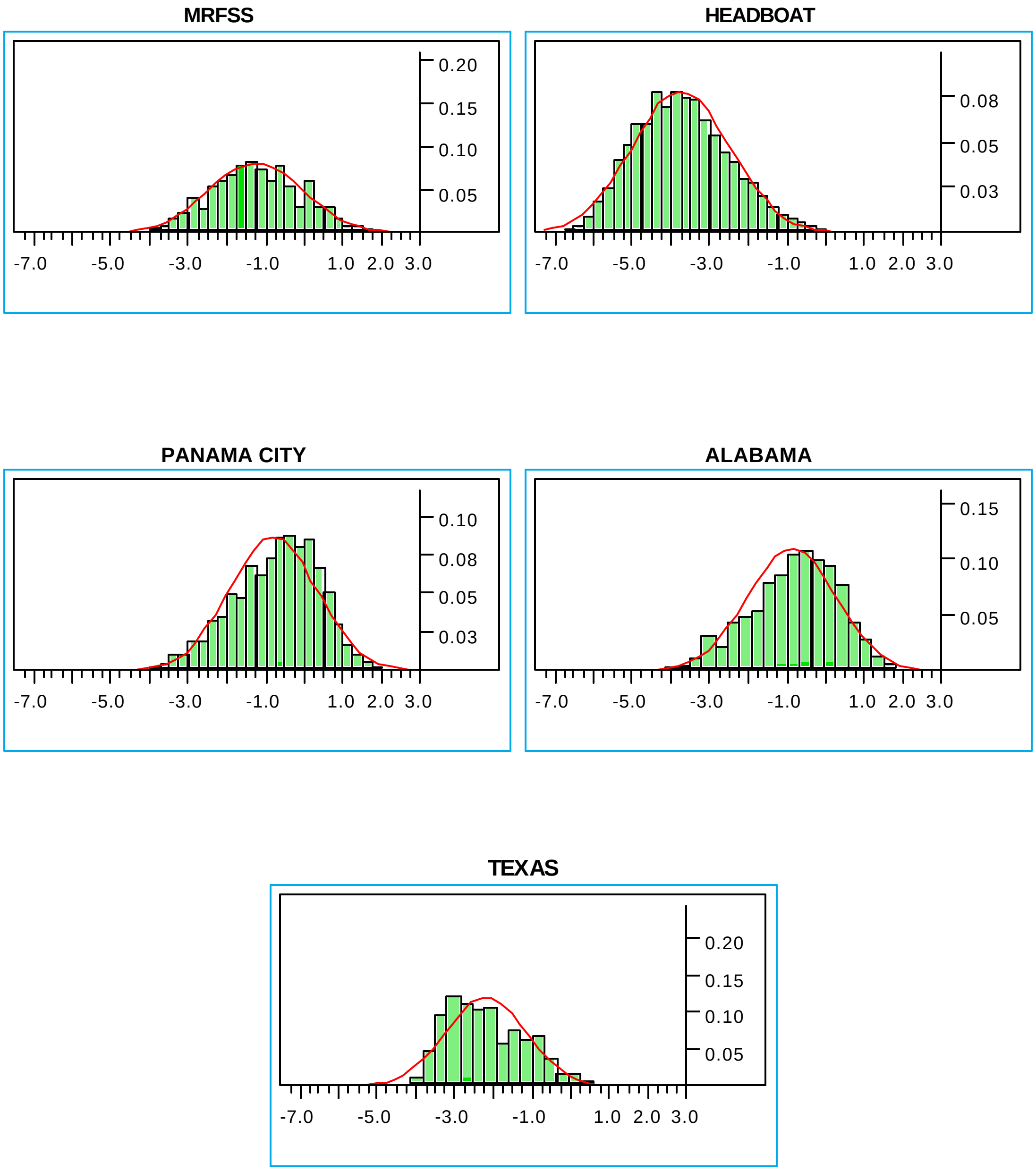


Figure 1. Frequency distributions of logarithm CPUE of successful trips of gray triggerfish from recreational survey data. The plots show density on lnCPUE. Catch rates are given in numbers of fish (fish/angler hour). The line represents the estimated normal distribution of the data.

Table 1. Deviance analysis tables for recreational gray triggerfish catch rates using the delta lognormal model. Proportion positive/total observations assumed a binomial error distribution. The dependent variable is the total number of fish caught per hour per angler. P refers to the Chi-square test probability (alpha=5%) test between two consecutive model specifications. Factors and interactions with total deviance$5% were selected and are shown in shaded areas.

RECREATIONAL SECTOR

MRFSS

Model factors positive catch rates values	d. f.	Residual deviance	Change in deviance	% of total deviance	*p*
NULL	1	6362.71			
YEAR	18	5840.91	521.8	33.7%	< 0.001
... + STATE	4	5650.55	190.4	12.3%	< 0.001
... + MODE	3	5631.02	19.5	1.3%	< 0.001
... + AREA	4	5588.24	42.8	2.8%	< 0.001
... + TARGET	1	5518.19	70.0	4.5%	< 0.001
... + SEASON	2	5465.22	53.0	3.4%	< 0.001
... + YEAR:STATE	50	5157.96	307.3	19.8%	< 0.001
... + YEAR:MODE	35	5015.91	142.0	9.2%	< 0.001
... + YEAR:AREA	57	4908.29	107.6	7.0%	< 0.001
... + YEAR:TARGET	14	4883.85	24.4	1.6%	0.040
... + YEAR:SEASON	36	4814.54	69.3	4.5%	< 0.001

Model factors proportion positive catch rates values	d. f.	Residual deviance	Change in deviance	% of total deviance	*p*
NULL	1	19132.19			
YEAR	18	18557.51	574.7	3.6%	< 0.001
... + STATE	22	16491.44	2066.1	12.8%	< 0.001
... + SEASON	24	16281.05	210.4	1.3%	< 0.001
... + MODE	27	6114.02	10167.0	63.1%	< 0.001
... + AREA	31	3834.53	2279.5	14.1%	< 0.001
... + TARGET	32	3212.73	621.8	3.9%	< 0.001
... + YEAR*SEASON	68	3010.56	202.2	1.3%	< 0.001

HEADBOAT

Model factors positive catch rates values	d. f.	Residual deviance	Change in deviance	% of total deviance	*p*
NULL	0	86811.59			
YEAR	12	85135.20	1676.4	6.3%	< 0.001
... + STATE	3	64349.30	20785.9	78.7%	< 0.001
... + SEASON	2	62959.73	1389.6	5.3%	< 0.001
... + YEAR:STATE	36	60763.72	2196.0	8.3%	< 0.001
... + YEAR:SEASON	24	60396.07	367.7	1.4%	< 0.001

Model factors proportion positive catch rates values	d. f.	Residual deviance	Change in deviance	% of total deviance	*p*
NULL	1	46.52381			
YEAR	12	44.83039	1.69342	4.0%	1.000
... + STATE	3	7.9974	36.83299	87.6%	< 0.001
... + SEASON	2	7.42834	0.56906	1.4%	0.752
... + YEAR:STATE	36	5.27057	2.15777	5.1%	1.000
... + YEAR:SEASON	24	4.47764	0.79293	1.9%	1.000

Table 1. (Continued).

PANAMA CITY					
Model factors positive catch rates values	**d. f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
NULL	0	8113.768			
YEAR	7	7690.60	423.172	22.7%	< 0.001
… + AREA	8	6736.15	954.4	51.2%	< 0.001
… + SEASON	2	6597.41	138.7	7.4%	< 0.001
… + YEAR:AREA	39	6346.85	250.6	13.4%	< 0.001
… + YEAR:SEASON	13	6285.42	61.4	3.3%	< 0.001
… + AREA:SEASON	15	6249.67	35.8	1.9%	0.002
Model factors proportion positive catch rates values	**d. f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
NULL	0	86.75046			
YEAR	7	82.24468	4.50578	5.7%	0.7200
… + STATE	4	46.66724	35.57744	44.9%	< 0.001
… + AREA	4	28.02606	18.64118	23.5%	< 0.001
… + SEASON	2	26.95972	1.06634	1.3%	0.5867
… + YEAR:STATE	25	17.8025	9.15722	11.6%	0.9984
… + YEAR:AREA	22	11.74364	6.05886	7.6%	0.9997
… + YEAR:SEASON	13	10.75838	0.98526	1.2%	1.0000
… + SEASON:AREA	16	7.4894	3.26898	4.1%	0.9997

ALABAMA					
Model factors positive catch rates values	**d. f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
NULL	1	2041.552			
YEAR	4	1958.341	83.211	50.7%	< 0.001
… + SEASON	2	1905.92	52.421	31.9%	< 0.001
… + YEAR:SEASON	7	1877.459	28.461	17.3%	< 0.001
Model factors proportion positive catch rates values	**d. f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
NULL	1	8646.614			
YEAR	4	8645.849	0.765	2.4%	0.9431
… + SEASON	2	8619.232	26.617	81.8%	< 0.001
… + YEAR:SEASON	7	8614.061	5.171	15.9%	0.6391

TEXAS					
Model factors positive catch rates values	**d. f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
NULL	1	562.3247			
YEAR	15	552.5328	9.7919	8.0%	0.8326
… + AREA	2	545.1547	7.3781	6.0%	0.0250
… + SEASON	2	540.3293	4.8254	3.9%	0.0896
… + YEAR:AREA	30	480.4296	59.8997	48.9%	< 0.001
… + YEAR:SEASON	26	449.408	31.0216	25.3%	0.2275
… + AREA:SEASON	4	439.731	9.677	7.9%	0.0462
Model factors proportion positive catch rates values	**d. f.**	**Residual deviance**	**Change in deviance**	**% of total deviance**	***p***
NULL	1	7757.3524			
YEAR	15	7679.8294	77.523	4.2%	< 0.001
… + AREA	17	5955.0071	1724.8223	92.7%	< 0.001
… + SEASON	19	5895.9803	59.0268	3.2%	< 0.001

Table 2. Recreational sector. Random effects evaluation for delta lognormal mixed model specifications. Highlighted rows refer to the final model.

RECREATIONAL SECTOR

MRFSS

RANDOM TESTS	-2 RES Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Positive Catch					
Year State Season Mode Area	13283.58	-6642.79	-6645.96		
Year State Season Mode Area *Year*Area*	13170.65	-6587.33	-6593.67	112.93	2.2353E-26
Year State Season Mode Area *Year*Area Year*State*	13149.52	-6577.76	-6587.28	21.13	4.2916E-06
Year State Season Mode Area *Year*Area Year*State Year*Season*	13137.03	-6572.51	-6585.21	12.49	4.0914E-04
Year State Season Mode Area *Year*Area Year*State Year*Season Year*Mod*	13084.87	-6547.43	-6563.3	52.16	5.1158E-13

HEADBOAT

RANDOM TESTS	-2 RES Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Positive Catch					
Year State Season	159299.1	-79650.6	-79655		
Year State Season Year*State	157606.8	-78805.4	-78814.3	1692.3	0
Year State Season Year*State Year*Season	157375.2	-78690.6	-78703.9	231.6	2.6694E-52

PANAMA CITY

RANDOM TESTS	-2 RES Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Positive Catch					
Year State Area Season	17785.39	-8893.69	-8897.05		
Year State Area Season *Year*State*	17695.65	-8849.82	-8856.53	89.74	2.7161E-21
Year State Area Season Year*State *Year*Area*	17650.46	-8828.23	-8838.29	45.19	1.7882E-11
Year State Area Season *Year*State Year*Area Year*Season*	17622.96	-8815.48	-8828.89	27.5	1.5709E-07
Year State Area Season *Year*State Year*Area Year*Season Area*Season*	17612.86	-8811.43	-8828.2	10.1	1.4827E-03

ALABAMA

RANDOM TESTS	-2 RES Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Positive Catch					
Year Season	4730.526	-2366.26	-2368.93		
Year Season *Year*Season*	4721.647	-2362.82	-2368.16	8.879	2.8847E-03

TEXAS

RANDOM TESTS	-2 RES Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Positive Catch					
Year Area Season	1511.413	-756.707	-758.805		
Year Area Season *Year*Season*	1510.967	-757.483	-761.68	0.446	5.04E-01
Year Area Season Year*Season*Year*Area*	1501.881	-753.941	-760.235	9.086	2.58E-03
Year Area Season *Year*Season Year*Area Area* Season*	1500.565	-754.283	-762.676	1.316	2.51E-01
Proportion Positives					
Year Area Season	383.5551	-192.778	-194.167		
Year Area Season *Year*Area*	371.0854	-187.543	-190.322	12.4697	4.14E-04
Year Area Season *Year*Area Year*Season*	371.0854	-188.543	-192.711	0	1.00E+00
Year Area Season *Year*Area Area*Season*	361.2482	-183.624	-187.793	9.8372	1.71E-03
Year Area Season *Year*Season Year*Area Area* Season*	360.9467	-184.473	-190.032	0.3015	5.83E-01

Table 3 . Nominal and delta lognormal standardized CPUE indices for gray triggerfish from recreational survey data. CPUE units are number of fish/angler hour.

MRFSS

Year	Nominal	Standard	CV
1981	0.01454	0.02923	47.10%
1982	0.00386	0.02641	42.87%
1983	0.00698	0.01899	44.68%
1984	0.00357	0.00847	56.61%
1985	0.00272	0.00985	57.15%
1986	0.02873	0.04165	36.44%
1987	0.00781	0.01809	38.44%
1988	0.01407	0.05353	35.17%
1989	0.01885	0.08643	34.80%
1990	0.02307	0.10552	36.41%
1991	0.02542	0.08428	33.97%
1992	0.01564	0.07310	31.18%
1993	0.00864	0.05082	34.13%
1994	0.00874	0.05032	32.73%
1995	0.00575	0.03895	35.97%
1996	0.00707	0.03325	36.22%
1997	0.00675	0.03270	33.70%
1998	0.00900	0.03524	32.89%
1999	0.00768	0.03021	31.53%

HEADBOAT

Year	Nominal	Standard	CV
1986	0.00851	0.00828	147.78%
1987	0.00894	0.00833	144.09%
1988	0.01762	0.01180	114.25%
1989	0.02219	0.01730	88.38%
1990	0.03801	0.02705	61.15%
1991	0.02595	0.02371	70.35%
1992	0.03010	0.02425	65.64%
1993	0.02459	0.02351	67.24%
1994	0.02582	0.01938	77.01%
1995	0.02384	0.01372	97.60%
1996	0.02357	0.01477	94.91%
1997	0.01990	0.01118	106.56%
1998	0.01768	0.01026	117.38%

PANAMA CITY

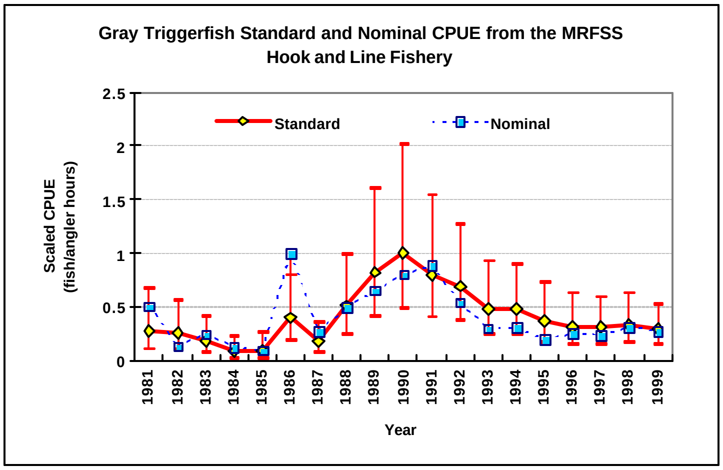
Year	Nominal	Standard	CV
1989	0.09282	0.28874	30.60%
1990	0.26740	0.37156	32.15%
1991	0.48079	0.31247	29.33%
1992	0.35190	0.38472	28.49%
1993	0.51404	0.33463	34.49%
1994	0.56815	0.44076	28.52%
1995	0.22909	0.44667	27.73%

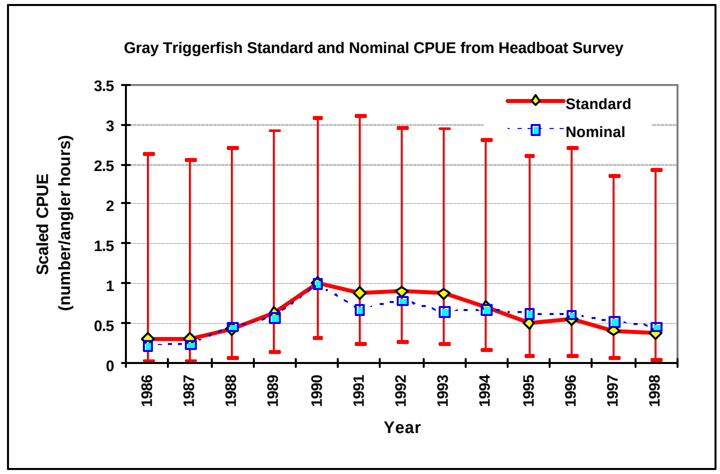
ALABAMA

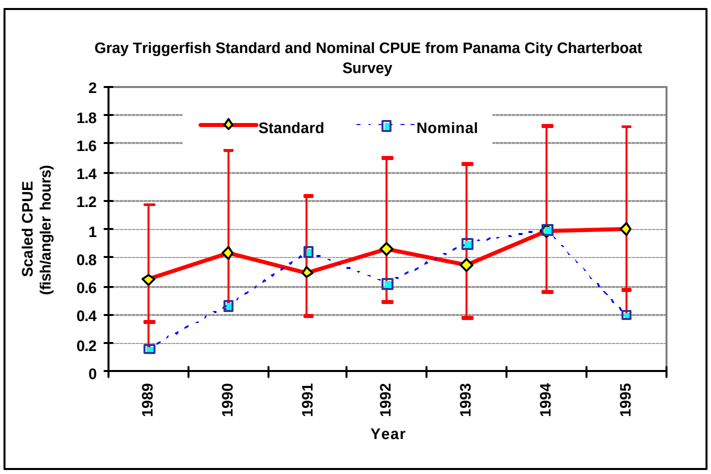
Year	Nominal	Standard	CV
1991	0.84120	0.14492	28.46%
1992	0.92154	0.13550	30.19%
1993	0.66591	0.07176	36.06%
1994	0.66605	0.08390	34.02%

TEXAS

Year	Nominal	Standard	CV
1983	0.00037	0.00300	364.21%
1984	0.00065	0.00306	357.50%
1985	0.00093	0.00335	312.86%
1986	0.00050	0.00184	502.57%
1987	0.00042	0.00245	384.43%
1988	0.00102	0.00604	230.39%
1989	0.00125	0.00505	266.15%
1990	0.00134	0.00406	287.77%
1991	0.00065	0.00277	369.28%
1992	0.00148	0.00329	332.67%
1993	0.00072	0.00364	315.74%
1994	0.00079	0.00456	265.87%
1995	0.00067	0.00252	370.78%
1996	0.00066	0.00236	409.34%
1997	0.00063	0.00199	425.23%
1998	0.00012	0.00100	788.95%







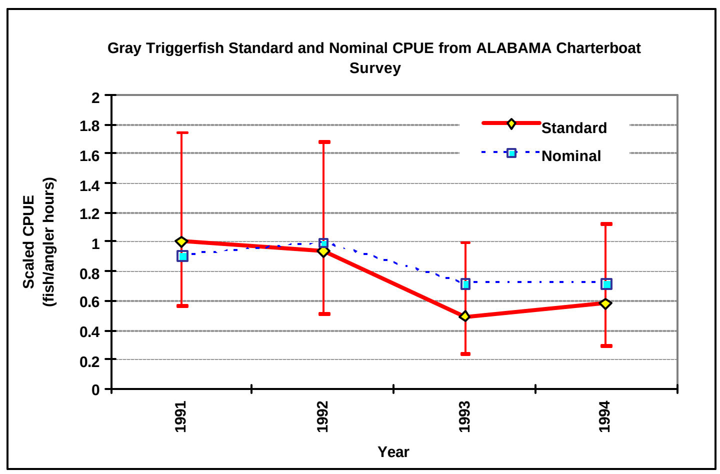
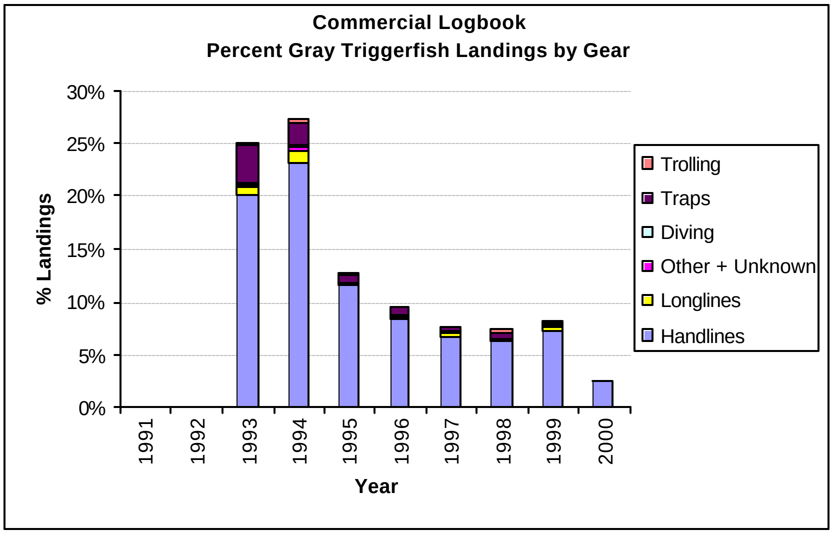


Figure 2 Scaled nominal and delta lognormal standardized catch rates (CPUE) of gray triggerfish from recreational survey data. CPUE units are number of fish/angler hour. The solid line represents the average of the standardized catch rates (± 95% CI); the dotted line represents the nominal average CPUE.



GEAR	% LANDINGS
Handlines	85.96%
Traps	8.46%
Longlines	3.32%
Trolling	1.19%
Other + Unknown	0.74%
Diving	0.33%

Figure 3. Commercial logbook data. Percent gray triggerfish landings by gear.

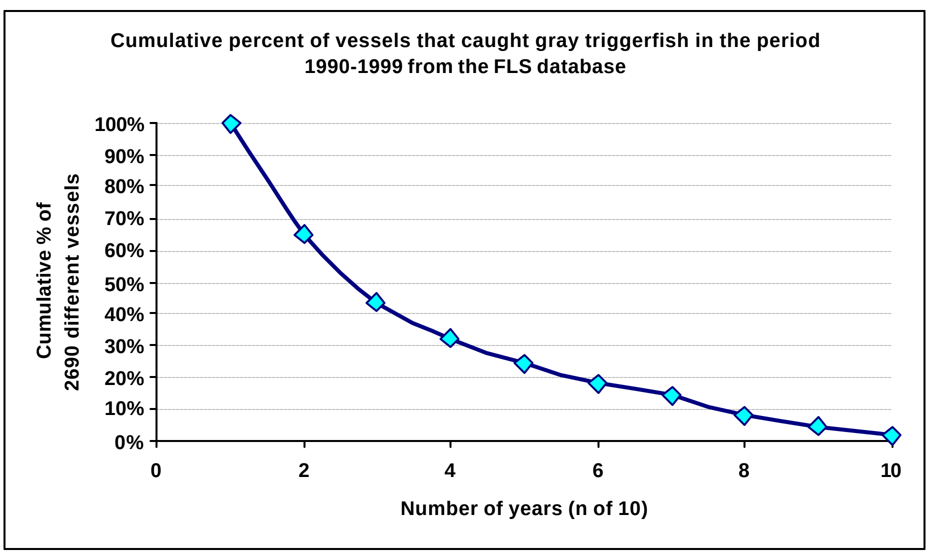


Figure 4. Cumulative percentage of vessels that caught gray triggerfish in the Gulf of Mexico during the period 1990-1999 from the Florida Logbook System (FLS) database.

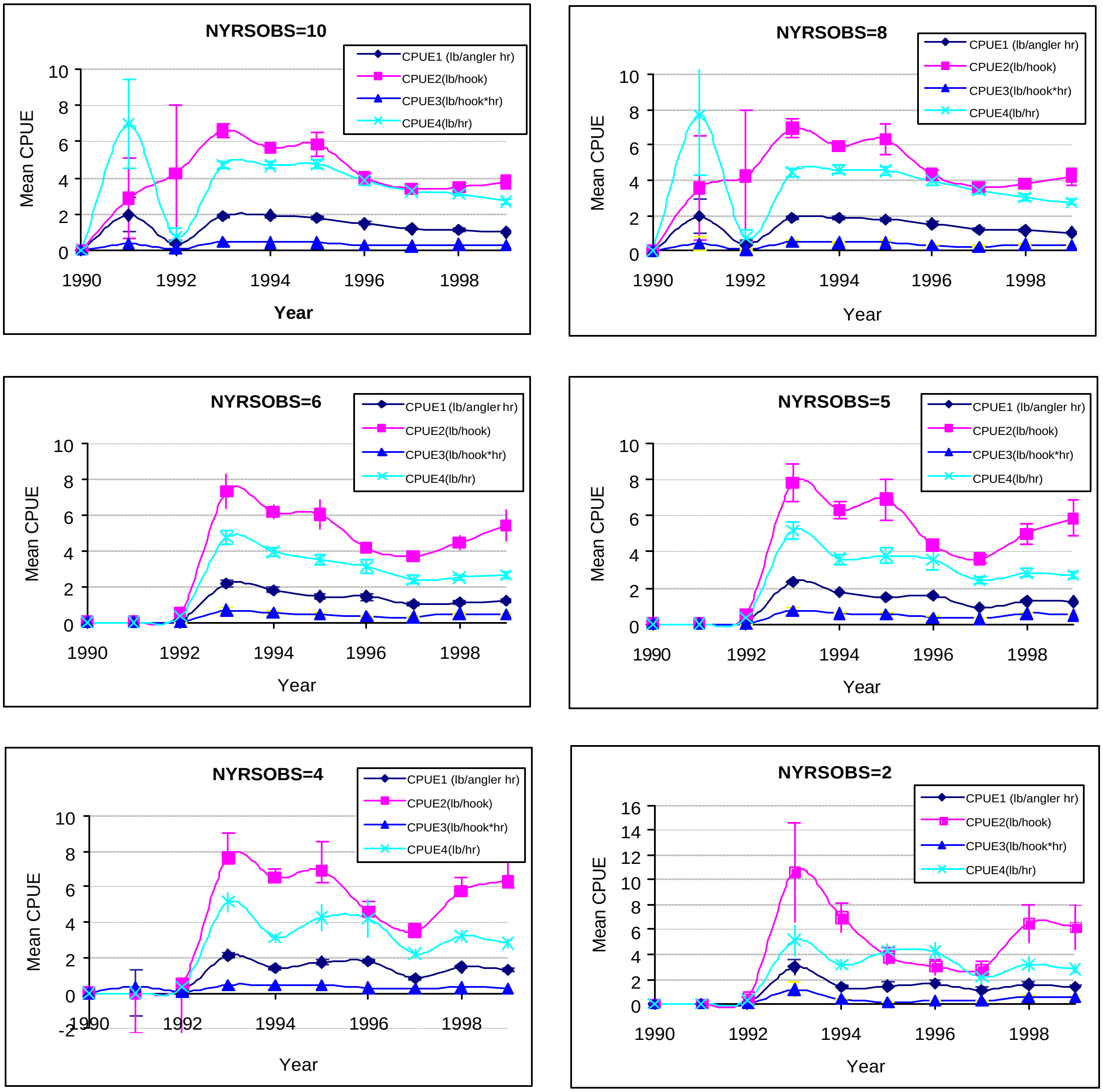


Figure 5. Nominal commercial CPUEs by number of years where individual vessels caught gray triggerfish in the period 1990-1999. NYRSOBS= number of years where gray triggerfish was observed in the catch. Units are: CPUE1= pounds/angler*hour, CPUE2= pounds/hook, CPUE3= pounds/hook*hour, CPUE4=pounds/hour.

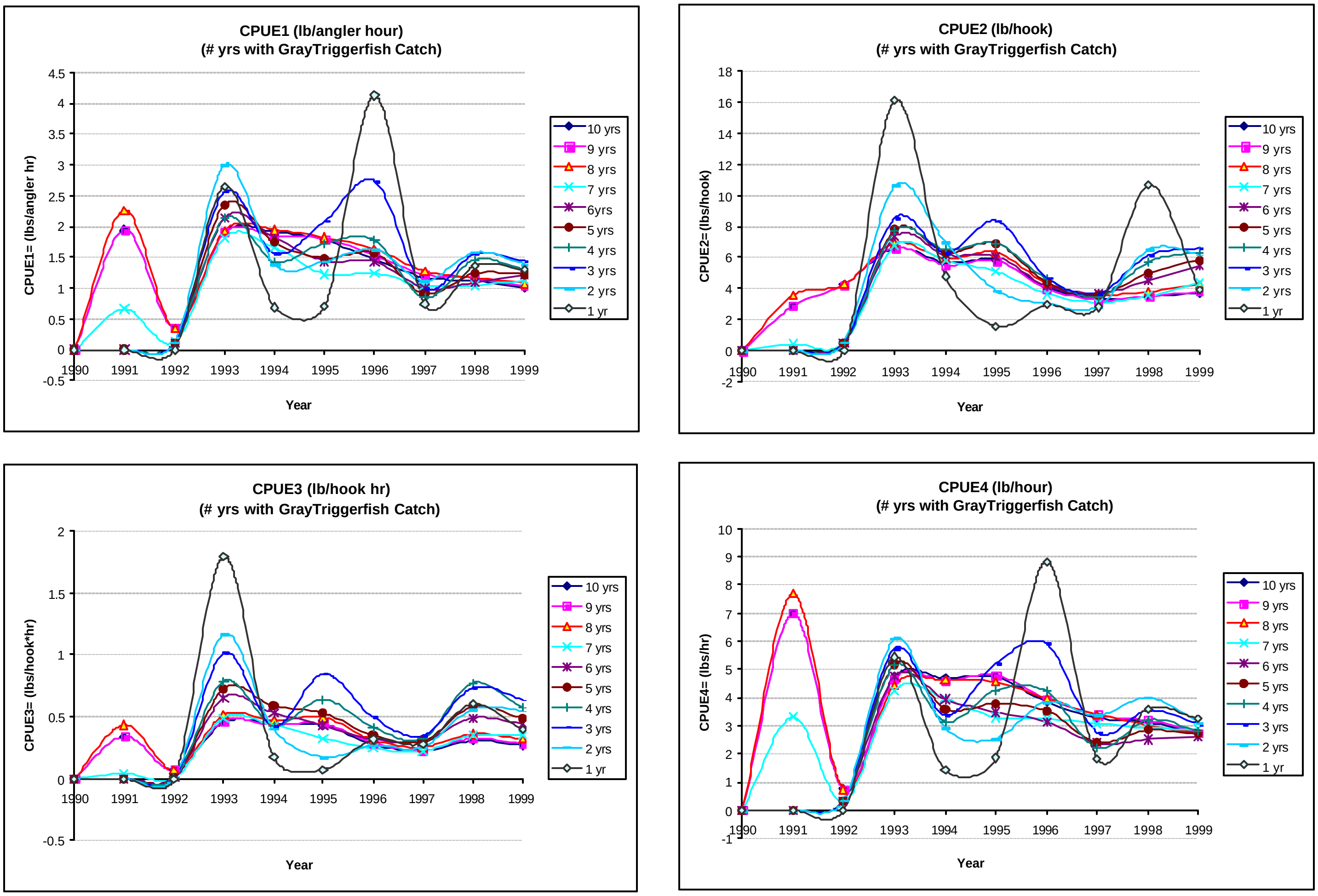


Figure 6. Nominal commercial catch rates for Gulf of Mexico gray triggerfish by number of years the species was caught by individual vessels.

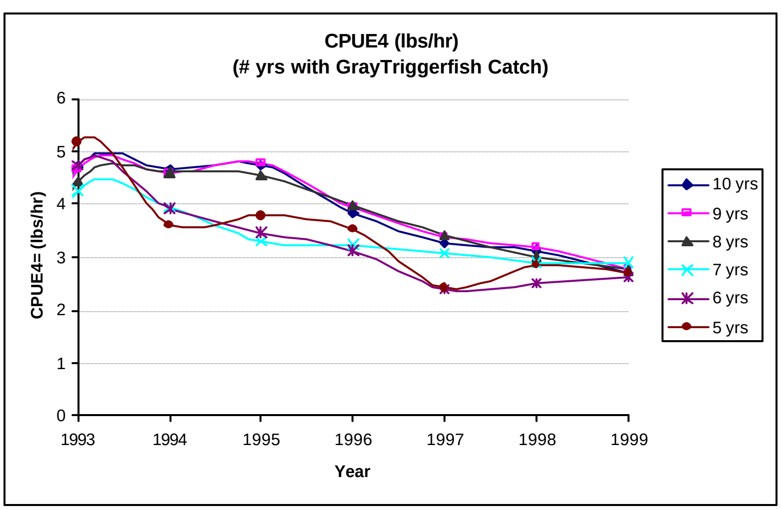


Figure 7. Nominal commercial CPUE4 with gray triggerfish present in the catch for 5 years or more, selected for standardization and use in production model analysis.

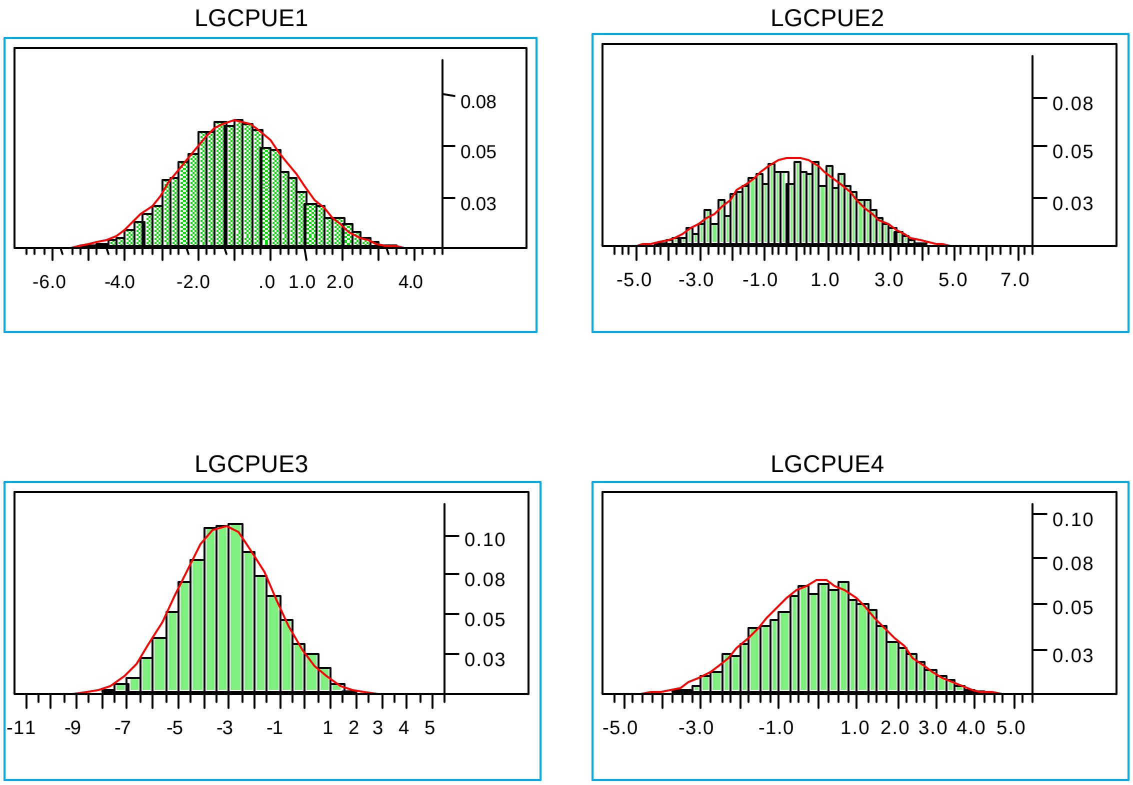


Figure 8. Frequency distributions of logCPUE of successful trips of gray triggerfish from commercial logbook data (handlines only). The plots show density on lnCPUE. The line represents the estimated normal distribution of the data. Catch rates are given in: CPUE1=pounds/angler*hour, CPUE2=pounds/hook, CPUE3= pounds/hook*hour, CPUE4=pounds/hour.

Table 4. Deviance analysis tables for commercial gray triggerfish catch rates using the delta lognormal model. Separate analyses were conducted for different units of fishing effort and CPUE. Units for each index are given in parenthesis. Proportion positive/total observations assumed a binomial error distribution. P refers to the Chi-square test probability (alpha=5%) test between two consecutive model specifications. Factors and interactions with total deviance$5% were selected and are shown in shaded areas.

COMMERCIAL SECTOR (HANDLINES)

CPUE2 (lb/hook)

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	p
NULL	1	45769.14			
YEAR	6	44600.79	1168.4	9.6%	< 0.001
... + AREA	22	35563.09	9037.7	74.1%	< 0.001
... + SEASON	2	35030.55	532.5	4.4%	< 0.001
... + YEAR:AREA	124	33773.07	1257.5	10.3%	< 0.001
... + YEAR:SEASON	12	33573.92	199.2	1.6%	< 0.001

Model factors proportion positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	p
NULL	1	129.53			
YEAR	6	128.57	1.0	0.9%	0.987
... + AREA	22	44.28	84.3	81.7%	< 0.001
... + SEASON	2	43.14	1.1	1.1%	0.565
... + YEAR:AREA	130	26.92	16.2	15.7%	1.000
... + YEAR:SEASON	12	26.38	0.5	0.5%	1.000

CPUE3 (lbs/hook*hr)

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	p
NULL	1	50687.23			
YEAR	6	49284.99	1402.2	16.4%	< 0.001
... + AREA	22	44065.93	5219.1	61.2%	< 0.001
... + SEASON	2	44045.84	20.1	0.2%	< 0.001
... + YEAR:AREA	124	42421.13	1624.7	19.1%	< 0.001
... + YEAR:SEASON	12	42159.77	261.4	3.1%	< 0.001

Model factors proportion positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	p
NULL	1	129.53			
YEAR	6	128.57	1.0	0.9%	0.987
... + AREA	22	44.28	84.3	81.7%	< 0.001
... + SEASON	2	43.14	1.1	1.1%	0.565
... + YEAR:AREA	130	26.92	16.2	15.7%	1.000
... + YEAR:SEASON	12	26.38	0.5	0.5%	1.000

CPUE4 (lbs/hr)

Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	p
NULL	1	43472.74			
YEAR	6	42983.21	489.5	6.8%	< 0.001
... + AREA	23	37597.25	5386.0	75.1%	< 0.001
... + SEASON	2	37566.67	30.6	0.4%	< 0.001
... + YEAR:AREA	130	36425.63	1141.0	15.9%	< 0.001
... + YEAR:SEASON	12	36302.77	122.9	1.7%	< 0.001

Model factors proportion positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	p
NULL	1	129.53			
YEAR	6	128.57	1.0	0.9%	0.987
... + AREA	22	44.28	84.3	81.7%	< 0.001
... + SEASON	2	43.14	1.1	1.1%	0.565
... + YEAR:AREA	130	26.92	16.2	15.7%	1.000
... + YEAR:SEASON	12	26.38	0.5	0.5%	1.000

Table 5. Commercial sector. Random effects evaluation for delta lognormal mixed model specifications. Separate analyses were conducted for different units of fishing effort and CPUE. Units for each index are given in parenthesis. Highlighted rows refer to the final model.

COMMERCIAL SECTOR (HANDLINES)

CPUE2 (lb/hook)					
RANDOM TESTS	-2 RES Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Positive Catch					
Year Area	54088.81	-27045.4	-27049.2		
Year Area *Year*Area*	53858.31	-26931.2	-26938.7	230.5	0.0000
Proportion Positive					
Year Area	233.7685	-117.884	-119.318		
Year Area *Year*Area*	228.8015	-116.401	-119.268	4.967	0.0258

CPUE3 (lbs/hook*hr)					
RANDOM TESTS	-2 RES Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Positive Catch					
Year Area	56882.11	-28442.1	-28445.8		
Year Area *Year*Area*	56638.56	-28321.3	-28328.8	243.55	0.0000
Proportion Positive					
Year Area	233.7685	-117.884	-119.318		
Year Area *Year*Area*	228.8015	-116.401	-119.268	4.967	0.0258

CPUE4 (lbs/hr)					
RANDOM TESTS	-2 RES Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Positive Catch					
Year Area	51836.7	-25919.4	-25923.1		
Year Area *Year*Area*	51579.01	-25791.5	-25799.1	257.69	0.0000
Proportion Positive					
Year Area	233.7685	-117.884	-119.318		
Year Area *Year*Area*	228.8015	-116.401	-119.268	4.967	0.0258

Table 6. Nominal and delta lognormal standardized CPUE indices for gray triggerfish from commercial logbook survey (handlines). Separate analyses were conducted with different CPUE units. Units for each index are given in parenthesis.

CPUE2 (lb/hook)

Year	Nominal	Standard	CV
1993	1.000	0.836	18.25%
1994	0.865	1.000	17.84%
1995	0.907	0.711	18.57%
1996	0.631	0.687	18.02%
1997	0.535	0.651	18.02%
1998	0.463	0.545	18.19%
1999	0.422	0.560	18.24%

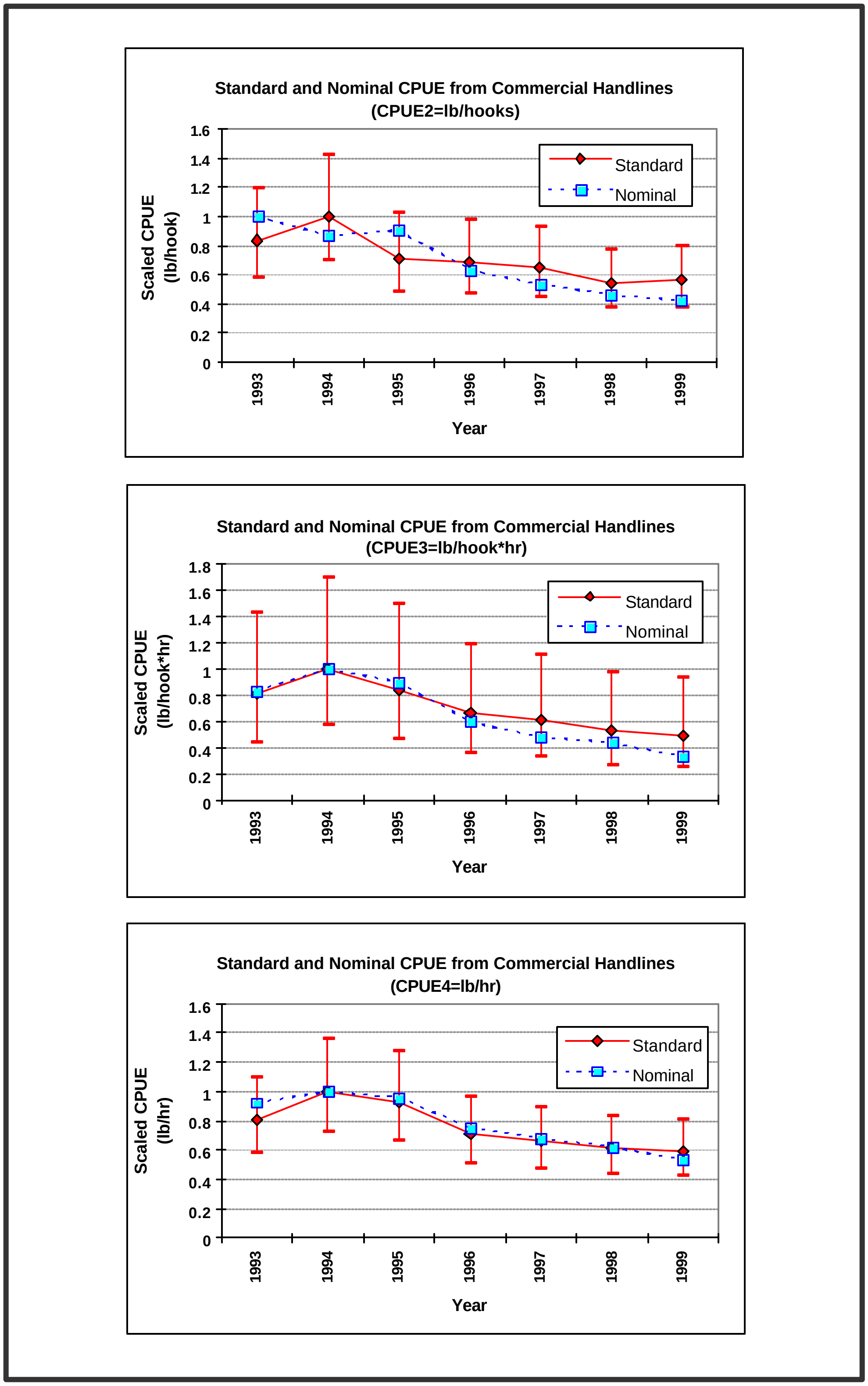
CPUE3 (lb/hook*hr)

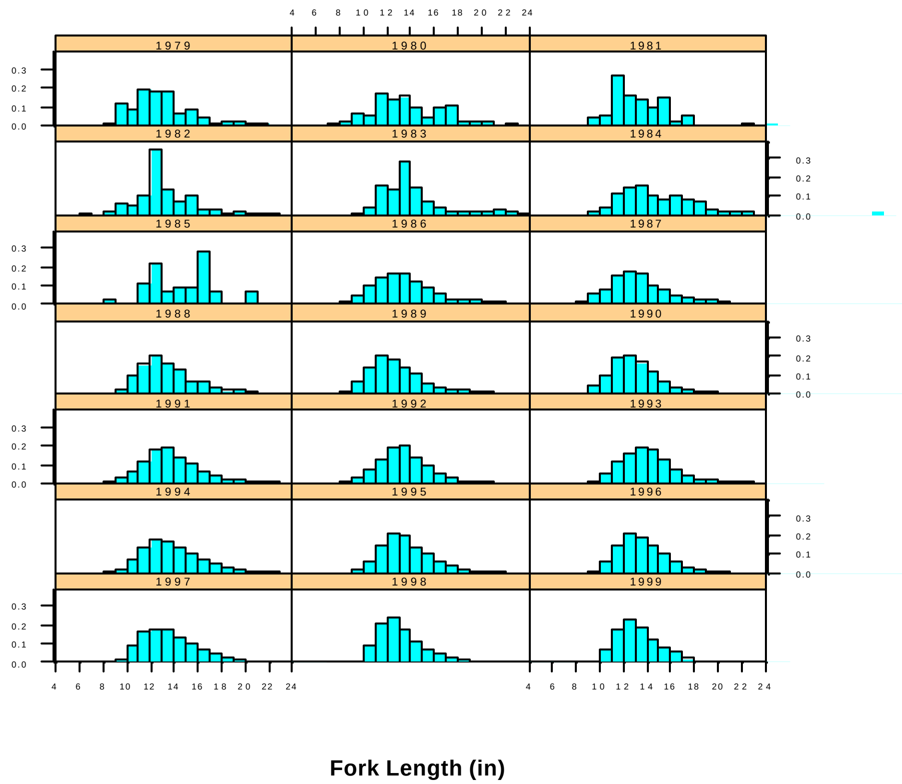
Year	Nominal	Standard	CV
1993	0.835	0.807	29.51%
1994	1.000	1.000	27.23%
1995	0.901	0.843	29.75%
1996	0.596	0.664	30.00%
1997	0.480	0.611	30.54%
1998	0.437	0.526	32.26%
1999	0.332	0.495	32.82%

CPUE4 (lb/hr)

Year	Nominal	Standard	CV
1993	0.924	0.804	15.99%
1994	1.000	1.000	15.60%
1995	0.958	0.928	16.18%
1996	0.752	0.711	15.70%
1997	0.680	0.658	15.68%
1998	0.623	0.610	15.78%
1999	0.532	0.594	15.85%

Figure 9. Scaled nominal and delta lognormal standardized catch rates (CPUE) of gray triggerfish from commercial logbook data. Units are: CPUE2=lbs/hook, CPUE3= lbs/hook*hr, CPUE4=lbs/hour. The solid line represents the average of the standardized catch rates (± 95% CI); the dotted line represents the nominal average CPUE.





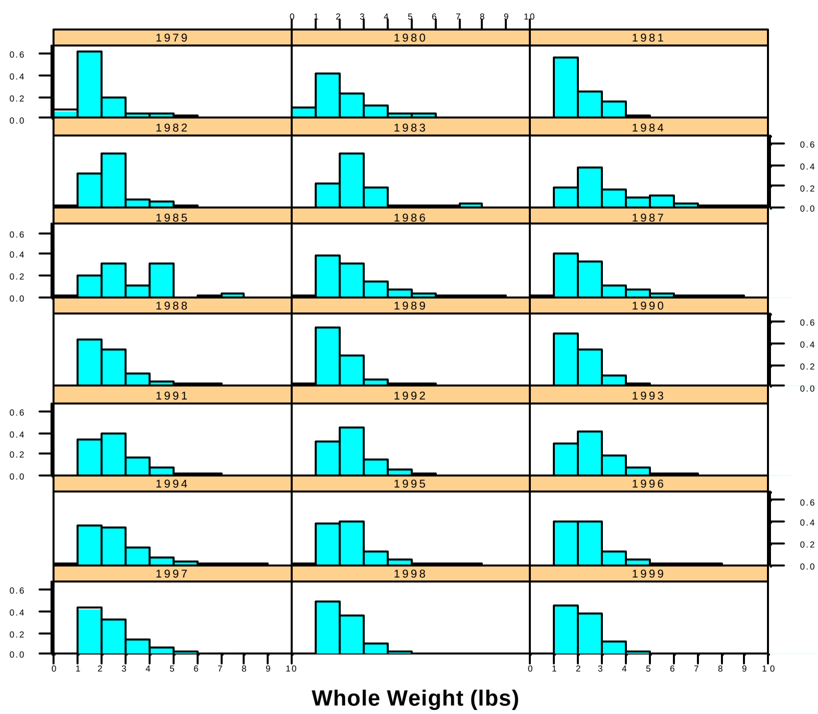


Figure 10. Size and weight frequency distributions by year for gray triggerfish from all recreational surveys combined (MRFSS, HEADBOAT, TPWD) for years 1979-1999.

Table 7. Mean size (fork length) and mean weight (whole) of gray triggerfish measured from the MRFSS (1981-1999), HEADBOAT (1986-1998) and TPWD (1983-1998) recreational surveys.

MRFSS

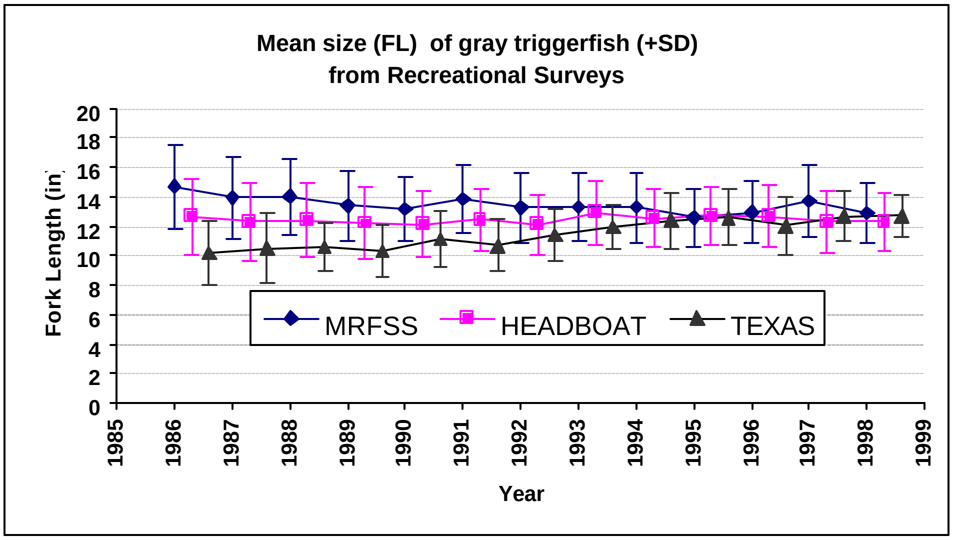
Year	N obs	Mean FL (in)	SD	N obs	Mean weight (lb)	SD
1981	80	12.99	2.46	81	1.84	1.45
1982	188	12.67	2.39	188	1.91	1.04
1983	139	13.72	2.75	139	2.46	1.45
1984	68	14.57	3.70	69	3.23	3.61
1985	46	14.22	2.64	49	2.88	1.61
1986	123	14.71	2.83	128	2.97	1.92
1987	422	13.92	2.77	424	2.42	1.47
1988	397	14.00	2.54	420	2.49	1.78
1989	210	13.37	2.40	230	2.00	1.15
1990	313	13.15	2.14	323	2.26	1.35
1991	658	13.83	2.33	667	2.46	1.30
1992	1412	13.24	2.35	1436	2.18	1.30
1993	400	13.29	2.31	401	2.17	1.30
1994	381	13.28	2.40	392	2.18	1.32
1995	325	12.59	1.94	340	1.84	0.98
1996	187	12.93	2.11	195	1.96	1.20
1997	501	13.69	2.47	515	2.30	1.34
1998	1374	12.90	2.09	1379	1.88	1.05
1999	2128	12.59	1.90	2128	1.78	0.92
Total	9352			9504		

HEADBOAT

Year	N obs	Mean FL (in)	SD	N obs	Mean weight (lb)	SD
1986	469	12.67	2.59	546	1.99	1.37
1987	552	12.32	2.61	607	1.81	1.87
1988	597	12.42	2.48	676	1.74	1.48
1989	1352	12.21	2.40	1458	1.64	1.16
1990	2071	12.13	2.27	2161	1.64	2.36
1991	1638	12.46	2.09	1666	1.68	0.93
1992	2499	12.11	2.06	2510	1.58	0.91
1993	1373	12.92	2.13	1375	1.91	1.07
1994	2137	12.54	2.02	2167	1.77	1.00
1995	1735	12.70	1.90	1760	1.81	0.89
1996	1501	12.68	2.08	1564	1.84	1.61
1997	1149	12.30	2.04	1218	1.65	0.94
1998	1486	12.30	2.01	1586	1.66	1.00
Total	18559			19294		

TEXAS

Year	N obs	Mean FL (in)	SD	N obs	Mean weight (lb)	SD
1983	153	10.98	2.15	153	1.24	0.84
1984	175	11.26	2.41	175	1.35	0.86
1985	93	9.02	1.64	93	0.68	0.39
1986	49	10.19	1.75	49	0.97	0.54
1987	80	10.51	1.90	80	1.07	0.64
1988	137	10.59	1.82	137	1.09	0.67
1989	92	10.33	1.73	92	1.00	0.49
1990	115	11.14	1.46	115	1.22	0.46
1991	80	10.72	1.93	80	1.13	0.61
1992	93	11.43	1.90	93	1.35	0.88
1993	95	11.95	1.96	95	1.53	0.73
1994	149	12.39	1.71	149	1.67	0.63
1995	134	12.59	1.43	134	1.72	0.56
1996	83	12.05	1.82	83	1.57	0.72
1997	100	12.66	2.43	100	1.87	1.30
1998	24	12.73	1.42	24	1.77	0.55
Total	1652			1652		



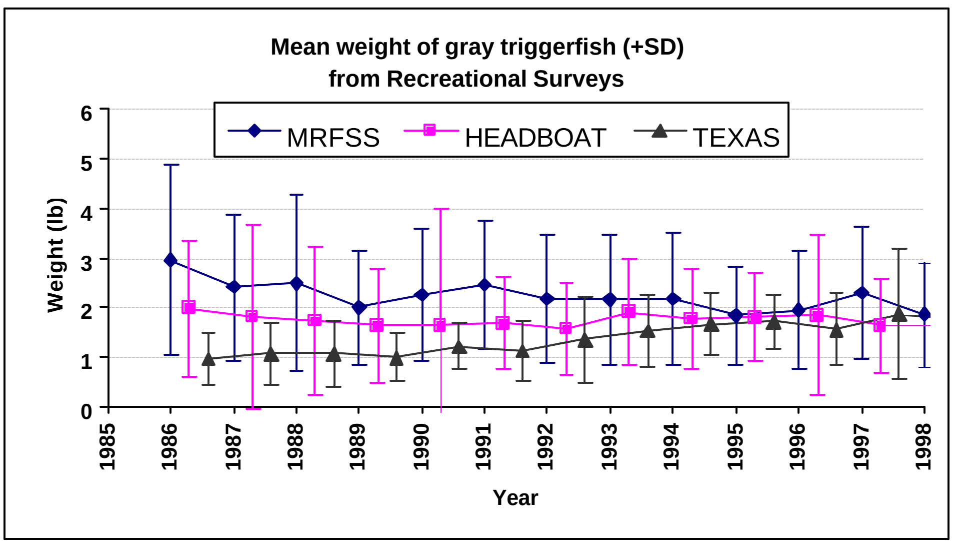


Figure 11. Mean size FL (in) and mean whole weight (lbs) of gray triggerfish measured from recreational surveys.

Table 8. Mean weight estimates for recreationally harvested gray triggerfish by year, state and fishing mode. Conversions from fork length used Wt= (8.975E-4) $FL^{2.96}$ and from total length used Wt= (9.953E-4)$Len^{2.773}$ (equations taken from Goodyear and Thompson, 1993). Mean weight estimates by year, state, and mode correspond to the mean estimate where the sample size exceeded 25 individuals; where the sample size was less than 25, the state or gulfwide annual mean was substituted following the same convention. Units are in pounds.

SHORE MODE

Year	TX	LA	MS	AL	FLW
1986					
1987					
1988					
1989					
1990				2.25	2.29
1991				2.47	2.61
1992					1.90
1993					2.06
1994				2.38	
1995					1.53
1996					
1997					2.19
1998					

CHARTER

Year	TX	LA	MS	AL	FLW
1986		2.92		3.27	2.77
1987	1.07	2.37	2.42	2.49	2.48
1988	1.09	2.49	2.49	2.63	2.38
1989	1.00		2.00	2.49	1.32
1990	1.22	2.35	2.26	2.33	2.36
1991	1.13	2.36		2.53	2.63
1992	1.35	1.92	2.18	2.32	2.06
1993		2.17	2.17	2.32	2.23
1994	1.67	1.76	2.18	2.42	1.95
1995		2.15	1.84	2.00	1.54
1996	1.57	1.96	1.96	2.11	1.87
1997	1.87	2.30	2.30	2.52	2.27
1998	1.77	1.98		1.93	1.80

HEADBOAT

Year	TX	LA	MS	AL	FLW
1986	1.66	1.99		2.22	2.54
1987	1.85	1.76		1.89	1.41
1988	1.87	1.45		1.70	2.12
1989	1.65	1.76		1.72	1.25
1990	1.76	3.36		1.51	1.45
1991	1.95	1.93		1.62	1.68
1992	1.42	1.82		1.62	1.27
1993	2.00	2.33		1.70	1.91
1994	1.88	2.07		1.53	1.84
1995	1.99	2.05		1.61	1.41
1996	1.95	1.90		1.62	3.01
1997	2.08	1.73		1.60	1.19
1998	2.15	2.01		1.51	1.35

PRIVATE/ RENTAL

Year	TX	LA	MS	AL	FLW
1986	0.96	2.85		3.17	2.77
1987	1.08	2.34	2.42	2.46	2.33
1988	1.08	2.49		2.63	2.36
1989	1.00	2.00		2.36	1.28
1990	1.23	2.32	2.26	2.25	2.29
1991	1.13	2.36	2.46	2.47	2.61
1992	1.38	1.99	2.18	1.96	1.73
1993	1.53	2.17	2.17	2.31	1.62
1994	1.66	1.87	2.18	2.38	2.03
1995	1.73	2.15	1.84	1.90	1.53
1996	1.54	1.96	1.96	2.11	1.49
1997	1.87	2.30	2.30	2.53	1.65
1998	1.77	1.98	1.88	2.09	1.82

Table 9. Recreational harvest estimates for Gulf of Mexico gray triggerfish by year, state and fishing mode for the period 1986-1998. The estimates are based on the MRFSS, the NMFS Headboat Survey, and the Texas Parks and Wildlife size-frequency samples and catch estimates. The weight estimates are the sums of products of the annual harvest and mean weight estimates for each state by mode. Units are in number of fish and pounds.

SHORE MODE

	TX		LA		MS		AL		FLW		TOTAL GULF	
Year	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)
1986												
1987												
1988												
1989												
1990							30765	69110.80	27485	62822.86	58250	131933.66
1991							5664	14005.10	41830	109051.24	47494	123056.35
1992									27981	53217.52	27981	53217.52
1993									4193	8640.34	4193	8640.34
1994							1265	3005.03			1265	3005.03
1995									2782	4246.00	2782	4246.00
1996												
1997									1161	2541.34	1161	2541.34
1998												

CHARTER

	TX		LA		MS		AL		FLW		TOTAL GULF	
Year	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)
1986			1725	5034.83			13958	45672.05	394155	1090586.11	409838	1141292.98
1987	1388	1486.39	1803	4280.67	13	31.45	10267	25524.13	463119	1148154.63	476590	1179477.28
1988	203	220.51	1341	3343.96	909	2266.71	85830	226103.59	320627	762023.00	408910	993957.77
1989	102	102.15			4655	9332.47	129322	322245.14	247969	328516.17	382048	660195.93
1990	315	382.97	5093	11963.28	82	185.34	319420	743223.57	278075	655178.75	602985	1410933.92
1991	137	154.83	56613	133506.24			94231	237936.32	552407	1455492.61	703388	1827090.00
1992	1870	2531.50	14410	27736.13	72	157.22	91477	212366.30	245723	507377.86	353552	750169.01
1993			16834	36469.64	930	2014.78	95899	222753.25	269815	601475.04	383478	862712.71
1994	30	49.97	22272	39167.95	1360	2965.27	64069	155193.51	420498	821712.07	508229	1019088.77
1995			28497	61294.13	1148	2116.05	114976	229686.07	258845	397585.92	403466	690682.18
1996	26	40.80	4913	9628.90	4443	8707.75	76716	162087.58	105903	197686.62	192001	378151.65
1997	815	1523.79	2250	5177.36	1733	3987.72	72837	183561.00	102112	231509.58	179747	425759.45
1998	7902	14013.55	5148	10171.74			58608	113154.07	123962	223276.85	195620	360616.21

HEADBOAT

	TX		LA		MS		AL		FLW		TOTAL GULF	
Year	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)
1986	15642	25965.57	407	809.09			23209	51452.66	6797	17243.84	46055	95471.16
1987	16085	29728.32	612	1076.82			16602	31299.06	7206	10155.44	40505	72259.63
1988	39569	74052.96	1927	2802.05			22609	38412.74	5846	12375.41	69951	127643.16
1989	23589	38896.87	1355	2383.57			39033	67303.66	18820	23592.46	82797	132176.56
1990	21762	38181.08	3915	13163.86			93659	141552.51	14043	20407.97	133379	213305.42
1991	24100	46936.58	7028	13599.08			53014	85968.51	6038	10150.66	90180	156654.83
1992	35890	50928.09	5862	10677.64			62408	101187.20	7965	10147.91	112125	172940.84
1993	38226	76559.80	5958	13863.58			53022	90198.04	6823	13065.41	104029	193686.82
1994	50034	94116.14	6678	13793.39			49259	75291.49	5624	10370.61	111595	193571.63
1995	47925	95567.33	3916	8035.06			42187	67969.12	4493	6326.81	98521	177898.32
1996	37501	73181.71	2828	5369.38			33016	53588.75	4400	13239.48	77745	145379.33
1997	28731	59740.14	496	858.23			27295	43583.15	8227	9814.52	64749	113996.04
1998	15222	32756.41	881	1767.42			29324	44217.83	8357	11295.01	53784	90036.68

PRIVATE/ RENTAL

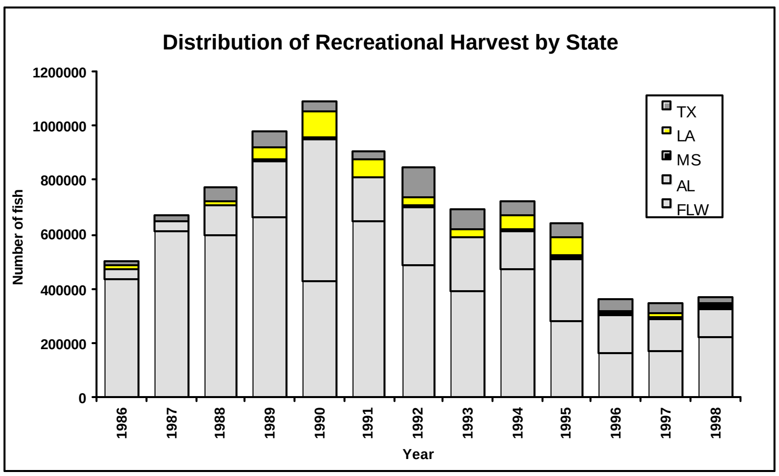
	TX		LA		MS		AL		FLW		TOTAL GULF	
Year	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)
1986	4394	4204.94	8643	24599.49			2222	7045.59	34769	96202.23	50028	132052.25
1987	5134	5522.10	2029	4742.69	1429	3457.07	4224	10376.61	144248	335685.70	157064	359784.17
1988	13797	14908.93	7449	18575.08			941	2478.89	272253	642455.96	294440	678418.86
1989	32589	32628.79	49453	99144.66			38941	91771.82	395901	505027.56	516884	728572.83
1990	8763	10766.60	89754	208453.67	9291	20999.94	75263	169071.55	110495	252560.00	293566	661851.75
1991	8793	9951.52	1055	2486.68	1399	3447.63	10177	25164.19	47553	123971.16	68977	165021.17
1992	70559	97241.46	13435	26772.10	3607	7876.10	57701	113162.18	209148	362556.31	354450	607608.15
1993	39204	60086.21	1619	3507.45	983	2129.60	52531	121338.75	110030	178259.22	204367	365321.22
1994	6272	10410.83	18788	35134.28	3022	6589.00	24761	58820.25	50259	101877.64	103102	212831.99
1995	4439	7662.17	38499	82807.41	7968	14687.04	73409	139527.67	15504	23662.81	139819	268347.11
1996	2291	3525.15	2068	4053.03	1876	3676.74	32087	67794.26	52559	78261.38	90881	157310.55
1997	4150	7759.19	13233	30449.77	1629	3748.41	18315	46347.05	61472	101184.71	98799	189489.12
1998	2950	5231.58	2961	5850.53	8505	15948.70	16192	33835.05	92527	168117.54	123135	228983.40

Table 9. Recreational harvest estimates for Gulf of Mexico gray triggerfish by year, state and fishing mode for the period 1986-1998 (continued).

ALL MODES

	TX		LA		MS		AL		FLW		TOTAL GULF	
Year	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)	N	Wt(lbs)
1986	20036	30170.5114	10775	30443.40604	0	0	39389	104170.3009	435721	1204032.177	505921	1368816.396
1987	22607	36736.814	4444	10100.18244	1442	3488.5152	31093	67199.80025	614573	1493995.77	674159	1611521.081
1988	53569	89182.4009	10717	24721.08781	909	2266.713	109380	266995.2268	598726	1416854.366	773301	1800019.795
1989	56280	71627.8132	50808	101528.2296	4655	9332.4654	207296	481320.6165	662690	857136.1922	981729	1520945.317
1990	30840	49330.6577	98762	233580.8051	9373	21185.276	519107	1122958.427	430098	990969.5815	1088180	2418024.748
1991	33030	57042.9308	64696	149591.9984	1399	3447.6277	163086	363074.1161	647828	1698665.68	910039	2271822.353
1992	108319	150701.048	33707	65185.87294	3679	8033.3129	211586	426715.6829	490817	933299.6027	848108	1583935.519
1993	77430	136646	24411	53840.66415	1913	4144.3755	201452	434290.0353	390861	801440.0174	696067	1430361.093
1994	56336	104576.936	47738	88095.62378	4382	9554.2666	139354	292310.2838	476381	933960.3166	724191	1428497.427
1995	52364	103229.503	70912	152136.602	9116	16803.094	230572	437182.8555	281624	431821.5418	644588	1141173.596
1996	39818	76747.6482	9809	19051.31279	6319	12384.488	141819	283470.5936	162862	289187.4803	360627	680841.523
1997	33696	69023.1289	15979	36485.3493	3362	7736.1226	118447	273491.1992	172972	345050.1509	344456	731785.951
1998	26074	52001.5468	8990	17789.68684	8505	15948.703	104124	191206.9544	224846	402689.3977	372539	679636.29

Figure 12. Recreational harvest in numbers of fish for Gulf of Mexico gray triggerfish by state and fishing mode for the period 1986-1998.



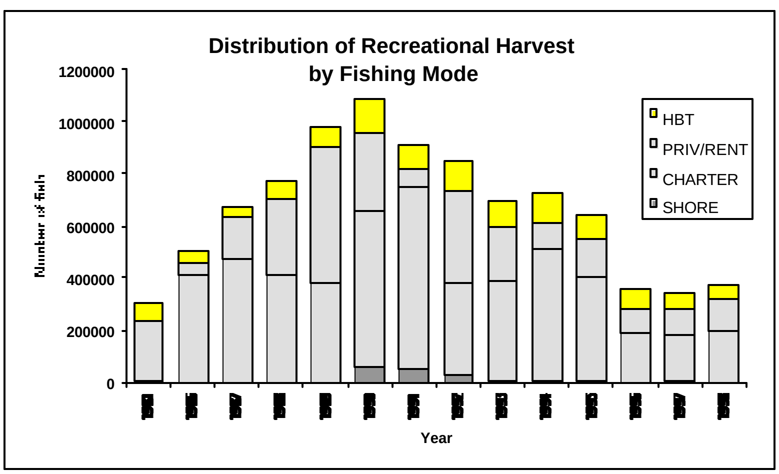


Table 10. Commercial harvest estimates in weight for Gulf of Mexico gray triggerfish by year and state for the period 1986-1998. The estimates based on the SEFSC General Canvass Program.

Year	TX	LA	MS	AL	FLW	TOTAL GULF
1986	572	14493	4008	5881	70978	95932
1987	289	21941	5550	3778	92742	124300
1988	1885	36980	8242	7641	140790	195538
1989	429	60856	7682	10389	238974	318330
1990	6951	69798	9027	16613	359553	461942
1991	6242	90572	7991	6993	332674	444472
1992	7941	101495	12433	6551	321883	450303
1993	11287	128947	38273	10413	374260	563180
1994	15428	119758	15382	8389	247156	406113
1995	26168	75744	22681	5268	208449	338310
1996	17226	79331	12644	2867	152502	264570
1997	15022	50583	8813	2534	109682	186634
1998	20944	34378	10120	1288	107651	174381
1999	12452	50030	5613	1709	118248	188052

Figure 13. Estimated Gulf of Mexico gray triggerfish annual landings by weight for the commercial sector for the period 1986-1998.

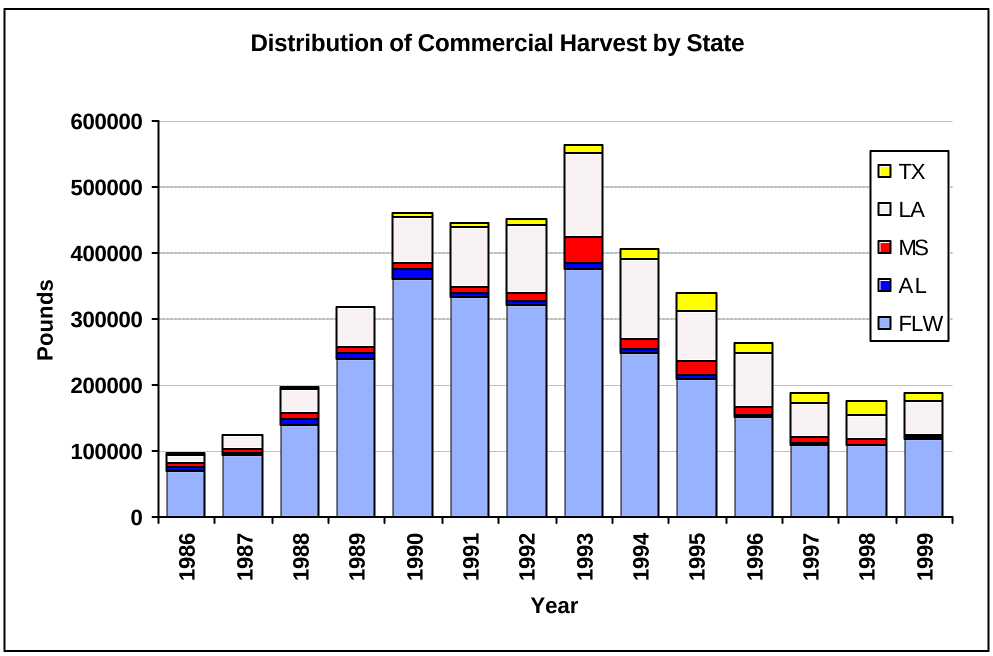


Table 11. Estimated Gulf of Mexico gray triggerfish annual landings by weight for the commercial and recreational sectors for the period 1986-1998.

Year	Commercial	Recreational	Total Gulf
1986	95932	1368816	1464748
1987	124300	1611521	1735821
1988	195538	1800020	1995558
1989	318330	1520945	1839275
1990	461942	2418025	2879967
1991	444472	2271822	2716294
1992	450303	1583936	2034239
1993	563180	1430361	1993541
1994	406113	1428497	1834610
1995	338310	1141174	1479484
1996	270593	680842	951435
1997	186634	731786	918420
1998	174381	679636	854017

Figure 14. Estimated Gulf of Mexico gray triggerfish annual landings by weight for the commercial and recreational sectors for the period 1986-1998.

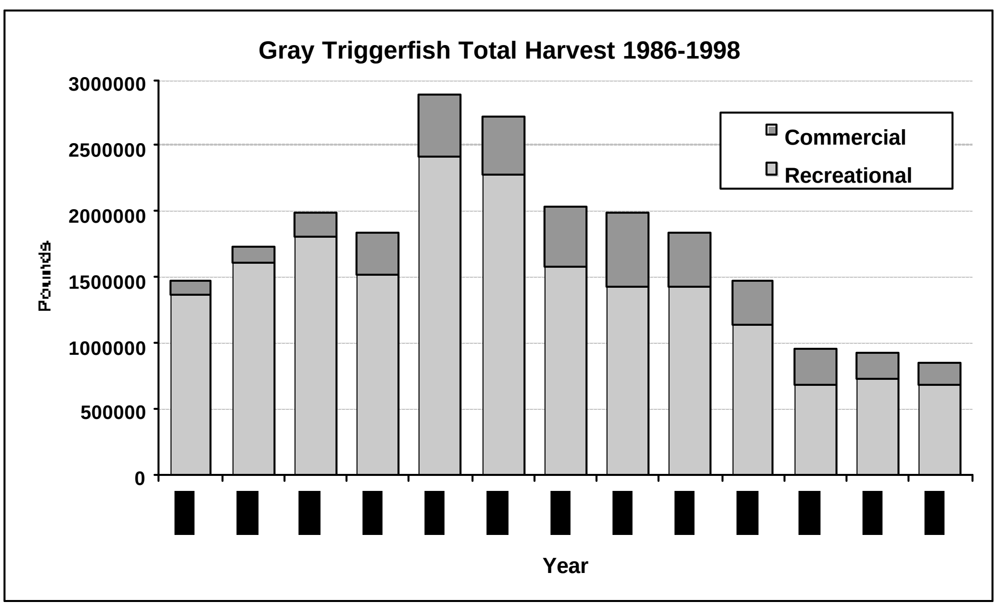
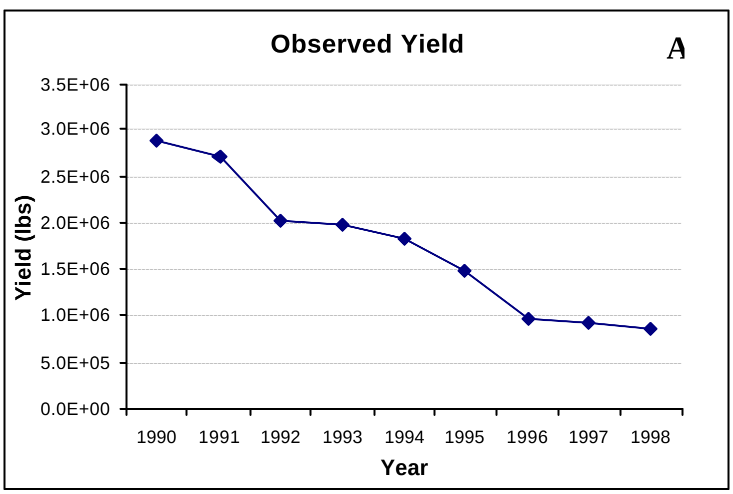


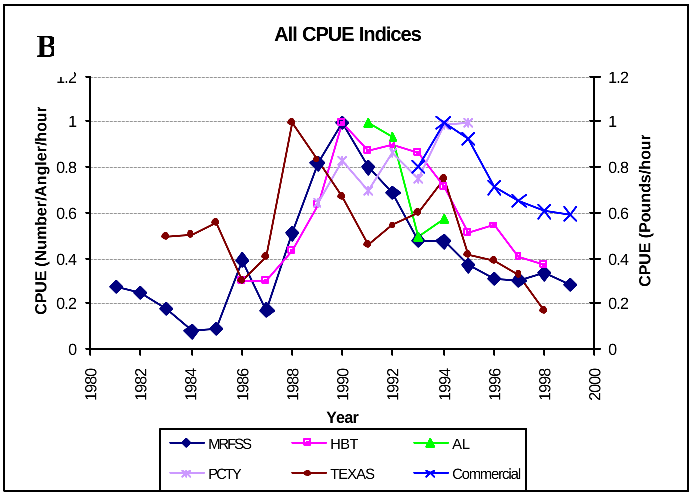
Table 12. Annual yield and CPUE index data used to fit ASPIC production model.

RECREATIONAL INDICES					
MRFSS			HEADBOAT		
Year	CPUE(num/angler hour)	Yield (wt)	Year	CPUE(num/angler hour)	Yield (wt)
1986	0.39	1273345	1986	0.31	95471
1987	0.17	1539261	1987	0.31	72260
1988	0.51	1672377	1988	0.44	127643
1989	0.82	1388769	1989	0.64	132177
1990	1.00	2204719	1990	1.00	213305
1991	0.80	2115168	1991	0.88	156655
1992	0.69	1410995	1992	0.90	172941
1993	0.48	1236674	1993	0.87	193687
1994	0.48	1234926	1994	0.72	193572
1995	0.37	963275	1995	0.51	177898
1996	0.32	535462	1996	0.55	145379
1997	0.31	617790	1997	0.41	113996
1998	0.33	589600	1998	0.38	90037

COMMERCIAL INDEX		
LOGBOOK-HEADBOAT		
Year	Std CPUE (pounds/hour)	Yield (wt)
1986	--	95932
1987	--	124300
1988	--	195538
1989	--	318330
1990	--	461942
1991	--	444472
1992	--	450303
1993	0.80	563180
1994	1.00	406113
1995	0.93	338310
1996	0.71	270593
1997	0.66	186634
1998	0.61	174381

Figure 15. Gray triggerfish data from the Gulf of Mexico used to fit production model (ASPIC). **(A)** Total yield. **(B)** Overlay of all standardized recreational and commercial CPUEs constructed in this study. **(C)** Standardized CPUE trajectories selected for use in ASPIC. Recreational CPUE units are in number of fish per angler hour, commercial CPUE units are in pounds per hour.





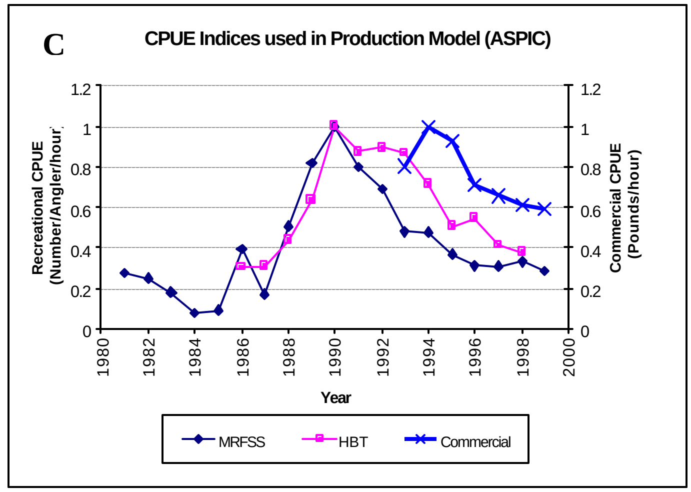


Figure 16. Results of ASPIC production model analyses. **(A)** Fixing the intrinsic rate of increase from r = 0.5 to 2.0. **(B)** Fixing the starting biomass ratio from B_1/B_{MSY} = 0.5 to 2.0. **(C)** Fixing B_1/B_{MSY} = 0.5 to 1.0 and r = 0.1 to 2.0. **(D)** Fixing B_1/B_{MSY} = 0.5 to 1.5 and MSY= 1.5E+06 to 3.5E+06. Only parameter combinations that allowed the model to converge are shown.

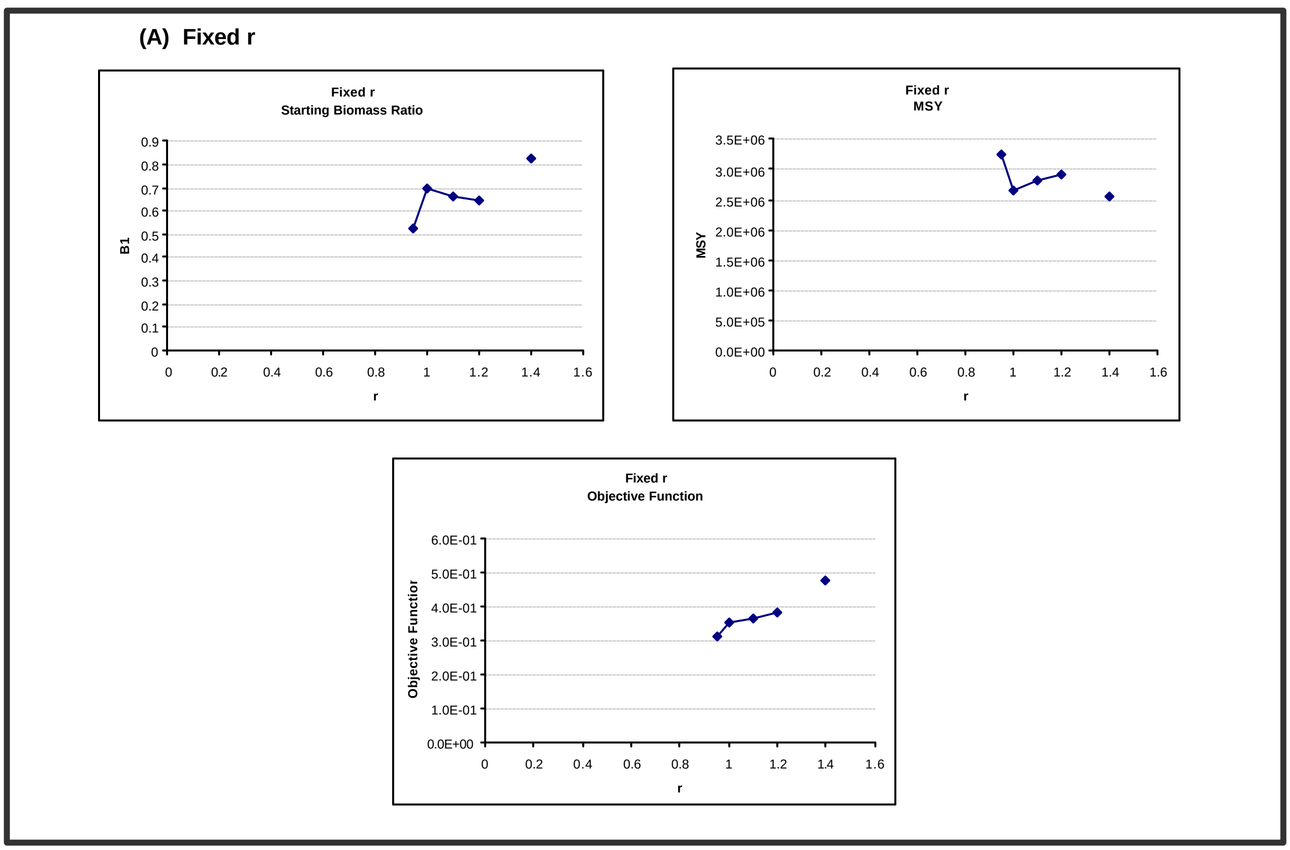
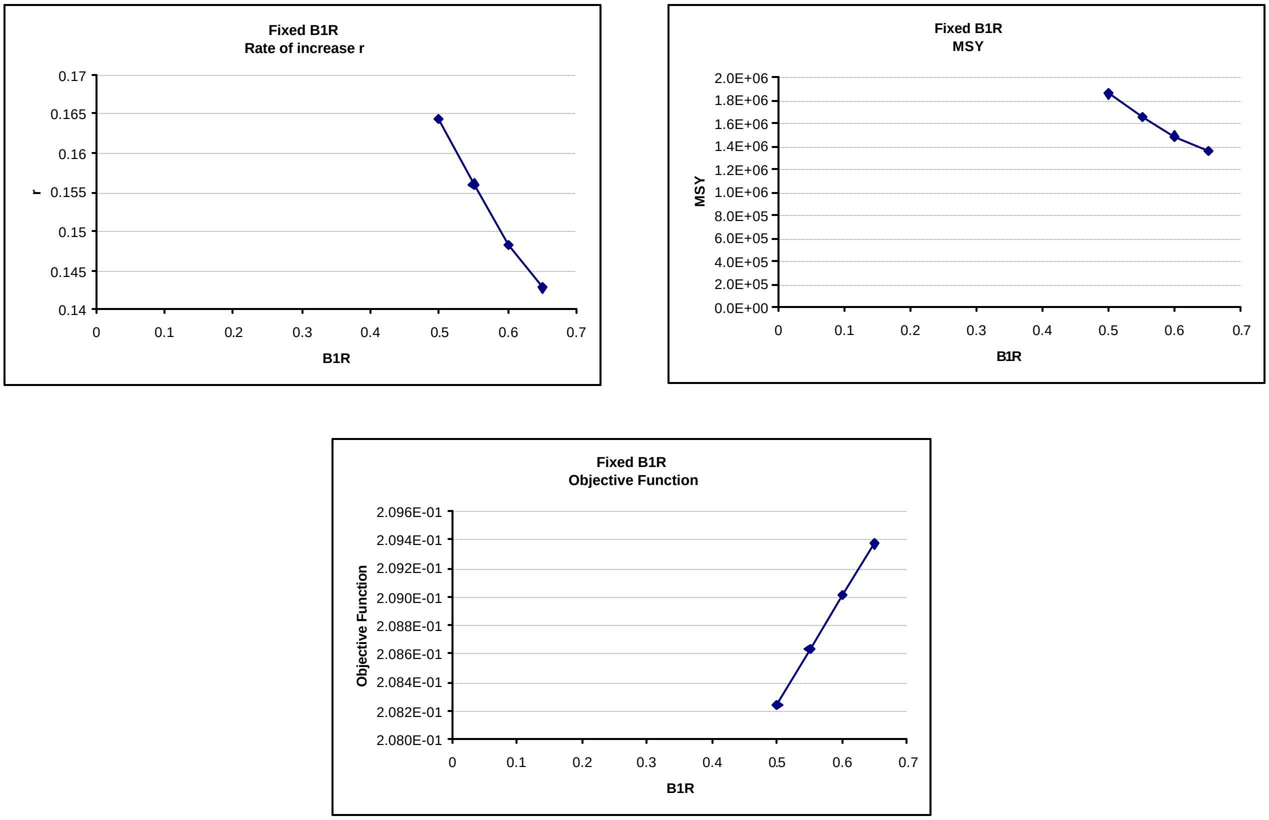


Figure 16. (Continued).

(B) Fixed B1/B_{MSY}



(C) Fixed B1/B_{MSY} and r

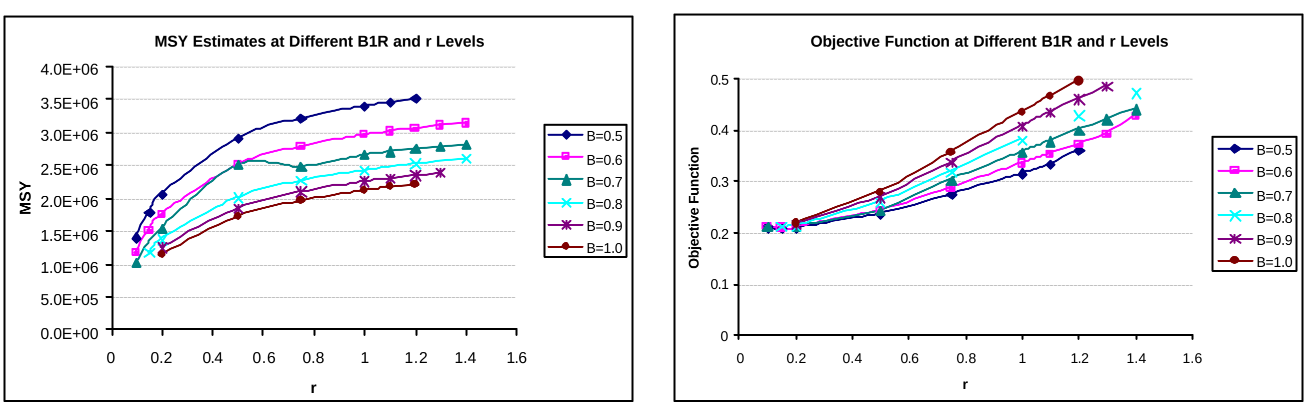


Figure 16. (Continued).

(D) Fixed B1/B_{MSY} and MSY

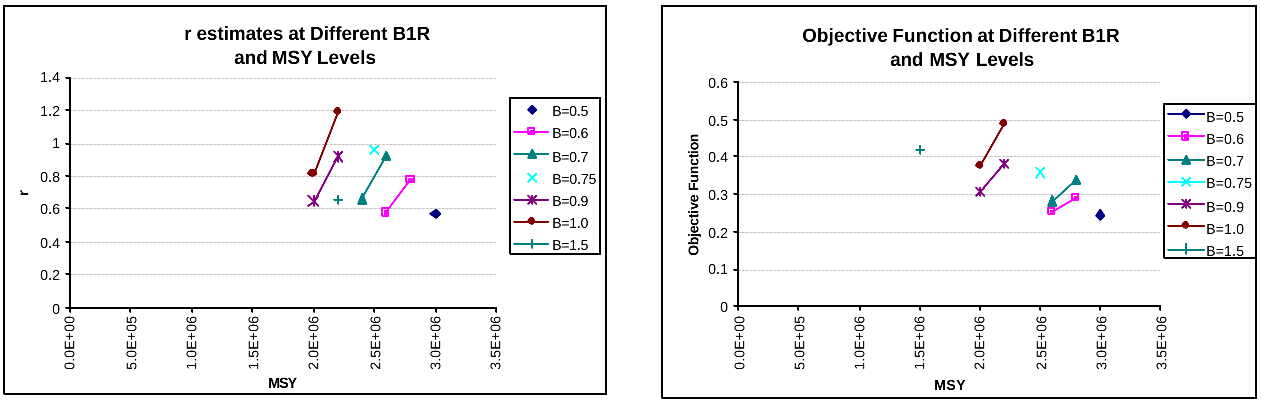


Table 13 . Results of two bootstapped production model analyses for gray triggerfish in the Gulf of Mexico. In Model (2), constraints were placed on parameters and *r* was held constant at *r*=1.0. Resulting parameters from Model (2) were used as initial guess values for Model (1), and no parameters were fixed. The two models thus differ in initial guess values and the number of parameters estimated by ASPIC. Each analysis included a bootstrap with 1,000 trials. Nonparametric bias-corrected 80% confidence intervals are derived from the bootstrap within ASPIC.

MODEL 1 (r=1.0)

Parameter	Bias-corrected estimate	Ordinary estimate	80% Lower CL	80% Upper CL	Relative IQ range
Model Parameters					
B1ratio	0.672	0.697	0.531	1.070	30.2%
K	1.09E+07	1.06E+07	8.14E+06	1.30E+07	20.4%
r	1	1	1	1	0.0%
q(1)	2.97E-07	2.92E-07	2.70E-07	3.20E-07	8.7%
q(2)	4.00E-07	3.93E-07	3.63E-07	4.28E-07	8.5%
q(3)	6.68E-07	6.57E-07	6.01E-07	7.33E-07	10.1%
Management Benchmarks					
MSY	2.72E+06	2.65E+06	2.03E+06	3.24E+06	20.4%
Bmsy	5.43E+06	5.31E+06	4.07E+06	6.48E+06	20.4%
Fmsy	0.5	0.5	0.5	0.5	0.0%
fmsy(1)	1.68E+06	1.71E+06	1.56E+06	1.85E+06	8.8%
fmsy(2)	1.25E+06	1.27E+06	1.17E+06	1.38E+06	8.7%
fmsy(3)	7.48E+05	7.61E+05	6.82E+05	8.32E+05	10.2%
B_{1999}/B_{MSY}	0.196	0.208	0.152	0.294	33.3%
F_{1998}/F_{msy}	1.651	1.620	1.437	1.879	13.7%

Table 13. (Continued.).

Parameter	Bias-corrected estimate	Ordinary estimate	80% Lower CL	80% Upper CL	Relative IQ range
MODEL 2 (No fixed parameters)					
Model Parameters					
B1ratio	0.525	0.532	0.506	0.554	3.8%
K	1.06E+07	1.06E+07	1.01E+07	1.23E+07	3.5%
r	1.287	1.277	1.224	1.346	3.9%
q(1)	3.83E-07	3.75E-07	3.41E-07	4.06E-07	7.0%
q(2)	5.18E-07	5.04E-07	4.66E-07	5.55E-07	8.3%
q(3)	8.63E-07	8.43E-07	7.48E-07	9.48E-07	10.7%
Management Benchmarks					
MSY	3.41E+06	3.37E+06	3.28E+06	3.48E+06	3.0%
Bmsy	5.29E+06	5.27E+06	5.05E+06	6.14E+06	3.5%
Fmsy	0.644	0.638	0.612	0.673	3.9%
fmsy(1)	1.69E+06	1.70E+06	1.60E+06	1.82E+06	5.7%
fmsy(2)	1.26E+06	1.27E+06	1.18E+06	1.36E+06	7.1%
fmsy(3)	7.56E+05	7.57E+05	6.91E+05	8.35E+05	9.3%
B_{1999}/B_{MSY}	0.155	0.164	0.128	0.192	21.7%
F_{1998} /Fmsy	1.666	1.648	1.481	1.898	12.9%

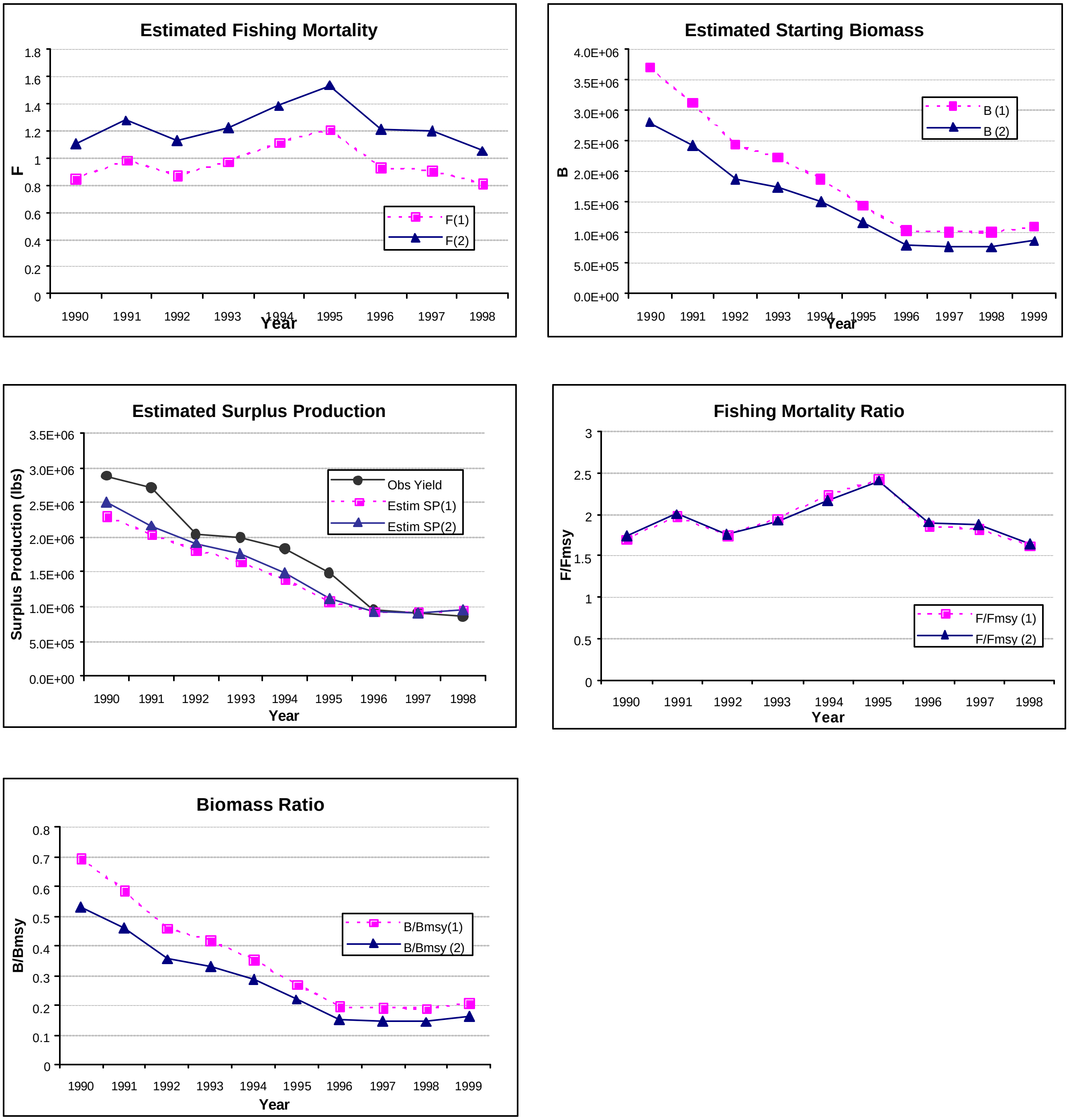
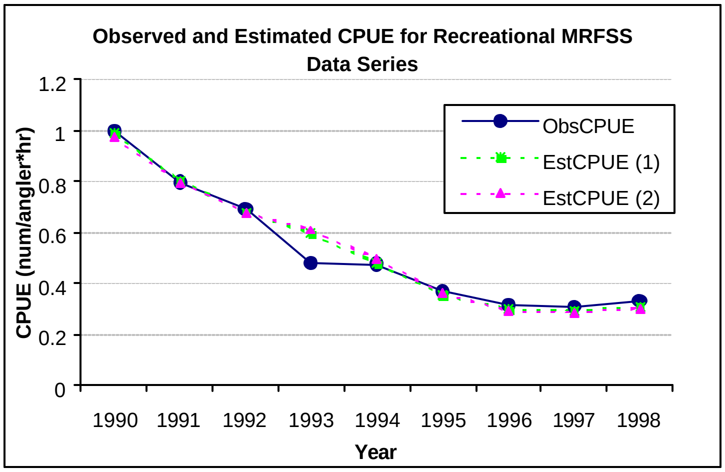
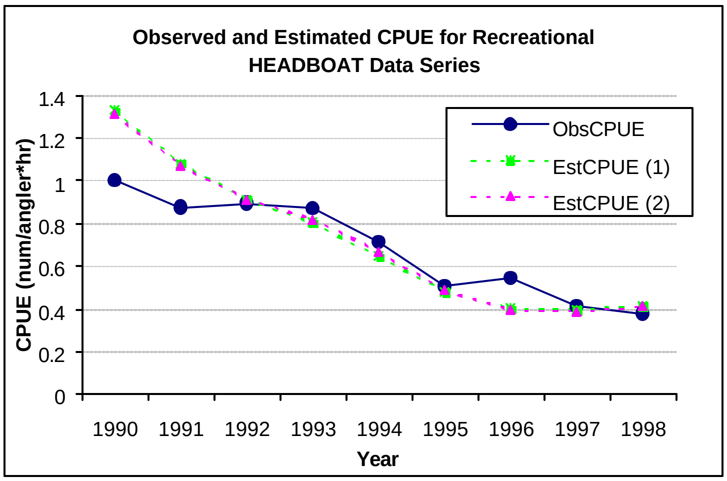


Figure 17. Estimated population trajectories (non-bootstrapped) of two production model analyses (ASPIC) of gray triggerfish in the Gulf of Mexico. In Model (1) r=1.0. The dashed line and squares represent the results from Model (1); the solid line and triangles represent the results from Model (2).





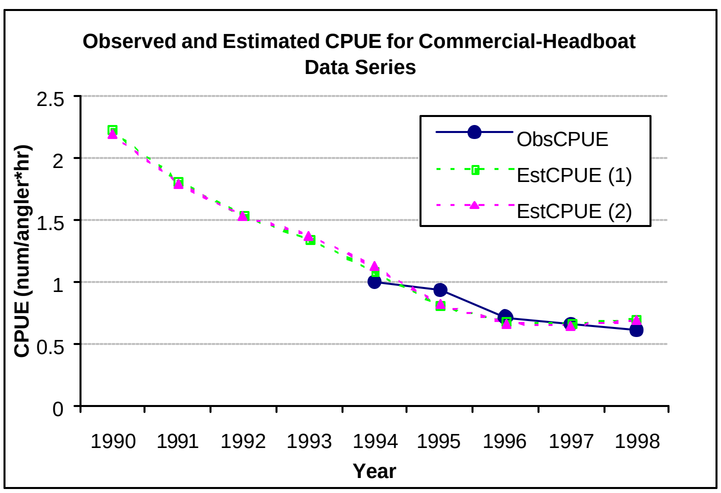


Figure 18. Goodness-of-fit of two production model analyses (ASPIC) by data series (user group). In Model (1) *r* was held fixed at *r*=1.0. In Model (2) all parameters were estimated by ASPIC. The solid line represents the observed values and dashed lines represent the estimated values for each model (1 and 2).

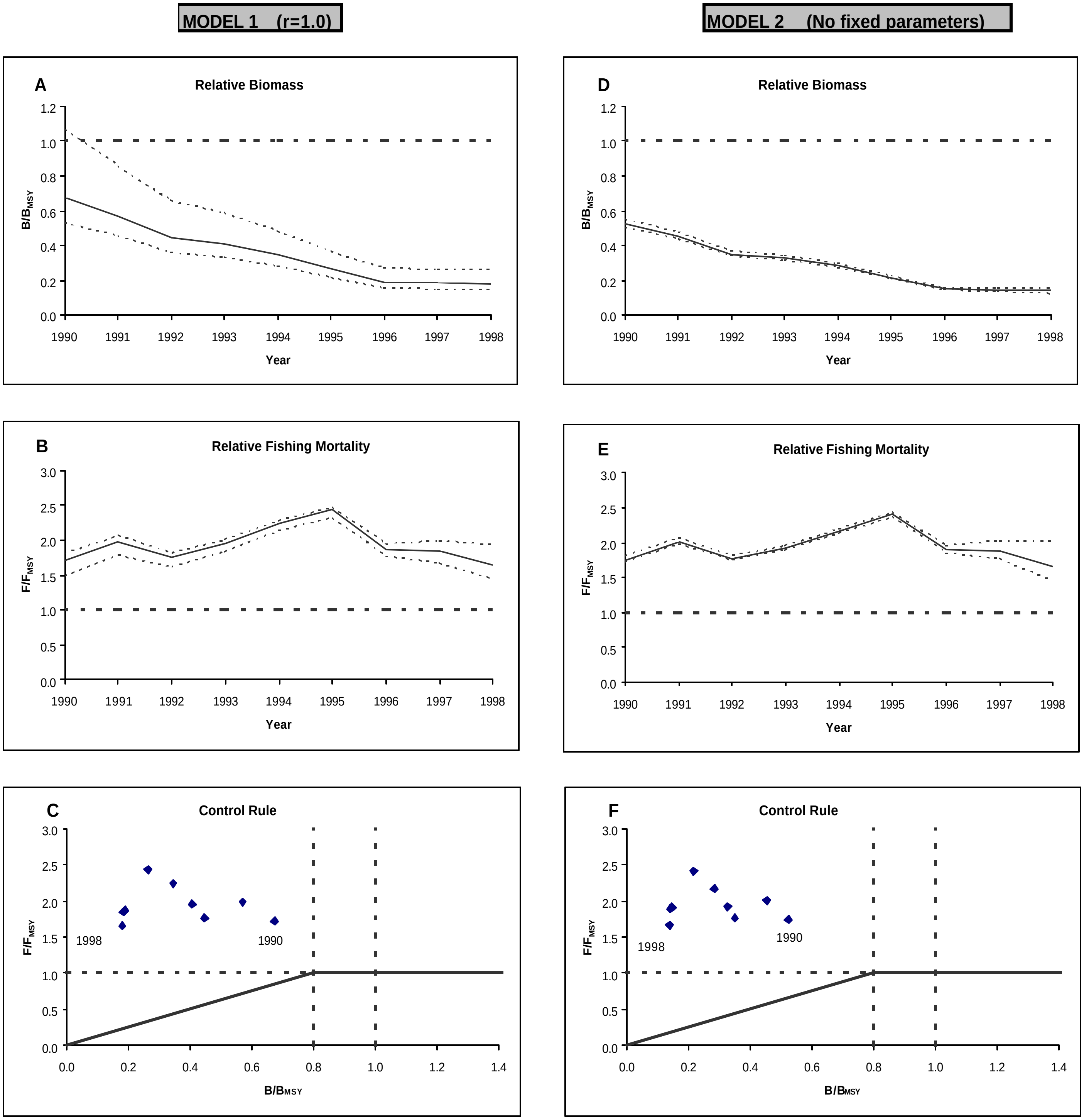


Figure 19. Estimated trajectories of relative biomass and relative fishing mortality, and control rule plots from two production model (ASPIC) runs. Panels (A), (B), and (C) correspond to Model 1 (constant *r*=1.0) and panels (D), (E), and (F) to Model 2 (no fixed parameters).

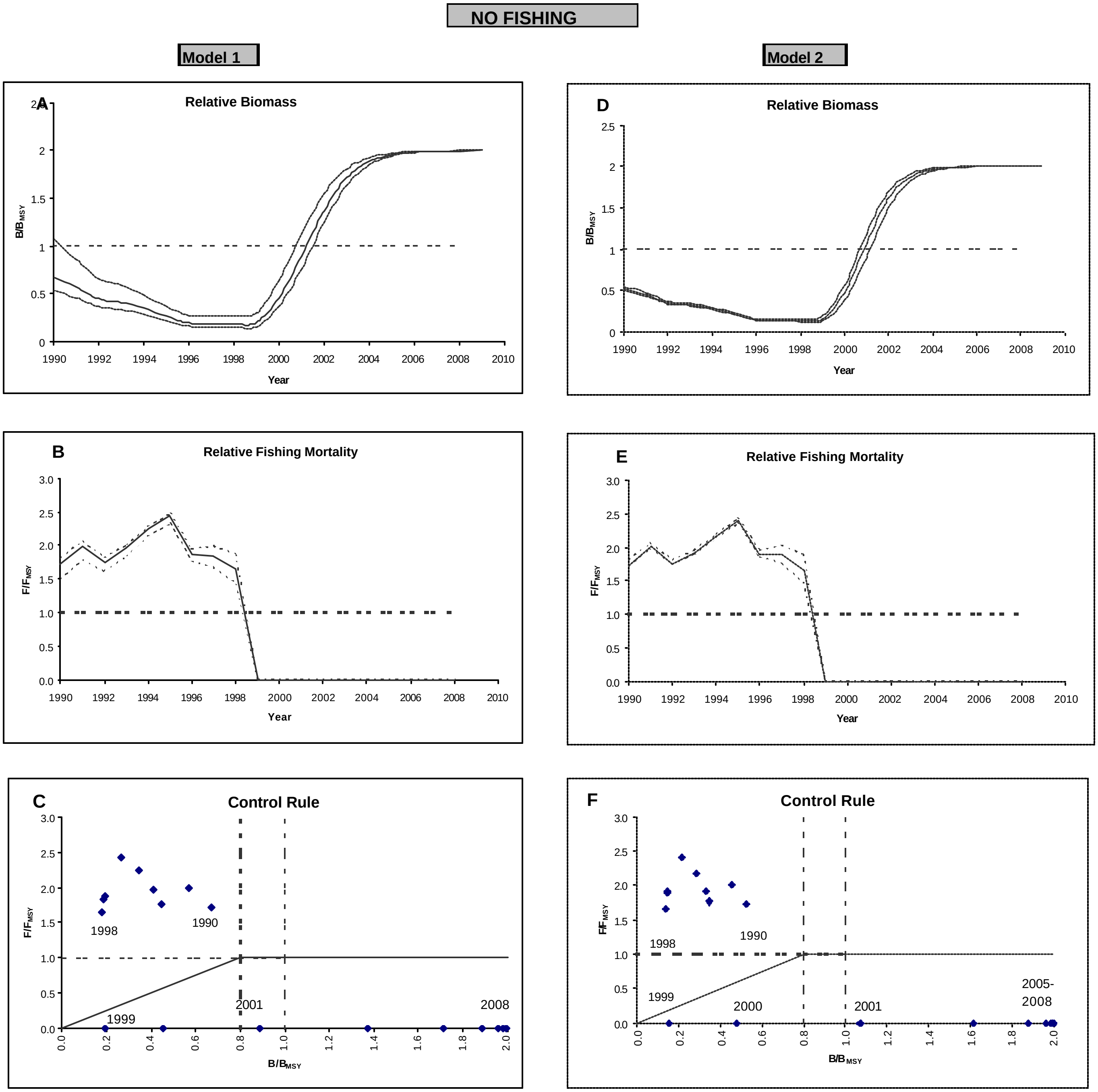


Figure 20. Projected trajectories of B/B_{MSY}, F/F_{MSY}, and control rule plots under a no fishing scenario. Panels (A), (B), and (C) correspond to ASPIC Model 1 (constant r=1.0) and panels (D), (E), and (F) to Model 2 (no fixed parameters).

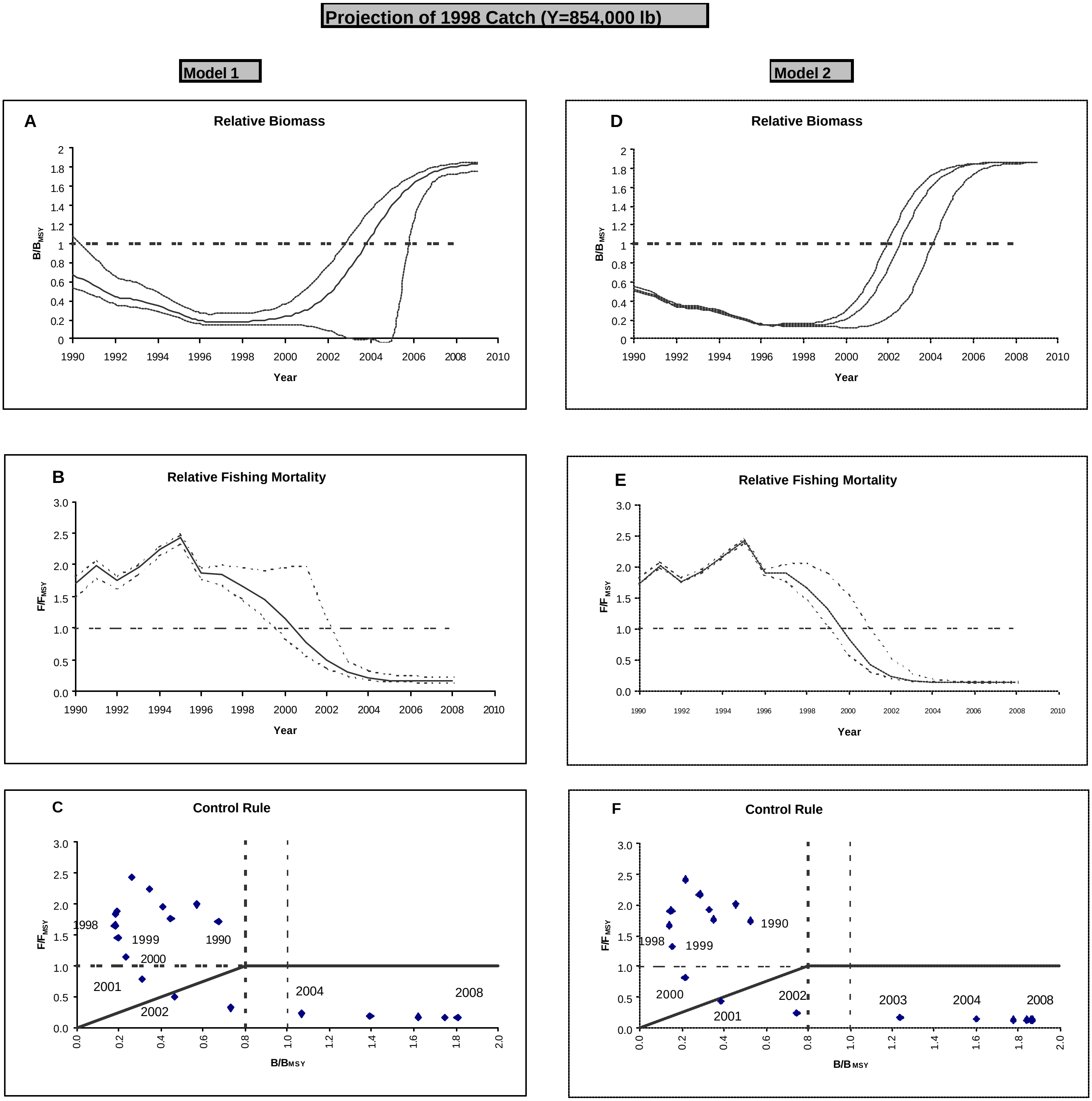


Figure 21. Projected trajectories of B/B$_{MSY}$, F/F$_{MSY}$, and control rule plots assuming a constant (current) catch scenario. The 1998 catch value (854,000 pounds) is repeated for ten years. Panels (A), (B), and (C) correspond to ASPIC Model 1 and panels (D), (E), and (F) to Model 2.

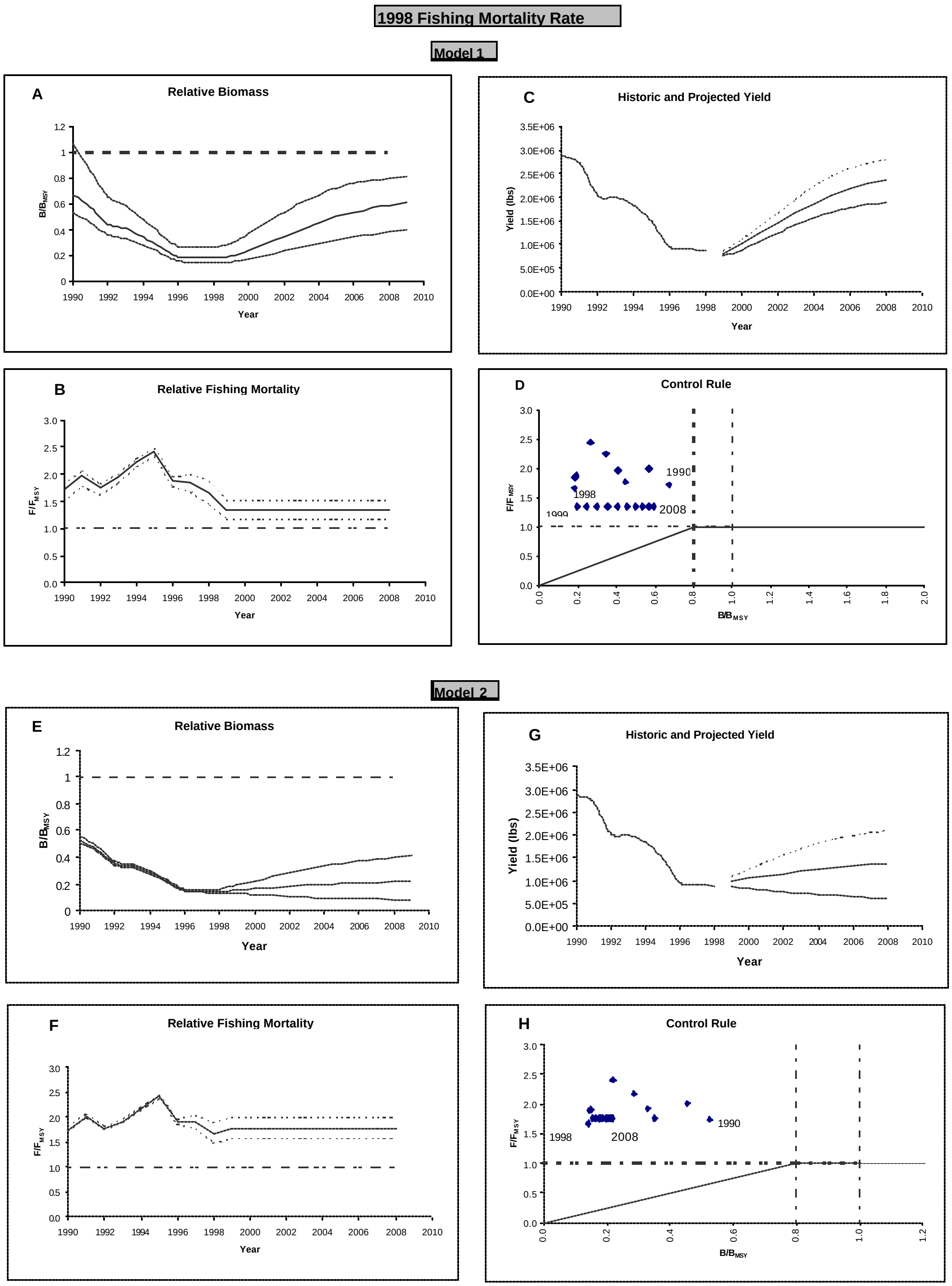


Figure 22. Projected trajectories of B/B_{MSY}, F/F_{MSY}, yield, and control rule plots assuming status quo fishing mortality. The 1998 F value (F=0.81 in Model 1, F=1.052 in Model 2) is repeated for ten years. Panels (A), (B), (C), and (D) correspond to ASPIC Model 1and panels (E), (F), (G), and (H) to Model 2.

Appendix A. Bayesian Surplus Production Model using WinBugs.

Due to the high dependence of ASPIC results upon the parameter constraints, an alternative production model was applied to the gray triggerfish data. This alternative model is the Bayesian Surplus Production (BSP) model of Meyer and Millar (1999) modified to emulate the ASPIC calculations. The modification consisted of adding a variable to account for the ratio of biomass in the first year of the simulation to biomass at maximum sustainable yield. The software used for the Gibbs sampling is WinBugs (freeware available at http://www.mrc-bsu.cam.ac.uk/bugs/winbugs/contents.shtml). The code and data for the BSP is given at the end of this appendix.

When Bayesian models are run with non-informative priors the posterior distributions should approximate bootstrap confidence intervals from equivalent maximum likelihood approaches, as seen in the most recent Georges Bank yellowtail flounder assessment. However, this equivalence holds true only when the data is sufficient to estimate parameters in the model. In the case of gray triggerfish, the data available do not seem sufficient to adequately estimate model parameters with non-informative priors. This is seen both in ASPIC and BSP when no constraints are placed upon the parameters, the estimate of r is near zero and the model interprets the fishery as a “mining” operation. Thus, prior information must be incorporated into the assessment. This was done using ASPIC by fixing parameter values or placing tight constraints on the searched parameter space. In BSP, prior information can quantitatively be incorporated, with the posterior distributions directly reflecting the prior assumptions. This appendix contains three examples of prior assumptions applied to the gray triggerfish data. These three examples do not represent actual prior beliefs but rather are shown to demonstrate the dependence of the posteriors upon the priors. If this approach is chosen to provide management advice for gray triggerfish, then appropriate priors will need to be used in the model.

The three examples change only the prior assumption on the r parameter of the BSP from non-informative to highly informative. The other prior distributions are all non-informative. The prior distribution for r is a uniform distribution in all three cases: U(0.01,1.99), U(0.5,1.5) and U(0.9,1,1). Summary statistics for the posteriors of r, K and MSY related parameters for the three examples are given in Table A1 and the phase plots for the three examples are given in Figure A1. As expected, r and K are highly negatively correlated over the three examples and MSY increases with increasing r. Not as expected is the high degree of skewness in the r posterior distributions (Figure A2) in all three cases. This skewness, even with tight priors, means that the lower bound for r has more influence on the posterior than the upper bound. Thus, if true priors for r are to be created, more attention should be paid to the lower bound than the upper bound.

Reference

Meyer, R. and R.B. Millar. 1999. BUGS in Bayesian stock assessments. Can. J. Fish. Aquat. Sci. 56: 1078-1086.

Table A1. Summary of posterior distributions under three different priors for r based on 2 chains of 50,000 samples after a 1000 sample burn in.

	node	mean	sd	MC error	10%	median	90%
r ~ U(0.01,1.99)							
	r	0.1455	0.1374	0.005594	0.02811	0.1105	0.2883
	K	24.97	9.977	0.4106	14.3	22.28	40.93
	MSY	0.8148	0.7069	0.03028	0.1775	0.6175	1.713
	BMSY	12.48	4.989	0.2053	7.149	11.14	20.47
	FMSY	0.07276	0.06872	0.002797	0.01405	0.05526	0.1442
r ~ U(0.5,1.5)							
	r	0.6354	0.146	0.005476	0.5129	0.5874	0.817
	K	17.75	9.693	0.4454	9.585	14.14	33.18
	MSY	2.83	1.84	0.08574	1.429	2.227	5.104
	BMSY	8.875	4.846	0.2227	4.793	7.07	16.59
	FMSY	0.3177	0.07299	0.002738	0.2565	0.2937	0.4085
r ~ U(0.9,1.1)							
	r	0.9804	0.0556	0.000861	0.9121	0.9718	1.065
	K	16.53	9.681	0.4472	8.06	12.94	31.81
	MSY	4.048	2.374	0.1098	1.976	3.169	7.789
	BMSY	8.266	4.841	0.2236	4.03	6.472	15.91
	FMSY	0.4902	0.0278	0.000431	0.456	0.4859	0.5325

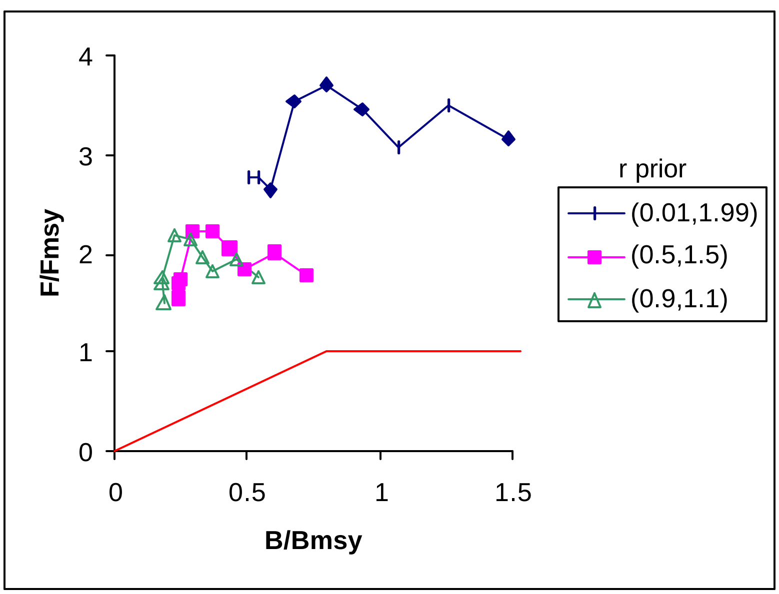


Figure A1. Phase plot from Bayesian surplus production model under three different priors for r.

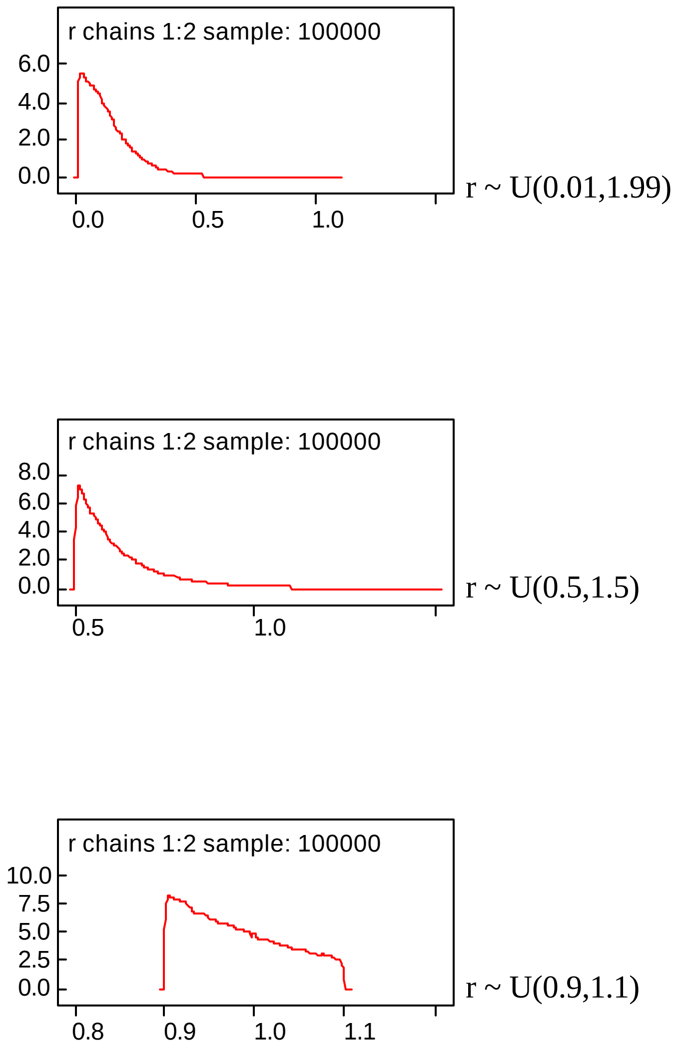


Figure A2. Posterior distributions for parameter r in the Bayesian surplus production model under different priors (denoted to the right of each posterior distribution).

WinBugs Code

```
# Bayesian Surplus Production Model (Meyer and Millar 1999 CJFAS 56:1078-1086)
# note units are millions of pounds
# modified to include B1ratio as a parameter to emulate ASPIC

model bspb1ratio
{
# Prior distributions
K ~ dunif(1.0,50.0)
r ~ dunif(lowerbound,upperbound)
iqMRFSS ~ dgamma(0.001,0.001)I(0.1,1000)
qMRFSS <- 1/iqMRFSS
iqHB ~ dgamma(0.001,0.001)I(0.1,1000)
qHB <- 1/iqHB
iqCOMM ~ dgamma(0.001,0.001)I(0.1,1000)
qCOMM <- 1/iqCOMM
isigma2 ~ dgamma(4.0,0.01)
sigma2 <- 1/isigma2
itau2MRFSS ~ dgamma(2.0,0.1)
tau2MRFSS <- 1/itau2MRFSS
itau2HB ~ dgamma(2.0,0.1)
tau2HB <- 1/itau2HB
itau2COMM ~ dgamma(2.0,0.1)
tau2COMM <- 1/itau2COMM
B1ratio ~ dunif(0.1,3)

# compute B as proportions of K each year
Pmean[1] <- log(B1ratio/2.0)
P[1] ~ dlnorm(Pmean[1],isigma2)I(0.001,3)
for (i in 2:9){
        Pmean[i] <- log(max(P[i-1]+r*P[i-1]*(1-P[i-1])-C[i-1]/K,0.0001))
        P[i] ~ dlnorm(Pmean[i],isigma2)I(0.0001,3)
        }

# indices
# MRFSS
for (i in 1:9){
        ImeanMRFSS[i] <- log(qMRFSS*K*P[i])
        IMRFSS[i] ~ dlnorm(ImeanMRFSS[i],itau2MRFSS)
        residMRFSS[i] <- IMRFSS[i]-qMRFSS*K*P[i]
        }
# Headboat
for (i in 1:9){
        ImeanHB[i] <- log(qHB*K*P[i])
        IHB[i] ~ dlnorm(ImeanHB[i],itau2HB)
        residHB[i] <- IHB[i]-qHB*K*P[i]
        }
# Commercial (note offset to start in year 5)
for (i in 1:5){
        ImeanCOMM[i] <- log(qCOMM*K*P[i+4])
        ICOMM[i] ~ dlnorm(ImeanCOMM[i],itau2COMM)
        residCOMM[i] <- ICOMM[i]-qCOMM*K*P[i+4]
        }

# management parameters
MSY <- r*K/4
FMSY <- r/2
BMSY <- K/2
```

```
for (i in 1:9){
        B[i] <- P[i]*K
        F[i] <- C[i]/B[i]
        Fratio[i] <- F[i]/FMSY
        Bratio[i] <- B[i]/BMSY
        }
}
# end model
```

Inits 1

```
list(
P=c(0.5,0.5,0.5,0.5,0.5,0.5,0.5,0.5,0.5),
r=1.0,
K=2.0,
iqMRFSS=10,iqHB=10,iqCOMM=10,
isigma2=100,
itau2MRFSS=100,itau2HB=100,itau2COMM=100,B1ratio=0.5)
```

Inits 2

```
list(
P=c(1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0,1.0),
r=1.0,
K=2.0,
iqMRFSS=10,iqHB=10,iqCOMM=10,
isigma2=100,
itau2MRFSS=100,itau2HB=100,itau2COMM=100,B1ratio=1)
```

Data

```
list(
C=c(2.879967,2.716294,2.034239,1.993541,1.834610,1.479484,0.951435,0.918420,0.854017),
IMRFSS=c(1,0.798686323,0.692725293,0.481591119,0.476903019,0.369144684,0.315112402,0.30990834,0.333967974),
IHB=c(1,0.876718967,0.89668334,0.869380228,0.716404616,0.507410188,0.546172301,0.413510912,0.379198522),
ICOMM=c(1,0.928154184,0.711026109,0.657762002,0.610113529),
lowerbound=0.9,upperbound=1.1)
```