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EVALUATING MANAGEMENT ACTIONS FOR SPOTTED SEATROUT, *CYNOSCION NEBULOSUS*, IN MISSISSIPPI WITH AN AGE-STRUCTURED PROJECTION MODEL

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ABSTRACT: Spotted seatrout, *Cynoscion nebulosus*, is an important recreational fishery in the coastal waters of the Gulf of Mexico and is the most sought after gamefish in coastal Mississippi. The management of *C. nebulosus* is state-specific, and unlike other similarly managed species, data on both population structure and movement support the existence of local sub-stocks. It is important for each state to clearly examine its own sub-stock in the context of its own state fishery in order to properly manage for local sustainability. We used an age-structured assessment model to examine the status (1993–2005) of the Mississippi *C. nebulosus* population and to project forward several probable management actions (i.e., length limits) while also accounting for uncertainty in both fishing mortality and annual recruitment. Model results suggest annual fishing mortality for Mississippi *C. nebulosus* is close to F_{msy} , but that spawning stock biomass (SSB) is not below SSB_{msy} . This suggests the sub-stock is currently stable, but with high fishing pressure and a high dependence on annual recruitment to the fishery. Projections suggest that when uncertainty in angler effort and annual recruitment are included in the analysis, more conservative management actions are warranted in order to achieve both higher fishery yield and stable SSB.

INTRODUCTION

Spotted seatrout, *Cynoscion nebulosus*, is an important recreationally and commercially harvested species in all states bordering the northern Gulf of Mexico (GOM, GSMFC 2001). In particular, the landings of *C. nebulosus* have been increasing in coastal Mississippi state waters since 1995 as spotted seatrout are the dominant target of recreational anglers within the state. While historically the commercial harvest of *C. nebulosus* has been high, recreational landings have represented over 90% of total landings since 1981 (NMFS Fisheries Statistics Section unpublished data). As a result, the recreational management of *C. nebulosus* in Mississippi is a significant issue that receives a lot of public attention.

Although *C. nebulosus* is harvested across the northern GOM coast, there is evidence that there is not a single GOM stock but multiple sub-stocks. *Cynoscion nebulosus* is a non-migratory estuarine-dependent species (Gold and Richardson 1998) that can be found in a variety of coastal habitats, but is generally found in shallow water (< 1 m) associated with rooted vegetation (GSMFC 2001). Data from tagging studies in Mississippi and elsewhere indicate that individual adult fish are highly unlikely to travel more than 15 km both within and between years (Moffett 1961, Baker and Matlock 1993, Hendon et al. 2002). These data support the idea that there are sub-stocks of *C. nebulosus* differentiable at a scale consistent with each GOM state, and it is reasonable to generate both independent stock assessments and management regulations for each GOM state. This is consistent with existing management in that *C. nebulosus* are managed independently within each state as a part of a cooperative agreement between states (GSMFC 2001).

Regulations for the recreational harvest of *C. nebulosus*

vary greatly by GOM state (Table 1). Yet, all five states have adopted a proxy for maximum sustainable yield (MSY) based on the spawning potential ratio (SPR). The SPR measures the reproductive potential of the fished stock in comparison to the reproductive potential of the virgin (i.e., unfished) stock. The SPR proxy can be estimated from age-structured landings data and provides an easily interpretable benchmark against which to determine stock status. Not all states have a target SPR value but all 5 states report the SPR for their state as part of their respective stock assessment.

The recreational fishery for *C. nebulosus* in Mississippi is particularly important in comparison to other state-managed fisheries. An analysis of angler interview data for Mississippi indicates that *C. nebulosus* is the dominant target species among anglers in Mississippi (National Marine Fisheries

TABLE 1. Current fishery regulations for *Cynoscion nebulosus* by Gulf of Mexico (GOM) state. SPR—spawning potential ratio.

State	Minimum size limit (in)	Daily Bag limit	Target SPR
Florida	15-20*	5	35%
Alabama	14	10	30%
Mississippi	13	15	n/a
Louisiana	12	25	18%
Texas	15-25**	10	30%

*FL allows 1 fish/day > 20" TL

** TX allows 1 fish/day > 25"

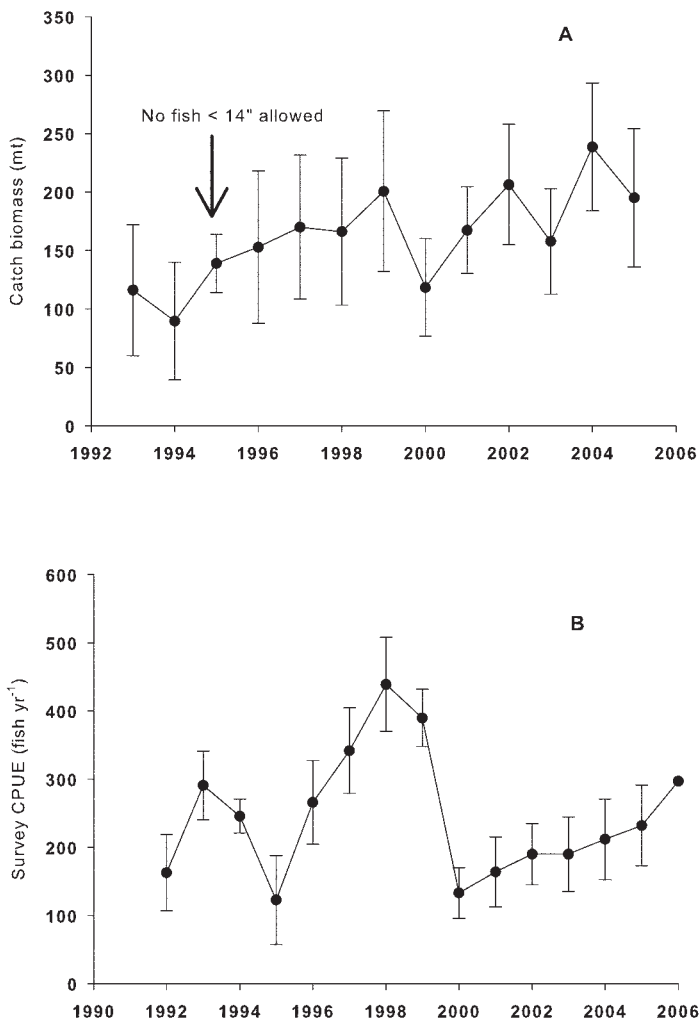


Figure 1. Time series of catch for *Cynoscion nebulosus* in Mississippi. A. Female recreational catch. B. Index catch per unit effort (CPUE) from fishery-independent data. Arrow in upper panel indicates only major regulatory change between 1993 and 2005. Error bars are ± 1 se.

Service Fisheries (NMFS) Statistics Division, pers. comm., Mississippi Department of Marine Resources (MS-DMR, unpublished data). However, Mississippi has not established formal benchmarks for assessment of stock status and while benchmarks have been established in several other states, these benchmarks, and the associated management regulations, should not be applied to assessment of the Mississippi stock without some examination of the projected effect.

Management of *C. nebulosus* in Mississippi has undergone several changes over the last 30 years, but has been relatively stable between 1995 and 2007. Since initial adoption, recreational management regulations have included both a minimum length limit and a daily quota (i.e., bag limit) for harvest. The daily quota has ranged from 10 to 50 but has been set at 15 since 1996. Minimum length limits have ranged from 12" (305 mm) to 14" (356 mm) total length (TL) but were set at 14" from 1995 to 2006. In 2007 the minimum length limit was reduced to 13" (330 mm) TL.

The recent change in the length limit was initially proposed based on public comments that the 14" length limit resulted in a high level of sub-legal catch and release for near-shore anglers (MS-DMR, unpublished public comments). No formal stock assessment of *C. nebulosus* in Mississippi is available to evaluate this change in the management regulations.

Management regulations for recreational fisheries, like those for commercial fisheries, are primarily focused on maximizing harvest and/or angler satisfaction while also maintaining a stable population (Hilborn and Walters 1992). Achieving this dual objective in a recreational fishery is complicated by highly variable effort, highly variable catch per unit effort (CPUE), and low reporting rates for landings. Common management options include setting a maximum CPUE (i.e., daily quotas) combined with length limits to protect spawning stock biomass (SSB) and maintain a target SPR. The influence of either bag limits or minimum length limits on fishing mortality is greatly affected by variability in the rate of recruitment, as well as changes in angler effort through time. Evaluating the appropriateness of management actions under these circumstances can be difficult and involves much uncertainty regarding the effect on long-term population stability.

Quantitative models offer a powerful tool for both the assessment of fishery stocks and the evaluation of potential management decisions (Hilborn and Walters 1992). In particular, statistical catch at age (SCAA) models allow individual cohorts to be tracked through time as a method for estimating total population mortality rate, recruitment, and SSB. Such models also provide a framework for the evaluation of management actions by projecting fishery yield and SSB based on estimated changes in fishing mortality and future recruitment. This approach has been used to establish future status and compare management actions for Atlantic cod (*Gadus morhua*, Reich and DeAlteris 2009), lake whitefish (*Coregonus clupeaformis*, Mohr et al. 2007), and North sea plaice (*Pleuronectes platessa*, Hoff and Frost 2008).

In the case of *C. nebulosus*, SCAA models provide an approach for exploring the relative influence of the range of management regulations applied across the 5 GOM states on the Mississippi stock. This analysis is not therefore a formal assessment of the stock, but rather an exploration of possible management outcomes with a stock assessment model that we hope is a step towards a formal assessment in the future. In this study we applied an SCAA model to examine the Mississippi population of *C. nebulosus* with 3 objectives: (1) to estimate current stock status of the Mississippi population relative to MSY-based benchmarks, (2) to evaluate the range of minimum length limits currently applied to *C. nebulosus* across the GOM in terms of their relative effect on population sustainability in Mississippi, and (3) to explore the effect of changes in future recruitment and angler effort on population sustainability and how

these factors should affect management decisions. The focus on minimum length limits as the primary management tool was based on current discussions regarding management of *C. nebulosus* in Mississippi and the need to understand the influence of length limits on population stability.

METHODS

Data used for this model assessment of *C. nebulosus* were a combination of fishery independent and fishery dependent data. Recreational landings (1993–2005) of *C. nebulosus* were estimated from creel data collected in Mississippi as a part of the Marine Recreational Fisheries Statistics Survey (MRFSS; NMFS Fisheries Statistics Section unpublished data; Figure 1A). These data included both landings and dead discards as model input. A time series (1993–2005) of fishery independent catch per unit effort (CPUE) was used to constrain the

model and came from a gillnet survey conducted monthly at eight survey sites along the Mississippi Gulf coast (Figure 1B; University of Southern Mississippi – Center for Fisheries Research and Development (CFRD) unpublished data). While there is a commercial harvest of *C. nebulosus* in Mississippi, these landings are small (about 10% of total landing; NMFS Fisheries Statistics unpublished data) and are not affected by recreational management actions. Commercial harvest is almost entirely hook and line with a 14" length limit and a 40,000 lb annual quota since 1986 (MS-DMR, unpublished data). Commercial harvest was included in the model as a separate but constant fishing mortality term.

Length frequency of the catch as reported by MRFSS was converted to age frequency for females only based on estimates of sex ratio at length (Figure 2A) and year-specific age-length keys (ALK) that were both based on *C. nebulosus* collected, sexed, and aged by the University of Southern Mississippi CFRD ($n = 3,524$, mean = 244/yr). Model input also included estimates of percent maturity at age for spotted seatrout in Mississippi (Brown-Peterson and Warren 2001, Brown-Peterson et al. 2002). Growth rates of female spotted seatrout in Mississippi were also estimated from size-at-age and biomass-at-age data collected independent of the fishery (Figure 2B, C; 1993–2006, CFRD unpublished data). Natural mortality of spotted seatrout in Mississippi was estimated to be 0.3 for all model simulations based on an analysis of longevity and growth parameters used in previous assessments (GSMFC 2001).

Model description

The model assessment was conducted using a SCAA Model (ASAP2; NMFS NEFSC Fisheries Toolbox <http://nft.nefsc.noaa.gov/>). The ASAP2 model is a non-linear optimization model that estimates average fishing mortality and spawning stock biomass by age class based on minimization of an objective function that describes model fit to fishery landings, index CPUE, as well as fishery and index age compositions. Nine age classes were included in model simulations (age 0–8) with no plus group. The model fit was constrained both by estimates of variability for each data input source (Table 2) and a Beverton-Holt stock-recruitment function with an initial steepness of 0.6 (Haddon 2001). The initial steepness value was chosen to be neutral, however final steepness was fully estimated by the model and was not strongly influenced by the initial value. Error structure for both fishery landings and index CPUE were assumed to be lognormally distributed while error structure for the age compositions had a multinomial distribution. Effective sample size for the multinomial distribution was set at 200 for all years based on mean annual coverage of the age data used to build the ALK. The ASAP2 model has been used to conduct formal stock assessments of several fish stocks including red grouper, *Epinephelus morio*, and yellow tail flounder, *Pleuronectes ferrugineus*, (Schirripa et al. 1999, Legault et

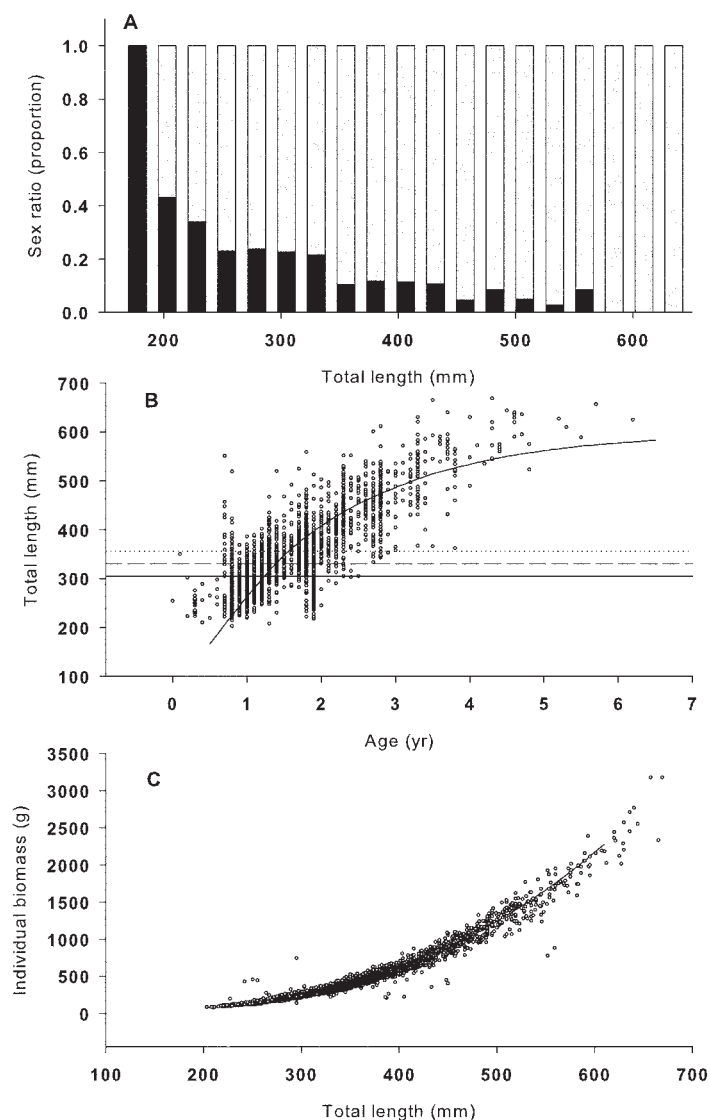


Figure 2. Metrics for *Cynoscion nebulosus* in Mississippi. A. Sex ratio. Black bars are males and grey bars females. B. Total length at age for females. Reference lines indicate cutoff for 12" (—), 13" (---), and 14" (···) length limits. C. Biomass at total length for females. Points in panels B and C are individual fish ($n = 3,524$).

TABLE 2. Input parameters for the age-structured model. Initial value is the value input to the model which remained constant if Fixed (F), but could change during the optimization if Estimated (E). Selectivity values for length limits of 12 and 13" were only used to perform model projections.

Parameter	Initial value	F/E	Final value	Model component
Natural mortality	0.3	F	0.3	Estimate non-fishing mortality
Steepness	0.6	E	0.8	Stock-recruitment curve
CV of rec. catch	0.2	F	0.2	Weight on model fit
CV of comm. catch	0.1	F	0.1	Weight on model fit
CV of recruitment	0.5	F	0.5	Weight on model fit
CV of Index catch	0.2	F	0.2	Weight on model fit
Selectivity age-0 12"	0.1	F	0.1	Age-specific component of directed fishing mortality used in projection
Selectivity age-1 12"	1	F	1	Age-specific component of directed fishing mortality used in projection
Selectivity age ≥ 2 12"	1	F	1	Age-specific component of directed fishing mortality used in projection
Selectivity age-0 13"	0.05	F	0.05	Age-specific component of directed fishing mortality used in projection
Selectivity age-1 13"	0.8	F	0.8	Age-specific component of directed fishing mortality used in projection
Selectivity age ≥ 2 13"	1	F	1	Age-specific component of directed fishing mortality used in projection
Selectivity age-0 14"	0.03	*E/F	0.03	Age-specific component of directed fishing mortality used in projection
Selectivity age-1 14"	0.6	*E/F	0.54	Age-specific component of directed fishing mortality used in projection
Selectivity age ≥ 2 14"	1	*E/F	1	Age-specific component of directed fishing mortality used in projection
Unexploited stock size	455,000	E	492,000	Virgin stock size used to estimate benchmark SPR
Index selectivity (all ages)	1	E	0.2 (age-0) 0.8 (age-1) 1 (age-2+)	Age-specific catchability of gillnet survey

*Selectivity values for 14" limit were used for initial optimization and were estimated. These values were then fixed for the projection.

al. 2006). The ASAP2 model was used (1) to estimate stock status (1993–2005) of *C. nebulosus* including estimates of SSB and age-specific fishing mortality rate (F_a), (2) to estimate uncertainty for current stock status, and (3) to conduct projections of relative SSB and female fishery yield for a range of management scenarios (See Model projections section). The model input data were for females only because of our emphasis on the influence of management on reproductive capacity and population stability. The influence of management on relative fishery yield is presented as a tool for discussing the tradeoffs between population stability and harvest but is not a measure of total fishery yield as about 14% of the total harvest is estimated to be male (Figure 2A).

Reference benchmarks for the fishery were selected based on common benchmarks used for stock assessments of *C. nebulosus* in other states (GSMFC 2001). No benchmarks have been established for *C. nebulosus* in Mississippi, however several other states have chosen reference points based on SPR (Table 1). For this assessment we report MSY, Fishing mortality rate at MSY (F_{msy}), SSB_{msy} , and Fishing mortality rate at an SPR of 30% ($F_{30\%}$). Fishery reference points are addressed in more detail in the Discussion.

Uncertainty estimates for model output including fishery benchmarks were based on a Markov Chain Monte Carlo

(MCMC) simulation involving 200 model runs selected from 200,000 overall runs with an initial burn in of 1,000 runs. Each run is a repeat of the base model with randomly selected values for each input parameter from the appropriate distribution with the best fit parameter value as the mean. The MCMC approach is a well-established method for estimating uncertainty in model estimates based on variability in model parameters (Haddon 2001). All parameters were assigned a lognormal error structure with the exception of catch at age data which were assigned a multinomial error structure. In addition a retrospective analysis was conducted that involved a series of model simulations with the final year reduced by 1 to identify any retrospective patterns in the data time series.

Model projections

The baseline results of the SCAA model were projected forward for a period of 12 yr (2003–2015) based on a range of both management actions and biological conditions. This projection period was chosen to allow for an initial transition period (~5 yr) to a stable outcome. Projections were conducted at three length limit restrictions 12", 13" and 14" and 4 projected fishing mortality rates ($F_{current}$, 125% of $F_{current}$, 150% of $F_{current}$, and $F_{30\%}$). Length limits were simulated with shifts in the age-specific selectivity of the fishery in the model (Table 2). Selectivity changes were based on the

probability of a legal sized fish being in a particular age class, which was estimated using a cumulative ALK (1993–2005; CFRD unpublished data). These age-specific probabilities were also adjusted to account for delayed release mortality of sub-legal fish based on reported numbers of fish released alive (NMFS Fisheries Statistics Section unpublished data) and an estimated 72 h mortality rate of 10% based on an observational study ($n = 478$ fish; R. Hendon, unpublished data). All other components of the base model run remained consistent with the optimized results given in Table 2. In addition, these projections were repeated with one of 2 recruitment patterns. Either annual recruitment of age-0 fish was allowed to shift according to the model-estimated stock recruitment curve or age-0 recruitment was held constant at an average value for the last 5 yr of the dataset (2000–2005). The constant recruitment option assumes that recruitment may have reached a biological maximum (e.g., habitat limitation). The output from these projections is a time series for SSB and fishery yield over the proceeding 5 yr based on management and biological conditions. Output from model projections was relative change in SSB and female yield expressed as the proportion of either SSB or yield in 2006 under current conditions for length limits and fishing

mortality. Differences between the model projections were based either on differences in linear slope analyzed with an ANCOVA or differences in terminal year value with an ANOVA.

RESULTS

The SCAA model provided a good fit to the overall objective function with most of the error contained in the fit to fishery age composition (71%). This was expected as the age composition of the catch was dominated by age-1 and age-2 fish leaving little latitude for the model fit. Most of the lack of fit occurred as an overestimation of age-1 fish and underestimation of age-2 fish in the catch, but the total deviance was small (Figure 3). The stock recruitment function provided a meaningful constraint on the abundance of age-0 fish each year with a final steepness value of 0.8.

The MCMC and retrospective analyses indicated a low level of variability about the predictions of average F (across age classes) and SSB with a generally increasing pattern in uncertainty towards the final year in the assessment (Figure 4). In addition, the retrospective analysis suggested retrospective pattern in the model fit was present with strongest influence in the final 2 yr of the assessment with CV in-

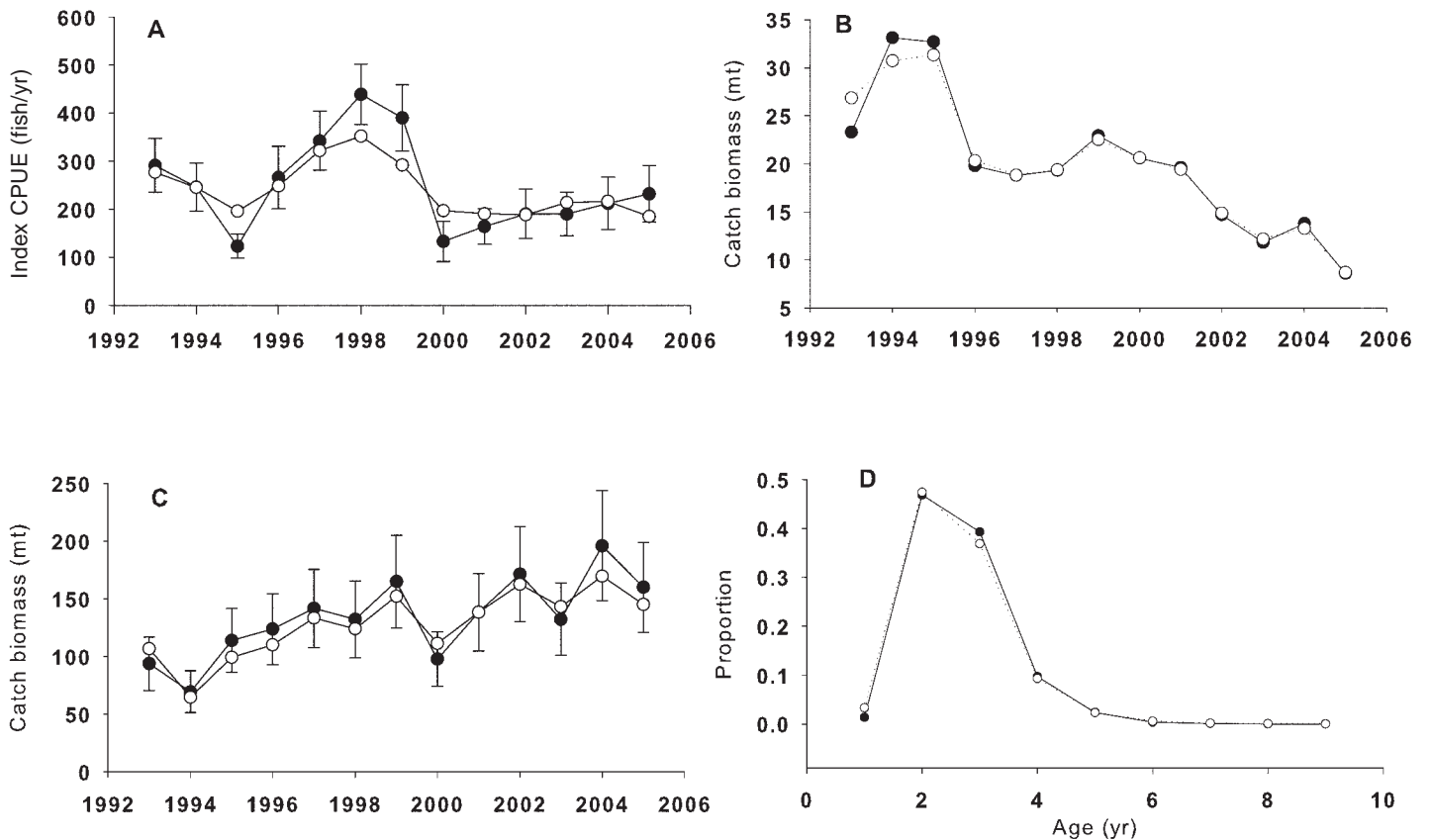


Figure 3. SCAA model fit. A. Index CPUE. B. Total commercial catch biomass. C. Total recreation catch biomass. D. Age composition of the recreational catch pooled across years. Closed symbol indicates observed data and open symbol indicates prediction of the age-structured model. Error bars are ± 1 se.

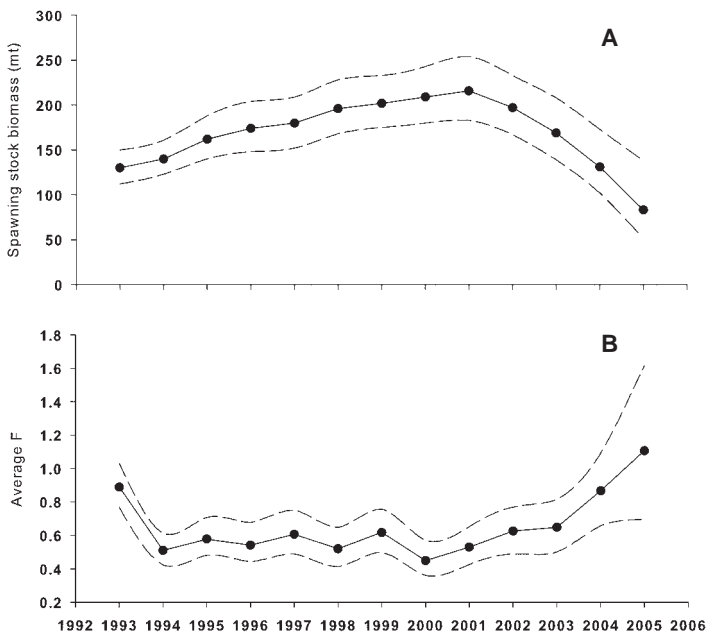


Figure 4. Time series of model simulations based on a Monte Carlo analysis. A. Median spawning stock biomass (SSB). B. Average fishing mortality rate (F). Solid line—Monte Carlo analysis, dashed error lines—5th and 95th percentiles.

creasing to > 1, so projections were initiated in 2003 and run for an additional 2 yr (i.e., final projection year 2015) to minimize the effects of retrospective pattern on the projections. Overall variability in model estimates (model CV 16%, 1993–2005) was used to analyze projection results.

Spawning stock biomass in 2003 was estimated in the model to be 169 mt (95% CL 75–426 mt) and the probability that SSB_{2003} exceeded SSB_{msy} was estimated to be 71% (Figure 5A). The model estimated an increasing trend in SSB between 1993 and 2001 and then a decreasing trend until 2003 (Figure 4A). The net change in SSB between 1993 and 2003 (39 mt) was estimated to be greater than the uncertainty of model output (95% CI \pm 23 mt), suggesting a significant increase over this period.

Fishing mortality rate in 2003 was estimated to be 0.65 (95% CL 0.50–0.82). The probability that current F exceeds F_{msy} is about 17% (Figure 5B). The trend in average fishing mortality was positive over the entire time series (Figure 4B), however the trend is flat from 1994 to 2000 after which F began to rise more rapidly suggesting most of the increase in fishing mortality has occurred in recent years.

Forward projections of the model indicated that changes in the trend in relative female yield for the recreational fishery changed as a function of length limits, but the magnitude and direction of change is dependent on the level of fishing mortality and the projected recruitment rate (Figure 6). Using the model stock recruitment function and F at or above $F_{current}$, relative female yield was at or above 1 in 2006 at all size limits (Figure 6A, C, E). Relative female yield increased initially at all size limits for $F_{current}$ and 125% of $F_{current}$, but then began to decrease after 2008 with

the most rapid decrease for the 12” size limit. The slope of relative yield at 12” was significantly different (ANCOVA; $p < 0.008$) than either 13 or 14” at $F_{current}$ and at 125% of $F_{current}$. The slopes were all negative at 150% of $F_{current}$, but were not significantly different ($p = 0.074$). At $F_{30\%}$ relative female yield increased monotonically to over 200% of the yield in 2006 with no significant difference in slope between length limits (ANCOVA; $p = 0.3$; Figure 6G).

The influence of length limits and fishing mortality rate on relative yield were reduced if recruitment of age-0 fish was capped at the 5 yr average (Figure 6B, D, F, H). Relative yield declined initially for all F at or above $F_{current}$, but the slope increased to near zero by 2010. For $F_{30\%}$ the trend was initially positive and then flat after 2008 for the rest of the projection period (Figure 6H). However, no significant differences in slope were detected ($p > 0.1$) among length limits at any value of F. The stable value for relative yield after 2010 was not significantly different among levels of F (ANOVA; $p > 0.1$) or among length limits (ANOVA; $p > 0.1$). This recruitment driven stable point for the projection was 60–70% of the estimated female yield in 2005.

Spawning stock biomass was also projected to be influenced by length limit, recruitment pattern, and fishing mortality rate (Figure 7). If a stock recruitment function was used in the projection with $F = F_{current}$, SSB was predicted to increase by 66% by 2015 with a length limit of 14”, but decline by 23% and 53% at 13” and 12” respectively (Figure 7A). If F was set at either 125% or 150% of $F_{current}$, then the trend in SSB had a negative slope for all length limits with SSB declining by 60–80% at 125% of $F_{current}$ and 80–95% at 150% (Figure 7C, E). The slope for 12” was significantly lower at 125% of $F_{current}$ (ANCOVA, $p = 0.004$) than the slope at either 13” or 14”. No significant difference in slope was detected at 150% of $F_{current}$ ($p = 0.64$). For $F_{30\%}$ the projected trend in SSB had a strongly positive slope for all three length limits with the slope at 12” significantly lower ($p < 0.001$) than at either 13” or 14” (Figure 7G).

Model projections of SSB changed somewhat when recruitment of age-0 fish was capped at the 5 yr average (Figure 7B, D, F, H). Projected SSB between 2003 and 2015 declined initially for all length limits and all F at or above $F_{current}$. The

TABLE 3. Model generated reference benchmarks for the *C. nebulosus* recreational fishery in Mississippi. Values in parentheses are 95% confidence limits.

Benchmark	Estimated value
$F_{current}$	0.65 (0.50–0.82)
F_{msy}	0.7 (0.63–0.77)
MSY	24.9 mt
SSB_{msy}	120 mt (15–453)
$F_{30\%}$	0.37

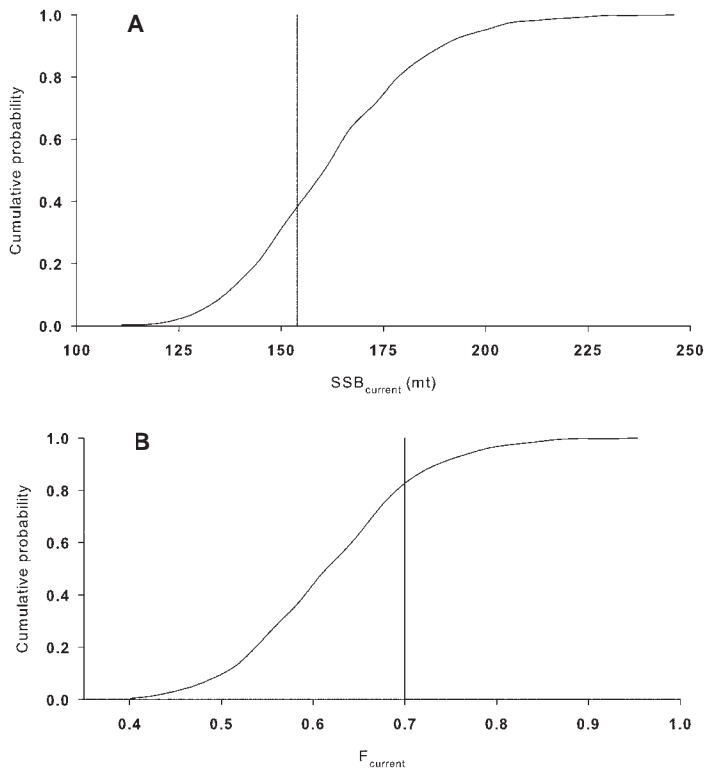


Figure 5. Cumulative density function the model run based on Monte Carlo analysis. A. Spawning stock biomass (SSB). B. average $F_{current}$ for the terminal year. Vertical lines indicate model estimates of SSB_{msy} and F_{msy} respectively.

trend was flat for all length limits at $F_{30\%}$ (Figure 7H). All projections with a fixed recruitment rate stabilized by 2010 and the final year SSB differed by level of F , but only the ending value at $F_{30\%}$ (21% increase from 2003) differed significantly from the other three values of F examined (ANOVA, $p < 0.03$).

DISCUSSION

Projections made with an SCAA model are sensitive to uncertainty in future conditions such as recruitment and fishing effort. In some cases, patterns in future conditions can be well estimated and used to make specific predictions of future stock status (Mohr et al. 2007, Hoff and Frost 2008, Reich and DeAlteris 2009). In the case of *C. nebulosus* in Mississippi, too much uncertainty exists regarding future recruitment and angler behavior to make predictions. Yet, we can project the state of the stock in the future relative to current conditions and in so doing gain some useful insight on the sensitivity of the population to specific actions. There is both process uncertainty and observation uncertainty present in such projections that are difficult to separate and quantify. However, the use of an MCMC approach to estimate overall uncertainty should allow for a combined estimate, which allows for an estimate of the risk of exceeding benchmarks associated with specific management actions, as well as trends in relative stock condition through time.

The results of the model analysis indicate that the influ-

ence of changes in the minimum legal length limit for *C. nebulosus* is dependent on both future recruitment and future changes in angler effort. Yet, certain consistencies did emerge across the range of length limits tested in the model. The largest length limit of 14" produced the highest relative yield in the terminal year and the highest SSB in all but the most conservative level of fishing mortality rate. In contrast, the smallest length limit (12") produced the lowest terminal year relative yield and the lowest projected SSB in all simulations. There was variance in the similarity of projected outcomes for a length limit of 13" and it seems that 13" and 14" differ most as management actions under current conditions and are more similar if fishing mortality is either raised or lowered significantly. Fishing at $F_{30\%}$ always produced the highest yields and the largest increase in SSB across all minimum length limits. In the case of $F_{30\%}$, relative yield may not comprehensively emulate objectives for a recreational fishery, as this increase is driven by the increase in abundance of larger, older fish. The model indicated that stock abundance would increase as well, but not as much as yield.

When recruitment was held constant at the 5 yr average, the projection results always stabilized after about 5 yr and remained constant thereafter. The exact level of stability was dependent on fishing mortality rate, but not on the minimum length limit, which suggests that if current recruitment levels are limiting then a lot of fishery yield is lost as pre-recruit mortality even at lower levels of F . This finding supports the idea that recruitment limitation (e.g., via habitat loss) may be as important as management actions to fishery yield.

Recruitment of *C. nebulosus* in coastal Mississippi has not been comprehensively examined, but research suggests coastal aquatic vegetation is an important limiting component. *Cynoscion nebulosus* has been shown to be highly dependent on rooted macrophytes for nursery habitat (Rozas and Minello 1998, GSMFC 2001), and a study of nursery source habitat in Mississippi Sound indicated that a higher proportion of adults had a chemical signature consistent with a nursery area having a higher than average density of sea grasses (Comyns et al. 2008). Juveniles may also be using emergent macrophytes such as salt marsh as habitat (Chester and Thayer 1990), but studies have found a strong preference for both emergent and submerged rooted macrophytes (GSMFC 2001). Both submerged sea grass and emergent marsh have been in general decline in coastal Mississippi (Moncreiff et al. 1998) and this suggests that nursery habitat may be in decline, which will contribute to limiting future recruitment to the fishable stock.

If nursery habitat might be limiting to recruitment in the future, it becomes more important to establish an SPR benchmark that is adequate to allow for reductions in juvenile survivorship. Only one scenario was tested that involved a theoretical benchmark SPR ($F_{30\%}$) and the result was much higher SSB with a stock-recruitment relationship, but no

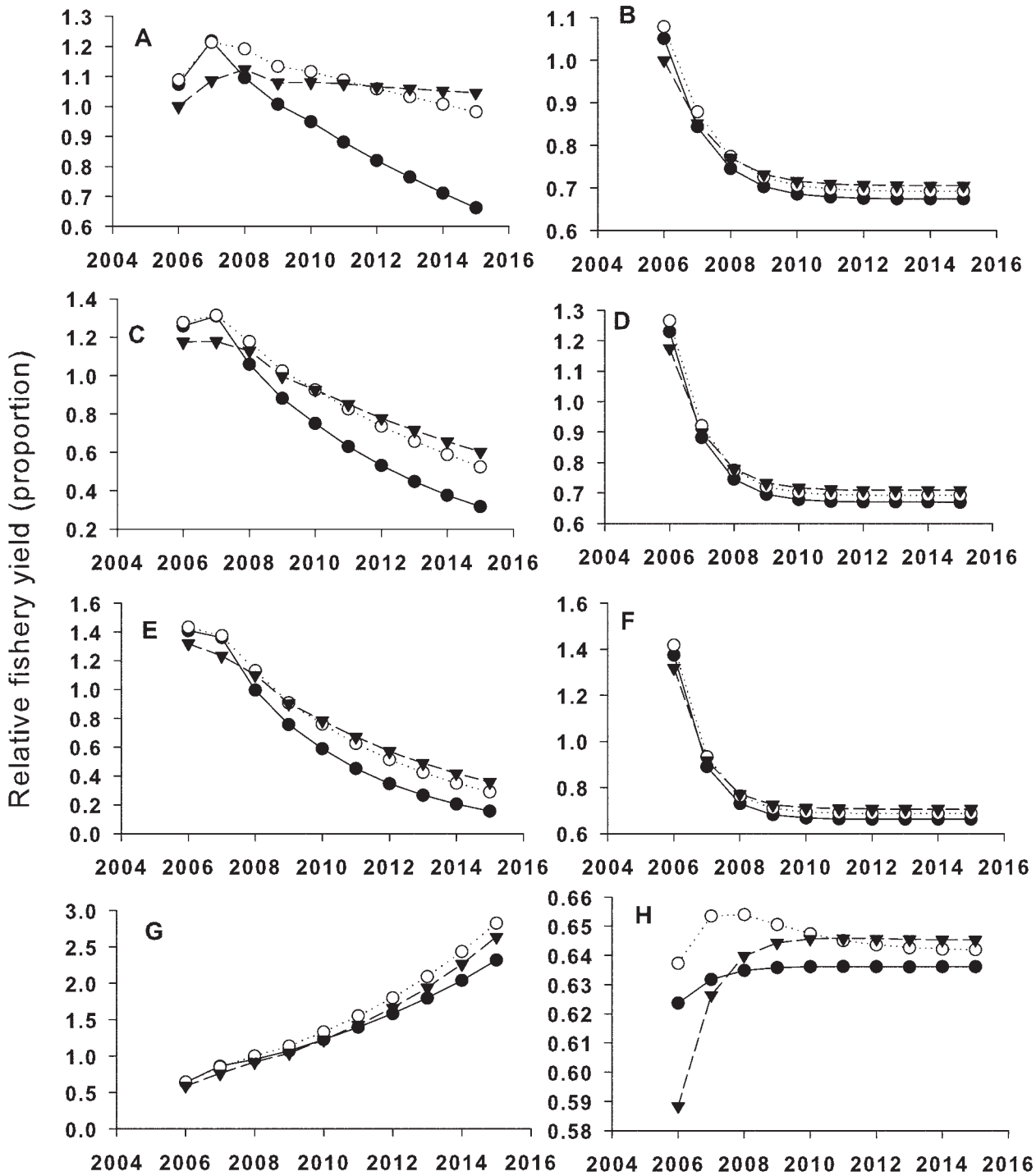


Figure 6. Model-based projections of relative female yield for the *Cynoscion nebulosus* recreational fishery. Relative fishery yield is expressed as proportion of estimated yield in 2006 under current conditions for F and minimum length limits. Panels are for 4 levels of fishing mortality (A, B - $F_{current}$; C, D - $125\% F_{current}$; E, F - $150\% F_{current}$; and G, H - $F_{30\%}$) and either model predicted (left) or constant (right) recruitment. Each panel contains a projection for 3 theoretical length limits: 12" (●), 13" (○), or 14" (▲). See text for details.

real difference if recruitment was capped. This outcome demonstrates that management actions to mediate loss of essential habitat may have limited value once the habitat is lost.

While Mississippi does not have a target SPR, data suggest the current SPR of the Mississippi stock is below the reported target values for other GOM states (Table 1). The

transitional SPR has been independently estimated to be between 6 and 13% from 1993 to 2005 (R. Hendon, unpublished data). The applicability of these benchmark values for the Mississippi stock has not been evaluated and our use of $F_{30\%}$ should not be interpreted as an endorsement of this value for management. Yet, our model projections suggest

that allowing stock SPR to fall further is likely to result in a declining SSB and relative yield, while increasing SPR ultimately will both increase yield and SSB, despite the decline in harvest needed to accomplish this objective. Changes in the minimum length limit should influence stock SPR, as

indicated by changes in projected SSB in the model, but other factors affecting fishing mortality are also important.

Changes in fishing mortality not associated with management regulations are most strongly affected by changes in angler effort. Angler effort in the future is highly uncertain as

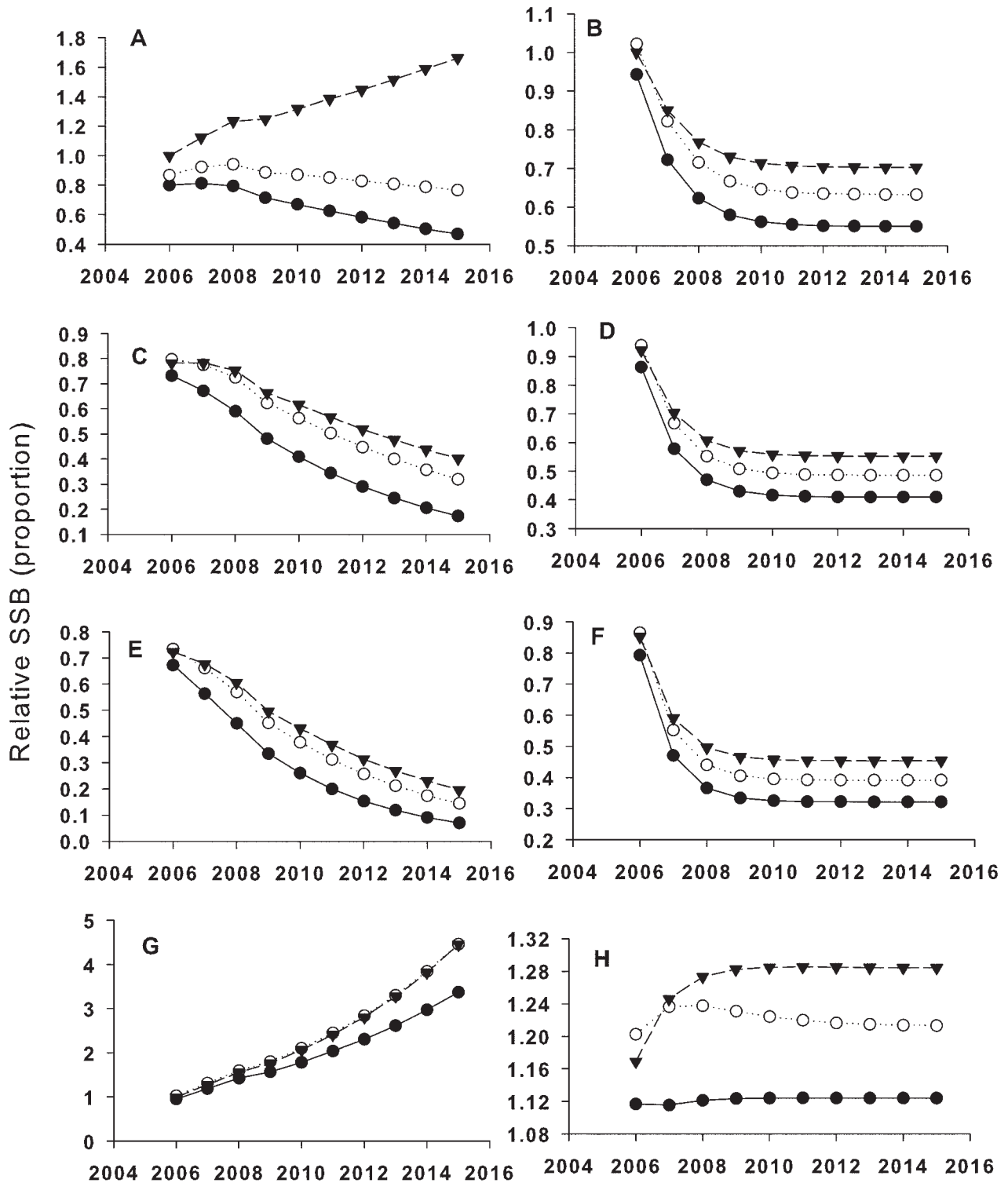


Figure 7. Model-based projections of relative spawning stock biomass (SSB) for *Cynoscion nebulosus*. Relative biomass is expressed as the proportion of SSB estimated in 2006 under current conditions for F and minimum length limits. Panels are for four levels of fishing mortality (A, B - $F_{current}$; C, D - $125\% F_{current}$; E, F - $150\% F_{current}$; and G, H - $F_{30\%}$) and either model predicted (left) or constant (right) recruitment. Each panel contains a projection for three theoretical length limits: 12" (●), 13" (○), or 14" (▲). See text for details.

recreational fishing has been shown to respond to a variety of influences including costs of fishing, individual objectives of fishing (e.g., food vs. trophy fishing), and angler access (GSMFC 2001). In the case of *C. nebulosus* in Mississippi, creel data indicate that angler effort has increased from around 800,000 trips/yr in 1993 to over 1,000,000 trips/yr between 2000 and 2004 (MS-DMR unpublished data). Model results suggest that while fishing mortality has been consistently close to F_{msy} since 1993, recreational catches have been slowly increasing over this time period. Commercial catches have been falling but this is thought to be a result of declining effort. This suggests that both population abundance and angler effort have increased since 1993. The model estimated an increasing trend in F and a decreasing trend in SSB since 2000, which further suggests that population abundance may have reached a peak while angler effort continues to rise. If this is true, any increase in fishing mortality due to changes in the length limit would only increase this trend.

Creel data indicate that a reduction in the legal length limit for *C. nebulosus* may also result in an increase in angler effort in the future. Fish size distribution appears to shift upwards away from shore due to the higher abundance of mature females associated with the barrier islands (GSMFC 2001), so there is a presumed negative relationship between minimum length limits and angler access since shore-bound or small boat anglers have more access to smaller fish. The true response is highly uncertain. In fact there is a high reported catch and release for near shore sub-legal fish when the length limit is 14" (MS-DMR, unpublished data), and a reduction in the size limit may result in a transfer of release mortality into harvest. However, data also suggest release mortality, even after 72 h, is less than 10% (R. Hendon, unpublished data), and while illegal harvest may increase this number, it remains likely that a reduction in the length limit is likely to increase the target value of *C. nebulosus* and result in more angler effort.

The model projections combining lower length limits (12–13") with increased fishing mortality are more likely to be consistent with angler behavior under these assumptions. The current average F for female *C. nebulosus* in Mississippi is very close to F_{msy} . Our analysis suggests that after accounting for uncertainty, population stability is more likely if F remains stable or is reduced. In particular, the recent downward trend in SSB suggests that any further increase in harvest will negatively affect SPR.

Independent of angler response, model results suggest a 14" size limit is most consistent with maintaining or increasing SPR. Estimates of SPR for *C. nebulosus* in Mississippi appear very sensitive to fishing mortality for age-1 fish. *Cynoscion nebulosus* are 80% mature by age-2 but only 45% mature at age-1 (Brown-Peterson and Warren 2001) and data suggest they have a mean size of 12" at age-1 and a mean size of 14.6" at age-2 (CFRD unpublished data).

Based on model input data and accounting for differences in length-specific fecundity (Brown-Peterson and Warren 2001), annual egg production is 41% from age-1 and 44% from age-2 fish, so spawning potential is highly dependent on newly-mature age-1 and age-2 fish and should be very sensitive to an increase in mortality for these fish. The best strategy for population stability, based on model results, is to protect age-1 fish until they spawn at least once. Model projections indicate this strategy might be possible at either a 13 or a 14" length limit, but after accounting for future uncertainty is most likely with a 14" length limit. The positive trend in SSB predicted by the model between 1993 and 2000 also suggests that the 14" size limit combined with lower angler effort resulted in a stable population over this period.

Statistical catch at age models are valuable tools for both estimating stock status and projecting the effects of future changes in condition. One key strength of the approach is the ability to account for uncertainty in the model estimates. Uncertainty can have many sources but the most common are uncertainty due to model structure (i.e., process) and uncertainty due to variability in the data (i.e., observation uncertainty). In particular the model is sensitive to observation uncertainty present in estimates of catch at age taken from MRFSS surveys. The MRFSS program has been criticized for observer bias and inconsistent levels of coverage through time (NRC 2006). This has resulted in a high coefficient of variation between years for these data that must be carried through to model output. In this case, the importance of these data to overall model fit was down-weighted to partially account for bias in the MRFSS data and its influence on uncertainty estimates is thought to be small.

Cynoscion nebulosus should be managed on a state by state basis based on the results of tagging (e.g., Hendon et al. 2002) and genetic (Gold et al. 1999) studies. Several states along the Gulf Coast have established SPR-based benchmarks for assessing stock status but over a fairly broad range of relative SSB (Table 1). Our results suggest that in Mississippi, the most robust strategy is to protect SSB at age-1 in order to maintain a high level of recruitment. *Cynoscion nebulosus* is the dominant sportfish in coastal waters (GSMFC 2001) with a higher directed effort on this species in comparison to other neighboring states with a more diverse inshore fishery. While it is difficult to make a definitive statement regarding why the Mississippi fishery may require more conservative benchmarks for population stability it is likely related to this high directed effort and the decline in coastal vegetation over time. In general it will be important to set meaningful benchmarks for population stability that reflect local conditions, and these actions can be appropriately evaluated using quantitative tools such as SCAA models prior to implementation, which should greatly improve the manager's ability to maintain a stable and productive fishery for the future.

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