Analysis of Atlantic Sea Scallop (*Placopecten magellanicus*) Fishery Impacts on the North Atlantic Population of Loggerhead Sea Turtles (*Caretta caretta*)

Recent Issues in This Series:

188. **Northeast Regional Commercial Fishing Input-Output Model**, by Scott R. Steinback and Eric M. Thunberg. NTIS Access. No. PB2007-104394. April 2006. v + 54 p., 2 figs, 15 tables. *[Online publication only.]*

189. **Essential Fish Habitat Source Document: Sea Scallop, *Placopecten magellanicus*, Life History and Habitat Characteristics. 2nd ed.** By Deborah R. Hart and Antonie S. Chute. September 2004. v + 21 p., 6 figs., 2 tables. NTIS Access. No. PB2005-104079. [*Online publication only.*]

190. **Essential Fish Habitat Source Document: Atlantic Cod, *Gadus morhua*, Life History and Habitat Characteristics. 2nd ed.** By R. Gregory Lough. November 2004. vi + 94 p., 27 figs., 5 tables, 1 app. NTIS Access. No. PB2006-101528. [*Online publication only.*]

191. **Essential Fish Habitat Source Document: Northern Shortfin Squid, *Illex illecebrosus*, Life History and Habitat Characteristics. 2nd ed.** By Lisa C. Hendrickson and Elizabeth M. Holmes. November 2004. v + 36 p., 13 figs., 1 table. NTIS Access. No. PB2005- 101437. [*Online publication only.*]

192. **Essential Fish Habitat Source Document: Atlantic Herring, *Clupea harengus*, Life History and Habitat Characteristics. 2nd ed.** By David K. Stevenson and Marcy L. Scott. July 2005. vi + 84 p., 40 figs., 7 tables. NTIS Access. No. PB2005-107567. [*Online publication only.*]

193. **Essential Fish Habitat Source Document: Longfin Inshore Squid, *Loligo pealeii*, Life History and Habitat Characteristics. 2nd ed.** By Larry D. Jacobson. August 2005. v + 42 p., 20 figs., 1 table. NTIS Access. No. PB2005-110684. [*Online publication only.*]

194. **U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments -- 2005**. By Gordon T. Waring, Elizabeth Josephson, Carol P. Fairfield, and Katherine Maze-Foley, eds. Dana Belden, Timothy V.N. Cole, Lance P. Garrison, Keith D. Mullin, Christopher Orphanides, Richard M. Pace III, Debra L. Palka, Marjorie C. Rossman, and Fredrick W. Wenzel, contribs. March 2006. v + 392 p., 45 figs, 79 tables, 5 app., index. NTIS Access No. PB 2007-104395.

195. **A Large Marine Ecosystem Voluntary Environmental Management System Approach to Fisheries Practices**. By Frank J. Gable. December 2005. v + 84 p., 38 figs., 10 tables. NTIS Access. No. PB____-_____.

196. **Essential Fish Habitat Source Document: Haddock, *Melanogrammus aeglefinus*, Life History and Habitat Characteristics. 2nd ed**. By Jon K.T. Brodziak. December 2005. vi + 64 p., 27 figs., 2 tables. NTIS Access. No. PB2006-103439. *[Online publication only.]*

197. In preparation by author.

198. **Essential Fish Habitat Source Document: Bluefish, *Pomatomus saltatrix*, Life History and Habitat Characteristics. 2nd ed**. By Jon K.T. Brodziak. December 2005. vi + 89 p., 48 figs., 5 tables, 1 app. NTIS Access. No. PB2006-103439. *[Online publication only.]*

199. **Distribution and Abundance of Fish Eggs Collected during the GLOBEC Broad-Scale Georges Bank Surveys, 1995-1999**. By John D. Sibunka, Donna L. Johnson, and Peter L. Berrien. August 2006. iv + 72 p., 28 figs., 1 table. NTIS Access. No. PB____-_____. *[Online publication only.]*

200. **Essential Fish Habitat Source Document: Black Sea Bass, *Centropristis striata*, Life History and Habitat Characteristics (2nd ed.** By Amy F. Drohan, John P. Manderson, and David B. Packer. February 2007. vi + 68 p., 33 figs., 2 tables. NTIS Access No. PB____-_____. *[Online publication only.]*

201. **U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments -- 2006**. By Gordon T. Waring, Elizabeth Josephson, Carol P. Fairfield, and Katherine Maze-Foley, eds. Dana Belden, Timothy V.N. Cole, Lance P. Garrison, Keith D. Mullin, Christopher Orphanides, Richard M. Pace III, Debra L. Palka, Marjorie C. Rossman, and Fredrick W. Wenzel, contribs. March 2007. vi + 378 p., 92 figs, 84 tables, 5 app., index. NTIS Access No. PB____-_____.

202. **Evaluation of Northern Right Whale Ship Strike Reduction Measures in the Great South Channel of Massachusetts**. By RL Merrick and TVN Cole. March 2007. NTIS Access No. PB____-_____.

203. **Essential fish habitat source document: Spiny dogfish, *Squalus acanthias*, life history and habitat characteristics, 2nd edition**. By LL Stehlik. December 2007. NTIS Access No. PB____-_____.

204. **An Evaluation of the Northeast Region's Study Fleet pilot program and Electronic Logbook System: Phases I and II**. By Michael C. Palmer, Susan E. Wigley, John J. Hoey, and Joan E. Palmer. December 2007. NTIS Access No. PB____-_____.

205. In preparation by author.

206. **Growth of Black Sea Bass (Centropristis striata) in Recirculating Aquaculture Systems.** By Dean M. Perry, David A. Nelson, Dylan H. Redman, Stephan Metzler, and Robin Katersky. October 2007. NTIS Access No. PB____-_____.

Analysis of Atlantic Sea Scallop (*Placopecten magellanicus*) Fishery Impacts on the North Atlantic Population of Loggerhead Sea Turtles (*Caretta caretta*)

Richard Merrick and Heather Haas

National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543

Editorial Notes

Species Names: The NEFSC Editorial Office's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes, mollusks, and decapod crustaceans and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals. Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

Statistical Terms: The NEFSC Editorial Office's policy on the use of statistical terms in all technical communications is generally to follow the International Standards Organization's handbook of statistical methods.

Internet Availability: This issue of the NOAA Technical Memorandum NMFS-NE series is being as a paper and Web document in HTML (and thus searchable) and PDF formats and can be accessed at: http://www.nefsc.noaa.gov/nefsc/publications/.

TABLE OF CONTENTS

ABSTRACT

An estimated 619 loggerhead turtles of various age and sex classes were taken annually during 1989-2005 in all components of the US Atlantic sea scallop (*Placopecten magellanicus*) fishery. We provide here a quantitative assessment of the potential for these takes to jeopardize the continued existence of the US Atlantic Ocean population of loggerhead sea turtles (*Caretta caretta*). A population viability analysis (PVA) was used to estimate quasi-extinction likelihoods under conditions with and without fishery effects. This PVA used US index nesting beach data for 1989-2005 to estimate the loggerhead population trend μ (mean growth rate) and variance σ^2. The starting population (N_0) for the exercise was the sum of nesting females estimated from the 2005 nest count in the North Carolina to Florida area. The base model (with fishery bycatch) was developed by using estimates of μ (-0.022), σ^2 (0.012), N_0 (34,881) and a quasi-extinction threshold of 250 adult females. Quasi-extinction likelihoods were bootstrapped (1000 iterations) under baseline conditions to derive confidence intervals. The μ for each bootstrap iteration was drawn from a normally distributed random sampling of μ values lying within the 95% confidence interval around the original μ. The model was then rerun with the estimated annual fishery mortality of adult females (102 turtles) added back into the population, thus changing the trend ($\mu = -0.019$, $\sigma^2 = 0.012$, and $N_0 = 34,881$). Results of the two models were similar; the quasi-extinction probabilities were zero at 25, 50, and 75 years, and 0.01 at 100 years for both analyses. Median times to quasi-extinction were 207 years versus 240 years, and the number of bootstrap simulations with extinction probabilities greater than 0.05 in 100 years was 258 and 178, respectively. These results suggest that the annual take of loggerhead sea turtles in the US fisheries for Atlantic sea scallops, though detectable, does not significantly change the calculated risk of extinction of the population of adult female Western North Atlantic loggerheads over the next 100 years.

INTRODUCTION

Loggerhead sea turtles (*Caretta caretta*) are incidentally captured in US dredge and trawl fisheries for Atlantic sea scallops (*Placopecten magellanicus*) in the US Mid-Atlantic region. Increased federal observer coverage of these fisheries allowed the National Marine Fisheries Service (NMFS) to estimate the annual bycatch of loggerhead turtles in the fisheries through 2005 (Murray 2004a, 2004b, 2005, 2007). Recent observer reports document takes through 2007. As loggerhead turtles are a threatened species under the US Endangered Species Act (ESA), NMFS, under Section 7 of the ESA, must ensure that continuation of the sea scallop fisheries is not likely to jeopardize the continued existence of the species.

Impacts of US fisheries (e.g., Atlantic sea scallop, Mid-Atlantic bottom trawl, pelagic longline, and Gulf of Mexico/Southern Atlantic commercial shrimp) on the western North Atlantic loggerhead sea turtle population have been analyzed by Southeast Fisheries Science Center (SEFSC) staff and the loggerhead sea Turtle Expert Working Group (TEWG 1998, 2000; SEFSC 2001; Epperly et al. 2002). However, reduced loggerhead nesting on southeastern US beaches suggests these analyses require updating. The TEWG is currently working on a reanalysis, but the limited data available on current population parameters (e.g., stage specific survival) suggest that the previous demographic models may be difficult to revise.

We provide here an alternative quantitative approach to the assessment of the risk the US Atlantic sea scallop fisheries have of jeopardizing the continued existence of the western North Atlantic Ocean populations of loggerhead sea turtles. This approach is simpler than previously used for western North Atlantic (WNA) loggerheads and is similar to that used by Snover (2005) in her analysis of the impact of the Western Pacific Pelagics Fisheries on several Pacific sea turtle species. We use a population viability analysis (PVA) to estimate quasi-extinction likelihoods under conditions with and without fishery effects. The PVA is count-based (Dennis et al. 1991; Morris et al. 1999; Holmes 2001; Morris and Doak 2002; Snover 2005) which will allow the use of the only relatively complete and available population time series—<u>index</u> nesting beach[1] counts for 1989-2005. As such, the analyses focus on the <u>viability of the adult female portion of the population</u> and should not be considered to model viability of the entire population.

We first present the PVA results under baseline conditions by using the rate of change of the adult female population (which implicitly includes the mortalities from the scallop and other fisheries) and the 2005 count of adult females estimated from all beaches in the Southeast based on an extrapolation from nest counts. We then adjust the rate of change by adding back the fisheries take and rerunning the PVA. The results of these two analyses are then compared by using the probability of quasi-extinction at 100 years to assess the impact of the takes in the Atlantic sea scallop fisheries.

At the outset, we point out three caveats to the interpretation of these analyses. First, the current negative nesting beach trends are at odds with some in-water survey results (e.g., Epperly et al. 2007). Secondly, the current negative trend in adult female abundance has likely been

---

[1] Index beaches are a limited series of beaches which are regularly monitored for nesting activity. In Florida, the Index Nesting Beach Survey (INBS) has coordinated a detailed monitoring program since 1989 to measure seasonal productivity, allowing comparisons between beaches and between years. In Florida, 33 beaches (of 190 surveyed beaches) are included in the INBS program. Similar programs exist in states further north.

influenced by mortality events that have occurred over several decades. As such, a model based on current nesting beach trends may overestimate the effect of current takes on the likelihood of extinction for the population.   Finally, we stress that our analyses should not be used to assess the likely fate of the population but should only be used to assess the impact of the fisheries for Atlantic sea scallops on the population trajectory of adult female loggerhead sea turtles. A thorough review of loggerhead population trends is provided by Witherington et al. (2006, in review).

METHODS

Data

Population trend data

A time series of population counts (or some index of the population) was needed through 2005 to estimate the population trend for the PVA. The time series needed to be longer than 10 years for the PVA to be more than marginally useful (Morris et al. 1999; Morris and Doak 2002).

Loggerhead nest counts (a proxy for the adult female population) are available for southeastern US index nesting beaches from 1989 to 2005 for the Northern (NC, SC, and GA) and Peninsular Florida subpopulations (NMFS in review, FWRI 2007). These are the subpopulations with the greatest nesting populations. Two other southeastern United States subpopulations have index beach nest counts available from 1996 (Dry Tortugas FL) and 1998 (Northern Gulf [AL, FL]) onwards (NMFS in review). These are the two smallest subpopulations, and since at least 1996 they have constituted a small fraction of the population (e.g., in 2005 they accounted for only 3% of the total number of index beach nests). Because nest counts were available for only a relatively brief period, these two subpopulations were excluded from the trend analysis for 1989-2005. Note that we did include the nest counts for all four subpopulations as part of a supporting analysis for the 1996-2005 period. Finally, these count data were used directly, without any adjustments for remigration[2] or nests per female, to determine the population trend.

Current abundance data

An estimate of adult female abundance in 2005 was necessary for use as the starting point for the PVA. The 2005 estimate of adult female abundance was derived by first summing nest counts from all beaches surveyed in the southeastern United States, including all beaches surveyed in 2005 in NC, SC, GA, FL, and AL (NMFS in review, FWRI 2007, SCDNR 2007). Only index beach nests counts were available for the Dry Tortugas and Northern Gulf subpopulations, so the total nest count is biased low. We then adjusted the sum to estimate adult females:

$$N_{AF} = (\text{Number of nests/Nests per female}) * \text{Remigration interval}$$

---

[2] Remigration is used here to mean the number of years between visits by adult females to nesting beaches and is not to be confused with the repeat visits within a single year which are included in the nests per female estimate.

Use of a constant value for nests per female and remigration interval is problematic as both parameters vary to some degree. For example, limited food resources can lead to decreased reproductive fitness because of natural and human driven fluctuations in prey availability. Moreover, if the age structure of the population changes, the number of nests per female will change. The available datasets do not characterize this variability, nor is it known whether such variability is random or associated with environmental change. Because of these uncertainties, we generally used conservative parameter values.

Estimates of nests per female vary widely, in part because of observational issues. Estimates adjusted for missed nesting suggest the mean number of nests per female per season in US waters ranges from 2.8 to 4.2 (Frazer and Richardson 1985; Schroeder et al. 2003). We used 4.2 nests per female.

Published estimates for the average remigration intervals of WNA loggerhead sea turtles on US beaches vary from 2.5 to 2.7 years (Richardson et al. 1978; Bjorndal et al. 1983; Schroeder et al. 2003). We used the 2.5 year remigration estimate.

Fishery mortality data

Estimates of loggerhead bycatch in the US Atlantic sea scallop fisheries are available for 2003-2005 for scallop dredge gear and for 2004-2005 for scallop trawl gear (Murray 2004a, 2004b, 2005, 2007). There is a wide range amongst the annual values, and two approaches for deriving an estimate for our model were considered. One approach was based on using the mean annual sea scallop dredge fishery bycatch for 2003-2005 ([749+180+0]/3=310; Murray 2004b, 2007) added to the midpoint of the range of estimated sea scallop trawl fishery bycatch from six bycatch estimates for 2004-2005 (136 turtles; Murray 2007) as the estimate of average annual total loggerhead sea turtles caught in the sea scallop fisheries (446 turtles). An additional 20 loggerheads were estimated to have been caught in groundfish bottom trawl fisheries where sea scallops were the primary catch (Murray 2006). Summing across fisheries suggests that the annual loggerhead bycatch in sea scallop related fisheries in 2004-2005 might be 466 animals.

The second approach used the take estimates in the Atlantic Sea Scallop Fishery Management Plan (FMP) Biological Opinion. This included only the 2003-2004 sea scallop dredge fishery bycatch (biennially 929 loggerhead sea turtles) added to one of the sea scallop trawl fishery bycatch estimates (268 loggerhead sea turtles biennially) and the 20 turtles estimated to be taken annually in groundfish bottom trawls for an average annual bycatch of 619 loggerhead sea turtles in the fishery.

We used the value of 619 loggerhead sea turtles as our estimate of the annual bycatch in the sea scallop fisheries of loggerhead sea turtles of various age and sex classes.

This total loggerhead sea turtle bycatch estimate (N_B=619 turtles) then needed to be adjusted downward to estimate the annual mortality of adult female loggerheads (N_{AF}) associated with the US sea scallop fisheries:

$$N_{AF} = (N_B*F_{US} *F_M *F_{M-F} *F_L) + (N_B*F_{US} *[1-F_M]*F_{IM-F} * F_{IM-R} *F_L)$$

where:

F_{US} = proportion of the bycatch from the US population

F_M = proportion of bycatch mature

3

F_{M-F} = proportion of the adult bycatch assumed to be female

F_{IM-F} = proportion of the immature bycatch assumed to be female

F_{IM-R} = relative reproductive value of juvenile neritic turtles

F_L = proportion of the bycatch considered as lethal takes

Again, where there was a range of parameter values, we selected the value that generated the greatest impact by the sea scallop fisheries on the loggerhead population:

1. F_{US} - Genetic samples taken from loggerhead sea turtles captured in the sea scallop fisheries indicated that 88-93% of the animals are from the US nesting population (Haas et al. in review). This is comparable to the ~92% reported by Bass et al. (2004) for the Albemarle-Pamlico Sounds area of NC. We used a value of 93%.
2. F_M - Loggerheads captured in both gear types are expected to be of the same age classes. Loggerhead sea turtles observed bycaught in sea scallop fisheries ranged in size from 62 cm to 107 cm curved carapace length (CCL)(mean = 79.2 cm CCL, SD = 11.6, NE Fishery Observer Program database). The cutoff between sexually immature and mature loggerhead sea turtles appears is in the range of 87 to 100 cm CCL (NMFS in review; SEFSC 2001). CCL data were available for 42 turtles taken in the fishery; 35 (83.3%) were less than 87 cm CCL. As such, we used 0.833 as the proportion of immatures taken in the fisheries.
3. F_{M-F} and F_{IM-F} – There are few data available on the sex classes of loggerheads bycaught in the sea scallop fisheries. We, therefore, used data available from loggerhead captures and strandings. These data suggest that the mature and immature sex ratio in Northeast waters is approximately two females per male (TEWG 2000).
4. F_{IM-R} – Estimated bycatch of immature loggerheads was adjusted to account for the natural mortality expected prior to their recruitment as breeding adults. Wallace et al. (in press) present estimates in the range of 0.28 to 0.32 for the relative reproductive value of the neritic juvenile stage of loggerhead sea turtles found stranded along the US Atlantic coast (mean CCL = 78.5, SD = 16.6). Given the similarity in size of these loggerheads to those taken in the sea scallop fishery (mean CCL = 79.2, SD = 11.6), it appears reasonable to use this estimation of reproductive value for immature juvenile turtles taken in the sea scallop fishery. We, therefore, used 0.32 as the estimate for juvenile reproductive value.
5. F_L - Observer reports from the 2003-2005 fisheries suggest that the percentage of loggerhead sea turtles released alive and uninjured was 22.7-25% for scallop dredge gear and 100% for trawl gear (Murray 2004a, 2004b, 2005, 2007). This compares to the 36% and 88.5% used in the Atlantic Sea Scallop FMP Biological Opinion. We, therefore, used 0.227 and 0.885 for dredge and trawl gear, respectively.

Because of the differences in loggerhead captures in the trawl and dredge fisheries, the number of adult female mortalities was estimated separately for each fishery and then combined.

4

Together this series of adjustments provides an estimate of the annual mortality (in numbers) of US adult female loggerheads caused by the bycatch in the US Atlantic sea scallop fisheries.

Model

The Dennis Model is a density-independent model of population growth, which uses a diffusion approximation to compute the probability of quasi-extinction (i.e., reaching a low threshold population size) in a randomly varying environment:

$$N_{t+1} = N_t \lambda_t$$

Application of the model requires that two key parameter values be estimated to make inferences regarding population growth rates and quasi-extinction risks:

μ – the arithmetic mean of the log population growth rate
σ^2 – variance of the log population growth rate

Holmes (2001) suggests the use of running sums as a means of reducing bias associated with sampling error and stage-specific counts. We calculated running sums as:

$$R_j = N_i + N_{i+1}$$

where j=1,2,3 … (q-1), q is the number of censuses in dataset, N represents the population size, and R_j represents the population size at time j from the running sums. Without using the running sums approach (1 yr intervals), the trend was -0.0063 and the variance was 0.038. We evaluated running sums of 2 yr, 3 yr, and 4 yr to calculate the annual estimate of R_j and found that the 3 and 4 yr running sums produced the same rate of change (-0.0216), which was slightly different from the 2 yr interval (-0.0220). With the smaller variance in the trend for the 3 and 4 yr running sums (0.006 and 0.003, respectively), the result would be that a 3 or 4 yr interval would lead to reduced probabilities of quasi-extinction in 100 yrs. Following our rule of using conservative parameter values, we decided to use a 2 yr interval for the final analysis.
Then μ was calculated as:

$$\mu = (\sum log(R_{j+1}/R_j)/t$$

Similarly, σ^2 is calculated as the variance over the series of log (R_{i+1}/R_i) values. The μ and σ^2 are then used to estimate r (the instantaneous rate of change) and λ (Dennis et al. 1991):

$$r = \mu + \sigma^2/2$$
$$\lambda = e^{(r)}$$

Estimation of the extinction risk requires a population size at extinction (N_{ext}). The population size at extinction can assume several values, with 0 equal to the true extinction. Rather then focusing entirely on total extinction ($N_{ext} = 0$), the concept of quasi-extinction risk has been developed (Ginzburg et al. 1982), where quasi-extinction risk is the probability that a

population will fall below a given threshold ($N_{ext} > 0$). There is no generally agreed upon level for quasi-extinction, though it is commonly considered to be a threshold population size below which the population would be critically endangered or effectively extinct. For large vertebrates, a variety of numerical values have been considered for this threshold (e.g., from 20 to 500). We considered using either 50 or 250 adult females as our estimate of quasi-extinction. Our reasons for considering fifty animals were: (1) there is general consensus in the conservation genetics community that large vertebrate populations cannot fall below 50 breeding animals and still maintain genetic integrity (Shaffer 1981; Franklin 1980), (2) the International Union for Conservation of Nature (IUCN)(2008) considers this to be one of the two threshold numerical values for a "critically endangered" population category, and (3) to provide comparability with the value used in the 2004 Pacific sea turtle bycatch PVA prepared by Snover (2005). IUCN uses 250 mature animals as an alternative threshold value for "critically endangered" populations when there is evidence of a population decline. Given the apparent decline in nesting in the southeastern United States, it appears reasonable to use 250 as our threshold value for quasi-extinction. The IUCN includes all mature animals in this value and not just adult females, so using 250 adult females as the threshold provides a doubly conservative threshold.

Morris and Doak (2002) describe the probability of reaching a quasi-extinction threshold (N_{ext}) by using the following function:

$$g(t|\mu, \sigma^2, d) = \frac{d}{\sqrt{2\pi\sigma^2 t^3}} \exp\left[\frac{-(d + \mu t)^2}{2\sigma^2 t}\right]$$

with $d = \log(N_0/N_{ext})$, and N_0 is the population size at the beginning of the analysis period. To calculate the total probability of reaching N_{ext} at some future time T, the cumulative distribution function (which is the preceding function integrated from $t = 0$ to T) is applied:

$$G(T|\mu, \sigma^2, d) = \exp\left[\frac{-2\hat{\mu} d}{\hat{\sigma}^2}\right] \Phi\left[\frac{-d + \hat{\mu} T}{\sqrt{\hat{\sigma}^2 T}}\right] + \Phi\left[\frac{-d - \hat{\mu} T}{\sqrt{\hat{\sigma}^2 T}}\right]$$

where $\Phi(z)$ is the standard normal cumulative distribution function (Morris and Doak 2002).

Morris and Doak (2002) outlined an approach for deriving the quasi-extinction time cumulative distribution function confidence intervals by using bootstrap estimation procedures. We used a similar approach, sampling from a random distribution drawn from within the 95% confidence interval for μ and σ^2 and replicated 1000 times to estimate the confidence intervals around the cumulative probability of reaching N_{ext} at some future time T.

Modeling Steps

The base model (with fisheries bycatch) was run over a 1,000 yr period with the estimates of μ, σ^2, N_0 beginning in 2005 and quasi-extinction threshold of 250 adult female loggerheads (Dennis et al. 1991; Holmes 2001; Morris and Doak 2002; Snover 2005). The 1,000 year time horizon was necessary so that we could determine the median time to extinction. Quasi-extinction likelihoods were then bootstrapped under baseline conditions to derive confidence

intervals. The μ for each bootstrap iteration was drawn from a normally distributed random sampling of μ values lying within the 95% confidence interval around the original μ.

The model was modified to add back in the annual loggerhead bycatch in the Atlantic sea scallop fisheries. First, we adjusted the annual estimated bycatch in the fisheries (dredge and trawl) of loggerhead sea turtles for all age and sex classes to derive an estimate of total adult females removed from the population. We then calculated the rate of adult female removals for 2005 by dividing the bycatch by the total adult female population in 2005. This rate was then added into the population instantaneous growth rate (r) for each year from 1989 to 2005, and a revised μ and σ^2 was calculated. The model (without fishery bycatch) was then run with the revised estimates of μ, σ^2, and N_0. We bootstrapped quasi-extinction likelihoods under the new model's conditions to derive confidence intervals.

Evaluation of Results

The primary metric we used to compare the results of the two PVAs (with and without the fishery mortalities) was the cumulative probability of quasi-extinction at 100 years (based on recommendations on acceptable risk of extinction in DeMaster et al. 2004). Secondary metrics included the number of bootstrap replicates with a probability of extinction > 0.05 in 100 years and the median times to extinction[3]. We analyzed the sensitivity of the 1989-2005 model to changes in the population trend by comparison with the trend from 1996-2005. We also compared extinction probabilities at take levels that were two and ten times the documented levels of takes in the sea scallop fisheries.

RESULTS

Population Trends to Present

Loggerhead nest counts from the Northern and Peninsular subpopulations were summed (Fig. 1) and analyzed to develop the annual rates (λ) of population change for 1989-2005 (Table 1). The trend ($\mu = -0.022$, $\sigma^2 = 0.012$, Table 2) for 1989-2005 for the US Atlantic Ocean loggerhead adult female population suggests the adult female population is declining.

We used an estimate of 58,602[4] nests in 2005 in the southeastern United States (North Carolina to Alabama). This produced an estimate of 34,881 adult females when adjusted for nests per female (4.2 nests per female) and remigration interval (2.5 years).

The annual sea scallop fisheries bycatch mortality of adult female loggerheads was estimated to be 102 turtles (97 in the dredge fishery and 5 in the trawl fisheries). This estimate was derived from the total annual take of 619 loggerheads prorated for area of origin (0.930 from United States), maturity (0.833 immature), female proportion (0.67), reproductive value of juveniles (0.32), and fishery specific mortality (dredge = 0.773 and trawl = 0.115).

Given the 2005 population estimate of 34,881 adult females and a fishery-induced mortality of 102 adult females per year, the rate of adult female removals in the sea scallop

---

[3] The time when the quasi-extinction probability is 0.50
[4] This includes 2005 counts for all beaches in the Northern (NC = 560, SC = 4,233, GA = 1,145 nests) and Peninsular Florida (51,636 nests) subpopulations and index beaches in the Dry Tortugas (159 nests) and Northern Gulf (869 nests) subpopulations (NMFS in review; FWRI 2007; SCDNR 2007).

fishery was 0.0029 in 2005. These mortalities were added back into the population to produce a revised 1989-2005 μ of -0.019 (σ^2 = 0.012, Table 2).

Viability Analyses

Using the 1989-2005 model, the risk of quasi-extinction (N_{ext} = 250 adult females) at 100 years was 0.01 (Table 2, Fig. 2) with a median time to extinction of 207 years (Table 2). Over 1000 iterations of the model, 258 produced a probability of extinction at 100 years greater than 0.05.

Adding the Atlantic sea scallop fisheries-related loggerhead mortalities back into the population had only a small effect on population trajectory and extinction probabilities. The μ was -0.022 and -0.019 for the analyses with and without the fishery takes. The risk of quasi-extinction at 100 years remained 0.01 (Table 2, Fig. 3). The median time to extinction grew to 240 years (Table 2). Over 1000 iterations of the model, 178 produced a probability of extinction at 100 years greater than 0.05.

Results of the two analyses were similar (Table 2, Fig. 4). Both had quasi-extinction probabilities of zero (0) at 25, 50, and 75 and a probability of 0.01 at 100 years. Median times to quasi-extinction were similar (207 years versus 240 years). The number of simulations with extinction probabilities at 100 years greater than 0.05 was 258 and 178, respectively.

Model Sensitivity

An incorrect estimate of the population trend would significantly affect the model results. Therefore, we repeated this analysis with just the 1996-2005 time series. While this would generally be considered to be too short a time series for analysis, it does provide some insight into the capability of the model to detect risk of extinctions.

Loggerhead nest counts from all four subpopulations were summed (Table 3) and analyzed to develop the annual rates (λ) of population change for 1996-2005 (Table 4). The trend (μ = -0.049, σ^2 = 0.011, Table 2) for 1996-2005 for the US Atlantic Ocean loggerhead adult female population suggests even more strongly than the 1989-2005 analysis that the adult female population is declining. Again with the 2005 population estimate of 34,881 adult females and a fishery-induced mortality of 102 adult females per year, the rate of adult female removals in the sea scallop fishery was 0.0029 in 2005. These mortalities were added back into the population to produce a revised 1996-2005 μ of -0.046 (σ^2 = 0.011, Table 4).

There was little difference between the 1996-2005 analyses with and without the sea scallop fisheries mortalities (Tables 4, Fig. 5). The population trend remains similar; μ equals 0.049 and 0.046 for the two analyses. Cumulative probabilities of extinction are identical up until approximately the 75th year, and the median times to extinction were very similar for both 1996-2005 models (i.e., 98 versus 102 years). The number of simulations with extinction probabilities at 100 years greater than 0.05 was 940 and 922, respectively.

We also evaluated the model's sensitivity to changes in fishery mortality rates. Given that the 1989-2005 model showed probabilities of extinction at 100 years equal to zero for both the original model and the model with takes added back in, it was necessary to use the 1996-2005 model for this evaluation. We compared the results of adding the loggerhead mortalities caused by the Atlantic sea scallop fisheries (102 adult females) with adding back in mortalities that were two and ten times greater than that observed in the sea scallop fisheries (Fig. 6).

Ultimately, it appears that the probability of extinction at 100 years would be reduced to zero if ten times the number of adult females estimated to be taken by the Atlantic sea scallop fisheries were added back to the population.

DISCUSSION

These results suggest that mortalities of loggerhead sea turtles in the US Atlantic sea scallop dredge and trawl fisheries are detectable but have a relatively small effect on the trajectory of the adult female components of the WNA loggerhead sea turtles over the next 100 years. The 1989-2005 population trends, with and without the mortalities, were not significantly different, and the probability of reaching the quasi-extinction threshold (250 adult females) under both scenarios was 0.01. Median times to extinction for both were greater than 200 years. The only obvious difference was in the number of bootstrap simulations with a probability of extinction > 0.05 in 100 years.

The relatively large population size of adult females (34,881), the relatively small negative trend in the adult female population over 1989-2005 (r = -0.022 per year), and the number of adult female mortalities in the fisheries (102 per year) all contribute to the lack of effect. This lack of impact occurred despite the use, wherever possible, of values which generated the greatest consequence of the sea scallop fisheries takes of loggerheads. If less stringent values had been used, the effect would have been less. Patterson and Murray (2008) provide commentary on the effect that application of the precautionary principle to a PVA may have on "robust inference" and defensible policy.

Even a model as simple as the Dennis model is sensitive to parameter values and data inputs. Values calculated or selected for μ, $N_{ext,}$ and σ^2 were all influential. With respect to μ, we found that relatively small changes in the population trend produced profound changes in the probability of quasi-extinction at 100 years. For example, doubling the rate of decline in the base model (from -0.022 to -0.049) greatly increased the probability of extinction at 100 years from 0.01 to 0.54. In contrast, the level of bycatch mortality value removed from the population would need to be much greater than that observed in the sea scallop fisheries to have a major effect on the population trajectory. The comparison of the effect of different background mortalities (Fig. 6) suggests that up to ten times the level of loggerhead mortality in the sea scallop fisheries needs to be removed to stabilize the population. This small effect is important in that it suggests the relatively steep declining trend for 1996-2005 is being driven by some other, larger source of mortality.

Recognizing the influence of the population trend to the analysis, it is important to point out our assumption that the nesting beach data used in this analysis were representative of trends of the US loggerhead population. This was a practical decision; only the index beaches are counted annually in a systematic fashion. However, there is a risk in this assumption. We noted earlier the problem of juvenile in-water counts being at odds with the nesting trends. There is also some concern about the representativeness of the nest counts. If loggerhead nesting shifts systematically between years (either inside or outside of the index beach areas), then trends in the index nesting beach data may not represent the overall trend. For example, if loggerhead nesting is becoming more aggregated at the index sites (because of issues such as habitat protection), then the estimates may be biased high. Alternatively, if turtles nest outside of the time period (for example, earlier nesting caused by warmer climate conditions), then the index site estimates would be biased low. Work underway by the loggerhead TEWG and Florida's

Fish and Wildlife Research Institute will provide a substantive review of these trends. Our focus here was with evaluating the impact of the bycatch mortality in the Atlantic sea scallop fisheries on the future of the loggerhead population, and the impact of such biases on our analysis are likely immaterial. These biases could, however, significantly influence an analysis of population status and perhaps result in inappropriate management decisions.

The quasi-extinction value selected was also influential, but not as dramatically as the population trend. We evaluated N_{ext} values of 50 and 250 adult females. With the 1989-2005 base model, the probabilities of extinction at 100 years were 0.00 and 0.01 for 50 and 250 animals, respectively. Larger differences were observed in the 1996-2005 base model, where the values were 0.07 and 0.42 respectively. The latter, larger effect is likely due to the increased negative population trend. We also considered using the percent of decline approach suggested by Snover and Heppell (in press). We estimated the probability of reaching 50% of the current population size. Although risks of reaching the threshold were much higher (0.97 and 0.95 in 100 years) than with the 50 or 250 animal threshold, there were no significant differences between the base model and the model with takes added back in. Ultimately, we decided to use an absolute value of N_{ext} = 250 adult females largely because this analysis was designed to evaluate the risk of extinction resulting from mortalities in the scallop fisheries, and 250 animals better represents a threshold extinction value than does 50% of the current population size (N_{ext} = 17,441 adult females).

The model is also sensitive to changes in the variance; as the variance increases, the probability of extinction at any point in time increases, and as the variance decreases, probabilities of extinction decrease. Here it was assumed that the variance in the population trend is largely the same with and without the sea scallop fishery takes. Violations of this assumption would not change the interpretation of the sea scallop fisheries impacts, unless the take estimates were much higher relative to the population size and the variance in the takes was large.

However, the largest issue with variance was not the influence on the outcome but the difficulty of providing meaningful tests of significance with large confidence intervals. Using bootstrap techniques produced much tighter confidence intervals, but trajectories would need to vary considerably to find statistical differences.

Finally, this analysis was undertaken to provide a simple evaluation of the effect that loggerhead bycatch in the Atlantic sea scallop fisheries could have on the future viability of the WNA loggerhead population. It was not designed to and should not be used to evaluate population status. For example, here we implicitly assume that adult female recruitment will not change in the future. This is a particularly troublesome assumption because there are data suggesting that the number of juvenile loggerhead sea turtles is increasing (e.g., Epperly et al. 2007). If the increase in juvenile abundance translates into increased adult female recruitment, then our estimates of extinction probabilities would be overestimated; however, the relationship between the models with and without fishery takes would not be fundamentally changed. A staged matrix model, incorporating age-class survival and fecundity, would provide a much better evaluation tool to assess population status (and fishery impacts).

An example of such an evaluation is provided by the US Fish and Wildlife Service's (USFWS) recent quantitative threats analysis for the Florida manatee (*Trichechus manatus latirostris*; Runge et al. 2007). The basis of this threats assessment is a comparative population viability analysis, which involves forecasting the Florida manatee population under different scenarios regarding the presence of threats, while accounting for process variation

(environmental, demographic, and catastrophic stochasticity) and parametric and structural uncertainty. Several steps were required: modifying an existing population model to accommodate the threats analysis framework, updating survival rates, estimating the fractions of mortality from various causes, modeling the threats themselves, and developing metrics to measure the impact of the threats. While the conceptual process followed in our analysis of loggerhead sea turtles and that used by the USFWS are similar, the additional information available from the USFWS exercise results from a stage-based projection model for Florida manatees, incorporating environmental and demographic stochasticity, catastrophes, density-dependence, and long-term change in carrying capacity.

However, recent data to support such an analysis of loggerhead sea turtles are incomplete. A comprehensive program to collect these data should be developed and implemented so that scientific analyses, such as those presented here, can be improved and the best possible scientific advice can be provided to NOAA managers tasked with conserving both turtle populations and fisheries.

ACKNOWLEDGMENTS

Table 1. Counts of loggerhead sea turtle (*Caretta caretta*) nests at index beaches for 1989-2005 by subpopulation, biannual totals, and rates of change (λ and r) by year (NMFS in review, FWRI 2007).

Year	Northern (NC, SC, GA)	Peninsular Florida	Total (N_i)	Two-year Running Sum (Rj)	Rate of Change (λ)	Inst. rate of change (r)
1989	1,421	39,091	40,512			
1990	2,466	50,266	52,732	93,244		
1991	2,127	52,802	54,929	107,661	1.1546	0.14377
1992	1,844	47,567	49,411	104,340	0.9692	-0.0313
1993	931	41,808	42,739	92,150	0.8832	-0.1242
1994	2,207	51,168	53,375	96,114	1.0430	0.04212
1995	1,484	57843	59,327	112,702	1.1726	0.15921
1996	1,969	52811	54,780	114,107	1.0125	0.01239
1997	1,100	43156	44,256	99,036	0.8679	-0.1417
1998	1,812	59918	61,730	105,986	1.0702	0.06782
1999	2,173	56471	58,644	120,374	1.1358	0.1273
2000	1,475	56277	57,752	116,396	0.9670	-0.0336
2001	1,242	45941	47,183	104,935	0.9015	-0.1037
2002	1,543	38125	39,668	86,851	0.8277	-0.1891
2003	1,998	40726	42,724	82,392	0.9487	-0.0527
2004	549	29547	30,096	72,820	0.8838	-0.1235
2005	1,766	34872	36,638	66,734	0.9164	-0.0873

Table 2. Model results based on 1989-2005 2-year running sum trend with a starting population size of 34,881 adult female loggerhead sea turtles (*Caretta caretta*) and quasi-extinction threshold equal to 250 adult females for base model and model with Atlantic sea scallop (*Placopecten magellanicus*) fishery takes added back into population.

	Base Model	With Fishery Takes Added Back In
Population Trend	-0.022	-0.019
Variance of trend	0.012	0.012
Upper confidence limit	0.039	0.042
Lower confidence limit	-0.084	-0.080
Quasi-extinction risk with 95% confidence interval in parentheses		
@ 25 years	0.00 (0, 0)	0.00 (0, 0)
@ 50 years	0.00 (0, 0)	0.00 (0, 0)
@ 75 years	0.00 (0, 0.09)	0.00 (0, 0.02)
@ 100 years	0.01 (0, 0.46)	0.01 (0, 0.31)
Median time to extinction	207 years	240 years

Table 3. Counts of loggerhead sea turtle (*Caretta caretta*) nests at index beaches for 1996-2005 by subpopulation, biannual totals, and rates of change (λ and r) by year (NMFS in review, FWRI 2007). Number in italics were interpolated from adjacent counts.

Year	Northern (NC, SC, GA)	Peninsular Florida	Dry Tortugas (Florida)	Northern Gulf (FL, AL)	Total (N_i)	Running sum (R_j)	Rate of change (λ)	Inst. rate of change (r)
1996	1,969	52,811	249	*166*	55,195			
1997	1,100	43,156	258	166	44,680	99,875		
1998	1,812	59,918	249	149	62,128	106,808	1.0694	0.0671
1999	2,173	56,471	292	235	59,171	121,299	1.1357	0.1272
2000	1,475	56,277	242	181	58,175	117,346	0.9674	-0.0331
2001	1,242	45,941	213	143	47,539	105,714	0.9009	-0.1044
2002	1,543	38,125	*210*	149	40,027	87,566	0.8283	-0.1883
2003	1,998	40,726	208	95	43,027	83,054	0.9485	-0.053
2004	549	29,547	159	114	30,369	73,396	0.88371	-0.1236
2005	1,766	34,872	*159*	120	36,917	67,286	0.91675	-0.0869

Table 4. Model results based on 1996-2005 2-year running sum trend with a starting population size of 34,881 adult female loggerhead sea turtles (*Caretta caretta*), and quasi-extinction threshold equal to 250 adult females for base model and model with Atlantic sea scallop (*Placopecten magellanicus*) fishery takes added back into population.

	Base Model	With Fishery Takes Added Back In
Population trend	-0.049	-0.046
Variance of trend	0.011	0.011
Upper confidence limit	0.037	0.040
Lower confidence limit	-0.135	-0.1322
Quasi-extinction risk with 95% confidence interval in parentheses		
@ 25 years	0.00 (0, 0)	0.00 (0, 0)
@ 50 years	0.00 (0, 0.03)	0.00 (0, 0.02)
@ 75 years	0.10 (0, 0.67)	0.06 (0, 0.57)
@ 100 years	0.54 (0.02, 0.98)	0.42 (0.01, 0.996)
Median time to extinction	98 years	102 years
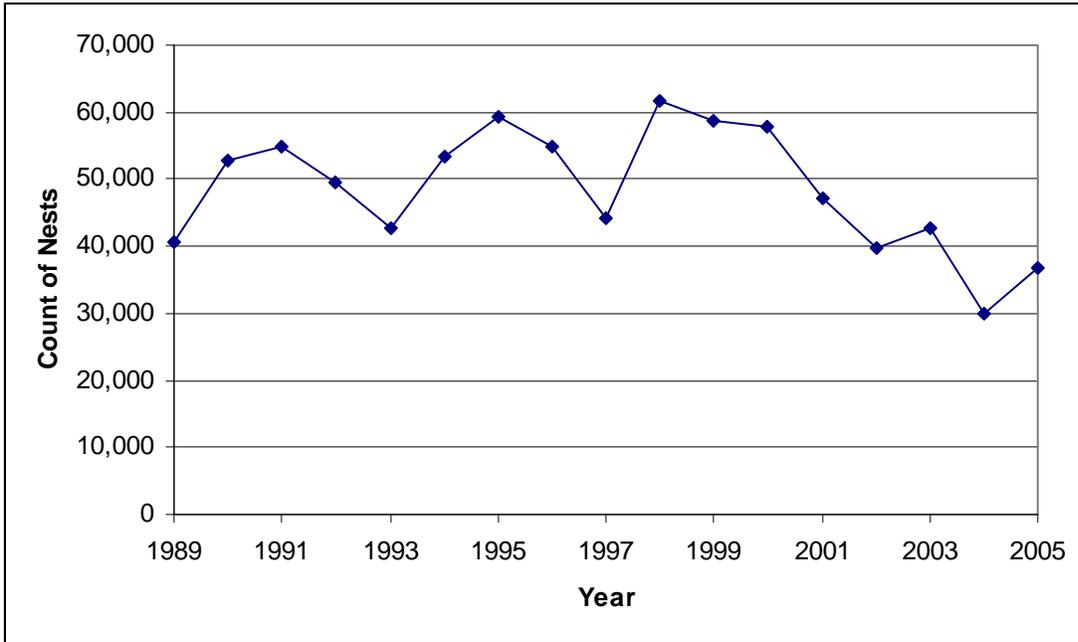
Figure 1. Number of Atlantic Ocean loggerhead sea turtle (*Caretta caretta*) nests recorded at US Northern (NC, SC, GA) and Peninsular Florida index beaches from 1989 to 2005 (NMFS in review, FWRI 2007).
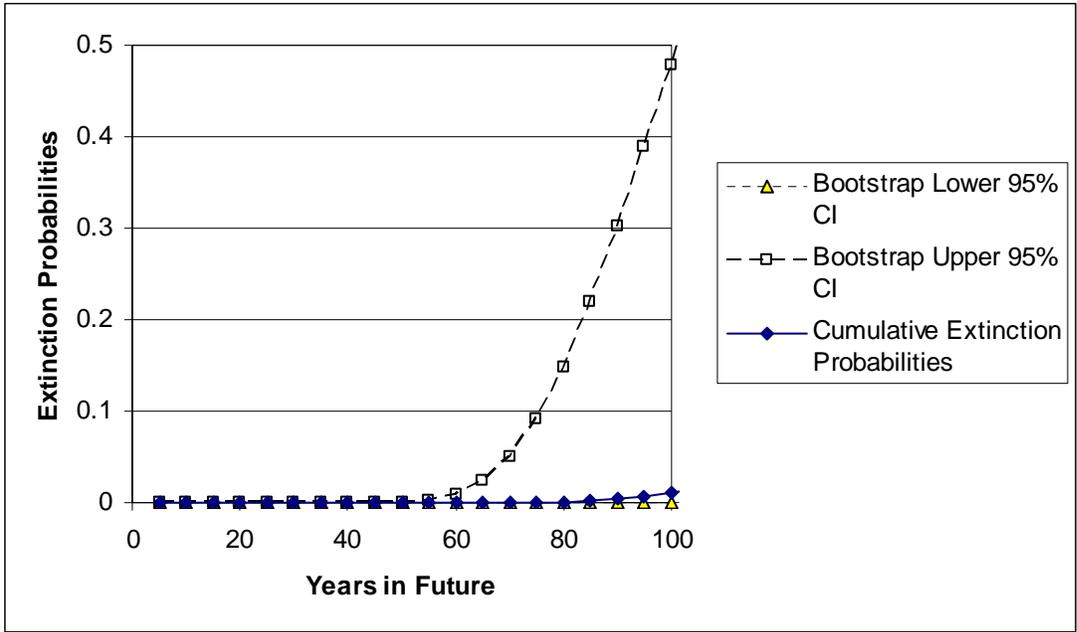
Figure 2. Cumulative quasi-extinction probabilities and confidence intervals (CI) for 1989-2005 base model with Atlantic sea scallop (*Placopecten magellanicus*) fishery takes for adult female western North Atlantic loggerhead sea turtles *(Caretta caretta)*. Quasi-extinction is equal to 250 adult female loggerhead sea turtles.
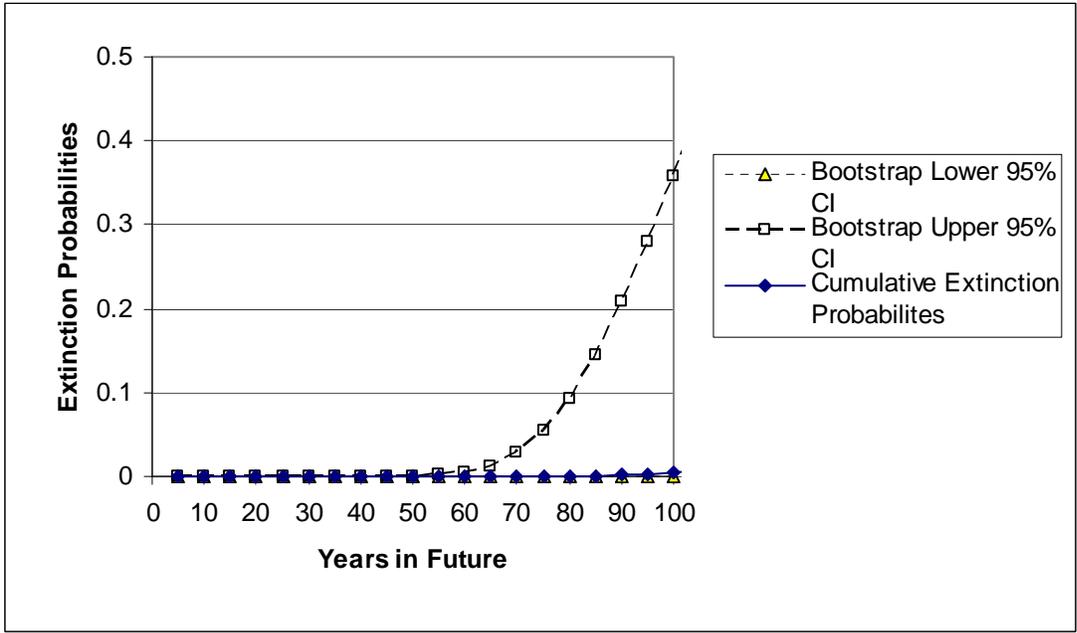
Figure 3. Cumulative quasi-extinction probabilities and confidence intervals (CI) for 1989-2005 model with Atlantic sea scallop (*Placopecten magellanicus*) fishery takes for adult female western North Atlantic loggerhead sea turtles *(Caretta caretta)* added back into population. Quasi-extinction is equal to 250 adult female loggerhead sea turtles.
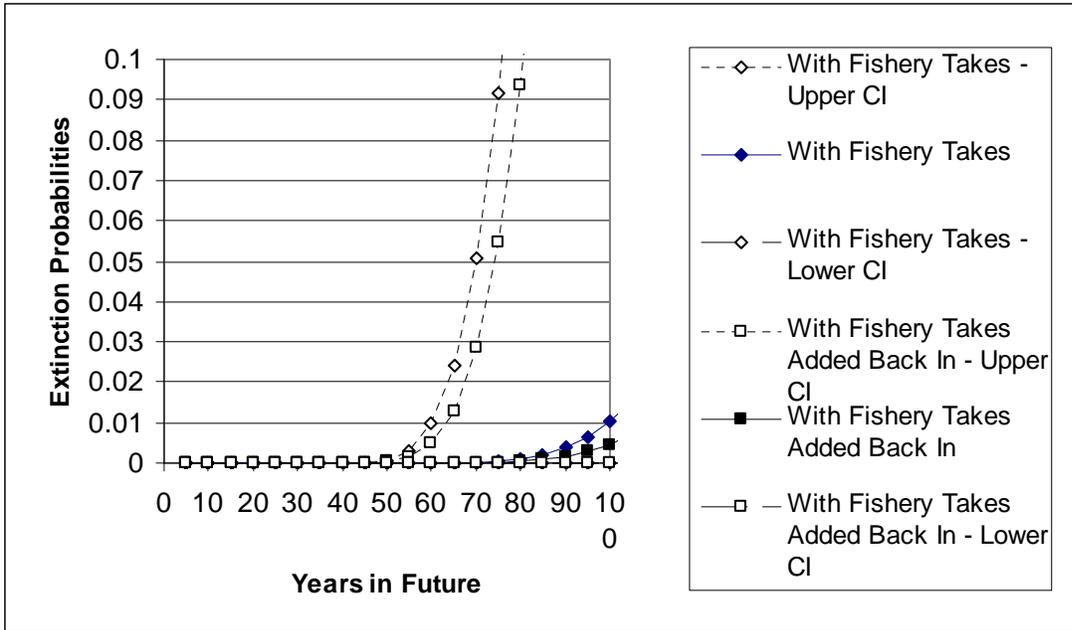
Figure 4. Comparison of cumulative quasi-extinction probabilities and confidence intervals (CI) of 1989-2005 models with and without Atlantic sea scallop (*Placopecten magellanicus*) fishery takes. Quasi-extinction is equal to 250 adult female loggerhead sea turtles *(Caretta caretta)*. Note vertical scale runs only through $P_{EX} = 0.10$.
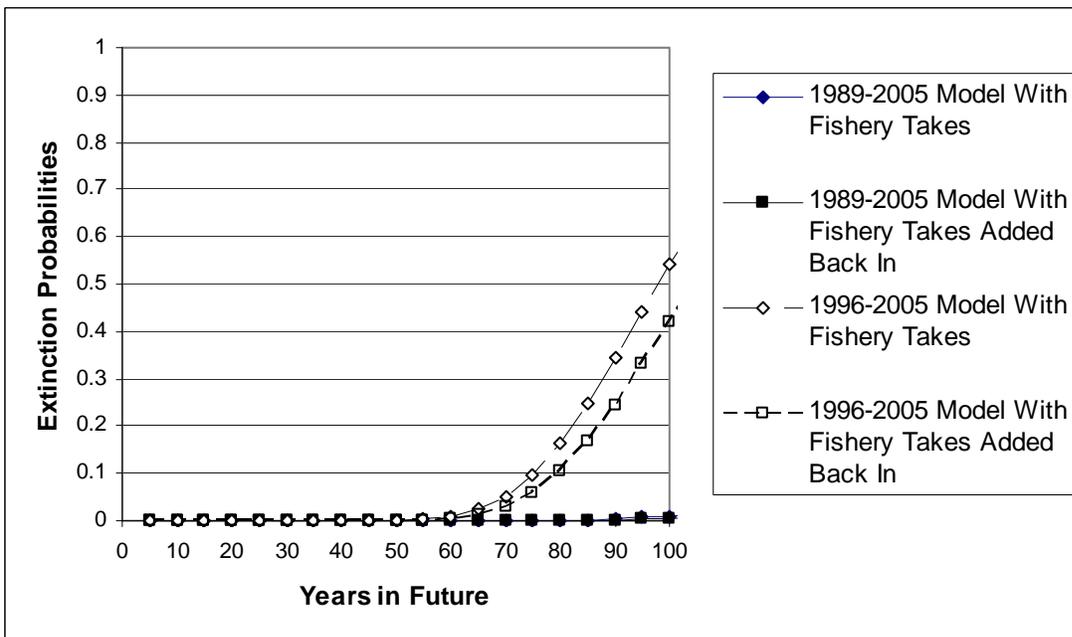
Figure 5. Extinction trajectories for models with and without Atlantic sea scallop (*Placopecten magellanicus*) fishery takes with original 1989-2005 population trajectory compared to 1996-2005 trajectory. Quasi-extinction is equal to 250 adult female loggerhead sea turtles *(Caretta caretta)*.
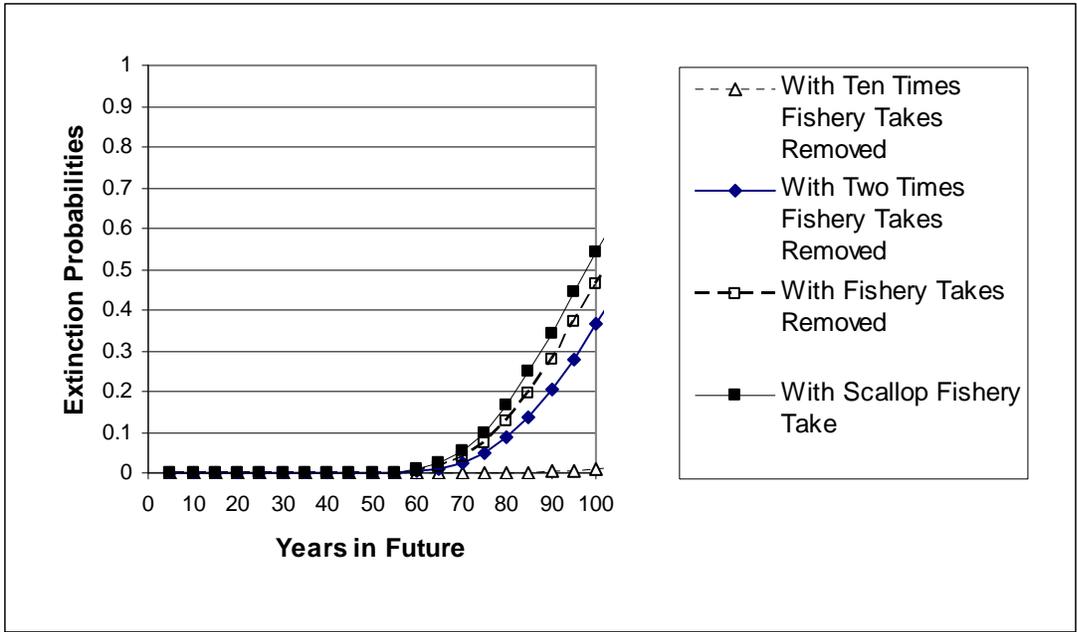
Figure 6. Cumulative quasi-extinction probabilities for 1996-2005 models with various levels of mortality removed from the trend. Fishery takes estimated as one time (the Atlantic sea scallop [*Placopecten magellanicus*] fisheries) versus two and ten times the original sea scallop fishery take level. Quasi-extinction equal to 250 adult females loggerhead sea turtles (*Caretta caretta*).

REFERENCES CITED

Bass AL, Epperly SP, Braun-McNeill J. 2004. Multi-year analysis of stock composition of a loggerhead turtle (*Caretta caretta*) foraging habitat using maximum likelihood and Bayesian methods. Cons Gen. 5:783-796.

Bjorndal KA, Meylan AB, Turner BJ. 1983. Sea turtles nesting at Melbourne Beach, Florida. I. Size, growth and reproductive biology. Biol Conserv. 26:65–77

DeMaster D, Angliss R, Cochrane J, Mace P, Merrick R, Miller M, Rumsey S, Taylor B, Thompson B, and R. Waples. 2004. Recommendations to NOAA Fisheries: ESA listing criteria by the Quantitative Working Group, 10 June 2004. NOAA Tech Memo. NMFS-F/SPO-67, 85 p.

Dennis B, Munholland PL, Scott JM.1991. Estimation of growth and extinction parameters for endangered species. Ecol Monogr. 61:115–143.

Epperly S, Avens L, Garrison L, Henwood T, Hoggard W, Mitchell J, Nance J, Poffenberger J, Sasso C, Scott-Denton E, Yeung C. 2002. Analysis of sea turtle bycatch in the commercial shrimp trawl fisheries of southeast U.S waters and the Gulf of Mexico. NOAA Tech Memo. NMFS-SEFSC-490. 99 pp.

Epperly S, Braun-McNeill J, Richards PM. 2007. Trends in catches rates of sea turtles in North Carolina, USA. Endangered Species Research 3:283-293.

Franklin IR. 1980. Evolutionary change in small populations. In: Soule ME, Wilcox BA, editors. Conservation Biology: An Evolutionary-Ecological perspective. Sunderland (MA): Sinauer; p.135-150.

Frazer NB, Richardson JI. 1985. Annual variation in clutch size and frequency for loggerhead turtles, *Caretta caretta*, nesting at Little Cumberland Island, Georgia, USA. Herpetologica 41(3):246-251.

[FWRI] Fish and Wildlife Research Institute. 2007. Sea turtle nesting feature page. http://research.myfwc.com/features/category_sub.asp?id=2309. Accessed March 2008.

Ginzburg LR, Slobodkin LB, Johnson K, Bindman AG. 1982. Quasi extinction probabilities as a measure of impact on population growth. Risk Analysis, 21:171–181.

Haas H, LaCasella E, Leroux R, Milliken H, Hayward B. In review. Characteristics of sea turtles incidentally captured in the US Atlantic sea scallop dredge fishery. Fisheries Research.

Holmes E. 2001. Estimating risks in declining populations with poor data. PNAS. 98(9):5072-5077.

[IUCN] International Union for Conservation of Nature. 2008. IUCN Red List of threatened
    species: 2001 categories & criteria (version 3.1).
    http://www.iucnredlist.org/info/categories_criteria2001

Morris W, Doak D, Groom M, Kareiva P, Fieberg J, Gerber L, Murphy P, Thompson D. 1999.
    A Practical Handbook for Population Viability Analysis. New York (NY): The Nature
    Conservancy Press; 83 pp.

Morris WF, Doak DF. 2002. Quantitative Conservation Biology: Theory and Practice of
    Population Viability Analysis. Sunderland (MA): Sinauer; 480 pp.

Murray KT. 2004a. Magnitude and distribution of sea turtle bycatch in the sea scallop
    (*Placopecten magellanicus*) dredge fishery in two areas of the Northwestern Atlantic Ocean,
    2001-2002. Fishery Bulletin. 102(4):671-681.

Murray KT. 2004b. Bycatch of sea turtles in the Mid-Atlantic sea scallop
    (*Placopecten magellanicus*) dredge fishery during 2003. Northeast Fish Sci Cent Ref Doc.
    04-11; 25 pp.

Murray KT. 2005. Total bycatch estimate of loggerhead turtles (*Caretta caretta*) in the 2004
    Atlantic sea scallop (*Placopecten magellanicus*) dredge fishery. Northeast Fish Sci Cent Ref
    Doc. 05-12; 22 pp.

Murray KT. 2006. Estimated average annual bycatch of loggerhead sea turtles (*Caretta caretta*)
    in US Mid-Atlantic bottom otter trawl gear, 1996-2004. Northeast Fish Sci Cent Ref Doc.
    06-19; 26 pp.

Murray KT. 2007. Estimated bycatch of loggerhead sea turtles (*Caretta caretta*) in US Mid-
    Atlantic scallop trawl gear, 2004-2005, and in sea scallop dredge gear, 2005. Northeast Fish
    Sci Cent Ref Doc 07-04; 30 pp.

National Marine Fisheries Service (NMFS). In review. Draft recovery plan for the US Atlantic
    population of the loggerhead sea turtle (*Caretta caretta*). Second Revision. NOAA Tech
    Memo NMFS-FPR-   ; 283 pp.

Patterson BR, Murray DL. 2008. Flawed population viability analysis can result in misleading
    population assessment: A case study for wolves in Algonquin park, Canada. Biol Cons.
    141:669-680.

Richardson TH, Richardson JI, Ruckdeschel C, Dix MW. 1978. Remigration patterns of
    loggerhead sea turtles (*Caretta caretta*) nesting on Little Cumberland Island and
    Cumberland Island, Georgia. In: Henderson G.E, editor. Proceedings of the Florida and
    interregional conference on sea turtles. St. Petersburg (FL): Florida Marine Research
    Publications Number 33; p. 39-44.

Runge MC, Sanders-Reed CA, Langtimm CA, Fonnesbeck CJ. 2007. A quantitative threats analysis for the Florida manatee (*Trichechus manatus latirostris*). US Geological Survey Open-File Report 2007-1086; 34 pp.

Schroeder BA, Foley AM, Bagley DA. 2003. Nesting patterns, reproductive migrations, and adult foraging areas of loggerhead turtles. In: Bolten AB, Witherington BE, editors. Loggerhead sea turtles. Washington (DC): Smithsonian Institute Press; p. 114–124.

Shaffer ML. 1981. Minimum population sizes for species conservation. Biosci. 31:131-134.

Snover M. 2005. Population trends and viability analyses for Pacific marine turtles. PIFSC Internal Report IR-05-008; 33 pp.

Snover ML, Heppell S.S. In press. Application of diffusion approximation for risk assessments of sea turtle populations. Ecol Appl.

[SCDNR] South Carolina Department of Natural Resources. 2006. Loggerheadlines July-December 2006. http://www.dnr.sc.gov/seaturtle/lhl.htm. Accessed March 2008.

[SEFSC] Southeast Fisheries Science Center. 2001. Stock assessments of loggerhead and leatherback sea turtles and an assessment of the impact of the pelagic longline fishery on the loggerhead and leatherback sea turtles of the western North Atlantic. NOAA Tech Memo NMFS-SEFSC-455; 343 pp.

[TEWG] Turtle Expert Working Group. 1998. An assessment of the Kemp's ridley (*Lepidochelys kempii*) and loggerhead (*Caretta caretta*) sea turtle populations in the western North Atlantic. NOAA Tech Memo NMFS-SEFSC-409; 99 pp.

[TEWG] Turtle Expert Working Group. 2000. Assessment update for the Kemp's ridley and loggerhead sea turtle populations in the western North Atlantic. NOAA Tech Memo NMFS-SEFSC-444; 115 pp.

Wallace BP, Heppell SS, Lewison RL, Kelez S, Crowder LB. In press. Reproductive values of loggerhead turtles in fisheries bycatch worldwide. J Appl Ecol.

Witherington B, Herren R, Bresette M. 2006. *Caretta caretta* – loggerhead sea turtle. Chelonian Res Mono. 3:74-89.

Witherington B, Kubilis P, Brost B, Meylan A. In review. Decreasing annual nest counts in a globally important loggerhead sea turtle population. Ecol Appl.