The Status of the United States Population of Night Shark, *Carcharhinus signatus*

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ABSTRACT—Night sharks, Carcharhinus signatus*, are an oceanic species generally occurring in outer continental shelf waters in the western North Atlantic Ocean including the Caribbean Sea and Gulf of Mexico. Although not targeted, night sharks make up a segment of the shark bycatch in the pelagic longline fishery. Historically, night sharks comprised a significant proportion of the artisanal Cuban shark fishery but today they are rarely caught. Although information from some fisheries has shown a decline in catches of night sharks, it is unclear whether this decline is due to changes in fishing tactics, market, or species identification. Despite the uncertainty in the decline, the night shark is currently listed as a species of concern due to alleged declines in abundance resulting from fishing effort, i.e. overutilization.*

To assess their relevance to the species of concern list, we collated available information on the night shark to provide an analysis of its status. Night shark landings were likely both over- and under-reported and thus probably did not reflect all commercial and recreational catches, and overall they have limited relevance to the current status of the species. Average size information has not changed considerably since the 1980's based on information from the pelagic longline fishery when corrected for gear bias. Analysis of biological information indicates night sharks have intrinsic rates of increase (r) about 10% yr^{-1} and have moderate rebound potential and an intermediate generation time compared to other sharks. An analysis of trends in relative abundance from four data sources gave conflicting results, with one series in decline, two series increasing, and one series relatively flat. Based on the analysis of all currently available information, we believe the night shark does not qualify as a species of concern but should be retained on the prohibited species list as a precautionary approach to management until a more comprehensive stock assessment can be conducted.

Introduction

The first fishery management plan for shark populations in waters of the United States (U.S.) Atlantic Ocean and Gulf of Mexico was developed in 1993 (NMFS, 1993). Because species-specific catch and life history information was limited, sharks were grouped and managed under three categories (large coastal, small coastal, and pelagic) based on known life history, habitat, market, and fishery characteristics (NMFS, 1993). The Fishery Management Plan of the Atlantic tunas, swordfish, and sharks (NMFS, 1999) added a fourth category and prohibited the retention of 19 species of sharks (Prohibited Species management category) based on a precautionary approach for species with little or no biological information that were thought to be highly susceptible to overexploitation.

The U.S. Endangered Species Act (ESA) is designed to provide for the conservation of endangered and threatened species and to take appropriate steps to recover a species. When a species is listed as endangered under the ESA, it is afforded all protections of the ESA, including the development and implementation of recovery plans, requirements that Federal agencies use their authority to conserve the species, and prohibitions against certain practices, such as taking individuals of the species.

Generally, species are considered for listing under the ESA if they meet the definition of an endangered or threatened species and that status is the result of one or any combination of the following factors: 1) present or threatened destruction, modification, or curtailment of its habitat or range; 2) overutilization for commercial, recreational, scientific, or educational purposes; 3) disease or predation; 4) inadequacy of existing regulatory mechanisms; or 5) other natural or manmade factors affecting its continued existence. In establishing its species of concern list, NMFS determined that factors related to the demography and vulnerability of a species will be evaluated to determine whether the species represents a species of concern (71 CFR 55431). NMFS developed the following factors to be considered in evaluating vulnerability: 1) abundance and productivity, or magnitude of decline (in terms of recent and historical rates); 2) natural rarity and endemism; 3) distribution; and 4) life history characteristics.

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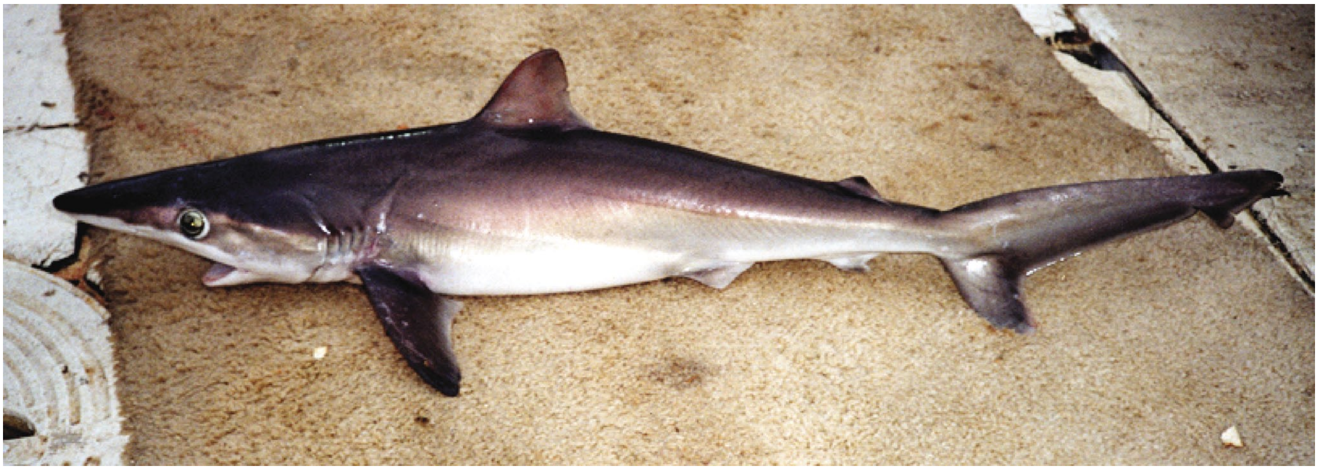

Figure 1.—A night shark captured in the swordfish pelagic longline fishery.

The night shark, *Carcharhinus signatus* (Fig. 1) is a medium-sized shark (maximum reported size 276 cm total length) characterized by a gray blue body with a long snout, an interdorsal ridge, and large green eyes. Night sharks are similar in morphology to silky, *C. falciformis*, and dusky, *C. obscurus*, sharks and are usually distinguished from these species by the placement of the first dorsal fin and the length of the second dorsal fin free rear tip (Castro, 1983). Night sharks have broad upper teeth with prominent basal serrations with distinct notches along margin and oblique cusps (Bigelow and Schroeder, 1948; Garrick, 1985). They are an oceanic species generally occurring in outer continental shelf waters in the northwest Atlantic Ocean from Delaware south to the Florida Straits including the Caribbean Sea and Gulf of Mexico (Bigelow and Schroeder, 1948; Compagno, 1984). Night sharks are generally found from 50 to 600 m in depth (Compagno, 1984) but specimens have been collected from 26 to 2,000 m (Bigelow and Schroeder, 1948; Branstetter, 1981). The World Conservation Union (IUCN) currently lists night shark globally as vulnerable based on population declines throughout its western Atlantic Ocean range due to target and bycatch exploitation by fisheries (Santana el al., 2006).

In the northwest Atlantic Ocean, night sharks historically comprised a significant proportion of the artisanal Cuban shark fishery, making up to 60–75% of the catch from 1937 to 1941 (Martinez, 1947). Beginning in the 1970's with the development of the swordfish fishery, anecdotal evidence suggested a substantial decline in the abundance of this species. Guitart-Manday (1975) documented a decline in the mean weight per unit of effort for night sharks from 53.4 kg in 1971 to 21.1 kg in 1973. Night sharks comprised 26.1% of the shark catch in a segment of the pelagic longline fishery from 1981 to 1983 (Berkeley and Campos, 1988), but this declined to 0.3% and 3.3% of the shark catch in 1993 and 1994, respectively, based on observer data (Beerkircher[1]). Further, photographic evidence from marlin tournaments in south Florida showed that large night sharks were caught daily in the 1970's but are rarely captured today (Castro et al., 1999).

The night shark is currently listed as a Prohibited Species (NMFS, 1999) but was originally petitioned and added to the Candidate Species List[2] under the Endangered Species Act in 1997. NMFS identified the night shark as an ESA candidate species due to alleged declines in abundance resulting from fishing effort (i.e. overutilization). On 15 April 2004, NMFS announced the establishment of a species of concern list, a description of the factors that it will consider when identifying species of concern, and revision of the ESA Candidate Species List.[3] NMFS transferred 25 candidate species, including night sharks, to the species of concern list.

Although information from some fisheries has shown a decline in catches of night sharks, it is unclear whether this decline is due to changes in fishing tactics, markets, species identification or real population declines. Furthermore, no studies have estimated the demography and productivity of the night shark, which is necessary in its evaluation as a species of concern. Our goal was to collate all available information on the night shark to provide a preliminary analysis of its status and assess its relevance to the list of species of concern.

Materials and Methods

Life History

Life history information is currently not available for night shark populations in the northwest Atlantic Ocean. To construct demographic models, we summarized all available life history information from the literature and conducted analyses from those data where appropriate.

[1]Beerkircher, L. Unpubl. data on file at NMFS, Southeast Fish. Sci. Cent., 75 Virginia Beach Dr., Miami, FL 33149.

[2]Online at http://www.nmfs.noaa.gov/pr/species/concern.

[3]NMFS, Revision of Candidate Species List Under the Endangered Species Act, 2004, Federal Register paper 69 FR 19975)

Natural Mortality, Productivity, and Elasticity Estimation

The instantaneous rate of natural mortality (M) was estimated through multiple indirect life history methods described extensively elsewhere (see Cortés, 2002, and references therein). The maximum age-specific estimate from those values produced that most likely represented the life history for sharks was selected as a proxy to account for a density-dependent compensatory response that would be expected to occur at low population density, and was then used in a life table/matrix population model approach. Two methods for calculating population growth rates were used: life tables and Leslie matrix population models. These allow calculation of net reproductive rate (R_0), generation length (T) (Caughley, 1966), finite population growth rate ($\lambda = e^r$), and elasticities (proportional sensitivities; Caswell, 2001) for age-0 survival or fertility, juvenile survival, and adult survival. Other quantities of interest, such as the steepness of the stock-recruit curve and the maximum lifetime reproductive rate at low population densities, were also calculated.

Productivity was also calculated through a modified demographic technique that incorporates concepts of density dependence (Smith et al., 1998). In this method, rebound potentials or productivity (r_z) is calculated at the population level producing MSY (maximum sustainable yield), which is assumed to occur at Z = 1.5M (Z = total instantaneous mortality rate).

To incorporate uncertainty in our knowledge of vital rates for this species, we conducted a Monte Carlo simulation, a projection process which involved randomly selecting a set of life-history traits (derived from this study and published literature) from the probability density functions describing each individual trait, and calculating λ, T, and age-0, juvenile, and adult survival elasticities in the life table/matrix population model approach and productivity (r_z) in the modified demographic technique. This process was repeated 10,000 times, yielding frequency distributions, means, and confidence intervals (calculated as the 2.5th and 97.5th percentiles) for parameter estimates. All simulations were run with MS Excel spreadsheet software equipped with risk analysis and matrix algebra software and MS Visual Basic.[4]

Catch Analysis

U.S. commercial landings of night sharks were compiled based on NMFS northeast regional and southeast regional general canvass data which is based on the quantity of seafood products that are sold to established (licensed) wholesale and retail seafood dealers, and the Southeast Fisheries Science Center quota monitoring data based on southeastern region permitted shark dealer reports. The larger of the two reported landings of night shark (southeast regional general canvass landings data vs. the SEFSC quota monitoring data) was taken as the actual landed volume for that species in the southeast. The reported northeast regional general canvass landings for night sharks were then added to obtain the total commercial landings. Northeast regional and southeast regional general canvass landings data are reported in whole weight (ww) and were further expressed as dressed weight (dw) by using a conversion factor of 1.96 (Cortés and Neer[5]). Landings in the SEFSC quota monitoring system are reported in dressed weight.

Recreational fishing estimates (in numbers of fish) were obtained from three data collection programs: the Marine Recreational Fishery Statistics Survey (MRFSS), the NMFS Headboat Survey (HBOAT) operated by the SEFSC Beaufort Laboratory, and the Texas Parks and Wildlife Department Recreational Fishing Survey (TPWD). Dead discards of night sharks in fisheries targeting tuna and tuna-like species were compiled from mandatory logbooks on longline and other vessels (Large Pelagic Logbook) and observer reports from these fisheries (SEFSC Pelagic Longline Observer Program) as reported in various publications (details are given in Cortés and Neer[5]). The majority of these vessels (90%) use longline gear (Cramer, 2002). Discards are typically recorded in numbers and whole weight and were further expressed as dressed weight as above. Dead discard estimates were available starting in 1987.

Size Information

Length information for night sharks was obtained from the SEFSC Pelagic Longline Observer Program. Regression analysis was used to examine trends in size with time (year).

Catch Rate Analysis

Databases were examined for the presence of night sharks, and nominal catch rates by year were calculated. Where appropriate, catch rates were standardized using a form of generalized linear model analysis. In most cases, a two-part generalized linear model analysis originally proposed by Lo et al. (1992) was utilized. The method models the proportion of sets with positive catches (where at least one shark was caught) assuming a binomial distribution with a logit link function, whereas the second step models the catch rates or catches of sets with positive catches assuming a lognormal or Poisson distribution, respectively. Time, area, and fishery operational factors were considered as potential influences on catch rates, if available.

For each generalized linear model, a stepwise approach to quantify and eliminate factors was employed (Ortiz and Arocha, 2004). First, a null model was run with no factors to reflect the distribution of the nominal data. Each potential factor was then added to the null model one at a time. Any factor that caused a reduction in deviance per degree of freedom was added to the base model if the factor was significant based on a Chi-Square test ($p<0.05$) and if the reduction in deviance per degree of freedom was at least 1%. This process was repeated, adding factors individu-

[4]Mention of trade names or commercial firms does not imply an endorsement by the National. Marine Fisheries Service, NOAA.

[5]Cortés, E., and J. A. Neer 2005. Updated catches of Atlantic sharks. Southeast Data, Assessment, and Review Document LCS05/06-DW-16. U.S. Dep. Commer., NOAA, NMFS, Southeast Fish. Sci. Cent., Panama City, FL, 58 p.

ally from the most to the least influential until no factor met the criteria. Because of the low sample size and its influence on the ability of the model to converge, we considered only first-order interactions. Regardless of its significance, year was kept as a factor in the final model. Parameterization of each model was accomplished using the SAS statistical computer software.[6]

After selecting the set of fixed factors and interactions for each error distribution, all interactions that included the factor year were treated as random interactions (Ortiz and Arocha, 2004). This process converted the basic models from generalized linear models into generalized linear mixed models. The final model determination was evaluated using the Akaike Information Criterion (AIC) and Schwarz's Bayesian Criterion (BIC; Littell et al., 1996). Models with smaller AIC and BIC values are preferred to those with larger values. These models were fit using a SAS macro, GLIMMIX (Wolfinger and O'Connell, 1993), and the MIXED procedure in the SAS statistical computer software. Relative indices of abundance were calculated as the product of the year effect least squares means from the two independent models. The standard error of the combined index was estimated with the delta method (Appendix 1 in Lo et al., 1992). Trends in abundance were further analyzed with regression techniques.

Results

Life History and Demography

Age and Growth

Santana and Lessa (2004) aged 317 night sharks collected off the northeast coast of Brazil between 1995 and 1999. The von Bertalanffy growth model fit to those age data estimated growth parameters as $L_\infty = 265$ cm total length (TL), $K = 0.11$ yr^{-1} and $t_0 = -2.69$ yr for females, and $L_\infty = 256$ cm TL, $K = 0.12$ yr^{-1} and $t_0 = -2.54$ yr for males (Table 1). The oldest aged specimens were 17 yr. The age at which 95% of L_∞ (i.e. theoretical longevity; Fabens, 1965) is reached was 30.4 and 27.9 yr for females and males, respectively.

Reproduction

Based on 744 specimens from the southwestern equatorial Atlantic Ocean, Hazin et al. (2000) estimated the sizes of maturity were 200–205 cm TL and 185–190 cm TL for female and male night sharks, respectively. Age at maturity was estimated at 8 yr for males and 10 yr for females (Hazin et al., 2000). Copulation appears to take place during the month of February in the southwest Atlantic Ocean, but its timing is unknown for areas above 10°N Latitude. Females give birth to 4–15 pups (mean litter size 11.1) of 50–60 cm TL (Hazin et al., 2000; Carlson[7]).

Productivity, Natural Mortality, and Elasticity

Instantaneous rates of natural mortality (M) estimated through a variety of methods ranged from 0.92 to 0.65 yr^{-1} when expressed as annual rates of survivorship. Pup survival at low population density was 0.84 yr^{-1}. Productivity (rebound potential) was 0.021 yr^{-1} when the population level that produces MSY is assumed to occur at Z=1.5M. With the life table/Leslie matrix approach, estimated population growth rate (λ) was 1.101 yr^{-1} (1.075–1.124 95% confidence intervals).

Mean (and 95% confidence intervals) generation time was 13.8 yr (12.6–15.3), net reproductive rate was 3.8 (2.7–5.2), maximum lifetime reproductive rate was 3.24 (2.3–4.4), and steepness was 0.44 (0.36–0.52). Population growth rate elasticities were 6.9% (6.3–7.5%) for fertility, 65.7% (60.8–70.6%) for juvenile survival, and 27.3% (22.3–32.5) for adult survival.

Exploitation

Commercial Fishery

While night sharks are not targeted, the high value and demand for shark fins, along with species identification issues, usually result in some night sharks being retained despite the species being prohibited since 1999. Since 1995, commercial landings have averaged 1,414 kg dressed weight (dw), with the highest reported landings (3,605 kg dw) occurring in 1999 and the lowest (10 kg dw) in 2002 (Table 2). No commercial landings have been reported since 2003.

Night sharks are primarily caught in pelagic longline fisheries as bycatch. According to data from the pelagic logbook program, an average of 441 night sharks were discarded dead per year during 1987–2002. Peak numbers of discards occurred in 2000, when night sharks were first prohibited, but since 2002 no night sharks have been reported discarded dead. Data from the pelagic longline observer program indicate that of the 1,655 night sharks observed caught since 1994, 12.5% were kept, 64.2% were discarded dead, and 22.5% were released alive. Beerkircher et al. (2002) stated that night sharks comprised 12.4% of the total shark bycatch reported by fisheries observers aboard U.S. pelagic longline vessels in 1992–2000. In contrast, Berkeley and Campos (1988) reported night sharks were 26.1% of the total shark catch in a study on pelagic shark bycatch from the swordfish fishery off southeast Florida during 1981–1983.

Recreational Fishery

Recreational catches of night sharks have been variable (Table 2). In 1982, 2,300 sharks were reported caught but no night sharks were reported again until 1986 (12). Since 1987, annual recreational catches of night sharks have ranged from 460 to 0. No night sharks have been reported caught since 2000. Additional data from the large pelagic survey, which collects catch rate information on rod and reel and handline fisheries off the coast of the eastern United States from Virginia through Massachusetts, indicate only 8 night sharks were recorded during 1986–2005 (Brown[8]).

[6]PROC GENMOD; Version 8.02 of the SAS System for Windows 2000. SAS Institute Inc.

[7]Carlson, J. Unpubl. data on file at NMFS, Southeast Fish. Sci. Cent., 3500 Delwood Beach Road, Panama City, FL 32408

[8]Brown, C. October, 2006. NMFS, Southeast Fish. Sci. Cent., 75 Virginia Beach Dr., Miami, FL 33149. Personal commun.

Table 1.—A summary of life history parameters for night sharks. All length values are in cm total length. Fecundity is the mean number of pups and the number in parentheses represents the ranges reported.

Parameter	Male	Female	Combined	Area of study	Source
Theoretical maximum length (L_∞)	256.5	265.4	270.0	Southwest Atlantic Ocean	Santana and Lessa, 2004
Growth coefficient (K, yr^{-1})	0.124	0.114	0.112	Southwest Atlantic Ocean	Santana and Lessa, 2004
Time at zero length (t_o, yr)	–2.538	–2.695	–2.705	Southwest Atlantic Ocean	Santana and Lessa, 2004
Maximum observed age (yr)	17	17		Southwest Atlantic Ocean	Santana and Lessa, 2004
Theoretical maximum age (yr)	27.9	30.4		Southwest Atlantic Ocean	Santana and Lessa, 2004
Age at maturity (yr)	8	10		Southwest Atlantic Ocean	Hazin et al., 2000
Length at maturity	185–190	200–205		Southwest Atlantic Ocean	Hazin et al., 2000
Fecundity (pups)		11.1 (4–15)		Southwest Atlantic Ocean	Hazin et al., 2000
Size at birth			50–60	Northwest Atlantic Ocean	This study, Compagno, 1984

Average Size

Fork lengths from the pelagic longline observer program from 1994 to 2005 show a generally flat trend (Fig. 2). No significant relationship was found in length over time ($p = 0.65$, $r^2 = 0.0002$). In a pilot study of the swordfish longline fishery off Florida's East Coast conducted during 1981–83, Berkeley and Campos (1988) reported the average size of night sharks caught was 150.4 cm FL. Average size was 96.5 cm FL in 1994 and 101.7 cm FL in 2005. These observations indicate a decrease in average size of about 40 cm since the early 1980's. However, samples from Berkeley and Campos (1988) may have been obtained from night sharks caught using wire leaders as opposed to monofilament leaders utilized in the pelagic longline fishery. The effect of various leader types on shark catchability is a subject of further investigation, but recent fishery-independent pelagic surveys using wire leaders reported an average size for night sharks ($n = 26$) of 140 cm FL (Ingram[9]).

Table 2.—Estimates of total catches and dead discards for night sharks from U.S. Atlantic waters, 1981 to 2005.

	Landings		Bycatch		
	Commercial[1]	Recreational[2]	Pelagic longline discards[3]		
Year	Dressed wt (kg)	No.	No.	Whole wt (t)	Dressed wt (kg)
1981		0			
1982		2,300			
1983		0			
1984		0			
1985		0			
1986		12			
1987		10	0	0	0
1988		460	0	0	0
1989		57	0	0	0
1990		0	0	0	0
1991		29	0	0	0
1992		54	0	0	0
1993		58	22	0.16	82
1994		42	380	3.26	1,667
1995	2,882	245	128	1.26	644
1996	3,469	379	0	0	0
1997	15	90	0	0	0
1998	1,520	133	921	20.25	10,353
1999	3,605	50	1,586	20.62	1,054
2000	1,247	24	4,100	88.57	45,283
2001	2,679	0	1,233	24.96	12,761
2002	10	0	0	0	0
2003	121	0	0	0	0
2004	0	0	0	0	0
2005	0	0	0	0	0

[1] Data for 1995–2005 are the sum of the Southeast Quota Monitoring System/Southeast General Canvass Program and the dealer weighout estimates.
[2] Except for 1982 and 1988, all recreational catches are from the NMFS Headboat survey.
[3] Pelagic longline discards are estimated from commercial logbook data and observer reports.

Catch Rates

We examined 11 potential historic and current data sources (Table 3) for the presence of night sharks. Of the data sources examined, we determined that only four data sources contained adequate information for the calculation of standardized catch rate series, as follows.

NEFSC Longline Surveys

The NMFS, and its predecessor agencies, the Bureau of Commercial Fisheries (BCF) and the Bureau of Sport Fisheries and Wildlife (BSFW), have conducted periodic longline surveys for swordfish, tuna, and sharks off the east coast of the United States since the early 1950's. The initiation of shark surveys in 1961 at the BSFW-Sandy Hook Marine Laboratory (SHML) responded to concerns about shark attacks off the coast of New Jersey and resort owner demands for legislation that would require sport and commercial fishermen to fish further offshore. While surveys predominantly relied on longline gear, early sampling also used chain bottom gear, gillnets, and sport fishing gear. In subsequent years, monitoring of sport fishing tournaments during summer months complemented dedicated surveys on research vessels and opportunistic trips aboard commercial and sport fishing vessels. Early experimentation with different tag types ultimately lead to the establishment of the ongoing Cooperative Shark Tagging

[9]Ingram, W. August, 2007. NMFS, Southeast Fish. Sci. Cent., P.O. Drawer 1207, Pascagoula, MS 39568. Personal commun.

Program currently based at the NMFS Narragansett Laboratory (NARR). After the initial coastal surveys were conducted between 1961 and 1965, there was a gradual transition from coastal work to offshore effort along the edge of the continental shelf and associated Gulf Stream waters. The shark research program moved from SHML to NARR in the early 1970's.

A total of 1,916 longline set records were recorded from historic cruise files. These included: 340 sets by the BSFW-SHML between 1961 and 1970; 1,488 sets on NMFS-NARR surveys between 1975 and 1996; 44 sets from cruises sponsored by other institutions where NARR staff participated; and 44 sets from opportunistic deployments of scientists aboard volunteer commercial vessels. Only sets that were conducted in depths greater than 100 m, surface water temperatures less than 30° Celsius, at latitudes of 39° or less, and with pelagic sharks as the target species were used in these analyses. Of the 1,916 total sets, 224 sets had sufficient data and were used to model catch rates of night sharks. Night sharks were represented in 10.7% of the sets. Factors considered in the generalized linear models of night shark catch rates were year, area (long. <34.5°W, long. 34.5–37°W, long. 37.1–39°W), season, temperature, and leader type (wire or monofilament).

The final generalized linear mixed model for NEFSC night shark catch rates included year as a single fixed factor in the binomial model of the proportion of positive sets and the factors year and area in the Poisson model of positive catch sets (Table 4). An offset of the natural log of the number of hooks was used in the Poisson model.

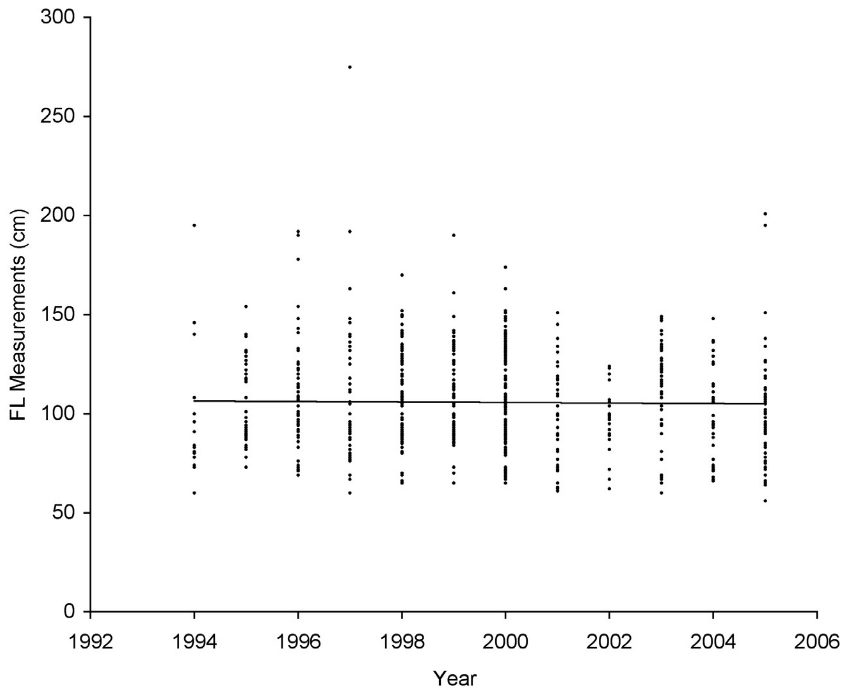

Figure 2.—Lengths of night sharks measured in the Pelagic Longline Observer Program, 1994–2006. The line indicates a linear regression fit to the data

There were no longline sets conducted in 1967, 1970, 1972, 1974, 1975, 1982, 1987, 1990, 1993, or 1995 that met the criteria for inclusion in these analyses. From the longline sets that were included, there were no catches of night sharks during 1968, 1969, 1976, 1977, 1978, 1983, 1988, 1989, 1992, 1994, or 1996. There is an overall decreasing trend in relative abundance for the NEFSC time series during the years covered from 1966 to 1996 (Figure 2). This trend is largely driven by the high relative abundance at the beginning of the time series (1966), which is the result of a single high catch set in a year with low effort (three sets total in 1966).

SEFSC Pelagic Data Program Longline Logbook

The Pelagic Longline Logbook (PLL) Data Program records the fishing and non fishing activity of fishermen who are required to report their fishing activity via logbooks submitted for each trip. The

Table 3.—A summary of data sets examined for the presence of night sharks. Years refers to the time period covered by the data set, beginning with the oldest. A year followed by a dash denotes an ongoing survey or program. Type refers to whether the index is from a commercial or recreational source, or is fishery-independent from a scientific survey. Area indicates the area covered by the survey or fishery. An asterisk indicates the series was utilized in a generalized linear model analysis.

Data Set	Years	Type	Area
SEFSC Mississippi Laboratories Historical Survey	1954–1957	Scientific Survey	Gulf of Mexico
NEFSC Laboratory Longline Surveys*	1961–1996	Scientific Survey	NW Atlantic Ocean
Japanese Commercial Logbook Program	1971–2006	Commercial	NW Atlantic Ocean
R/V *Geronimo* Longline Survey	1977–1994	Scientific Survey	NW Atlantic Ocean
Japanese Longline Observer Program	1978–1988	Commercial	NW Atlantic Ocean, Gulf of Mexico
Large Pelagic Survey	1986–	Recreational	Mid-NW Atlantic Ocean
Pelagic Longline Logbook Program*	1986–	Commercial	NW Atlantic Ocean, Gulf of Mexico
Pelagic Longline Observer Program*	1992–	Commercial	NW Atlantic Ocean, Gulf of Mexico, Caribbean Sea
Berkeley and Campos (1988)	1981–1993	Commercial	East Florida, Atlantic Ocean
Shark Bottom Longline Observer Program*	1994–	Commercial	NW Atlantic Ocean, Gulf of Mexico
Mississippi Laboratories Pelagic Longline Survey	2004–2006	Scientific Survey	NW Atlantic Ocean, Gulf of Mexico

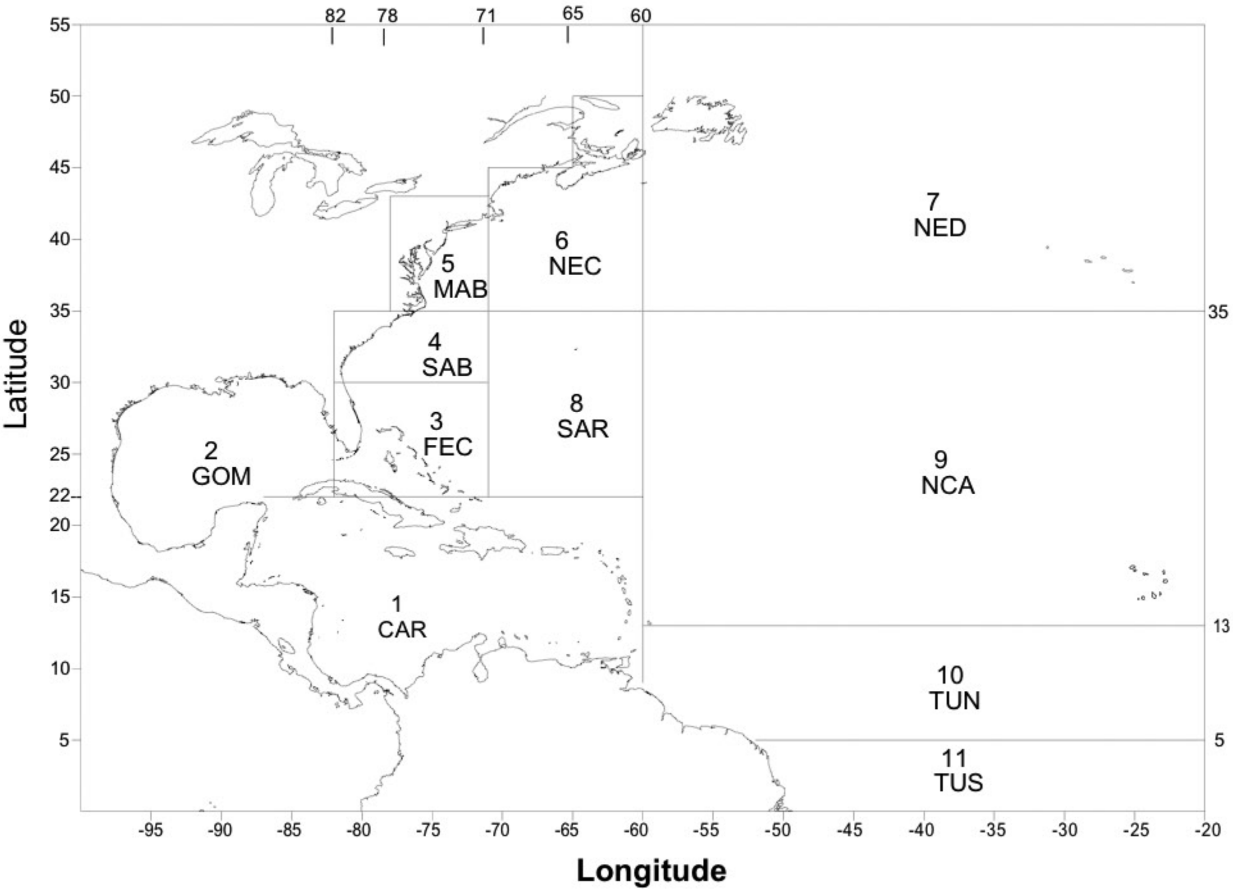

Figure 3.— Map of the western North Atlantic Ocean. Areas are as follows: 1) Caribbean Sea (CAR), 2) Gulf of Mexico (GOM), 3) Florida East coast (FEC), 4) South Atlantic Bight (SAB), 5) Mid-Atlantic Bight (MAB), 6) New England coastal (NEC), 7) Northeast distant waters (NED or Grand Banks), 8) Sargasso Sea (SAR), 9) North Central Atlantic (NCA), 10) Tuna North (TUN), and 11) Tuna South (TUS).

PLL was initiated in 1986 for the pelagic longline fishery in the U.S. northwest Atlantic Ocean, Gulf of Mexico, and Caribbean Sea. Because this fishery uses gear that is set for a relatively long period (6–10 h), catch and effort data are collected for each set. Fishermen are required to report the number of each species caught, the number of animals retained or discarded alive or discarded dead, the location of the set by statistical grid, the types and size of gear, and the duration of the set.

The longline fishing grounds for the U.S. fleets extend from the Grand Banks in the North Atlantic to lat. 5–10°S, off the South American coast, including the Caribbean Sea and the Gulf of Mexico. Eleven geographical areas of longline fishing are defined for classification. These include: the Caribbean Sea, Gulf of Mexico, Florida East Coast, South Atlantic Bight, Mid Atlantic Bight, New England coastal, Northeast distant waters, Sargasso Sea, North Central Atlantic, Tuna North, and Tuna South (Fig. 3).

Table 4.—Factors retained in the final models of proportion of positive sets (binomial) and positive catch (lognormal or Poisson) of night sharks for the generalized linear models with associated Akaike Information Criterion (AIC).

Data Set	Model	Factors	AIC
NEFSC Laboratory Longline Surveys	Binomial	Year	971.0
	Poisson	Year+Area	53.5
Pelagic Longline Logbook Program[1]	Binomial	Area+Swordfish Quartile+Year Year*Area Year*Quarter	30.4
	Lognormal	Year+Area+Tuna Quartile Year*Area Year*Quarter	28.2
Pelagic Longline Observer Program[1]	Binomial	Area+Year+Swordfish Quartile+Quarter Year*Quarter Year*Area Tuna Quartile*Area	25.2
	Lognormal	Area+Year+Quarter+Tuna Quartile+Lightstick Year*Quarter Year*Area	26.2
Shark Bottom Longline Observer Program	Binomial	Year	5444.1
	Lognormal	Year+Depth	27.2

[1] From Cortés et al. (2007).

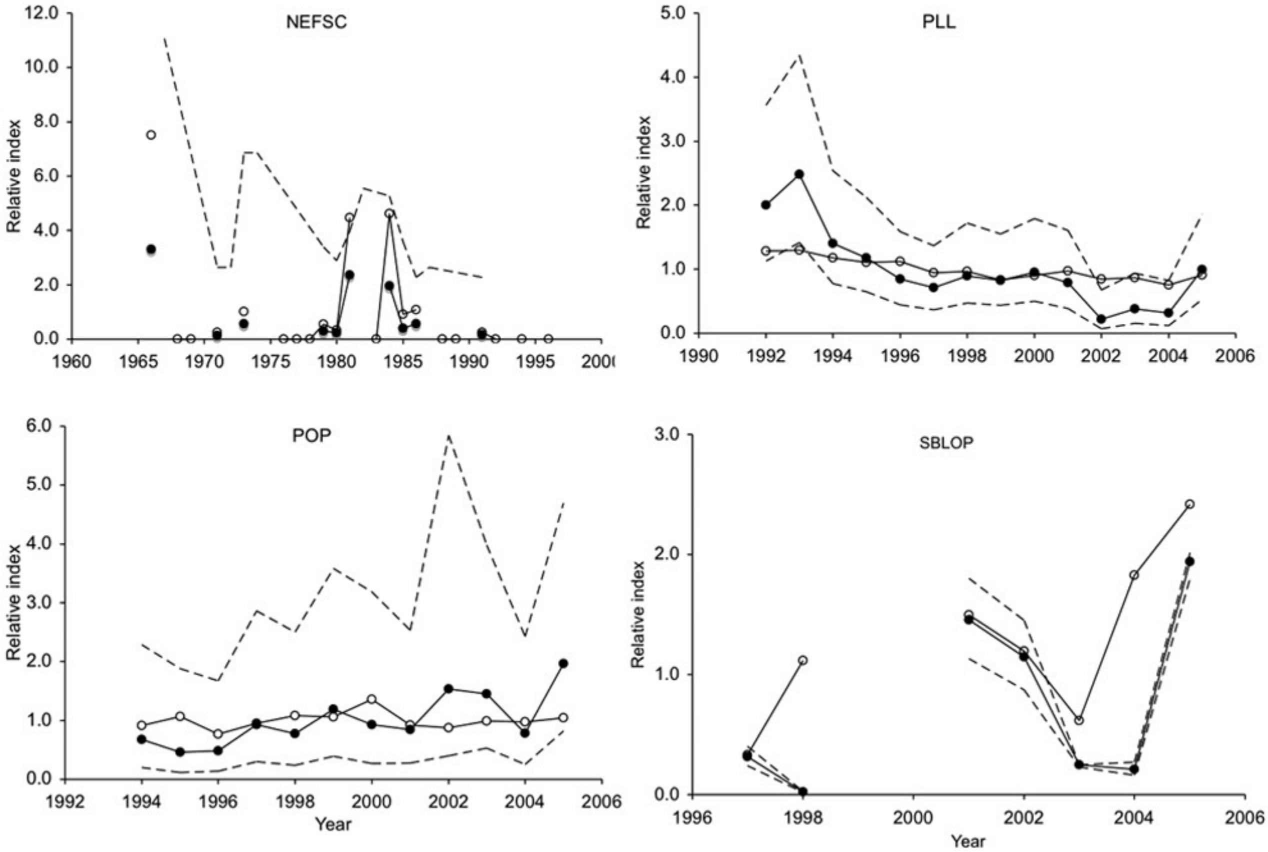

Figure 4.—Standardized relative index of abundance (solid circles) for night sharks from scientific surveys from the Northeast Fisheries Science Center (NEFSC), Pelagic Longline Logbook Program (PLL), Pelagic Longline Observer Program (POP), and the Shark Bottom Longline Observer Program (SBLOP) based on the final model. Nominal data (circles) are plotted for comparison. Confidence limits (95%) for the standardized index are dotted lines.

Data from the U.S. pelagic longline logbooks are available for 1986–2005. However, night sharks were not included in the logbooks until 1992. Night sharks made up 1.4% of the total recorded sets (2,567) since 1992. In a previous study, Cortés et al. (2007) standardized catch rates for night sharks based on methodology outlined in Brooks et al.[10] The effect of the following factors was considered in the generalized linear model: year, area, yearly quarter, fishing gear (bottom or pelagic longline), light sticks (1 or 0, depending on whether light sticks were used or not), and experiment (Y or N, depending on whether the observation was part of experimental fishing in the Northeast Distant Zone).

A proxy for target species was defined based on the proportion of swordfish or tuna catch to total catch per trip and was grouped into categories, corresponding to the quartiles 0–25%, 26–50%, 51–75% and 76–100% of these proportions (i.e. quartile for nominal tuna catch rate (per 1,000 hooks) and quartile for nominal swordfish catch rate (per 1,000 hooks)). This target variable was assumed to control for effects on night shark catch rates associated with changes of fishing operations when the fleets switch among targeted species. Further details of the results of the analysis are reported in Cortés et al. (2007).

The relative standardized index of abundance from that study initially decreased from 1992 to 1996 (Fig. 4). After 1996, the abundance index was relatively stable, with a decline in 2002 followed by an increase again in 2005 to levels prior to 2002. Overall, the logbook index showed a declining trend, largely driven by a steep decline from 1992 to 1993.

SEFSC Pelagic Data Program Longline Observer Program

The Pelagic Longline Observer Program at the NMFS SEFSC began in May of 1992. POP monitors the U.S. pelagic longline fleet ranging from the Grand Banks to Brazil and in the Gulf of Mexico. POP currently targets 8% coverage of the vessels based on the fishing effort of the fleet. Observers record fish species, length, sex, location, and other environmental information. The

[10]Brooks, E. N., M. Ortiz, L. K. Beerkircher, P. Apostolaki, and G. Scott 2004. Standardized catch rates for blue shark and shortfin mako shark from the U.S. pelagic logbook and U.S. pelagic observer program, and U.S. weightout landings. ICCAT working doc.: SCRS/2004/111, 18 p.

information collected is used to evaluate the harvest and status of the pelagic fish stocks and is important in assessing the effectiveness of management measures to control harvest levels.

Although the observer program has been in place since 1992, night sharks were not reported caught until 1994 (only 2 night sharks reported in 1993 and 1 in 1992). Night sharks were captured in 13.9% of the total observed sets since 1994. Cortés et al. (2007) also developed catch rates for night sharks based on this data source and methods similar to those described previously. In contrast to the pelagic logbook data, the relative abundance index based on observer data increased from beginning to end of the time series (Fig. 4). Relative abundance was 0.67 (lower 95% confidence limits (LCL)= 0.19, upper 95% confidence limits=2.29) sharks per 10,000 hooks in 1994 and 1.96 (LCL=0.82, UCL=4.69) sharks per 10,000 hooks in 2005.

SEFSC Shark Observer Program Bottom Longline

The shark bottom longline fishery is active in the Atlantic Ocean from about the Mid Atlantic Bight to south Florida and throughout the Gulf of Mexico. The bottom longline gear targets large coastal sharks, but small coastal sharks, pelagic sharks, and dogfish species are also caught. Observer coverage from 1994 through the 1st trimester season of 2005 was coordinated by the Commercial Shark Fishery Observer Program (CSFOP), Florida Museum of Natural History, University of Florida, Gainesville, Fla. (Burgess and Morgan[11]). Starting with the 2nd trimester season of 2005, responsibility for the fishery observer program was transferred to NMFS Southeast Fisheries Science Center's Panama City Laboratory.

Although data from the bottom longline observer program are available since 1994, night sharks were not reported caught until 1997. Since 1997, night sharks were reported on 2.2% of all observed hauls. Because most sets in this fishery were made with bottom longline gear that targeted coastal sharks, we believe many fishing trips that targeted coastal sharks had a low probability to capture night sharks. In the absence of detailed and reliable data regarding specific pelagic fishing location, bait choice, and other factors, we used an association statistic to attempt to identify trips with a higher probability of catching night sharks. The association statistic was developed using the species composition of the catch as described by Cass-Calay and Bahnick[12] and applied to goliath grouper, *Epinephelus itajara* (Cass-Calay and Schmidt[13]) and smalltooth sawfish, *Pristis pectinata* (Carlson et al., 2007):

$$\text{Association statistic} = \frac{\left(\dfrac{\text{Trips with Night Shark+Species} \times}{\text{Trips with Night Shark}}\right)}{\left(\dfrac{\text{Trips with Species} \times}{\text{Total Trips}}\right)}$$

We calculated the association statistic for all species reported by 100 or more fishing trips during 1997–2005. After calculating the association statistic, all trips were excluded from the 1997–2005 data set unless a trip kept or released a night shark or one of the top three species identified as an associate was kept or released. Bignose shark, *Carcharhinus altimus,* was calculated to have the highest associated statistic, followed by silky shark and scalloped hammerhead shark, *Sphyrna lewini*.

After refinement using the association statistic, night sharks were reported on 9.6% of all observed hauls. The effects of the following factors were considered in the generalized linear model: year, season, area, depth, bait type, hook type, and time of day. For the binomial model, year as a single fixed factor explained most of the deviance in the probability of catching at least one night shark. When modeling the positive trips, the factors year and depth explained the greatest deviance from the null model (Table 4). No interactions were found to be significant. The relative abundance based on bottom longline observer data indicated an increase in abundance (Fig. 4). Relative catch per unit effort increased from 0.31 (LCL=0.24, UCL=0.40) sharks per 100,000 hook hours in 1997 to 1.93 (LCL=1.80, UCL=2.01) sharks per 100,000 hook hours in 2005. Night sharks were not observed caught in 1999 or 2000.

Discussion

Several demographic and vulnerability criteria are considered when evaluating whether a species should be added, retained, or removed from the species of concern list. These criteria include distribution, including its natural rarity and endemism, abundance related to historic and recent magnitudes of decline, and life history characteristics, and productivity. We evaluated these criteria relevant to the night shark listing as a species of concern.

Distribution and Endemism

Night sharks do not appear to be naturally rare nor are they endemic to any discrete location in U.S. waters. An examination of all available data sources indicates night sharks are found along the outer continental shelf and upper slope areas throughout the Gulf of Mexico, in the northwest Atlantic Ocean as far north as Massachusetts, and in the Caribbean Sea (Fig. 5). Areas of concentration appear to be located off the east coast of Florida and South Carolina, and the Florida Straights, whereas night sharks are more uncommon in the Gulf of Mexico and in waters north of North Carolina (37°N latitude).

The distributional pattern of the night shark today appears to match well that of historical studies. Guitart-Manday

[11]Burgess, G. H. and A. Morgan. 2003. Commercial shark fishery observer program. Renewal of an observer program to monitor the directed commercial shark fishery in the Gulf of Mexico and south Atlantic:2002(2) and 2003(1) fishing seasons. Final Report, NMFS, Highly Migratory Species Manage. Div. Award NA16FM1598, 15 p.

[12]Cass-Calay, S. L., and M. Bahnick. 2002. Status of the yellowedge grouper fishery in the Gulf of Mexico: Assessment 1.0. NOAA, NMFS Sustain. Fish. Div. Contrib. SFD-02/03-172, 67 p.

[13]Cass-Calay, S. L., and T. W. Schmidt. 2003. Standardized catch rates of juvenile goliath grouper, *Epinephelus itajara*, from the Everglades National Park Creel Survey, 1973–1999. NOAA, NMFS, Sustain. Fish. Div. Contrib. SFD-2003-0016, 17 p.

(1975), Castro (1983), and Berkeley and Campos (1988) reported night sharks common in the southeast United States, especially in the Florida Straights. Early pelagic survey cruise records from the Gulf of Mexico rarely if ever reported the capture of night sharks (Bullis and Captiva, 1955; Wathne, 1959; Iwamoto, 1965). Recent scientific pelagic surveys in the Gulf of Mexico also report few captures ($n = 3$) of night sharks.[14]

Characteristics and Productivity

Life History

A comparison of life history traits for other pelagic sharks indicates night sharks exhibit intermediate age and growth characteristics to those of other pelagic sharks (Table 5). For example, the blue shark, *Prionace glauca*, has been reported to have growth completion rates (i.e. Brody growth coefficient, K) of 0.13 yr^{-1}, age at maturity of 5.0 yr, and longevity of 6–16 yr (Skomal and Natanson, 2003). Night sharks displayed lower K values (0.11 yr^{-1}) and higher age at maturity (10 yr) and longevity (17 yr) estimates. These growth characteristics are closest to those exhibited by the silky shark (K = 0.10 yr^{-1}, age at maturity = 12 yr, longevity = 22 yr) among pelagic species.

In addition to life history characteristics, night sharks exhibit population parameters that fall between those of the blue and porbeagle, *Lamna nasus*, sharks. Night sharks can be placed in the upper-half along the "fast-slow" continuum of life history traits and population parameters for sharks identified by Cortés (2002: Fig. 2). The night shark has moderate rebound potential and an intermediate generation time. In addition, probabilistic elasticity analysis indicated that population growth rates of night sharks are more sensitive to survival of the juvenile and adult stages than to fecundity, as is common for many sharks. Analysis of life history data indicated night sharks population growth rates (r) are on the order of 10% yr^{-1} when life history estimates simulate a maximum compensatory response. In contrast, species like porbeagle and dusky sharks (also species of concern) have considerably lower levels of productivity ($r \approx$ 2–5% yr^{-1}). Recent stock assessments indicate populations of porbeagle and dusky sharks have declined by up to 90% and 80% from virgin biomass, respectively (Campana et al., 2002; Cortés et al.[15]).

Figure 5.—Distribution of observed night sharks captured from all scientific surveys and observer programs.

Abundance

An analysis of trends in abundance from multiple data sources gave conflicting results. The single historic time series (NEFSC), spanning from 1961 to 1996, showed no clear trend in night shark relative abundance. Although this survey is long term, it came from areas that are primarily on the periphery of the night shark's range and likely do not represent core abundance estimates. The analysis of pelagic longline logbook data showed declines in relative abundance up to 55% since 1992. In contrast, the trend in abundance was positive for night shark from the pelagic longline observer program that samples the same universe of commercial fishing vessels although at a much reduced level (5–8%

[14]Cruise Results, 03/08/2005–04/06/2005, Pelagic Fish Longline Survey, NOAA Ship OREGON II, Cruise OT-05-02 (263), NMFS, Southeast Fish. Sci. Cent., Mississippi Lab., Pascagoula Facility, P.O. Drawer 1207, Pascagoula, MS 39568-1207, 15 p.

[15]Cortés, E., E. N. Brooks, P. Apostolaki, and C. A. Brown. 2006. Stock assessment of dusky shark in the U.S. Atlantic and Gulf of Mexico. NOAA, NMFS, Southeast Fish. Sci. Cent., Sustain. Fish. Div. Contrib. SFD-2006-014, 155 p.

Table 5.—A comparison of life history characteristics and population parameter estimates for the night shark derived in this study with those for other pelagic species. Values reported are for females. Age, growth, and reproductive information was summarized from studies by Castro and Mejuto (1995), Bonfil et al. (1993), Mollet et al. (2000), Lessa et al. (1999), Natanson et al. (2002), Jensen et al. (2002), Skomal and Natanson (2003), and Natanson et al. (2006). Productivity values are from Au et al. (In press) but may have used vital rates different from those listed here for calculation. All other values are from Cortés (in press).

Species	K (yr^{-1})	Longevity (yr)	Age at maturity (yr)	Fecundity (yr^{-1})	Generation time (T; yr)	Population growth rate (λ; yr^{-1})	Productivity ($r_{Z=1.5M}$)
Night	0.11	17	10	5.5	13.8	1.10	0.021
Blue	0.13	16	6	18.5	8.4	1.25	0.060
Oceanic whitetip	0.09	11	4.5	3.1	11.1	1.07	0.066
Porbeagle	0.06	25	13	4.0	18.5	1.05	—
Shortfin mako	0.09	32	18	4.2	24.8	1.01	0.049
Silky	0.10	22	12	5.1	14.3	1.08	0.042

of total effort) compared to the pelagic logbook data. The trend in abundance from the bottom longline observer program also indicated an increase in relative abundance.

Linear regression analysis of each CPUE series on year shows that only two of the four series had statistically significant slopes (Table 6). The pelagic logbook series decreased about 9% per year, while the pelagic longline observer series increased about 9% per year. The NEFSC data decreased about 1% per year while the shark bottom longline observer increased about 20% per year, but neither of these trends was statistically significant.

Table 6.—Results of linear regression analysis on relative catch rates. S.E.= standard error.

Data set	Years	Slope	Slope S.E.	R^2	Significance F
NEFSC Laboratory Historical Longline Survey	1961–1996	–0.017	0.015	0.04	0.257
Commercial Pelagic Longline Logbook Program	1992–2005	–0.089	0.021	0.59	0.001
Pelagic Longline Observer Program	1994–2005	0.093	0.026	0.56	0.005
Shark Bottom Longline Observer Program	1997–2005	0.219	0.138	0.26	0.158

The changes in relative abundance obtained from the observer data could be the result of factors unaccounted for in the analysis. At the initiation of the pelagic longline observer program, observers reported very few night sharks, but many more were reported as the observer program developed. The increasing trend could be related to better observer identification skills as the program developed, whereas during the early years of the pelagic longline observer program observers were more likely to misidentify night sharks or report them as "unidentified sharks" (Beerkircher et al. 2002; Cortés et al., 2007). Similarly, increases in night sharks from the shark bottom longline observer program could be in part the result of changes in vessel selection. In the early years of the shark bottom longline program, observer coverage was voluntary, which limited the spatial and temporal sampling of animals caught in this fishery. After 2001, observer coverage became mandatory, and vessel selection increased to the entire sampling universe of the fishery.

Confusion over reporting practices, misreporting, and species misidentification could explain in part the decline in night sharks from the analysis of the pelagic logbook data. Before implementation of the first U.S. Atlantic Shark Management Plan in 1993, all fishermen targeting sharks or other pelagic longline fishermen targeting swordfish or tunas reported shark landings in the pelagic longline logbook. However, after implementation of the management plan, fishermen could temporarily report to a new logbook program designed for fishermen targeting sharks from 1993 to 1995. After 1995, fishermen again had the option to continue reporting to the pelagic longline program or to a coastal fisheries logbook program that also includes longline gear. There is also a tendency to under-report bycatch over time as fishermen develop a growing perception that those reports result in increasingly restrictive management regimes (Cortés et al., 2007). Additional factors that may have affected the analyses are confusion of night sharks with silky and dusky sharks, changes in hook size and type which are not reported in the logbooks, and fishing depth related to the tuna species targeted.

Despite the uncertainty and caveats associated with these analyses, night sharks are still a relatively common species. Information from the pelagic longline observer program indicates that night sharks are not rare and currently are the third-most abundant shark species captured in the pelagic longline fishery off the southeast United States (Beerkircher et al. 2002). Scientific survey operations in the western North Atlantic Ocean since 2004 also report the frequent capture of night sharks especially in areas off North Carolina.[16] Average size since the early 1980's has remained relatively stable suggesting that growth overfishing has not been occurring. Moreover, if we consider removing the first few years (e.g. 1992–93 for the pelagic logbook and 1994–95 for the pelagic observer programs) when uncertainties with reporting practices for logbooks and species identification may have occurred, the trend in abundance is relatively stable with some potential increases in night sharks in the pelagic observer data.

Conclusion

Night sharks are not naturally rare nor endemic to any discrete location in U.S. waters, have moderate rebound potential, and are among those sharks on the upper-half along the "fast-slow" continuum of life history traits and population parameters as described in Cortés (2002). Further, abundance

[16]Cruise Results, 02/01/2006-03/21/2006, Longline Survey Pelagic Sharks and Finfish, NOAA Ship OREGON II, Cruise OT-06-02 (269), NMFS, Southeast Fish. Sci. Cent., Mississippi Lab., Pascagoula Facility, P.O. Drawer 1207, Pascagoula, MS 39568-1207, 10 p.

data indicates night sharks have not suffered large magnitudes in decline. Thus, based on the analysis of all current available information, we believe the night shark should be removed from the NMFS species of concern list but retained on the prohibited species list as a precautionary approach to management until a more comprehensive assessment of the status of the stock can be conducted.

We recognize that the U.S population of night sharks is highly "conservation-dependent" and can be affected by fishing pressure, as is the case for populations of other pelagic and large-bodied coastal sharks. However, unless there is some major change in pelagic fishing effort or in the population's migratory patterns, the current protection afforded this species by the Consolidated Atlantic Highly Migratory Species Fishery Management Plan (NMFS, 2006) (i.e. prohibited species status) should ensure the species does not suffer any increased reduction in population size. Night shark landings were likely both over- and under-reported in the past and they probably do not reflect all commercial landings and overall have limited relevance to the current status of the species. However, landings data do provide corroborative evidence that in some cases the prohibited status of night sharks has reduced harvesting of the species since 2002.

Our conclusion is inconsistent with information presented in Castro et al. (1999), who reported a large decline (as a percentage of sharks caught) in night sharks since the 1930's and 1940's. Castro et al. (1999) also indicated that night sharks are currently rare off the southeast United States. However, much of the information presented in Castro et al. (1999) was from non-standardized catch information, and areas outside U.S. waters (e.g. northwest coast of Cuba). The reported declines could have been the result of local population reductions off Cuba, changes in fishing and marketing tactics, or problems with species identification. While it is likely that populations of night sharks have declined relative to virgin biomass, the magnitude of the decline is likely not as great as that indicated by Castro et al. (1999).

The use of relative abundance indices as indicators of population status for sharks without complete assessment models has been the subject of debate (Burgess et al. 2005a, b; Baum et al., 2005). In lieu of a full stock assessment, we have attempted to assess the status of night sharks using a combination of catch, catch rates, and productivity of the species. After careful examination of available information it is likely the available data, in particular catch data, are insufficient for a full stock assessment model. However, in data-poor situations, Porch et al. (2006) proposed the use of a "catch-free" stock assessment model that has been used for assessment of goliath grouper (Porch et al., 2006), blue sharks (ICCAT, 2004), shortfin makos (ICCAT, 2004), and dusky sharks (Cortés et al.[15]). Future research could attempt the application of a "catch-free" model for the assessment of night sharks. However, we feel the application of this model will likely result in high levels of uncertainty with potentially the same conclusion we have derived herein.

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