

## **Part III**

# **ASSESSMENT OF THE IMPACT OF THE PELAGIC LONGLINE FISHERY ON LOGGERHEAD AND LEATHERBACK SEA TURTLES OF THE NORTH ATLANTIC**

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# CHAPTER 1. DESCRIPTION OF THE ATLANTIC OCEAN AND MEDITERRANEAN SEA PELAGIC LONGLINE FISHERIES

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The United States is one of at least 23 other countries that fished in the Atlantic Ocean and Mediterranean Sea with pelagic longlines during 1990-1997 (Carocci and Majowski 1998). The Atlantic pelagic longline fisheries typically consist of a free floating mainline that supports multiple baited gangions. Pelagic longline vessels target sharks (*Carcharinus spp.*), swordfish (*Xiphias gladius*), and various tunas (*Thunnus spp.*), particularly yellowfin, bigeye, and albacore, depending on season and geographic location. The various swordfish fisheries in the Atlantic Ocean and Mediterranean Sea have recently been described by Folsom (1997a,b, Folsom *et al.* 1997, Brewster-Geisz *et al.* 1997, Barrett *et al.* 1998, Weidner and Arocha 1999, Weidner *et al.* 1999a,b). The fisheries are extensive, diverse, and dynamic and are economically important. The fishermen are able to change gear configurations and fishing strategies, depending on target species, location, and time of year. Domestically, the U.S. pelagic longline fishery has been described from a mandatory logbook system implemented and managed by the National Marine Fisheries Service (NMFS), Southeast Fisheries Science Center (SEFSC) in Miami, Florida (Cramer and Adams 2000). Additional information on the U.S. longline fleet is from the NMFS, SEFSC pelagic observer program (Lee and Brown 1998). Hoey and Moore (1999<sup>1</sup>) also provide a summary description of the U.S. pelagic longline fishing gear, fishing strategy, and catch composition using observer data and Witzell (1999) provided a description of distribution and relative abundance sea turtle takes by the U.S. longline fleet using NMFS, SEFSC 1992-1995 logbook data.

Most of the foreign high seas fisheries in the Atlantic Ocean are basically similar to those of the United States, in that they fish multiple days and fish many miles of line per day. However, the Mediterranean longline fisheries of Italy, Greece, and Malta, apparently fish smaller vessels than the larger oceanic fleets. They set once per night, relatively close to shore, and return to port between sets (Argano *et al.* 1992, De Metrio *et al.* 1983, Gramentz 1989, Panou *et al.*, 1991<sup>2</sup>, 1992<sup>3</sup>).

Most nations that fish pelagic longline gear in the North and South Atlantic Oceans, Gulf of Mexico, Caribbean Sea, and Mediterranean Sea belong to the International Commission for

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<sup>1</sup> Hoey, J.J. and N. Moore. 1999. Captain's report: multi-species catch characteristics for the U.S. Atlantic pelagic longline fishery. MARFIN Grant – NA77FF0543 and SK Grant – NA86FD113 from National Marine Fisheries Service, Silver Spring, MD to National Fisheries Institute, Inc., Arlington, VA., 78 pp.

<sup>2</sup> Panou, A., S. Moschonas, L. Tselentis, and N. Voutsinas. 1991. Incidental catches of loggerhead turtles, *Caretta caretta*, in swordfish long lines in the Ionian Sea, Greece. Unpublished Report. Institute of Zoology University of Munich, Federated Republic of Germany, Munich, 6 pp.

<sup>3</sup> Panou, A., G. Antypas, Y. Giannopoulos, S. Moschonas, D. Mourelatos, G. Mourelatos, Ch. Mourelatos, P. Toumazatos, L. Tselentis, N. Voutsinas, and V. Voutsinas. 1992. Incidental catches of loggerhead turtles, *Caretta caretta*, in swordfish long lines in the Ionian Sea, Greece. Unpublished Report. Institute of Zoology University of Munich, Federated Republic of Germany, Munich, 8 pp.

the Conservation of Atlantic Tunas (ICCAT). This is the international research and management organization that manages the tuna and billfish species affected by longlines in the Atlantic Ocean. Fisheries data such as yield (landings), catch per unit effort (CPUE), individual sizes and weights are collected by ICCAT countries and used in stock assessments and for regulatory considerations. There are many countries that fish pelagic longlines in the Atlantic and Mediterranean Sea, and other countries may move from one geographic area to another, changing target species depending on fishing success and ICCAT regulations. Some fishing vessels operate under another nation's flag or otherwise do not report landings under any particular country. These landings are designated NEI (Not Elsewhere Included).

The reported longline yields of swordfish and tunas were tabulated from the ICCAT data base (CATDIS, found at [www.iccat.org](http://www.iccat.org) or [www.iccat.es](http://www.iccat.es) under the Statistics and Monitoring Section). These data are sent to the United Nations Food and Agricultural Organization (FAO) for inclusion in the Atlas of Tuna and Billfish Catches (Carocci and Majkowski 1998). The CATDIS data were summarized by region, year (1990-1997) and species group (tunas and swordfish) for the U.S. and for all other nations combined. Regions were defined as Mediterranean Sea, North Atlantic (data coded north of 9° N) and tropics (data coded as 10° south of the equator to 9° north of the equator). Note that data are coded for 1° square cells and are labeled with the degree latitude of its southern boundary. Thus, data coded as 9°N represents yield attributed to fishing between 9° and 10°N. Consequently, although we refer to the Tropics as 10°S to 9°N, that represents fishing between 10°S and 10°N. Similarly the North Atlantic, labeled as >9°N, represent fishing at and north of 10°N.

Swordfish and tuna landings were summarized by nation for the years 1990-1997 combined (Figures 1-3). Countries with relatively little yield were eliminated for graphics clarity. However, these countries will be listed in descending order of yield value. The United States pelagic longline fleet is a major producer of swordfish and tuna in the north Atlantic. The U.S. fleet is of less importance in the tropics, and is not a component of the Mediterranean Sea fishery.

North Atlantic (Fig. 1):

The top three countries landing swordfish were Spain, United States, and Canada, and the top producers of tunas were Japan, Taipei, and United States. The following countries landed less than 1,800 mt of swordfish: Taipei, Brazil, NEI, Trinidad, Morocco, Cyprus, Venezuela, Korea, Mexico, Cuba, United Kingdom, Bermuda, Peoples Republic of China, and Grenada. The following countries landed less than 1,800 mt of tunas: Canada, Belize, Grenada, Brazil, Peoples Republic of China, Cuba, France, and Ireland.

Tropics (Fig. 2):

The top producers of swordfish were Spain, Japan, and Taipei, and the top producers of tunas were Japan, Taipei, and Honduras. The following countries landed less than 2,500 mt of swordfish: Brazil, United States, Korea, Portugal, Cuba, Peoples Republic of China, and Equatorial Guinea. The countries that landed less than 2,500 mt of tunas were Spain, Libya, United States, Cuba, Venezuela, Peoples Republic of China, USSR, Portugal, and Equatorial Guinea.

Mediterranean Sea (Fig. 3):

The top producers of swordfish were Italy, Greece, and Morocco, and the top producers of tunas were Italy, NEI (Not Elsewhere Included), and Spain. Those countries reporting less than 500 mt for swordfish were Malta and Japan, and those countries reporting less than 500 mt of tunas were NEI, Cyprus, Peoples Republic of China, Croatia, and Taipei.

The U.S. portions of the total catches are shown in Figures 4 and 5. It is unclear how well yields of one target species will reflect the relative efficiency of a fleet at catching other species, *e.g.* sea turtles. To examine the indications of U.S. fishing efficiency relative to swordfish and tunas, sample CPUE data from ICCAT were examined for 1990-1996. Catch in that data set were primarily recorded in number of fish. The sampled CPUE data (Figures 6-9) indicates that the U.S. accounted for less than 10% (5%-8%) of the sampled hooks fished in the North Atlantic Ocean. If total numbers of hooks (effort) data were available for all nations, it is expected that the U.S. proportion would be lower. This is because a large fraction of the total U.S. pelagic longline effort is included in the sample, while other nations do not report sampled effort and, of those nations that do report samples, it is not known what fraction of fishing effort is actually reported.

In the North Atlantic, the U.S. fleet was roughly 4-8 times more efficient (proportion catch/proportion hooks) than the other fleets at catching swordfish and about 2-3 times more efficient at catching tunas (Figure 6). There was less information on U.S. fishing in the Tropics (Figure 8) because of less effort, but the calculated efficiencies were generally lower for swordfish (from equally efficient to 12 times more efficient with all but 2 years at roughly equal efficiency to 3 times more efficient.), and lower for tunas (about 1.5-2 as efficient). Examination of a subsection of the North Atlantic (Caribbean) revealed markedly different efficiencies. The U.S. fleet was about 3-5 times more efficient at catching swordfish, but less efficient than other sampled fleets at catching tunas (from about 0.1 to about 0.3 times as efficient). In summary, it appears that:

1. The U.S. longline fleet accounts for a relatively small proportion of total hooks fished in the Atlantic Ocean.
2. The relative fishing efficiency of the U.S. fleet at catching swordfish and tunas varies spatially, and probably temporally.
3. There likely are differences that occur in fishing efficiencies at catching non-target species (including sea turtles) between fleets both temporally and spatially.

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## North Atlantic

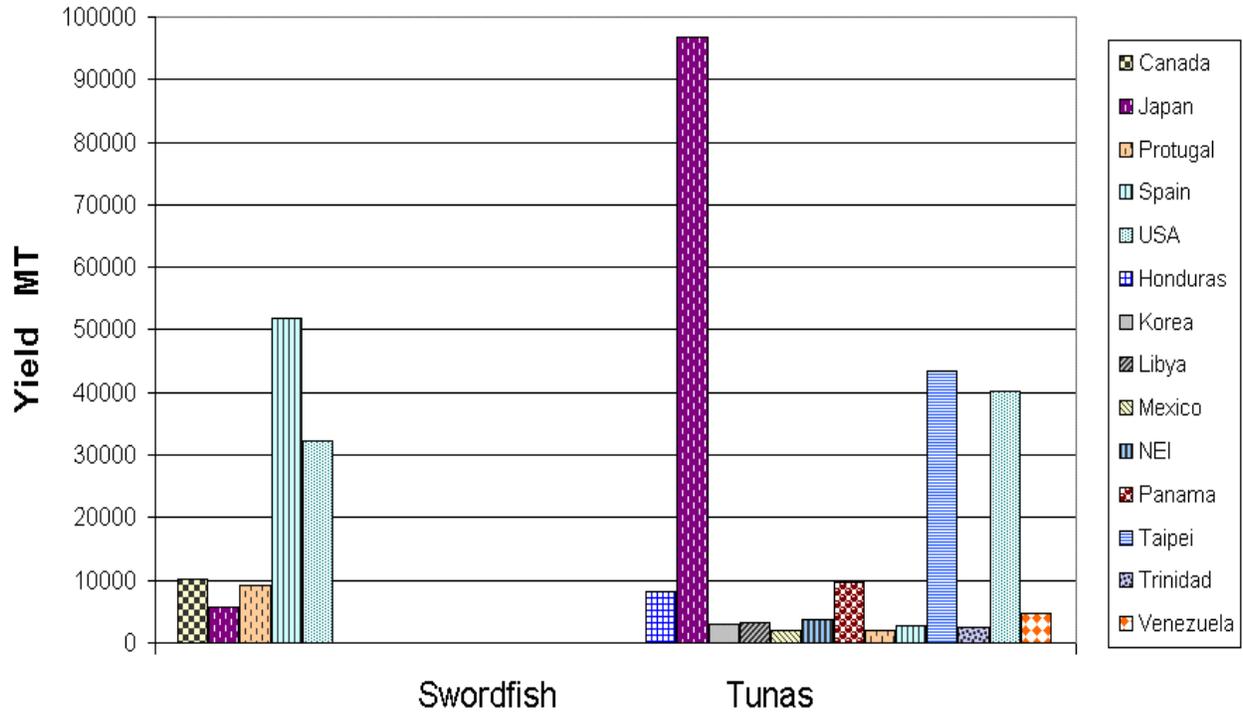


Figure 1. Yield of swordfish and tunas from the North Atlantic Ocean (Data from Carocci and Majkowski 1998).

Nations with yields <1800 MT were not included in this graph. Listed in descending order for swordfish these include Taipei, Brazil, NEI, Trinidad, Morocco, Cyprus, Venezuela, Korea, Mexico, Cuba, UK, Bermuda, Peoples Republic of China, and Grenada. For tunas these include Canada, Belize, Grenada, Brazil, Peoples Republic of China, Cuba, France, and Ireland.

## Tropics

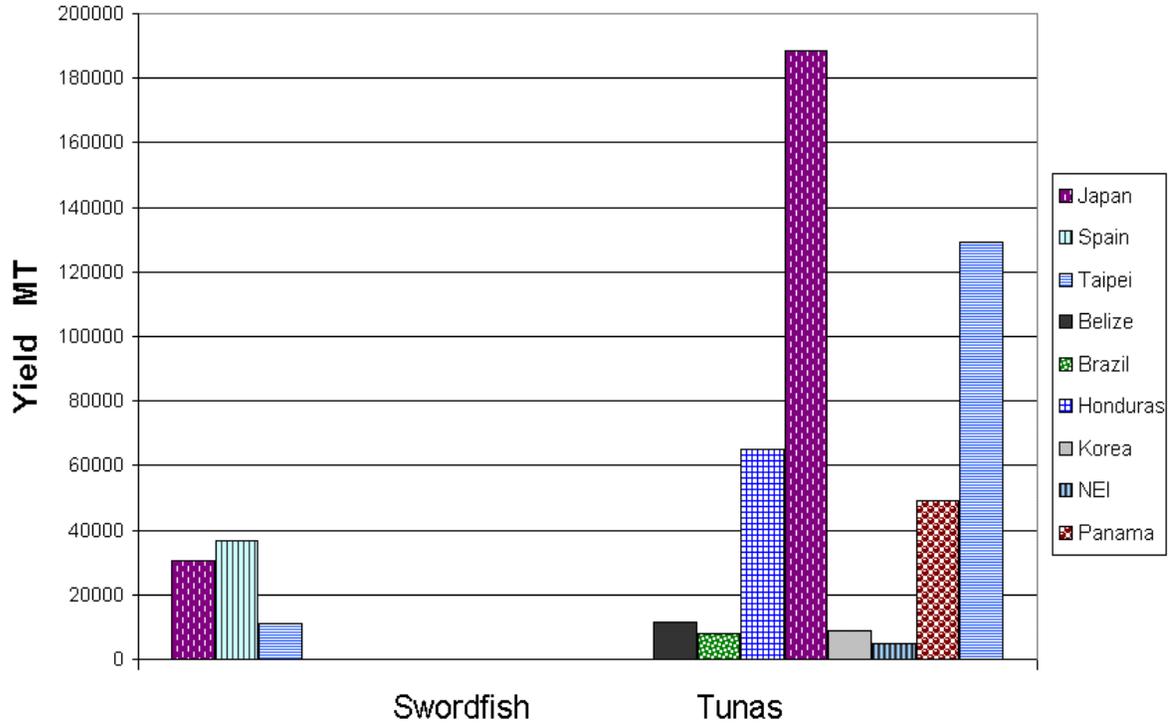


Figure 2. Yield of swordfish and tunas from the Tropical Atlantic Ocean (Data from Carocci and Majkowski 1998).

Nations with yields < 2500 MT were not included in this graph. Listed in descending order for swordfish these include Brazil, U.S.A, Korea, Portugal, Cuba, Peoples Republic of China, and Equatorial Guinea. For tunas these include Spain, Libya, U.S.A, Cuba, Venezuela, Peoples Republic of China, USSR, Portugal, and Equatorial Guinea.

## Mediterranean

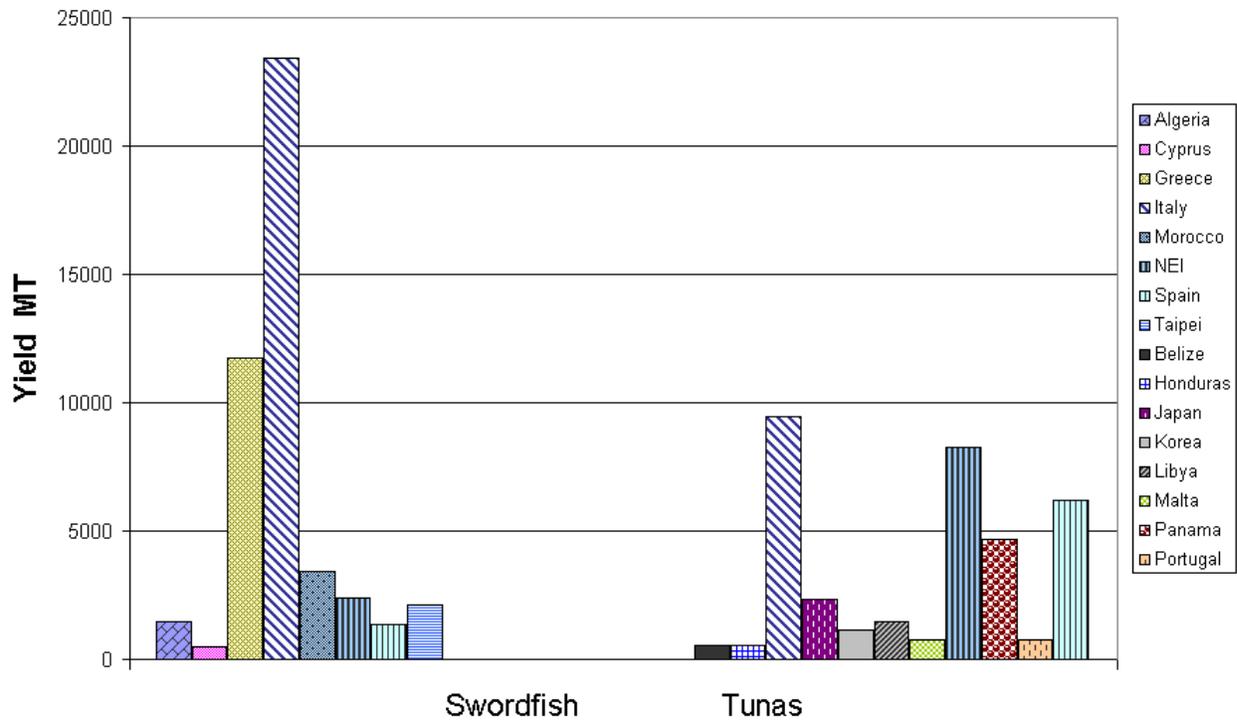


Figure 3. Yield of swordfish and tunas from the Mediterranean Sea (Data from Carocci and Majkowski 1998).

Nations with yields < 500 MT were not included in this graph. Listed in descending order for swordfish these include Malta and Japan. For tunas these include NEI, Cyprus, Peoples Republic of China, Croatia, and Taipei.

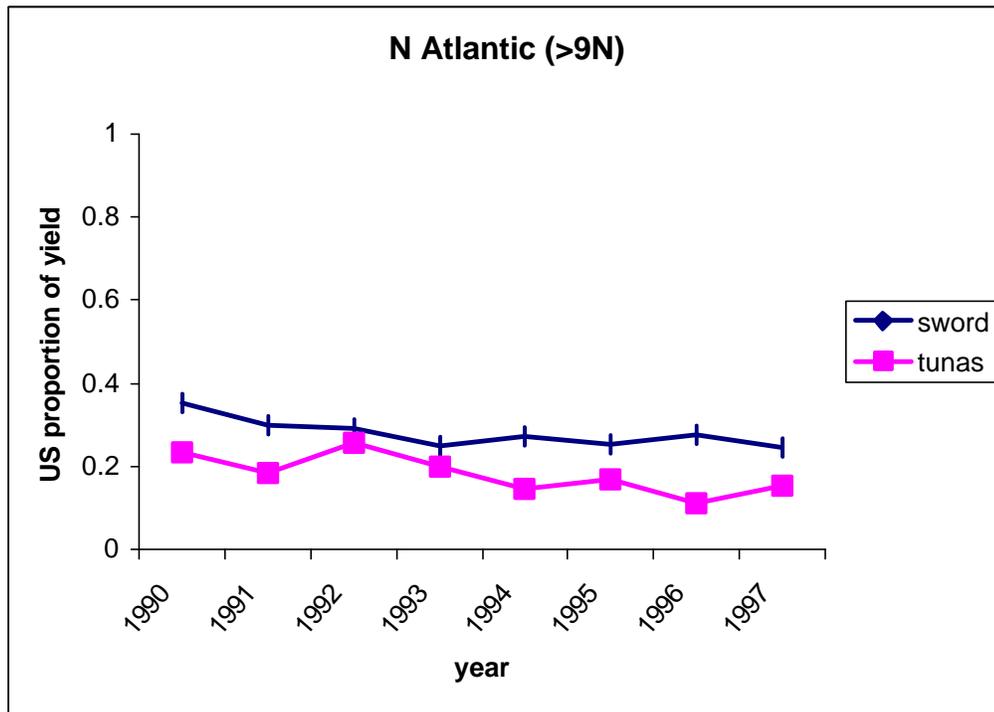


Figure 4. Proportion of the total yield of swordfish and tunas taken from the North Atlantic by the U.S. pelagic longline fleet.

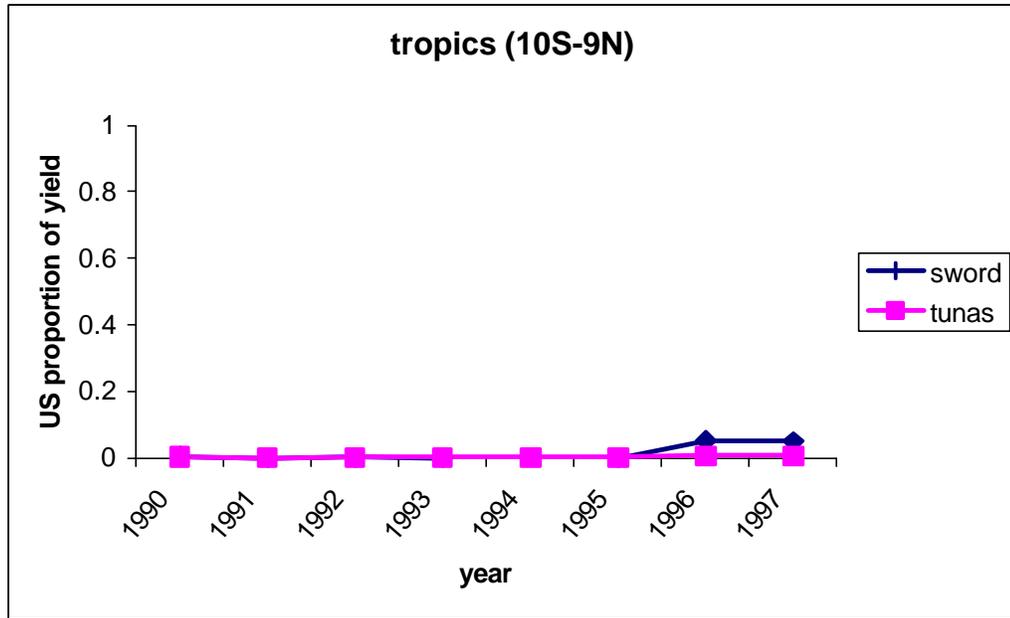


Figure 5. Proportion of the total yield of swordfish and tunas taken from the Tropical Atlantic by the U.S. pelagic longline fleet.

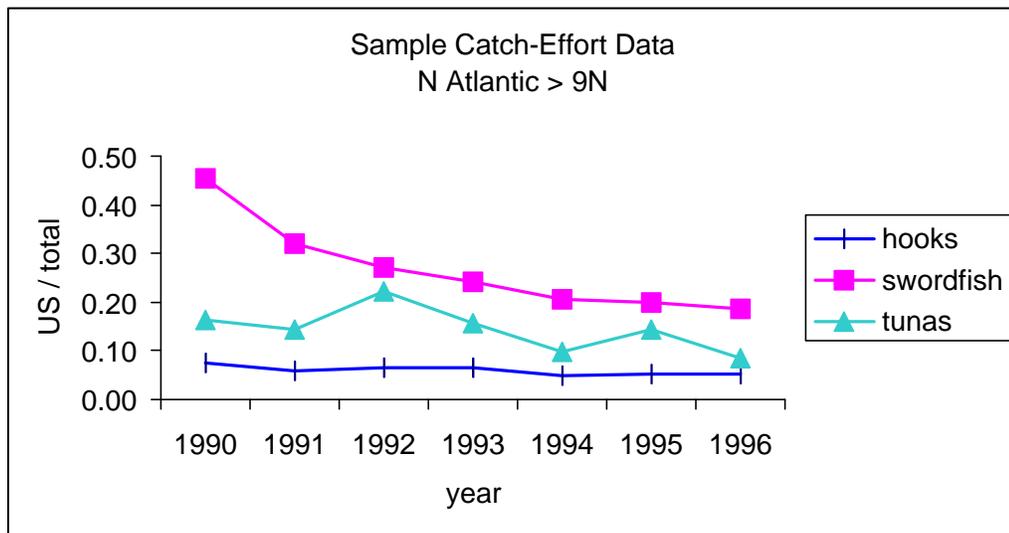


Figure 6. Proportion of total hooks, swordfish and tunas (in numbers of fish) in ICCAT catch/effort samples from the North Atlantic accounted for by the U.S. pelagic longline fleet.

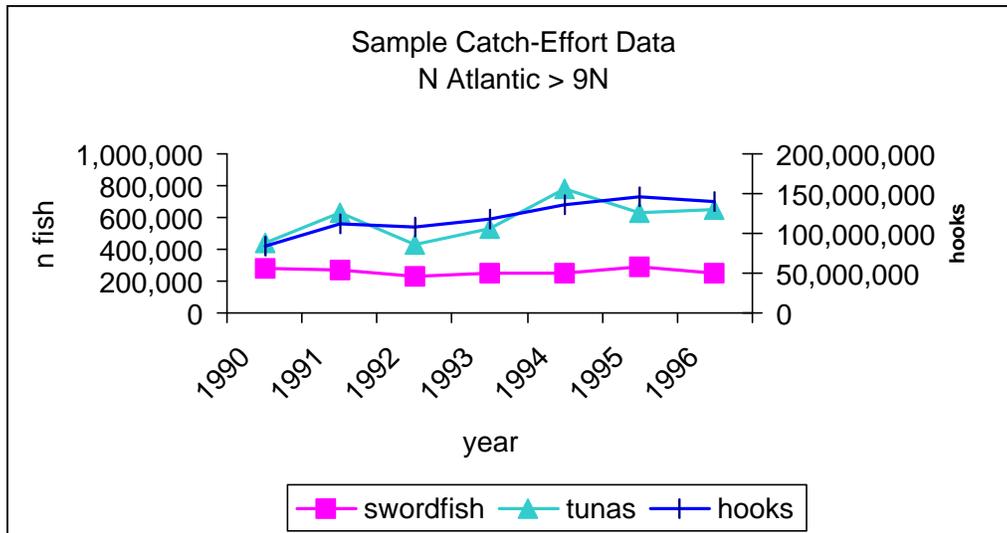


Figure 7. Numbers of hooks, swordfish and tunas, from ICCAT catch/effort samples from pelagic longliners in the North Atlantic.

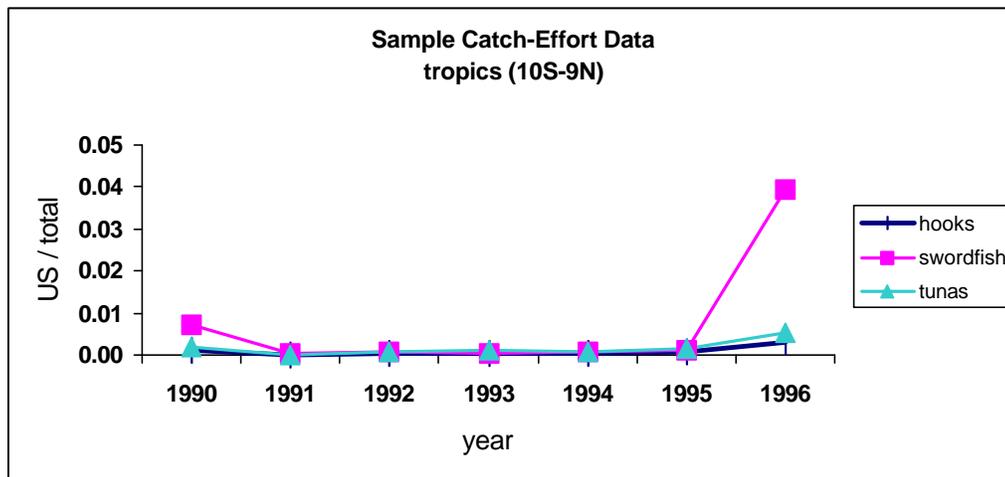


Figure 8. Proportion of total hooks, swordfish and tunas, (in number of fish) in ICCAT catch/effort samples from the Tropical Atlantic accounted for by the U.S. pelagic longline fleet.

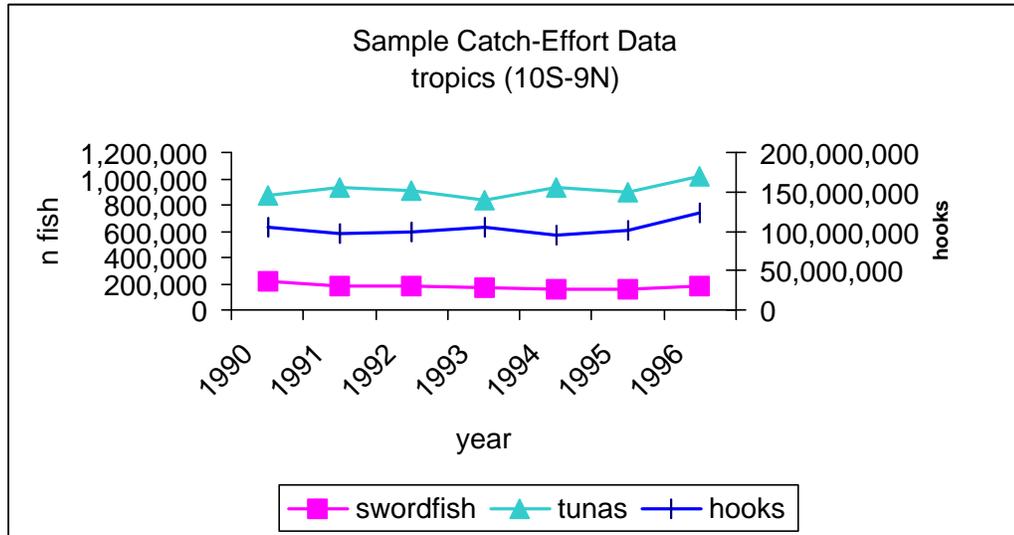


Figure 9. Numbers of hooks, swordfish and tunas, recorded in ICCAT catch/effort samples from pelagic longliners in the Tropical Atlantic.

## CHAPTER 2. ANALYSIS OF MARINE TURTLE BYCATCH BY THE U.S. ATLANTIC PELAGIC LONGLINE FLEET

Cynthia Yeung

### Introduction

The U.S. pelagic longline fleet targeting tuna (*Thunnus spp.*) and swordfish (*Xiphias gladius*) in the North Atlantic (including the Caribbean Sea and the Gulf of Mexico) occasionally interacts with marine turtles (Berkeley *et al.* 1981; Hoey and Bertolino 1988). Turtles are hooked or entangled, resulting inevitably in injury or in extreme cases, death. In this paper, the bycatch of marine turtle by the said fleet in 1992-1999 is estimated and factors that influenced bycatch rates are examined.

The bycatch of marine turtles by the U.S. pelagic longline fishery in 1992-1997 and 1998 has been estimated previously using the delta-lognormal method (Pennington 1983). The bycatch estimates were based on a random sample of the longline fishing vessels on which trained observers were placed. Due to the random nature of the sampling and relatively low sampling fractions, not all time-area strata have been observed. Thus, pooling observations between strata is necessary to estimate fleet-wide bycatch. In several previous reports (Johnson *et al.* 1999; Yeung 1999*a,b*), the robustness of the bycatch estimates from several different pooling schemes for bycatch rates were examined, from the lowest level of pooling (stratified estimates by year-quarter-grouped fishing area (NAREA)) to the highest level of pooling (stratified estimates by year-large fishing region (MAREA), where MAREA is the result of pooling NAREA). For those analyses, however, no estimates were made for strata that remained without observed effort after pooling, even though there was unobserved effort reported by the fishing fleet.

Here, the delta-lognormal method is again used to obtain estimates of the mean and variance of longline turtle bycatch for 1992-1999, but a criterion of a minimum number of observed sets ( $N_{min}$ ) is used to determine the level of pooling from which to estimate bycatch rates for a time-area stratum. By this approach, estimates are made for all strata. This method was applied effectively to the estimation of tuna and swordfish catches by the U.S. Atlantic pelagic longline fleet (Brown, in press). A preliminary report on the estimated bycatch of marine turtles and mammals based on this method has been prepared earlier (Yeung *et al.* 2000<sup>4</sup>). According to this pooling method, the levels of 1) quarter, 2) year and 3) NAREA are successively pooled in that order until the criterion is met. The order of pooling followed the increasing order of significance of these three factors in an ANOVA model on bycatch rate. With this dynamic pooling method, if observer effort is adequate according to  $N_{min}$  in a basic year-quarter-NAREA

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<sup>4</sup> Yeung, C., S. Epperly, and C. A. Brown. 2000. Preliminary revised estimates of marine mammal and marine turtle bycatch by the U.S. Atlantic pelagic longline fleet, 1992-1999 National Marine Fisheries Service Miami Laboratory PRD Contribution Number 99/00-13, SEFSC Miami, Fla. Revised tables with estimates through 1999 are in Appendix 3 and data on turtles observed in 1999 and 2000 are in Appendix 3 and turtles and observers comments are detailed in Appendix 4.

stratum, then an estimate is obtained based on the observed bycatch rate of the stratum and the data independence of the basic stratum is maintained; otherwise, bycatch rate will be extrapolated from some other strata that ideally should have similar characteristics. The main objective is to avoid leaving empty cells with no estimates available. Results from this delta-lognormal- $N_{min}$  method are compared with an alternative estimation method using generalized linear modeling (GLM) with the delta approach (Stefánsson 1996). GLM and regression trees methods are also used to shed light on the factors that influence the bycatch rates of marine turtles.

## **Methods**

### ***Data Sets***

Systematic sampling by scientific observers on board U.S. pelagic longline vessels in the Atlantic permitted to land and sell swordfish was implemented in 1992, under the mandate of the 1991 amendments to the U.S. Fishery Management Plan (FMP) for Atlantic Swordfish. The estimated bycatch rates of marine turtles in the pelagic longline fishery are based on observer sampling data collected and maintained by the NMFS Southeast Fisheries Science Center (SEFSC) (Lee and Brown 1998).

The Atlantic Large Pelagic Logbook database, also maintained by the SEFSC, contains daily fishing effort reported by all U.S. Atlantic longline vessels landing swordfish and tuna as required under the Atlantic Swordfish Fishery Management Plan since 1986 (Cramer and Adams 2000). Notwithstanding errors due to misreporting, fishery-reported effort from the logbook (reported effort) is taken to represent the actual permitted effort expended by the U.S. pelagic longline fleet in the North Atlantic.

Observed bycatch rates are raised to the amount of reported effort in the logbook for estimating total bycatch. The unit of effort is an individual set (gear deployment) that fished at least 100 hooks and included tunas and/or swordfish among the declared target species – application of this criterion results in reported effort about 10% higher compared to effort reported to target only tunas and/or swordfish. Effort is grouped by fishing area, the smallest area grouping is AREA (Fig. 1). The eleven AREAs are further grouped into six NAREAs, which are the areal strata used here for bycatch analysis. Effort missing location data are proportionally distributed among AREAs based on the distribution of known set locations for the pertinent year and calendar quarter. Effort missing calendar quarter data within a fishing area are proportionally distributed among quarters based on the distribution of effort across quarters within the area. Only about 1% of the effort data are missing time and/or area information.

Apart from systematic revisions to the data sets since the previous reports that may have led to changes, the effort data are treated slightly differently compared to previous reports. The fishing location was previously defined by where the longline was set to begin fishing, but here is defined by the location where the haul-back of the longline began after fishing. Also, the parts of a set that were interrupted (*e.g.*, when the main line was severed) previously were defined as separate sets, but now are combined as a single set.

In addition to the essential time-area information on the fishing set, gear and effort information are also recorded on observed trips. Some gear and effort characteristics are potentially influential on bycatch of marine turtles (Kleiber 2000<sup>5</sup>). A subset of these gear-effort variables (Table 1) is selected for exploratory analysis, including GLM and regression tree analysis conducted with the S-PLUS software (MathSoft 1997), to identify significant factors that may be incorporated into models for predicting bycatch rates.

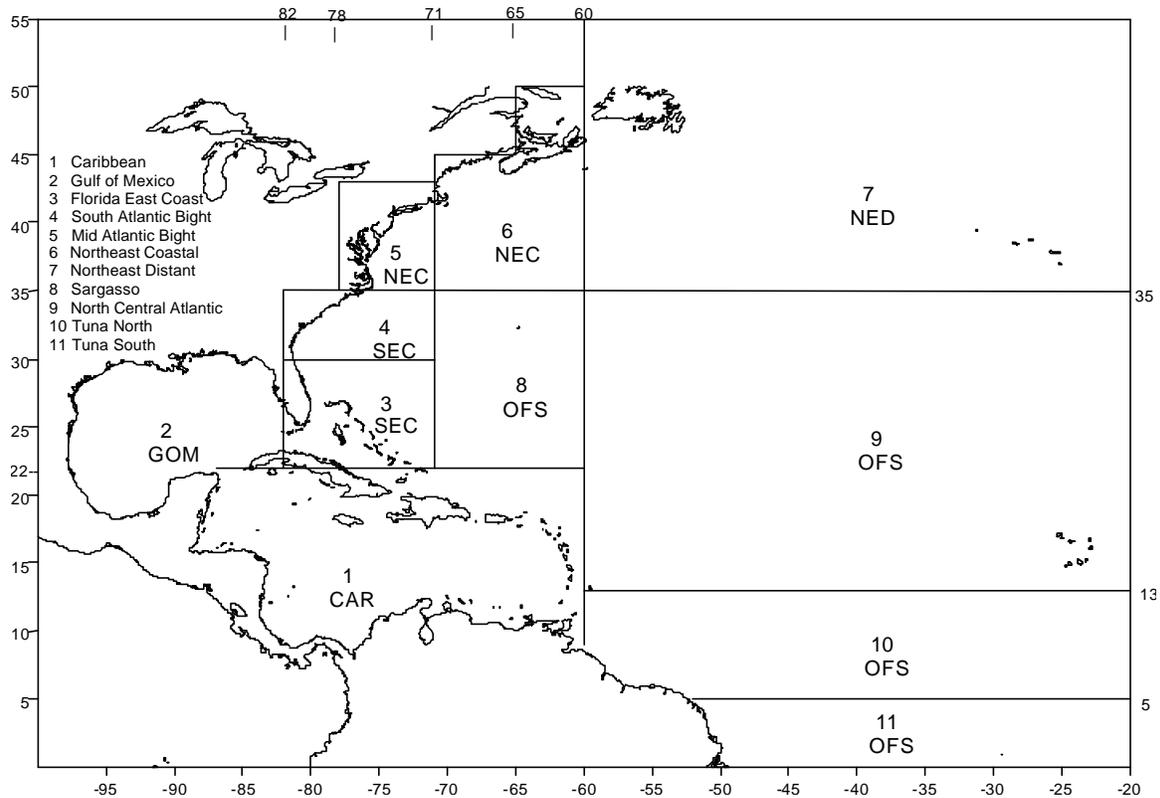


Figure 1. The eleven geographical areas (AREA) used to classify U.S. Atlantic pelagic longline fishing effort. AREAs are further arranged into 6 grouped strata (NAREA): 1) Southeast Coastal (SEC) = AREAs 3 and 4; 2) Northeast Coastal (NEC) = AREAs 5 and 6; 3) the Offshore South (OFS) = AREAs 8, 9, 10, and 11. Each one of the AREAs: 4) Caribbean (CAR), 5) Gulf of Mexico (GOM), and 6) Northeast Distant (NED), is also a distinct NAREA.

<sup>5</sup> Kleiber, P. 2000. Working group on reducing turtle bycatch in longline fisheries. Report of First Meeting. September 12–13, Los Angeles, U.S.A. Unpublished report. National Marine Fisheries Service, SWFSC, Honolulu, Hawaii, 11 pp.

Table 1. Time-area and gear-effort variables considered for predictors in the GLM approach. Strikeover variables are omitted from consideration because of any combination of the following reasons: 1) insufficient data, 2) collinearity with other selected variables, 3) insignificant effect on the catch rate in exploratory analysis.

Variable type: E=effort G=gear C=catch c=categorical q=quantitative

	<u>VARIABLE</u>	<u>DESCRIPTION</u>
	<u>set</u>	
Cc	year	
Cc	area	
Cc	month	
	<u>target catch</u>	
Cq	<del>shkn</del>	number of shark caught
Cq	swfn	number of swordfish caught
Cq	<del>tuna</del>	number of tuna caught
	<u>longline length</u>	
Eq	<del>MAINLEN</del>	mainline length (nm)
Eq	HOOKSET	number of hooks set
Eq	SOAKDUR	soak duration (hrs)
Eq	<del>FLOATNUM</del>	number of floats used
Eq	LITENUM	number of light sticks used
Eq	<del>RATLRNUM</del>	number of rattlers used
Eq	<del>SRFLTNUM</del>	number of surface lights used
Gq	<del>HKSBELT</del>	max hooks between floats
Gq	<del>GANGDIS</del>	gangion distance
Gq	<del>GANGCNT</del>	gangion count
	<u>longline depth</u>	
Gq	GANGLEN	gangion length (ft)
Gq	LEADLEN	leader length (in)
Eq	<del>HKDEPMIN</del>	max hook depth (fm)
Eq	<del>HKDEPMAX</del>	min hook depth (fm)
	<u>bait</u>	
Eq	<del>BAITNUM</del>	
Ec	BAITKND	01-Mackerel, 02-Herring, 03-Squid, 04-Artificial, 05-Sardine, 06-Scad, 99-Other
Ec	<del>BAITTYP</del>	1-Whole, 2-Cut, 3-Live, 9-Other
Ec	BAITCON	1-Frozen, 2-Semi-frozen, 3-Thawed, 4-Fresh, 5-Salted, 9-Other
	<u>temperature</u>	
Eq	TEMP	mean of begin/end set/haul temp (F)
	<u>hook</u>	
Gc	<del>HKBRAND</del>	hook brand
Gc	HKPATRN	hook pattern
Gc	<del>HKSIZE</del>	hook size
	<u>auxiliaries</u>	
Gc	<del>LITECOLR</del>	light stick color
Gc	GANGCOLR	gangion color
Gc	LEAD	leader used?
Ec	<del>LITESTX</del>	light sticks used? 1=yes, 2=no
Ec	<del>SRFLITE</del>	surface lights used?
Ec	<del>RATLR</del>	rattlers used?

## Catch Estimation

Delta lognormal bycatch estimation with pooling criterion  $N_{\min}=5$

The delta-distribution or delta-lognormal method (Pennington 1983) provides minimum variance unbiased (MVU) estimators of means and variances for sampling data that contain many zero observations and the non-zero observations are lognormally distributed. The sample mean as an estimator in that case may overestimate the population mean, and the variance of the sample mean can be very large. The robustness of the delta-lognormal estimators depends on the assumption of lognormal distribution of the non-zero (positive) observations (Myers and Pepin 1990; Syrjala 2000).

The delta-lognormal method is a possible approach for estimating the observed bycatch rates of turtles. The observation unit is a longline fishing set, and the observed response is the bycatch rate = number caught per 1000 hooks (*cph*). A quantile-quantile plot of the distribution function of the ln-transformed positive bycatch rates ( $lcph:\{lcph>0\}$ ) for all species and the normal distribution shows departures from linearity at the tail ends that is not unexpected of small to moderate sample sizes (Fig. 2a), and it appears unlikely that any other parametric distribution will fit the sample data substantially better (Fig. 2b). The lognormal distribution may thus be an “acceptable” approximation for all practical purposes. The same trends apply whether for all species combined ( $n=429$ ), loggerheads ( $n=198$ ), or leatherbacks ( $n=201$ ). The rare turtle species in the bycatch - green, hawksbill, and Kemp’s Ridley, cannot be tested separately because of the extremely low sample sizes (total  $n=30$ ).

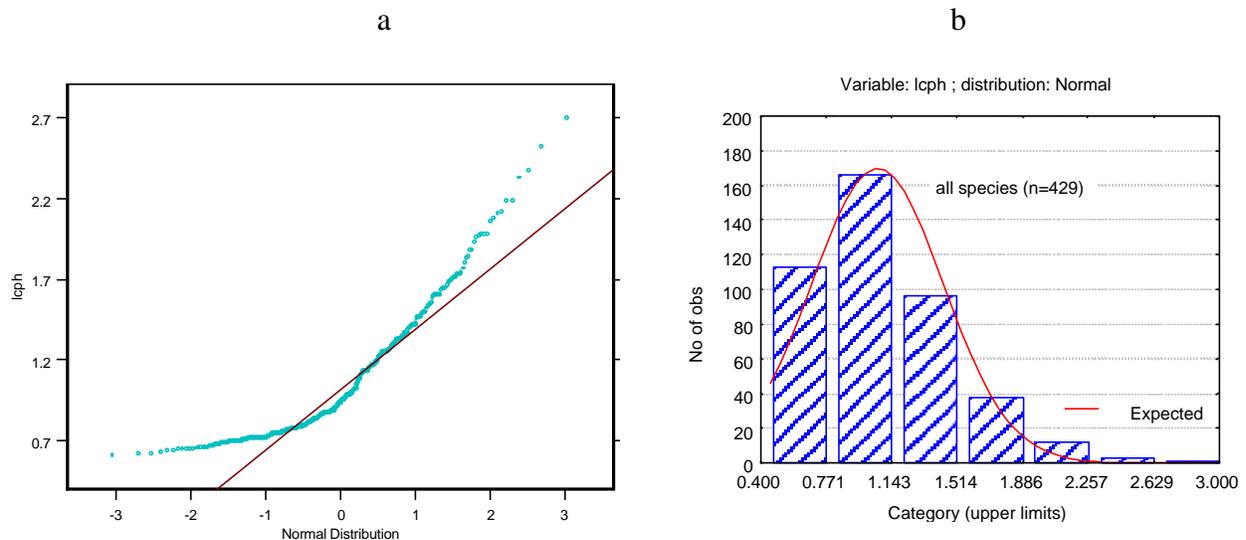


Figure 2. a) Quantile-quantile plot of the distribution function of observed ln-transformed positive bycatch rates  $\{lcph>0\}$  for all species and the normal distribution; b) frequency comparison of the same observed data and the fitted distribution.

The bycatch estimates are constructed as a product of the proportion of positive sets and the average bycatch rate of the positive sets (Pennington 1983). Estimated bycatch for a basic time-area stratum (year-quarter-NAREA),  $C$ , is estimated as:

$$C = H \frac{m_c}{N} e^L G_{m_c} \left( \frac{s_L^2}{2} \right), \quad (1)$$

$H$  = reported number of hooks set, divided by 1000,

$m_c$  = number of sets in which a non-zero bycatch was observed (positive sets),

$N$  = total number of sets observed,

$$L = \sum L_i / m_c,$$

$$s_L^2 = \frac{\sum (L_i - L)^2}{m_c - 1}, \text{ where}$$

$L_i = \ln(\text{bycatch}_i / \text{hooks}_i \times 1000) = \text{lcphi}_i$ , ln-transformed bycatch rate for the  $i^{\text{th}}$  positive set,  
 $i=1, \dots, m_c$ ,

$L$  = mean of  $L_i$ ,

$s_L^2$  = sample variance of  $L_i$ ;

and the function  $G_{m_c} \left( \frac{s_L^2}{2} \right)$  is:

$$G_{m_c} \left( \frac{s_L^2}{2} \right) = 1 + \frac{m_c - 1}{m_c} \left( \frac{s_L^2}{2} \right) + \sum_{j=2}^{\infty} \frac{(m_c - 1)^{2j-1}}{m_c^j (m_c + 1)(m_c + 3) \dots (m_c + 2j - 3)} \times \frac{\left( \frac{s_L^2}{2} \right)^j}{j!}. \quad (2)$$

Numerically, the series is computed over  $j$  terms, until a convergence criterion of <0.001 change in the function is achieved (usually less than 10 terms are required). The estimate of variance of the bycatch takes the form:

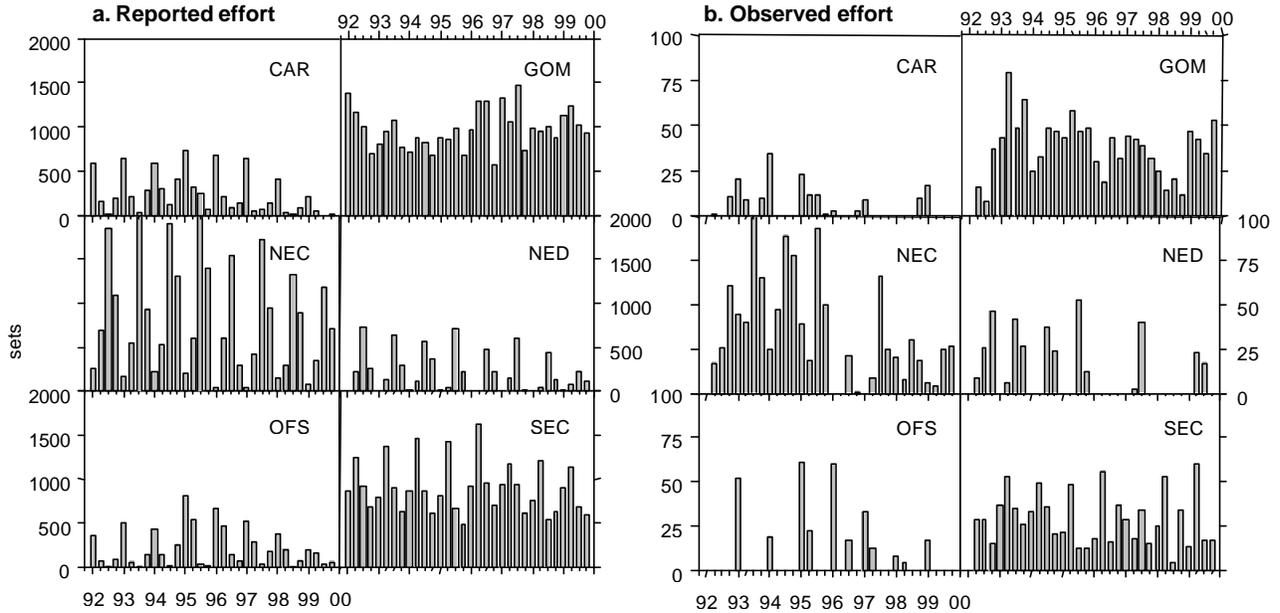
$$V(C) = \frac{m_c}{N} (He^L)^2 \left[ \frac{m_c}{N} G_{m_c}^2 \left( \frac{s_L^2}{2} \right) - \left( \frac{m_c - 1}{N - 1} \right) G_{m_c} \left( \frac{m_c - 2}{m_c - 1} \frac{s_L^2}{2} \right) \right]. \quad (3)$$

Bycatch estimates by stratum are assumed independent, and the proportion of positive sets ( $m_c/N$ ) and reported number of hooks ( $H$ ) are treated as constants within a stratum and thus uncorrelated with the bycatch rate. The coefficient of variation for the stratum-wise estimate of bycatch is:

$$CV = \frac{\sqrt{V(C)}}{C}. \quad (4)$$

In the previous reports (Johnson *et al.* 1999; Yeung 1999a; 1999b), when there was no observer effort (= fishing set) for a particular analytical stratum, *i.e.*,  $N=0$ , the mean bycatch rate  $L$  and the proportion of positive sets,  $m_c/N$  were not estimated. Thus, no estimate of bycatch was made for the stratum even though there was reported fishing effort ( $H>0$ ) in the logbook. Quarters lacking observed effort occurred mainly in the NAREAs of CAR, NED, and OFS, all relatively far from the continental U.S. coast (Fig. 1) and where U.S. pelagic longline fishing effort is typically low (Fig. 3). When observed effort is pooled across quarters within a NAREA-year stratum, cells lacking observed effort only occur in OFS in 1992, and NED in 1996 and 1998 (Fig. 3).

Figure 3. Quarterly a) reported sets and b) observed sets by NAREA, 1992-1999.



Pooling allows extrapolation of bycatch rate to a basic time-area stratum that has no observed effort using data from related strata. A possible disadvantage of pooling is that it may smooth out the inherent heterogeneities among time-area strata and distort bycatch patterns and trends. Pooling is therefore applied only when necessary by assessing whether a criterion of a minimum number of observed sets ( $N_{min}$ ) is met for a basic stratum. To determine the order of factors to pool, the effect of year, quarter, and NAREA on the bycatch rate was evaluated with the ANOVA model

$$L_j = \text{year} + \text{quarter} + \text{NAREA},$$

where  $L_j = \ln(\text{bycatch}_j/\text{hooks}_j + 1)$ ,  $j = 1, 2, \dots, N$  is the bycatch rate (including zeros) in the  $j^{\text{th}}$  observed set. The model was assessed for 1) all turtle species combined, 2) leatherbacks, and 3) loggerheads. In each case, NAREA is responsible for the greatest model effect, followed by year and then quarter (Table 2). The standard pooling priority order of quarter, year, and NAREA is established according to the increasing order of variance explained attributed to the effect, i.e. pooling similar levels first. Next, a low  $N_{min}$  of 5 sets and a high of 30 sets observed are arbitrarily chosen to be tested, emulating what have been used in bluefin tuna assessment (Brown, in press). Both produced bycatch estimates of similar magnitudes, which indicates both criteria resulted in similar amount of pooling (Yeung *et al.* 2000<sup>4</sup>). The criterion of  $N_{min} = 5$  was chosen to potentially minimize the necessity to pool in most cases. The stepwise pooling procedure is thus: in the absence of observer data for a stratum, data are first pooled across quarters to obtain a minimum sample size of 5 observed sets. Should the pooling across quarters not suffice to achieve the  $N_{min}$ , data are then pooled across years, and if still failing the criterion, data are lastly pooled across NAREAs to obtain an estimate of  $L$  and  $m_c/N$ , for the stratum. The variance for the bycatch  $V(C)$  is then estimated over the pooled stratum.

Table 2. ANOVA of time-area effects on ln-transformed bycatch rate (*lcph*) of marine turtles

Model: *lcph* = year + NAREA + quarter

\*\*\* Analysis of Variance Model \*\*\*  
Type III Sum of Squares

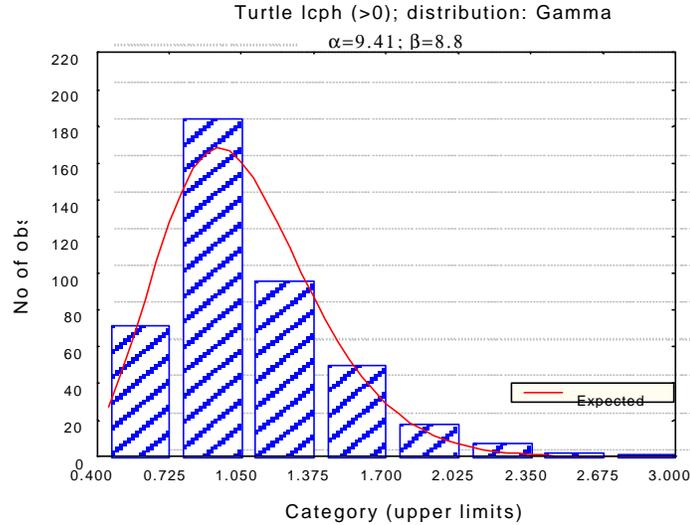
1) All species					
	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
yr	7	6.4282	0.91831	9.1049	0.00000000
narea	5	68.8221	13.76443	136.4712	0.00000000
quarter	3	1.0619	0.35396	3.5094	0.01465468
Residuals	4016	405.0520	0.10086		
2) Leatherback					
yr	7	0.9559	0.136559	2.67591	0.00918291
narea	5	7.7804	1.556083	30.49174	0.00000000
quarter	3	0.4050	0.135015	2.64565	0.04747834
Residuals	4016	204.9482	0.051033		
3) Loggerhead					
yr	7	5.3014	0.757339	12.78133	0.00000000
narea	5	28.8476	5.769524	97.37008	0.00000000
quarter	3	0.4804	0.160132	2.70249	0.04398371
Residuals	4016	237.9623	0.059254		

### Bycatch estimation by delta-GLM approach

There is concern that delta-lognormal estimators are not robust to seemingly small departures of the distribution of the positive observations from lognormal, in which case the delta-lognormal estimators may be positively-biased (Syrjala 2000). For comparison, an alternative method of estimating bycatch is used that combines the delta approach with GLMs to predict bycatch rate from predictor variables. Stefánsson (1996) described this maximum likelihood estimation method that calls for the fitting of a GLM to 0/1 binary observations, and another GLM to the positive observations.

Two models are fitted with the observed bycatch and effort data. The probability of a positive set is modeled as a random response variable, *bcatch*, (= 1 if *lcph*>0, = 0 if *lcph*=0) using a binomial model with a logit link function. The fitted response is the expected probability of a positive set  $\Pr(bcatch=1) = p$ . A separate GLM relates the expected bycatch rate of positive sets (*lcph*>0) to the linear predictor by the gamma distribution and a log link function. The gamma distribution fit to the positive bycatch rates (Fig. 4) is similar to lognormal fit (Fig. 2), and models with gamma-log and gaussian-identity link functions produced similar results. The gamma distribution has been suggested to be preferable in fisheries data in some cases where there is a considerable probability of small observations, though the gain may be minor (Stefánsson 1996). It is used here mainly as a comparison with the delta-lognormal distribution. Analysis of deviance is used to evaluate significant predictor variables and select the final models.

Figure 4. Frequency comparison of the observed ln-transformed positive bycatch rate  $\{lcph>0\}$  of all turtle species and the fitted gamma distribution (parameters:  $\mathbf{a}$ -shape;  $\mathbf{b}$ -scale).



The fitted log<sub>e</sub>-transformed bycatch rate  $lcph$  from the gamma model is back-transformed by

$$cph = \exp(lcph) - 1,$$

where  $cph$  = bycatch per 1000 hooks =  $\mathbf{m}$  the expected bycatch rate for positive sets. The estimated overall catch rate at a time-area stratum,  $\hat{X}$ , is then

$$\hat{X} = p\mathbf{m} \quad (5)$$

where  $p$  = expected probability of a positive set from the binomial model. The variance of the estimated overall catch rate is calculated as

$$V(\hat{X}) = p\mathbf{s}^2 + \mathbf{m}^2p(1-p) = \mathbf{m}^2[p(1+1/\mathbf{a}) - p^2], \quad (6)$$

where  $\mathbf{a}$  = shape parameter and  $\mathbf{s}^2 = \mathbf{m}^2/\mathbf{a}$  = variance of the estimated gamma function (Stefánsson 1996). The coefficient of variation of the estimate is

$$CV = \frac{\sqrt{V(\hat{X})}}{\hat{X}}$$

Finally, the total estimated bycatch per stratum,  $\hat{C}_g$ , is calculated as

$$\hat{C}_g = \hat{X} \times H,$$

where  $H$  = total reported number of hooks set for the stratum, divided by 1000, as defined in eq. (1) (the subscript  $g$  distinguishes the delta-GLM model bycatch estimate from the delta-lognormal catch estimate).

There are no prior assumptions of homogeneity in the structure of zero or non-zero observations in this estimation approach, but a parametric function has to be assumed nonetheless to link the mean and variance of the predicted response to the linear predictor, and thus like the delta-lognormal method it is not distribution-free. In this method, missing cell

values are estimated based on factor level averages, an alternative to the pooling used in the delta-lognormal method. The GLM approach can serve to evaluate the effect of different factors on the bycatch rate and incorporate multiple significant factors to model bycatch rate. However, the fit of GLMs can be hampered by unbalanced data structure and missing cells. It may not a superior method to delta-lognormal for sparse data as in this case, but an alternative. Maximum likelihood estimations for GLMs in this analysis are made with available routines in the S-PLUS software (MathSoft 1997).

## **Results And Discussion**

### ***Delta-lognormal bycatch estimates***

Reported nominal effort (number of fishing sets) in 1992-1999 shows that fishing effort and trends varied among NAREAs (Fig. 3a). Intra-annually, effort in the northern NAREAs of NEC and NED peaked in the 3<sup>rd</sup> quarter, and was lowest in the 1<sup>st</sup> quarter. The reverse annual trend is apparent in the southern NAREAs of OFS and CAR, where effort peaked in the 1<sup>st</sup> quarter and was lowest in the 3<sup>rd</sup> quarter. SEC had peak effort in the 2<sup>nd</sup> quarter, whereas effort in GOM was distributed relatively evenly among quarters. Average effort was highest in GOM, NEC, and SEC in the coastal zone of continental U.S. With the exception of GOM, annual nominal effort was somewhat lower in other NAREAs in recent years. For the coastal NAREAs of GOM, NEC, and SEC, annual observed effort was  $\leq 5\%$  of reported effort, and the quarterly distribution of observed effort approximated the reported trend. The distant NAREAs of CAR, NED, and OFS received more sporadic observer coverage and often none at all (Fig. 3b).

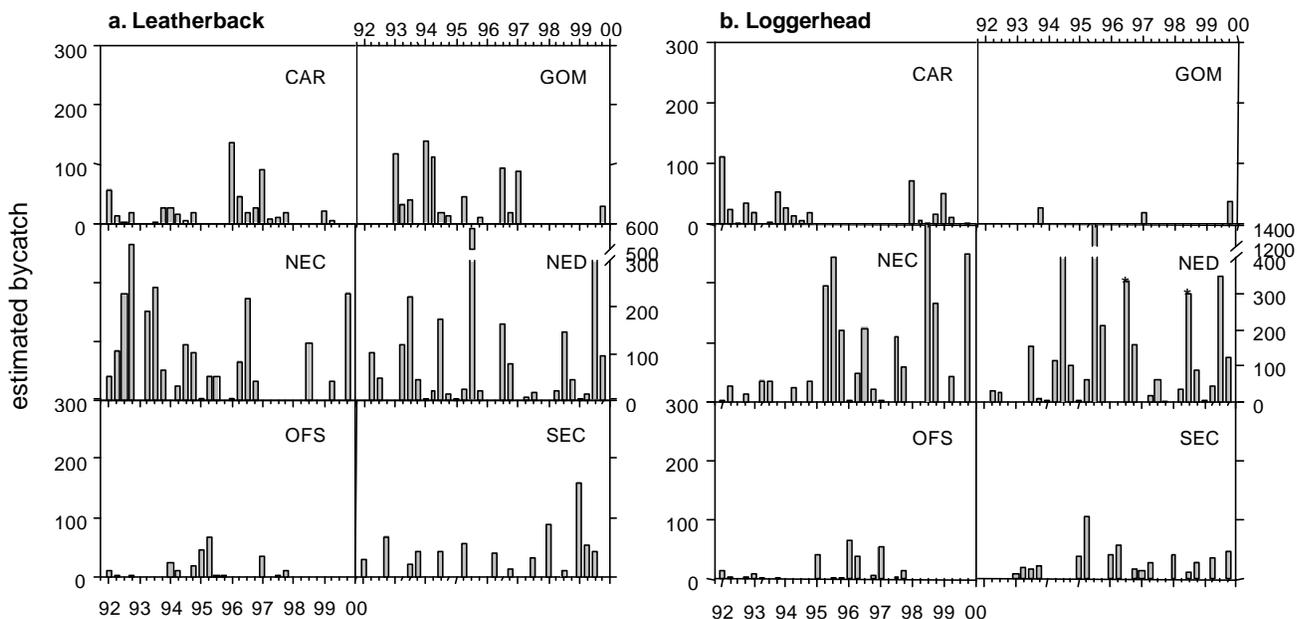
Between 1992-1999, 4032 longline sets were observed, of which 429 (~11%) caught turtles. Most of the turtles caught in the longline were either loggerheads or leatherbacks (Table 3). It is likely that the green, hawksbill, and Kemp's Ridley takes were mis-identifications, and were in fact loggerheads, the most common hard-shelled turtle taken in the fishery (Hoey 1998; Witzell 1999). Of the turtles caught, rarely were any observed to be dead (Table 3), but this does not discount the possibility that those observed to be released alive might have sustained serious or fatal injuries. The results of expanding observed bycatch rates estimated by the delta-lognormal method to the level of reported effort show that estimated mean bycatch ( $CV \leq 1$ ) of loggerheads and leatherbacks were highest in NED and NEC (Fig. 5), and peaked generally in the 3<sup>rd</sup> quarter in accordance with the quarterly trend in fishing effort. An estimated 100-200 leatherbacks were caught in the peak quarter in the NEC and NED (Fig. 5a). Exceptionally high estimated bycatch of leatherbacks occurred in NEC 1992 (265,  $CV=0.28$ ), NED 1995 (580, 0.17) and NED 1999 (384, 0.31).

Estimated mean bycatch of loggerheads were generally higher in NED than NEC (Fig. 5b). High bycatch years in NEC were 1995, 1998, and 1999 with 200-300 loggerheads estimated caught in the 3<sup>rd</sup> quarter. For NED, estimated mean bycatch of loggerheads exceeded 300 in the 3<sup>rd</sup> quarter of 1994-1996, and 1998-1999 - extreme highs occurred in 1994 (1001, 0.17) and 1995 (1413, 0.2). Note that in 1996 and 1998 there was no observed effort in NED (Fig. 3), therefore the bycatch estimates were based on pooled bycatch rates for all the other years combined. Considering that the reported effort in NED was a factor of 3-4 lower than in NEC, the comparable bycatch estimates between the two areas distinguish NED as the area of highest catch rates of leatherbacks and loggerheads.

Table 3. Numbers and species of marine turtles caught in longline sets observed between 1992-1999. The number observed as dead is a subset of the total number caught.

species	caught	dead	sets
loggerhead	355	4	198
leatherback	263	1	201
green	15	2	11
hawksbill	3	0	3
Kemp's Ridley	2	0	2
unidentified	14	0	14

Figure 5. Estimated quarterly bycatch of a) leatherback and b) loggerhead turtles by the delta-lognormal method. The asterisks in loggerhead-NED indicate where there was no actual observed effort for the quarter. Note change in y-axis scale for NED.



### ***Bycatch Factors***

Of the available gear-effort factors in the observer data set, many were eliminated from consideration for predictors of bycatch rate because of too much missing data, collinearity with other predictors, or having insignificant effect on the bycatch rate. The remaining subset of factors (Table 1) was evaluated closely and further screened before entering GLM and regression tree models. The time-area factors were analyzed in greater detail as month and AREA instead of as the quarter and NAREA factors that were actually used in bycatch estimation.

In swordfish longlining, the use of light sticks is standard and has a significant positive effect on the turtle bycatch rate (Witzell 1999). Seventy percent of the observed sets used light sticks. The number of light sticks used in a set (LITENUM) is significantly correlated with the bycatch rate, as well as with other variables such as the number of surface lights, rattlers, floats, mainline length, and gangion distance. Obviously, the number of light sticks used is a function of the length of the longline set. However, the number of hooks set (HOOKSET), hooks between floats (HKSFBFLT), and soak duration (SOAKDUR) have negative correlations with the number of light sticks. HKSFBFLT can be dropped since it is highly correlated HOOKSET. LITENUM, HOOKSET, and SOAKDUR in the “longline length” class of factors (Table 1) are retained for further analysis.

Other significant factors retained are gangion length (GANGLLEN), which represents the class of depth-related factors, hook pattern (HKPATRN), the condition of the bait (BAITCON), and the kind of bait (BAITKND). Of the miscellaneous auxiliary factors in Table 1, those that are significant and are not correlated with other already selected factors are gangion color (GANGCOLR) and whether leaders were used (LEAD). The bycatch rate of turtles (*lcph*) is highly correlated with the numbers of swordfish caught (swfn) ( $r=0.30$ ,  $Pr<0.0001$ ). The numbers of sharks (srkn) and tunas caught (tunn) are also significantly correlated with swfn (srkn:  $r=0.19$ ,  $Pr<0.0001$ ; tunn:  $r= -0.15$ ,  $Pr<0.0001$ ), but their correlations with *lcph* are not as strong as that of swfn. The reduced subset of factors is shown in Table 1 as the ones that are not strikeouts.

An initial GLM with bycatch rate as the response was fitted using the reduced subset of factors with no interaction terms (Table 4a). The time-area factors of year, month, AREA, with their two-factor interactions, and the significant gear-effort factors of BAITCON, swfn, HKPATRN, and LEAD from the initial GLM are retained for input into another GLM (Table 4b). In the second GLM, only swfn among the gear-effort factors remains significant, as are all time-area factors and their interactions (Table 4b).

Due to the unbalanced nature of the data and the sparse observations particularly of gear-effort variables, GLM results could be somewhat misleading. Regression tree modeling is a robust and flexible method, and can handle nonlinear relationships, high order interactions, and missing values (De’ath and Fabricus 2000). It gives visual and easily interpretable results directly on the levels of the factors. It is thus applied to the reduced subset of factor (Table 1) for another attempt at identifying key factors influencing turtle bycatch rates.

The resultant full regression tree model (size = 96 terminal nodes) is of *lcph* for all turtle species combined using the reduced subset of factors in Table 1. The first four nodes are based on the factors AREA, year, and surface temperature (temp), which account for the largest proportional reduction (~30%) in deviance (Fig. 6a). Subsequent branching only reduces small proportions of deviance at a high cost of model complexity. Compare to the full tree of 96 nodes, the pruned tree of 4 nodes only has an increase of residual mean deviance of +0.029 (Fig. 6). The pruned tree in Fig. 6b identifies the terminal nodes and their respective fitted response (*lcph*). The length of the vertical branch is roughly proportional to the deviance explained by the node from which it is grown. The first and most important split is between NED (g) to the right branch and the other AREAs to the left. The second split is among years within NED – between

1992, 1993, 1997 to the left and 1994, 1995, 1999 to the right (no observed data for 1996, 1998). The left group has already been identified before as the low bycatch years, and the right group as the high bycatch years (Fig. 3). The third split is by temperature under the years 1994, 1995, 1999 years, with lower temperatures accounting for a lower *lcph*. The substitution of temperature in the tree model for month in GLM as one of the three significant predictors of bycatch rate is not contradictory, as both month and temperature are indicators of seasonality.

Table 4. GLMs of bycatch rate with time-area factors and reduced subset of gear-effort factors.

a. GLM with reduced subset of factors with no interaction terms

NOTE: Due to missing values, only 2026 of 4032 observations can be used in this analysis.

Dependent Variable: *lcph*

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	69	20.5252181	0.2974669	3.98	<.0001
Error	1956	146.0204001	0.0746526		
Corrected Total	2025	166.5456182			

R-Square 0.123241      Coeff Var 341.1795      Root MSE 0.273226      *lcph* Mean 0.080083

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	7	0.83073132	0.11867590	1.59	0.1339
month	11	1.42537395	0.12957945	1.74	0.0603
AREA	10	4.08954806	0.40895481	5.48	<.0001*
BAITCON	4	2.02694385	0.50673596	6.79	<.0001*
BAITKND	5	0.29753419	0.05950684	0.80	0.5516
LITENUM	1	0.11588307	0.11588307	1.55	0.2129
HOOKSET	1	0.00787284	0.00787284	0.11	0.7454
SOAKDUR	1	0.02239024	0.02239024	0.30	0.5840
swfn	1	0.39373659	0.39373659	5.27	0.0217*
temp	1	0.11558896	0.11558896	1.55	0.2135
HKPATRN	21	3.31880536	0.15803835	2.12	0.0022*
GANGCOLR	5	0.38701935	0.07740387	1.04	0.3941
LEAD	1	0.23100816	0.23100816	3.09	0.0787*

\* significant effect at  $\alpha=0.1$

b. GLM repeating 1. less insignificant factors and with year-month-area interactions

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	290	47.0281703	0.1621661	2.36	<.0001
Error	1764	121.0550384	0.0686253		
Corrected Total	2054	168.0832087			

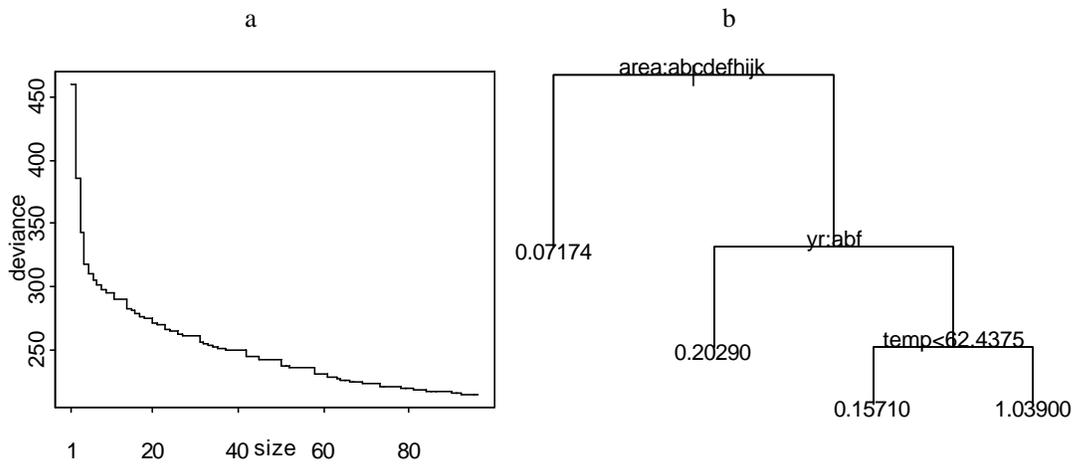
R-Square 0.279791      Coeff Var 329.2710      Root MSE 0.261964      *lcph* Mean 0.079559

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	7	1.13290782	0.16184397	2.36	0.0213*
month	11	2.45835156	0.22348651	3.26	0.0002*
AREA	10	3.42810423	0.34281042	5.00	<.0001*
BAITCON	4	0.46219792	0.11554948	1.68	0.1511
swfn	1	0.26045106	0.26045106	3.80	0.0516*
HKPATRN	17	1.65370565	0.09727680	1.42	0.1185
LEAD	1	0.07761345	0.07761345	1.13	0.2877
year*month	66	7.05860717	0.10694859	1.56	0.0031*
year*AREA	40	5.11287667	0.12782192	1.86	0.0009*
month*AREA	53	6.50548469	0.12274499	1.79	0.0005*
year*mon*AREA	72	4.96852382	0.06900728	1.01	0.4662

Figure 6. Regression tree model of time-area and gear-effort factors on the response of bycatch rate (*lcp*) of all turtle species combined. The mean residual deviance of the full and pruned models are given. a) the plot of the deviance against the number of terminal nodes (size) of the tree model grown, b) shows the pruned model with the fitted response at each node. The length of the vertical branch is roughly proportional to the deviance explained by the node from which it is grown.

Full model:  $lcp = year + month + AREA + BAITCON + BAITKND + LITENUM + HOOKSET + SOAKDUR + swfn + temp + HKPATRN + GANGCOLR + LEAD$   
 Number of terminal nodes: 96      Residual mean deviance: 0.0652 = 215.1 / 3299

Pruned model:  $lcp = AREA + year + temp$   
 Number of terminal nodes: 4      Residual mean deviance: 0.09392 = 318.5 / 3391



Key to 6b:

area: a-CAR b-GOM c-FEC d-MAB e-NCA f-NEC g-NED h-SAB I-SAR j-TUN k-TUS

yr: a-92 b-93 c-94 d-95 e-96 f-97 g-98 h-99

Regression trees constructed separately for loggerheads and leatherbacks gave similar results as for all species combined. Both first split into NED and the other AREAs. For leatherbacks, the subsequent branches are year, month, and temperature, in order of importance. For loggerheads, it is year, temperature, and month. However, lower temperature accounts for a slightly higher catch rate of leatherback, but the opposite is true for loggerhead, so temperature as a factor may be possibly be species-specific. Given that the intra-annual distribution of observed effort emulates reported effort and tends to be concentrated in one specific quarter, the month and temperature factors have to be cautiously interpreted. For NED, fishing peaked in the 3<sup>rd</sup> quarter, which is likely to have a higher average temperature than the average temperature of the other quarters combined. GLM and the regression tree model analysis both essentially indicate that area and time of fishing as the most important predictors of bycatch rate, and temperature a possible covariate.

### *Delta-GLM bycatch estimates*

#### Probability of a positive set

Several binomial models were compared by analysis of deviance and the AIC statistic in a stepwise regression procedure, beginning with the full model that includes time-area factors (year, quarter, NAREA) and all gear-effort factors in the reduced subset as in Table 4a. None of the gear-effort factors nor the time factor of quarter contributes significantly to the model. The “best” model involves only year and NAREA:

$$bcatch = NAREA + year + year * NAREA.$$

The predictors in the model are listed in decreasing order of importance (according to mean deviance = deviance/df), which has been tested valid for each species (Table 5). NAREA is again confirmed as the most important factor.

This model was fitted to each species. Leatherbacks and loggerheads, which were most common in the bycatch and have the most positive sets, share a similar fitted pattern showing that the expected probability of a positive set ( $p$ ) is highest in NED, particularly the years 1995 and 1999, and 1994 as well for loggerheads (Fig. 7). The apparent peaks in years 1996 (loggerhead:  $p = 0.99 \pm 0.11$  s.e.) and 1998 (leatherback:  $0.81 \pm 1.74$ ; loggerhead:  $0.77 \pm 2.39$ ) in NED, however, are not based on any actual observations in these years (Fig. 3) and carry very high uncertainty. Other NAREA of moderate probability of bycatch are CAR and NEC. Fitted  $p$  is mostly zero for each year-NAREA for the rare greens, hawksbills, and Kemp’s Ridleys. These results are in strong agreement with the delta-lognormal estimates and regression tree analysis.

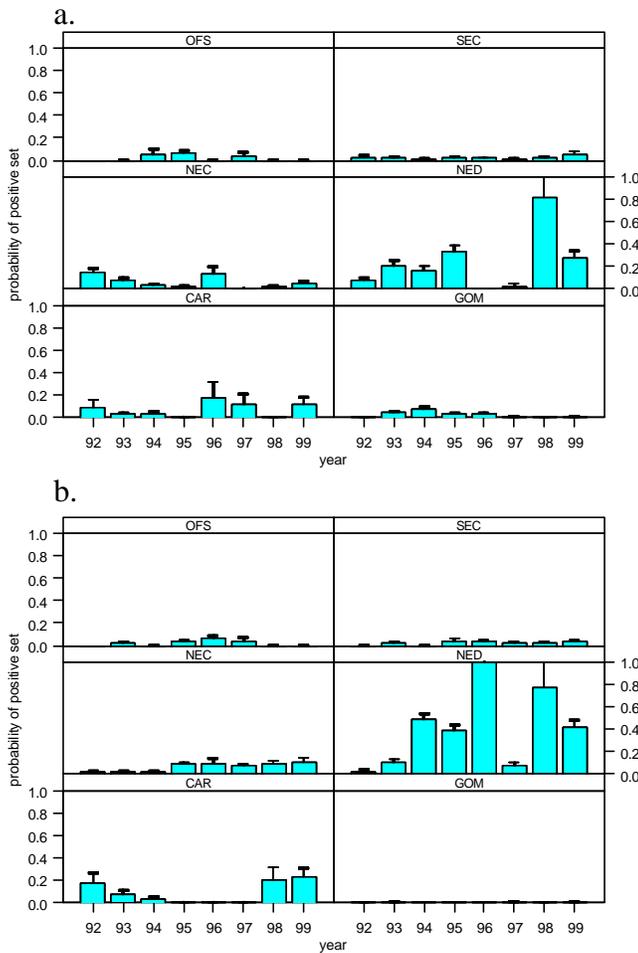
Table 5. Analysis of deviance of the binomial model for the probability of positive set,  $bcatch = year + NAREA + year * NAREA$ .

Response: *bcatch*

Terms added sequentially (first to last)

	Df	Deviance	Resid. Df	Resid. Dev	F Value	Pr(F)
<b>a. Leatherback</b>						
NULL			4031	1597.292		
yr	7	45.4679	4024	1551.824	7.29440	1.020363e-008
narea	5	117.0881	4019	1434.736	26.29813	0.000000e+000
yr:narea	32	100.5779	3987	1334.158	3.52968	8.915000e-011
<b>b. Loggerhead</b>						
NULL			4031	1579.559		
yr	7	47.3457	4024	1532.213	8.70338	1.199050e-010
narea	5	312.9231	4019	1219.290	80.53281	0.000000e+000
yr:narea	32	81.4260	3987	1137.864	3.27430	1.632598e-009

Figure 7. The expected probability of a positive set (+ s.e.) modeled on year, NAREA, and their interaction in a binomial model for a) leatherbacks; b) loggerheads.



### Bycatch rate of positive sets

A similar selection process for the binomial model is applied for the gamma model for a) all species combined, b) leatherbacks and c) loggerheads. Due to sparse data, separate gamma models cannot be fitted to rare species such as greens, hawksbills and Kemp's ridley. Instead the all species fitted model is used for those species. The most important factors remain the time-area factors for each of these three categories, with slight variations on the order and degree of significance, although NAREA is invariably the most important. A "best" model for all species, which includes year\*NAREA interaction,

$$lcp = \text{year} + \text{NAREA} + \text{quarter} + \text{year} * \text{NAREA}, \{lcp > 0\},$$

is suitable for the two single species also (Table 6). The residuals of each of the three fitted models approximate the normal distribution, showing reasonable model fits (Figure 8).

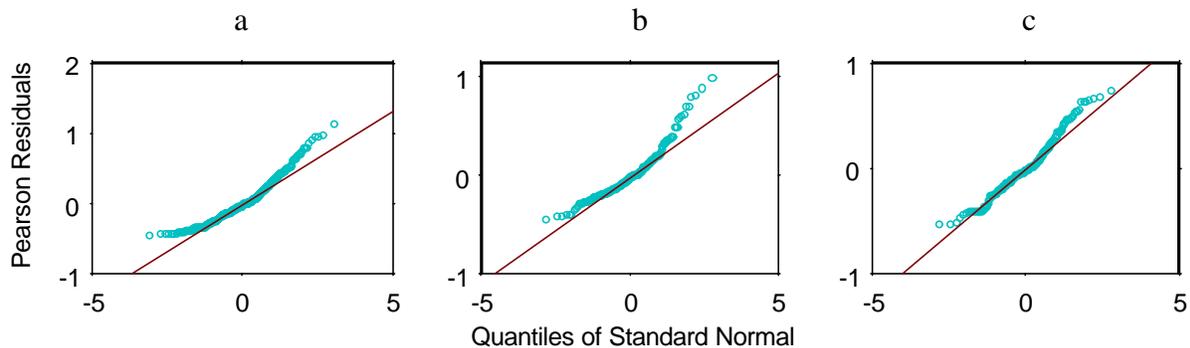
Table 6. Analysis of deviance of the gamma log-link models for bycatch rate for positive sets,  $\{lcp_h > 0\}$ , of a) all species; b) leatherbacks; c) loggerheads.

Response: *lcp<sub>h</sub>*

Terms added sequentially (first to last)

	Df	Deviance	Resid. Df	Resid. Dev	F Value	Pr(F)
<b>a. All species</b>						
NULL			428	46.35774		
yr	7	3.369571	421	42.98817	5.184267	0.00001165
narea	5	4.483531	416	38.50464	9.657414	0.00000001
quartr	3	1.197666	413	37.30697	4.299571	0.00532184
yr:narea	27	3.554925	386	33.75204	1.418004	0.08322637
<b>b. Leatherbacks</b>						
NULL			200	17.65148		
yr	7	1.459332	193	16.19215	2.641661	0.0130186
narea	5	1.349223	188	14.84292	3.419279	0.0057858
quartr	3	0.713974	185	14.12895	3.015657	0.0316335
yr:narea	23	2.550594	162	11.57836	1.405188	0.1149731
<b>c. Loggerheads</b>						
NULL			197	24.97021		
yr	7	3.842434	190	21.12778	6.076786	0.0000026
narea	5	3.463001	185	17.66478	7.667400	0.0000017
quartr	3	0.440150	182	17.22463	1.624221	0.1857846
yr:narea	19	2.220263	163	15.00436	1.293649	0.1938116

Figure 8. Pearson residuals of the gamma model  $lcp_h = \text{year} + \text{NAREA} + \text{quarter} + \text{year} * \text{NAREA}$ ,  $\{lcp_h > 0\}$ , fitted to a) all species; b) leatherbacks; c) loggerheads.



Delta-GLM bycatch estimates for leatherbacks and loggerheads are derived from their respective species-specific fitted binomial and gamma models. The bycatch estimates for each of the other species are derived from their respective species-specific fitted binomial models and the all-species gamma model.

The quarterly delta-GLM bycatch estimates for leatherbacks and loggerheads are plotted in Fig. 9 for a comparison with the delta-lognormal estimates in Fig. 5. In terms of general

trends and magnitudes, the point estimates derived from the two methods are quite similar. The quarterly estimates for leatherbacks in NED 1998, where there was no actual observed effort, are exceptions. The extremely high leatherback bycatch estimates for the 3<sup>rd</sup> and 4<sup>th</sup> quarters of NED 1998 are affected by the aforementioned high uncertainty in the predicted probability of positive set ( $p$ ), low number of observations, and the status of NAREA as a high bycatch area, and therefore should be interpreted conservatively. The NED 1995 3<sup>rd</sup> quarter peak for leatherbacks in the delta-lognormal estimates is also present in the delta-GLM estimates, but at ~400 animals compared to the ~600 animals estimated by the delta-lognormal method. For both leatherbacks and loggerheads in CAR, NEC, NED, and OFS, the patterns of bycatch from both methods match very well visually (Figs. 5 and 9), especially in the characteristic 3<sup>rd</sup> quarter peaks. The GLM method eliminated many of the zero cells of the lognormal estimates, most obviously in GOM and SEC for leatherbacks, but annual sums of the bycatch estimates in each NAREA are of similar magnitudes.

The GLM method produced much higher and probably more realistic CVs for the estimates ( $\leq 13$  for loggerheads and leatherbacks, higher still for rare species, see Table 7) than the delta-lognormal method ( $\leq 1$ , with  $CV=1$  where there is no measure of variability due to lack of data). This partly reflects that the fits of the GLMs may not be optimal, and the linear predictors do not adequately explain the observed bycatch rates. The main problem may be the sparse data in combination with the low bycatch rates. The bycatch estimates, CVs, and annual sums of the rare species by the two methods are tabulated for comparison in Table 7.

Figure 9. Estimated quarterly mean bycatch of a) leatherback and b) loggerhead turtles by the delta-GLM method. Note change in y-axis scale for second-row panels.

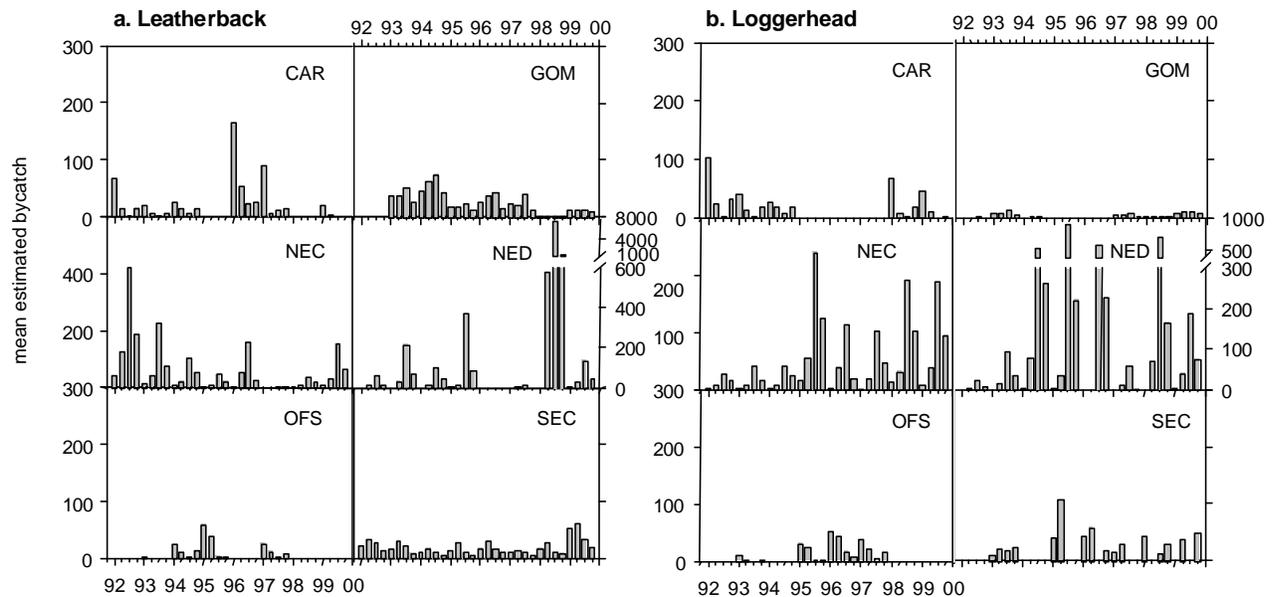


Table 7. Comparison of the quarterly bycatch estimates and associated coefficient of variation (CV) from the delta-lognormal and delta-GLM methods for rare species. The extremely high CV's from the delta-GLM method resulted from extrapolation to strata with no observed data, and some of these estimates are so out of range that they are not presented (empty cells).

	yr	qtr	narea	delta-lognormal		delta-GLM			
				estimated catch	cv	estimated catch	cv		
<b>KEMPS RIDLEY</b>	94	1	NEC			1	16		
	94	2	NEC			2	16		
	94	3	NEC	26	1	10	16		
	94	4	NEC			6	16		
	97	1	OFS	17	1	14	6.96		
	97	2	OFS			7	6.96		
	97	3	OFS	1	0.98	1	6.96		
	97	4	OFS	4	0.98	6	6.96		
	92	1	OFS	1	0.98	NA	NA		
	<b>Total</b>					49	47		
<b>UNIDENTIFIED</b>	95	1	CAR			3	280.8		
	95	2	CAR			1	280.8		
	95	3	CAR			2	280.8		
	93	1	GOM			4	15.86		
	93	2	GOM	10	1	4	15.86		
	93	3	GOM			6	15.86		
	93	4	GOM			4	15.86		
	94	1	GOM	20	1	4	12.83		
	94	2	GOM			5	12.83		
	94	3	GOM			6	12.83		
	94	4	GOM			4	12.83		
	97	1	GOM	23	1	10	12.95		
	97	2	GOM			9	12.95		
	97	3	GOM			17	12.95		
	97	4	GOM			8	12.95		
	99	1	GOM	24	1	15	9.7		
	99	2	GOM			16	9.7		
	99	3	GOM			17	9.7		
	99	4	GOM	14	1	13	9.7		
	92	1	NEC	1	0.98	2	10.58		
	92	2	NEC	24	1	6	10.58		
	92	3	NEC	21	1	20	10.58		
	92	4	NEC			11	10.58		
	93	1	NEC			1	16.85		
	93	2	NEC			2	16.85		
	93	3	NEC			10	16.85		
	93	4	NEC			4	16.85		
	99	1	NEC			1	8.23		
	99	2	NEC	4	0.98	5	8.23		
	99	3	NEC			28	8.23		
	99	4	NEC	24	1	15	8.23		
	94	2	NED	1	0.98	2	8.49		
	94	3	NED	13	0.99	14	8.49		
94	4	NED			7	8.49			
96	3	NED	1	0.98					
96	4	NED	1	0.98					
98	3	NED	1	0.98					
92	1	OFS	1	0.98					
97	1	OFS	18	1	14	6.96			
97	2	OFS			7	6.96			
97	3	OFS	1	0.98	1	6.96			
97	4	OFS	5	1.01	6	6.96			
95	1	SEC	86	0.69	34	4.9			
95	2	SEC	85	0.7	68	4.9			
95	3	SEC			30	4.9			
95	4	SEC			18	4.9			
<b>Total</b>					378	454			

	yr	qtr	narea	delta-lognormal		delta-GLM			
				estimated catch	cv	estimated catch	cv		
<b>GREEN</b>	95	1	CAR				1	462.9	
	95	2	CAR				0	462.9	
	95	3	CAR				1	462.9	
	95	4	CAR				0	462.9	
	93	1	GOM	19	1	4	15.86		
	93	2	GOM			4	15.86		
	93	3	GOM			6	15.86		
	93	4	GOM			4	15.86		
	92	1	NEC	3	0.68	4	7.44		
	92	2	NEC	48	0.69	12	7.44		
	92	3	NEC			40	7.44		
	92	4	NEC			22	7.44		
	94	1	NEC			2	11.29		
	94	2	NEC	7	1	4	11.29		
	94	3	NEC	26	1	20	11.29		
	94	4	NEC			13	11.29		
	92	2	NED			11	4.59		
	92	3	NED			48	4.59		
	92	4	NED	36	0.52	15	4.59		
	93	2	NED			2	8.98		
	93	3	NED	12	1	12	8.98		
	93	4	NED			5	8.98		
	96	3	NED	11	0.75				
96	4	NED	5	0.77					
98	2	NED	1	0.81					
98	3	NED	10	0.75					
98	4	NED	3	0.74					
95	1	SEC			9	9.95			
95	2	SEC			17	9.95			
95	3	SEC	40	1	7	9.95			
95	4	SEC			5	9.95			
<b>Total</b>					221	268			
<b>HAWKSBILL</b>	92	1	NEC			2	10.58		
	92	2	NEC			6	10.58		
	92	3	NEC			20	10.58		
	92	4	NEC	18	1	11	10.58		
	98	1	NEC	17	1	2	8.98		
	98	2	NEC			5	8.98		
	98	3	NEC			31	8.98		
	98	4	NEC			18	8.98		
	96	3	NED			83	10.05		
	96	4	NED			30	10.05		
	97	1	SEC	16	1	6	10.05		
97	2	SEC			7	10.05			
97	3	SEC			6	10.05			
97	4	SEC			3	10.05			
<b>Total</b>					53	230			

## Summary

The delta-lognormal method is used to estimate bycatch of marine turtle in the U.S. Atlantic pelagic longline fishery in 1992-1999. Estimates are based on quarterly observed effort and grouped by six fishing areas or NAREAs. To avoid missing or poor estimates where there are no or very few observation units (set) in a basic year-quarter-NAREA stratum, a criterion is set so that if a basic stratum has less than 5 ( $=N_{min}$ ) observed sets, the levels of quarter, year, and then NAREA will be pooled successively in that order until  $N_{min}$  is achieved. Pooling is necessary only in the offshore NAREAs of CAR, OFS, and NED and only up to the level of quarters with rare exceptions. The  $N_{min}$  of five is selected in an attempt to balance the need for reasonable estimates and preserving inherent variability among strata. A similar pooling method was used to estimate retained catch of commercial species from the U.S. Atlantic pelagic longline fishery with results similar to values reported in the commercial landings reporting system (Brown *et al.* 2000). Where there is a paucity of actual observations, this method may be an acceptable alternative when applied with a consideration of its limitations. The choice of  $N_{min}$ , for example, should be subjected to further analysis. The annual summed observed bycatch and the estimated bycatch obtained by the delta-lognormal method are presented in Table 8. The CVs for the annual summed estimates are based on the assumption of independence of estimates among basic strata.

The delta-GLM approach to bycatch estimation is analogous to the delta-lognormal in that it separately accommodates zero and non-zero observations, which both yield important information on bycatch. One of advantages offered by the delta-GLM method over the delta-lognormal is that it avoids the complication of pooling strata and provides explicit models for the probability of a set resulting in turtle bycatch in a stratum and the mean bycatch rate for those positive sets (Stefánsson 1996). GLM also allows the testing of factors influential to bycatch and the incorporation of those factors in the prediction of bycatch. In terms of bycatch estimates, however, there is no considerable gain in using the delta-GLM over the delta-lognormal method, and both are based on the tenuous assumption of a parametric distribution of a rather small sample data set. Quarterly patterns and trends in the bycatch of each NAREA correspond well between the two methods (Figs. 5 and 9). Although the delta-GLM method in some cases resulted in a more even distribution of bycatch intra-annually, the annual summed bycatch estimates are reasonably close to those of the delta-lognormal (Table 7). The delta-GLM method is more cumbersome than the delta-lognormal, and the GLM models are by no means optimally fitted. The binomial models fitted only accounted for approximately 20-30% of the total deviance or variation explained (Table 5), while the gamma models are slightly better with 30-40% (Table 6). The CVs of the bycatch estimates from the delta-GLM method may suffer from poor model fits, but may actually be more realistic than those of the delta-lognormal estimates. The primary reason for high CVs, however, is the sparseness of the data and also the nature of the data, in which the probability of a positive set tends to be extremely low.

Loggerheads and leatherbacks are the marine turtle species most often caught in pelagic longline. Results of the bycatch analysis show that NEC and NED are the two areas of highest bycatch of these species (Fig. 5), and peak bycatch occurred in the 3<sup>rd</sup> quarter of the year at the height of fishing effort (Fig. 3). Considering the relatively low effort in NED compared to NEC, their comparable magnitude of estimated bycatch marks NED as an area of extraordinarily high

bycatch rate. There is no distinguishable monotonic trend in bycatch, but that may be affected by the lack of observed effort in some quarters and for the entire 1996 and 1998 for NED.

Analysis of the observed data show that time-area factors are far more influential on bycatch than gear-effort factors. The task remains the unraveling of the biological and physical factors that are masked by time and space.

Table 8. Annual summed observed and delta-lognormal estimates of total marine turtle bycatch and the subset that were dead when released in the U.S. pelagic longline fishery (CL= confidence limit; CV =coefficient of variation).

species	observed		estimated catch	upper 95% CL	lower 95% CL	CV	estimated			
	year	catch					dead	upper 95% CL	lower 95% CL	CV
loggerhead	92	6	293	1149	78	0.79	0			
loggerhead	93	23	417	1414	142	0.69	9	46	2	1
loggerhead	94	88	1344	2392	859	0.3	31	158	6	1
loggerhead	95	129	2439	4542	1405	0.33	0			
loggerhead	96	13	917	2713	322	0.6	2	10	0	0.98
loggerhead	97	17	384	1281	124	0.68	0			
loggerhead	98	15	1106	3225	395	0.59	1	5	0	0.98
loggerhead	99	64	991	2089	510	0.39	23	117	5	1
leatherback	92	28	914	2716	353	0.6	88	449	17	1
leatherback	93	66	1054	2603	463	0.49	0			
leatherback	94	42	837	2433	328	0.59	0			
leatherback	95	61	934	2093	520	0.43	0			
leatherback	96	10	904	2074	231	0.44	0			
leatherback	97	7	308	1498	66	0.96	0			
leatherback	98	4	400	1411	120	0.72	0			
leatherback	99	45	1012	2786	410	0.55	0			
green	92	10	87	266	29	0.62	30	154	6	1
green	93	2	31	158	6	1	0			
green	94	2	33	169	6	1	0			
green	95	1	40	205	8	1	0			
green	96	0	16	60	4	0.76	2	10	0	0.98
green	98	0	14	52	4	0.75	1	5	0	0.98
hawksbill	92	1	20	102	4	1	0			
hawksbill	97	1	16	82	3	1	0			
hawksbill	98	1	17	87	3	1	0			
Kemp's Ridley	92	0	1	5	0	0.98	0			
Kemp's Ridley	94	1	26	133	5	1	0			
Kemp's Ridley	97	1	22	112	4	1	0			
unidentified	92	1	26	133	5	1	0			
unidentified	93	2	31	158	6	1	0			
unidentified	94	2	34	173	7	1	0			
unidentified	95	4	171	587	50	0.7	0			
unidentified	96	0	2	10	0	0.98	0			
unidentified	97	2	47	241	9	1	0			
unidentified	98	0	1	5	0	0.98	0			
unidentified	99	3	66	338	14	1	0			

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## CHAPTER 3. SIZES OF SEA TURTLES INCIDENTALLY CAPTURED IN ATLANTIC AND MEDITERRANEAN PELAGIC LONGLINE FISHERIES AND THEIR NATAL ORIGINS

Wayne N. Witzell and Sheryan P. Epperly

Pelagic longline fisheries may impact several species of sea turtle. However, it is unlikely that the U.S. Atlantic fleet encounters substantial numbers of hard-shell turtles other than loggerheads. Witzell (1999) edited the U.S. pelagic logbook to include only leatherback and loggerhead turtles. This was based on the known distribution, abundance, and biology of sea turtles in the areas fished, and the fact that some vessel captains and observers were unable to accurately identify turtles encountered<sup>6</sup>. There is the possibility hard shell turtles other than loggerheads could occasionally be taken, but there have been no photographs taken to date or green, ridley, or hawksbill turtles taken by the U.S. Atlantic fleet.

### Sizes

There is little data on the sizes of sea turtles incidentally captured in various Atlantic Ocean and Mediterranean Sea longline fisheries. Data for loggerhead sea turtles are summarized in Table 1. No information was found on incidentally caught leatherback turtle sizes in any Atlantic or Mediterranean Sea longline fishery.

The most pertinent published study is by Witzell (1999) who summarized observer data from the U.S. Grand Banks swordfish fishery. These data indicate that immature loggerhead turtles (41-70 cm CCL) are captured, with a mean size of 55.9 cm. Bolten *et al.* (1993) reported that turtles from an eastern Atlantic tuna fishery ranged in size from 42-82 cm CCL. The Witzell (1999) data and the Bolten *et al.* (1993) data are very similar and are presented in Fig. 1.

Bolten *et al.* (1993) reported that dip net caught turtles were significantly smaller (12.5-62.5 CCL) than the longline caught turtles (42.5-67.5 CCL) from the same area, indicating that the longlines selectively harvest larger immature turtles than the dip nets. Conclusions drawn from results of expanded sample sizes of the Azores dip net (Bjorndal *et al.* 2000) and longline caught turtles (Bolten *et al.* 2001<sup>7</sup>) remain unchanged (Fig. 2).

The loggerhead turtles caught in the Mediterranean Sea also appear to be immature turtles. The largest sample size (N=856) is reported by Aguilar *et al.* (1995) from the western Mediterranean. These animals averaged 48.1 cm (27-76 cm). Turtles from the central

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<sup>6</sup> Dr. Molly Lutcavage, New England Aquarium, Boston, MA. Personal Communication (phone) to Wayne Witzell, National marine Fisheries Service, SEFSC, Miami, Fla., January 30, 2001.

<sup>7</sup> Bolten, A.B., H. Martins, E. Isidro, R. Ferreira, M. Santos, A. Giga, B. Riewald, and K. Bjorndal. Preliminary results of an experiment to evaluate effects of hook type on sea turtle bycatch in the swordfish longline fishery in the Azores. Bolten, A.B., University of Florida, E-mail to Nancy Thompson and Sheryan Epperly, National Marine Fisheries Service, SEFSC, Miami, Fla., Jan. 14. 2001.

Mediterranean Sea ranged from 35-75 cm (Argano *et al.* 1992, Panou *et al.* 1992<sup>8</sup>) and averaged 57.0 cm (Argano *et al.* 1992).

Loggerheads of the sizes reported above captured in the open ocean most likely are pelagic juveniles, although this size range also represents the overlap in sizes of pelagic and small benthic juveniles (Bjorndal *et al.* 2000). Laurent *et al.* (1998) proposed that between the strict oceanic pelagic stage and the benthic stages, immature turtles may live through an intermediate neritic stage in which they switch between pelagic and benthic foods and habitats. Furthermore, it is likely that some animals are not pelagic juveniles, as adults are known to make migrations between foraging grounds and nesting beaches across open ocean waters (see Part I.) and benthic juveniles have been reported to migrate well offshore seasonally (Epperly *et al.* 1995, Shoop and Kenney 1992, Mullin and Hoggard 2000<sup>9</sup>).

### **Natal Origins**

There is no information about the natal origins of loggerheads captured by the Atlantic fleets. However, studies of foraging ground animals on the North American continental shelf and estuarine waters and of stranded animals in the western North Atlantic indicate that animals of different origins mix on the foraging grounds, with the large South Florida subpopulation dominating everywhere, but with decreasing contribution northward (see Part I and TEWG 1998, 2000). Studies of pelagic animals captured in the vicinity of the Azores indicated that 71-72% of the animals originated from the South Florida subpopulation, with 17-19% of the animals originating from the northern subpopulation and 10-11% from the Quintana Roo, Mexico subpopulation (Bolten *et al.* 1998). The Azores samples, dipnetted from the ocean's surface, represent an admixture of pelagic animals. The size distribution of these animals is significantly different (smaller) than animals taken on the longlines (Fig. 2). If there is no sorting by natal origin in the pelagia and these smaller animals represent the same genetic mix as would be found in the larger animals taken by the longline, we can assume that these results also represent the natal origins of animals caught by the U.S. domestic longline fleet on the high seas in the eastern Atlantic.

In the Mediterranean Sea, 45-47% of the loggerheads captured in pelagic longlines (presumably pelagic stage animals) originate from western North Atlantic rookeries (Laurent *et al.* 1998) whereas none of the animals captured in trawls (presumably benthic stage animals) were from the western North Atlantic. Of the animals from the Western North Atlantic, 2% were from the northern subpopulation, the remainder were attributed to the South Florida subpopulation. Thus, it appears that both the eastern and western basins of the Mediterranean

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<sup>8</sup> Panou, A., G. Antypas, Y. Giannopoulos, S. Moschonas, D.G., D. Mourelatos, G. Mourelatos, Ch. Mourelatos, P. Toumazatos, L. Tselentis, N. Voutsinas, and V. Voutsinas. 1992. Incidental catches of loggerhead turtles, *Caretta caretta*, in swordfish long lines in the Ionian Sea, Greece. Unpublished Report. Institute of Zoology, University of Munich, Germany, 8 pp

<sup>9</sup> Mullin, K.D. and W. Hoggard. 2000. Visual surveys of cetaceans and sea turtles from aircraft and ships, p. 111-322. In R.W. Davis, W.E. Evans, and B. Würsig, eds. Cetaceans, sea turtles and seabirds in the northern Gulf of Mexico: distribution, abundance and habitat associations. Unpublished report. USGS/BRD/CR--1999-0006, OCS Study MMS 2002-002. Department of Marine Biology, Texas A&M University, Galveston, Texas.

Sea are utilized by pelagic loggerheads originating from the western North Atlantic but these animals leave the Mediterranean before switching to their benthic life stage.

In fall 2000, 18 genetic samples were taken from loggerhead turtles captured on the Grand Banks and 16 of them have been sequenced<sup>10</sup>. Two haplotypes were discerned: A (56.3%) and B (43.7%). Haplotypes A and B have been found in all 3 nesting assemblages in the United States and B also has been found in the nesting population of Mexico and Greece (Encalada *et al.* 1998). The sample size is too small to yet determine the proportions of the subpopulations represented.

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<sup>10</sup> Peter Dutton, National Marine Fisheries Service, SWFSC, La Jolla, Calif. Personal Communication (E-Mail) to Sheryan Epperly, National Marine Fisheries Service, SEFSC, Miami, Fla., January 20, 2001.

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Witzell, W.N. 1999. Distribution and relative abundance of sea turtles caught incidentally by the U.S. pelagic longline fleet in the western North Atlantic ocean, 1992-1995. Fishery Bulletin 97:200-211.

Table 1. Documented loggerhead sea turtle sizes incidentally captured by various longline fleets.

		Mean (cm)	Range	StDev	N
Atlantic Ocean					
Location fished	Grand Banks	55.9	41-70	6.5	98
Vessel Flag	U.S.A.				
Target Species	Swordfish				
Reference	Witzell (1999)				
Location fished	Azores	--	42-82	--	224
Vessel Flag	Spain				
Target Species	Tuna, Swordfish, Blue Sharks				
Reference	Bolten <i>et al.</i> (1993, 1994, 2001 <sup>11</sup> )				
Mediterranean Sea					
Location Fished	Western Med. Sea	48.1	27-76	-	856
Vessel Flag	Spain				
Target Species	Swordfish				
Reference	Aguilar <i>et al.</i> (1995)				
Location Fished	Ionian Sea	35-75	20-100	-	59
Vessel Flag	Greece				
Target Species	Swordfish				
Reference	Panou <i>et al.</i> (1992) <sup>12</sup>				
Location Fished	Central Med. Sea	57.0	35-69.5	9.9	38
Vessel Flag	Italy				
Target Species	Swordfish				
Reference	Argano <i>et al.</i> (1992)				

<sup>11</sup> Bolten, A.B., H. Martins, E. Isidro, R. Ferreira, M. Santos, A. Giga, B. Riewald, and K. Bjorndal. Preliminary results of an experiment to evaluate effects of hook type on sea turtle bycatch in the swordfish longline fishery in the Azores. Bolten, A.B., University of Florida, E-mail to Nancy Thompson and Sheryan Epperly, NMFS/SEFSC/Miami, FL, January 14, 2001.

<sup>12</sup> Panou, A., G. Antypas, Y. Giannopoulos, S. Moschonas, D. Mourelatos, G. Mourelatos, Ch. Mourelatos, P. Toumazatos, L. Tselentis, N. Voutsinas, and V. Voutsinas. 1992. Incidental catches of loggerhead turtles, *Caretta caretta*, in swordfish long lines in the Ionian Sea, Greece. Unpublished Report. Institute of Zoology, University of Munich, Germany, 8 pp

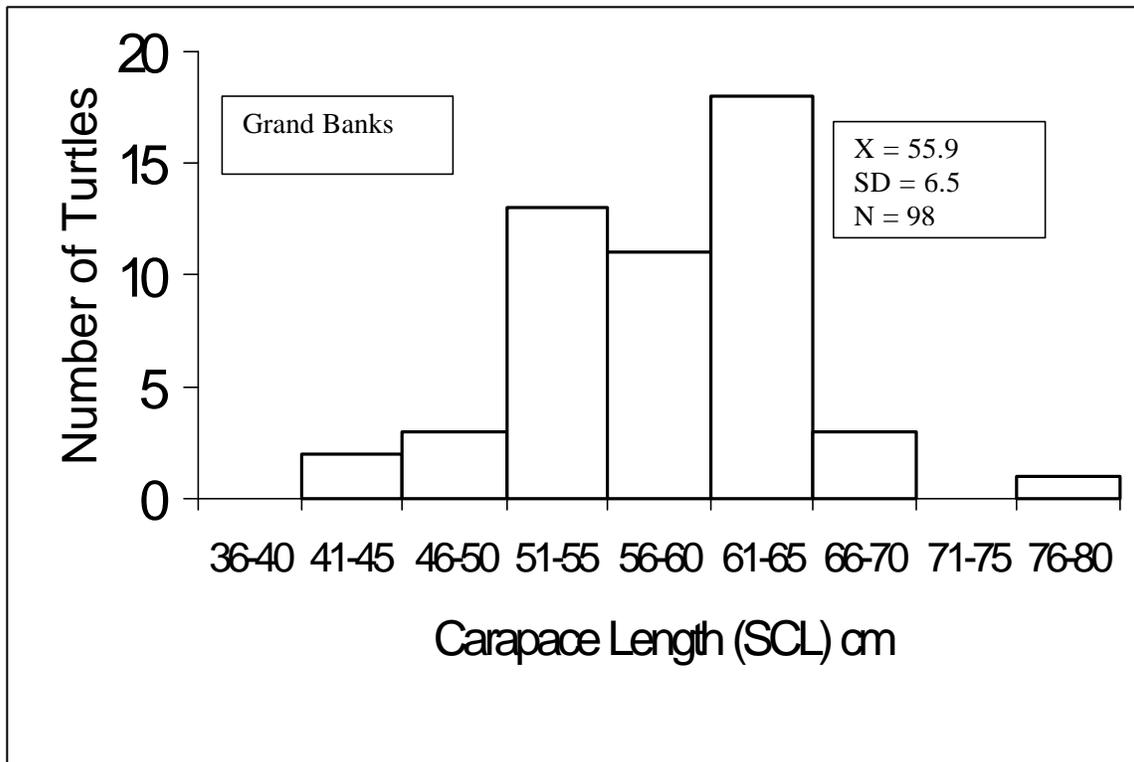


Figure 1. Sizes of longline caught loggerhead (*Caretta caretta*) turtles from the U.S. Grand Banks swordfish fishery (above) (original data from Witzell 1999) and the Spanish Azores tuna fishery (below) (Bolten *et al.* 1993; data from Figure 2).

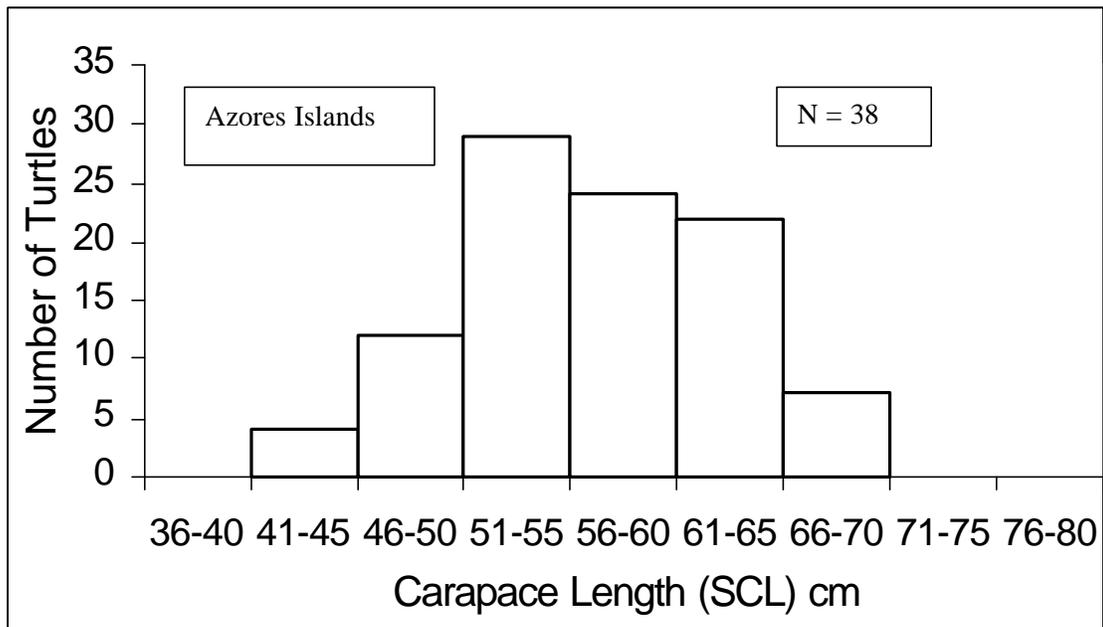


Figure 2. Length frequency histogram of dip netted and longline caught loggerhead turtles near the Azores (reproduced from Bolten *et al.* 1993).

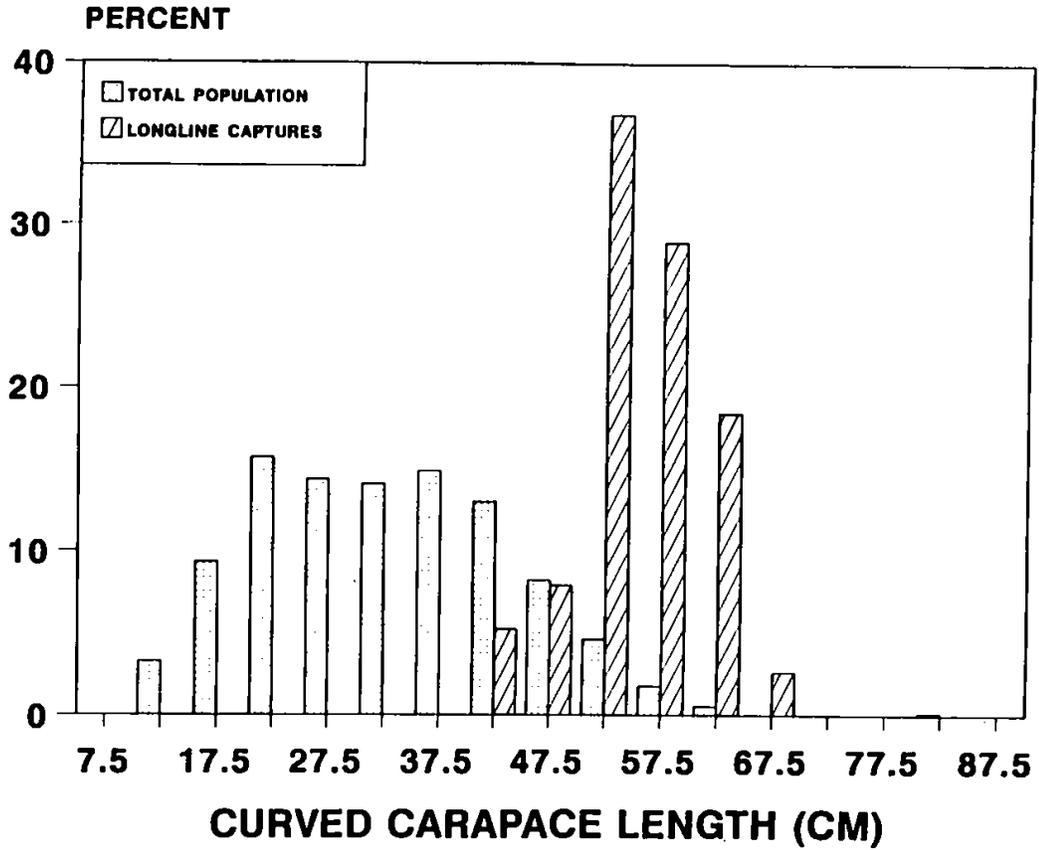
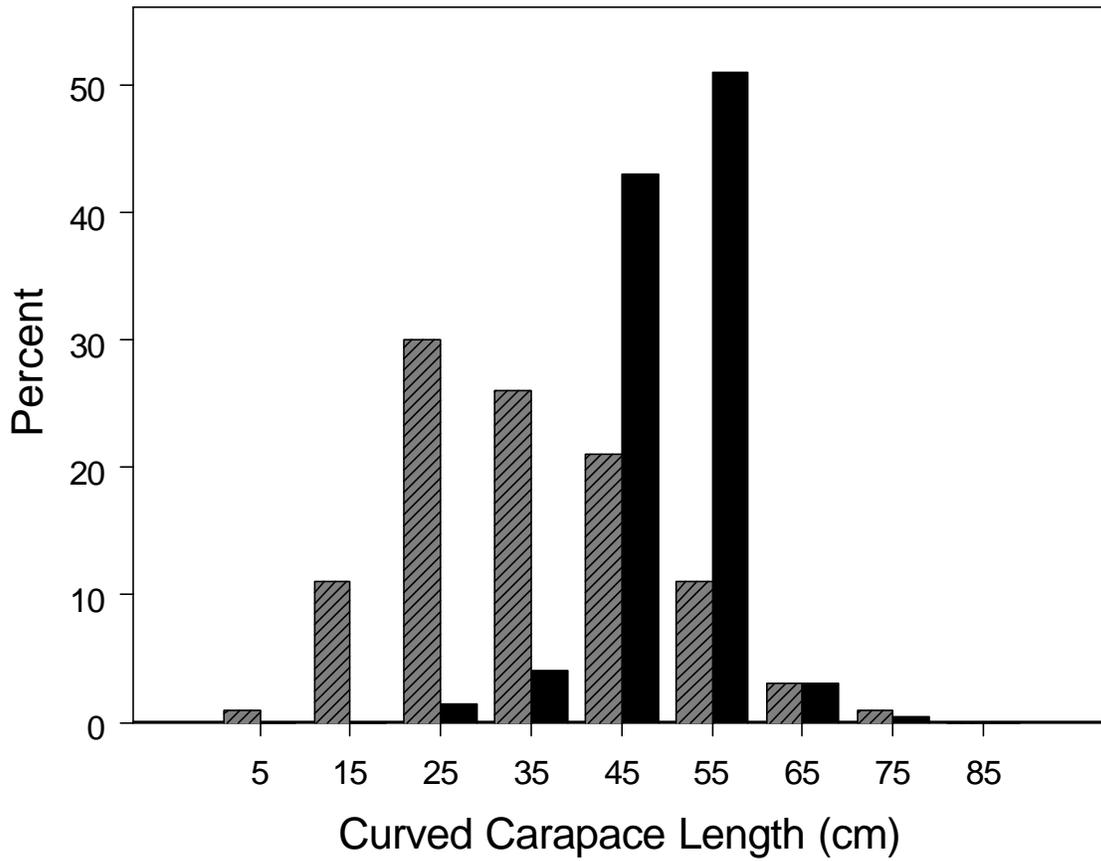


Figure 2.--Comparison of the size distributions of all loggerheads in the waters around the Azores ( $n = 731$ ) and those captured by the longline fishery in the Azores ( $n = 38$ ). The frequency distributions are significantly different (Kolmogorov-Smirnov two-sample test,  $P < 0.001$ ).

Figure 3. Length frequency of loggerhead turtles from the Azores Islands. Hatched bars = dip netted turtles, N=1,692 (includes less than 100 longline captured turtles, also) (Bjorndal *et al.* 2000). Solid bars = longline experiment, July-December 2000, N=224<sup>13</sup>. The frequency distributions are significantly different (Kolmogorov-Smirnov two-sample test, (KS=0.6522, P<0.0001).



<sup>13</sup> Bolten, A.B., H. Martins, E. Isidro, R. Ferreira, M. Santos, A. Giga, B. Riewald, and K. Bjorndal. Preliminary results of an experiment to evaluate effects of hook type on sea turtle bycatch in the swordfish longline fishery in the Azores. Bolten, A.B., University of Florida, E-mail to Nancy Thompson and Sheryan Epperly, National Marine Fisheries Service, SEFSC, Miami, Florida, January 14, 2001.

## **CHAPTER 4. REVIEW OF POST CAPTURE MORTALITY AND SELECTED MORTALITY RATES**

Office of Protected Resources, National Marine Fisheries Service

The Office of Protected Resources (F/PR) was tasked by William Hogarth, Deputy Assistant Administrator for Fisheries to review information on marine turtle mortality in longline fisheries and to make a recommendation regarding the estimation of post-interaction mortality. In addition, F/PR was directed to convene a workshop to further address the issue of mortality estimation. Finally, the Southeast Region requested input on this issue in order to incorporate any new information into their analyses of the impact of the Atlantic longline fishery on marine turtles.

### **Summary Findings**<sup>14</sup>

1. F/PR recommends the use of revised serious injury/mortality criteria for defining levels of injury to turtles interacting with longline fishing gear (see below).
2. F/PR recommends that 50% of longline interactions with all species of sea turtles be classified as lethal and 50% be classified as non-lethal. The 50% lethal classification is based on our analysis and evaluation of the range of mortality discussed in several investigations for lightly and deeply hooked turtles. Our recommendation assumes additional mortality under normal fishing conditions, where turtles are infrequently boarded, and gear can be assumed to be left on turtles at a greater rate than when an observer handles a turtle for a defined experiment.

### **Serious Injury/Mortality Criteria**

In November, F/PR received from SEC staff a preliminary strawman of serious injury/mortality criteria (Attachment A). F/PR reviewed the document in consultation with SEC sea turtle staff, who agreed that a revision was needed for greater clarity and to focus reviewer comments. F/PR revised the strawman (Attachment B) and solicited input from 33 persons including veterinarians, scientists, and gear and industry experts. F/PR received a total of 7 responses from 4 veterinarians, 2 scientists, and 1 gear/industry expert. A copy of all responses is attached, including comments from F/ST staff, responding to the draft strawman developed by the SEC (Attachment C). Attachments referred to herein are in Appendix 4.

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<sup>14</sup> Donald R. Knowles, National Marine Fisheries Service, PR, Silver Spring, Md. Personal Communication (Memo) to Joseph E. Powers, National Marine Fisheries Service, SERO, St. Petersburg, Fla.. Marine turtle mortality resulting from interactions with longline fisheries. 9 pp., January 4, 2001. Attachments referred to therein are in Appendix 4.

## Reviewer Comments

Respondents were not able to quantitatively assess criteria for determining whether a particular interaction between a turtle and longline gear will result in mortality. This is not surprising given the multitude of factors involved, including, but not limited to, the nature of the interaction, the duration of the interaction (*i.e.*, time elapsed from the interaction to removal of the animal from the gear), environmental conditions at capture, species, physiological status when captured (*e.g.*, turtle recently surfaced, turtle attempting to surface), turtle size, turtle behavior as the gear is retrieved, how the turtle is handled and the lack of baseline information on what constitutes a healthy turtle from which criteria for injury may be established. While not providing quantitative guidance, respondents did however provide important qualitative assessments of longline interactions. These assessments ranged from likely to recover (for superficial external hooking injuries) to likely long-term impact with eventual death if not treated (for ingested hooks). In general, respondents raised more questions than they answered. These questions are useful in that they will help to develop and focus the upcoming workshop to further discuss these complex issues. Despite the questions, and range of comments, there were a number of responses in common that shed light on the assessment of lethal and non-lethal interactions between sea turtles and pelagic longline gear.

Two respondents suggested variations on the injury categories described in the strawman. Their comments generally agreed with the strawman's categories, except that both suggested an additional description for 'moderate' or 'minor' injury that would include visible injuries that are determined to be superficial, and interactions where the gear has been removed and the animal is not weakened. PR assumes that injuries described in this category would not result in mortality, but might reduce the animal's fitness. Therefore, a new category of observed "minor or moderate" injury is proposed.

The remaining comments can be grouped into three general categories: hooking, hooking with trailing line, and entanglement. The respondents generally indicated that the degree of damage that may result from hooking is dependent upon where on the body the hook penetrated, the depth of penetration, and the length of time the hook is present. Infection, whether localized or systemic, was another important factor in determining whether the turtle would survive the hooking event. One respondent stated that he had seen turtles with ingested hooks that were apparently healthy while other ingested hooks can cause death. Another respondent stated that any turtle with an ingested hook could be in grave danger. Physiological stresses resulting from the hooking event (*e.g.*, fighting the hook) was also pointed out as a concern. Respondents categorized trailing line (*i.e.*, line that is left on the turtle), particularly line that is trailing from an ingested hook, as a significant risk. Line trailing from an ingested hook is likely to be swallowed which may occlude the gastrointestinal tract and lead to eventual death. Trailing line may become snagged and may result in further entanglement with potential loss of appendages that may affect mobility, feeding, predator evasion, or reproduction. Several respondents felt that the level of risk is dependent on the size and robustness of the turtle in relation to the length of line that is left on the turtle. Characteristics of the monofilament line may also play a role in the risk of further entanglement.

F/PR believes that the reviewer's responses clearly indicate that interactions with longline gear pose a risk to the turtle and that many variables affect that level of risk. These variables cannot be quantitatively ascertained from the existing observer records. Assigning a mortality level to each specific type of interaction based on existing records and current knowledge would be extremely difficult. Revised criteria for determining injury are provided below.

### **Revised Criteria for Determining Injury for Sea Turtle-Longline Fishery Interactions**

#### I. Non-serious injuries:

1. Entanglement in monofilament line (mainlines, gangion line, or float line) where there are no visible injuries (cuts and/or bleeding), the gear is completely removed, and the turtle swims strongly away from the vessel.

#### II. Minor or Moderate injury:

1. Visible injuries determined to be superficial and interactions where the gear has been removed and the animal is not weakened (this category would not include ingested hooks under III. 4, below).

#### III. Serious injuries may result in mortality, or reduced ability to contribute to the population when released alive after the interaction:

1. Entanglement in monofilament line (mainline, gangion line, or float line) that directly or indirectly interferes with mobility such that feeding, breeding or migrations are impaired.
2. Entanglement of monofilament line (mainline, gangion line, or float line) resulting in substantial wound(s) (cuts, constriction, bleeding) on any body part.
3. Hooking external to the mouth resulting in substantial wound(s) (cuts, constriction, bleeding) with or without associated external entanglement and/or trailing attached line.
4. Ingestion of hook in beak or mouth (visible), with or without associated external entanglement and/or trailing attached line.
5. Ingestion of hook in the mouth, throat area, esophagus or deeper, with or without associated external entanglement and/or trailing attached line.

### **Estimating Post-Interaction Sea Turtle Mortality**

F/PR has reviewed the results of research on post-hooking mortality of sea turtles interacting with longline fisheries and has discussed results with several experts. The research to determine post-hooking mortality is based primarily on satellite tracking of hard-shell turtles after their treatment for hooking/entanglement and release. The transmitters are placed on the carapace of the turtle and data are downloaded from a satellite link at pre-determined intervals when the turtle is on the surface. Some transmitters also measure the turtle's diving behavior. The lack of any satellite transmission after 30 days may be categorized as an unsuccessful track and probable turtle mortality. Properly functioning transmitters should operate anywhere from 9-18 months. The failure rate of transmitters is minimal and attachment to the turtle shell is

certain, so that the sinking of the turtle after death is assumed when transmissions are no longer received after 30 days. However it is important to note that this one-month criterion cannot be evaluated for its direct relation to mortality and the actual “cut-off” for assuming mortality may be significantly higher or may be lower.

### ***Post-Hooking Studies: Hawaii***

Studies aimed at elucidating post-longline hooking mortality using satellite telemetry devices are ongoing in the Hawaii longline fishery operating in the north central Pacific. These studies have focused on olive ridleys, loggerheads, and to a lesser extent green turtles (G. Balazs, personal communication<sup>15</sup>). Turtles selected as part of the study are limited to those that are lightly hooked or have deeply ingested hooks. The term “lightly hooked” refers to hooks that are imbedded externally on the turtle or imbedded in the mouth or beak, and that can be removed with relative ease and without causing additional injury. The term “deep ingested” implies a hook that is not visible when the mouth is open or only part of the hook can be seen when viewed in the open mouth, in either case the “deep ingested” hook cannot be removed in the field without causing further harm. Turtles selected to carry transmitters are boarded using dip nets. Observers remove the hook and all line before beginning the transmitter attachment on lightly hooked turtles. The treatment of turtles that have deep ingested hooks differs in that the line is removed to a point as close to the hook as possible, but the hook (and in some cases attached line) remains. The transmitter attachment procedure takes several hours from start to finish, after which the turtle is released. There were no turtles studied that were entangled only and no control turtles (*i.e.*, non-hooked, wild turtles) in the same environment have been tagged as part of this study. Ongoing studies in the Eastern Tropical Pacific (ETP) may provide a control group of turtles against which to compare those tagged in the north central Pacific. However, ETP sample sizes remain small and life history stages differ for some species (*e.g.*, mature adult olive ridleys intercepted during their breeding migrations in the ETP) thus complicating comparability (P. Dutton, personal communication<sup>16</sup>).

Results of the Hawaii-based study, to date, are summarized in a November 2000 report by the NMFS Southwest Fisheries Science Center (NMFS 2000a<sup>17</sup>). The data are complex and some of the tracking is ongoing. However, initial results are available. The study included 35 loggerheads, 11 olive ridleys, and 3 green turtles. Of the 49 turtles outfitted with satellite transmitters (30 deep ingested, 19 lightly hooked), 30.6% (n=15) produced no transmissions or transmissions that did not exceed one month in duration (these are not considered “successful trackings”). Of these 15 turtles, four were lightly hooked (21.1%) and 11 were deeply hooked (36.7%). Analyses to test for differences in transmission time distribution, mean transmission time and mean distance traveled in the Hawaii-based study between lightly hooked and deeply

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<sup>15</sup> George Balazs, National Marine Fisheries Service, SWFSC, Honolulu, Hawaii. Personal Communication to Barbara Schroeder, National Marine Fisheries Service, PR, Silver Spring, Md.

<sup>16</sup> Peter Dutton, National Marine Fisheries Service, SWFSC, La Jolla, Calif. Personal Communication to Barbara Schroeder, National Marine Fisheries Service, PR, Silver Spring, Md., January 2001.

<sup>17</sup> NMFS. 2000a. Post-hooking survival research of marine turtles (analyzed by D. Parker and G. Balazs). Unpublished Report. National Marine Fisheries Service, SWFSC, Honolulu, Hawaii, November 2000, 20 pp.

hooked turtles revealed no significant differences. Twenty-seven percent (27%) of the lightly hooked loggerheads and 42% of the deeply hooked loggerheads were classified as non-successful tracks. Seventeen percent (17%) of the lightly hooked olive ridleys and 20% of the deeply hooked olive ridleys were classified as non-successful tracks. Sample sizes of green turtles (n=3) were too small to produce meaningful results.

Reliability of transmitters is an important consideration in studies employing satellite telemetry to elucidate the behavior and migrations of sea turtles. Four “types” of transmitters were used in the Hawaii-based study. No significant differences were found in the comparison of different duty cycles or battery types for the duration of tracking for turtles that produced successful tracks (NMFS 2000b<sup>18</sup>).

We believe the cessation of transmissions within a one-month period and the absence of transmissions post-release (collectively termed “non-successful tracks”) from 30.6% of the tagged turtles can be considered a minimal indicator of post-hooking mortality in this study. We believe it is unlikely that mechanical failure of the transmitters or separation of the transmitter from the turtle would cause such a result. Satellite telemetry studies on post-nesting hawksbills in the Caribbean, utilizing similar, though not identical units, resulted in only one tagged turtle (2.5%) from which no transmissions were documented and catastrophic failure of the telemetry unit is suspected (B. Schroeder, personal communication<sup>19</sup>). Studies deploying over 100 similar, though not identical tags (primarily Telonics ST-14 units and a smaller number of Wildlife Computer SDR units) on post-nesting loggerhead and green turtles in Florida and studies on post-nesting green turtles in Hawaii and elsewhere in the Pacific have resulted in no total failures (Balazs, personal communication<sup>20</sup> and Schroeder, personal communication<sup>21</sup>). In these studies, cessation of transmissions within short periods of time (*e.g.*, less than one month, but not total failure) are also relatively uncommon when proven attachment techniques and transmitter designs are used.

### ***Post-Hooking Studies: Eastern Atlantic***

Similar, though not identical studies are being conducted in the eastern Atlantic in an attempt to elucidate post-longline hooking mortality of immature loggerheads. This research includes wild-captured turtles (*i.e.*, not hooked) from the same area as turtles incidentally captured in the Azores swordfish longline fishery (considered “control turtles”) and was conducted in two discrete segments - Fall 1998 and Summer 2000 using Wildlife Computers

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<sup>18</sup> NMFS. 2000b. Post-hooking survival research of marine turtles: duty cycle and battery configuration analyses. Unpublished Report. National Marine Fisheries Service, SWFSC, Honolulu, Hawaii, Oct. 2000, 8 pp

<sup>19</sup> Barbara Schroeder, National Marine Fisheries Service, PR, Silver Spring, Md. Personal Communication.

<sup>20</sup> George Balazs, National Marine Fisheries Service, SWFSC, Honolulu, Hawaii. Personal Communication to Barbara Schroeder, National Marine Fisheries Service, PR, Silver Spring, Md., January 2001.

<sup>21</sup> Schroeder, B., National Marine Fisheries Service, PR, Silver Spring, Md., Personal Communication.

satellite-linked Time-Depth Recorders (Bjorndal *et al.* 1999<sup>22</sup>; Riewald *et al.* 2000<sup>23</sup>). Sample sizes are considerably smaller than the Hawaii-based study, 9 turtles have been wild-captured, 3 were lightly hooked (in mouth), and 6 turtles were deeply hooked. As in the Hawaii-based studies, turtles captured incidental to the swordfish fishery were “treated” - for lightly hooked turtles, hooks and all gear were removed and for deeply hooked turtles the monofilament line was cut at the wire leader. Turtles in the Azores study were typically released within 2-4 days of capture as opposed to several hours post-capture in the Hawaii-based study. Results from the Fall 1998 study indicated that several months after capture and release all of the turtles continued to transmit, though one of the control turtles was transmitting only sporadically and with insufficient to obtain location fixes (Bjorndal *et al.* 1999). Results from the Summer 2000 study indicate that as of the end of October 2000, two of the four transmitters on control turtles and five of the six transmitters on hooked turtles continued to function. Using criteria similar to the Hawaii-based study for “successful tracks”, one of the control turtles and one of the hooked turtles ceased transmitting within one month after release. Analyses to date have focused on diving behavior and movement patterns and directions. A diurnal pattern in dive behavior was evident for most hooked and control turtles, distribution of dives for hooked turtles were skewed toward longer dives and shallower dives and hooked turtles did not show the bimodal distributions of maximum dive depths that were characteristic of control turtles (Riewald *et al.* 2000). Riewald *et al.* (2000) opines that transmitters that provide dive profiles are necessary to determine whether transmitter failure is due to mortality or mechanical causes and describes the diving activity of one of the hooked turtles (still transmitting) as indicative of a dead, floating turtle, buffeted by waves. Data analyses are ongoing by the contractor.

### ***Post-Hooking Studies: Mediterranean***

A third study approached the question of post-hooking mortality in a different way. Aguilar *et al.* (1995), working in the western Mediterranean kept in captivity sea turtles that had been incidentally captured in the Spanish longline fishery with the aim of estimating the mortality rate of individuals with hooks still in their bodies. While the exact details of the study are not clearly elucidated, the assumption is that turtles held in captivity for observation had ingested a hook. It is unclear whether line attached to these hooks was removed to the maximum extent possible, but it is reasonable to assume that this was the case. Of 38 turtles reported by Aguilar (1995) 11 died in captivity, 6 expelled the ingested hook prior to their release (range of days to expulsion 53-285), 15 turtles were released prior to expulsion of the hook (range of days to release 81-123), and 6 turtles taken in 1991 remained under observation at the time the paper was written and the fates of these turtles are unknown. Excluding the 6 turtles for whom the fates are unknown, 34.4% died, 18.8% expelled the hook and 46.9% were released without hook expulsion (see ranges of days in captivity above). As with the Hawaii-based study and the Azores-based study, turtles used in this study also underwent some level of “treatment”, including removal of trailing line (reasonably assumed though not explicitly stated), maintenance

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<sup>22</sup> Bjorndal, K.A., A.B. Bolten, and B. Riewald. 1999. Development and use of satellite telemetry to estimate post-hooking mortality of marine turtles in the pelagic longline fisheries. NMFS-SWFSC Administrative Report H-99-03C, Department of Zoology, University of Florida, Gainesville, 25 pp.

<sup>23</sup> Riewald, B., A.B. Bolten, and K.A. Bjorndal. 2000. Use of satellite telemetry to estimate post-hooking behavior and mortality of loggerhead sea turtles in the pelagic longline fishery in the Azores. NMFS-SWFSC Final Report Order No. 40JJNF900114. Unpublished report. Department of Zoology, University of Florida, Gainesville, 28 pp.

in a captive environment where food was regularly provided and where predator avoidance was not a factor. While it may be argued that turtles are further stressed under captive conditions, we believe that the captive environment represents a less stressful environment for an injured turtle (*i.e.*, one that has ingested a hook). Additionally, the Aguilar study assumes that the 15 turtles (46.9%) released before hook expulsion survived, an assumption that cannot be quantitatively determined. One respondent to the request for comments on mortality criteria opined that without definitive necropsies, Aguilar’s results can not be used to address post-hooking mortality. Based on our assessment of the study, we believe that the 34.4% observed mortality reported in the Aguilar paper is a minimal estimate of mortality for ingested hooks in the wild.

### ***Entanglement***

None of the studies discussed herein involved turtles that were only entangled, not hooked, in longline gear. The applicability of the results of the studies reviewed above to “entangled only” turtles is a valid question to explore. Comments on the draft strawman suggested that the characteristics of longline monofilament make it unlikely to remain on an “entangled only” turtle once the turtle is cut free from the gear. Data from the Hawaii longline fishery observer program from 1994-1999 indicate that the overwhelming majority of interactions involving hard shelled turtles involve hooking, not entanglement only (Table 1). Hawaii longline observer records indicated that leatherback turtles are more frequently only entangled in the gear, although nearly 75% of the time, hooking is involved (Table 1). Of the eight leatherbacks observed “entangled only”, 25% (n=2) were dead, 37.5% (n=3) were recorded as “okay”, and 37.5% (n=3) were recorded as “injured”.

Data from the Atlantic HMS longline fishery observer program indicate similar levels of “entanglement only” for loggerheads and leatherbacks. The vast majority of loggerheads are hooked while leatherbacks interact with the gear slightly differently - a greater percentage are “entangled only” (Table 2). All of the leatherbacks observed “entangled only” were alive when the gear was retrieved.

Table 1. Breakdown of type of gear interaction, hooked (includes lightly hooked, deeply hooked) vs. entangled only (no hooking involved), 1994-1999 Hawaii longline observer program (McCracken 2000<sup>24</sup>).

Species	Hooked	Entangled Only	Not Recorded	TOTAL
<i>C. caretta</i>	143 (97.3%)	3 (2.0%)	1 (0.7%)	147
<i>D. coriacea</i>	29 (72.5%)	8 (20.0%)	3 (7.5%)	40
<i>L. olivacea</i>	32 (100%)	0	0	0
<i>C. mydas</i>	8 (100%)	0	0	8

<sup>24</sup> McCracken, Marti L. 2000. Estimation of Sea Turtle Take and Mortality in the Hawaiian longline fisheries. NMFS-SWFSC Administrative Report H-00-06. Unpublished Report. NMFS/SWFSC/Honolulu, HI, 29 pp

Table 2. Breakdown of type of gear interaction, hooked (includes lightly hooked, deeply hooked) vs. entangled only (no hooking involved), 1999 Atlantic longline observer program. (Data source: J. Hoey (unpublished report, 2000<sup>25</sup>, summary of 1999 NMFS observer data for HMS Atlantic longline).

Species	Hooked	Entangled Only	Not Recorded	TOTAL
<i>C. caretta</i>	60 (93.8%)	1 (1.6%)	3 (4.7%)	64
<i>D. coriacea</i>	26 (57.8%)	12 (26.7%) <sup>26</sup>	7 (15.6%)	45
Unknown	1 (33.3%)	2 (66.7%)	0	3

### **Conclusions and Recommendations**

The Aguilar *et al.* (1995) results and the results of the Hawaii-based study, for mortality from deeply ingested hooks, 34.4% and 42% respectively, are similar. Preliminary data from the Azores study, with very limited sample sizes, indicating a 33.3% mortality from deeply ingested hooks is also in the same range, assuming one month criteria and contractor interpretation of diving behavior. Whether these results are corroborative or purely coincidental cannot be qualitatively determined. The mortality range for lightly hooked and deeply hooked hard-shelled turtles in the Hawaii-based study is 17 - 42%, based on a one-month criteria established for successful vs. non-successful tracks.

This one-month criterion cannot be evaluated for its direct relation to mortality and the actual “cut-off” for assuming mortality may be significantly higher or may be lower. It is important to remember that the turtles used in all studies underwent a level of treatment (*e.g.*, line and/or hook removal as well, recuperative time on deck, captive maintenance) that undoubtedly improved their survival outlook. We believe that mortality rates in the wild, under actual fishing conditions are likely higher than mortality rates indicated by the studies reviewed herein. Given the available information, as well as adopting a risk-averse approach that provides the benefit of the doubt to the species where there are gaps in the information base<sup>27</sup>, F/PR

<sup>25</sup> Hoey, J. 2000. Unpublished summary of 1999 observer record comments on sea turtle interactions in the Atlantic HMS fishery. National Marine Fisheries Service, ST, Silver Spring, Md., 9 pp.

<sup>26</sup> Four of eight turtles may have been hooked in addition to entangled, hooking location unknown.

<sup>27</sup> The Endangered Species Act Section 7 consultation process requires NMFS to use the best available scientific and commercial data. The Services established criteria to ensure that the information used in the Section 7 consultation process was reliable, credible, and representative of the best available data (59 FR 34271; July 1, 1994). To the extent practicable, NMFS must use primary and original sources of information including, but not limited to, anecdotal, oral, and gray literature as well as published documents. If data gaps exist that would help determine the impacts to listed species and the action agency intends to proceed with the proposed action, NMFS must proceed with the existing information and is expected to provide the benefit of the doubt to the species concerned with respect to such gaps in the information base (H.R. Conference Report No. 697, 96th Congress, 2nd Session 12 (1979)).

recommends that 50% of longline interactions be classified as lethal and 50% be classified as non-lethal. The 50% lethal classification considers the range of mortality discussed above for lightly and deeply hooked turtles and assumes additional mortality under normal fishing conditions, where turtles are infrequently boarded, and gear can be assumed to be left on turtles at a greater rate than when an observer handles a turtle for a defined experiment. Observer efforts to disentangle turtles and to remove trailing line can sometimes be described as heroic and while we believe that some fisherpersons will undertake similar efforts, others will not. As discussed above, most of the respondents to the NMFS request for comments/information on post-hooking mortality characterized gear left on turtles as a serious problem, especially trailing line which would be a significant risk to the turtle, especially when ingested hooks are involved. While these studies are limited to hard-shelled turtles, in the absence of evidence to suggest that interactions with leatherbacks would result in higher survival rates, we recommend that the 50% mortality figure be applied to leatherbacks as well as hard-shelled turtles. One respondent to the request for input on mortality criteria commented that leatherbacks are not as resilient as hard-shelled turtles and that actions such as hooking, lifting from the water, and ingestion of hooks and lines may have more damaging and long lasting impacts. Our review of the available information does not suggest that a differential mortality estimate can be applied to lightly hooked vs. deeply hooked vs. “entangled only” turtles at this time. While we believe that lightly hooked turtles and “entangled only” turtles, especially those that have trailing line and hooks removed have a greater chance of survival than deeply hooked turtles, the data do not exist to provide for a differential apportionment. In reality, the figure may be higher than 50% for deeply hooked turtles and lower than 50% for lightly hooked and “entangled only” turtles. In the future, refinements to these estimates can be made if additional information is gathered and further evidence can be provided to quantitatively define post-hooking mortality. Data collected by observers must be standardized and of sufficient detail and description to assess and categorize the interaction. F/PR intends to convene an expert workshop in early 2001 to further discuss the question of sea turtle survival following interactions with longline gear and to refine, if possible, post-interaction survival rates.

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## CHAPTER 5. SUMMARY OF TAKES BY THE PELAGIC LONGLINE FISHERY IN THE ATLANTIC OCEAN AND MEDITERRANEAN SEA

Joanne Braun-McNeill and Wayne N. Witzell

### Summary of Takes

The pelagic longline fishery for tuna and swordfish incidentally captures loggerhead and leatherback sea turtles (see Table 8 of Chapter 2 and Appendices 2 and 3). Loggerhead juveniles, during their pelagic life stage, circumnavigate the North Atlantic via the Atlantic Gyre and are exposed sequentially to a series of longline fisheries that primarily target swordfish and tuna. Because leatherbacks utilize the open ocean during all life stages, they are exposed to pelagic fishing gears throughout their entire life history. Loggerhead turtles readily ingest baited hooks (Witzell 1999). While leatherbacks are more likely than loggerheads to become captured through entanglement in the main and branch lines than ingestion of the baited hooks (Witzell 1984, Tobias 1991, Witzell 1999), there have been reports of leatherbacks ingesting the squid bait used on swordfish longline gear (Skillman and Balazs 1992). According to the National Marine Fisheries Service mandatory Pelagic Logbook Program records for the U.S. fleet, loggerhead and leatherback CPUE was greater with vessels utilizing light sticks (targeting swordfish) than vessels without (targeting tuna) (Witzell 1999). It has been suggested that leatherbacks are attracted to the lightsticks used by vessels targeting swordfish, perhaps mistaking the light sticks for bioluminescent schyozoa and then becoming entangled in the line (Witzell 1999). This relationship, however, could not be demonstrated from observer data where analyses indicated that sea turtle (both loggerhead and leatherback) interactions were not positively influenced by the use of lightsticks (Hoey 1998<sup>28</sup>). Most fishery-reported U.S. fleet longline interactions with loggerhead and leatherback turtles occur from the Mid-Atlantic Bight to areas northward. (Witzell 1999). Observer data, however, revealed greater loggerhead interactions in the Caribbean and the Gulf of Mexico for certain years (Figs. 1 and 2). Noteworthy was that marine turtle bycatch estimated from observer data was significantly higher ( $p < 0.05$ ) than that reported in logbooks (Johnson *et al.* 1999) indicating that an assessment method dependent upon the fishery's self-reporting has limitations. According to observer records, an estimated 7,891 loggerhead and 6,363 leatherback sea turtles were captured by the U.S. Atlantic tuna and swordfish longline fisheries 1992-1999 of which 66 loggerhead and 88 leatherbacks were estimated to have been released dead (Table 8 of Chapter 2). Some of those released alive may not have survived. The National Marine Fisheries Service Office of Protected Resources recommends that 50% of longline interactions with all species of sea turtles be classified as lethal (Table 1) and 50% be classified as non-lethal (see Chapter 4).

The U.S. longline fleet accounts for a relatively small proportion (<5-8%) of total hooks fished in the Atlantic Ocean compared to the other nations conducting longline fishing in this

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<sup>28</sup> Hoey, J.J. 1998. NEFSC pelagic longline data review & analysis of gear, environmental, and operating practices that influence pelagic longline interactions with sea turtles. Final contract report NOAA Contract - 50EANA700063. Unpublished report from National Fisheries Institute, Inc., Arlington, Va. to National Marine Fisheries Service Northeast Regional Office, Gloucester, Mass., 32 pp.

area (see Chapter 1), but accounts for an average of 28% and 18% respectively, of the swordfish and tuna landed from the North Atlantic. These other nations include Taipei, Brazil, Trinidad, Morocco, Cyprus, Venezuela, Korea, Mexico, Cuba, U.K., Bermuda, Peoples Republic of China, Grenada, Canada, Belize, France, and Ireland (Carocci and Majkowski 1998). In the tropics, Brazil, Korea, Portugal, Cuba, Peoples Republic of China, Equatorial Guinea, Spain, Libya, Cuba, Venezuela, USSR, and Portugal prosecute swordfish and tuna longline fisheries in addition to the U.S. (Carocci and Majkowski 1998). Unfortunately, leatherback incidental capture data for these other nations is limited. From 1987-1998, observers from the International Observer Program in the Scotia-Fundy Region aboard longline vessels in the north Atlantic Ocean reported the incidental capture of 25 leatherback sea turtles; the highest incidental catch of leatherbacks was in 1995 (n=10 turtles) and 1998 (n=8 turtles) (James 2000).

Uruguayan longliners targeting tuna and swordfish in the southwest Atlantic reported loggerhead and leatherback captures for the years 1994-1996 with a CPUE of 1.8/1000 hooks; an estimated 98.1% were released alive (Achaval *et al.* 2000). Observers of the Mexican longline tuna fishery in the Gulf of Mexico reported 2 loggerhead and 43 leatherback sea turtles incidentally captured in 37 fishing trips (8.5% of the total effort) (Ramirez and Ania 2000). Of the leatherbacks, 42% were caught by becoming entangled in monofilament fishing line. Estimated incidental capture of sea turtles (both loggerheads and leatherbacks) in this fishery is 5 turtles/100 trips; mortality is estimated to be 1.6 turtles/100 trips (Ramirez and Ania 2000). In Belize, longline fishing for sharks is reportedly catching leatherbacks (Smith *et al.* 1992). Incidental capture information for the longline fisheries prosecuted in the tropics also is very limited. The longline fishery in Antigua/Barbuda is estimated to catch 100 or more loggerhead and leatherback sea turtles each year (Fuller *et al.* 1992). In St. Vincent and the Grenadines, "some" leatherbacks also are caught by longlines (Scott and Horrocks 1993). Although there are longline vessels in the coastal waters of Barbados, no bycatch data is available (Horrocks 1992). Local longliners at Anegada in the British Virgin Islands have caught "some" leatherbacks (Eckert *et al.* 1992, Cambers and Lima 1990, Tobias 1991).

The longline fisheries prosecuted in the Mediterranean Sea include the countries of Algeria, Cyprus, Greece, Morocco, Spain, Italy, Malta, Taipei, Belize, Honduras, Japan, Korea, Libya, Panama, and Portugal (Carocci and Majkowski 1998). Considerably more loggerhead than leatherback sea turtles were reported incidentally captured in these fisheries. The Italian longline fleet targeting swordfish reported the incidental capture of 275 loggerhead and only a 'few' leatherback sea turtles from 1978-1986 (De Metrio and Magalfonou 1988), 1,817 loggerheads but only 6 leatherbacks from 1978-1981 (De Metrio *et al.* 1983), and 650 loggerheads and no leatherbacks from 1981-1990 (Argano *et al.* 1992). Out of a total of 1,098 loggerheads reported captured by the Spanish longline fleet from 1991-1992, only 2 leatherbacks were reported (Aguilar *et al.* 1995). Loggerheads observed captured in the Spanish swordfish fishery during the years 1986-1995 ranged from 443-8389 (mean=4417); estimated number captured ranged from 1,953-19,987 (mean=11,673) (Camiñas 1997). Malta's swordfish longline fishery was estimated to catch 1,500-2,500 loggerhead but no leatherback sea turtles; an estimated 500-600 loggerheads were killed (Gramentz 1989). From 1989-1991, 116 loggerhead

but no leatherback sea turtles were caught in 531 fishing trips; an estimated 70-100 loggerhead turtles are captured annually with multiple recaptures noted (Panou *et al.* 1991<sup>29</sup>, 1992<sup>30</sup>).

### **Impacts of the Pelagic Longline Fishery on Sea Turtle Populations**

It is very difficult to identify the impact of a fishery on sea turtle populations as the response of the populations is based on the cumulative impacts from all sources. The environmental baseline against which the pelagic longline fishery is being evaluated can be found in Appendix 1 and is discussed in the Impacts sections of both the loggerhead and leatherback stock assessment reports (Part I and Part II).

An important consideration in assessing fishery impacts on sea turtle populations is whether or not interactions result in mortality and subsequent loss to the population. Sea turtles that are stressed as a result of being forcibly submerged rapidly consume oxygen stores, triggering an activation of anaerobic glycolysis, and subsequently disturbing the acid-base balance, sometimes to lethal levels (Lutcavage and Lutz 1997). Forced submergence for extended periods is marked with metabolic acidosis as a result of high blood lactate levels and recovery may be as long as 20 hours (*Ibid.*). Additional factors such as size, activity, water temperature, and biological and behavioral differences between species also bear directly on metabolic rates and aerobic dive limits and will therefore also influence survivability after a gear interaction. In addition, disease factors and hormonal status may also play a role in anoxic survival during forced submergence. Although turtles released “unharmd” do not have visible injuries, they may have been stressed from being caught or entangled in gear. Recent necropsy results from the Hawaiian fishery (Work 2000<sup>31</sup>) indicated that there seems to be a higher incidence of observed drowning mortality in the Hawaiian fishery than the Atlantic fishery, possibly to differences in fishing strategy (lines are fished deeper in the Pacific) and/or turtle species composition (7 olive ridleys, 2 greens, 2 leatherbacks). In Atlantic observers’ records for 1992-1996, only one observed leatherback turtle out of 82 was obviously moribund and only 1 loggerhead out of 51 turtles (hard-shelled) appeared dead (Lee and Brown 1998). Work also concluded that mortality rates using the “lightly hooked” vs. “deeply hooked” criteria may not be satisfactory criteria to determining probability of survival.

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<sup>29</sup> Panou, A., S. Moschonas, L. Tselentis, and N. Voutsinas. 1991. Incidental catches of loggerhead turtles, *Caretta caretta*, in swordfish long lines in the Ionian Sea, Greece. Inst. Zool. Univ. Munich, Germany. Unpublished Report. Institute of Zoology, University of Munich, Germany, 6 pp.

<sup>30</sup> Panou, A., G. Antypas, Y. Giannopoulos, S. Moschonas, D. Mourelatos, G. Mourelatos, Ch. Mourelatos, P. Toumazatos, L. Tselentis, N. Voutsinas, and V. Voutsinas. 1992. Incidental catches of loggerhead turtles, *Caretta caretta*, in swordfish long lines in the Ionian Sea, Greece. Unpublished Report. Institute of Zoology, University of Munich, Germany, 8 pp.

<sup>31</sup> Work, T.M. 2000. Synopsis of finding of sea turtles caught by the Hawaii-based pelagic longline fishery. Unpublished Report. U.S. Geological Survey, National Wildlife Health Center, Hawaii Field Station, Honolulu, Hawaii, 5 pp.

In areas of turtle concentrations (*e.g.*, Mediterranean Sea, Grand Banks) turtles have been reported to have been hooked from two to eight times (Panou *et al.* 1991<sup>32</sup>, 1992<sup>33</sup>, Gramentz, 1989, Argano *et al.* 1992, Witzell 1999, Hoey and Moore 1999<sup>34</sup>). This not only compounds mortality estimates, but it also complicates take estimates. Current bycatch estimates do not take into consideration that an animal may be captured multiple times. Also, we do not yet have serious injury criteria upon which an animal may be assessed for likelihood of survival and therefore we are assuming that 50% of all animals interacting with the pelagic longlines subsequently die as a result of that interaction, regardless of where hooked, amount of line remaining on the animal, or the species (Table 1).

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<sup>32</sup>Panou, A., S. Moschonas, L. Tselentis, and N Voutsinas. 1991. Incidental catches of loggerhead turtles, *Caretta caretta*, in swordfish long lines in the Ionian Sea, Greece. Inst. Zool. Univ. Munich, Germany. Unpublished Report. Institute of Zoology, University of Munich, Germany, 6 pp.

<sup>33</sup>Panou, A., G. Antypas, Y. Giannopoulos, S. Moschonas, D. Mourelatos, G. Mourelatos, Ch. Mourelatos, P. Toumazatos, L. Tselentis, N. Voutsinas, and V. Voutsinas. 1992. Incidental catches of loggerhead turtles, *Caretta caretta*, in swordfish long lines in the Ionian Sea, Greece. Unpublished Report. Institute of Zoology, University of Munich, Germany, 8 pp.

<sup>34</sup>Hoey, J.J. and N. Moore. 1999. Captain's report: multi-species catch characteristics for the U.S. Atlantic pelagic longline fishery. MARFIN Grant – NA77FF0543 and SK Grant – NA86FD113 from National Marine Fisheries Service, Silver Spring, MD to National Fisheries Institute, Inc., Arlington, VA, 78 pp.

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Table 1. Estimated deaths of sea turtles in the U.S. Atlantic pelagic longline fishery. Mortality estimates are 50% of the total bycatch estimates (see Chapter 2, Table 8).

Species	1992	1993	1994	1995	1996	1997	1998	1999
Loggerhead	147	209	672	1220	459	192	553	496
Green	44	16	17	20	8	0	7	0
Hawksbill	10	0	0	0	0	8	9	0
Kemp's Ridley	1	0	13	0	0	11	0	0
Unidentified	13	16	17	86	1	24	1	33
All hardshell turtles*	214	240	719	1325	468	235	569	529
Leatherback	457	527	419	467	452	154	200	506

\* Assuming all unidentified turtles are hardshell turtles.

Figure 1. Hardshell and leatherback turtles reported captured in the U.S. pelagic longline fleet's logbooks and effort reported therein.

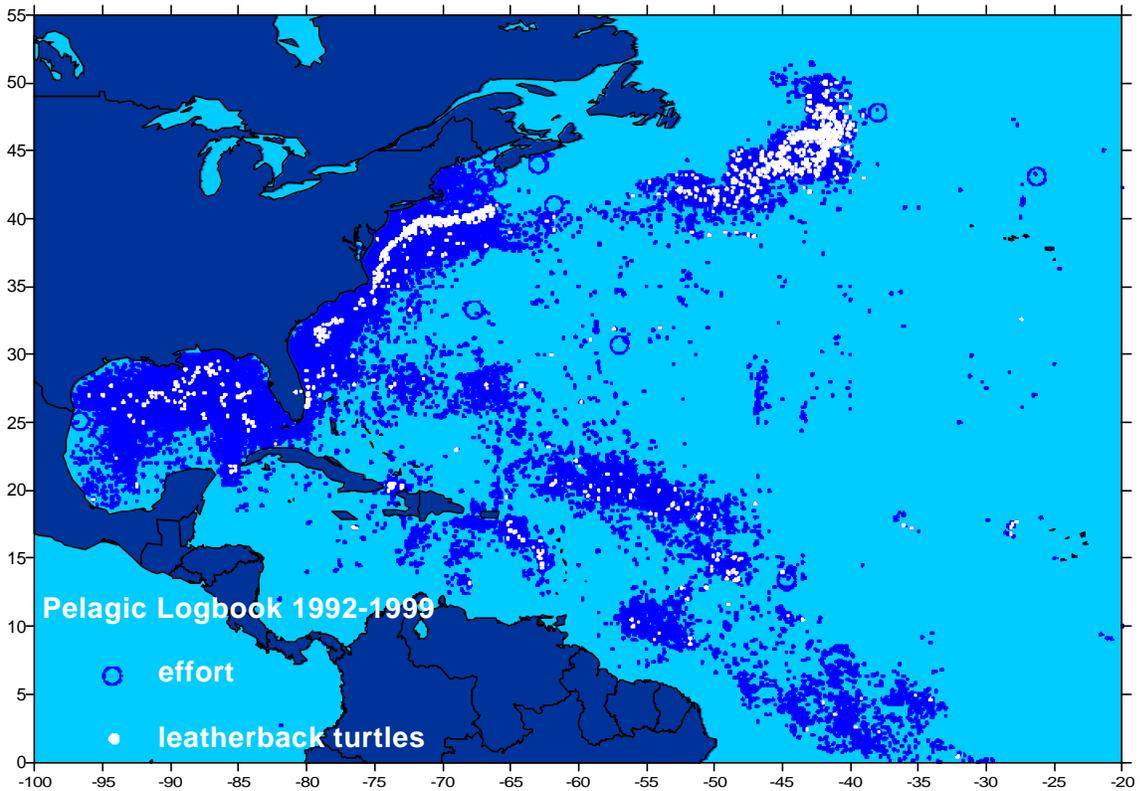
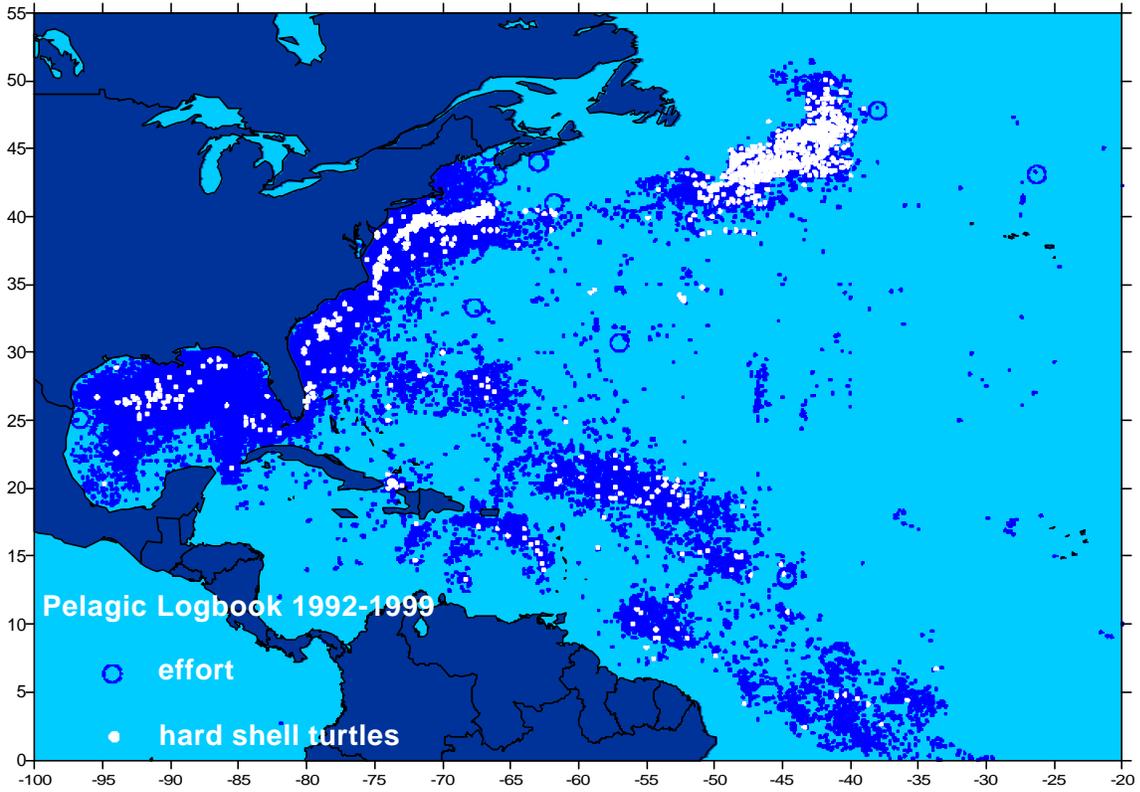
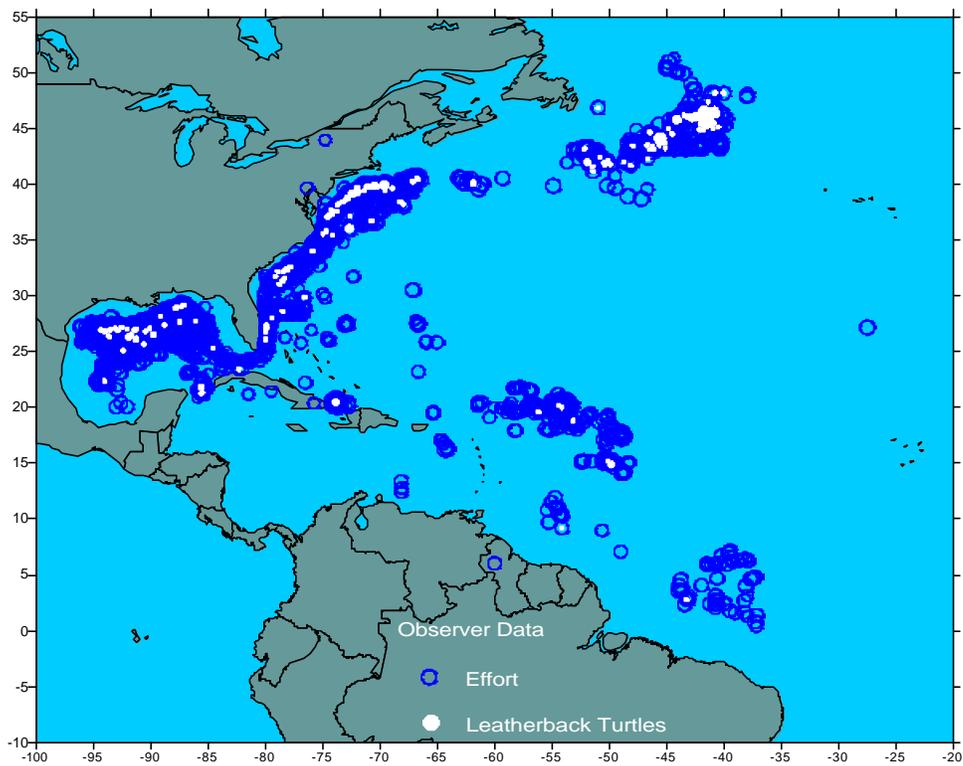
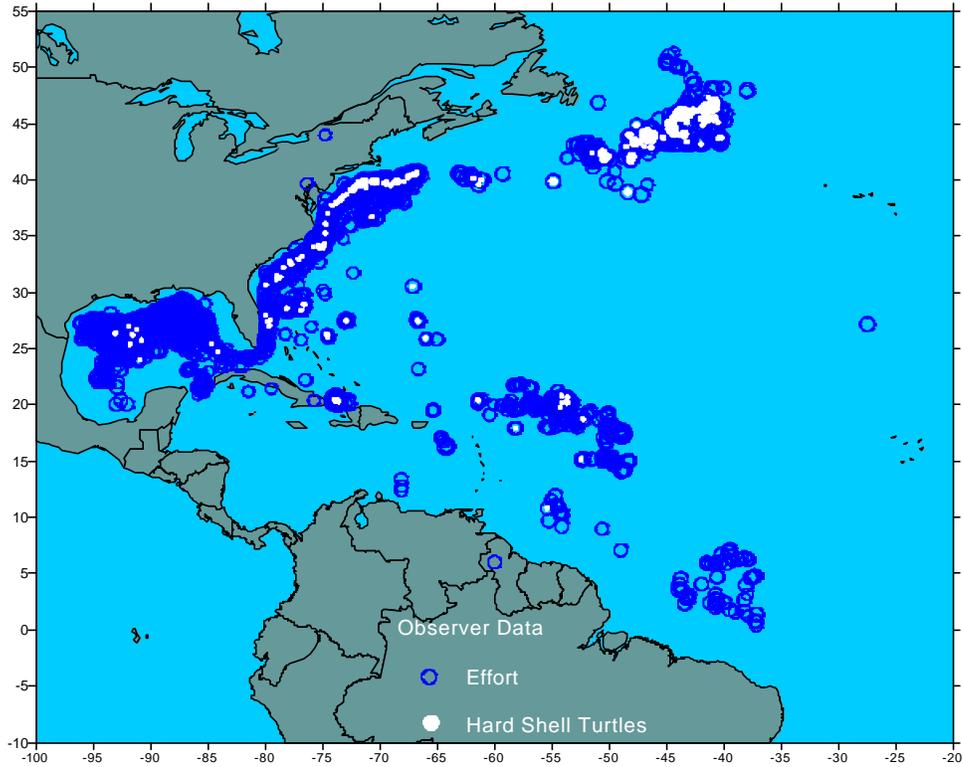


Figure 2. Hardshell and leatherback sea turtle captures reported by observers in the U.S. pelagic longline fleet and observed fishing effort.



## CHAPTER 6. IMPACT OF THE PELAGIC LONGLINE FISHERY ON LOGGERHEAD SEA TURTLES

Sheryan P. Epperly, Melissa L. Snover, and Larry B. Crowder

The loggerhead sea turtle (*Caretta caretta*) occurs throughout the temperate and tropical regions of the Atlantic, Pacific, and Indian Oceans (Dodd 1988). Its range of habitat includes open ocean waters, continental shelves, bays, lagoons, and estuaries. Loggerheads in the Western North Atlantic nest on high-energy beaches between the latitudes of 18° and 35° North. At least 5 subpopulations have been identified as management units and there may be more. Loggerheads are long-lived species which typically cannot withstand high exploitation rates, whether intentional or incidental (Heppell *et al.* 1999).

The impact of the pelagic longline fishery on loggerhead sea turtle management units must be assessed in the context of existing sources of mortality. Appendix 2 identifies known sources of anthropogenic impacts on sea turtle populations. Relative to the identified domestic (U.S.) sources, if we assume that 50% of all takes by the pelagic longline fishery result in mortality (see Chapter 5, Table 1), the impact of the pelagic longline fishery on loggerhead sea turtles, in terms of numbers of animals removed from the population, is second only to that of the shrimp fishery. However, survival of interactions in both of these fisheries might be increased through NMFS regulatory actions.

NMFS has taken steps to reduce the mortality of sea turtles in the shrimp fishery and is proposing further actions. Federal regulations have required turtle excluder devices (TEDs) in shrimp trawls at least seasonally since 1990. In early 2000 NMFS published an advance notice of proposed rulemaking (65 FR 17852-17854, April 5, 2000). The agency is proposing technical changes to the requirements for TEDs, including modifying the size of the escape opening to allow the larger benthic immature and adult turtles to escape. Epperly and Teas (1999<sup>35</sup>) determined that the body depth of loggerhead turtles is exceeding the minimum required TED height openings before the turtles can reach maturity. Turtles with deeper bodies than the height opening cannot escape; hence existing TEDs likely only are beneficial to the small benthic immature stage of loggerheads.

Heppell *et al.* (in press) constructed matrix projection models to assess the impacts of different TED effectiveness scenarios on population growth. They looked at 2 models, one using parameters from previous matrix models and one using parameters consistent with new information about growth rates of loggerheads. They initiated the model runs with a population declining at a rate of 5% per year. In the model runs where only small turtles benefit from the use of TEDs, the rate of decline in population growth rates slowed, however, the trend was still negative. Only when small and large benthic turtles both benefited with decreases in mortality did the population trend become positive. Including reductions in mortality for adult sized animals increased population growth rates further.

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<sup>35</sup> Epperly, S.P. and W.G. Teas. 1999. Evaluation of TED opening dimensions relative to size of turtles stranding in the Western North Atlantic. Unpublished Report. National Marine Fisheries Service Southeast Fisheries Science Center Contribution PRD-98/99-08, 31 pp., Miami, Fla.

In Part I we revised the models of Heppell *et al.* (in press) with new vital rate information and looked at 4 models representing different possible stage durations and lengths of time to maturity. We initiated our model runs at three different population growth rates, at declines of 5% and 3% per year and a stable population at 0% change per year. We also looked at three different possible sex ratios where the proportion of female offspring were 0.35, 0.50 and 0.80. See Part I for model results.

Through the current reinitiation of consultation on the pelagic longline fishery, NMFS may be able to identify reasonable and prudent alternatives that would effect some proportional reduction in mortality of sea turtles by the pelagic longline fishery. Some measures to reduce mortality already are in place and others are under consideration (see Chapter 8). Effective early 2001 all Atlantic pelagic longline vessels issued Federal Highly Migratory Species permits must carry on board dipnets and line clippers and must comply with requirements for the use for these and for the handling of incidentally caught sea turtles (65 FR 60889-60892, October 13, 2000). This measure was designed to reduce the mortality rate of captured sea turtles by providing devices to facilitate the removal of hooks and line from the turtles.

We examined the effect of two possible regulations: (1) the expanded TED regulations and (2) unidentified regulations that would effect some proportional reduction in mortality by the pelagic longline fishery. These actions would be affecting two different life stages of loggerheads. The TED regulations would positively affect survival in the benthic immature and adult stages. A decrease in the mortality due to the pelagic longline fishery would positively affect survival of the pelagic immature stage.

These regulatory effects are evaluated relative to the first of the recovery goals set for the species (NMFS and USFWS 1991):

1. The adult female population in Florida is increasing and in North Carolina, South Carolina, and Georgia, it has returned to pre-listing levels (N.C.=800 nests/season; S.C.=10,000 nests/season; Ga.=2,000 nests/season). The above conditions must be met with data from standardized surveys which will continue for at least 5 years after delisting.
2. At least 25 percent (560 km) of all available nesting beaches (2,240 km) are in public ownership, distributed over the entire nesting range and encompassing at least 50 percent of the nesting activity within each State.
3. All priority one tasks have been successfully implemented.

We evaluate the population trajectories of the annual numbers of nesting females under different management scenarios: (1) expanded TED regulations in the absence of any regulation of the pelagic longline fishery, (2) regulation of the pelagic longline fishery alone to effect an increase in survival of pelagic animals, and (3) the combination of both regulations. The number of nesting females can be related to the number of nests identified in the recovery goal by assuming that a female, on average, lays 4.1 clutches of eggs/season (Murphy and Hopkins

1984<sup>36</sup>). In 1990 an estimated 7,737 nests were observed in the northern subpopulation, translating to 1,887 nesting females (TEWG 2000). Thus, all the model runs begin with an adult female population size of 2,000 animals in 1990. At the time the recovery plan was written management units had not been identified. The beaches of North Carolina, South Carolina, and Georgia roughly approximate the nesting range of the northern subpopulation but the subpopulation's nesting range also includes northern Florida. From 1990 to 1998, the contribution of northern Florida to total nest numbers for the northern subpopulation averaged 21% (TEWG 2000). Thus the recovery goal of 12,800 nests/season for North Carolina, South Carolina and Georgia translates to an estimated 15,488 nests/season for the northern subpopulation, corresponding to 3,777 nesting females per season.

In Part I, we considered 4 models, each based on different stage lengths and time to maturity. We found that for the combination of parameters in model 2, the pelagic survival rates were unreasonably high, 0.91 and 0.99, and not likely to be representative of actual annual pelagic stage survival rates for loggerheads. Hence, we consider only models 1, 3, and 4 in this impact assessment. For each of the 3 models, we looked at three possible initial population growth rates for the northern subpopulation, -5% per year (suggested for South Carolina trends in TEWG (1998) and used in models by Heppell *et al.* (in press), -3% per year (estimated for Little Cumberland Island, Georgia trends by Frazer (1983) and used in models by Crouse *et al.* (1987) and Crowder *et al.* (1994) and 0% per year (suggested by a preliminary meta-analysis of nesting trends (see Appendix 1 of this document for the revised analyses)). For this impact assessment we again consider all three possible population growth rates as there is evidence for each of them and we cannot eliminate any one of them unequivocally.

Within each of these population growth rates we considered 3 possible sex ratios. From our analysis of sex ratios of the individual subpopulations (Part I), we estimated 35% female hatchlings are produced in the northern nesting subpopulation and 80% in the south Florida subpopulation. To be consistent with the historical models we also consider a 50% production of female offspring. In summary there are 27 different model scenarios: 3 different stage durations (Models 1, 3, and 4) (see Tables 11-14 in Part I), 3 different pre-TED regulations population growth rates, and 3 different sex ratios.

### **Expanded TED Regulations**

We first looked at the effect of expanded TED regulations on population growth rates. The models were initiated with a population at stable age distribution for annual survival rates incorporating a 30% reduction in mortality for small benthic turtles and subsequently run with annual survival rates incorporating 30% reductions in mortality for large benthic juveniles and adults. The models run at a sex ratio of 0.5 are most comparable to Heppell *et al.* (in press) (Fig. 1). Heppell *et al.* (in press) found that an initial population growth rate of -5% would achieve positive population growth rates with similar mortality reductions. We found that while positive growth rates are achieved for the model representative of historical population parameters (Model 1), positive growth rates are not achieved for the new population vital rates (Models 3

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<sup>36</sup> Murphy, T.M. and S.R. Hopkins. 1984. Aerial and ground surveys of marine turtle nesting beaches in the southeast region, U.S. Final report to National Marine Fisheries Service Southeast Fisheries Science Center. Unpublished Report. South Carolina Marine Resources Department, Charleston, S.C., 52 pp.

and 4). Population growth rates are positive for all models at the remaining two initial population growth rates (-3% and 0%, Fig. 1)

At a sex ratio of 0.35, which results in a fecundity value that is likely more representative of the northern subpopulation, a similar trend is seen though proportionately reduced and populations only achieve stable growth (0%) when the initial population is declining at -3% per year (Fig. 2). When the production of female offspring increases to 80%, the expanded TED regulations (% change in pelagic survival equals 0) result in increasing population trends in all cases except for Model 4, which has the longest stage durations, at a population that is initially declining at a rate of -5% per year (Fig. 3). Population trajectories are plotted in Figs. 5-7, 9-11, and 13-15 as a 0% change in pelagic survival. The initial increases in nesting females in each of these plots results from increased survival of adults and increased numbers of large benthic juveniles reaching maturity. Once the pulse of large benthic juveniles has aged through to adults (length of time equal to the duration of the large benthic juvenile stage), the numbers of nesting females levels out or begins to decline depending on the population growth rate. Other shifts will occur once the offspring of the increased number of adults reach maturity, however this can only be seen in the plots for Model 1 (Fig. 5, 9, and 13) as time series were not run long enough for Models 3 and 4 (Fig. 6, 7, 10, 11, 14, and 15).

### **Changes in Pelagic Juvenile Annual Survival Rates**

We next examined how a potential regulation of the pelagic longline fishery to affect an increase in survival of pelagic animals would impact population growth rates. For the same 27 model scenarios described above, we increased and decreased pelagic juvenile annual survival rates by 5 and 10%. These models were again initialized with survival rates representing a 30% reduction in mortality in the small benthic juvenile stage.

At a sex ratio of 0.35 and a population initially declining at a rate of 5% per year, reductions in pelagic mortality rates alone are not enough achieve increasing population growth rates with the exception of a 10% increase in survival in Model 1 (Figs. 16 and 17). If the initial population is stable, increases in pelagic juvenile survival rates proportionately increase annual population growth rates beyond that affected by reduced mortality in small benthic juveniles alone (represented by the 0% annual population growth rate). However, decreases in pelagic juvenile survival reduce or negate the benefits of increased small benthic juvenile survival and at a 10% reduction in pelagic juvenile survival, populations are in decline (Fig. 16). The population trajectories for the numbers of nesting females associated with each population growth rate in Fig. 16 are plotted in Figs. 17-19. As the trajectories consider adults only, no benefits or negative impacts of changes in juvenile survival rates are seen until the effected stages reach maturity, or the sum of the lengths of the small and large benthic juvenile stages. As discussed in the above section, the effects of the increased/decreased numbers of offspring from the changes in numbers of nesting females result in another pulse in the population a generation later.

Similar but proportionately more positive trends are seen when you increase fecundity with sex ratios of 0.50 and 0.80 (Figs. 20-27). When populations are exhibiting only slight increases in growth rates (less than about 0.5%), decreases in pelagic juvenile survival rates

result in decreasing population growth rates. Conversely, when populations are slightly decreasing as in Fig. 20,  $\lambda=0.97$ , Model 3 and Fig. 24,  $\lambda=0.97$ , and Model 4, increases in pelagic juvenile annual survival rates achieve positive population growth rates.

### **Combination of Expanded TED Regulations and Changes in Pelagic Juvenile Annual Survival**

To look at the combination of both regulations, we initialized the models in the same manner described above and ran them with 30% reductions in mortality for large benthic juveniles and adults with pelagic juvenile survival rates increased and decreased at 5 and 10%.

At a sex ratio of 0.35, the highest survival rate scenario (+10% for pelagic juvenile survival) decreased the -5% per year population decline to almost 0% for the models incorporating updated stage durations (3 and 4) (Figs. 4-7) and resulted in increasing trends for sex ratios of 0.50 and 0.80 (Figs. 8-15). At initial population declines of 3% per year, expanded TED regulations alone achieve 0 population growth and the additional benefit of increased pelagic juvenile survival result in positive trends (Figs. 4-7). When the initial population is stable, increases in survival for all benthic stages maintain positive population growth rates even at decreases in pelagic juvenile survival of 10% for all sex ratios (Figs. 4-15).

### **Population Recovery**

Because of the uncertainties involved in parameterizing these models, the population trajectory plots should not be used to quantitatively assess population size (Heppell *et al.* in press). However, in a general analysis of the plots it is apparent that some of the model combinations for the 0.35 sex ratio will not achieve the recovery goals of 3,777 nesting females per year in the time span modeled (NMFS and USFWS 1991). We believe that the stage durations of Models 3 and 4 are most representative of loggerhead growth rates for the northern subpopulation. For initial declining population growth rates of 5% and 3%, none of the regulation scenarios result in recovered populations within 25 years (Figs. 6, 7, 18 and 19) for these two models. This is due to the long benthic juveniles stages of these two models (24 and 33 years respectively), and the fact that there is a time lag before the benefits of increased juvenile survival results in increasing number of nesting females on the beach. The scenarios with increased survival for all in-water life-stages result in much more rapid recoveries (Figs. 6 and 7 compared to Figs. 18 and 19). If the populations were stable prior to the 1990 TED regulations, then the populations represented by Models 3 and 4 at a 0.35 sex ratios appear to be recovering, again at a much faster rate if all in-water stages have increased survivorship. (Fig. 6, 7, 18, 19). Decreased pelagic juvenile survival neutralizes or negates the recovery.

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Figures 1-3. Annual population growth rates for expanded TED regulations that reduce mortality in all benthic stages by 30%. Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.50 for Figure 1, 0.35 for Figure 2 and 0.80 for Figure 3.

Figure 1

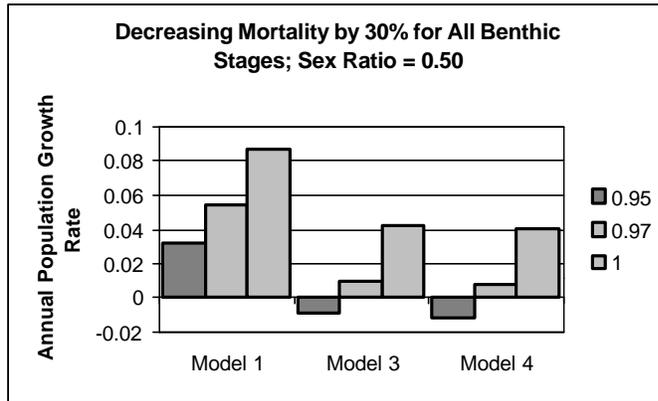


Figure 2

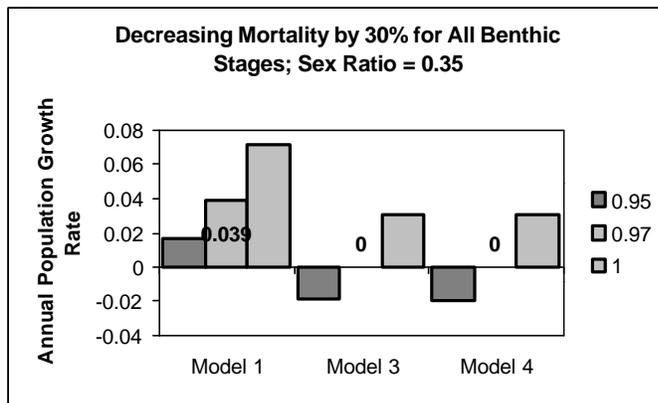


Figure 3

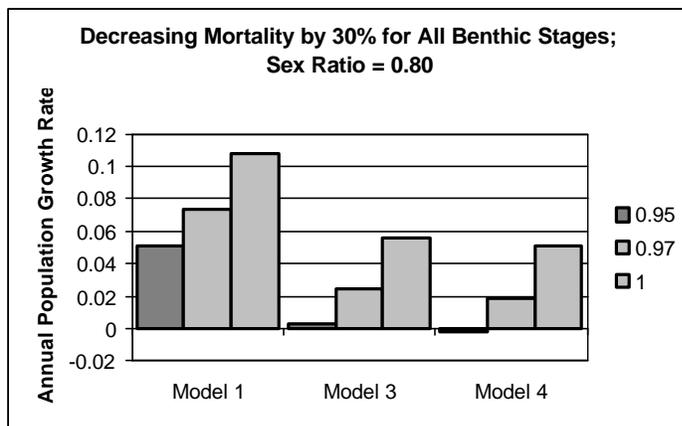


Figure 4. Annual population growth rates for expanded TED regulations that reduce mortality in all benthic stages by 30%. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.35.

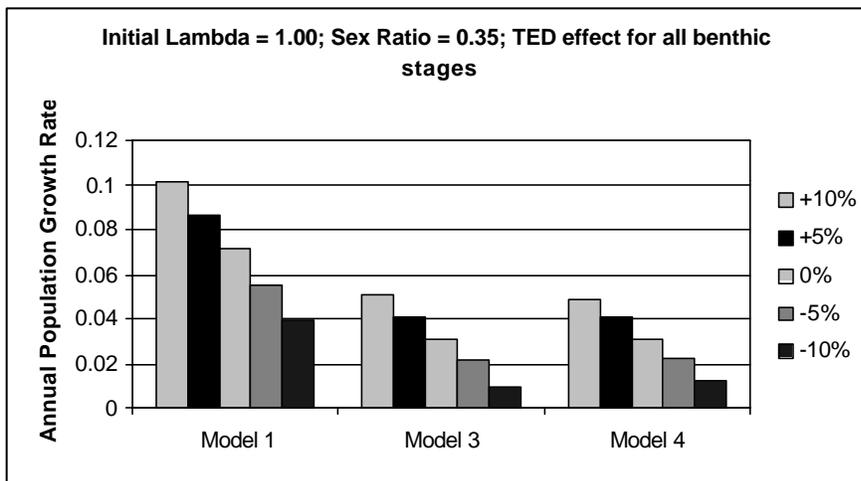
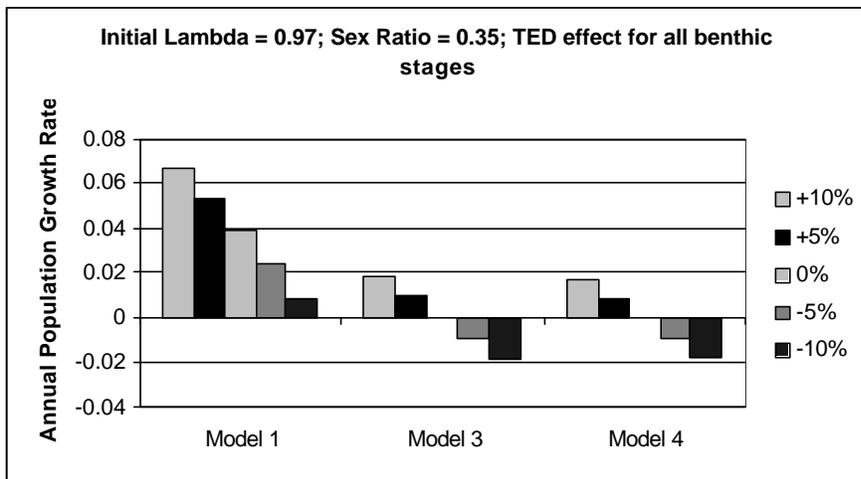
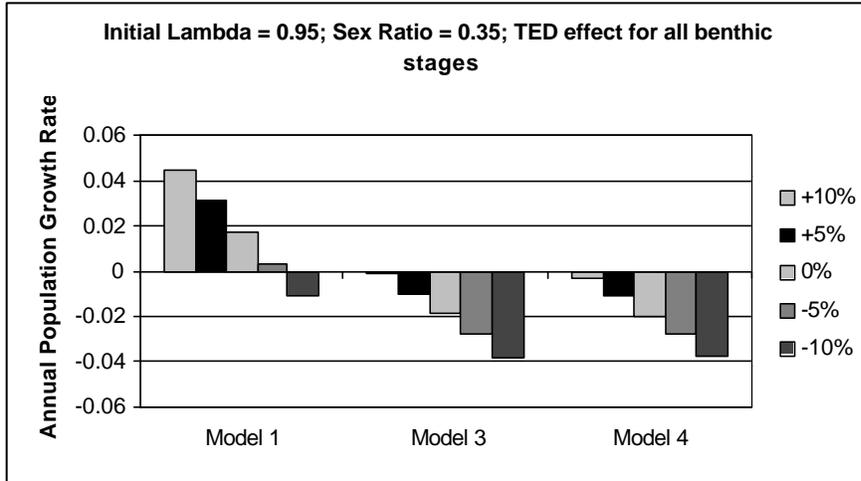


Figure 5. The population trajectories for expanded TED regulations that reduce mortality in all benthic stages by 30% under the Model 1 scenario. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.35.

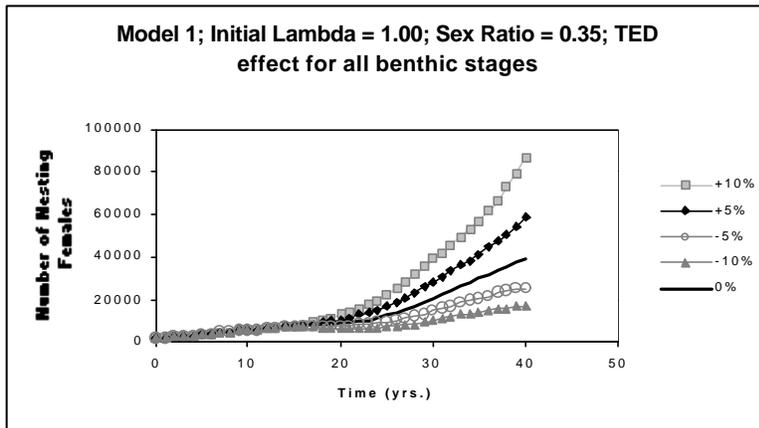
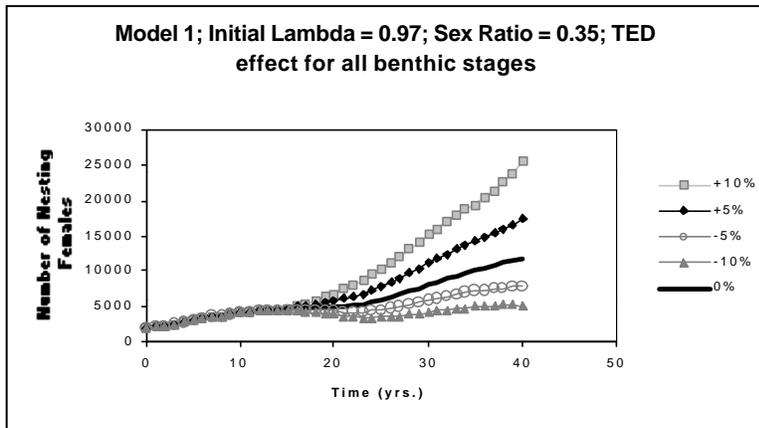
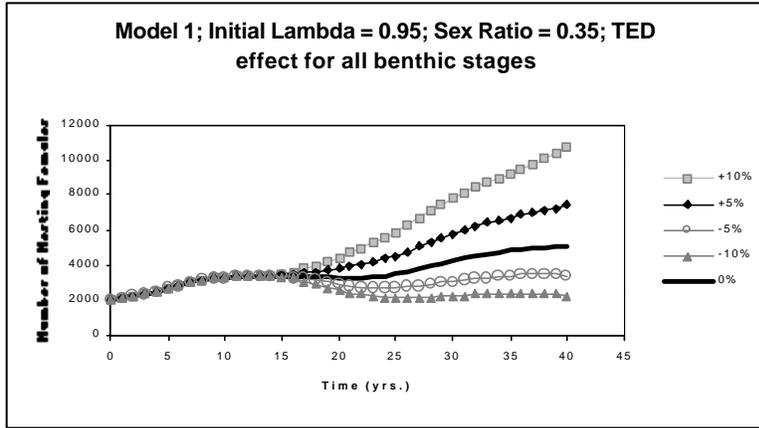


Figure 6. The population trajectories for expanded TED regulations that reduce mortality in all benthic stages by 30% under the Model 3 scenario. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.35.

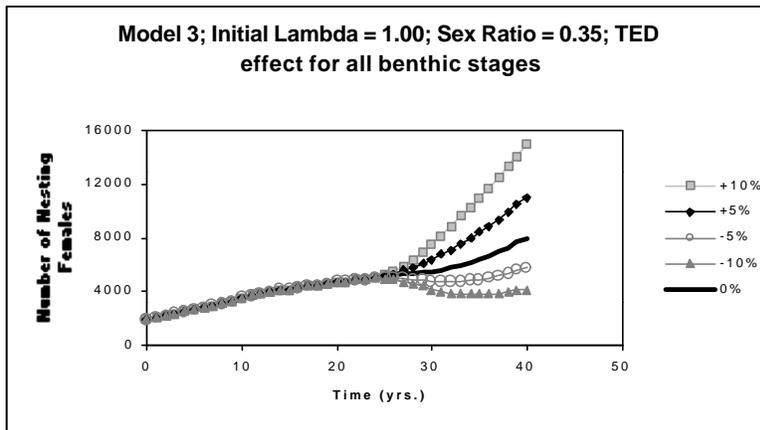
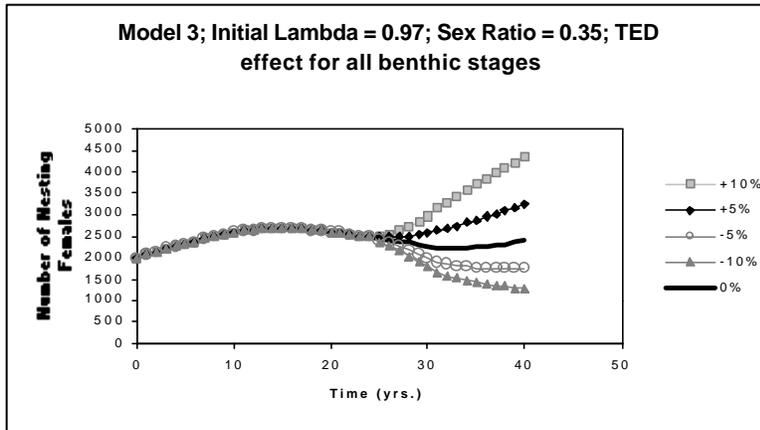
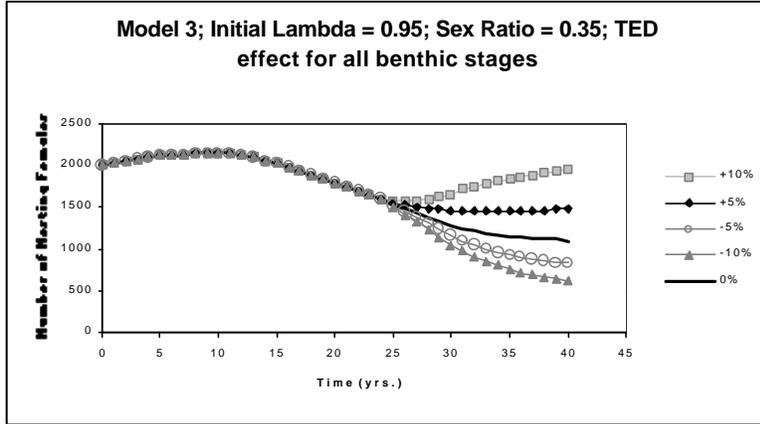


Figure 7. The population trajectories for expanded TED regulations that reduce mortality in all benthic stages by 30% under the Model 4 scenario. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.35.

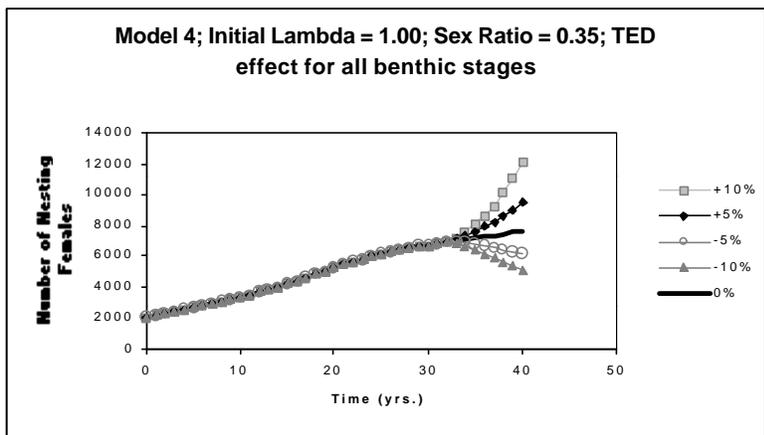
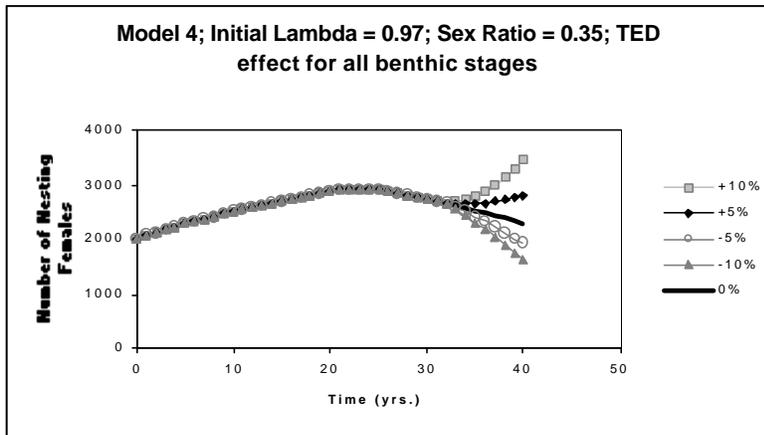
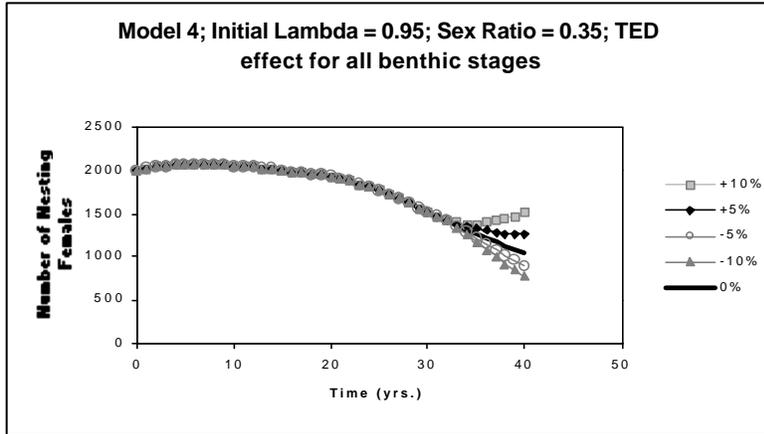


Figure 8. Annual population growth rates for expanded TED regulations that reduce mortality in all benthic stages by 30%. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.50.

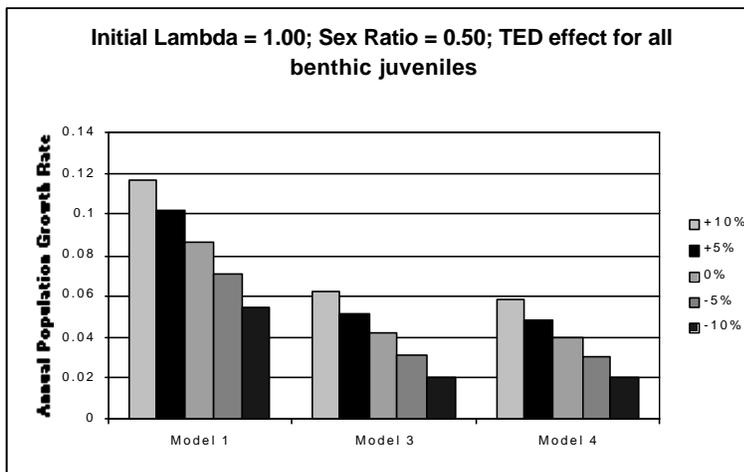
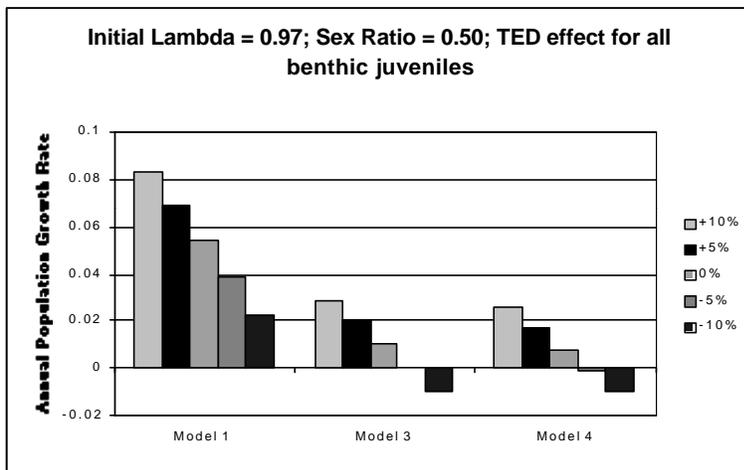
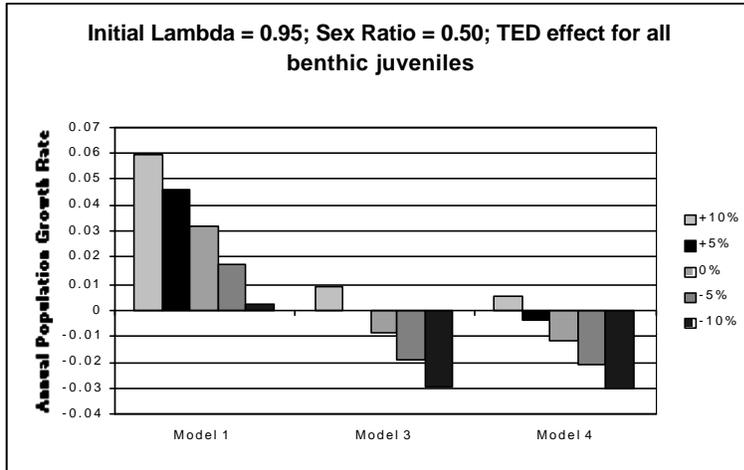


Figure 9. The population trajectories for expanded TED regulations that reduce mortality in all benthic stages by 30% under the Model 1 scenario. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.50.

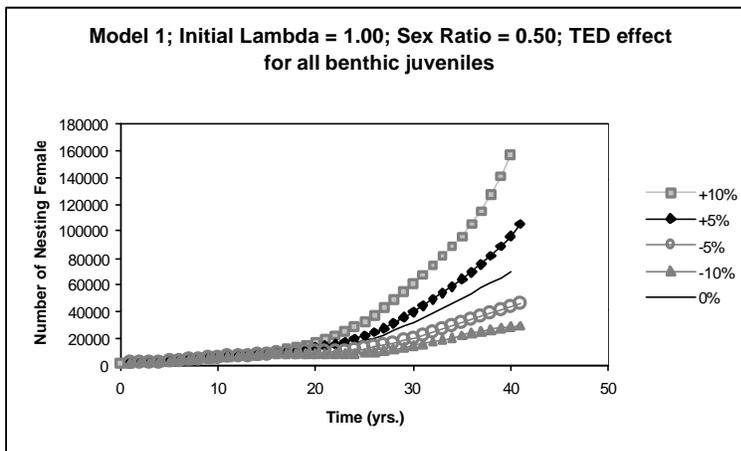
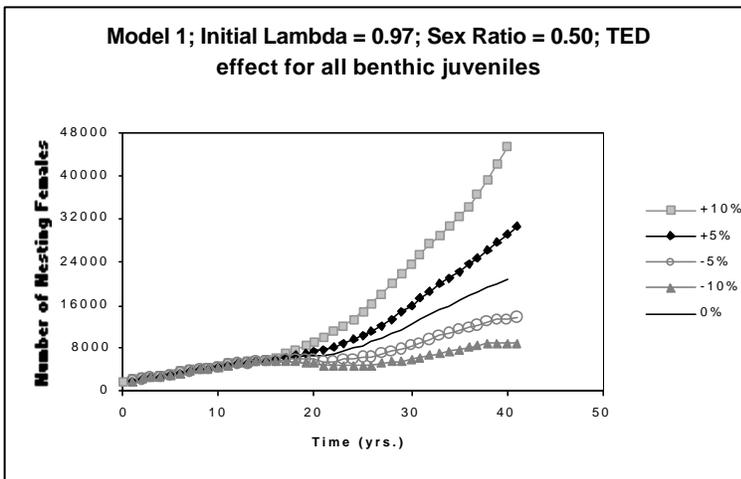
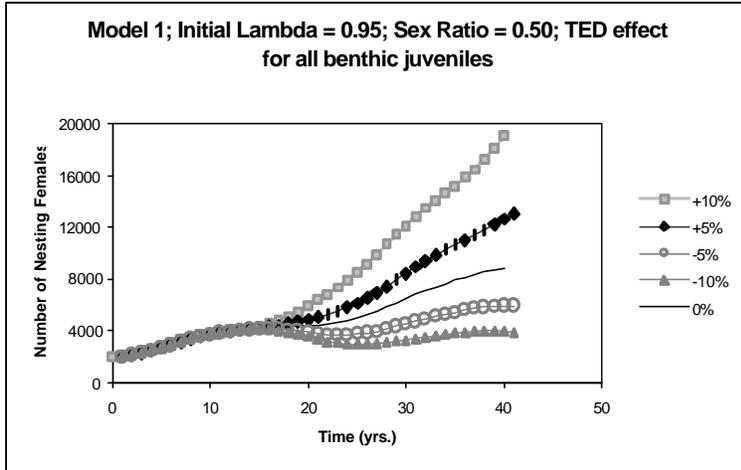


Figure 10. The population trajectories for expanded TED regulations that reduce mortality in all benthic stages by 30% under the Model 3 scenario. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.50.

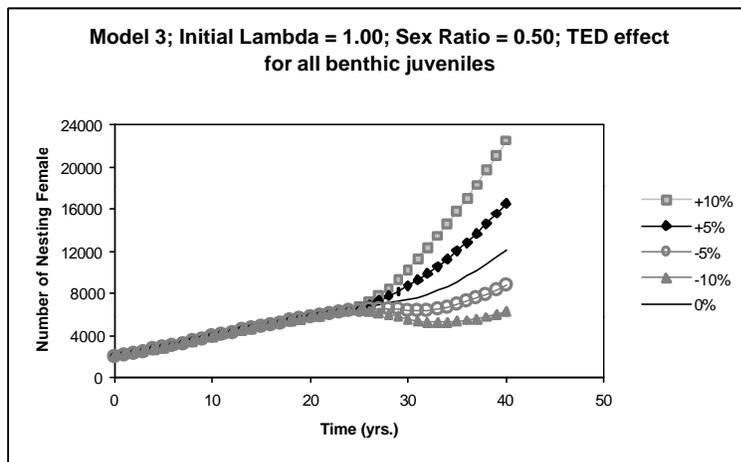
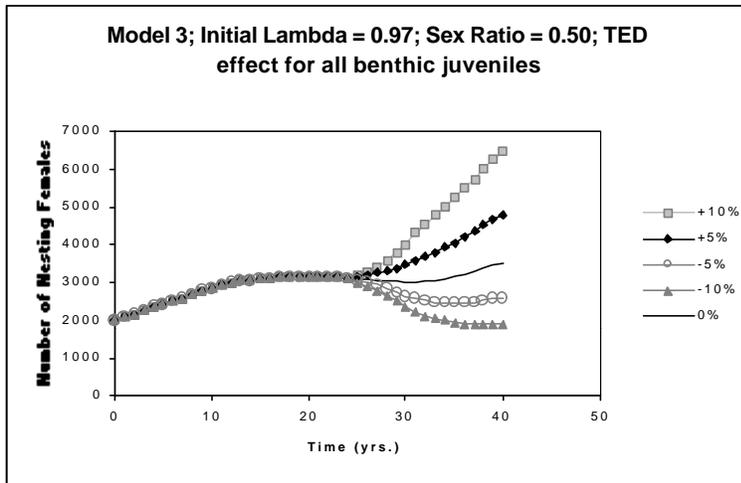
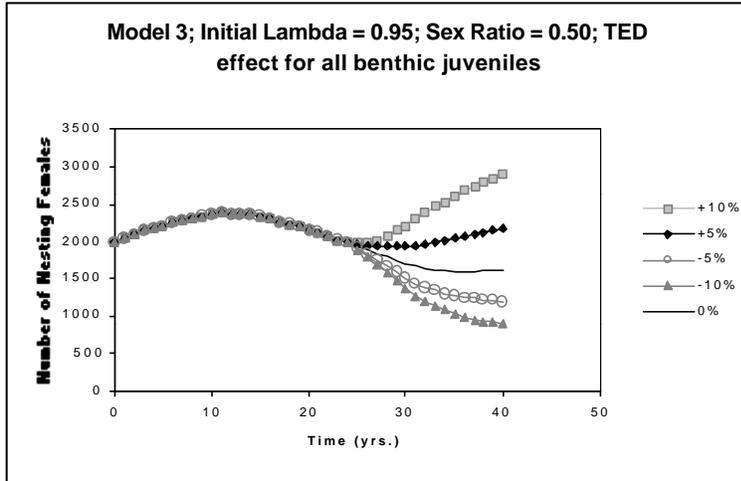


Figure 11. The population trajectories for expanded TED regulations that reduce mortality in all benthic stages by 30% under the Model 4 scenario. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.50.

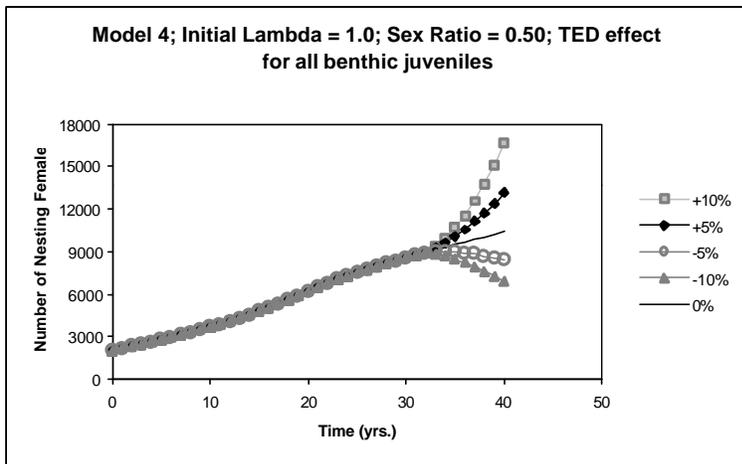
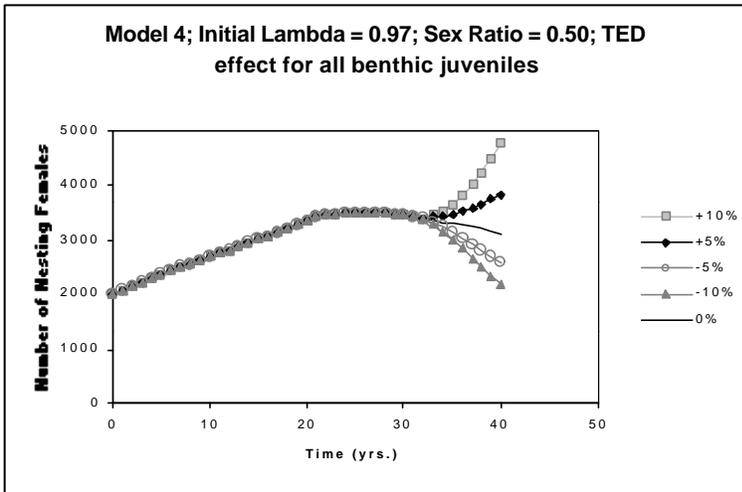
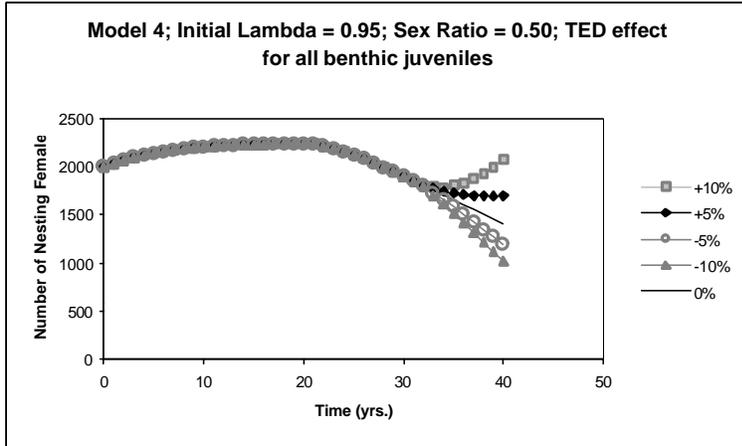


Figure 12. Annual population growth rates for expanded TED regulations that reduce mortality in all benthic stages by 30%. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.80.

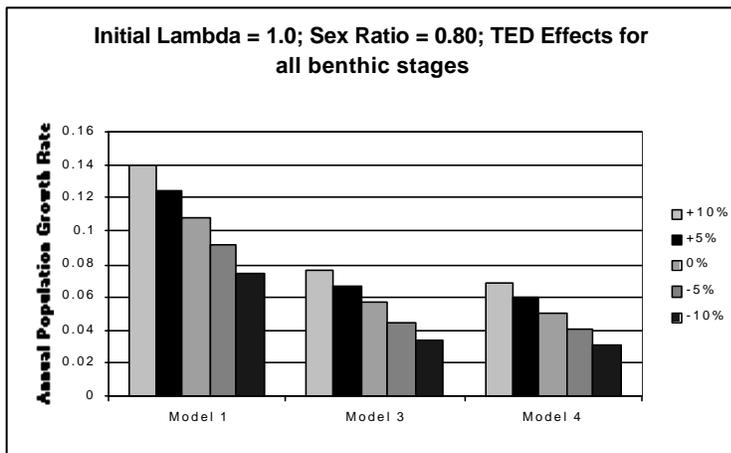
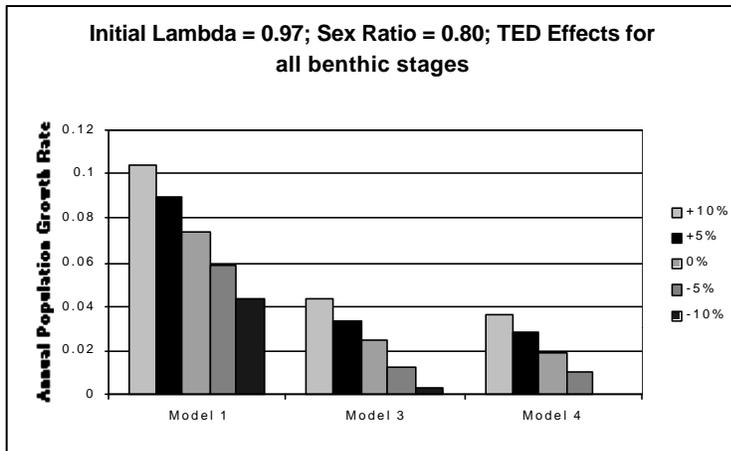
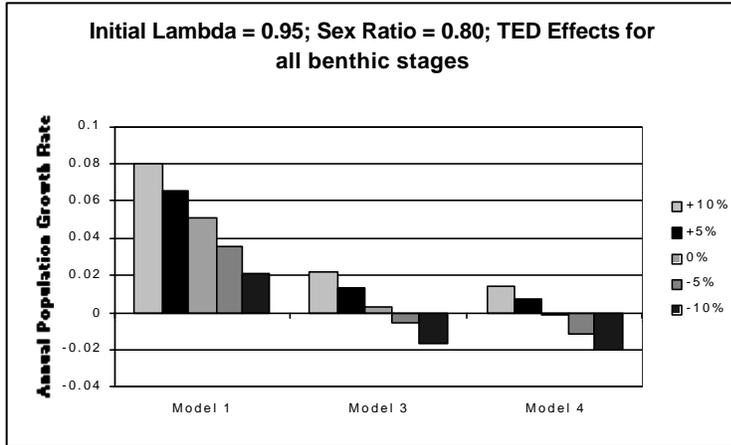


Figure 13. The population trajectories for expanded TED regulations that reduce mortality in all benthic stages by 30% under the Model 1 scenario. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.80.

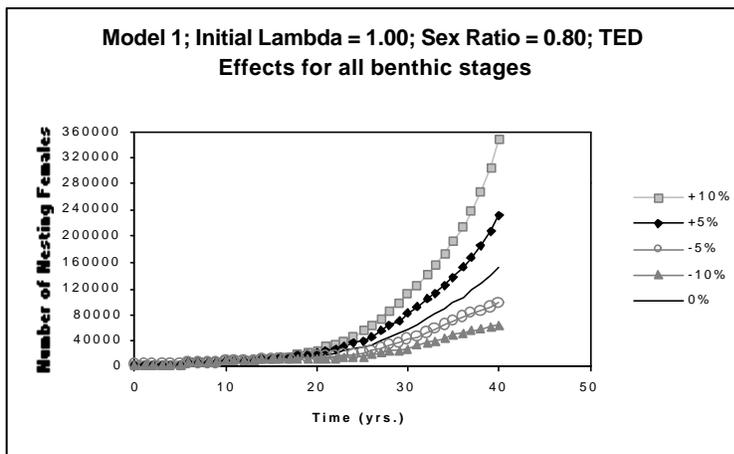
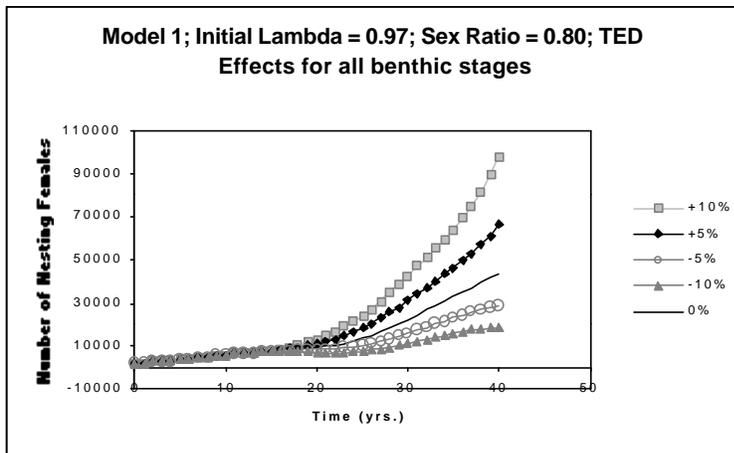
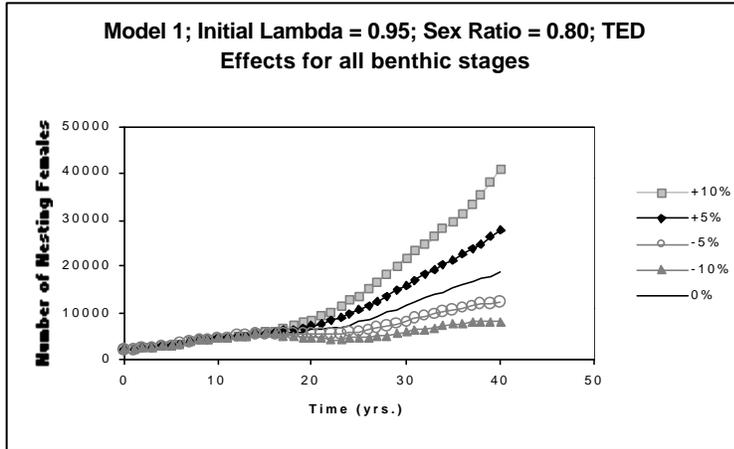


Figure 14. The population trajectories for expanded TED regulations that reduce mortality in all benthic stages by 30% under the Model 3 scenario. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.80.

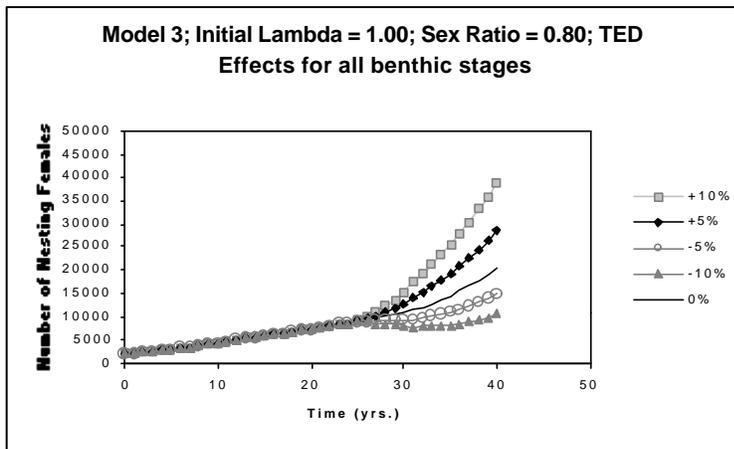
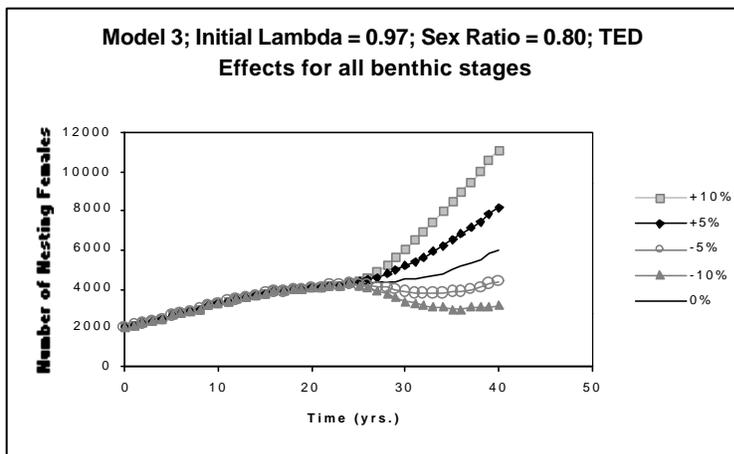
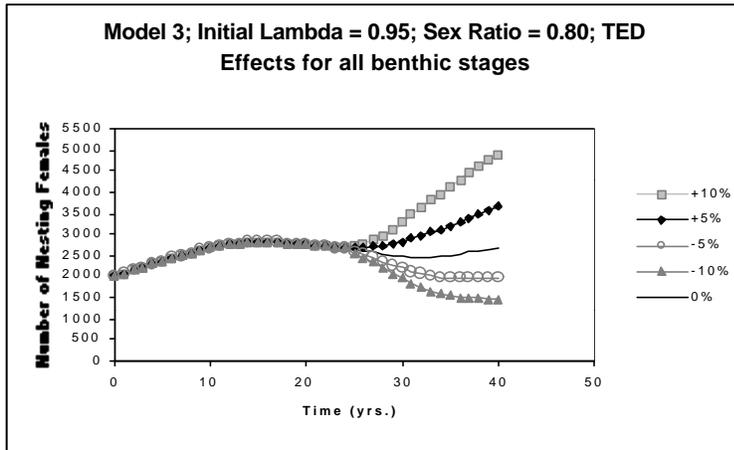


Figure 15. The population trajectories for expanded TED regulations that reduce mortality in all benthic stages by 30% under the Model 4 scenario. The 0% value represents the baseline pelagic juvenile survival rate calculated in Part I. The other values represent percent increases or decreases in pelagic juvenile survival rates from baseline (combination of pelagic longline fishery regulations and expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.80.

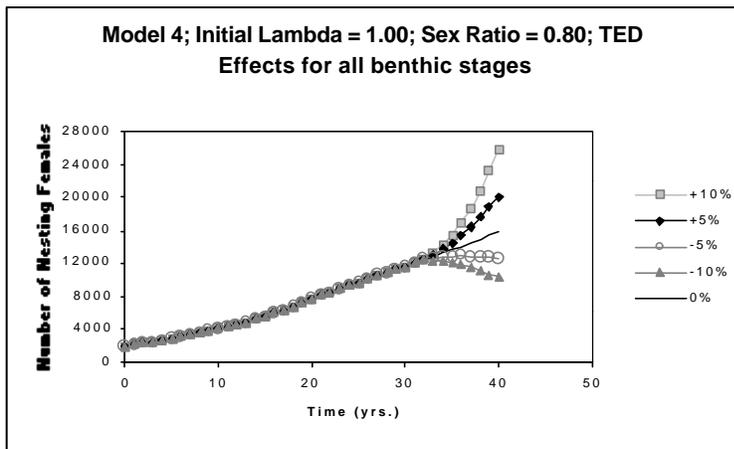
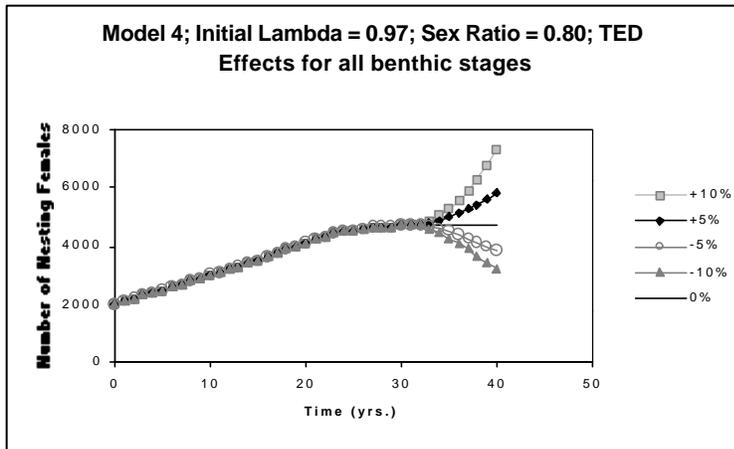
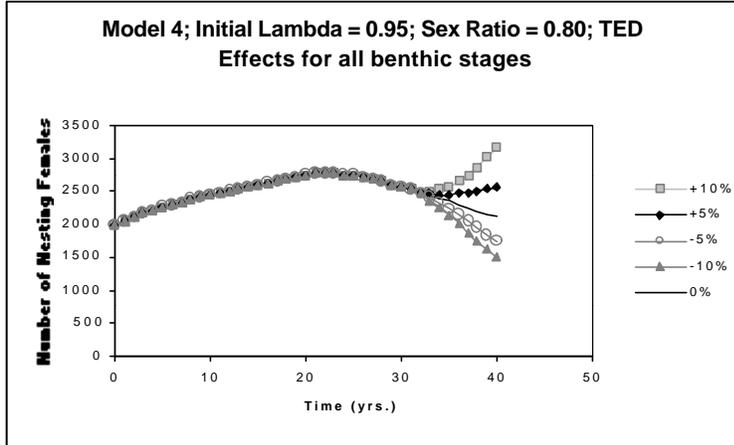


Figure 16. Annual population growth rates increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.35.

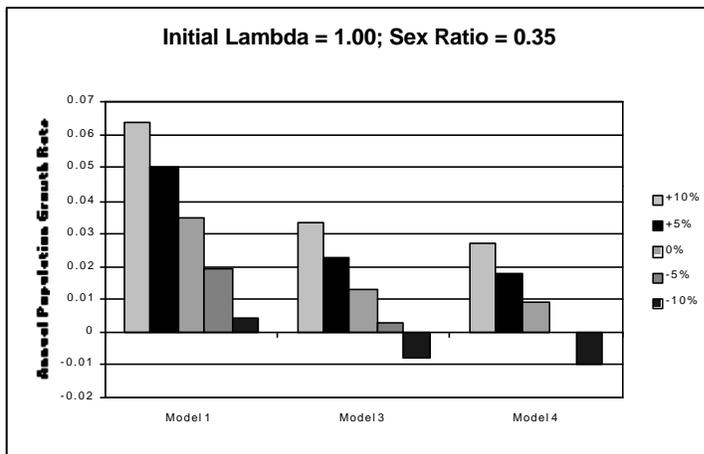
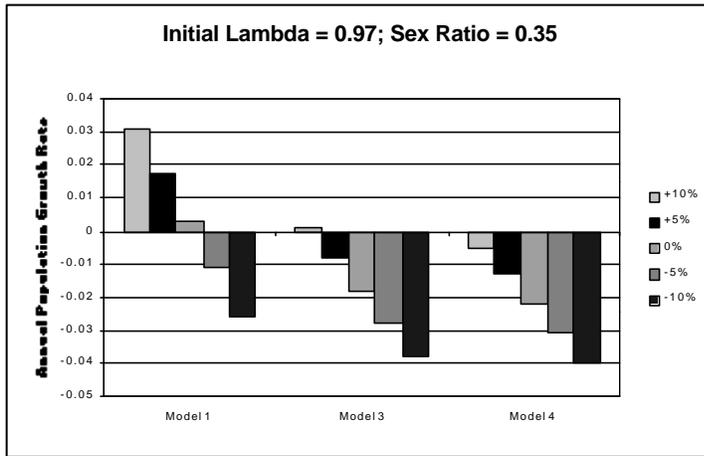
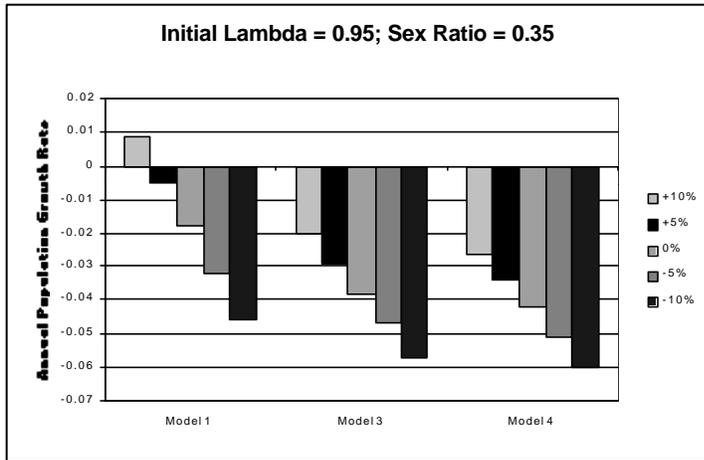


Figure 17. The population trajectories for the Model 1 scenario resulting from increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.35.

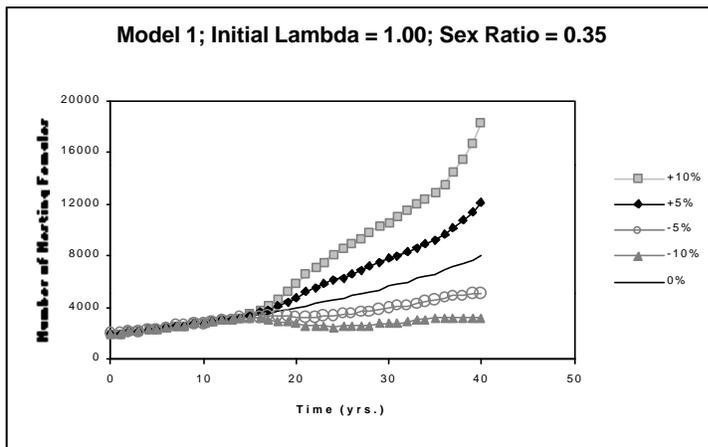
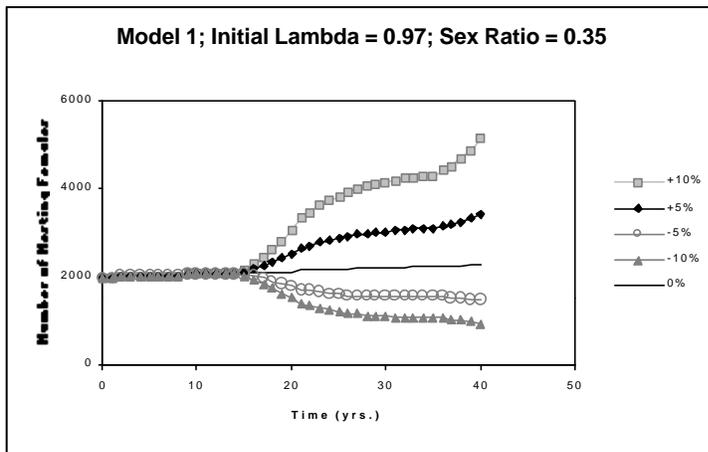
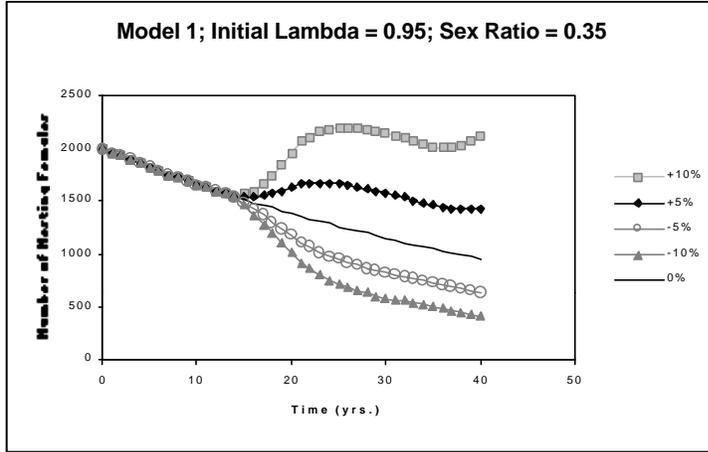


Figure 18. The population trajectories for the Model 3 scenario resulting from increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.35.

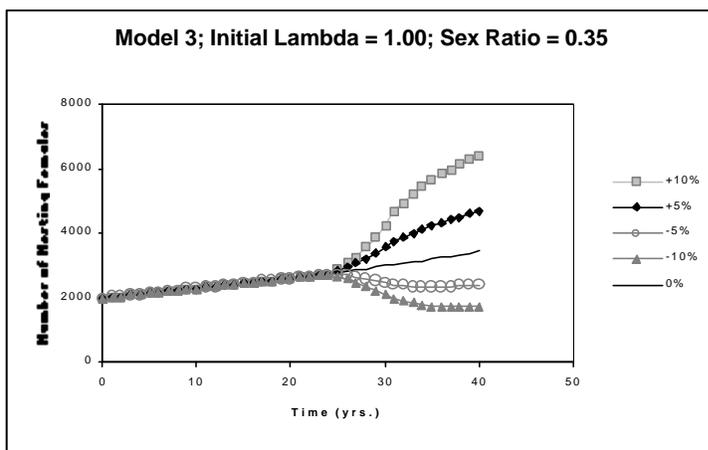
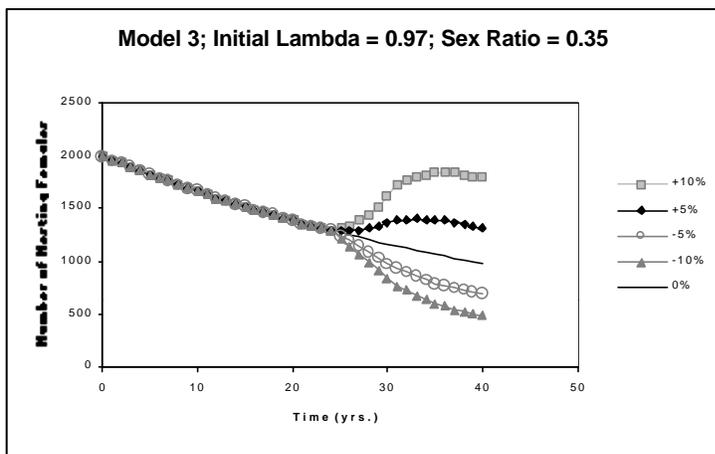
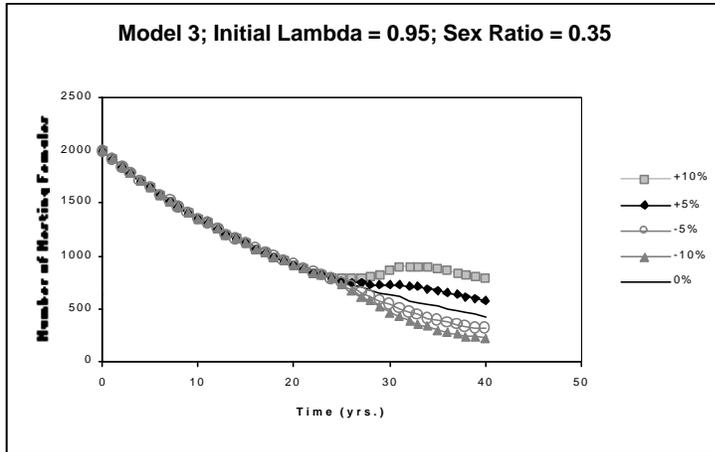


Figure 19. The population trajectories for the Model 4 scenario resulting from increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.35.

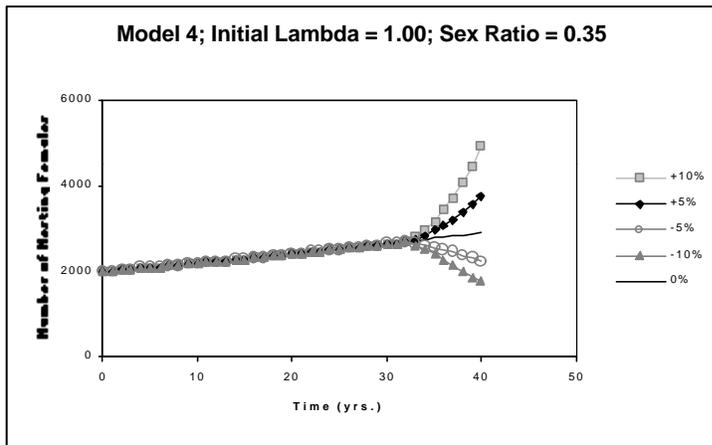
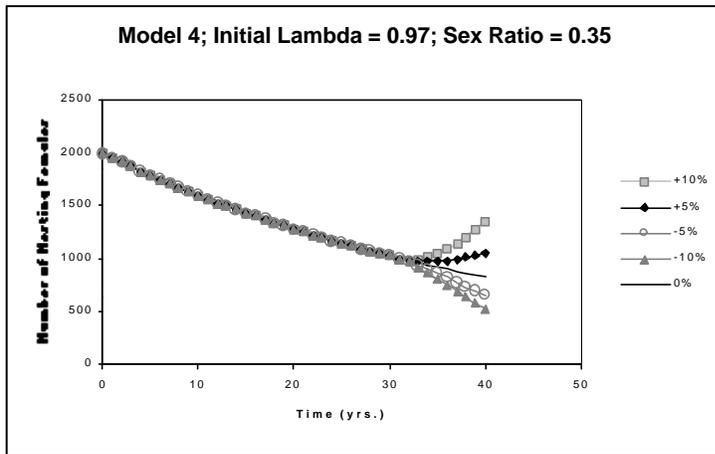
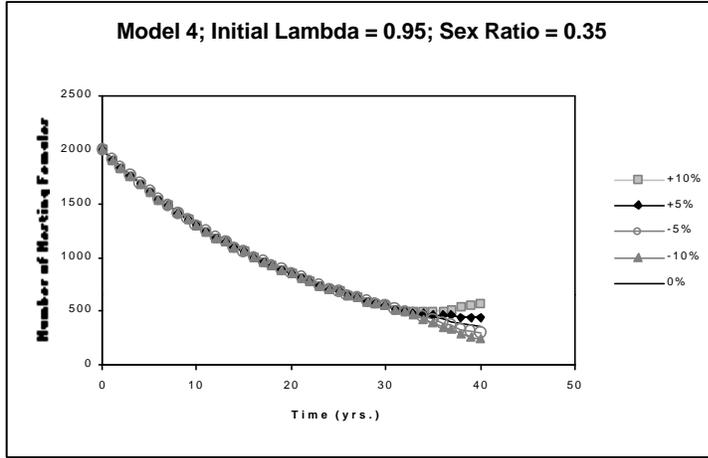


Figure 20. Annual population growth rates increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.50.

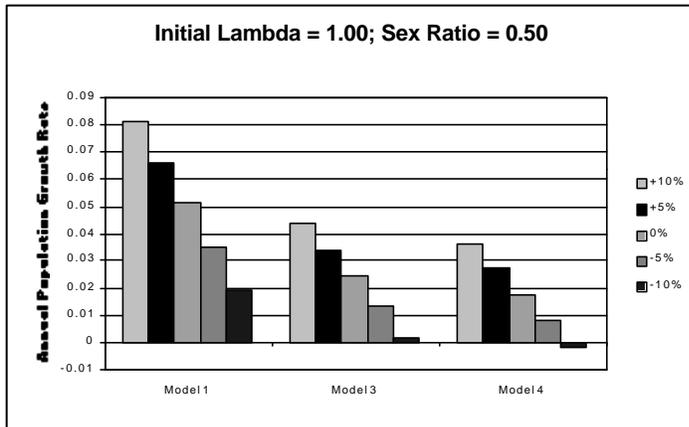
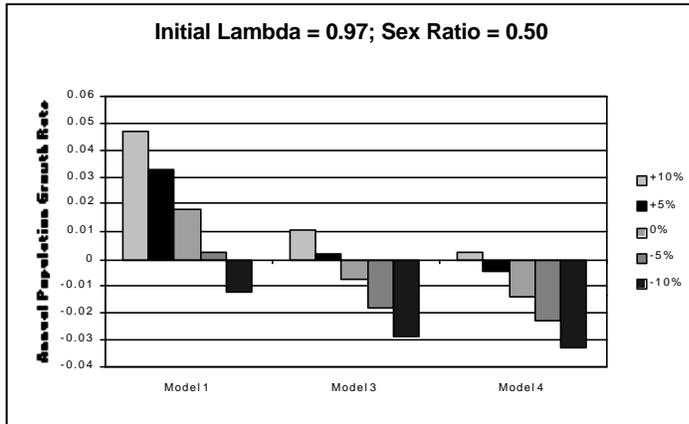
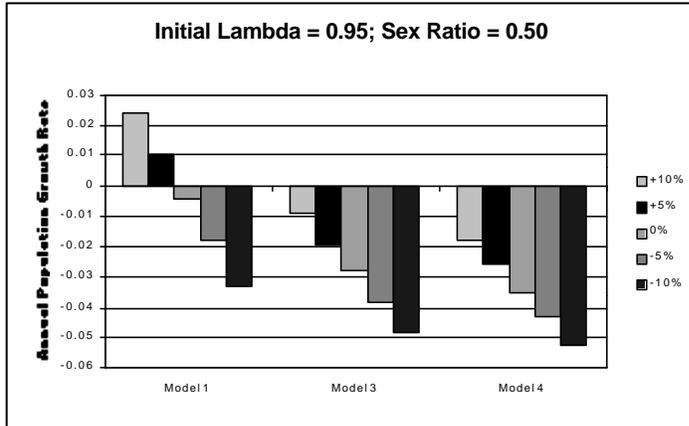


Figure 21. The population trajectories for the Model 1 scenario resulting from increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.50.

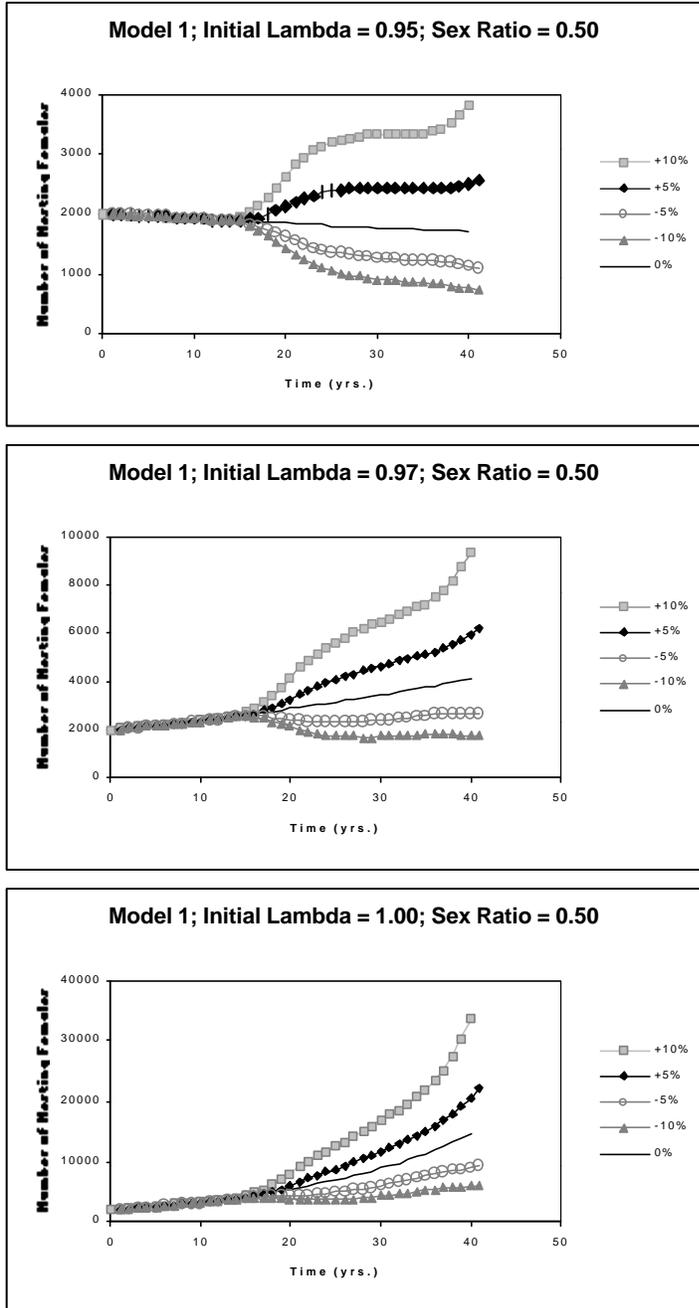


Figure 22. The population trajectories for the Model 3 scenario resulting from increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.50.

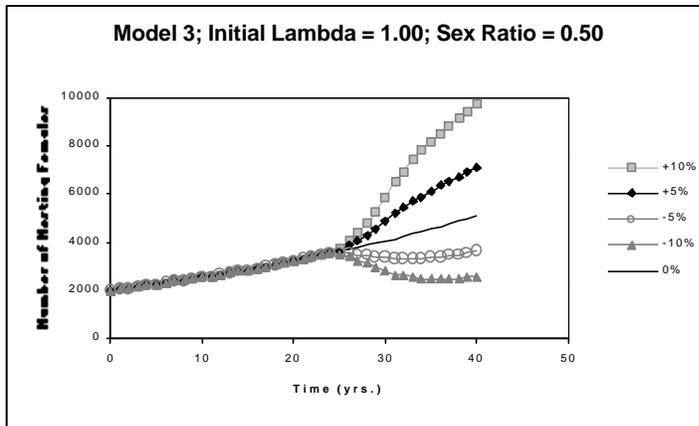
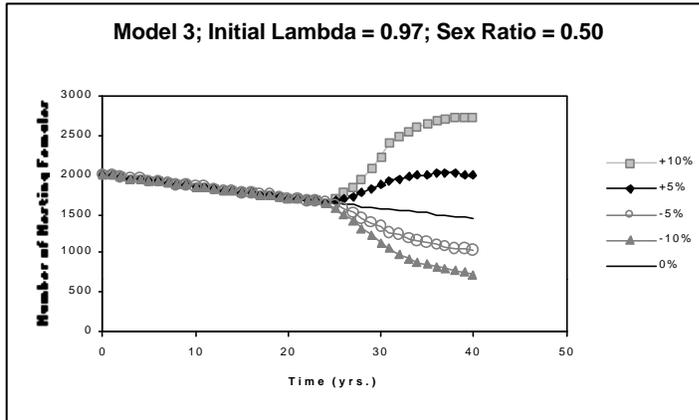
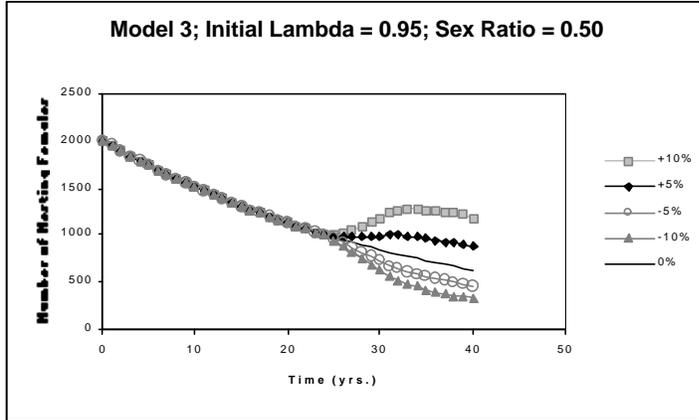


Figure 23. The population trajectories for the Model 4 scenario resulting from increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.50.

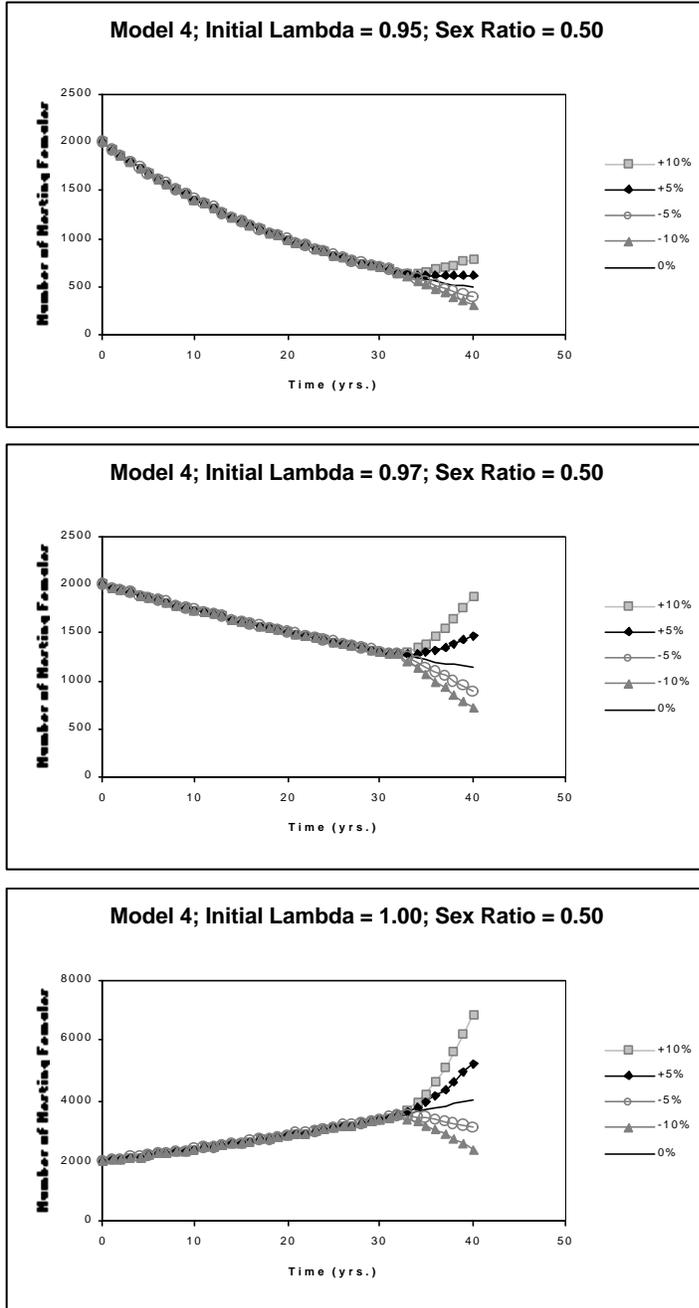


Figure 24. Annual population growth rates increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.80.

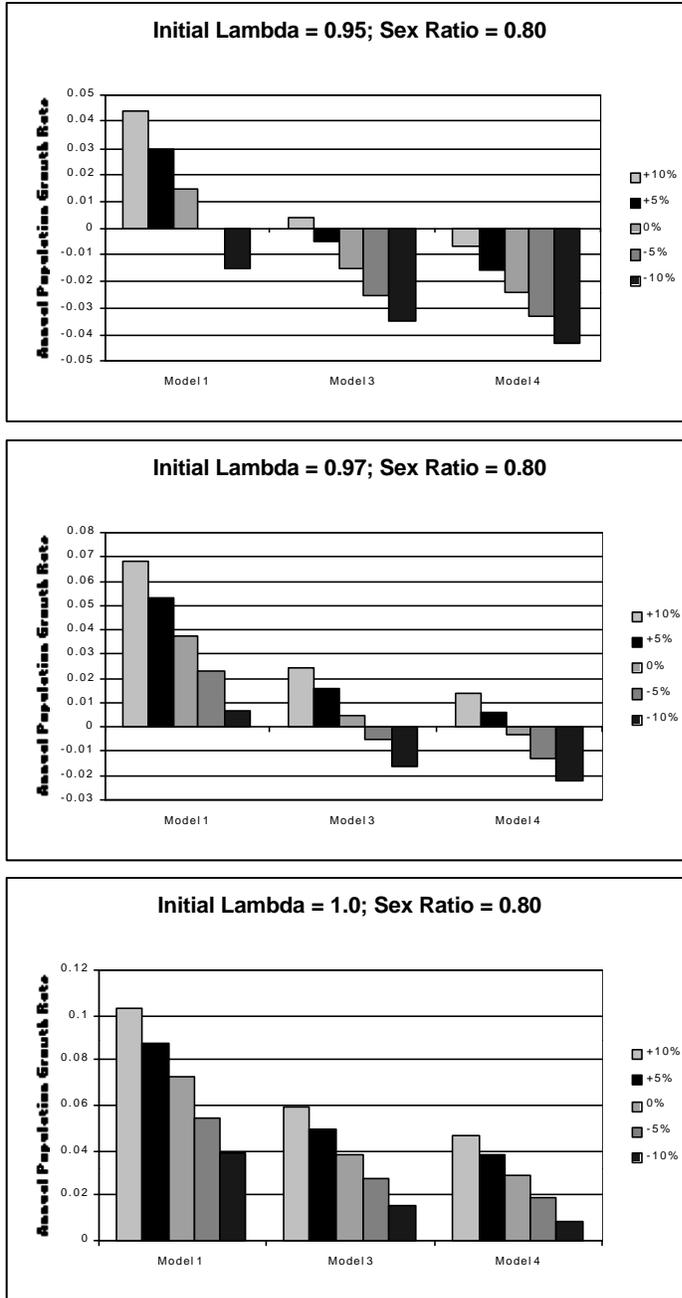


Figure 25. The population trajectories for the Model 4 scenario resulting from increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.80.

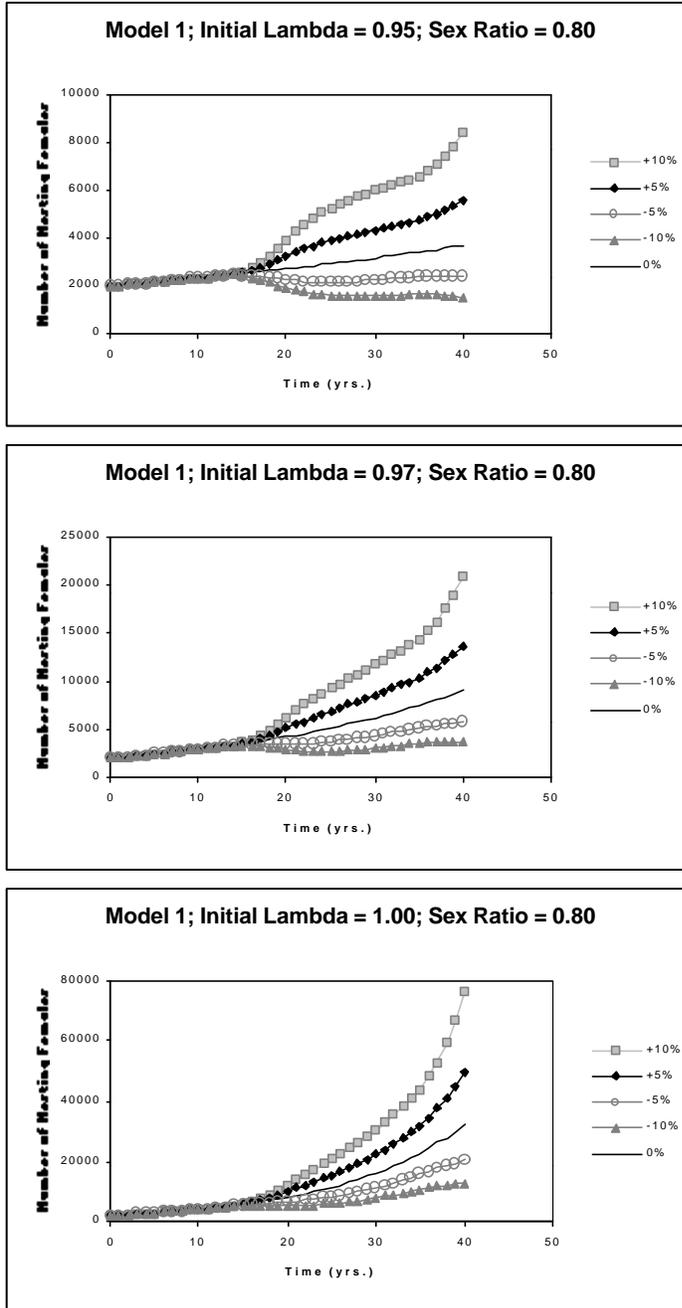


Figure 26. The population trajectories for the Model 3 scenario resulting from increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.80.

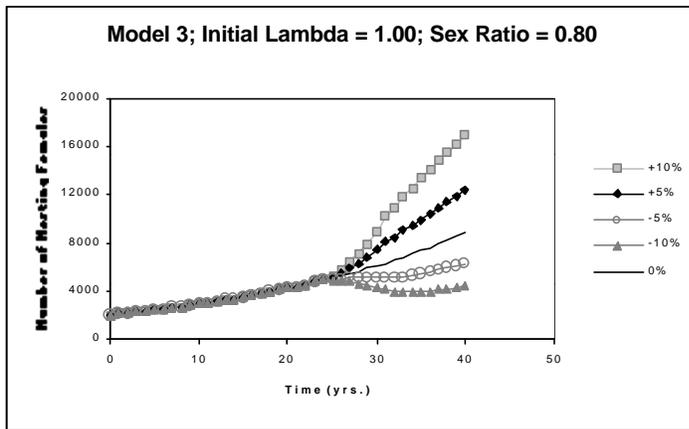
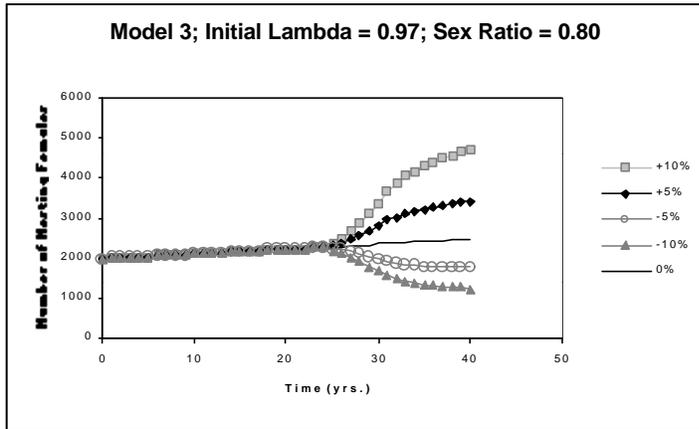
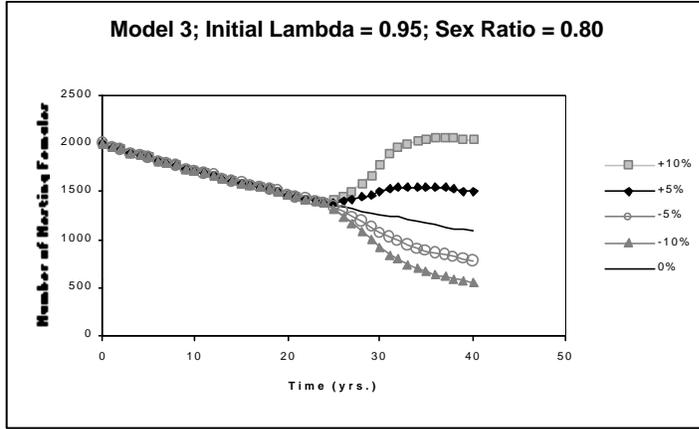
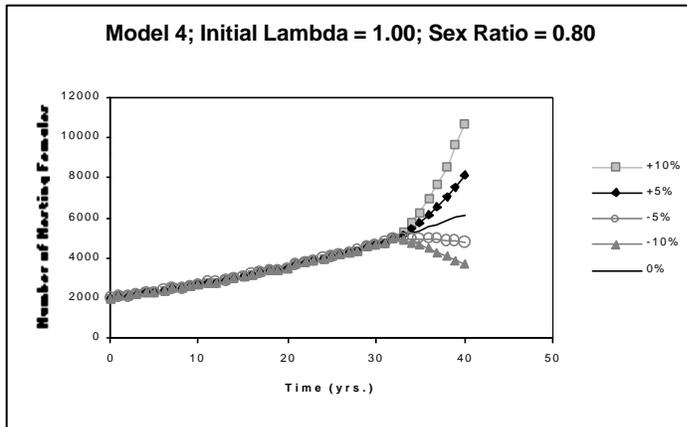
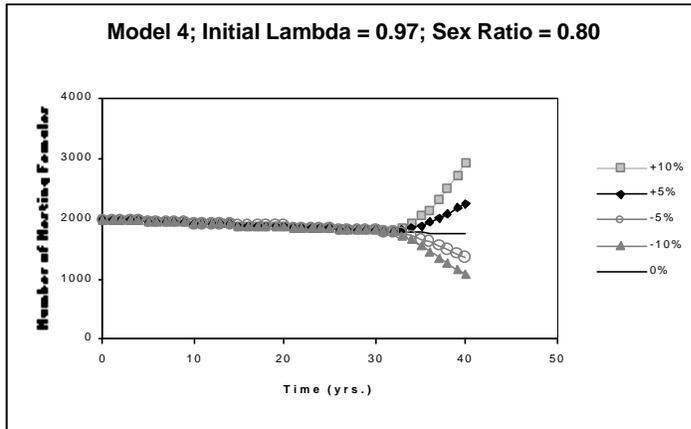
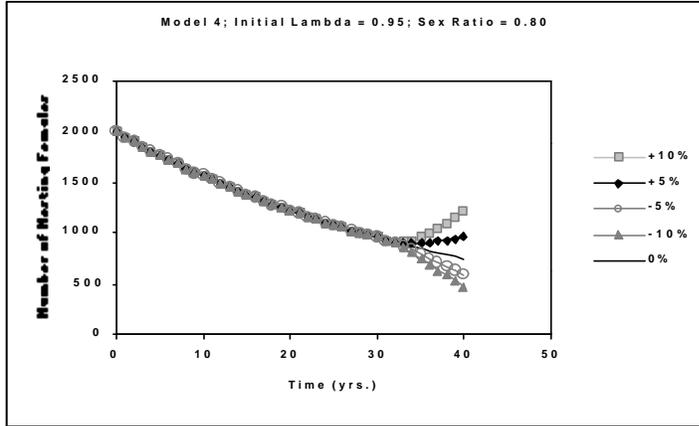


Figure 27. The population trajectories for the Model 4 scenario resulting from increases and decreases in the annual pelagic juvenile survival rate (-10%, -5%, 0%, +5% and +10%) and a 30% decrease in mortality for small benthic juveniles only (no expanded TED regulations). Models were based on pre-1990 population growth rates of -5%, -3% and 0% (equivalent to  $\lambda$  values of 0.95, 0.97 and 1.0). Proportion of female offspring is 0.80.



## CHAPTER 7. IMPACT OF THE PELAGIC LONGLINE FISHERY ON LEATHERBACK SEA TURTLES

Nancy B. Thompson

Leatherback turtles are the largest of the sea turtle species and display a large range within the Atlantic Ocean and in the western North Atlantic Ocean, including the Caribbean Sea and Gulf of Mexico (Pritchard and Trebbau 1984). They inhabit all the oceans of the world and are found in both coastal and pelagic waters and unlike the other turtle species, all life history stages beyond the egg are found in the pelagic zone (Pritchard and Trebbau 1984). They may grow rapidly achieving sexual maturity in as little as 3-6 years or may not reach maturity until as late as 19 years (Rhodin 1995, Zug and Parham 1996). They nest frequently (up to 7 nests per year) during a nesting season and nest about every 2-3 years. During each nesting, they produce about 100 eggs or more in each clutch and thus, can produce 700 eggs or more per nesting season (Shultz 1975). Hatchlings through subadults may remain in warm tropical/subtropical waters and when reaching lengths greater than 100 cm carapace length, demonstrate seasonal movements in the western North Atlantic and range as far north as Canadian waters in the summer. Turtles that arrive in northern waters can be derived from any Atlantic nesting beach and based on ocean currents such as the south to north direction of the Gulf Stream, are from the South American and U.S. beaches. Turtles in northeastern waters are generally > than 100 cm curved length which is consistent with fishers in northeastern U.S. and the Grand Banks encounter.

Dutton *et al.* (1999) describes stock structure and concludes that there may be distinct nesting subpopulations along the western North Atlantic coast. They conclude at this time that turtles nesting in St. Croix/Puerto Rico and Trinidad are different from each other and different from all other nesting areas in the Western North Atlantic based on their genetic analyses. Turtles nesting in Florida could not be distinguished from those nesting in the nor from those from the Indian Ocean. They offer several hypotheses about why there is little difference between these nesting “populations” and caution that these results alone should not be used to describe stock structure. However, this does mean that the ability to assign turtles to nesting beaches when away from nesting beaches would be limited to mainland v. St. Croix/Puerto Rico v. Trinidad using their methods.

Regardless of hypothesized stock structure, the decline measured on beaches of northern South America, which support the largest nesting aggregation in the western North Atlantic Ocean, is of immediate concern and the causes need to be identified. The trend in nesting females in the U.S. has been increasing for the past 20 years (Appendix 1). Measurable trends in the major nesting area, beaches along the northern coast of South America, were increasing from the 1970's to the early 1990's and have been decreasing since 1992 (*Ibid.*). Looking at the nesting numbers for the South American beaches suggests nesting may be cyclic or in fact is on a real decline since 1992 which contrasts with nesting in the U.S. which has increased nearly 5-fold from the early 1980's to the present. The question that remains to be explored is why is nesting declining along the northern South American coast whereas it has been increasing in the Caribbean and Florida during the same time period. An answer to this question is explored with

a series of hypotheses and within the context of an impact of the U.S. longline fishery in the western North Atlantic.

Estimated annual leatherback turtle bycatch from the U.S. longline fishery from 1992 to 1999 ranges from 308-1054. Turtles are caught in all waters from the Gulf of Mexico to the Grand Banks with the largest estimated bycatch in the spring and summer in northeast U.S., southeast Canadian, and international waters. Applying the 50% mortality criterion results in estimated mortalities as presented in Table 1 of Chapter 5, and these range then from 154 to 527 turtles killed annually by the U.S. longline fishery. Estimates of total bycatch suggest that the estimated annual mortality from each of these areas (NED, NEC) in spring and summer (in the hundreds) is on the average about an order of magnitude higher (in the tens) than in other areas. It is reasonable to assume that there are takes and kills by the foreign vessels in this area and the magnitude of these takes could be considerable given the effort from these fleets as compared to that from the U.S. fleet

When examining all takes in all human activities for which we have data or estimates, (Appendix 1), it is clear that for U.S. activities only, the pelagic longline fishery and the estimated take from the commercial shrimp trawl fishery (estimated at 650 per year) in combination are the largest known sources of anthropogenic mortality. Under a regime of constant mortality, as more turtles enter the water, more will likely be caught.

While turtles killed by the longline fishery in the sampling areas off the northeast U.S. coast are likely > 100 cm carapace length, those killed off the southeast U.S. coast, the Gulf of Mexico, and the Caribbean can be of any length unless there is some size selectivity of the gear as there is in loggerheads (Bolten and Bjorndal 1994). The lengths of animals stranding throughout the Gulf of Mexico and along the southeast U.S. coast while ranging from < 30 cm curved carapace length, are primarily greater than 130 cm curved carapace length (See Part II). These animals represent only those dying in waters close enough to the coast to have stranded and may not be representative at all of the size distributions of turtles in offshore waters where deaths are unlikely to result in strandings. However, at least in the southeast U.S., these turtles may be representative of what is taken by the shrimp fishery and other coastal fishing. Sizes of turtles at sexual maturity have been observed as minimally about 120 cm carapace length with an average minimum of about 140 cm carapace length (Marquez 1990). Thus, turtles taken by fishing in coastal waters and longline fishing in northeastern waters are large juvenile to adult sizes.

Recovery criteria for the leatherback turtle in U.S. western North Atlantic waters (NMFS and FWS 1992) are used to consider de-listing and are: (1) the adult female population increases over the next 25 years, as evidenced by a statistically significant trend in the number of nests at Culebra, Puerto Rico, and St. Croix, U.S.V.I. and along the east coast of Florida, and (2) nesting habitat encompassing at least 75 percent of nesting activity in the U.S.V.I., Puerto Rico and Florida is in public ownership and, (3) all priority one tasks have been successfully implemented. The first criterion requires an increasing trend in nesting females in 3 index beaches under control by the United States. Based on trend analyses (Appendix 1), the number of leatherback nests on Florida and U.S.V.I. beaches is increasing at 10.3% and 7.5% per year, respectively, since 1979. However, the largest leatherback rookeries in the western North

Atlantic remain along the northern coast of South America in French Guiana and Suriname. While Spotila *et al.* (1996) indicated that turtles may have been shifting their nesting from French Guiana to Suriname due to beach erosion, analyses show that the overall area trend in number of nests has been negative since 1987 at a rate of 15.0% per year (Appendix 1). Chevalier *et al.* (1999) suggest that this decline could be from both reduced hatching success (as low as 22% -35% per year) and takes of nesting females by coastal fishing. Previously, Chevalier and Girondot (2000) suggested that Suriname beaches up to 1992 had shown increases in nesting and hypothesized that this increase, which correlated with the decline along French Guiana beaches, was a result of shifts in nesting activity. However, recent trend analyses show a decline overall in these beaches since 1987. The decline in the major nesting areas for leatherbacks has been clearly described and the cause of this decline needs to be identified.

To determine the cause of the decline in nesting in the beaches of the Guianas, a series of hypotheses are offered: (1) the trends represent a natural cycle in nesting of leatherback turtles in this region; (2) natal homing in leatherbacks is imprecise and the turtles are nesting elsewhere and not reported or observed nor recognized as migrated from another rookery; (3) the mortality rate for female turtles has increased over the past 10 years relative to the previous 25 or so for turtles nesting in the Guianas but not increased to the same extent on females nesting on U.S. beaches; (4) the mortality rates for any or all life history stages for turtles derived from Guianas beaches is higher than that for turtles derived from U.S. beaches. The following is a discussion of each hypothesis:

1. There is a natural, decadal cycle in female nesting. Biological cycling of this sort is typically seen as a density dependent response to organisms that can increase in numbers very rapidly and as a biological phenomenon for this species does not seem logical. However, Schulz (1975) describes the Suriname beaches along the coast of South America as dynamic and undergoing regular cycles of erosion and accretion which means beach availability cycles. Schulz (1975) also indicates that over the past few centuries the availability of nesting beach to sea turtles in general has been rare along the Suriname coast as beaches have appeared only relatively. Schulz (1975) indicates that these cycles are in about 10 year periods. Chevalier *et al.* (1999) suggest that there are shifts in nesting along this coastal region and that turtles have been shifting nesting activity from French Guiana to Suriname as a result of beach availability and quality.
2. Turtles have shifted to other nesting beaches and may be unreported. Genetic studies indicate that turtles nesting on Florida beaches and beaches of the Guianas beaches are not distinguishable and the increases seen in Florida beaches as well as those throughout the Caribbean, could be from South American nesting females. From 1992 to 1997, the numbers of nests in French Guiana decreased from about 50,000 nests to less than 15,000 nests, a 75% decrease in total nests reported. This same relative amount of decrease in nests was reported for Suriname beaches. While the rate of increase in nesting on U.S. beaches is similar to the decrease seen in South America, the total numbers of nests is much less than expected if all females have shifted to U.S. beaches. This type of emigration could explain the lack of distinction seen in mainland nesting Atlantic leatherbacks, but would not explain the differences maintained between the insular populations and the mainland population. In the eastern North Atlantic Ocean, nesting in

Gabon is estimated at almost 5,000 females and has been described as stable (Spotila *et al.* 1996). What other nesting is occurring along the West African North Atlantic coast is not known. The level of decrease in the South American beaches reflects the increase in nesting seen from U.S. beaches for the same period of time. However, the overall annual total number of nests is still significantly less for U.S. than South American beaches.

3. The mortality rate for adult females has increased over the past ten years causing a decrease in the number of nesting females. For decreases in nesting to be observed on South American beaches but not U.S. beaches suggests that this may be true for turtles nesting in South America only. Spotila *et al.* (1996) indicated that the number of turtles killed in the South American offshore fishery had increased “dramatically”. It is not known what the magnitude of this increase is and cannot be identified as the cause of the decline, but neither can it be discounted as a direct cause of the decrease. Coastal gillnet fisheries and shrimp trawling do occur in the Guianas and could be contributory to mortality (Chevalier *et al.* 1999, Chevalier and Girondot 2000). Shrimp trawlers in these waters are not required to use TED’s (Chevalier and Girondot 2000). The decreases seen at these beaches and increases in nesting in U.S. beaches, suggests that some source of mortality may be effecting the South American nesting females and not effecting the U.S. and Caribbean nesting females. Of course, the signal may yet to be measured on U.S. beaches but this would suggest differential growth rates as well, with turtles nesting along South America growing faster resulting in a measurable decrease in females before observed in other nesting beaches. Given the range and movements of these turtles, it would be expected these turtles exhibit the same growth rates.
4. The mortality rates for any or all life history stages have increased. This increase in mortality rate could be impacting turtles from U.S. beaches and throughout the Atlantic as well and we have yet to measure this as decreases on the nesting beach but are seeing the effect on South American beaches. The same argument about differential growth rates would have to be applied here as for hypothesis 3. The proportion of turtles by nesting beach origin is likely variable in any given year due to turtles essentially utilizing the entire Atlantic Ocean basin and exhibiting even transoceanic movements. Assuming that the longline fishery and other human activities away from the nesting beach do not discriminate based on beach of origin, then it would be expected that this mortality would be observed as decreases in all nesting areas. Either the signal has not been measured in U.S. beaches or this mortality is selective for turtles from South American beaches only.

Any mortality from U.S. longline fishing would be expected to produce the same effect for all western North Atlantic leatherback turtles regardless of beach of origin or “population” if they were mixing on the high seas. For longline effort measured in total hooks fished, the U.S. effort is less than 10% of the total effort or hooks in the North Atlantic as prosecuted by nations party to ICCAT (see Chapter 1), but the U.S. accounts for 25-33% (mean=28%) of the swordfish yield, 1990-1997 and 11-26% (mean=18%) of the tunas yield from the North Atlantic. Thus, efficiency of the U.S. fleet as compared with foreign fleets and based on CPUE is 4-8 times greater for swordfish and 2-3 times greater for tunas. How this efficiency relates to the capture of sea turtles is not known. The bycatch rate of sea turtles is most significantly correlated with

swordfish catch, and secondly to shark, but negatively correlated with tuna (all species) (Chapter 2). Results also indicate that effort in terms of number of hooks set is not significant compared to the time-area factors. However, whether based on effort or yield when determining the relative impact of the domestic fishery relative to the foreign fleet, it is clear that the foreign fleet, when overlapping with the U.S. fleet, catches and kills turtles. Again, this mortality would not be expected to be selective and target turtles by beach of origin.

Turtles are taken and killed by the U.S. pelagic longline fishery. The total effort as measured in total hooks is larger for the foreign fleet than the U.S. fleet, although the magnitude of this take and mortality is not known and may be larger than that by the U.S. fleet alone. The greatest overlap in effort and numbers of leatherback turtles occurs in the entire western North Atlantic (Figure 7, Chapter 8). Thus, it would be expected that this mortality would be evidenced on nesting beaches throughout the western North Atlantic Ocean. It is possible, but unlikely that this signal has not been observed in U.S. beaches. Takes and mortality from the U.S. longline fishery are relatively large and while could be contributory especially for populations undergoing other significant stresses, it is difficult to argue that this alone explains the decreases observed in the largest nesting area of the western North Atlantic. This fishery, in combination with the foreign longline fleets and coastal fishery could produce sufficient mortality to result in the decreases evident on South American nesting beaches.

On the other hand, large removals of eggs alone could produce the same result and, if turtles do grow to maturity within 5 years, would be evidenced on the nesting beach quickly. There is compelling evidence to suggest that whatever is causing the decline in nesting females along the South American coast is not effecting the numbers of females nesting on U.S. and Caribbean beaches at this time or is measurable on U.S. beaches at this time. It remains to be seen if turtles are emigrating from South American beaches to U.S. and others, there is still a possibility given the cyclic nature of the South American beaches and the inability to distinguish subpopulations at this time. Chevalier *et al.* (1999) suggest that observers need to be placed on vessels fishing working off the coastal Guianas and that tag recapture experiments need to be conducted to determine the effects of fishing on these nesting females and to determine emigration rates, respectively. To determine the impact of the longline fleets (both U.S. and foreign) on these “populations”, first there must be some apportionment of turtles by nesting beach origin, then stage or age specific mortality rates must be quantified. These parameters could be determined by research and monitoring including: continuing to pursue genetic studies to describe stock structure; continuing to place observers on vessels coupled with studies such as use of archival tags to determine mortality rates; pursuing methods to age leatherback turtles and subsequently develop growth models; and exploring methods for estimating stage or age specific mortality rates. While there are takes and kills by the pelagic longline fishery and these takes may be contributory to declines observed, it appears that the U.S. nesting numbers are increasing. It is clear that the immediate concern is that French Guiana and Suriname must work towards identifying the causes of decline along their beaches. Without this effort, even with the elimination of takes by the longline fishery, it appears unlikely that these declines would be reversed. If immediate measures to reduce identified mortalities are implemented by French Guiana and Suriname, these alone may be sufficient to reverse the declines.

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## CHAPTER 8. EVALUATION OF POSSIBLE REASONABLE AND PRUDENT ALTERNATIVES BEING CONSIDERED

Wayne N. Witzell, Ransom A. Myers, and Sheryan P. Epperly

There are a number of possible reasonable and prudent alternatives being discussed to allow the continuation of the pelagic longline fishery. Several workshops have been held with scientists and industry to discuss possible means to reduce both the number of interactions and the mortality resulting from those interactions. A few are reviewed below with what little information is available.

### Hook Styles

A variety of fishhook styles are used in the pelagic longline fisheries 2000 (D. Lee, personal communication<sup>37</sup>). Boats may fish several styles of hooks at any one time depending on target species and hook availability. The traditional “J” style hooks are commonly used for swordfish and the circle hooks are commonly used for tunas. It has been proposed that a change in style of hooks used during pelagic longline fishing may effect the survival of sea turtles captured incidental to their fishing operations<sup>38,39</sup>. That optimism arose from promising results on other taxa.

Recent studies of circle and “J” hooks in the U.S. recreational fisheries for billfish and bluefin tunas have provided interesting results. Significantly more sailfish were jaw hooked, including corner of mouth, using circle hooks (98%) than with “J” hooks (44%). Only 2% of the sailfish were deeply hooked using circle hooks but 46% of the “J” hooked sailfish were deeply hooked (Prince *et al.* in press). Additionally, deep hooking by circle hooks with severely offset points was comparable (44%) with the deep hooking percentage for “J” hooks (Prince *et al.* in press).

There was a significant association between hook type and hook location ( $p < 0.05$ ) found in the U.S. catch and release recreational fishery for Atlantic bluefin tuna, *Thunnus thynnus* (Skomal *et al.* in press). In that study, 94% of the bluefin tuna caught with circle hooks were jaw and 3.9% were hooked in the pharynx or esophagus while 52% caught with straight “J” hooks were jaw hooked and 34% were hooked in the pharynx or esophagus. Based on these results, Skomal *et al.* (in press) estimated that 4% of the circle hooked captures and 28% of the straight

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<sup>37</sup> Dennis Lee, National Marine Fisheries Service, SEFSC, Miami, Fla.. Personal communication to Wayne Witzell, National Marine Fisheries Service, Miami, Fla., January 13, 2001.

<sup>38</sup> Kleiber, P. and C. Boggs. 2000. Workshop on reducing sea turtle takes in longline fisheries. Miami, August 31-September 1, 1999. Unpublished Report. National Marine Fisheries Service, SWFSC, Honolulu, Hawaii, 16 pp.

<sup>39</sup> Working Group on Reducing Turtle Bycatch in the Hawaii Longline Fishery, Report of First Meeting September 12-13, 2000 Los Angeles. Unpublished Report. National Marine Fisheries Service, SWFSC, Honolulu, Hawaii, 11 pp.

hook captures would have resulted in mortality, and recommended that circle hooks be promoted for use in catch and release recreational fisheries for juvenile bluefin tuna.

An experiment was designed to study gear effects on sea turtle bycatch by the pelagic longline fishery.<sup>40</sup> Preliminary data concerning the use of “J” and circle hooks experimentally fished on commercial Spanish longline vessels in the Azores Islands July-December 2000 is now available (A. Bolten, personal communication<sup>41,42,43</sup>) The experiment consisted of 93 longline sets, each set consisting of 1,500 hooks baited with squid. The target species were swordfish and blue sharks. Three hook types were tested: straight “J”(Mustad #76800 D 9/0), reversed/offset “J” (30-32°) (Mustad #76801 D 9/0), and circle (Mustad #39960 ST 16/0). The hooks were alternated along the set and because there were 8 hooks between buoys, the relationship between hook type and hook position on the gear varied. The order of gear set was thus: large buoy with radar reflector, 4 small buoys, large buoy, four small buoys, large buoy with reflector, etc.(Alan Bolten, personal communication<sup>44</sup>). The branchline (gangion) length, including leader, was 14 m and they were spaced 45 m apart along the mainline. Buoy lines were 5.4-14.4 m long: line length on large buoy with radar reflector was 14.4 m, large buoy line length was 10.8 m, and the line length on the small buoys was 5.4 or 10.8 m, depending on fishing conditions and was determined by the captain. A single 25.4 m vessel was used throughout the experiment.

A total of 232 loggerhead, 4 leatherback, and 1 green turtle were caught. Catch per unit effort (CPUE) for all species combined was estimated at 1.7 turtles/1,000 hooks. There was no significant difference in the total numbers of turtles caught by each hook type (Chi-square test,  $p=0.136$ ). However, there was a significant difference among the 3 hook types in the location of hooking in the turtles (Chi-square test,  $p<0.001$ ):

#### Percent Hooked in the Throat

Standard “J” Hook	57%
Offset “J” Hook	46%
Circle Hook	11%

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<sup>40</sup> Bolten, A.B., H.R. Martins, and K.A. Bjorndal, eds. 1998. Workshop to design an experiment to determine the effects of longline gear modification on sea turtle bycatch rates. Unpublished report. University of Florida and Departamento de Oceanografia e Pescas, Gainesville, FL and Horta, Portugal, 54 pp.

<sup>41</sup> Alan Bolten, University of Florida, Gainesville. Personal communication (E-Mail) to Sheryan Epperly, National Marine Fisheries Service, SEFSC, Miami, Fla., November 16, 2000.

<sup>42</sup> Bolten, A.B., University of Florida, Gainesville. Personal communication (Phone) to Sheryan Epperly, National Marine Fisheries Service, SEFSC, Miami, Fla., January 15, 2001.

<sup>43</sup> Bolten, A., H. Martins, E. Isidro, R. Ferreira, M. Santos, A. Giga, B. Riewald, and K. Bjorndal. Preliminary results of an experiment to evaluate effects of hook type on sea turtle bycatch in the swordfish longline fishery in the Azores. Unpublished report, 2 pp.. A.B. Bolten, University of Florida, Gainesville. Personal communication (E-Mail) to Nancy Thompson and Sheryan Epperly, National Marine Fisheries Service, SEFSC, Miami, Fla, January 13, 2001.

<sup>44</sup> Bolten, A.B., University of Florida, Gainesville. Personal communication (E-Mail) to Sheryan Epperly, National Marine Fisheries Service, SEFSC, Miami, Fla., January 24, 2001.

Additionally, there was a tendency for more turtles to be caught on hooks closest to buoys, but there was no significant effect of hook position along the mainline on turtle bycatch (Chi-square test,  $p = 0.515$ ).

The use of circle hooks to reduce sea turtle serious injury shows encouraging results. The presumption is that animals that ingest the hooks are less likely to survive an interaction than animals that are hooked in the mouth. Use of circle hooks would reduce the number of animals ingesting the hook, but not the total number being hooked. However, changing from “J” to circle hooks may adversely affect the catching success for target species, particularly for the swordfish fleet. In the Azores experiment, there was a significant difference among the hook types in the numbers of swordfish caught (Chi-square test,  $p < 0.001$ ). The circle hook caught 262 swordfish and the “J” hook caught 381 swordfish, a 31.1% reduction.

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Skomal, G.B., B.C. Chase and E.D. Prince. In press. A comparison of circle and straight hooks relative to hooking location, damage, and success while catch and release fishing for Atlantic bluefin tuna. In American Fisheries Society Special Publication. National Symposium on Catch and Release in Marine Recreational Fisheries, December 5-8, 1999.

## **Time-Area Closure**

### ***Supplemental Bycatch Analysis to Determine Times and Areas of High Interactions***

Bycatch data from 1992-1999 was obtained from the U.S. Pelagic Observer Program for both loggerhead and leatherback turtles. Generalized additive models were used to analyze the data. Seasonal bycatch of loggerhead and leatherback turtles appear similar within geographical regions. Number of turtles caught is higher in more northern locations, particularly in the Northeast Atlantic Ocean. For both turtle species, catches in the more southern regions are limited to the winter months. Patterns of catch in the coastal regions may follow migratory patterns: the southern bycatch decreases with day of the year in the Gulf of Mexico, while along the coast of New England it increases. Peak bycatch numbers for the loggerhead (Fig. 1) and leatherback (Fig. 2) occur in the Northeast Distant Atlantic region during mid-August.

The most recent Biological Opinion for the Highly Migratory Species Fishery<sup>45</sup> included a reasonable and prudent alternative (RPA) which would effectively close the fishery in the Northeast Distant Area (NED) from July-December. The NED has been identified as an area of high turtle interactions. The NMFS SEFSC was asked to evaluate whether a time/area closure smaller than the entire geographic extent and temporal duration given in the RPA could achieve the same degree of reduction in turtle takes with less impact on target catch. The SEFSC provided the following analysis.<sup>46</sup> The conclusion was that the interactions occur throughout the entire NED and not just in some small portion of it. An “L” shaped portion of the NED was closed under an emergency regulation for the period October 10, 2000-April 9, 2001 (65 FR 60899-60892, October 13, 2000).

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<sup>45</sup> Endangered Species Act - Section 7 Consultation Biological Opinion. Reinitiation of Consultation on the Atlantic Pelagic Fisheries for Swordfish, Tuna, Shark and Billfish in the U.S. Exclusive Economic Zone (EEZ): Proposed Rule to Implement a Regulatory Amendment to the Highly Migratory Species Fishery Management Plan; Reduction of Bycatch and Incidental Catch in the Atlantic Pelagic Longline Fishery, 118 pp. Consultation conducted by National Marine Fisheries Service, Office of Protected Resources, Silver Spring, Md., June 30, 2000.

<sup>46</sup> Turtles involved with longline gear in the Gand [sic] Banks. Unpublished report. National Marine Fisheries Service Southeast Fisheries Science Center, Miami, FL. Attachment to E-Mail from Joseph Powers, National Marine Fisheries Service, SERO, St. Petersburg, Fla. to Karyl Brewster-Geisz, National Marine Fisheries Service, SF, Silver Spring, Md., August 25, 2000.

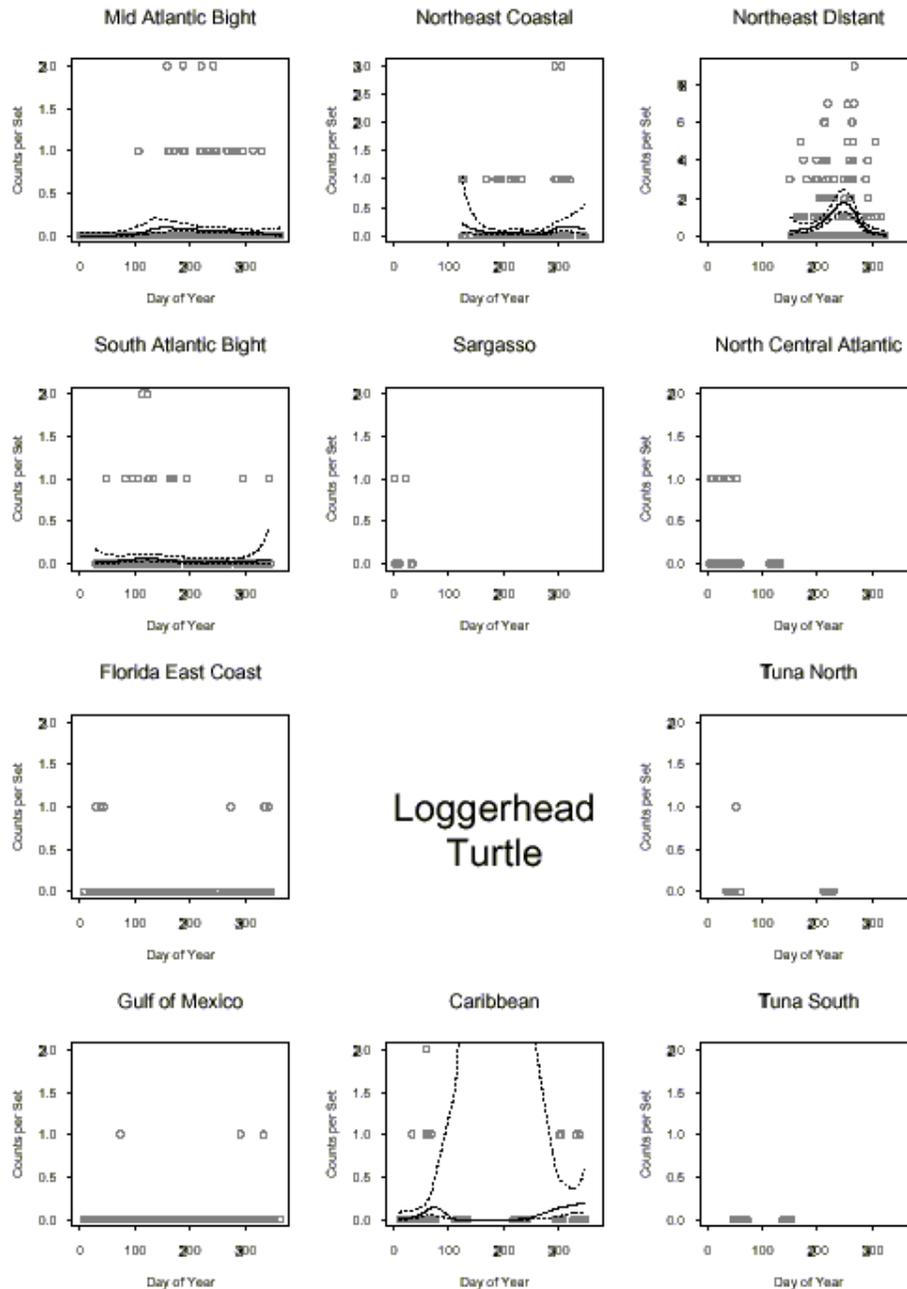


Figure 1. Seasonal counts of loggerhead turtles caught during each longline set from 1992 to 1999 (open circles). Fitted values from the model are given by a solid line and their point wise upper and lower confidence intervals are given by dotted lines. Individual plots represent 11 areas and are displayed in a pattern that roughly follows their relative north/south and east/west geographical location.

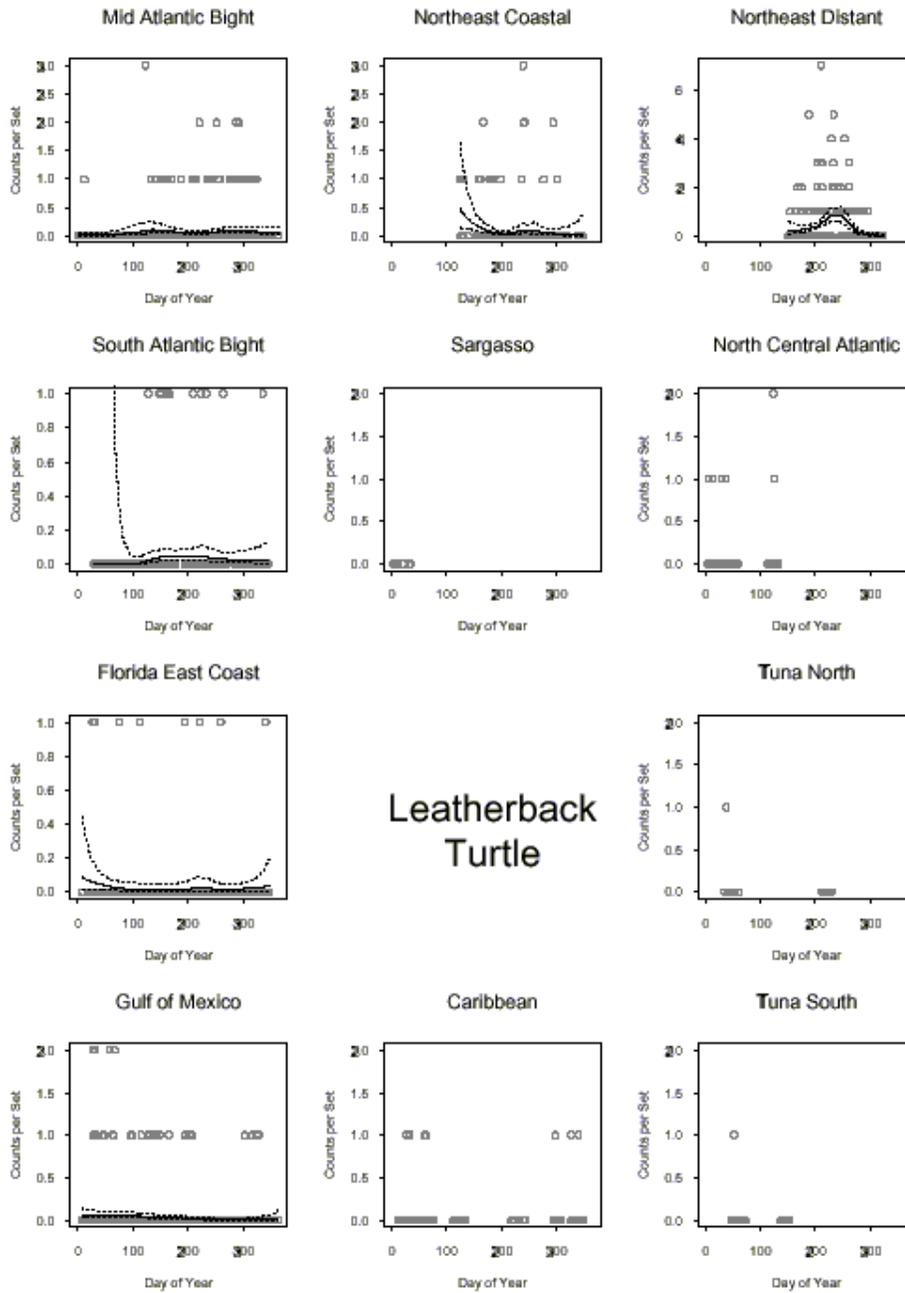


Figure 2. Seasonal counts of leatherback turtles caught during each longline set from 1992 to 1999 (open circles). Fitted values from the model are given by a solid line and their point wise upper and lower confidence intervals are given by dotted lines. Individual plots represent 11 areas and are displayed in a pattern that roughly follows their relative north/south and east/west geographical location.

### *Turtles Involved with Longline Gear in the Grand Banks*

Data from the large pelagic logbook and the NMFS observer file were used to identify times and locations of turtle involvement with longline gear in the Grand Banks during the months July through December.

#### Description of data sources

Large pelagic logbook (LPL):

U.S. Atlantic, Caribbean and Gulf of Mexico fishing vessels which land swordfish have been required to provide daily records of effort and catch since October 1986. Numbers of turtles involved, injured, and killed have been reported to this file since 1992. Although a variety of gear types are represented, the predominant gear type (90% of vessels reporting) is longline gear. Fishing effort in this area is seasonal. Very little effort was reported in December.

Table 1. Numbers of turtles reported involved, injured, or killed by pelagic longline vessels in the Grand Banks between July and December 1992-1999.						
	Green	Hawksbill	Kemp's Ridley	Leather-back	Logger-head	unknown
involved	74	129	16	793	2020	10
injured	1	0	0	6	35	0
killed	0	0	0	8	3	0

NMFS Observer (NMFSO):

National Marine Fisheries Service observers have observed a random sample of longline vessels targeting swordfish and tuna since 1992. Numbers of fish and turtles landed, discarded dead and discarded alive are recorded in this file as well as gear and location information.

Table 2. Numbers of turtles observed released alive or killed by pelagic longline vessels in the Grand Banks between July and December 1992-1999.				
	Green	Leatherback	Loggerhead	unknown
released alive	8	106	225	1
released dead	1	0	0	0

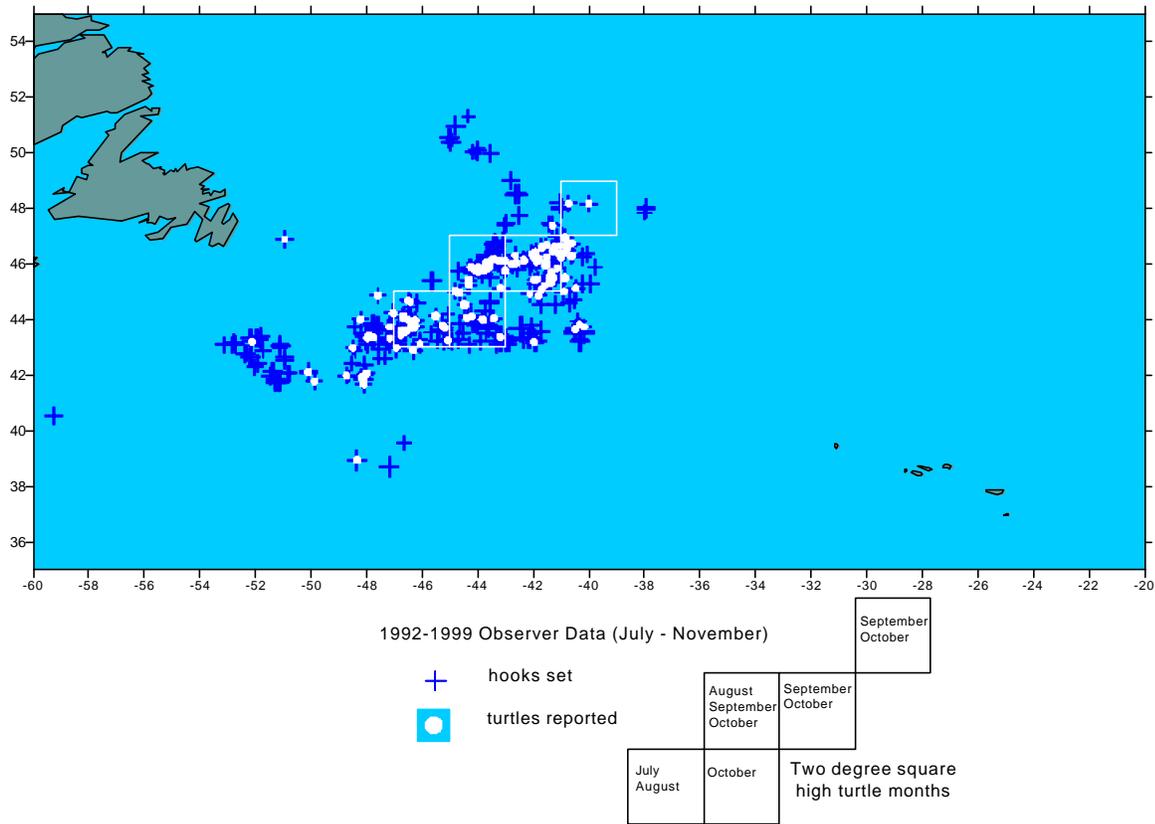


Figure 3. Locations of observed effort (hooks set) and turtle involvement (turtles reported) from NMFSO from July through November are shown on this map. Squares indicate areas of highest turtle involvement. The relevant months of high involvement for each square are indicated by listing the months in the square diagram above this caption.

Observer data were grouped within each year by month and two degree square. A GLM model was run: all turtles reported vs year and month-square. The number of hooks reported in the month-square was used as a weighting variable. Month-squares were ranked based on the LSMEAN value from the GLM. The ten month-squares with the highest estimated turtle involvement (based on the LSMEAN values) are shown in Figure 3. The month written inside the square indicates that the square was high for that month.

Table 3 gives the percentage decreases in turtles involved (relative to total involvement in the Grand Banks July-Dec), effort in hooks, and catch of other species resulting from closure of the U.S. fishery in the Grand Banks, using NMFS Observer data. Table 5 gives the same information based upon Large Pelagic Logbook data. Decreases resulting from closures of high month-squares (based on NMFSO) are shown in Table 4.

Table 3. The percent decrease with total closure for month based on observer records.

	All Turtles	Swordfish	Tuna	Mako	Swordfish	Blue	HOOKS
		Landed		Sharks	Dead Disc	Sharks	
total	341	6240	1904	892	1703	11263	265744
July	28%	39%	22%	60%	50%	30%	35%
August	25%	16%	4%	20%	18%	18%	14%
September	36%	19%	23%	9%	15%	13%	16%
October	9%	24%	29%	8%	13%	29%	26%
November	2%	3%	23%	3%	4%	10%	9%

Table 4. The percent decrease with closure of high two degree squares for month based on observer records.

	All Turtles	Swordfish	Tuna	Mako	Swordfish	Blue	HOOKS
		Landed		Sharks	Dead Disc	Sharks	
July %	6%	8%	3%	14%	10%	10%	6%
Aug %	9%	4%	0%	4%	3%	3%	4%
Sept %	24%	13%	15%	6%	9%	7%	10%
Oct %	1%	9%	7%	3%	3%	7%	8%

Table 5. The percent decrease with total closure for month based on logbook records.

	All Turtles	Swordfish	Tuna	Mako	Swordfish	Blue	HOOKS
Month		Landed		Sharks	Dead Disc	Sharks	
	3095	119237	23659	6846	11936	273307	4749322
July	36%	22%	14%	39%	30%	20%	22%
August	24%	27%	19%	28%	22%	29%	25%
September	24%	29%	31%	17%	23%	23%	26%
October	15%	19%	23%	13%	19%	21%	20%
November	1%	3%	12%	3%	5%	7%	7%
December	0%	0%	1%	0%	0%	0%	0%

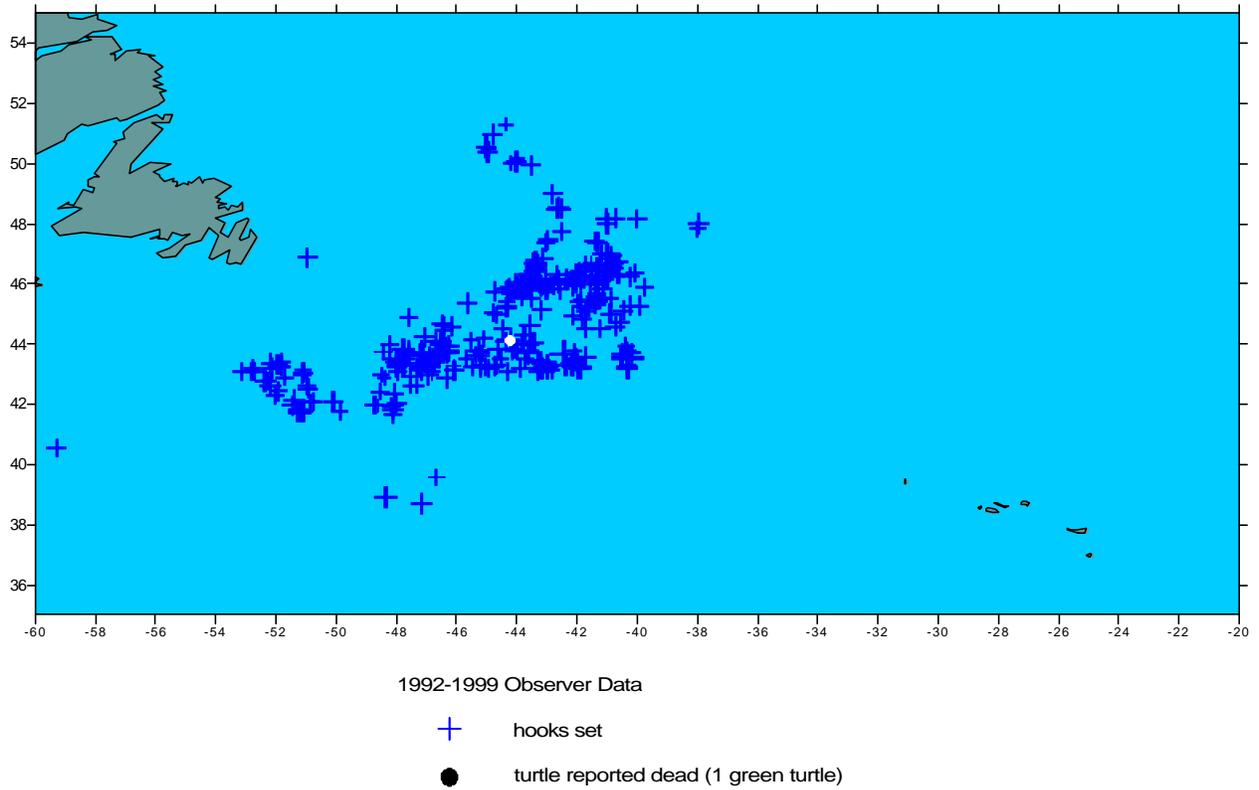


Figure 4. Location of turtles reported dead. (NMFSO)

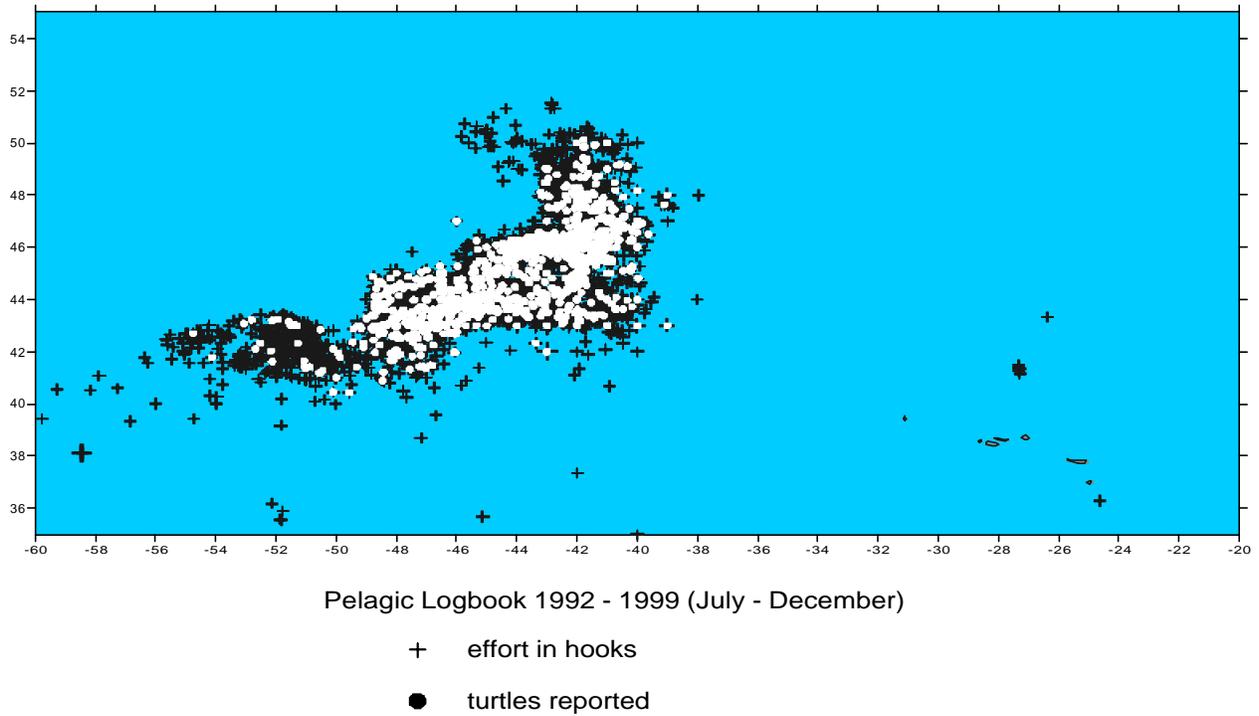


Figure 5. Locations of reported effort (hook set) and turtle involvement (turtles reported) from LPL form July through December are shown on this map

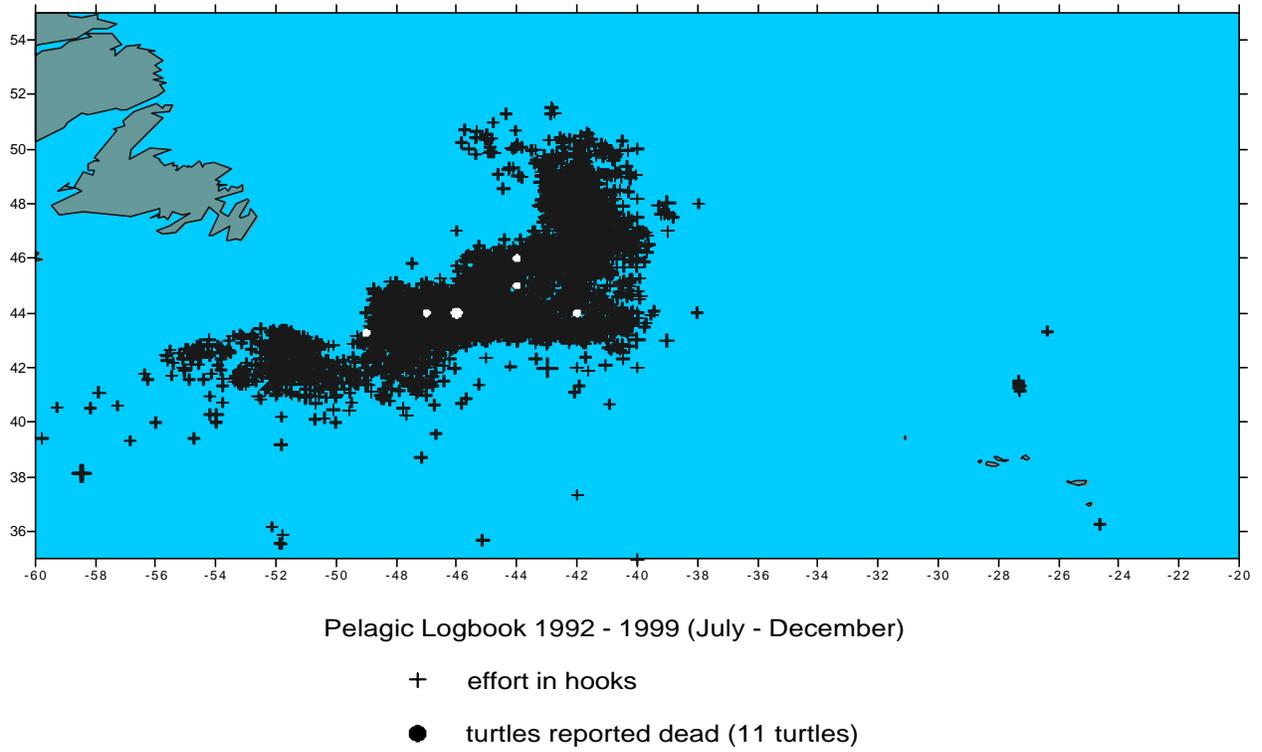


Figure 6. Locations of turtles reported killed (LPL)

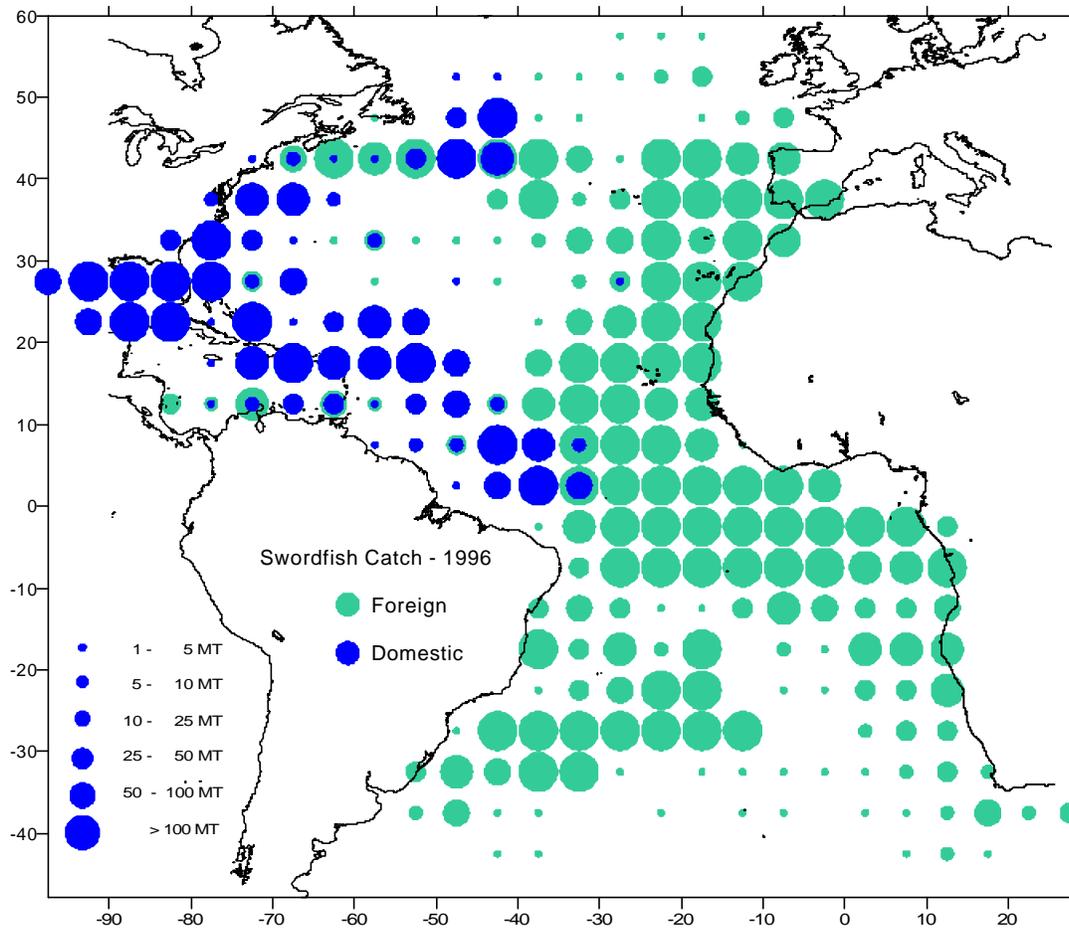


Figure 7. Domestic (U.S.) and foreign swordfish catch in 1996. Foreign catch data are incomplete and includes only North American, Asian, and Spanish reported landings. Notably not included are catches from Caribbean, Central and South America, and other European countries.

In response to a request from the NMFS Office of Sustainable Fisheries, the SEFSC provided the results of a GLM model run on the logbook data for 2 degree latitude/longitude squares (J. Cramer personal communication<sup>47</sup>) (Table 5) and output from these analyses were provided (J. Cramer personal communication<sup>47</sup>) (Appendix 5). The conclusions were the same as from analyses based on the observer data.

Table 5. The number of reported interactions (LPL) with sea turtles by the pelagic longline fleet. The first square is between 43° to 45° N latitude and 45° to 47° W longitude. The number is in the center of the two degree square. These are the highest 10 month/squares with 1 being the highest LSMEAN from the GLM.

logbook square	July	August	September	October
4446	8			
4642	1	4	3	
4644	2		6	
4640		9		
4442	7			
4248				5
5044			10	

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<sup>47</sup> Jean Cramer, National Marine Fisheries Service, SEFSC, Miami, Fla. Personal Communication (E-Mail) to Karyl Brewster-Geisz, National Marine Fisheries Service, SF, Silver Spring, Md., August 28, 2000.

## **Evaluation of the Effect of Sea Surface Temperature and Time of Set on Sea Turtle Bycatch off the Northeast U.S.**

One of the alternative reasonable and prudent alternatives identified in the most recent Biological Opinion was to manage all pelagic longline vessels fishing north of 35° N latitude so that they fish only in waters with sea surface temperatures cooler than 64° C. It furthermore stipulated that gear shall not be set prior to 10 p.m.<sup>48</sup>

### ***Sea Surface Temperature***

Previous analyses have described factors that appear to influence rates of sea turtle interactions with the Atlantic pelagic longline fishery and suggested that sea surface temperature or time of set may influence the probability of interacting with a sea turtle (Hoey 1998<sup>49</sup>, Hoey and Moore 1999<sup>50</sup>). The datasets used for those analyses were updated through 1999 and graphed (Fig. 8 and 9) to assess the effect of sea surface temperature on turtle bycatch in the Northeast U.S. (MAB and NEC areas) and Northeast Distant (NED) fishing areas (Hoey 2000<sup>51</sup>) (see Chapter 2 for definition of these areas).

These data are difficult to interpret because they do not represent a random sample of water temperatures in the 2 areas and the patterns observed may be an artifact of the distribution of fishing effort (Fig. 10). While it appears that the distribution of turtles may be affected by water temperature (a reasonable conclusion since sea turtles generally are poikilothermic), there is no clear pattern for swordfish, the primary target species in the area. The pattern observed for the target species is completely opposite in the two areas, with swordfish tending to be caught at a higher rate at higher temperatures on the Grand Banks and caught at a higher rate at lower temperatures in the Northeast Coastal Area. Thus, an attempt to restrict the fishery to cooler waters where turtles are less likely to occur cannot be done without some potential impact on the catch of the target species.

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<sup>48</sup> Endangered Species Act - Section 7 Consultation Biological Opinion. Reinitiation of Consultation on the Atlantic Pelagic Fisheries for Swordfish, Tuna, Shark and Billfish in the U.S. Exclusive Economic Zone (EEZ): Proposed Rule to Implement a Regulatory Amendment to the Highly Migratory Species Fishery Management Plan; Reduction of Bycatch and Incidental Catch in the Atlantic Pelagic Longline Fishery, 118 pp. Consultation conducted by National Marine Fisheries Service, Office of Protected Resources, Silver Spring, Md., June 30, 2000.

<sup>49</sup> Hoey, J. 1998. NEFSC pelagic longline data review & analysis of gear, environmental, and operating practices that influence pelagic longline interactions with sea turtles. Unpublished Report. National Fisheries Institute, Inc., Arlington, VA Final Contract Report NOAA-Contract – 50EANA700063 to National Marine Fisheries Service Northeast Regional Office, Gloucester, MA, 32 pp.

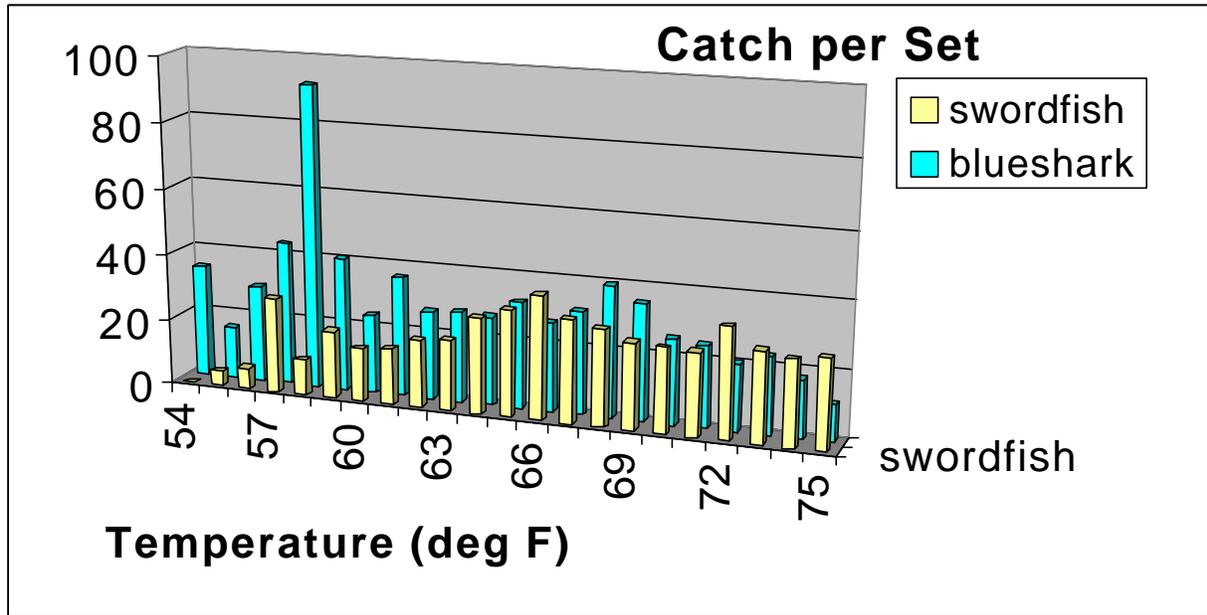
<sup>50</sup> Hoey, J. and N. Moore. 1999. Captain's report. Multi-species catch characteristics for the U.S. Atlantic pelagic longline fishery. Unpublished Report. National Fisheries Institute, Arlington, VA report for National Marine Fisheries Service Southeast Regional Office, St. Petersburg, FL (MARFIN Grant – NA77FF0543) and Northeast Regional Office, Gloucester, MA (Saltonstall-Kennedy Grant – NA86FD0113), 78 pp.

<sup>51</sup> John Hoey, National Marine Fisheries Service, ST, Silver Spring, Md. Personal Communication (E-Mail) to K. Wang, National Marine Fisheries Service, SERO, St. Petersburg, Fla., June 2, 2000. Unpublished Report. Requested re-examination of gear, environmental, and opening practices associated with sea turtle longline interactions, 26 pp

Surface water temperature is shown in regression tree analysis to be an important factor in the rate of bycatch of leatherbacks and loggerheads in the NED area in certain years (see Chapter 2). For leatherbacks, the temperature effect is nested within the month effect, and for loggerheads, the month effect is nested within the temperature factor. For all species combined, lower temperature is associated with lower bycatch rate. While this association is true also for loggerheads only, for leatherbacks, lower temperature actually accounts for a slightly higher bycatch rate, so if indeed temperature is a significant factor in bycatch rate the interaction may be species-specific. Both temperature and month effects may however simply be a reflection on the seasonal distribution of fishing effort, since effort tends to be concentrated in the 3<sup>rd</sup> quarter in NED, which is likely to have a higher average temperature than in other quarters combined.

Figure 8. Catch rates of swordfish, blueshark, hardshell (Cheloniidae) and leatherback sea turtles in the Northeast Distant Area. (A) finfish catch per set and (B) sea turtle catch per set.

(A)



(B)

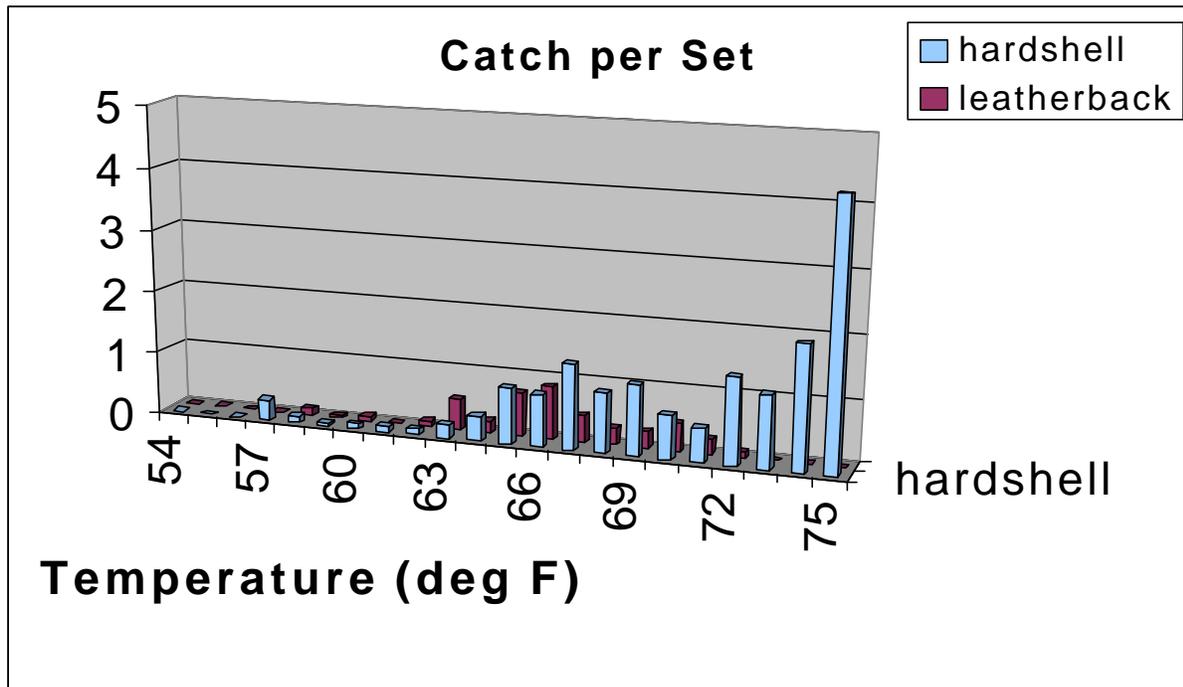
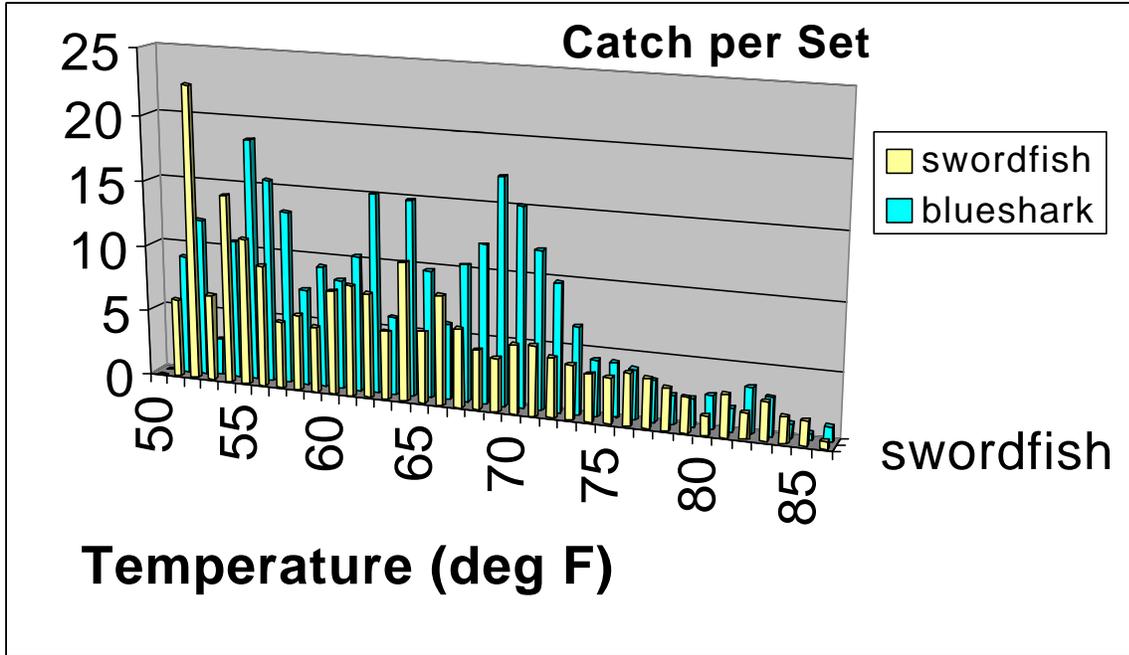


Figure 9. Catch rates of swordfish, blueshark, hardshell (Cheloniidae) and leatherback sea turtles in the Northeast Coastal Area. (A) finfish catch per hook and (B) sea turtle catch per hook.

(A)



(B)

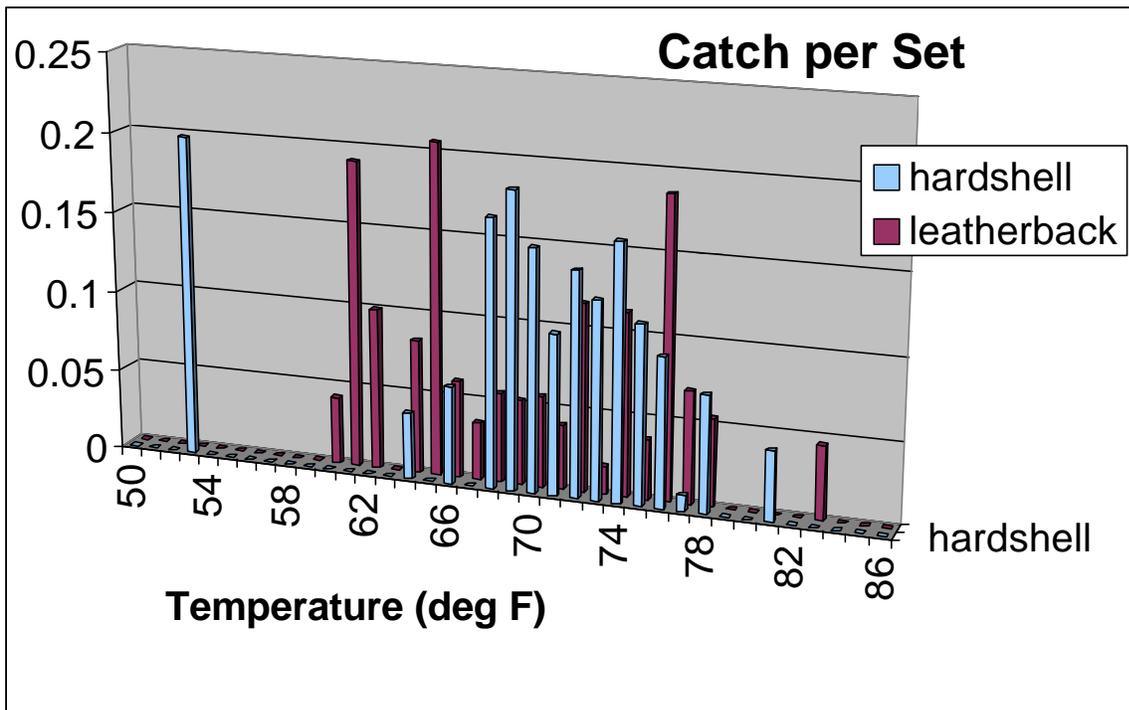
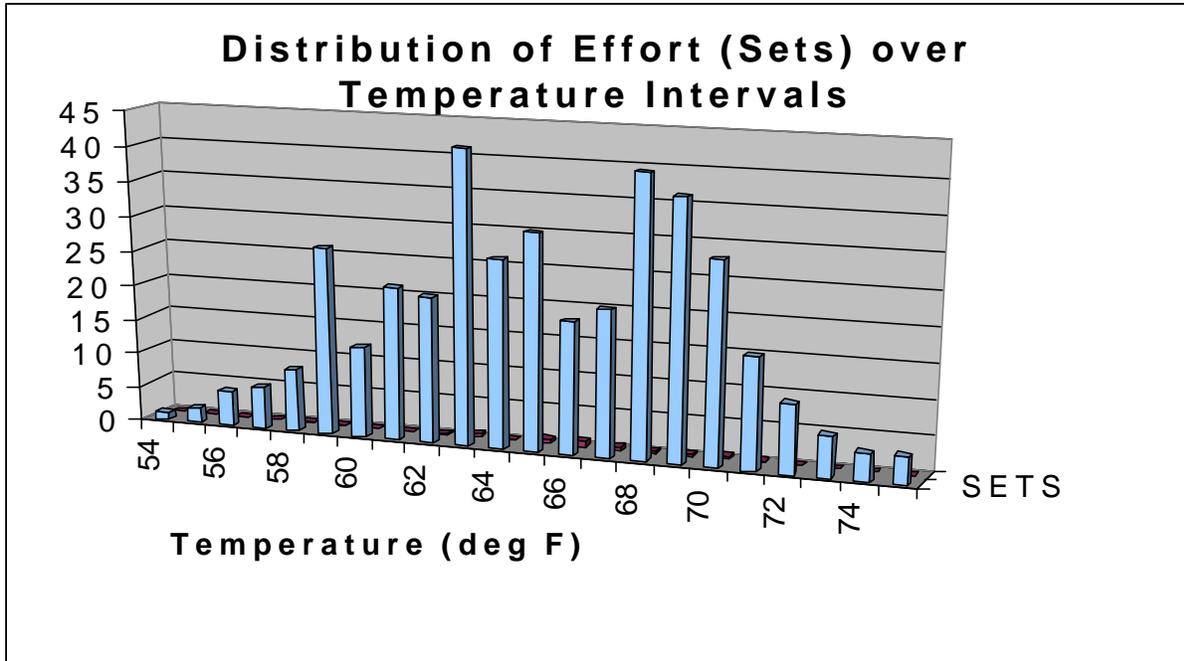
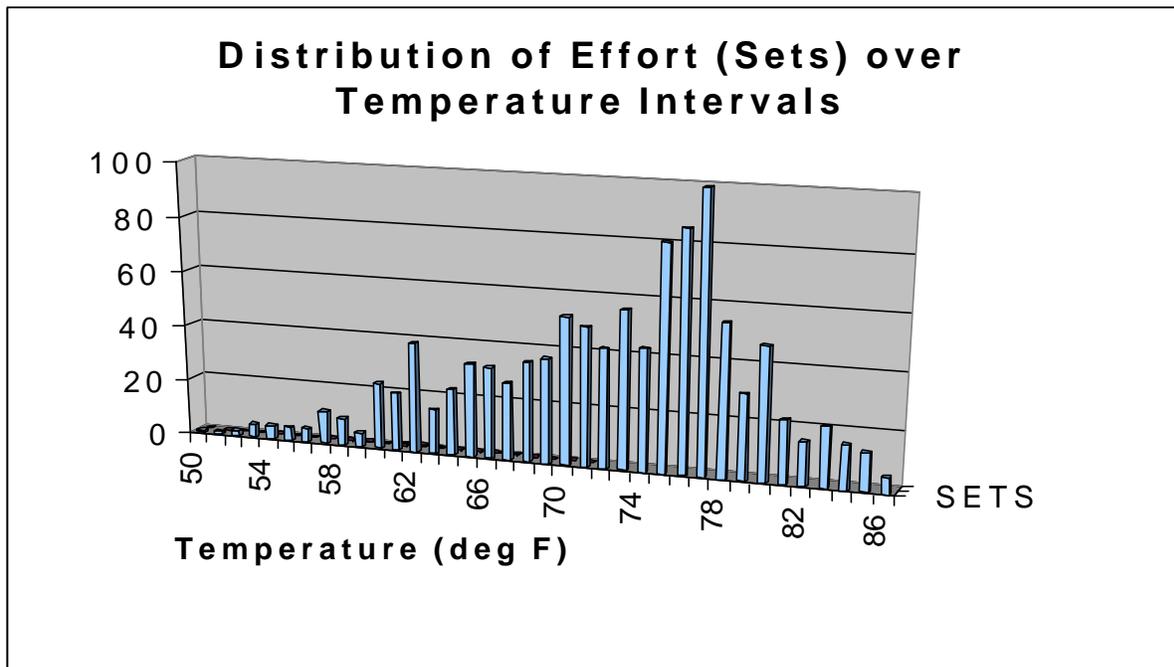


Figure 10. Distribution of effort (sets) across temperature intervals. (A) the Northeast Distant Area and (B) the Northeast Coastal Area.

(A)



(B)



### *Time of Set*

Likewise time of day when sets were made also did not represent a random sample of times throughout a day (Fig. 11). Turtles appeared to be captured whenever sets were made (Fig. 12).

Figure 11. Distribution of effort (sets) across time intervals.

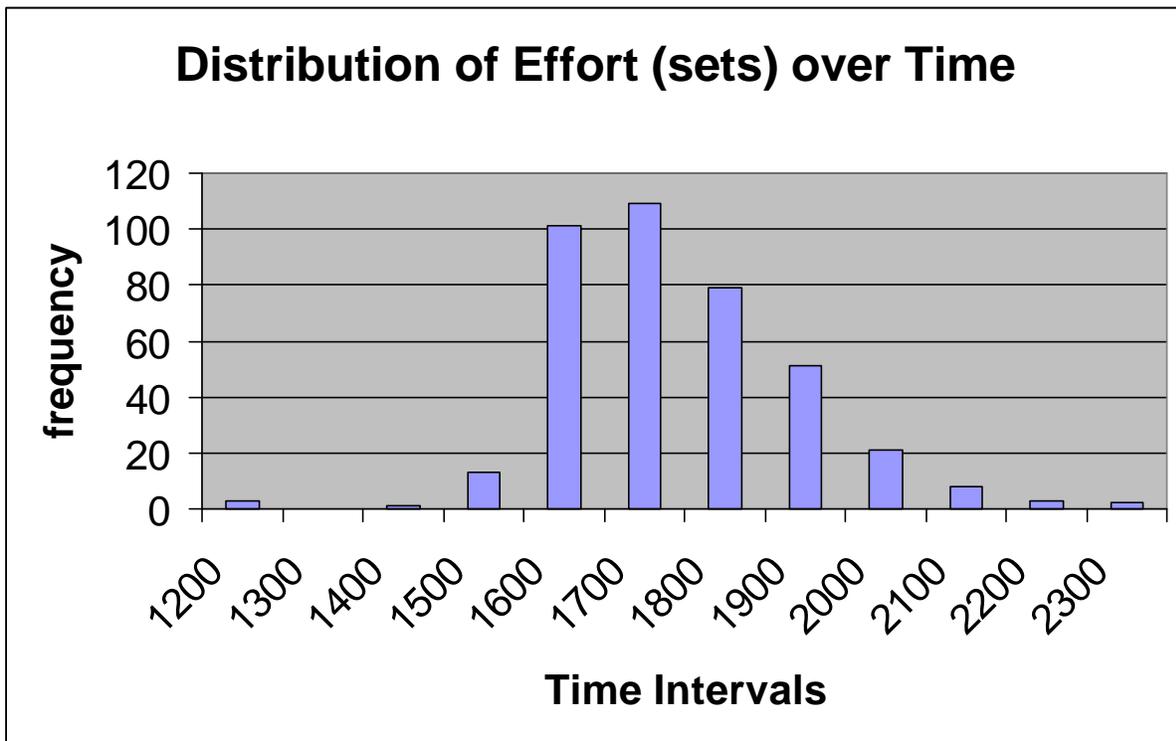
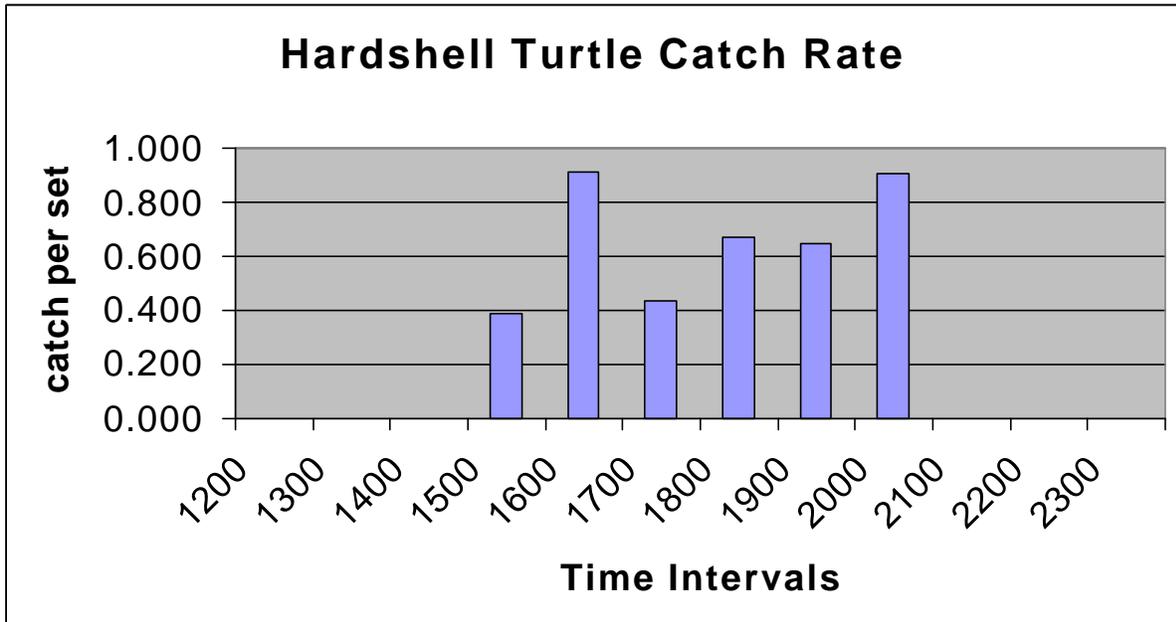


Figure 12. Catch rates of hardshell (*Cheloniidae*) and leatherback sea turtles in the Northeast Coastal and Northeast Distant Area. (A) hardshell turtles and (B) leatherback turtles.

(A)



(B)

