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Estimation of Mortality of Juvenile Blacktip Sharks, *Carcharhinus limbatus*, Within a Nursery Area Using Telemetry Data

(Elasmobranch Fisheries – Oral)

by

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Abstract

A population of young blacktip sharks was monitored over three years to determine their mortality rates using a series of acoustic listening stations. Based on these data it was possible to use several mortality estimators, including indirect life-history based methods and direct methods such as the Kaplan-Meier and SURVIV methods, to estimate natural, fishing and total mortality. Kaplan-Meier (61-91%) and SURVIV (62-92%) methods provided nearly identical total mortality rates during the first six months of life. This agreement suggests that these estimates are accurate for this population. All natural and fishing mortality occurred within the first 15 weeks of the study. This suggests that young sharks are most vulnerable to all types of mortality during this period. Sharks that survived beyond the first 15 weeks successfully left the nursery and were presumed to have migrated southward during fall months. These results provide critical information concerning the early life history of young sharks and the importance of nursery areas to the survival of young animals.

Introduction

Estimation of mortality is a critical factor in determining the status of fished species and is typically one of the most difficult parameters to define. Many scientists have estimated the mortality of fishes, including sharks, based on life history characteristics (e.g. Pauly, 1980; Vetter, 1988; Simpfendorfer, 1999a). However, as Branstetter (1990) pointed out, many of these analyses are based on the adult portion of the population. In fact, to account for the higher vulnerability of young sharks to natural mortality, researchers routinely double estimates calculated from life-history methods to represent increased mortality of the first year class (e.g. Smith and Abramson, 1990; Sminkey and Musick, 1996; Simpfendorfer, 1999b). Unfortunately, this calculation is often made with no direct evidence concerning the survivorship of this portion of the population.

Survival estimates in terrestrial studies are commonly calculated from telemetry data and these methods have recently been applied to aquatic populations (e.g. Bendock and Alexandersdottir, 1993; Hightower *et al*., 2001). The use of telemetry data allows the researcher to define the fate of animals within the study site by continuously monitoring or re-locating an animal. This removes the need to recapture marked individuals or to rely on tag reports from other individuals. Advancements in telemetry technology are providing opportunities to use these methodologies in aquatic systems where mortality estimates have mostly been based on life history characteristics or mark-recapture data. Mortality data have been particularly sparse in relation to juvenile stages of aquatic populations, and elasmobranchs are no exception. In this paper we will describe mortality for a population of juvenile blacktip sharks (*Carcharhinus limbatus*) within a coastal nursery area based on long-term acoustic telemetry data.

Methods

Blacktip sharks were collected by rod and reel fishing in a known coastal nursery area, Terra Ceia Bay, Florida. Sharks were landed in less than one minute and fitted with 16 mm x 65 mm acoustic transmitters (Vemco Ltd., Nova Scotia). All sharks were marked with an external dart tag (Hallprint, South Australia) for identification purposes, measured, weighed, sexed. Upon release, the long-term movement patterns of sharks were recorded by a series of acoustic listening stations (Heupel and Hueter 2001; Simpfendorfer *et al*., 2002). The acoustic array allowed sharks to be continuously monitored for the entire period they were present within the nursery area.

Defining fates of tagged sharks

The fate of individuals in the nursery area was determined through analysis of the long-term monitoring data. Sharks were classified into three categories: 1) Survivals – individuals that maintained continuous movement within the study site and/or were observed to swim out of the study site; 2) Natural mortalities – individuals that ceased movement within the study site or showed movement patterns more rapid than, and inconsistent with previous or typical movements (consistent with the faster rate of movement of a large predator that had consumed the small shark). This category includes all types of natural mortality (e.g. predation, starvation, disease); 3) Removals (censored) – individuals removed from the study site due to factors other than natural mortality or swimming out, such as harvest by fishermen. These individuals were typified by loss of signal detection from the animal while it was within the acoustic array. Many of these instances were validated by tag/transmitter returns from recreational fishermen.

Mortality Estimators

Natural mortality of *C. limbatus* was estimated using a range of indirect techniques based on life history data to provide a comparison to those estimated from telemetry data. Six estimators of constant lifetime mortality (Pauly, 1980; Hoenig, 1983; Jensen, 1996) and one method of age-specific mortality (Peterson and Wroblewski, 1984) were used. Survival of juvenile *C. limbatus* was also estimated with the nonparametric Kaplan-Meier procedure (Cox and Oakes, 1984; Pollock *et al*., 1989a, 1995). This approach computes the proportion of fish that die within the study period and allows for animals that are censored from the population (Pollock *et al*., 1989b). The final calculations of natural and fishing mortality were estimated from the telemetry data using a method described by Hightower et al. (2001) for striped bass. This method examines the number of animals in the study site at a specific time in comparison to the expected number of surviving animals at some future point in time. See Heupel and Simpfendorfer, 2002 for detailed methods).

Results

A total of 92 *C. limbatus*, were collected and fitted with transmitters over the course of three years. The sample size in 1999 was 18 (11 male, 7 female), in 2000 was 33 (20 male, 13 female), and in 2001 was 41 (14 male, 27 female). All individuals collected were neonates with open umbilical scars (mean total length = 62 cm) and were monitored within the study site from 1-167 days.

Monitoring histories were defined for all sharks in each year. During the three years, 23 sharks (25.3%) were censored, or removed from the study site (5 in 1999, 7 in 2000, 11 in 2001). Eight tagged shark recaptures were reported (34.8% of censored animals) from local anglers during this period with five transmitters returned. Twenty-eight (30.8%) cases of natural mortality occurred during the course of the study (7 in 1999, 9 in 2000, 12 in 2001). Five sharks died within 24 hours of release, with at least two of these animals appearing to have been consumed by a predator. These five individuals were excluded from mortality estimates since it is likely that their deaths were a direct result of the surgical procedure/handling. Most natural mortalities occurred within the first month of the study (mean = 12 days) but there were two animals that died after 55 and 66 days at liberty. Forty-one (42.9%) sharks were observed to swim out of the study site and were considered as survivals (6 in 1999; 17 in 2000; 18 in 2001). Logistic regression analysis showed no significant relationship between survival and shark size, sex, environmental variables, handling time, or release condition.

Calculation of Kaplan-Meier survival estimates varied among years. Survival estimates were lower for year 1 than those for years 2 and 3, probably due to small sample sizes in year 1 (Table 1). Similarly, animals tagged early in year 2 had to be excluded because small sample sizes caused exaggerated mortality for that year. Natural mortality was greatest within the first 15 weeks of the study period in each year, before leveling off at zero. Rates of fishing mortality also varied among years, but appeared to be greatest early in the season (May-July). After this point, fishing mortality leveled off at zero for the remainder of the summer months. Pooling data from all years to estimate survival from natural mortality revealed survival initially decreases, followed by a leveling off at approximately 0.5 (Fig. 1). Survival from fishing mortality, also showed a decline early in the season followed by a level period at a rate of approximately 0.5 (Fig. 1). The combined effects of fishing and natural mortality resulted in total mortality estimates ranging from 0.61-0.91 (Table 1).

Natural and fishing mortality rates were calculated by week based on the output of program SURVIV (Fig. 6). Natural mortality estimates ranged from 0 – 0.69 week^{-1} and fishing mortality estimates ranged from 0 – 0.79 week^{-1} but both were generally below 0.2 week^{-1}. While mortality rates varied among years, all years showed a consistent pattern where both natural and fishing mortality occurred within the first 15 weeks of the season (Fig. 6).

Discussion

Natural and fishing mortality rates of elasmobranch populations have traditionally been difficult to estimate and analyses have generally relied on life-history parameters. However, results of the current study have gone beyond previously available methods to provide a temporally explicit definition of mortality in a population of juvenile sharks. There are few available data with which to compare mortality estimates for neonate *C. limbatus*. Manire and Gruber (1993) provided the most comparable data by censusing a closed population of neonate lemon sharks (*Negaprion brevirostris*) in Bimini, Bahamas, for which they estimated that 44-61% of sharks die in the first year of life. The total mortality estimate for lemon sharks was lower than for neonate blacktip sharks, in part, because there was little or no fishing mortality for the lemon shark population (Manire and Gruber, 1993). The natural mortality estimate for neonate blacktip sharks for the period from May to November was similar to that for neonate lemon sharks for their entire first year. This suggests that the natural mortality of blacktip sharks in their first full year of life in Terra Ceia Bay is higher than for lemon sharks in Bimini, Bahamas.

Analysis of telemetry data in the present study provided the ability to directly estimate mortality for neonate *C. limbatus*. The Kaplan-Meier method estimated that over the course of a summer between 61% and 91% of neonates died, with all mortality occurring prior to week 15. The upper end of this range was based on the fewest data and is likely to overestimate mortality, as deaths among a small number of animals released early in the season heavily weighted the estimates. Program SURVIV results provided estimates of weekly natural and fishing mortality rates that were generally less than 0.2 week $^{-1}$ for the first 12 to 15 weeks in each year. However, these results are independent weekly estimates that are not directly comparable to Kaplan-Meier results. If the total mortality rates estimated by the SURVIV method are applied to a population equivalent to the total number of tags released in each year of the current study, a comparable estimate is obtained. This technique resulted in an estimate where 62-92% of neonate *C. limbatus* died. This result is almost identical to that estimated by the Kaplan-Meier method. The agreement between these two models suggests that the calculated natural and fishing mortality estimates are accurate for the population within Terra Ceia Bay.

The results of this study demonstrate that natural and fishing mortality of neonate *C. limbatus* in Terra Ceia Bay occurs in the first 12-15 weeks of life. If an animal survives this period, it has a high likelihood of surviving until leaving the nursery area in the fall. All of the animals released in the study were less than a month old, and many were only a few days old. Anecdotal evidence suggests that one cause of early mortality may be inexperience. This is supported by the fact that during this study sharks became increasingly difficult to capture and by August were rarely captured, although monitoring data indicate that sharks were still present in the area.

Estimation of natural mortality within elasmobranch populations is a common problem that has limited efforts to define the dynamics of species and design appropriate fishery management plans (Cortes, 1998). Previous authors have suggested that mortality rates for juvenile sharks are highest in the first year of life (e.g. Hoenig and Gruber, 1990; Manire and Gruber, 1993; Simpfendorfer, 1999b). The results presented here support those conclusions. In fact, the first few months of life appear to be the most critical time for survival of neonate *C. limbatus* in Terra Ceia Bay. Therefore the protection of nursery areas would be of significant value to animals in the first few months of life when mortality rates appear to be highest. The added impact of fishing pressure on this young portion of the population increases total mortality and future management plans may consider closing fishing for these young animals during the first few months of life.

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Table 1. Kaplan-Meier estimates of mortality for young of the year *Carcharhinus limbatus* based on natural, fishing and total mortality rates. Variance estimates are listed in brackets.

	1999	2000	2001	Pooled data
Natural mortality	0.70 (0.032)	0.32 (0.049)	0.44 (0.011)	0.52 (0.010)
Fishing mortality	0.60 (0.048)	0.41 (0.047)	0.42 (0.012)	0.51 (0.010)
Total mortality	0.91 (0.004)	0.61 (0.031)	0.66 (0.006)	0.75 (0.003)

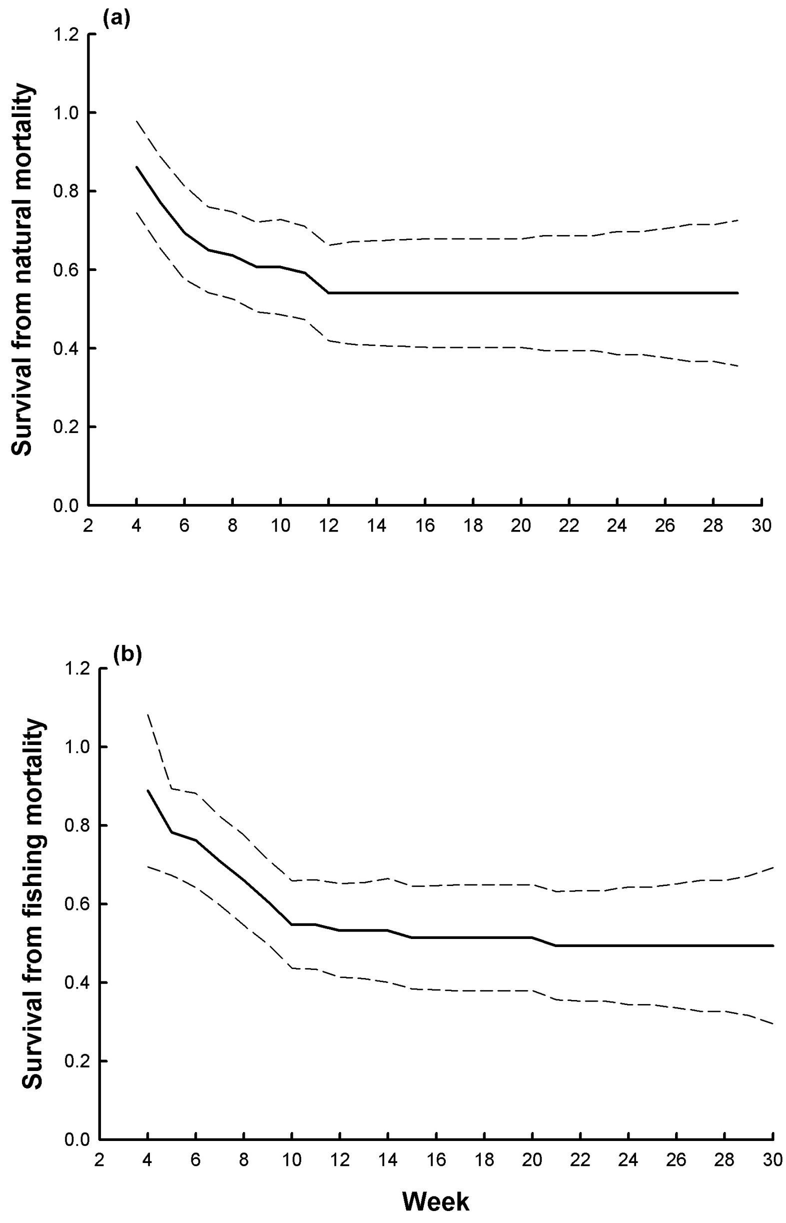

Fig. 1. Kaplan-Meier estimates of survival from (a) natural mortality and (b) fishing mortality for juvenile *C. limbatus* combined from all three years. Dashed lines indicate 95% confidence intervals. Graphs use the second week of May as week 1.