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Factors affecting recapture rates of raggedtooth sharks *Carcharias taurus* tagged off the east coast of South Africa

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Understanding differences in the recapture rate between different tags (A-, B- and C-types), capture methods (rock-and-surf anglers, scientific divers and Natal Sharks Board protection nets) and life-history stages (juvenile and adult) is critical in evaluating the results obtained from cooperative tagging programmes (CTPs). A generalised linear modelling approach, using a log-linear model, was used to determine significant differences in the probability of recapture between these various factors using data from the Oceanographic Research Institute and Port Elizabeth Museum CTPs. Between 1984 and 2004, a total of 3 385 raggedtooth sharks *Carcharias taurus* was tagged by volunteers from both programmes along the east coast of South Africa. A likelihood ratio test indicated significant differences in the probability of recapture between A- and C-type and B- and C-type tags ($p < 0.01$), between different capture methods ($p < 0.05$) and between juvenile and adult sharks ($p < 0.01$). A comparison of recapture rates between members of the CTPs also indicated a marked variability in the performance of individual taggers. The study highlights important data-quality issues inherent in large CTPs.

Keywords: *Carcharias taurus*, cooperative tagging programme, life-history stage, log-linear model, tagging method, tag type

Introduction

Cooperative tagging programmes (CTPs) rely on the joint participation of volunteer anglers and scientists (Scott et al. 1990, van der Elst 1990, Pepperell 1990, Kohler et al. 1998). They are often the only practical and cost-effective method for studying fish populations that make extensive migrations, cover large geographic regions or are 'rare-event species' (Oritz et al. 2003, Kohler and Turner 2001). Although CTPs provide valuable life-history and population dynamics information for management, there are also a number of inherent disadvantages (van der Elst 1990, Kohler and Turner 2001). Volunteer taggers sometimes fail to correctly identify species and report all the requested information (van der Elst 1990). Tag recaptures are often not reported (Fable 1990, van der Elst 1990, Dicken et al. 2006a) and there is often a marked variability in tagger performance (Hearn et al. 1987, van der Elst 1990), which can lead to high tag-shedding rates (Dicken et al. 2006a). These sources of bias could limit the validity of any inferences drawn from a study, such as movement patterns and abundance estimates (Stevens et al. 2000, Kohler and Turner 2001).

The first dedicated tagging programme of elasmobranchs in South Africa was initiated in 1964 by the Oceanographic Research Institute (ORI), to help devise protective measures against shark attack off the KwaZulu-Natal coast (Davies and Joubert 1966). In 1984, ORI initiated a CTP that was reliant on the joint participation of scientists and volunteer recreational anglers. This programme was designed to provide a logistically feasible means to obtain basic life-history and population dynamics information on a variety of teleosts and elasmobranchs (van der Elst 1990). The programme gained huge support, and by 2003 it had a membership of 4 126 anglers (Bullen et al. 2004). In 1994, the Port Elizabeth Museum (PEM) initiated a considerably smaller CTP, consisting of between 10 and 20 volunteer anglers. This programme focused primarily on the movement patterns of sharks off the east and west coasts of South Africa.

The raggedtooth shark *Carcharias taurus* is a common inshore species, regularly tagged by members of both tagging programmes. By 2005, a total of 3 385 *C. taurus* had been tagged (Dicken et al. 2007). Tag recaptures have provided important information on the segregation, and movement patterns of the juvenile (<1.8 m total length [TL]) and adult (>1.8 m TL) components of the population (Dicken et al. 2007), as well as data on tag-shedding and non-reporting rates (Dicken et al. 2006a). This information was used to develop a mark-recapture model to estimate the abundance of raggedtooth sharks in South Africa (Dicken et al. 2008). There are, however, a number of problems

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inherent to these tagging programmes that could limit the validity of the inferences drawn from the abovementioned studies. First, there is the problem concerning the non-standardisation of tag use. Volunteers tagged juvenile and adult *C. taurus* using a variety of different tags (A-, B- and C-type). Second, sharks are tagged using a variety of different capture methods; some are tagged underwater by scientific divers and others on land by rock-and-surf anglers (hereafter referred to as divers and anglers respectively), whereas some are tagged during capture in the bather-protection nets of the Natal Sharks Board (NSB). Third, there is high variability between the performances of different individual taggers.

This paper presents a log-linear generalised linear model to compare the recapture rate between the different tag types and capture methods used to tag *C. taurus* within the ORI and PEM tagging programmes. It also investigates differences in the probability of recapture between juvenile and adult sharks. Variability in the performance of individual taggers was also explored using a simple comparison in the recapture rates of sharks tagged by members of the CTPs. The aim of this study, using the South African CTP as an example, is to examine some possible data inconsistencies inherent to other CTPs elsewhere.

Material and methods

General methods

Sharks were tagged and released along the east coast of South Africa (Dicken et al. 2007). For the purposes of this study, the South African coastline was subdivided into 21 coastal areas, each 100 km long (Figure 1). This scale of division was considered sufficient to identify the major trends and patterns in the geographical variation of different tag types and capture methods used to tag *C. taurus*. A summary of the environmental characteristics and processes operating along the east coast of South Africa is provided in Dicken et al. (2006b).

Three different tags (A-, B- and C-type) were used by members of the CTPs. The A- and B-type are Hallprint-manufactured dart tags, comprised of a monofilament vinyl streamer attached to either a plastic barb (A-type) or stainless steel pointed head (B-type). All pertinent tag information, including the tag number, return address and telephone number (PEM only) of the tagging programme, were printed on the streamer. The C-type (locally manufactured) is a plastic disc tag, similar in design to the Jumbo Rototag. However, the issue of this tag to anglers was curtailed in 2001 due to excessive biofouling of the disc and its damage to the fins of tagged sharks (Bullen and Mann 2004).

Anglers used all three types of tags, whereas NSB net operators and divers used B-type tags only. Divers tagged sharks underwater using a Hawaiian sling, a device that consists of a spear shaft, to which the tag is attached, and a length of rubber tubing. When the rubber tubing is pulled back and released, the shaft is rapidly propelled forward and the tag is inserted into the shark. Anglers and the NSB net operators applied A- and B-type tags with a stainless steel tagging needle, which was used to drive the pointed head of the tag into the dorsal musculature at the base of the first dorsal fin. C-type tags were applied by means of an applicator, through a hole towards the base of the first dorsal fin created by a leather punch. The tag consists of two plastic discs (a male and female component) that are placed on either side of the hole, and then clipped together. All tag information is printed on the outside of the disc. It is important to note that due to the segregation of the *C. taurus* population by size, only adult sharks were caught in the bather-protection nets of the NSB (coastal areas 3–6) and those tagged underwater by divers (coastal areas 1, 2 and 5) (Figure 1).

Generalised linear modelling framework

The tag recapture rate (p_t) for year t can be determined from the number of sharks recaptured during year t, m_t, and the cumulative number of sharks tagged up to and including sampling year t that are available for recapture (M_t), such that $p_t = m_t/M_t$. The expected number of recaptured sharks in year t, given the total number of marked sharks available for recapture in year t, is provided by Seber (1982) as:

$$E\left[m_t \mid M_t\right] = p_t M_t \tag{1}$$

If the number of recaptured sharks is assumed to be Poisson-distributed and recapture rate is temporally independent and simply a function of the cumulative number of tagged sharks, the recapture rate can be estimated using a generalised linear model (GLM) with a Poisson error term and a log-link function of the form

$$\ln\left(\frac{E\left[m_t\right]}{M_t}\right) = p, \text{ and expressed as } \ln(E[m_t]) = \ln M_t + p. \tag{2}$$

If there is more than one explanatory variable (e.g. different tag types, life-history stages or capture methods), then $\ln(E[m_{ti}]) = \ln M_t + p_i$, where i is the explanatory variable index. Maximum likelihood estimates of p_i are obtained by non-linear minimisation of a negated Poisson log-likelihood function (without constants) of the form:

$$-\ln L(\underline{p} \mid \underline{m}, \underline{M}) = -\sum_t \sum_i \left(-E\left[m_{ti}\right] + m_{ti} \ln(E\left[m_{ti}\right])\right) \tag{3}$$

Hypothesis testing and model implementation

Three null hypotheses were chosen to test for differences on tag type, capture methods and life-history stage. Because not all tag types are used by all capture methods and not all life-history stages are sampled using the different capture methods (Table 1), the data needed to be summarised and three different models implemented. These are described as follows:

$$\ln\left(E\left[m^{\text{adults+juveniles}}_{t,\text{tag type}}\right]\right) = \ln M^{\text{adults+juveniles}}_{t,\text{tag type}} + p^{\text{adults+juveniles}}_{\text{tag type}}$$

$$\ln\left(E\left[m^{\text{B-tagged adults}}_{t,\text{capture method}}\right]\right) = \ln M^{\text{B-tagged adults}}_{t,\text{capture method}} + p^{\text{B-tagged adults}}_{\text{capture method}}$$

$$\ln\left(E\left[m^{\text{angling}}_{t,\text{life-history stage}}\right]\right) = \ln M^{\text{angling}}_{t,\text{life-history stage}} + p^{\text{angling}}_{\text{life-history stage}} \tag{4}$$

These three models tested the null hypotheses that there is no difference in recapture rates between (1) different tag types for all sharks (combined adults and juveniles) caught

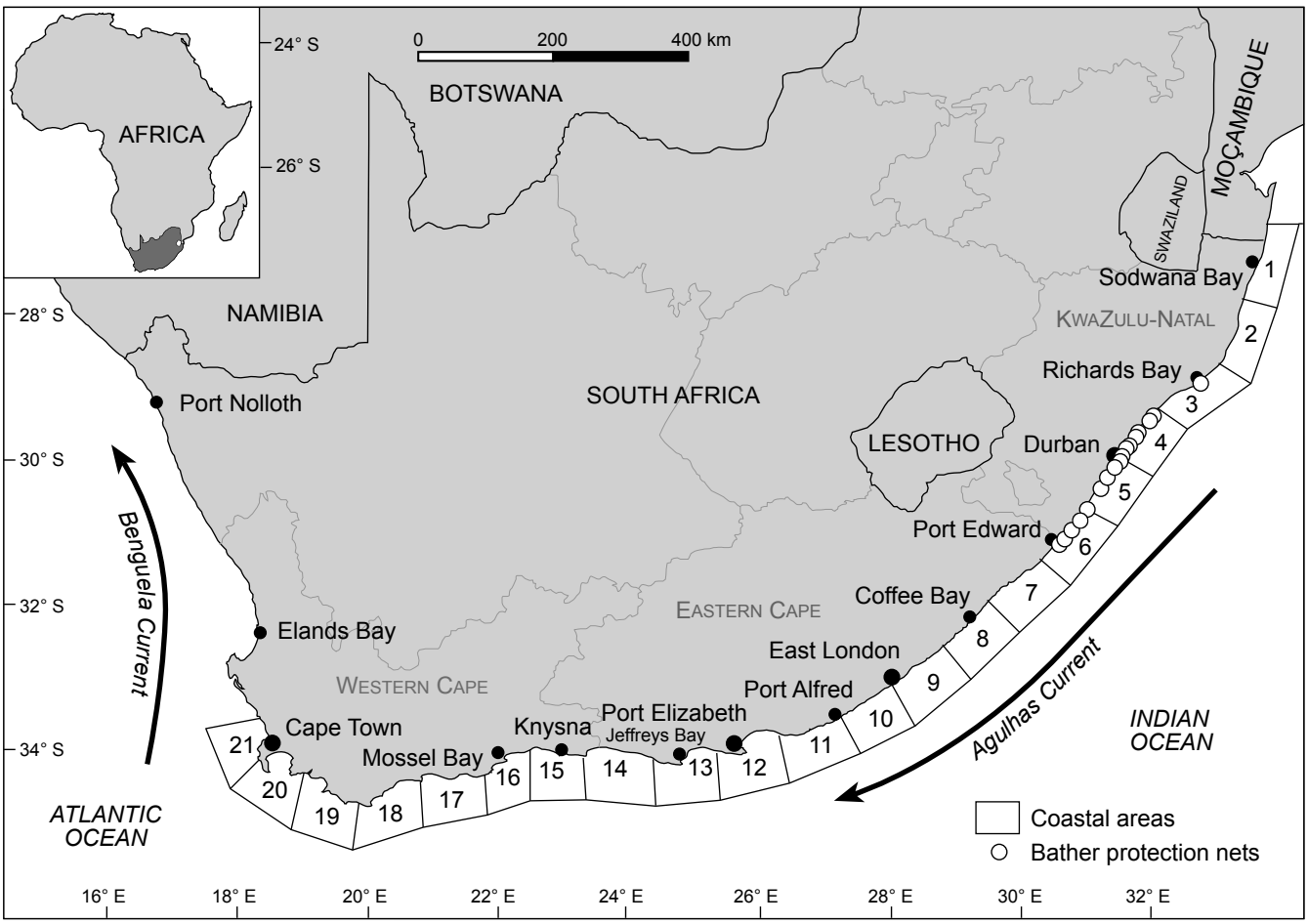

Figure 1: Map of South Africa showing the location of the 21 coastal areas (each 100 km long) used to indicate geographical variations in tag type and capture methods used to tag *C. taurus*

Table 1: Total number of recaptures and the cumulative number of raggedtooth sharks tagged from 1984 to 2004 in South Africa, by life-history stage (juvenile and adult), tag type (A, B and C) and capture method (scientific diving = SD, Natal Sharks Board nets = NSB and rock-and-surf angling = RS)

Life-history stage	Tag type	Capture method	Total recaptures (1984–2004)	Cumulative number tagged in 2004
Juvenile	A	SD	0	0
Juvenile	A	NSB	0	0
Juvenile	A	RS	14	90
Juvenile	B	SD	0	0
Juvenile	B	NSB	0	8
Juvenile	B	RS	78	600
Juvenile	C	SD	0	0
Juvenile	C	NSB	0	0
Juvenile	C	RS	25	332
Adult	A	SD	0	0
Adult	A	NSB	0	2
Adult	A	RS	6	108
Adult	B	SD	80	710
Adult	B	NSB	42	911
Adult	B	RS	26	259
Adult	C	SD	0	0
Adult	C	NSB	0	4
Adult	C	RS	13	340

by angling, (2) different capture methods for adult sharks tagged with B-type, and (3) adults and juveniles tagged with all tag types caught by anglers. The tagging datasets used in each of the log-linear models is summarised in Table 2.

A likelihood ratio test (Hilborn and Mangel 1997) was used to test each of the null hypotheses (and their pairwise differences) at a significance level of $\alpha = 0.05$.

It was assumed that all recaptured sharks were reported and that no marked sharks suffered post-release mortality.

Tagging variability

Variability in the performance of individual diver taggers was investigated by comparing the cumulative annual recapture rates of sharks tagged by members of the CTPs. Due to the influence of life-history characteristics, tag type and tagging location on recapture rates, comparisons were only made between taggers using B-type tags operating within the same geographical region (between areas 10 and 13; Figure 1).

Recapture rates were calculated using the method outlined in Oritz et al. (2003). If R_y represents the number of releases from an angler during year y, and $X_{y,i}$ is the number of recaptures of that angler's tagged sharks, in year y over the time period i, when $i \geq y$ and m is the first year of release, then the cumulative annual recapture rate (P_y) is calculated as:

$$P_y = \left(\frac{\sum_{i=m}^{y} X_{y,i}}{\sum_{i=m}^{y} R_y} \right) \times 100 \qquad (5)$$

Results

Tag type

Between 1984 and 2004, a total of 3 385 *C. taurus* were tagged and released by members of the CTPs. The annual number of sharks tagged varied from 16 in 1984 to 317 in 1990 (Figure 2), the most commonly used being B-type (n = 2 498), followed by C-type (n = 685) and A-type (n = 202). The increased use of A-type tags coincided with the discontinuation of C-type tags in 2001.

The number of recaptured B-type tags increased markedly from 2001 to 2004 (Figure 3), likely as a result of a greater focus on *C. taurus* tagging by the PEM during that period (Dicken et al. 2007). The number of other tag types recaptured remained relatively constant over the course of the study period. A likelihood ratio test indicated a significant difference in recapture rate between A- and C-type and between B- and C-type tags ($p < 0.01$; Table 1). This could be on account of A- and B-type tags having greater retention, or lower tag-induced mortality, than C-type tags.

Capture method

The majority of adult sharks were tagged with the B-type during capture in the NSB nets (n = 912) and by divers (n = 718), compared to anglers (n = 283). The number of sharks tagged annually using the different capture methods varied over the course of the study (Figure 4). The number of sharks tagged and released during capture in the NSB nets decreased in the last five years of the study, which coincided with a reduction in the number of nets, from 39 km in 1999 to 27 km in 2004 (Dudley and Simpfendorfer 2006). From 2001, the number of sharks tagged by anglers gradually increased as a result of the study by Dicken et al. (2007). Adult sharks were captured along the entire South African coast from areas 1 to 21 (Figure 1). The method of capture prior to tagging, however, varied geographically. Although anglers caught adult sharks in all areas, they were only tagged by divers in areas 1, 2 and 5 (90.1% of all taggings) and in the NSB nets from areas 3 to 6 (90.4% of all tagged sharks) (Figure 1).

The number of tagged sharks recaptured increased gradually over the course of the programme (Figure 5). There were significant differences in recapture rates between each of the three capture methods ($p < 0.05$) (Table 1). The results from the GLM should be viewed with caution due to the variability and paucity of input data. However, the data suggest that sharks tagged and released from the NSB nets may suffer a greater post-release mortality or tag-shedding rate than those tagged using other capture methods.

Life-history stages

From 1984 to 2004, a total of 1 032 juvenile and 2 344 adult *C. taurus* were tagged and released during the CTPs

Table 2: Generalised linear model dataset selections to compare the recapture rates for differing tag types, capture methods and life-history stages. Common superscripts within each hypothesis denote statistically similar recapture rates at $p > 0.05$

Null hypotheses	Datasets used	Factor	Recapture rate
1. Recapture rate is not affected by tag type (A, B and C)	Adult and juvenile sharks captured and tagged by anglers (common capture method)	A	0.018^a
		B	0.025^a
		C	0.005^b
2. Recapture rate is not affected by capture and tagging method (angler, diver, NSB)	Only adult sharks tagged with B-type (common tag type and life-history stage, because no juvenile sharks were caught in the NSB nets and only B-type tags were applied to sharks caught in the nets and by divers)	RS	0.016^a
		SD	0.009^b
		NSB	0.004^c
3. Recapture rate is not affected by life-history stage (juvenile and adult)	Adult and juvenile sharks captured and tagged by anglers (common capture method for all tag types)	Juvenile	0.029^a
		Adult	0.016^b

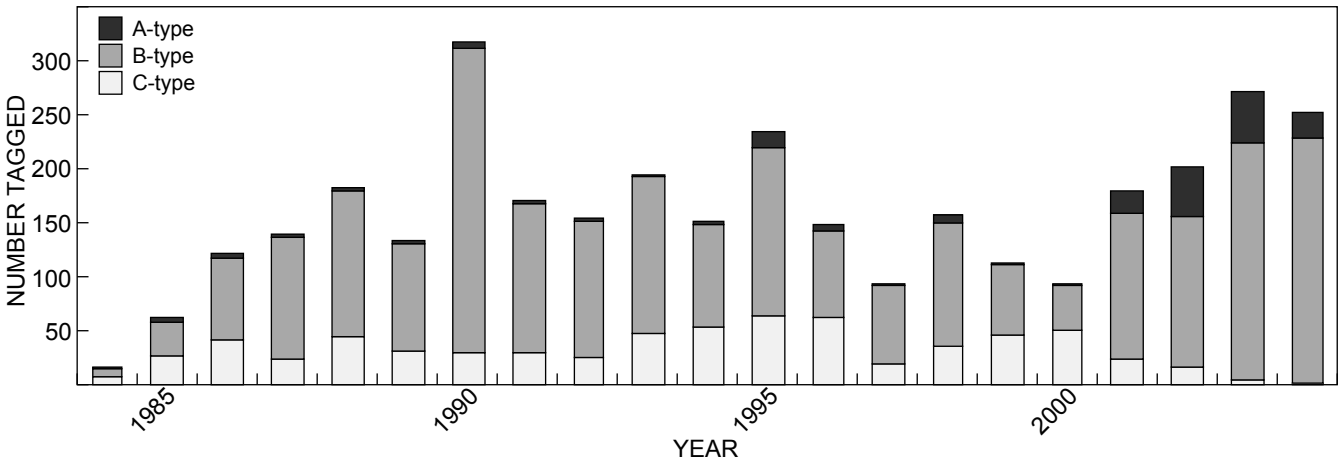

Figure 2: Total annual number of *C. taurus* tagged and released with A-, B-, or C-type tags in the ORI and PEM CTPs from 1984 to 2004

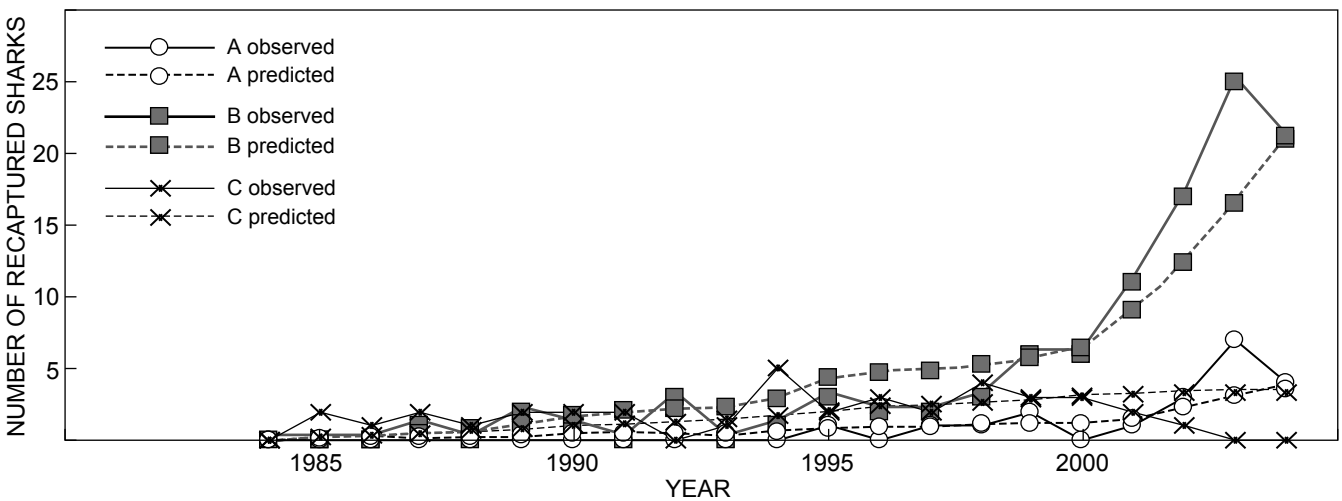

Figure 3: Observed and model-predicted number of A-, B- and C-type tag *C. taurus* recaptures, after capture and release by rock-and-surf anglers in the ORI and PEM CTPs from 1984 to 2004

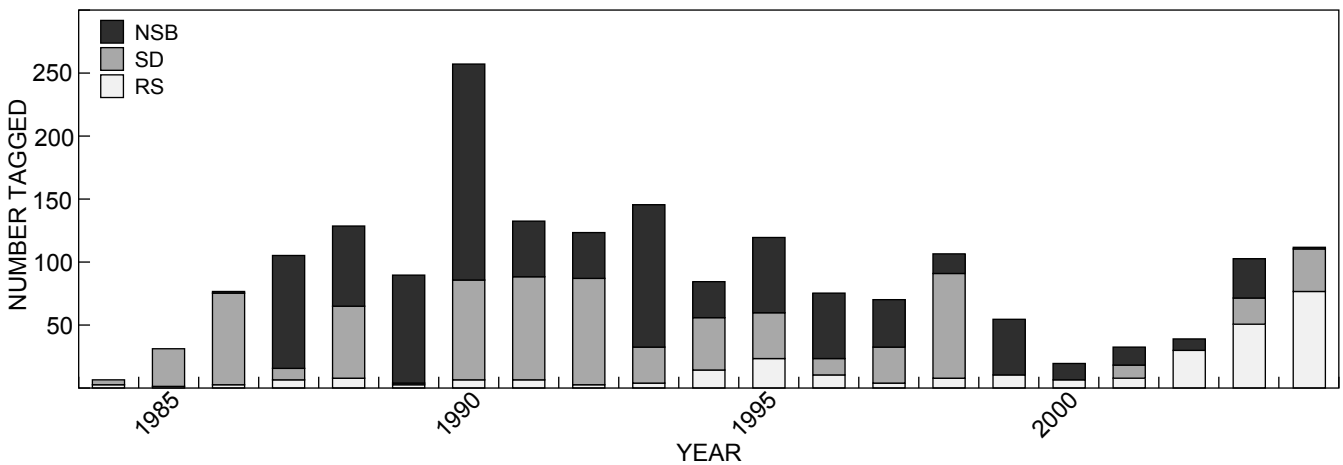

Figure 4: Total annual number of adult *C. taurus* tagged and released with B-type tags by the Natal Sharks Board (NSB), scientific divers (SD) and rock-and-surf anglers (RS) in the ORI and PEM CTPs from 1984 to 2004

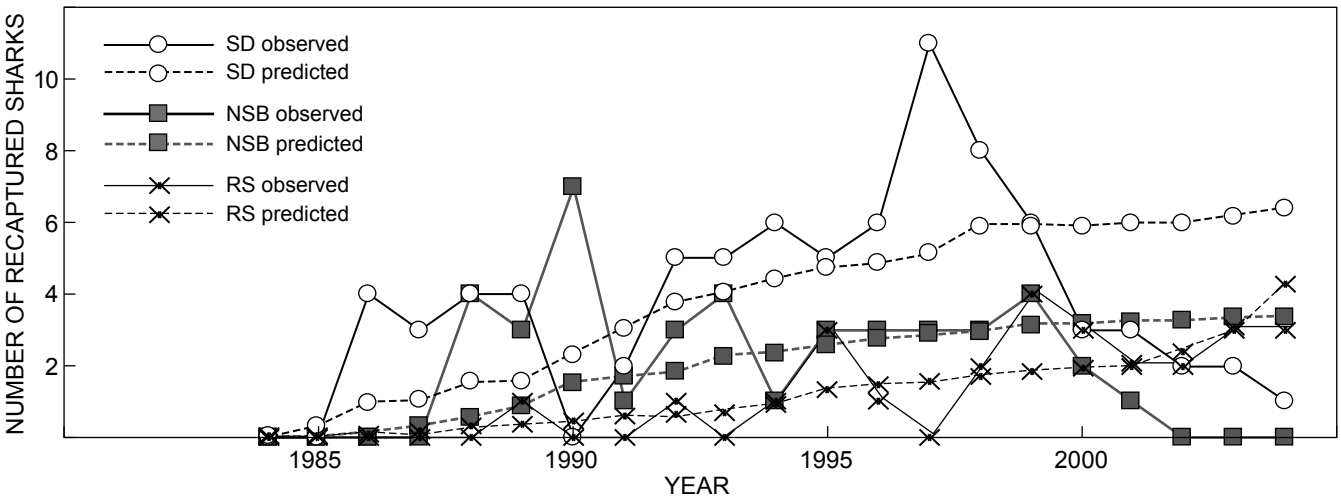

Figure 5: Observed and model-predicted number of adult *C. taurus* B-type tag recaptures after capture and release by the Natal Sharks Board (NSB), scientific divers (SD) and rock-and-surf anglers (RS) in the ORI and PEM CTPs from 1984 to 2004

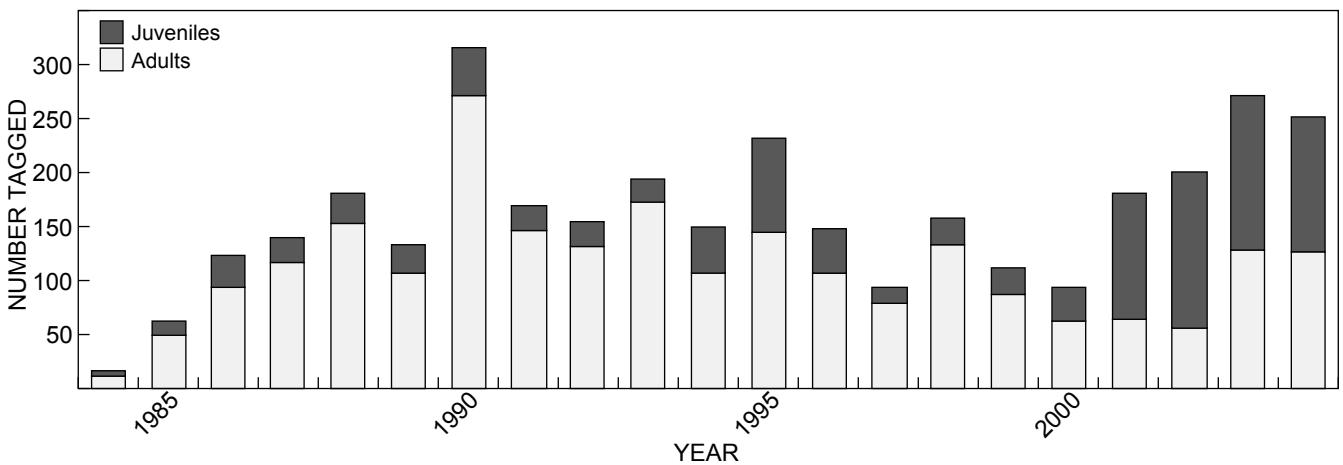

Figure 6: Total annual number of juvenile and adult *C. taurus* tagged and released by members of the ORI and PEM CTPs from 1984 to 2004

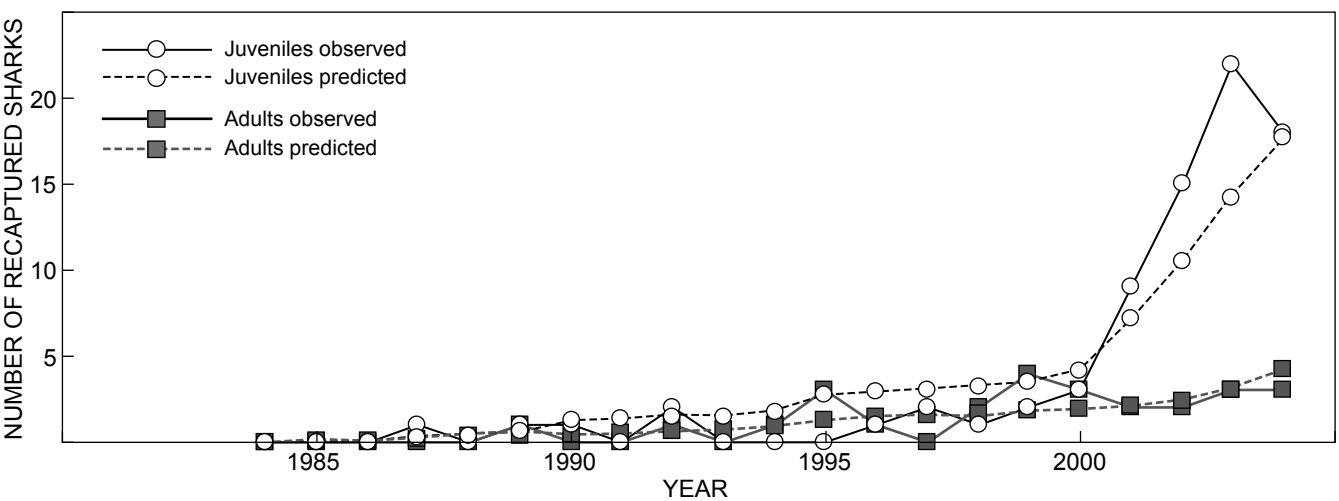

Figure 7: Observed and model-predicted number of juvenile and adult *C. taurus* recaptures, after capture and release by rock-and-surf anglers in the ORI and PEM CTPs from 1984 to 2004

(Figure 6). The number of recaptured juvenile sharks increased markedly from 2001 to 2004 (Figure 7). This is partially due to the increased number of juvenile sharks tagged in areas 10 and 13 during a distribution study on *C. taurus* over that period (Dicken et al. 2007). Juvenile sharks had a significantly higher ($p < 0.01$) recapture rate than adult sharks (Table 1).

Individual tagging variability

Tagging experience varied markedly between individual members of the CTPs; 277 (6.7%) of the 4 141 members had previous experience of tagging *C. taurus* and only 23 (0.6%) had tagged more than 10 sharks. Tag recapture rates were used to assess the performance of individual taggers. The recapture rate of sharks tagged by 18 different anglers (between areas 10 and 13) varied between 0% and 16.7%. There was not one recapture from a combined total of 207 sharks tagged by seven anglers.

Discussion

The probability of recapturing sharks tagged with A- and B-type tags was significantly higher than for those with C-type tags, suggesting that tag choice is an important variable influencing recapture rates. C-type tags (disc tags) are susceptible to entanglement and fouling in capture gear and vegetation (Olsen 1953, van der Elst 1990). Davies and Joubert (1966) estimated that 4% of dusky sharks *Carcharias obscurus* tagged with C-type tags lost their tags as a result of fouling in the bather protection nets of the NSB. Govender and Birnie (1997) reported a similar fouling rate for dusky sharks tagged with sheep-ear tags. Disc tags can also cause splitting and deterioration of the fin, especially in juvenile sharks (Kato and Carvallo 1967, Carrier 1985) with soft cartilaginous dorsal rays (Olsen 1953). For these reasons, the use of C-type tags was curtailed in 2001.

The three different capture methods (angler, diver and NSB) used to tag sharks had a significant impact on the probability of recapturing B-type tagged adult sharks. The probability of recapture was significantly lower for those sharks caught and tagged in the NSB nets compared to the other capture methods. A possible explanation is that many of the sharks that were tagged and released from the nets were physiologically stressed and suffered a greater post-release mortality than those captured by the other two methods. Increased mortality as a result of gear type has been reported for other shark species. Francis (1989) found that the recapture rate of trawl-caught rig *Mustelus lenticulatus* was less than those caught in setnets. Similarly, the recapture rate of various carcharhinid shark species caught in gillnets was one-half to two-thirds that of sharks that had been released after being handlined (Stevens et al. 2000).

The Hawaiian sling method used by divers is probably the least stressful of the three tagging methods. Underwater observations of the nurse shark *Ginglymostoma cirratum* (Pratt and Carrier 2001), the Pacific angel shark *Squatina californica* (Pittenger 1984) and raggedtooth sharks (MJS pers. obs.) tagged *in situ* have indicated that few of the sharks leave the tagging area and that there is minimal change in their behaviour after tagging. The Hawaiian sling, however, is imprecise and could potentially result in a high rate of tag loss. In contrast, the method used by the anglers, whereby the tags are carefully inserted, ensures a secure attachment. This is reflected in the higher probability of recaptures from angler-tagged sharks.

Juvenile sharks had a greater probability of recapture than adult sharks. This is perhaps not surprising as juvenile sharks typically remain for extended periods of time within a geographically distinct nursery area (Morrissey and Gruber 1993, Merson and Pratt 2001, Hueter et al. 2004), are less migratory and consequently are more prone to capture and recapture (Smale 2002). The site fidelity of raggedtooth sharks to summer nursery areas (Dicken et al. 2007) is another factor that increases their chance of capture.

This study highlights the inherent problem variability in individual tagger performance associated with CTPs. For example, on many occasions B-type instead of A-type tags were used on small (<25 kg) sharks. Incorrect tag application can cause tag loss and tag-induced mortality, resulting in reduced recapture rates (Begg et al. 1997, Kohler et al. 1998).

Tagging data is used extensively (between 50% and 80%) in fisheries management studies (Hilborn et al. 1990). Data from tagging programmes such as the one under study have been used to describe movement and distribution patterns of sharks (Francis 1988, Merson and Pratt 2001, Dicken et al. 2007). The marked variations in the performance of various tag types, tagging application methods and individual taggers identified in our study are perhaps not critical to the evaluation of such parameters. However, knowledge of the bias associated with tagging is important when estimating critical population parameters such as population size and exploitation rates, which are necessary for effective fisheries management.

CTPs provide an important communications bridge between scientists and resource users and inculcate a message of conservation. This study highlights some of the data problems that can result from the non-standardisation of tagging techniques. The development of better tags and increased outreach and educational activities should be adopted by such programmes to improve the quality and consistency of tagging data collected. Quantitative evaluation of the bias and errors inherent with these various inconsistencies could improve the interpretation of data obtained from CTPs worldwide. These factors should be carefully considered in the design and implementation of future CTPs, as well as in the management of existing CTPs, to improve the long-term quality and analysis of the tagging data collected.

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