

**USE OF SHARK SHAPES TO REDUCE INCIDENTAL CAPTURE OF SEA
TURTLES IN THE LONG-LINE FISHERIES**

A Thesis

by

ANGELA SUE BOSTWICK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2010

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee, André M. Landry, Jr.

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ABSTRACT

Use of Shark Shapes to Reduce Incidental Capture of Sea Turtles in the Long-Line Fisheries. (August 2010)

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Chair of Advisory Committee: Dr. André M. Landry, Jr.

An estimated 250,000 loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) sea turtles are taken each year as incidental catch by the pelagic long-line fishing industry. Various gear and bait modifications as well as time/area closures to fishing, enacted to reduce anthropogenic impacts on sea turtles, have been ineffective or incompatible with regional fishery interests. Chemosensory and auditory deterrents have yielded little benefit thus far in repelling sea turtles from long-lines. The fact that sea turtles are highly visual animals has precipitated studies of the efficacy of using shark shapes to repulse them from long-lines. Previous shark-shape studies yielded promising results, but their design lacked statistical rigor. The present study examined the response of 42 captive-reared loggerhead sea turtles (*Caretta caretta*) to a shark-shape model at the NOAA Sea Turtle Facility in Galveston, TX. To measure repulsive effect, time taken to consume squid bait beneath the shark model was compared to that for controls in which loggerheads were offered squid beneath a spherical object or a bare squid (i.e., no object control) in a captive setting. Additional responses compared among these three treatments were time spent near treatment,

number of breaths taken, approaches to the treatment, and avoidance behaviors displayed (e.g., turning carapace toward treatment).

Loggerheads exhibited anti-predator behavior toward the shark model, taking significantly more time to consume squid bait beneath the shark model than for the other two treatments. Turtles also spent significantly more time opposite the tank from the shark model, approached it less often, and exhibited more carapace turns to the model. Some avoidance of the spherical control object also was observed, but was not as pronounced as that displayed toward the shark model.

While a repulsive effect of the shark model was resolved during the aforementioned trials, application of such models to reducing long-line fishery bycatch would require further research to identify a plausible application; numerous shapes attached to long-line hooks would be very cumbersome. However, it may be plausible to develop a “boy’s day kite” shark model that would unfurl and “fly” underwater, and could possibly be clipped to buoy float lines.

DEDICATION

For my son, Pete

ACKNOWLEDGEMENTS

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INTRODUCTION

An estimated 250,000 sea turtles are caught incidentally every year by the pelagic long-line fishing industry worldwide; tens of thousands of these turtles consequently die (Lewison *et al.* 2004). Sea turtles in the pelagic realm often feed on prey near the surface (Parker *et al.* 2005, National Marine Fisheries Service and US Fish and Wildlife Service 2008), and occasionally dive to depths greater than 200 m. They are thus susceptible to ingesting pelagic long-line hooks or becoming entangled in the lines. Emerging research has shown that demersal long-lining is a threat to neritic juvenile and adult sea turtles as well (National Marine Fisheries Service and US Fish and Wildlife Service 2008). Population models suggest that sea turtles, which are long-lived and exhibit delayed maturity, cannot sustain elevated losses to the juvenile and adult age classes given their higher reproductive value, which is the number of offspring produced until death (Heppell *et al.* 2003, Lewison and Crowder 2007). Loggerhead (*Caretta caretta*) and leatherback sea turtles (*Dermochelys coriacea*) are species most frequently caught in the long-line fishery, although other species are captured on occasion (Gilman *et al.* 2006). In Latin America, incidental capture of large numbers of threatened olive ridleys (*Lepidochelys olivacea*) in the long-line fishery (Swimmer 2005) has resulted in a population decline (Frazier *et al.* 2007). Loggerheads are currently listed as threatened in U.S. waters (National Marine Fisheries Service and US Fish and Wildlife Service 2008), while leatherbacks are endangered (National Marine Fisheries Service 2007).

This thesis follows the style of Marine Fisheries Review.

Pacific populations of these two species have plummeted 80-95% in the last two decades and cannot survive if these losses continue (Lewison *et al.* 2004).

Turtle Bycatch – Life Stages Affected

Loggerhead hatchlings take up residency in the oceanic realm where they often associate with floating *Sargassum* within oceanic gyres and areas of down welling (Carr 1986). These young loggerheads remain in the pelagic realm an estimated 6.5-11.5 years, during which time they grow to 46-64 cm curved carapace length (CCL; Limpus and Limpus 2003). It is this juvenile pelagic stage of loggerheads that is most often caught in pelagic long-line fisheries. The average size of loggerheads caught in the swordfish long-line fishery in the Azores is 49.8 ± 6.2 cm CCL, which resembles the size classes caught in many other regions of the world (Bolten 2003). However, depending on variables such as the size and type of gear deployed, turtles as small as 19 cm CCL or as large as 118 cm CCL have been caught (Table 1; Wallace *et al.* 2008). In contrast, leatherbacks spend most of their lives in the oceanic environment, and are caught across a wide range of sizes (Watson *et al.* 2005).

Table 1. Average carapace length and size range (CCL) of loggerhead sea turtles caught in the pelagic long-line industry (adapted from Wallace 2008).

Ocean Basin	Area	Mean Size (CCL in cm) (\pm SD)	Size Range (CCL in cm)
N Atlantic	US Atlantic	75.2 (15.2)	39-118
N Atlantic	Azores	50.0 (7.4)	25-75
N Pacific	Hawaii	64.8 (9.9)	51-91
Mediterranean	Spain	54.4 (11.6)	20-80
Mediterranean	Italy	41.1 (10.3)	19-77

Turtle Bycatch – Methods of Reduction

The U.S. fishery accounts for 2% of the worldwide long-line landing effort (Lewison *et al.* 2004). To reduce sea turtle bycatch in U.S. waters, NOAA Fisheries Service mandated time and area closures beginning in 2001 and gear modifications, such as integration of circle hooks in the Atlantic pelagic long-lining industry, in 2004. Leatherback bycatch appears to have declined since these enactments, while loggerhead bycatch declined in 2005 and rose again in 2006. However, there are confounding factors, such as variable amounts of observer coverage in different study areas (Fairfield-Walsh and Garrison 2007), that detract from total confidence in these estimates. Watson *et al.* (2005) reported an 86-90% reduction in loggerhead bycatch after integration of circle hooks (when compared to that with standard J hooks) and a corresponding 57-65% reduction in leatherback capture.

Laboratory and field experiments designed to exploit biological differences between sea turtles and targeted pelagic fish have been conducted to develop a deterrent to sea turtle bycatch in long-line fisheries (Southwood *et al.* 2006). These studies explored chemoreception, hearing, vision and electroreception of sea turtles, with the goal of finding ways to repel turtles from long-lines without reducing the catch of targeted fish. The only repelling responses to date were elicited by placing a shark model in the vicinity of juvenile loggerheads (Hataway and Mitchell 2001, Higgins 2006) and a shark silhouette in the vicinity of green sea turtles (*Chelonia mydas*; Wang and Swimmer 2006, Wang *et al.* 2009).

Turtles are commonly preyed upon by tiger sharks (*Galeocerdo cuvier*) (Witzell 1987, Simpfendorfer *et al.* 2001), whereas, the great white shark (*Carcharodon carcharias*) may be the main predator of sea turtles in regions such as the Mediterranean Sea (Ferguson *et al.* 2000). Also, in some regions, initial recruitment of sea turtles to coastal waters may be associated with higher incidence of shark attack. Long-term studies in eastern Australia found that 24% of new loggerhead recruits in coastal foraging areas exhibited scars from a recent shark bite, whilst less than 1% of established residents exhibit scarring from a recent shark bites (Limpus and Limpus 2003).

Pilot studies conducted by the Sea Turtle and Pelagic Fish Sensory Biology Group investigated the efficacy of a shark shape or silhouette in repelling sea turtles (Swimmer and Brill 2006), given that sharks are the main predator of large juvenile and adult sea turtles (Marquez 1990). Turtles have been observed avoiding shark attacks by turning their carapace toward the predator (Hataway and Mitchell 2001, Heithaus *et al.* 2001, Higgins 2006). In preliminary studies using a shark model, captive loggerheads would stop and flee, turning their carapace sideways toward the shark when the predator came into view, even with squid bait beneath the shark (Hataway and Mitchell 2001, Higgins 2006). More studies are needed to characterize sea turtle response to a shark model and its potential use in reducing incidental bycatch in longlines and nets.

Preliminary field studies by Wang and Swimmer (2006) investigated the effectiveness of shark silhouettes placed on gill-nets in deterring green sea turtles from the nets. These researchers reported reduced turtle capture, but felt a larger sample size was needed to confirm the utility of shark shapes in deterring bycatch. An additional

study by Wang *et al.* (2009) determined that there was a significant reduction in the number of green sea turtles caught in the demersal gillnet fishery (59%) in the presence of black silhouettes of sharks. However, there was also a 55% reduction in the targeted species catch. Wang and Swimmer suggested that shark silhouettes may need to be something that turtles can see but that the fish cannot; if a shark is made of clear, UV-absorbent material then a turtle (which can see UV rays) would see it, but the target fish species would not (2006).

A study by Mott and Wyneken (2008) also suggested possible flight of turtles when exposed to shark silhouettes or elliptical shapes, but there were confounding factors that prevented a definite conclusion. Laboratory trials are an initial step in adequately assessing a sea turtle's innate response to a shark, given the difficulty of observing turtle reactions to a shark in the wild. Well-designed laboratory trials are one means of enabling turtle behavior(s) in the presence of a shark model to be filmed and, consequently, facilitating detailed analysis of constituent behavior(s).

Innate vs. Acquired Behavior

Predator avoidance is likely an innate behavior, as the absence of such behavior would be highly maladaptive in sea turtles. Captive-reared skinks exhibited avoidance behavior in response to the scent of a lizard-hunting snake; some of these lizards had never encountered the snake before and thus, this antipredator response must have been innate (Downes 2001). However, the skinks became habituated to the predator smell after a year, and ceased to avoid it. Environmental cues may elicit a behavior or further

development of a behavior (Alcock 2005); characteristics of an animal's particular habitat, such as number of predators present, have been found to play a highly important role in development of antipredator behavior (Brown 2003).

Research Objective

The objective of the study reported herein was to elicit and quantify any innate repelling response(s) of juvenile loggerhead sea turtles to a shark object, for purposes of evaluating its possible use as a sea turtle bycatch reduction method.

MATERIALS AND METHODS

In order to evaluate a shark model's potential for repelling sea turtles, time taken for a juvenile loggerhead to eat squid beneath a shark model was compared to that for controls in which 1) conspecifics had been offered squid beneath a spherical object or 2) a bare squid (i.e., no object control) in a captive setting. This study involved 42, 30-33 month-old (2005 year-class) captive-reared loggerheads held at the NOAA Sea Turtle Facility in Galveston, TX. These loggerheads averaged approximately 44 cm straight carapace length (38.2-48.4 cm SCL), a size similar to that of pelagic counterparts commonly taken as incidental by-catch in the long-line fishery.

Turtle Husbandry

Loggerheads in the NOAA Sea Turtle Facility were typically handled once every 28 days for weighing and measuring. They were rinsed with fresh water every morning for cleaning purposes, and were fed squid once weekly. Further details of the sea turtle daily husbandry routine at the NOAA Sea Turtle Facility can be found in Higgins (2003). Loggerheads scheduled for testing were fasted for 3 days beforehand to ensure they were receptive to the squid.

Experimental Tank

The experimental tank in which deterrent trials were conducted was 91.4 cm (3') wide, 73.7 cm (2'5") deep, and 406.4 cm (13'4") long, and contained a semicircular 71.7 cm (2'4")-long and 91.4 cm (3') wide acclimation chamber at one end (Figure 1). The

chamber was large enough to allow for free movement of the turtle, and prevented the turtle from viewing the treatment to which it would be subjected. The gate to the acclimation chamber was trackless to minimize noise upon raising, thus lessening distraction to the turtle. A pulley-brace assembly above the tank held the gate in place during the acclimation period. Additional weight added by three 2.7 kg (5 lb) dive weights provided further stability for the trackless gate.

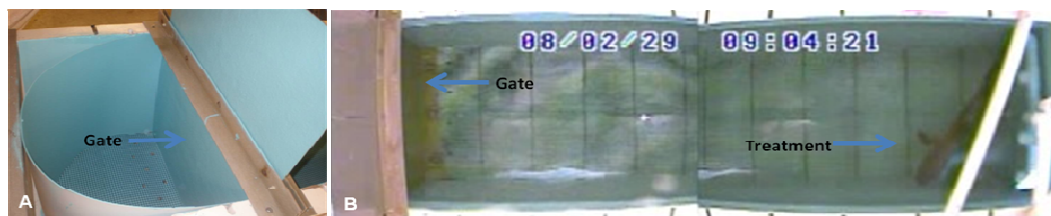


Figure 1. (A) The semicircular acclimation chamber. (B) The experimental tank, marked in 0.3 m (1-ft) increments for visual reference by the observer (viewed from above).

The tank's interior was painted light blue (Behr® “Cloudless”) to mimic the natural color of the pelagic environment. Each 30.5 cm (1 ft)-long section of the tank outside the acclimation chamber was marked by a black line (electrical tape) for visual aid to the observer in measuring turtle proximity to the treatments and quantifying associated behavior(s). A cotton canvas tent provided a shroud above the tank to render lighting conditions similar between trials, block UV penetration, and minimize outside distractions.

The tank was filled with filtered sea water from the Gulf of Mexico to a depth of 58.4 cm (1' 11'). Sea water was then be re-circulated into the tank by a Marinemate® ½

horsepower submersible pump at a rate of 302.8 L (80 gal) per minute. Water was drained into two sump drains beneath the acclimation chamber through twelve holes with a combined surface area of 60.8 cm² (9.4 in²) (Figure 2). Water temperature of the turtles' holding tanks, as well as the experimental tank, was taken before each trial. Water temperature was 26 to 30°C, preferably 28.5°C, which was the usual water temperature at the NOAA Sea Turtle Facility. Salinity typically averaged 30 ppt (Higgins 2003).

All trials were video recorded for subsequent analysis. Two video cameras above the tank recorded loggerhead behavior across the full length of the tank from the surface. Two tank-mounted cameras provided underwater perspectives of loggerhead behavior in response to each treatment - one filmed a treatment from the side while the other filmed a treatment as the turtle approached it after leaving the acclimation chamber. All four camera displays were viewed simultaneously on-screen during trials by means of a multiplexer unit. A digital clock on-screen was used to record the date and current time of day to the nearest second; this enabled exact timing of trials and calculation of time to eat squid beneath a treatment (Figure 2).

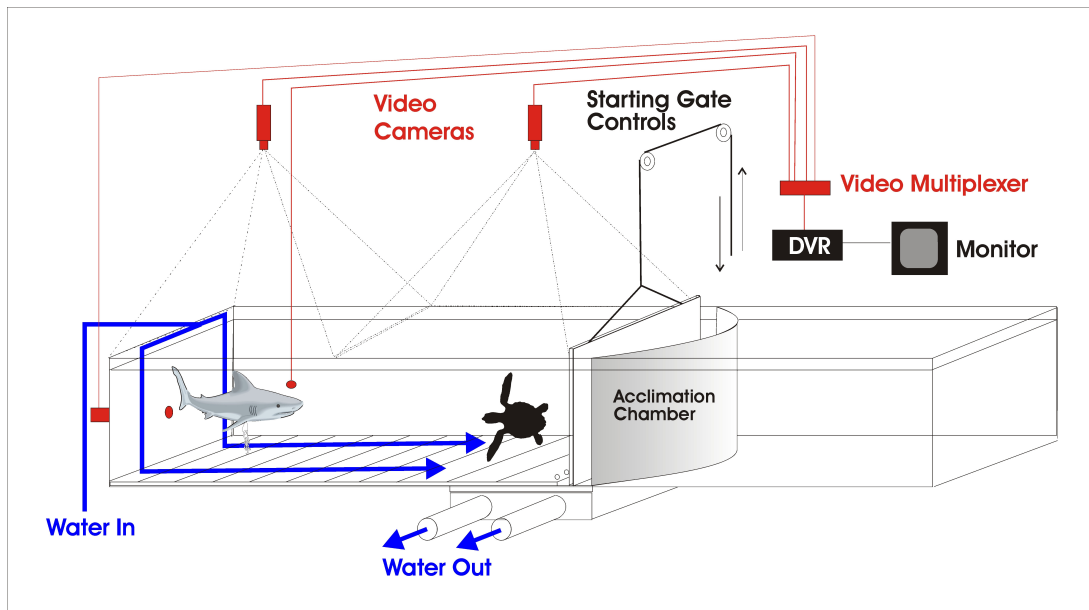


Figure 2. The experimental tank setup. Adapted from Higgins 2006.

Treatments

Three treatments were used in assessing juvenile loggerhead response to a predator: a shark shape with squid beneath, bare squid, and a sphere (control object) with squid beneath. The shark model was 91.4 cm (3') long, with a surface area of approximately 1,148.4 cm² (178 in²). It was molded from an actual black tip reef shark (*Carcharinus limbatus*) and painted black on the fin tips. It contained actual shark teeth, the counter-shading of a great white shark, and a blue metallic color resembling a shortfin mako shark (*Isurus oxyrinchus*) (Figure 3).



Figure 3. Shark model, exhibiting characteristics of three shark species.

The spherical control object was 27.9 cm (11”) in diameter and roughly equivalent in surface area ($1,225.8 \text{ cm}^2$ [190 in²]) to that of the shark model. It was spray-painted dark blue (Krylon Fusion for Plastic® “Patriotic Blue”) to contrast with the light blue tank.

The shark, sphere, and bare squid treatments were negatively buoyant, and hung from 5.1 cm (2”) PVC pipes on 13.6 kg (30 lb)-test clear-monofilament lines. The greater length of the shark required two clear lines to suspend it from the PVC pipe, while one line each was used for the sphere and bare squid. A modified clear plastic hairclip and clear monofilament line were used to hang squid beneath the shark and sphere.

For consistency, a squid was suspended from each treatment in approximately the same vertical position in the water column (15.2 cm or 6” from the bottom of the tank). An arbitrary “vertical limit” for position of the clip holding the squid was marked on the screens (25.4 cm or 10”); a trial in which the squid rose above the limit for more

than 40 seconds was eliminated from analysis (40 seconds was the median time taken to eat squid in trials with only squid).

Trial Protocol

Each turtle was exposed to all three treatments. Loggerheads were presented each of the three treatments in random order (bare squid, squid beneath sphere, and squid beneath shark) by randomly selecting numbers from out of a hat. Trials were conducted between 0800 and 1300, Monday, Tuesday, and Friday on five turtles per day; this allowed approximately 3 weeks between each turtle's individual trials to minimize possible learning effects. Turtles were placed in the semicircular acclimation chamber for a 15-minute acclimation period after the treatment was placed in the tank and water recirculation had been activated. Then the gate to the acclimation chamber was raised remotely by means of a line and pulley system. A 15-minute test period commenced from the time the turtle exited the acclimation chamber and reached the 0.9 m (3 ft) line. The turtle had to exit the start chamber within 10 minutes for the trial to be analyzed.

Data Analysis

Behavioral data compared among treatments included time spent on either side of the tank, number of approaches to treatment area [turtle needed to come within 0.6 m (2 ft) of treatment to be considered an approach], whether or not squid was eaten, time

taken to consume squid, number of breaths taken, and number of carapace turns (an abrupt turn of the carapace in response to being startled).

Linear regression with p-values computed from randomization tests was used to compare the aforementioned six behaviors among the three treatments; behavior = trial+day+treatment+prior, where day was nested within trial. Behaviors were randomized within each loggerhead in the analysis (to account for the dependency of observations taken on the same turtle). The variable “prior” was used to indicate whether a loggerhead had eaten the squid in a previous trial; prior was randomized within trial (“trial” is the first, second or third trial). An adjusted critical p value (.0098) was computed as described in Manly (2007) to account for there being six behaviors in the model.

RESULTS

Ten of 42 loggerheads failed to exit the acclimation chamber in the first trial, while 3 others did not in the second and third trials. Treatment (shark, sphere, or bare squid) did not significantly affect whether loggerheads exited the acclimation chamber ($p=0.442$); trials in which turtles failed to exit the chamber were thus excluded from analysis. In addition, strong currents in the tank and kinking in the monofilament line resulted in four of the bare squid treatments drifting above the vertical limit of 10 cm for more than 40 seconds; thus, they also were eliminated from analysis. The remaining 104 trials were analyzed. Outliers were not excluded from analysis. An adjusted critical value of 0.0098 was used for the regression analysis of all 6 behaviors, in accordance with advice of Manly (2007), with these behaviors being time taken to consume squid, whether or not squid was eaten, breaths taken, approaches, time spent near treatment, and number of carapace turns.

The percentage of time a loggerhead spent (time spent on left half of tank/total time) in the first 1.5 m of the tank (opposite the treatment, which was about 3 m from the acclimation chamber) was significantly different between treatments ($p=0.0043$) (Figure 3). Turtles spent 58% of their time on the opposite side of the tank from the shark, while 52% of their time was spent away from the sphere, and only 46% was spent away from the bare squid area (Figure 4). Also, the number of approaches to the treatment area (as defined by a turtle coming to within at least 0.6 m of the treatment) differed significantly among treatments ($p=0.0001$). Loggerheads approached the shark an average of 9.66

times, while approaching the sphere 12.97 times, and the bare squid area 15.79 times (Figure 5).

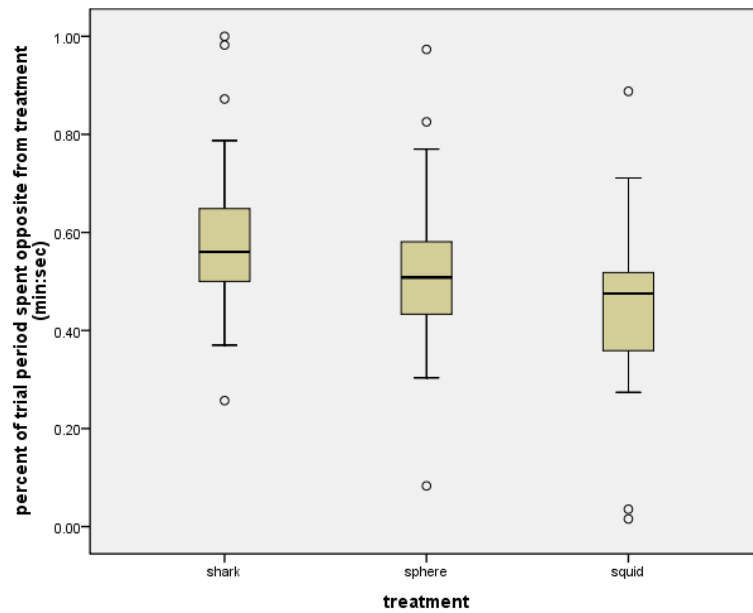


Figure 4. Percentage of time loggerheads spent on the opposite side of the tank from the treatment.

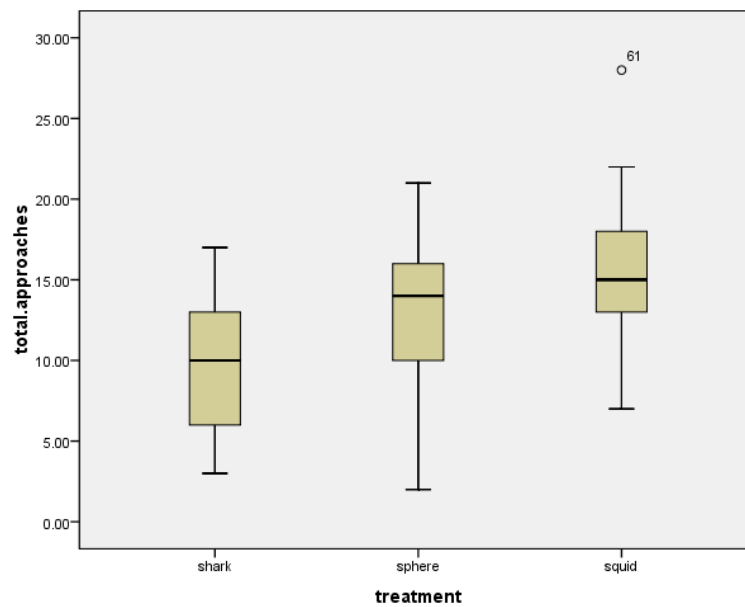


Figure 5. Number of approaches by loggerheads to respective treatments.

Whether loggerheads ultimately ate the squid within the 15 minute trial period was not found to be influenced by the treatment ($p=0.0640$). However, linear regression detected a difference in time taken to eat squid among treatments ($p=0.0046$). When averaged amongst all three trials, turtles took 4:58 min:sec to eat the squid beneath the shark. Contrastingly, turtles took 2:20 min:sec to consume squid beneath the sphere, and 2:12 min:sec to consume bare squid (Figure 6). Whether or not a loggerhead consumed the squid in a previous trial (“prior”) did not have a statistically significant effect on time to eat squid ($p=0.0107$).

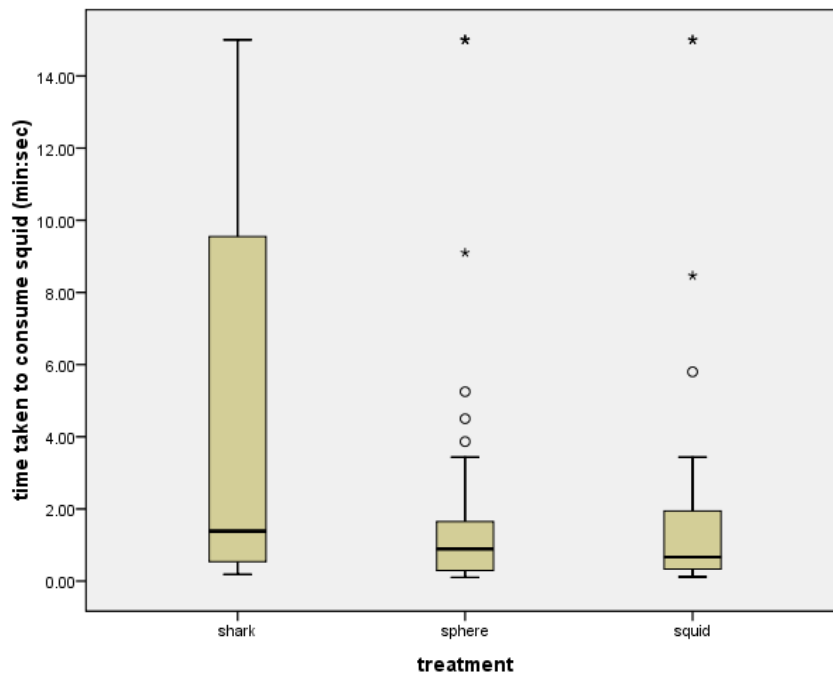


Figure 6. Average time taken for loggerheads to consume squid across treatments.

Loggerheads averaged fewer breaths in the presence of the shark shape, but the difference was not statistically significant ($p=0.0508$). Turtles averaged 5.8 breaths during trials with the shark, 7.5 with the sphere, and 7.4 with the bare squid (Figure 7).

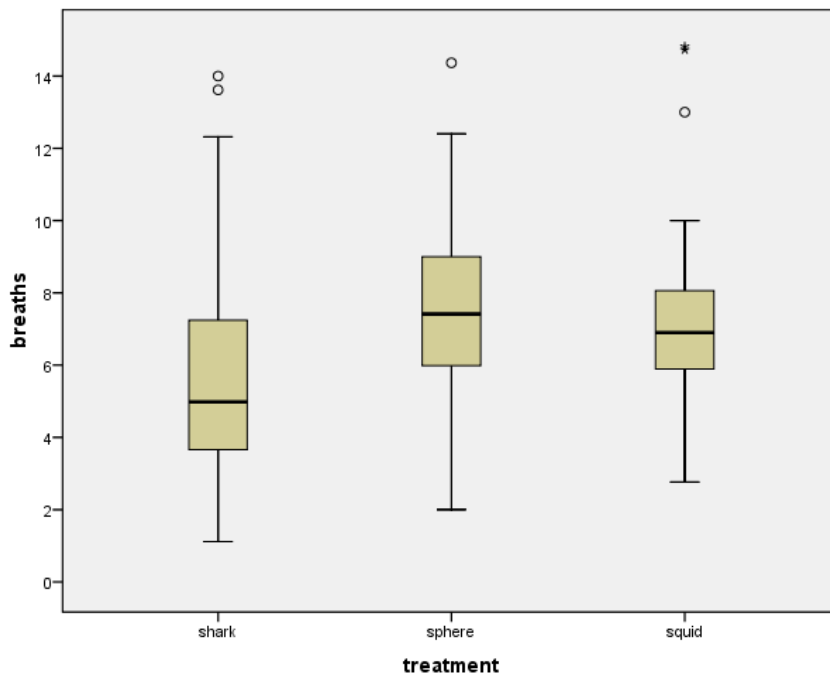


Figure 7. Number of breaths taken by loggerheads during exposure to respective treatments.

Regression analysis detected differences in the number of carapace turns displayed by loggerheads among the treatments ($p=.0013$) (Figure 8). On average, turtles displayed 1.29 carapace turns in the presence of the shark, compared to 0.35 with the sphere and 0.42 with the bare squid.

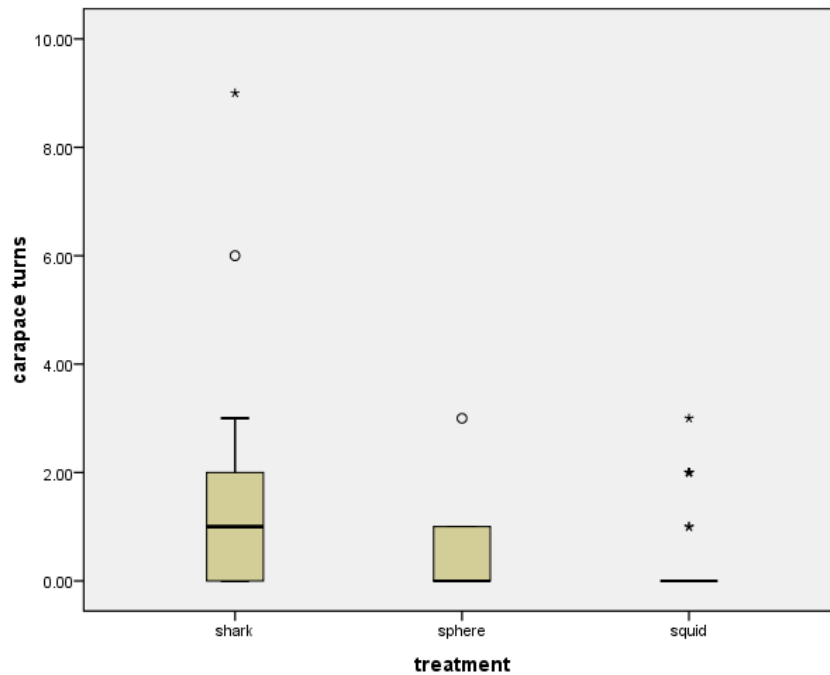


Figure 8. Number of carapace turns displayed by loggerheads in the presence of respective treatments.

Loggerheads were generally less active when exposed to the shark model. Many swam less, crawling slowly along the bottom in the presence of the shark. Some turtles exhibited the same behavior toward the spherical control object, although not as markedly so. Some turtles also would put their head to the wall of the tank, crawling side-first along the side of the tank toward the shark in a type of sideways crabwalk; this crabwalk was not observed with the spherical control object or bare squid. Loggerheads would walk within 0.3 m of the shark and then walk back toward the acclimation chamber, at a slightly faster pace than that of the approach. Many ultimately did approach the shark and eat the squid, after which they swam back and forth more freely in the water column, sometimes stopping to bite the shark fins, eyes, teeth, etc.

Similarly, some turtles were at first cautious to approach the sphere; however, after eating the squid they would then attack the sphere and swim about more freely.

Interesting Behaviors

Some loggerheads in this study used their foreflippers to assist in getting the squid off the hairclip. In addition, loggerheads in this study exhibited buccal oscillations; they would open and close their mouths continuously, seeming to push water over chemosensory organs with their throat. One loggerhead exhibited this behavior while sitting in a transfer basket out of water.

CONCLUSIONS

Loggerheads decreased their activity and became more demersal in the presence of the shark shape, exhibiting fewer approaches to the shark, and spending less time near the shark. Bottom-seeking behavior in the presence of sharks has also been observed with turtles in the wild. A green sea turtle in Moreton Bay, Australia was observed suddenly spiraling down to the sea floor, then remaining still for 3 minutes. During this time it was circled several times by large bull sharks (*Carcharhinus leucas*), which did not ultimately attack the turtle (Arthur 2008). Sideways crabwalking toward the shark may be a way of viewing the predator shape more clearly, for an animal with eyes on the side of its head, as well as a defensive posture.

A study on captive-reared skinks found that the lizards moved about and foraged more often in the absence of a predator scent, growing more rapidly than those in enclosures treated with predator scent (Downes 2001). Alcock (2004) stated, “If foraging exposes an animal to the risk of sudden death, then when that risk is high, we would expect foragers to sacrifice short-term caloric gain for long-term survival.” Indeed, turtles in the present study took significantly more time to consume the squid beneath the shark shape (4:58 on average), and some did not eat the squid at all, while they averaged 2:20 min:sec to consume squid beneath the sphere, and 2:12 min:sec to consume bare squid. Loggerheads had adequate motivation to locate squid, as they were fasted for 3 days prior to trials. However, many would initially approach no closer than 1 m (3 feet) to the shark and then retreat back toward the acclimation chamber. Their

initial avoidance of the spherical control object tended to be not as pronounced as that toward the shark model.

The the greater number of carapace turns in the presence of the shark indicates loggerheads were alarmed by the predator shape. Turning the carapace toward a shark model was also documented in exploratory trials by Higgins (2006) and Hataway and Mitchell (2001). Positioning the carapace toward a perceived threat, such as a shark, may be a means of preventing a pursuing predator's bite to more vulnerable areas of the turtle's body.

It is possible that turtles in the wild would exhibit stronger reactions to shark models as fear of sharks would be continually reinforced. Hataway and Mitchell (2001) speculated that pinfish (*Lagodon rhomboides*) avoiding a shark model provided a cue that strengthened turtle avoidance of the model; shark interactions with other animals may provide further cues to strengthen turtle avoidance of predator shapes. However, it is also possible turtles may acclimate to a shark model as well. Whether turtles in the wild would return after the first flight from the shark model is unknown. Test subjects for this study were confined in the tank with the shark. Some returned to re-inspect the shark when they reached the wall of the acclimation chamber and could not retreat further. Rather than remain at the opposite end of the tank from the shark, turtles would sometimes recommence exploratory behavior and approach the shark again. However, in the wild there would typically be plenty of space for a turtle to retreat, and no such obstacle to confine the turtle in the area with the shark shape.

Downes (2001) found that captive-reared skinks exhibited innate anti-predator behavior to the scent of a lizard-hunting snake. For that study, open, sun-lit areas were swabbed with the scent of the predatory snake. Although these areas were optimal for lizard basking and foraging, the animals avoided them when the scent of the snake was present. After a year, the lizards had ceased to avoid the smell. In discussing his study, Alcock (2004) states that the “risk assessed by lizards may have decreased over time in the absence of physical stimuli to reinforce the chemical cues.” Downes (2001) discussed instances in which reptiles have learned avoidance of a predator but she was not familiar with any other examples of such non-avoidance learning.

Decreased time to eat squid in successive trials was not quite statistically significant. Each of an individual turtle’s three trials was 3 weeks apart to minimize possible effects of learning. However, Angermeier and Hidalgo (1996) found that green sea turtles learned from their operantly-conditioned rewarded response, and retained memories for a long time. Another study found green turtles had retained memories of a operantly-conditioned response for at least a year (Manton 1972). However, operant conditioning may elicit more permanent learning than innate behavior trials, such as the present study.

Interesting Behaviors

Loggerheads have previously been observed using their flippers for manipulating food, using “pseudoclaws” on their forelimbs to tear food apart (Bels 2008). In addition, Manton (1972) described buccal oscillations such as those observed in the present study

as “throat pumping.” Walker (1952) observed that turtles use throat pumping only while active. Hochscheid (2005) confirmed that throat pumping ceases when a turtle is at rest on the bottom with eyes closed, and Houghton *et al.* (2008) used these “buccal oscillations” (also called gular pumping) as an indicator for a turtle’s state of consciousness. Such movements have been shown to be for olfactory purposes in other species (Walker 1952). It is possible that this behavior is for chemosensory purposes. The turtle from the present study that was seen throat pumping while out-of-water may have also been doing so for chemosensation.

Application to Fisheries Bycatch

While loggerheads in this study avoided the shark model, it may not be practical to place shark models on every long-line hook. The extra drag on the line incurred from numerous shark models would be very cumbersome. Further behavioral studies may be warranted to isolate repelling characteristics of the shark form, for incorporation into the long-line fishery. However, a study by Constantino and Salmon (2003) found that leatherback turtles attacked opaque objects such as circles, diamonds, and squares as food.

It might be plausible to clip a “boy’s day kite” shark shape on the buoy float lines, which would unfurl and “fly” underwater. Research regarding this possible application of a shark shape to fisheries bycatch reduction of sea turtles may be warranted.

Studies have shown that visual and chemical deterrents in combination are more effective for sea bird bycatch reduction than either alone (Southwood 2006). It is possible that a chemosensory repellent in combination with a visual one may be most effective for sea turtles as well. However, no effective olfactory repellent has been found to date for sea turtles (Lewison 2007).

The preliminary field experiments placing shark models on gillnets yielded promising results (Wang and Swimmer 2006), while further trials in 2009 found a significant reduction in number of green sea turtles captured. However, the targeted species capture was also greatly reduced (Wang *et al.* 2009). Further trials with a shark silhouette or shape could possibly use a clear, UV-absorbent material to present something that sea turtles, but not target fish species, can see (Wang and Swimmer 2006).

Gill net fisheries may possibly capture a greater number of turtles than do longline fisheries. In addition, the mortality for turtles captured in gill nets may be higher than that in the long-line fishery. However, further research is needed to fully understand these fisheries' impacts on sea turtles (Lewison and Crowder 2007).

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