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OPINION

HOOKS AND SEA TURTLES: A VETERINARIAN'S PERSPECTIVE

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ABSTRACT

Six out of seven species of marine turtles are endangered, with longline bycatch considered one of the main causes for the decrease of their populations. Recently, the use of large circle hooks has been shown to reduce the impact of longline fishing on sea turtles, both decreasing the number of sea turtles captured, and shifting the number of hookings to the mouth, as opposed to other anatomical locations. However, little is known about the true post-release mortality of captured turtles in relation to hook location and associated lesions, essential information to adequately determine gear impacts. Here I discuss, from a veterinarian's point of view, the lesions caused by hooks in different locations in captured sea turtles, and their possible effects, combining information gathered from personal experience, long-term studies on captive sea turtles, post-mortem analysis of stranded sea turtles, and results of satellite tagging studies. Although hooks in the mouth are generally considered low risk, there are sensitive structures in this area, such as the glottis or the jaw joint, which should be carefully considered. On the other hand, the esophagus has a strong muscular wall and is somewhat resistant to lesions, unless the hook lodges close to the heart or large blood vessels. Lines left trailing are by far the most dangerous part of the gear, and have very high chance of causing mortality. Adequate training of fishermen by experienced researchers is essential to reduce sea turtle mortality, and more research is urgently needed to confirm the effectiveness of circle hooks.

Six out of the seven existing species of marine turtles in the world are considered endangered or critically endangered (IUCN 2011). Although the decrease in sea turtle populations has been attributed to several causes (direct turtle and egg harvest, coastal development, nesting habitat destruction), the incidental capture of sea turtles by different types of fisheries is one of the main conservation issues for these species (Hall et al. 2000, Spotila et al. 2000, Lewison and Crowder 2007, Alessandro and Antonello 2010). Of the fishing gears involved, longline bycatch and related mortality seem to be one of the most important conservation problems, mainly for *Caretta caretta* (Linnaeus, 1758) and *Dermochelys coriacea* (Vandelli, 1761) (Camiñas et al. 2001, Lewison et al. 2004, DeFlorio et al. 2005, Gilman et al. 2006, Casale et al. 2007). Recently, a large number of studies have been conducted to identify ways to reduce the effect of shallow set longline gear on sea turtles, such as changing bait, changing depth of gear, changing the time of gear deployment and retrieval, reducing attraction, or changing the size and shape of hooks (Bolten and Bjorndal 2003, Shiode et al. 2005, Swimmer et al. 2005, Gilman et al. 2006, Baez et al. 2007, Wang et al. 2007, Brazner and McMillan 2008, Swimmer et al. 2010).

Of these, the use of circle hooks, rounder and wider than the traditional J-hooks, has gained general acceptance as having the greatest effect on mitigating the impact of shallow set longline on sea turtles without drastically affecting target species

catches. The use of large circle hooks in combination with mackerel bait has already been adopted and is in force by regulatory requirements in the Hawaii (US NMFS 2004a) and the North Atlantic (US NMFS 2004b) longline swordfish fisheries. Circle hooks are increasingly being tested and adopted in a growing number of longline fisheries around the world (Bolten and Bjorndal 2003, Watson et al. 2005, Minami et al. 2006, Hall et al. 2008, Rueda and Sagarminaga 2008, Piovano et al. 2009, Sales et al. 2010, Swimmer et al. 2010). However, in many experimental fishing trials, little attention is given to the lesions caused by circle hooks in captured sea turtles in comparison to J-hooks, or to the importance of improving onboard handling and hook-removal techniques to increase post-release survival.

When studying the effect of longline gear (or, in fact, any fishing gear) on sea turtle mortality, one should take into account both the capture rate (bycatch per unit effort) of turtles and the related mortality (Read 2007), be it direct or indirect. If, with any given mitigation method (e.g., the use of large circle hooks), the capture rate is greatly diminished, then the final percentage of sea turtle mortality due to the fishing is reduced simply because fewer sea turtles are being captured. In this case, the related mortality is not the primary issue because the bycatch has already been reduced. However, if the capture rate is only reduced by a small percentage, then it is essential to accurately evaluate the effect of this mitigation method on the animals' post-release mortality to assess its true effectiveness. Regarding circle hooks, large hooks (size 18 or larger) seem to effectively reduce the accidental capture of sea turtles (Largacha et al. 2005, Gilman et al. 2007, Sales et al. 2010), by up to 90% when combined with mackerel bait (Watson et al. 2005, Gilman 2011), showing a great advantage over J-hooks. However, small circle hooks (size 15 and smaller) are not always as effective at reducing the bycatch rate of turtles, regardless of bait type (Bolten and Bjorndal 2003, De la Serna et al. 2006, Gilman et al. 2006, Minami et al. 2006, Rueda and Sagarminaga 2008). Thus, it is important to assess their possible effect on related mortality in comparison to J-hooks. These small hooks are used by many artisanal longline fisheries around the world. Size 16 circle hooks (an intermediate size), also used in a number of longline fisheries around the world, can yield different results depending on the studies (Bolten and Bjorndal 2003, Piovano et al. 2009).

In the present study, lesions caused by hooks in different anatomical locations, and their possible influence on post-release mortality of captured sea turtles, are discussed from a clinical veterinarian's point of view. The potential effect of the lines of this gear on turtle mortality is also described. This review does not pretend to provide definitive answers to the problem of post-release mortality of sea turtles, something beyond present knowledge, but rather attempts to provide new considerations for biologists, ecologists, and fishery managers carrying out experimental fishing trials in longline fisheries.

Lessons Learned

There are few peer-reviewed studies adequately describing hook-related lesions in sea turtles, their evolution over time in captured animals, or detailed post-mortem examinations involving a large sample size of animals. Thus the present study relies mostly on available gray literature, personal communications with other sea turtle veterinarians and rescue center managers, and personal experience.

Figure 1. Removing a hook from a turtle on a longline fishing vessel in the eastern Pacific. Photo courtesy of Project OFCF-Japan, IATTC.

Three hook location categories are broadly considered in the different studies conducted by shallow set longline vessels: external, mouth, and swallowed, although there is some variation as to how researchers separate the latter two (Work and Balazs 2002, Chaloupka et al. 2004, Parker et al. 2005, Minami et al. 2006, Sasso and Epperly 2007, Casale et al. 2008). External hookings, as well as entanglements with no hooking episode, are generally accepted as low risk (Ryder et al. 2006), especially in hard-shelled turtles, since the gear is generally easy to remove, and when removed, usually leaves very mild or no lesions. However, there is some debate regarding hooks in the mouth and swallowed hooks, and their relation to post-release mortality.

Hooks in the Mouth.—It is generally accepted that circle hooks of any size have a tendency to be lodged in the mouth of captured turtles, in contrast to J-hooks, which tend to be swallowed (Bolten and Bjorndal 2003, Watson et al. 2005, De la Serna et al. 2006, Gilman et al. 2006, 2007, Minami et al. 2006, Read 2007, Brazner and McMillan 2008, Stokes et al. 2011). This primary difference is mostly due to the shape of the circle hooks, with the point perpendicular to the shank, preventing it from being lodged in the esophagus. However, it is somewhat surprising how many researchers accept that a swallowed hook causes a severe injury, and that a hook in the mouth causes mild injury. It has even been suggested that circle hooks reduce sea turtle mortality simply because of the change in location, even if the capture rate is not reduced (Read 2007, Alessandro and Antonello 2010).

Removing a hook from a turtle's mouth is relatively easy after adequate training if it is visible and easy to approach and handle (Fig. 1). However, circle hooks are harder to remove due to their circular shape (pers obs), an observation also shared by longline fishermen (Gilman et al. 2007, MRAG 2008, Piovano et al. 2009, Alessandro and Antonello 2010), and if not done carefully can lead to further injuries during removal if not done carefully. There are several sensitive tissues and structures in the mouth which, if affected, could lead to the animal's post-release death, even if the hook is removed (Ryder et al. 2006, Parga et al. 2008). The glottis is an example, with its

hermetically closing cartilages that protect the respiratory tract from the surrounding water. If damaged during the hook extraction process, water will drip into the lungs of the released sea turtle, potentially causing pneumonia and eventually death. Another sensitive area is the mandible bone and joint, one of the most common points of lodging of circle hooks. If the hook penetrates into the bone, it can cause osteomyelitis (bone infection; Alegre et al. 2008, Parga et al. 2008), which can spread to other bones if not treated. The tongue is another sensitive structure which is prone to infection (pers obs; Ben Higgins, Sea Turtle Program Manager Galveston, pers comm), although it is a rare hooking location. In fact, at an expert workshop on marine turtle longline post-interaction mortality, hook locations in the mouth such as "glottis," "jaw joint," and "soft palate," were included in the "higher risk category," together with "cervical esophagus" and "hook at heart level or below" (Ryder et al. 2006).

To my knowledge, only one study has been completed in captivity with turtles caught by circle hooks in the mouth (Alegre et al. 2006). Ten turtles were kept in captivity for 1 yr, and the evolution of the lesions assessed without any intervention. All animals were healthy by the end of the study except one, which developed osteomyelitis of the mandibular bone and needed antibiotics before release. For the remaining animals, most hooks caused more or less erosion of the mandible, which in turn allowed the hook to fall out without causing any further lesions. Post mortem studies on dead stranded turtles have found ulcerative and necropurulent stomatitis associated to the ingestion of fishing hooks to be the most frequent lesions found in the mouth, together with chronic injuries in the commissures related to fishing line (Oros et al. 2004).

Swallowed Hooks.—As mentioned previously, circle hooks do not usually get lodged in the esophagus of captured sea turtles (Gilman et al. 2007, Read 2007, Brazner and McMillan 2008, Stokes et al. 2011). However, when they do, they are much more difficult to remove, their round shape complicating the extraction process. Swallowed hooks are generally difficult to remove on board fishing vessels and, unless lodged in the proximal esophagus, their removal is not recommended. However, unlike in other species, the wall of the esophagus of marine turtles is very thick, muscular, and resistant (Díaz-Figueroa and Mitchell 2006). Therefore, if the line is not pulled, the chances of the animal surviving the interaction are quite high (Alegre et al. 2006, Valente et al. 2007). A medium sized hook (size of a C13 to C15, or similar size J-hook) left in the cervical esophagus should in most cases not be fatal to the turtle (pers obs). In one study conducted in captivity (Alegre et al. 2006), where 10 animals with J3 hooks lodged in the proximal to medial esophagus were observed over 2 yrs without medical intervention, no hooks caused problems, and 50% of them were expelled by the animals before the end of the observation period. Endoscopy of the remaining hooks revealed that none of them were causing any lesions in the esophagus. Similar positive results were apparently obtained by Minami et al. (2006) testing Japanese tuna hooks in captive animals, which survived over 1 yr, although very few details are given. However, Aguilar et al. (1995) documented a mortality rate of 20%–30% in sea turtles with swallowed hooks, although the previous handling of the animal on board the fishing vessels, as well as the conditions at captivity, exact location of hooks, and causes of death, were not well described.

Studies of animals stranded or admitted to rescue centers after interaction with longline hooks have indicated that chronic fibrosis of the esophageal wall may occur

Figure 2. Hauling an accidentally captured turtle on board with the aid of a net. Project Alnitak, Submon, NOAA. © J Sánchez/Submon.

(Oros et al. 2004), sometimes narrowing the esophagus without causing any further problems (Valente et al. 2007). Occasionally, esophageal perforations are encountered, developing infections which can spread to cause systemic septicemia (Oros et al. 2004). These perforations are especially dangerous in the caudal portion of the esophagus, close to the heart (Ryder et al. 2006, Casale et al. 2008). Hooks lodged in the stomach, with a much thinner wall, tend to cause perforation and a consequent coelomitis and death (Oros et al. 2004, Casale et al. 2008). According to Casale et al. (2008), these traumatic lesions in the stomach cause immediate mortality. However, in these studies the at-sea handling techniques used on the turtles are not known.

Lines.—By far the most dangerous part of a longline gear is the line (Valente et al. 2007, Casale et al. 2008, Alessandro and Antonello 2010). The most typical lesions seen in rescue centers and in stranded animals are those caused by pulling of the line, mostly when fishermen are hauling the animals on board without using a net. This technique tends to embed the hook deeper, causing more extensive lesions and even long tears at the point where it is lodged. The tightened line can also produce cuts in the beak and commissure in small animals (Oros et al. 2004). Therefore, a general recommendation is that captured turtles should be taken on board using a net, and never by pulling the line (Fig. 2). If the turtles are not hauled on board for gear removal, then the line should be cut as close to the hook as possible, usually with the aid of a long-handled line cutter. The use of such a tool is already mandatory in some longline fisheries, such as the Hawaii-based fishery (US NMFS 2004a), and is widely recommended elsewhere. When the lines are left long and with the hook still attached to the sea turtle, the animal experiences the highest probability of dying. Unfortunately, this is quite widespread in some fisheries around the world where sea turtles are not hauled on board (Guglielmi et al. 2000, Casale et al. 2008). The "best" scenario in these cases is that the line entangles one of the flippers, obstructing the blood supply and causing necrosis and eventually death of the tissues (Watson et al. 2005). If the line gets swallowed, then the normal peristaltic movements of the gastrointestinal tract tighten the line to such extent that the intestines gather around it,

eventually becoming ulcerated, necrotic, and severed, or resulting in intussusception (Bjorndal et al. 1994, Oros et al. 2004, Watson et al. 2005, Valente et al. 2007, Casale et al. 2008). The result is a slow and painful death. If the line gets swallowed without a lodged hook, then it might cause death due to obstruction as a tangled ball (Bjorndal et al. 1994).

Data Gathered from Satellite Transmissions

Studies using satellite transmitters on released turtles after longline bycatch generate valuable information on post-release mortality. However, so far only a small sample size is available, not enough to draw broad conclusions. Chaloupka et al. (2004) found that deep-hooked (with swallowed hooks) sea turtles were associated with a higher transmission failure rate than those shallow-hooked (with hooks in mouth or external) during the first 90 d, generating a mortality rate of 38% during the first week for deep-hooked sea turtles. Although use of Platform Terminal Transmitters (PTTs) did not enable distinction between tag failure, tag detachment, or turtle death, and thus this mortality rate is likely an overestimate, there may still be higher mortality associated with in the deep-hooked group (Casale et al. 2008). However, Parker et al. (2005), in a study comparing shallow- and deep-hooked turtles with PTTs, found no significant difference in survival for both groups, both experiencing a general mortality rate of 20%–40%. Similarly, using Pop-up Satellite Tags (PSATs), both Swimmer et al. (2006) and Sasso and Epperly (2007) found no difference in survival between shallow-hooked and control animals (19% mortality for both groups). In a recent study, Mangel et al. (2011) also found no difference in survival using PTTs in longline caught sea turtles with different injuries (both shallow- and deep-hooked). Although no mortality estimates were provided, the authors acknowledged that their results might indicate that "our understanding of what entails a minor or severe injury to a sea turtle is incomplete."

Unfortunately, once the sea turtle is released, unless mortality occurs immediately, it can be very difficult to distinguish between mortality due to the fishing interaction or due to any other cause, and this becomes increasingly difficult the longer the animals are tracked. Therefore, with satellite tracking it is difficult to relate mortality to specific injuries, but rather one can only measure differences in general annual survival between treatment and control animals (Sasso and Epperly 2007). Death after longline interaction can happen several weeks or even months later, making it sometimes impossible to draw conclusions. Another limitation from a clinical point of view is that the exact location of hooks, as well as lesions caused, are not well described, and in fact are sometimes mixed. For example, while some studies describe swallowed hooks as "any hook behind the glottis" (Work and Balazs 2002, Chaloupka et al. 2004), others do not specify (Parker et al. 2005, Minami et al. 2006), and others divide swallowed hooks between upper and lower esophagus (Casale et al. 2008). Good studies of the exact location of hooks and related lesions, together with data obtained from satellite transmissions, could greatly improve our understanding of post-release mortality for sea turtles.

Discussion

Although in general, many researchers still believe that hooks lodged in the mouth are better and less dangerous than hooks lodged in the esophagus of sea turtles, clear evidence of this is lacking. In fact, what happens to sea turtles after the interaction more likely depends on the size and material of the hook, the size and species of the sea turtle, the correct handling of the animal, and the habits and culture of the fishermen. For example, in parts of the world where a hook is expensive and fishermen cannot afford to lose them, then a circle hook lodged in the mouth is preferable (Casale and Cannavò 2003). On the other hand, in more developed areas, where a hook is not so valuable and fishermen just cut the line to release the animal (Guglielmi et al 2000), then it might be more beneficial for the sea turtle, considering its anatomy and physiology, to have the hook lodged in the esophagus.

Because fishermen will eventually be the ones handling turtles and removing hooks, it is important that fishermen be well trained by people with sufficient experience in the field. Therefore, knowledgeable and experienced fishery observers become essential when initiating a hook trial of any kind in any longline fishery.

There is still much to be learned before we can accurately evaluate post-release mortality in relation to hook location and related lesions, information which is essential to adequately determine the ultimate efficacy of different hook types. At present, data in Ryder et al. (2006) are being used as best available estimates of post-release mortality by fishery managers; however, given the scant knowledge of post-interaction mortality, these data should be considered with care, and treated as a rough estimation of an overall mortality range.

While each study method (satellite tagging, captive studies, information gathered from animals admitted to rescue centers, or stranded individuals) has its limitations, a combination of approaches should lead to a better understanding of the processes involved. Standardization of information collected, hooking categories, including anatomical locations of hook and burial depth, would facilitate comparison of results from different studies.

Finally, handling (hauling method and hook removal technique) of the animal should be described, and, if at all possible, photographs of the hook and related lesions should be taken, both before and after removal.

Basic recommendations agreed upon among fishery managers and researchers can and should be implemented when working with fishermen and fishery observers to reduce sea turtle mortality. These include: (1) cutting the line as close as possible to the mouth if the hook is not removed, (2) always hauling turtles with the aid of a dip-net, (3) taking care of the fragile structures in the mouth, (4) correctly using dehooking devices, and (5) not attempting to remove hooks unless they are visible.

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