https://doi.org/10.1186/s40317-018-0155-1

Animal Biotelemetry

TELEMETRY CASE REPORT

Sea turtles and survivability in demersal trawl fisheries: Do comatose olive ridley sea turtles survive post-release?

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Abstract

Incidental capture of air-breathing species in fishing gear is a major source of mortality for many threatened populations. Even when individuals are discarded alive, they may not survive due to direct injury, or due to more cryptic internal physiological injury such as decompression sickness. Post-release mortality, however, can be difficult to determine. In this pilot study, we deployed survivorship pop-up archival tags (sPAT) ($n = 3$) for an air-breathing species, the olive ridley sea turtle (*Lepidochelys olivacea*), one of the first studies to do so. We found that at least two of the three turtles survived after being captured in demersal fish trawl nets and being resuscitated from a comatose state following standard UN Food and Agriculture Organization guidelines. One turtle died; however, the absence of a change in light level but continued diving activity suggested that the turtle was likely predated. Whether capture contributed to the turtle's susceptibility to predation post-release is unknown, and average tow duration during this fishing trip was similar in duration to that of a turtle that survived (1.5 h). The two surviving turtles displayed normal horizontal and vertical movements based on previous tagging studies. This study suggests that resuscitation techniques may be effective; however, additional study is necessary to increase sample sizes, and to determine the severity of decompression sickness across different levels of activity and in other fishing gears. This will result in better population mortality estimates, as well as highlight techniques to increase post-release survivorship.

Keywords: Post-release mortality, Trawl fishing, Bycatch, Resuscitation, Decompression sickness, Olive ridley sea turtle

Background

Fisheries bycatch, or the incidental capture of non-target species in fishing gear, is a major human threat to marine species worldwide [1]. Air-breathing species may drown in nets or on lines used for fishing [2]. Generally, individuals captured as bycatch are not marketable species, either due to limited human demand or due to regulatory restrictions, and are discarded either dead or alive, or may be used as bait [1]. Sea turtles are a large marine species caught as bycatch, and the recovery of their populations worldwide has been impeded by bycatch in marine fisheries, particularly fishing trawls [3]. Trawls operate by towing a large funnel-shaped net across the sea bottom or through the water column to capture target species; however, trawls indiscriminately capture other species as well, including sea turtles that co-occur with target species such as shrimp and fish. Gear modifications such as turtle excluder devices (TEDs) have been introduced to reduce the capture of sea turtles in trawl nets. The use of TEDs has resulted in increase in some sea turtle

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populations [4]; however, TEDs are not required in many parts of the world, or across all fisheries that may come into contact with sea turtles [5].

Capture of sea turtles in trawls (and other gear types) can result in traumatic injury and in physiological impacts due to forced submergence (reviewed in [6]). While sea turtles have behavioral and physiological adaptations to reduce the potential of decompression sickness in their normal diving activity [7, 8], there is evidence that capture in fishing operations results in increased metabolic and locomotor activity, and exertional myopathy [9]. As a result, turtles experience physiological changes that likely override adaptations for reducing decompression sickness, resulting in deleterious effects [10]. In addition to death due to drowning, lactate levels may increase, stress-related hormones may increase, and turtles' ability to recover may be further impacted by increases in other blood chemistry values such as glucose, phosphorus, potassium and creatine phosphokinase that indicate metabolic disturbance [6, 8, 11–14]. As a result of these physiological impacts, many turtles are also brought onboard fishing vessels in a comatose state, where they are unresponsive but still alive. They can potentially be resuscitated from this state, and several protocols exist for resuscitation (e.g., [5, 15, 16]), of which one of the most common is elevation of the rear end of the turtle to allow the lungs to drain. Resuscitation may occur for up to 24 h, or until the turtle appears vagile and alert (reanimated) at which point it is released from the vessel.

Despite resuscitation, survivorship of sea turtles post-release is largely unknown, as physiological impacts may affect long-term survivorship, with decompression sickness of particular concern. Decompression sickness results from forced submergence and rapid ascension to the surface as nets are retrieved to the vessel [10, 17]. Decompression sickness occurs from rapid degassing of nitrogen from solutes, resulting in nitrogen gas bubble formation in the blood stream and tissues causing severe pathological impacts. This may result in death, though death may occur after a turtle has been released alive from a fishing vessel, making it difficult to know the true survivorship of turtles. When mortality occurs post-release, it can be difficult to account for this 'cryptic' source of mortality in population estimates and management efforts [18]. While telemetry devices have been used in the past to infer survivorship of sea turtles and other marine species [19–23], it has traditionally been difficult to definitively distinguish the failure of devices from death of a tagged animal [24, 25].

Recently, technology has been developed that allows for the determination of survivorship of marine species once they are released. Survivorship pop-up archival (sPAT) tags developed by Wildlife Computers Inc. (Redmond WA USA) are released from a tagged individual after 30 days unless putative death is detected prior to the programmed release date. A combination of light and depth levels is used to infer the animal death as a result of either: (a) floating continuously on the surface (floater) or (b) sank to the bottom (sinker). Tags that detach at 30 days post-release and where neither 'floater' nor 'sinker' states have been activated are considered survivors for the purposes of this study. Potential predation and subsequent ingestion of an animal can also be inferred by a lack of change in light levels, indicating that dawn and dusk were not detectable.

sPAT tags have been used to determine post-bycatch survivorship in several elasmobranchs including mako sharks (*Isurus oxyrinchus*, [26]), silky sharks (*Carcharhinus falciformis*, [27]), school sharks (*Galeorhinus galeus*, [28]), great hammerheads (*Sphyrna mokarran*, [29]) and spinetail devil rays (*Mobula japonica*, [30]) but application to air-breathing marine species subject to decompression sickness, such as sea turtles has been limited, though satellite tags have been used to infer survivorship but using more limited data (e.g., [19, 24]). Here, we deployed sPAT tags to determine survivorship of olive ridley sea turtles (*Lepidochelys olivacea*) captured in demersal fish trawling vessels in Gabon, Africa. Gabon regularly hosts four sea turtle species, including leatherback (*Dermochelys coriacea*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*) and olive ridley sea turtles [31–35]. Many of these species are caught in trawling nets; however, olive ridleys are caught in disproportionately large numbers compared to the number of individuals in the local population [36], making trawling of particular concern. We illustrate attachment design and procedure, and results of the deployment of three sPAT tags in pilot study conducted in 2016. We discuss

Fig. 1 Olive ridley turtle on deck of fishing vessel fitted with Wildlife Computers survivorship pop-up archival tag attached using a short tether to attach to the rear supracaudal scutes. Inset: survivorship tag

Table 1 Deployment information and fate of olive ridley turtles instrumented with survivorship tags

Turtle ID (PTT number)	Sex	Survived at 30 days?	Average trawl duration during the fishing trip (hh:min)	Depth at capture (m)	Carapace size cm (CCL, CCW)	Daily mean and range of max. depth (m)	Temperature: daily mean and range of max depth (°C)	Temperature: daily mean and range min depth (°C)	Capture date and tag pop-off date	Recovery time onboard vessel (min)	Days before tag pop-off	Straight-line distance between deployment and pop-off location (km), km/day
A (152524)	Male	Yes	01:25	12	69, 70	35.2 (16–49)	27.6 (25–30.2)	20.9 (19.8–23.2)	24 April 16, 24 May 16	63	30	270, 9
B (152525)	Female	No (floater)	01:21	17	71, 68	21.3 (21–22)	27.1 (26.4–27.2)	25.3 (24.6–26.6)	31 October 16, 03 November 16	90	3	56, 18.7
C (152526)	Female	Yes	03:30	14	66, 67	37.9 (15–56)	26.4 (26.0–27.6)	20.5 (17.6–27.0)	21 July 16, 20 August 16	130	30	27, 0.9

the potential implications of these results on the larger population, and implications for management.

Methods

Survivorship pop-up archival (sPAT) tags (Wildlife Computers, Redmond WA, USA; 124 mm length × 38 mm maximum height, approximately 60 g in air) were deployed on three olive ridley sea turtles captured in the commercial demersal fish trawl fishery in coastal Gabon, Africa (Fig. 1). Turtle excluder devices (TEDs) are required on shrimp trawling vessels in Gabon but not on demersal fish trawling vessels, which represent over 80% of the trawling fleet [36]. Two adult females and one adult male were instrumented with transmitters in April, July and October of 2016 (Table 1). Tags were attached opportunistically by trained fishery observers to turtles brought aboard in a comatose state (alive but unresponsive). Turtles were captured in demersal trawl gear, brought onboard the fishing vessel and resuscitated by elevating the rear end of the turtle. The tag was attached once the turtle was reanimated. Curved carapace length (CCL) was measured, and Inconel flipper tags (National Band and Tag Company, USA) attached to the front left and right flippers prior to release from the vessel. Release location and time were recorded, as was water depth at the capture location. Additionally, the average duration of trawls within each approximately 3-day fishing trip was recorded, however, the duration of individual trawls was not available.

Tag attachment and operation

Tags were attached to the turtle at the left or right supracaudal scute of the carapace (Fig. 1). A power drill was used to drill a small (approximately 3 cm diameter) hole in the scute, and tags were attached using a metal wire and crimps. Once deployed, tags were automatically activated by exposure to saltwater. Tags operated for up to 30 days. If a turtle died, the tag was released from the turtle via a corrodible pin. If a turtle was considered dead, it was classified into one of two groups based on the time–depth recorder within the tag: floated continuously on the surface for 24 h (floater), or sank to the bottom and remained at a consistent depth for 24 h (sinker). Additionally, the tag is designed to detect if there is a change in light level over a 24-h period in order to indicate potential predation events; if dawn or dusk were not detected, but change in depth occurs, this indicated the tag had likely been ingested. If mortality was not observed after 30 days, the tag was released via a corrosive pin and the turtle considered alive. The tag further reports if the corrodible pin has been broken or corroded when released within the 30-day period. The release location and survivorship status of the turtle, as well as daily minimum and maximum depth, daily minimum and maximum water temperature, and if there was a light level change over the 24-h period prior to release, were transmitted via the Argos satellite system once the tag was released.

Results

Of the three turtles instrumented, two of the turtles survived (Turtles A and C), while one is presumed dead (Turtle B) and was categorized as a 'floater' (Table 1). Data transmitted by the tag suggest that this turtle may have been predated as no change in the light level for 24 h was detected prior to tag release, but the tag was not recorded at the surface during that 24-h period (Fig. 2). Additionally, in the 24 h prior, the turtle was diving, though it is possible that the turtle died and was then consumed, or that the tag was consumed and not the turtle.

Average tow duration during the fishing trips during which Turtle A and B were caught were approximately 1.3 h; however, average tow durations for Turtle C's trip were considerably longer, averaging 3.5 h (Table 1). Turtles were caught in depths ranging from 12 to 17 m, with the presumed dead turtle (Turtle B) caught at the greatest depth (17 m; Table 1). Turtle movements varied considerably (Fig. 3). The greatest straight-line distance was 270 km south in 30 days (Turtle A; Table 1), but distance per day was as low as 0.9 km/d for Turtle C which appeared to remain in the vicinity where capture occurred near the mouth of the Komo Estuary. The Komo Estuary is adjacent to a known nesting site, and some olive ridley turtles nesting there are known to remain resident in the area for the months following nesting [37]. The nesting season occurs from September through March with a peak in November [32], and this turtle was recorded in the area in the area in July and August, further suggesting this may be a resident foraging ground during other parts of the year.

Turtles experienced mean minimum daily temperatures between 20.5 and 25.3 °C, with maximum mean daily temperatures of 27.6 °C (Fig. 2, Table 1). Maximum daily dive depths ranged from 21.3 to 37.9 m, though the tag attached to turtle B reported the shallowest depth (21.3) and collected only 3 days of data before presumed death and tag release (Fig. 2). The maximum dive depth recorded by any of the turtles was 56 m.

Discussion

Our results, while preliminary, suggest post-release mortality occurred in a single individual following resuscitation from a comatose state. Two of the three turtles

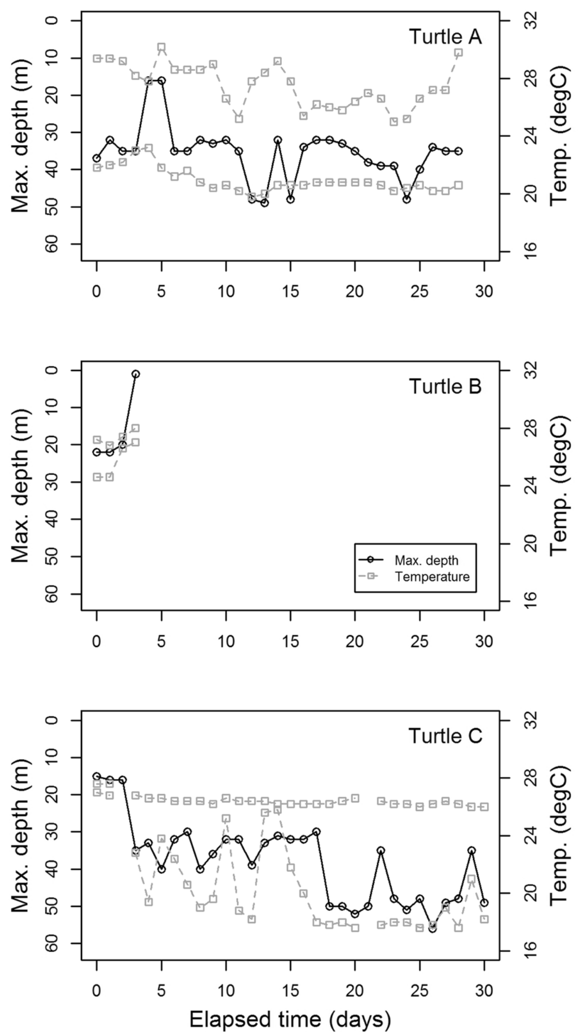

Fig. 2 Daily maximum depth (black) and minimum and maximum temperatures (gray) of three olive ridley turtles instrumented with Wildlife Computers survivorship pop-up archival tags (sPAT). Turtles A and C survived, and tags were programed to release after 30 days. Turtle B was characterized as a 'floater' as its maximum depth on the fourth day was 1 m; however, it was likely predated, as there was no change in light level on the third day, as indicated by the star

survived, and while a third died, it appears to be due to predation; however, it is unknown whether injuries or changes in behavior from trawl capture could have made it more susceptible to predation, or if it died and was then scavenged shortly thereafter. Depth of capture was greatest for the turtle that died (Turtle B 17 m; Table 1). Mean tow duration, however, for the turtle that died (Turtle B, 1:21) was similar (Turtle A, 1:25) or half as long (Turtle C, 3:30) as the turtles that lived, complicating speculation as to whether capture may have played a part in its death (though it should be noted that the exact tow duration for these capture events are unknown). No direct injuries to the turtle were observed, but it is possible that other physiological impacts such as aspirational pneumonia, exertional myopathy or decompression sickness may have occurred despite a relatively short tow time, resulting in increased susceptibility to predators. These results highlight the need for further research beyond this pilot study.

Implementation of onboard resuscitation is likely a useful post-capture management technique in this fishery, and mandating these techniques along with additional outreach to fishers, is worthwhile. The mean maximum dive depths for these instrumented turtles (Fig. 2) are similar to dive depths recorded for turtles in other parts of the world (Australia, [38, 39]; French Guiana, [40]), as well as from previous studies in this region on nesting female turtles [37], suggesting potentially 'normal' dive behavior of turtles post-release, though we caution that the tags did not collect the full dive profile data to allow us to fully assess behavior, and that Turtle B's tag collected only 3 days of data before death and subsequent release. We additionally caution that there may be a greater risk for decompression sickness when capture occurs at greater depths, or in other regions of the world where water temperatures are colder. Gabon resides on the equator and the turtles in this study encountered mean water temperatures between 20.5 and 27.6 °C (range 17.6–30.2 °C; Table 1). Solubility of nitrogen at depth increases proportionally with decreasing temperatures, so it is critical to conduct similar survivorship studies in more temperate regions where turtles are subject to bycatch, as well as on species that are likely to dive to greater depths or in fisheries where trawling occurs at greater depths.

Applying these preliminary results to the demersal fish trawl fishery in Gabon [36], survival following very basic resuscitation of trawl-captured sea turtles may be higher than expected, which would reduce the predicted mortality of ridleys in this trawl fishery by a proportion yet to be determined. We urge very strong caution in interpreting these results, however, given three factors. First, our sample size is low and second, captures occurred in relatively shallow, nearshore waters (between 12 and 17 m depth). Casale et al. [36] indicate that the fishery also occurs further offshore in relatively high density and in some cases nearing 200 m depths (see Figure 1 in [36]). These depths are likely to greatly influence ridleys susceptibility to decompression sickness and other associated physiological impacts as olive ridleys appear to spend considerable time on the seafloor bottom where they are caught in this fishery [37]. Third, mortality in this fishery may occur for non-comatose turtles released alive. Individuals that are hyperactive when brought onboard often

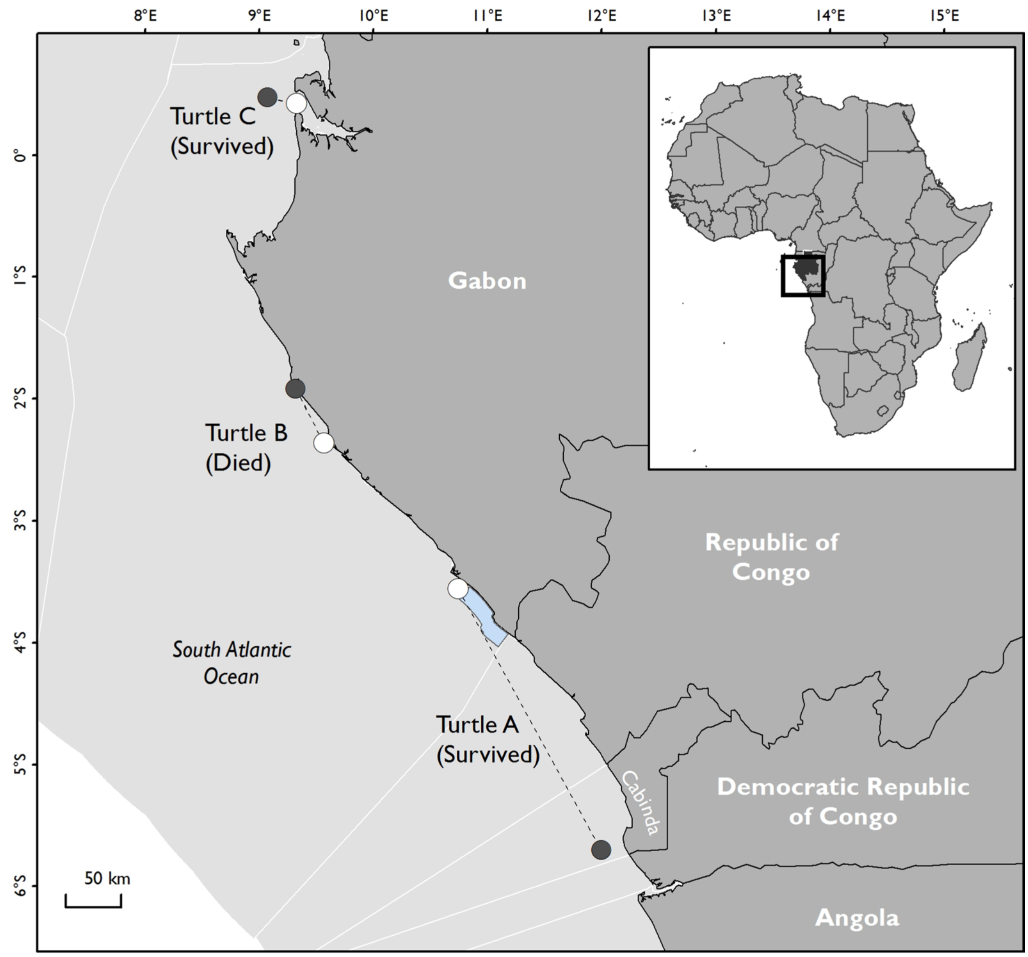

Fig. 3 Deployment (white circles) and pop-up (black circles) locations of three olive ridley turtles instrumented with Wildlife Computers survivorship pop-up archival tags (sPAT) and survivorship status of turtles A–C indicated (died or survived). Inferential movement between deployment and pop-up locations (black broken line). Inset map: African continent and Gabon (black filled polygon) with geographic extent of study region (black polygon)

subsequently develop decompression sickness [10, 17]. As a result, these turtles may subsequently die as they are likely to be released almost immediately after landing, as they are alive and animated. Our post-release survivorship estimates were biased toward turtles that were comatose upon landing, and turtles with a strong locomotor response would likely have been recorded as 'alive.' Post-release survival of hyperanimated turtles is another important area of study.

Understanding post-release mortality is critical, and studies have looked at post-release mortality across other gear types and fisheries. For example, turtles lightly hooked in longline fisheries show no difference between control turtles in diving behavior [22] or mortality [21, 22]. In coastal gillnets, post-release mortality was higher than in longlines (28.6% [41]). While we focus here on trawl gear, other gear types are used in the Central West African region that may impact turtles, including purse seines, longlines and gillnets. Artisanal gillnets are widespread in Gabon and other areas of Central West Africa, particularly in coastal and estuarine habitats where turtles are found, and these fisheries use long soak times (12 + h) [42, 43]. While depth does impact severity of decompression sickness, Fahlman et al. [17] provided evidence that the time of submergence is also critically important, as moderate and severe decompression sickness was observed more often when turtles were submerged for longer, such as in gillnets, even when set at moderate depths of only 10–20 m. This indicates a critical need to also conduct similar survivorship studies in gillnet fisheries where turtles are frequently caught in artisanal fishing operations [43], and to better understand how the combination depth and time of submergence may influence survivorship.

While this study suggests that post-release mortality may be moderate, Casale et al. [36] indicates that 6.2% of turtles are brought aboard fish trawling vessels already dead. In Gabon, TEDs are required for shrimp trawling vessels but not demersal fish trawl vessels. The majority of trawlers in Gabon target fish (87.5%, $n = 28$), and shrimp trawlers amount to only 12.5% of the Gabonese trawl fleet ($n = 4$), and largely operate in the bay of Port-Gentil, an isolated area approximately 250 km^2. There is clearly a need for TEDs in demersal fish trawling operations; however, TEDs operate by excluding large items from entering the cod end while retaining small items such as shrimp. In demersal fish trawling operations, large-bodied fish are targeted, so design needs to allow fishermen to maintain levels of target catch. Gabon is currently developing a design for TEDs adapted to its fish trawling fleet that will minimize sea turtle bycatch, and it is hoped it will soon be written into law.

Authors' contributions

SMM, MJW and AF conceived the study and conducted data analyses. All authors contributed to the data collection, logistics and the manuscript. All authors read and approved the final manuscript.

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Acknowledgements

We acknowledge the support and authorizations for this research and for Gabon's onboard observer program by the Agence Nationale des Peches et de l'Aquaculture, the Direction Generale des Pêches et de l'Aquaculture, the Agence Nationale des Parcs Nationaux and the Centre National de la Recherche Scientifique et Technologique.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request, though the majority of data generated or analyzed during this study are included in this published article.

Consent for publication

Not applicable.

Ethics approval and consent to participate

All federal, international, and institutional guidelines were followed, and this study was approved by and carried out in accordance with the recommendations of the Institutional Animal Care and Use Committee at Old Dominion University (IACUC Permit 15-016). Permissions to work with the study species were issued by the Gabon Agence Nationale des Parcs Nationaux (AEI5025, AR0010/12, AE140003). Gabon's onboard observer program is carried out with permissions from the Agence Nationale des Peches et de l'Aquaculture, the Direction Generale des Pêches et de l'Aquaculture, and the Centre National de la Recherche Scientifique et Technologique.

Funding

Funding for tags and equipment was provided by Old Dominion University. The Gabon Sea Turtle Partnership, which funded observer logistics, is funded by the Marine Turtle Conservation Fund (US Fish and Wildlife Service, Department of the Interior).

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Received: 12 March 2018 Accepted: 20 August 2018
Published online: 10 September 2018

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