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Hazards in hanging gardens: A report on failures of recognition by green turtles and their conservation implications

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A B S T R A C T

Marine species are experiencing unprecedented global impacts due to anthropogenic debris. Many recent studies have pointed out the hazards associated with marine litter ingestion, especially plastic debris – the most abundant and ubiquitous items in coastal and oceanic environments worldwide. In this study we provide the first in situ evidence of consumption of non-discarded synthetic rope fragments by green turtles. We explored the environmental risks to this endangered species associated with the grazing and consumption of anthropogenic debris in zones of human activity. Efforts to combat debris ingestion and reduce anthropogenic debris discharged into the world's oceans should be a priority for decision-makers and will need to involve multiple-approaches and the adoption of more environmentally friendly products and practices by the international community.

1. Introduction

The Green turtle (*Chelonia mydas*) is a globally endangered species registered in the IUCN Red List and also in the CITES treaty (Appendix I). This cosmopolitan chelonian has a complex life cycle and has exhibited gradual, or often dramatic, ontogenetic shifts in its diet and habitat use behavior. This could bring influences on food webs dynamics and structures and ecosystem services (Arthur et al., 2008; Morais et al., 2014; Jardim et al., 2015).

Although recent species conservation efforts have had positive effects on the status and number of sea turtle populations, threats to these chelonians are still very real, and include climate change, sea level alterations, hunting, bycatching, and marine pollution (Hawkes et al., 2009; Hamann et al., 2010). Marine litter, also called marine debris, is composed of materials that have been deliberately or accidentally discarded in coastal and marine environments (UNEP, 2009).

There are marine litter ingestion records for all seven sea turtle species (NOAA, 2014). Understanding how and why sea turtles are ingesting anthropogenic debris are key elements to understand the food web dynamics, species-habitat relationships, and marine animal health. Owing to the difficulties involved in observing marine species while feeding, little is currently known about how and why turtles and other marine animals ingest anthropogenic debris, giving rise to an array of hypotheses such as their consumption as a function of debris frequency in the environment (reflecting the opportunistic feeding habits of those animals), the association of natural food items with debris, or the resemblance of debris to natural prey items (Hamann et al., 2010; Schuyler et al., 2014a; Nelms et al., 2015).

The hypothesis of "plastic jellyfish" ingestion by sea turtles is well-supported as those flexible and translucent items resemble typical prey items such as jellyfish (Mrosovsky, 1981; Schuyler et al., 2012, 2014a). It remains unclear, however, why sea turtles ingest other types of anthropogenic debris, although different sea turtle species have different lifestyles and feeding preferences that would be expected to influence the probability, types, and amounts of debris they ingest (Schuyler et al., 2014a,b; Hayashi and Nishizawa, 2015).

We report here that feeding at algae-encrusted ropes may lead green turtles to ingest synthetic fragments from non-discarded objects. We also discuss the necessity of influencing decision-making processes related to endangered species conservation in light of the increasing hazards associated with the physical and chemical impacts of marine pollution.

2. Material and Methods

We were able to observe the feeding behavior of green turtles at algae-encrusted ropes during opportunistic observations at two sites used for the mooring and maintenance of boats near the city of Salvador,

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Bahia State, in northeastern Brazil (12°58′S, 38°30′W and 12°58′S, 38°31′W). We used the "ad libitum" technique (Altmann, 1974), which is adequate for recording opportunistic events, at observation distances of 3 to 5 m on a boat mooring platform.

We collected information covering the following parameters: species identifications, behavior, total feeding time (min), numbers of individuals, and the estimated curved carapace length (CCL).

At the conclusion of the feeding events, we inspected the ropes during free dives and also raised the submerged portions to assess any damage and wear caused by turtle feeding. We used the methodology described by Carson (2013) for plastic items bitten by fish on the evaluations of the ropes after the feeding events.

Additionally, algal samples were collected for taxonomic identification, and digital photographs were taken to document the visual observations. The algal species were processed and identified in the laboratory using specialized bibliographies (Joly et al., 1969; Nunes, 1998).

3. Results

On April 21, 2011, between 12:31 and 12:45h, we observed a juvenile individual of *Chelonia mydas* (approximately 40 cm CCL) swimming near moored boats (Fig. 1a).

Feeding activity initiated when the turtle hovered approximately 0.5-1.0 m below the water surface to graze at an algae-encrusted rope.

The turtle made repeated and ample bites on the rope, grazing on the target algae using its serrated beak.

After feeding, the green turtle remained relatively motionless, apparently resting, and then raised its head before quickly submerging and then moving out of sight.

A second event was registered on May 14, 2013, between 11:13 and 11:30h. On this occasion, a young turtle (approximately 50 cm CCL) spent part of its time swimming close to the surface (Fig. 1b) but also descending in the water column to depths where it was no longer visible from the surface, before quickly returning to the surface to breathe.

The turtle was observed approaching a nylon mooring rope while near the surface and then grazing at that object (Fig. 1c).

While grazing at the underside of the rope, the young turtle's behavior was similar to the previous feeding event; the turtle sometimes raised its head (Fig. 1d) and paused to rest, and then resumed its feeding activities. This individual would frequently take strong bites of algae, shaking the rope and leaving visible marks on it.

During this feeding event, a boat moored on a nearby platform started its engine, apparently startling the animal, and it swam away.

Two algae species were identified in the samples: *Cladophora* sp. (Cladophoraceae) and *Bryopsis pennata* (Bryopsidaceae).

The observed feeding by green turtles at algae-encrusted ropes followed their usual behavior of using their serrated beak to crop and/or break off clumps of algae while grazing.

We observed that the algae were taken with forceful and ample bites that exposed nylon rope filaments.

Most bites taken by the juvenile green turtles left grazing marks that could be clearly seen from the surface as well as underwater (while diving).

The ropes did not appear to be very old, but demonstrated considerable damage from the feeding events, with the removal of strand material.

These observations indicate that green turtles can accidentally ingest synthetic fragments when grazing on algae-encrusted mooring ropes.

4. Discussion

The present study provides the first *in situ* evidence of the consumption of synthetic rope fragments by green sea turtles while grazing at algae-encrusted mooring ropes.

These opportunistic observations represent an important step in exploring diverse aspects of the environmental impacts of anthropogenic debris on endangered species and the potential risks associated with algae grazing in zones of human activity. They also provide an opportunity to encourage companies to develop bio-friendly products and adopt proactive environmental stewardship practices in marine activities.

Several papers have reported the forage in shallow water bays by green turtles near zones of human occupation, increasing their exposure to human activities (Seminoff et al., 2002a; Hazel et al., 2009; Carman et al., 2014). Among the varied anthropogenic impacts on shallow water environments are the generation and inadequate disposal of wastes resulting in large accumulations of marine litter (Barnes et al., 2009).

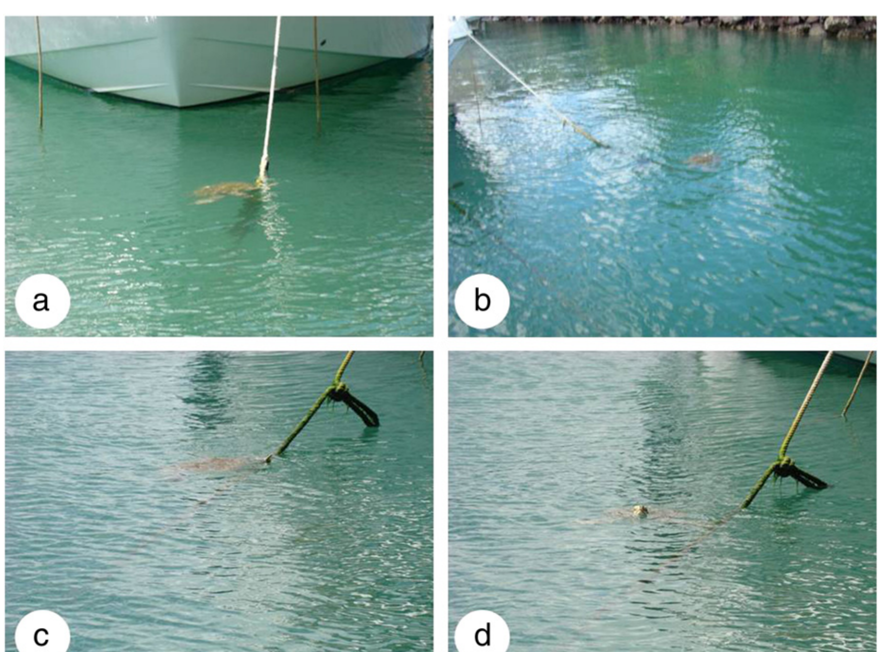

Fig. 1. a-d. Green turtle feeding behavior at algae-encrusted ropes.

The ingestion of marine litter by marine vertebrates (birds, turtles, fish, and marine mammals) is well documented (Ivar do Sul and Costa, 2014; Schuyler et al., 2014b; and references therein) and brings with it serious physical and chemical effects. They include impact to the gastrointestinal tract, suffocation, physical injuries, chronic infections, reduction of normal food intakes, and often death (Tourinho et al., 2010; Schuyler et al., 2014b; NOAA, 2014).

One successful approach to investigating how and why turtles ingest marine debris (Schuyler et al., 2014a) tested models predicting that turtles use visual clues to select their prey. The results supported the hypothesis that turtles select flexible and transparent debris (similar to jellyfish) that resembles their usual natural prey.

Less well understood, however, is whether the normal feeding habits of turtles can put them at risk when their natural food items are associated with foreign and potentially noxious substances. This information is of particular interest for orienting decisions that could help mitigate these problems.

Green turtles are known to alter their diets under near-shore conditions. During their coastal stages they demonstrate primarily herbivorous diets, selectively choosing grazing plots (Bjorndal, 1980; Seminoff et al., 2002a). Some populations demonstrate diversified diets (sea grasses, algae, and mangrove leaves and shoots), however, can also include small animals such as sponges, jellyfishes, mollusks, and crabs (Limpus and Limpus, 2000; Seminoff et al., 2002b; López-Mendilaharsu et al., 2005; Amorocho and Reina, 2007; Carrión-Cortez et al., 2010).

This opportunistic feeding on animal resources (e.g., mollusks and crabs) as well as debris is facilitated by their forceful bites and the serrated morphology of their beaks, as described by Marshall et al. (2014).

Juvenile green turtles may therefore accidentally ingest nylon rope fragments (and others such debris) when they bite at algae-encrusted ropes or graze in areas with discarded anthropogenic debris. Additional long-term field studies of this topic are being planned and should be relevant to our understanding of the impacts of marine debris on green turtles.

These records also serve to broaden discussions concerning the ingestion of non-discarded anthropogenic debris by marine wildlife, as the objects described here (ropes) were not actually disposed of in marine environments, but rather still in use.

Ropes made from natural fibers (hemp, manila, and cotton) have been used for many thousands of years (e.g., Egypt), with nylon fiber introduced in the 1930s by Dupont Corporation being widely employed since the Second World War. Modern ropes are now almost exclusively made of artificial fibers such as polyethylene (PE), polyester (PES), and polypropylene (PP) (McLaren, 2006), and have become ubiquitous components of nautical activities around the world. These products often have long lifespans and are widely used well beyond their recommended safety limits (Dantas et al., 2012). These changes in rope composition affect their flexibility, buoyancy, and endurance, but also cause many problems in coastal and marine environments (Gregory, 2009) and represent a significant source of marine litter.

Global analyses of the anthropogenic debris ingested by sea turtles have shown that ropes (or strings) are the third most widely ingested marine debris items (Schuyler et al., 2014b). Another problem associated with turtles feeding at algae-encrusted ropes is related to humans intentionally harming those animals as a response to economic losses caused by their damage to nautical equipment, fishing artifacts, and fisheries. Although turtles are protected through various international agreements, cases of human-induced injuries have been reported with turtles and other animals, such as cetaceans (Freitas Netto and Di Beneditto, 2008; Poli et al., 2014).

It will therefore be essential to encourage technological innovation on an industrial-scale to develop and market bioplastics that can reduce the impacts of marine debris ingestion.

We also suggest that environmental practices should be adopted in the management of marinas and harbors to clean, and periodically substitute, mooring ropes to help mitigate the problem of nylon debris ingestion by sea turtles. Fiscal and financial incentives could be set in place to contribute to the acquisition of new equipment and to properly dispose of rope wastes and other unneeded nautical equipment.

The involvement of the entire international community (scientists, governments, institutions, industries, and society in general) will be necessary to develop effective, low-cost conservation strategies and create a solid technical-scientific foundation to protect endangered species and manage marine litter. Firm commitments and well-defined targets among stakeholders will be essential to achieving a successful consensus for the reduction of anthropogenic debris in the world's oceans and the protection of marine ecosystem and food webs.

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References

Altmann, J., 1974. Observational study of behavior: sampling methods. Behaviour 49, 227–267.

Amorocho, D.F., Reina, R.D., 2007. Feeding ecology of the East Pacific green sea turtle *Chelonia mydas agassizii* at Gorgona National Park. Endanger. Species Res. 3, 43–51.

Arthur, K.E., Boyle, M.C., Limpus, C.J., 2008. Ontogenetic changes in diet and habitat use in green sea turtle (*Chelonia mydas*) life history. Mar. Ecol. Prog. Ser. 362, 303–311.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. B 364, 1985–1998.

Bjorndal, K.A., 1980. Nutrition and grazing behavior of the green turtle *Chelonia mydas*. Mar. Biol. 56, 147–154.

Carman, V.C., Acha, E.M., Maxwell, S.M., Albareda, D., Campagna, C., Mianzan, H., 2014. Young green turtles, *Chelonia mydas*, exposed to plastic in a frontal area of the SW Atlantic. Mar. Pollut. Bull. 78, 56–62.

Carrión-Cortez, J., Zárate, P., Seminoff, J.A., 2010. Feeding ecology of the green sea turtle (*Chelonia mydas*) in the Galápagos Islands. J. Mar. Biol. Assoc. UK 90, 1005–10113.

Carson, H.S., 2013. The incidence of plastic ingestion by fishes: from the prey's perspective. Mar. Pollut. Bull. 74, 170–174.

Dantas, D.V., Barletta, M., Costa, M.F., 2012. The seasonal and spatial patterns of ingestion of polyfilament nylon fragments by estuarine drums (Sciaenidae). Environ. Sci. Pollut. Res. 19, 600–606.

Freitas Netto, R.F., Di Beneditto, A.P.M., 2008. Interactions between fisheries and cetaceans in Espirito Santo State coast, southeastern Brazil. Rev. Bras. Zoociênc. 10, 55–63.

Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings -entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos. Trans. R. Soc. B 364, 2013–2025.

Hamann, M., Godfrey, M.H., Seminoff, J.A., Arthur, K., Barata, P.C.R., Bjorndal, K.A., Bolten, A.B., Broderick, A.C., Campbel, L.M., Carreras, C., Casale, P., Chaloupka, M., Chan, S.K.F., Coyne, M.S., Crowder, L.B., Diez, C.E., Dutton, P.H., Epperly, S.P., FitzSimmons, N.N., Formia, A., Girondot, M., Hays, G.C., Cheng, I.J., Kaska, Y., Lewison, R., Mortimer, J.A., Nichols, W.J., Reina, R.D., Shanker, K., Spotila, J.R., Tomás, J., Wallace, B.P., Work, T.M., Zbinden, J., Godley, B.J., 2010. Global research priorities for sea turtles: informing management and conservation in the 21st century. Endanger. Species Res. 11, 245–269.

Hawkes, L.A., Broderick, A.C., Godfrey, M.H., Godley, B.J., 2009. Climate change and marine turtles. Endanger. Species Res. 7, 137–154.

Hayashi, R., Nishizawa, H., 2015. Body size distribution demonstrates flexible habitat shift of green turtle (*Chelonia mydas*). Glob. Ecol. Conserv. 3, 115–120.

Hazel, J., Lawler, I.R., Hamann, M., 2009. Diving at the shallow end: Green turtle behaviour in near-shore foraging habitat. J. Exp. Mar. Biol. Ecol. 37, 84–92.

Ivar do Sul, J.A., Costa, M.F., 2014. The present and future of microplastic pollution in the marine environment. Environ. Pollut. 185, 352–364.

Jardim, A., López-Mendilaharsu, M., Barros, F., 2015. Demography and foraging ecology of *Chelonia mydas* on tropical shallow reefs in Bahia, Brazil. J. Mar. Biol. Assoc. U. K. 11, 1–10.

Joly, A.B., Ugadim, Y., Diaz, J.J., Yamagushi-Tomita, N., Cordeiro-Marino, M., Yoneshigue-Braga, Y., 1969. Additions to the marine flora of Brazil- X. Rickia São Paulo 4, 61–74.

Limpus, C.J., Limpus, D., 2000. Mangroves in the diet of *Chelonia mydas* in Queensland, Australia. Mar. Turt. Newsl. 89, 13–15.

López-Mendilaharsu, M., Gardner, S.C., Seminoff, J.A., Riosmena-Rodríguez, R., 2005. Identifying critical foraging habitats of the green turtle (*Chelonia mydas*) along the Pacific coast of the Baja California peninsula, Mexico. Aquat. Conserv. Mar. Freshwat. Ecosyst. 15, 259–269.

Marshall, C.D., Wang, J., Axayacatl Rocha-Olivares, A., Godinez-Reyes, C., Fisler, S., Tomoko Narazaki, T., Sato, K., Sterba-Boatwright, B.D., 2014. Scaling of bite performance with head and carapace morphometrics in green turtles (*Chelonia mydas*). J. Exp. Mar. Biol. Ecol. 451, 91–97.

McLaren, A.J., 2006. Design and performance of ropes for climbing and sailing. Proc. Inst. Mech. Eng. L J. Mater. Des. Appl. 220 (1), 1–12.
Morais, R.A., Santos, R.G., Longo, G.O., Yoshida, E.T.E., Stahelin, Gustavo David, Horta, P.A., 2014. Direct Evidence for Gradual Ontogenetic Dietary Shift in the Green Turtle, *Chelonia mydas*. Chelonian Conserv. Biol. 13 (2), 260–266.
Mrosovsky, N., 1981. Plastic jellyfish. Mar. Turt. Newsl. 17, 5–6.
National Oceanic and Atmospheric Administration Marine Debris Program (NOAA), 2014r. Report on the Occurrence and Health Effects of Anthropogenic Debris Ingested by Marine Organisms (Silver Spring, MD. 19 pp.).
Nelms, S.E., Duncan, E.M., Broderick, A.C., Galloway, T.S., Godfrey, M.H., Hamann, M., Lindeque, P.K., Godley, B.J., 2015. Plastic and marine turtles: a review and call for research. ICES J. Mar. Sci. 1–17.
Nunes, J.M.C., 1998. Catálogo de algas marinhas bentônicas do Estado da Bahia. Acta Bot. Malacitana Univ. Málaga 23, 5–21.
Poli, C., Lopez, L.C.S., Mesquita, D.O., Saska, C., Mascarenhas, R., 2014. Patterns and inferred processes associated with sea turtle strandings in Paraíba State, Northeast Brazil. Braz. J. Biol. 74 (2), 283–289.
Schuyler, Q., Townsend, K., Hardesty, B.D., Wilcox, C., 2012. To eat or not to eat: debris selectivity by marine turtles. PLoS One 7 (7), e40884.
Schuyler, Q., Wilcox, C., Townsend, K., Hardesty, B.D., Marshall, N.J., 2014a. Mistaken identity? Visual similarities of marine debris to natural prey items of sea turtles. BMC Ecol. 14, 14.1–14.7.
Schuyler, Q., Hardesty, B.D., Wilcox, C., Townsend, K., 2014b. A global analysis of anthropogenic debris ingestion by sea turtles. Conserv. Biol. 28, 129–139.
Seminoff, J.A., Resendiz, A., Nichols, W.J., 2002a. Home range of green turtles (*Chelonia mydas*) in a coastal foraging area in the Gulf of California, Mexico. Mar. Ecol. Prog. Ser. 242, 253–265.
Seminoff, J.A., Resendiz, A., Nichols, W.J., 2002b. Diet of the East Pacific green turtle, *Chelonia mydas*, in the central Gulf of California, Mexico. J. Herpetol. 36, 447–453.
Tourinho, P.S., Ivar do Sul, J.A., Fillmann, G., 2010. Is marine debris ingestion still a problem for the coastal marine biota of southern Brazil? Mar. Pollut. Bull. 60, 396–401.
UNEP, 2009. Marine Litter: A Global Challenge. UNEP, Nairobi (232 pp.).