Mar Biol
DOI 10.1007/s00227-015-2738-1

CrossMark

ORIGINAL PAPER

High frequency of occurrence of anthropogenic debris ingestion by sea turtles in the North Pacific Ocean

Kathryn R. Wedemeyer-Strombel[1] · George H. Balazs[2] · James B. Johnson[3] · Taylor D. Peterson[4] · Mary K. Wicksten[5] · Pamela T. Plotkin[4]

Received: 29 October 2014 / Accepted: 3 September 2015

Abstract Ingestion of anthropogenic debris can have deleterious effects on sea turtles. To study diet content of sea turtles, four species were opportunistically collected as deceased bycatch over 18 years (1993–2011) from pelagic longline fisheries based in American Samoa and Hawaii (North Pacific between 140°–170°W and 20°S–50°N). Diet contents were analyzed from 71 sea turtles: 45 olive ridleys (*Lepidochelys olivacea*), 22 greens (*Chelonia mydas*), 2 loggerheads (*Caretta caretta*), and 2 leatherbacks (*Dermochelys coriacea*). This study reports some of the highest frequencies of anthropogenic debris ingestion documented for sea turtles, with 83 % of all the sea turtles sampled ingesting anthropogenic debris. Within species, 91 % of greens and 82 % of olive ridleys ingested anthropogenic debris. This is the first published report of anthropogenic debris ingestion by olive ridleys outside of the Atlantic Ocean. Neither of the leatherbacks ingested anthropogenic debris. The average dry weight of anthropogenic debris ingested by individual olive ridleys and individual greens was 4 and 7 g, respectively. The total dry weights of anthropogenic debris ingested by the two loggerheads were 9 and 120 g. Plastics were the most prominent anthropogenic debris ingested, making up 95 % (405 g dry weight) of the total 427 g ingested. Increased ingestion of anthropogenic debris was found in olive ridleys collected during the winter, which corresponds with the wintertime increase in anthropogenic debris accumulated in the North Pacific Subtropical Convergence Zone. This study highlights the need to better understand the factors affecting anthropogenic debris ingestion and its sublethal effects.

Responsible Editor: B. Wallace.

Reviewed by M. Frick, J. Senko, J. Tomas.

Electronic supplementary material The online version of this article (doi:10.1007/s00227-015-2738-1) contains supplementary material, which is available to authorized users.

✉ Kathryn R. Wedemeyer-Strombel
krwedemeyer@gmail.com

[1] Department of Wildlife and Fisheries Sciences, Texas A&M University, 214C Heep Laboratory Building, TAMU 2258, College Station, TX 77842-2258, USA

[2] Pacific Islands Fisheries Science Center, National Marine Fisheries Service, Honolulu, HI 96818, USA

[3] Department of Biology, University of Oklahoma, Norman, OK 73019, USA

[4] Department of Oceanography and Marine Biology Graduate Interdisciplinary Program, Texas A&M University, College Station, TX 77843, USA

[5] Department of Biology, Texas A&M University, College Station, TX 77843-3258, USA

Introduction

Anthropogenic debris in marine ecosystems, including items ranging from microscopic particles to large flotsam (e.g., ghost nets), is an ever increasing problem (Derraik 2002; Sheavly and Register 2007; Moore 2008; Cozar et al. 2014). Human-generated debris can entangle or be ingested by marine organisms, which may result in drowning, perforation, and obstruction of the gastrointestinal system, reduced nutrient absorption, absorption of toxic plasticizers, and suppression of the immune system (Balazs 1985; Gregory 2009; Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF 2012; Gall and Thompson 2015). Anthropogenic debris entanglement and ingestion is a taxonomically widespread phenomenon, having been reported for at least

Published online: 18 September 2015

693 marine species to date (Laist 1997; Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF 2012; Gall and Thompson 2015). Thus, with the potential for serious impact to marine systems, it is important to understand which species are at high risk and what factors, such as temporal variation, influence anthropogenic debris ingestion (Ryan et al. 2009; Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF 2012; Gall and Thompson 2015).

Oceanographic events, such as those occurring in the North Pacific Subtropical Gyre, could be impacting the ingestion of anthropogenic debris by marine species. Located in the North Pacific Ocean, this gyre and its Subtropical Convergence Zone are well known to aggregate passive items, such as anthropogenic debris (Moore et al. 2001; Pichel et al. 2007; Howell et al. 2012; Law et al. 2014). As a result, the eastern region of this gyre has been named "The Great Pacific Garbage Patch" by popular media (Moore 2003). The Subtropical Convergence Zone changes seasonally, including a wintertime southern latitudinal shift evidenced by the Transition Zone Chlorophyll Front (Dameron et al. 2007; Howell et al. 2012). This shift is especially pronounced during El Niño events (Bograd et al. 2004; Pichel et al. 2007) and has been associated with an increase in anthropogenic debris concentrations in the Northwestern Hawaiian Islands (Morishige et al. 2007; Ribic et al. 2012).

Convergence zones are also important foraging habitat for many marine species including pelagic fish, sea birds, and sea turtles (Carr 1987; Polovina et al. 2001; Vilchis et al. 2006), thus increasing their exposure to anthropogenic debris. Polovina et al. (2004) found that loggerhead and green sea turtles in the North Pacific Ocean appear to move toward the wintertime southern latitudinal shift of the Subtropical Convergence Zone. This movement could lead to an increase in anthropogenic debris exposure during winter, with an exaggerated increase during El Niño events. Despite this potential seasonal threat, the relationship between seasonal variation in the Subtropical Convergence Zone and its effects on anthropogenic debris ingestion by marine species has received very little and only anecdotal documentation (Spear et al. 1995; Donohue and Foley 2007; Jacobsen et al. 2010).

To investigate the frequency of anthropogenic debris ingestion, and factors affecting its prevalence, we sampled the diet content of sea turtles collected from this region. As one of the most ubiquitous large marine vertebrates, opportunistic sampling of sea turtles in the North Pacific Ocean provides a unique opportunity to grasp the extent of anthropogenic debris ingestion in one of the most debris-ridden marine ecosystems. The North Pacific Ocean is home to five of the seven described sea turtle species (Wallace et al. 2010), all of which are on the IUCN Red List of Threatened Species (IUCN 2014): green (*Chelonia mydas,* endangered), olive ridley (*Lepidochelys olivacea*, vulnerable), loggerhead (*Caretta caretta*, endangered), leatherback (*Dermochelys coriacea*, vulnerable), and hawksbill (*Eretmochelys imbricata*, critically endangered). A 2012 review on the impacts of anthropogenic debris on marine biodiversity ranked all five species within the top 10 for reported incidences of entanglement and ingestion of anthropogenic debris (Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF 2012). Moreover, due to the potentially high susceptibility of sea turtle–anthropogenic debris interactions by ingestion (Balazs 1985; Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF 2012; Schuyler et al. 2013; Gall and Thompson 2015), understanding its frequency of occurrence is important in order to mitigate its impact.

The objective of the current study was to evaluate the diet contents of olive ridley, green, loggerhead, and leatherback sea turtles that were incidentally caught in North Pacific Ocean pelagic longline fisheries. Pelagic longline fisheries operate in the North Pacific Ocean and frequently interact with sea turtles (McCracken 2000; Lewison et al. 2004; Lewison and Crowder 2007), providing an opportunity to sample species that are both protected and difficult to encounter in the high seas. Thus, diet content analysis from these deceased sea turtles provides an opportunity to quantify the amount and frequency of anthropogenic debris ingestion. In particular, we explored patterns of anthropogenic debris ingestion among species, sea turtle size, collection year, season, and El Niño cycle. Understanding the frequency of occurrence of anthropogenic debris ingestion of these species in this area will provide a baseline for comparing with future studies on other species and in other areas.

Materials and methods

Sample collection

The National Oceanic and Atmospheric Administration (NOAA) staff in Hawaii collected sea turtles incidentally captured and killed in the American Samoa-based and Hawaii-based pelagic longline fisheries over an 18-year period across all four boreal seasons (1993–2011; see Parker et al. 2005 for collection methods). All sea turtles were captured by hook except for the two leatherbacks that were entangled in the fishing line. The global positioning system (GPS) location of capture for each turtle was recorded, and the turtles' carapace size (straight and curved) was measured. Sea turtles were stored in a freezer until the

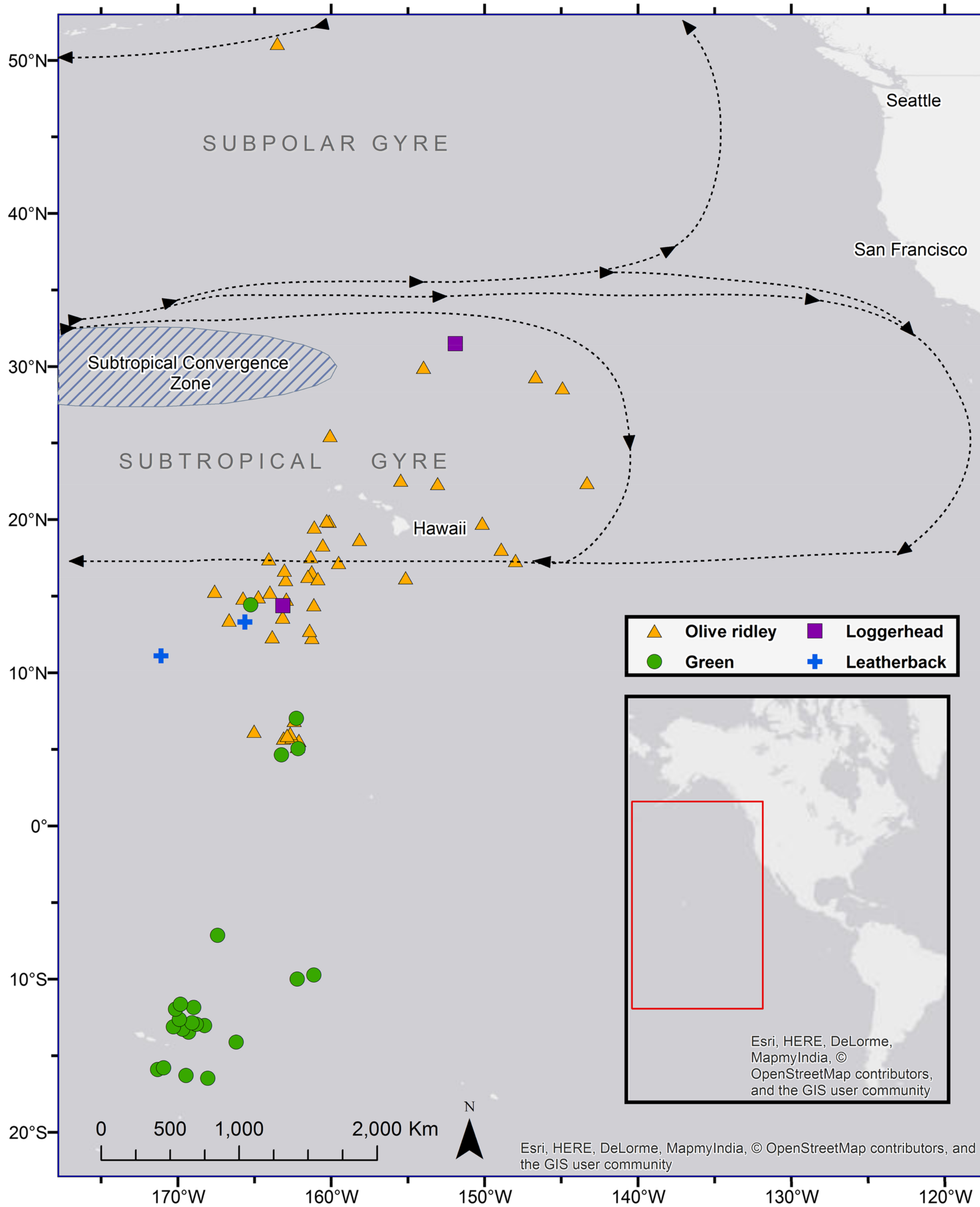

Fig. 1 GPS catch locations of olive ridley (*Lepidochelys olivacea*), green (*Chelonia mydas*), loggerhead (*Caretta caretta*), and leatherback (*Dermochelys coriacea*) sea turtles analyzed for diet content. NOAA observers collected sea turtles as bycatch on pelagic longline fisheries. Map was created in ArcGIS by K.R. Wedemeyer-Strombel, data from current study, projection UTM 4, 1:36,550,000. Schematic representation of currents (*dashed lines*), gyres and Subtropical Convergence Zone redrawn from Howell et al. (2012)

ship arrived in port. NOAA staff performed necropsies on the turtles, separated stomach only or whole gastrointestinal tract (GIT; including stomachs) from turtles, and placed their contents in 10 % neutral buffered formalin. Samples were drained before shipment to Texas A&M University. Upon receipt at Texas A&M, samples were rehydrated with 10 % neutral buffered formalin until analysis. The GPS coordinates of the capture location for each sea turtle were projected and classified by species (Fig. 1) using ArcMap 10.1 (ESRI, Redlands, California).

Table 1 Total percent composition by weight (in grams; $\%W_j$) of prey items (identified to lowest taxonomic order) found in the stomachs and/or gastrointestinal tract of olive ridley (*Lepidochelys olivacea*, $n = 45$), green (*Chelonia mydas*, $n = 22$), loggerhead (*Caretta caretta*, $n = 2$), and leatherback (*Dermochelys coriacea*, $n = 2$) sea turtles

Prey group	Olive ridley (*L. olivacea*) $\%W_j$ (g)	Green (*C. mydas*) $\%W_j$ (g)	Loggerhead (*C. Caretta*) $\%W_j$ (g)	Leatherback (*D. coriacea*) $\%W_j$ (g)
Anthropogenic debris	14	29	74	0
Osteichthyes				
Baitfish (Sama, *Cololabias saira*)	22	18	8	0
Actinopterygii	3	2	1	T
Actinopterygii eggs	1	0	0.4	0
Mollusca: Teuthoidea				
Cephalopoda	0.2	0.3	0.1	0
Mollusca: Gastropoda				
Ptenoglossa: *Janthina* spp.	1	6	0.6	0
Crustacea				
Lepadidae: *Lepas* spp.	34	0.4	0	0
Decapoda: crabs (*Planes* spp. and other unidentified)	T	0	0	T
Cnidaria: Hyrdrozoa: Hydroida				
Chordata: Urochordata				
Pyrosomatidae	T	T	0	0
Salpidae	7	3	0.2	94
Algae				
Sargassum spp.	0	10	T	0
Other				
Natural debris (wood, feathers, plant material, etc.)	0.5	2	0	0
Unidentified invertebrates	0	0.2	0	0
Chyme (unidentified digested material)	18	30	15	7

T = trace amounts (<0.1 g)

Diet analysis

Stomach and/or GIT samples were analyzed for 71 turtles, including olive ridley (25 stomachs, 20 GIT), green (20 stomachs; 2 GIT), loggerhead (1 stomach, 1 GIT), and leatherback (2 GIT). Stomach/GIT contents (depending on sample type collected during necropsy) were emptied into a 35-mm fine-mesh sieve, rinsed with water and drained. Using a binocular dissecting scope, prey items were identified to the lowest taxonomic level possible. Eight large prey categories were identified from the diet contents, which were further subdivided into 14 prey groups (Table 1). While anthropogenic debris is not necessarily natural prey, for ease of reporting we refer to all diet item categories as "prey groups." Fish were categorized as baitfish if they were whole or present as several large pieces and resembled the known baitfish species used by the pelagic longline fisheries (Sama, *Cololabias saira*). Small pieces and bone fragments were categorized as Actinopterygii (non-bait fishes). Unidentifiable gelatinous digested material was labeled as "chyme," and small unidentifiable pieces of shell were labeled as "unidentifiable invertebrates." Flotsam, such as wood, feathers, and plant material were identified as "natural debris." Plastic, rope, fishing line, and other anthropogenic debris were classified as "anthropogenic debris." Anthropogenic and natural debris were separated from other items and dried for 24 h at room temperature. All other prey items were placed in a drying oven at 60 °C for 24 h (Forbes 1999). After 24 h, all items were allowed to cool to room temperature before being weighed (Plotkin et al. 1993). For each specimen, mass (to the nearest 0.001 g) of each prey group and total dry weight of the stomach/GIT contents were estimated (Table S2).

To estimate the relative importance of prey groups, percent composition by weight for individuals ($\%W_i$) and for species ($\%W_j$) was calculated (Bowen 1996). We included chyme in the calculation of relative importance to account for the mass of prey items which have been digested (Bowen 1996). For each individual sea turtle, percent composition by weight of diet content (in grams) of each prey group ($\%W_i$) was estimated as follows:

$$\%W_i = \frac{\text{Weight of prey group for turtle } i}{\text{Total weight of all prey groups for turtle } i} \times 100$$

For each species, percent composition by weight of diet content of each prey group ($\%W_j$; in grams) was calculated as follows:

$$\%W_j = \frac{\text{Weight of prey group in all samples of turtle species } j}{\text{Total weight of all samples for turtle species } j} \times 100$$

Percent composition by weight of diet content by individuals ($\%W_i$) and species ($\%W_j$) for olive ridley and green sea turtles was arcsine square-root-transformed (Seminoff et al. 2002), hereafter referred to as transformed prey group percent composition by weight ($\%W_{iT}$ and $\%W_{jT}$, respectively). Due to low sample sizes for loggerhead and leatherback sea turtles, $\%W_i$ and $\%W_j$ were not transformed nor frequency methods applied. However, values for $\%W_j$ for both species are reported in Table 1.

In addition, percent frequency of occurrence ($\%F$) was calculated. Percent frequency of occurrence indicates the extent to which a given species uniformly select their diet (Bowen 1996), and unlike percent weight ($\%W_i$, $\%W_j$), percent frequency does not suffer from bias toward heavier prey items (Forbes 1999). Percent frequency of occurrence could not be calculated for loggerheads and leatherback turtles due to low sample sizes. Percent frequency of occurrence was calculated as:

$$\%F = \frac{\text{Number of samples of turtle species } j \text{ containing prey group}}{\text{Total number of samples for turtle species } j} \times 100$$

Statistical analyses

For olive ridley and green sea turtles, we evaluated normality of the transformed prey group percent composition by weight for individuals ($\%W_{iT}$) data matrix using Royston's Multivariate Normality Test (package "MVN"; Korkmaz and Goksuluk 2014; R Development Core Team 2014). $\%W_{iT}$ data were strongly non-normal (Royston's Multivariate Normality Test: $H = 691.56$, $P \leq 0.001$); thus, parametric methods were deemed inappropriate.

Before performing further analysis, we evaluated if samples from either the GIT or stomach were biased with respect to prey item composition using nonparametric permutation multivariate analysis of variance (perMANOVA) where $\%W_{iT}$ for all 14 prey groups were the dependent variables and gastrointestinal tract (stomachs or GIT) was the independent variable. Analysis was performed using the Vegan package (function "adonis"; number of permutations = 9999; Oksanen et al. 2013). We found no difference in percent composition by weight of prey items ($\%W_{iT}$) between stomach and full GIT samples (perMANOVA, $F(1,65) = 1.3$, $P = 0.268$). Thus, stomach and GIT were not evaluated further.

To compare transformed percent composition by weight of prey items ($\%W_{iT}$), we estimated medians (which is a more appropriate estimate of location for non-normal data; Sokal and Rohlf 1994) and corresponding confidence intervals for all 14 prey groups for olive ridley and green sea turtles. Nonparametric confidence intervals were estimated using bootstrap resampling (999 resamples; package "boot"; R Development Core Team 2014). A lack of overlap in confidence intervals between different prey items indicates prey items strongly differ from one another, and if a confidence interval does not overlap with zero for a given prey item, it suggests that the prey item is different from zero (Sokal and Rohlf 1994). This approach is preferable to multiple pairwise comparisons of $\%W_{iT}$, as that approach would result in an extreme number of comparisons within and among species (273 pairwise comparisons in total). However, just as with multiple pairwise comparisons, estimation of multiple confidence intervals suffers from increased type 1 error rates. Thus, a desired confidence level of 95 % is smaller in reality, i.e., less likely to have overlap and therefore could overestimate differences. To accommodate increased type 1 error rate variables, we increased the width of the confidence interval by dividing the desired confidence level (i.e., 95 %) by the number of variables (14) which yielded a corrected confidence level of 99.6 % (Sokal and Rohlf 1994).

To determine if sample year, sample season, El Niño cycle, and sea turtle size (straight carapace length, SCL) differed with respect to the transformed percent composition by weight of anthropogenic debris ingested among individuals ($\%W_{iT}$), the data were subjected to an analysis of variance (ANOVA) on ranks. ANOVA on ranks compares differences in means of the rank-transformed dependent variable and relaxes the assumptions of normality associated with traditional ANOVA (Conover and Iman 1981). Two rank ANOVAs were performed, one for green sea turtles and the other for olive ridleys. Both rank ANOVA models consisted of anthropogenic debris ingestion as the dependent variable and species, season, El Niño cycle, sea turtle size, and sample year as independent variables. Interaction terms were evaluated, and all were found to be non-significant (all $P \geq 0.07$) and were thus not included. We defined winter as December–February, spring as March–May, summer as June–August, and fall as September–November (i.e., boreal seasons). El Niño cycle was established based on Wang et al. (2012).

Results

The mean straight carapace length (SCL) for olive ridleys was 54.2 ± 1.1 cm, $n = 45$, and for greens was 41.8 ± 2.1 cm, $n = 22$. The two loggerheads sampled were

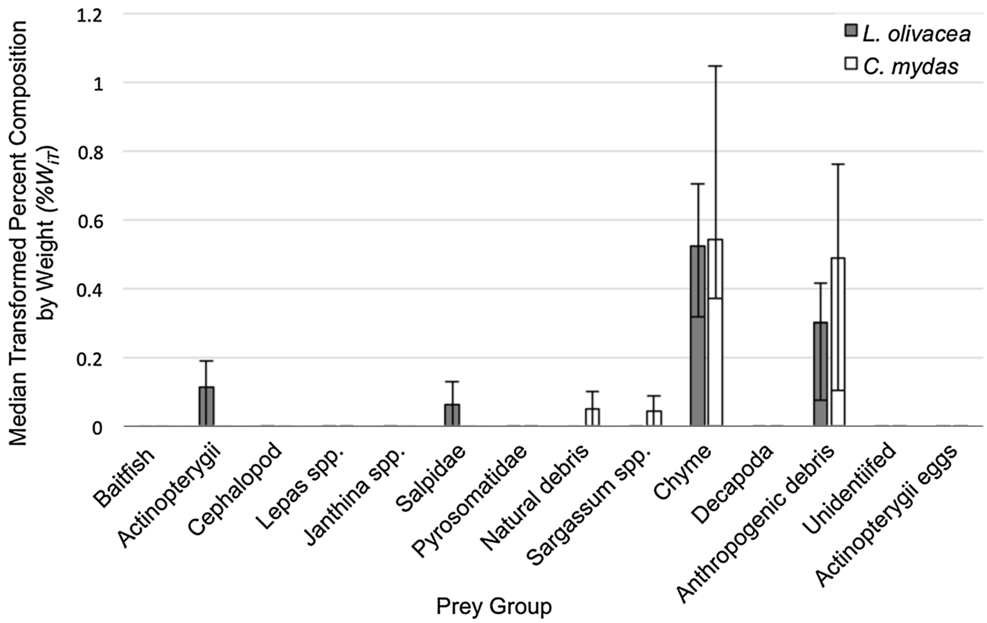

Fig. 2 Medians and adjusted nonparametric bootstrapped 99 % confidence intervals for transformed percent frequency of occurrence of prey groups (%W_{iT}). *Gray bars* represent olive ridleys (*L. olivacea*), and *white bars* represent *greens* (*C. mydas*)

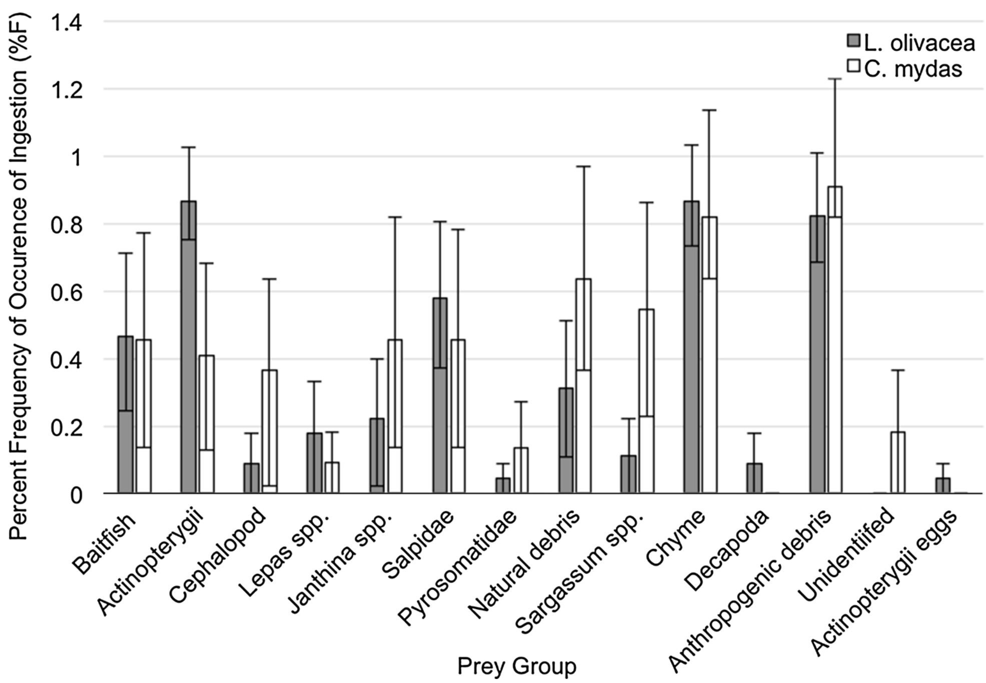

Fig. 3 Percent frequency of occurrence of ingestion (%*F*) of prey groups and associated adjusted nonparametric bootstrapped 99 % confidence intervals for olive ridleys (*L. olivacea, gray bars*) and *greens* (*C. mydas, white bars*)

57.5 and 68.2 cm SCL, and the two leatherbacks were 39.3 and 70.4 cm SCL (see Table S1 for curved carapace lengths).

Medians and confidence intervals for transformed percent composition by weight (%W_{iT}) suggest that chyme and anthropogenic debris were the only prey which were prominent components of the diet of green and olive ridley turtles (Fig. 2). The percent composition by weight (%W_j) for anthropogenic debris for olive ridleys was 14 %, for greens was 29 %, for loggerheads was 74 %, and for leatherbacks was 0 % (Table 1).

The percent frequency of occurrence (%*F*) and associated confidence intervals (Fig. 3) show that anthropogenic debris, chyme, Actinopterygii, baitfish, natural debris, and *Janthina* spp. were common prey items found in both green and olive ridley sea turtles. However, greens commonly consumed cephalopods and *Sargassum* spp., while olive ridleys consumed a greater frequency of Actinopterygii relative to green turtles (Fig. 3). Both species were found to have a high percent frequency of occurrence of anthropogenic debris with 82 %*F* for olive ridleys and 91 %*F* for green sea turtles.

ANOVA on ranks suggests that season had a significant relationship with the percentage of weight of anthropogenic debris for olive ridley but not for green sea turtles (Table 2). Medians and confidence intervals of percent composition by weight of anthropogenic debris across seasons suggest that olive ridley sea turtles ingested the most anthropogenic debris during the summer, fall, and winter (Fig. 4). This pattern of seasonal variation in ingestion was also found for percent frequency of occurrence of anthropogenic debris ingestion by olive ridley sea turtles (Fig. 5). Sea turtle size was also significantly associated with anthropogenic debris ingestion (Table 2). In green turtles, we observed a negative relationship between size and anthropogenic debris ingestion ($r = -0.42$), while in olive ridleys it was positive ($r = 0.30$). Year of collection and El Niño cycle did not have a significant association with anthropogenic debris ingestion for either green or olive ridley sea turtles (Table 2).

The variety of anthropogenic debris found in olive ridleys, greens, and loggerheads included a hair comb, plastic bags, fishing line, rope, plastic bottle caps, plastic bottle necks, polystyrene, and small plastic pieces of unidentified origin (both hard and soft; Figs. 6, 7, 8). One of the loggerheads ingested a toothbrush, 16 plastic bottle caps, and two plastic water bottle necks (Fig. 6). Plastic was the most prominent anthropogenic debris ingested. Of the 427.08 g (dry weight) of anthropogenic debris ingested by all species combined, 405.223 g (95 %) of it was plastic debris. Plastic accounted for 94 % of the dry weight of anthropogenic debris ingested by green turtles, 93 % for olive ridleys, 99 % for one loggerhead, and 93 % for the other loggerhead.

Table 2 ANOVA on ranks on transformed percent composition by weight of anthropogenic debris for (a) olive ridley (*Lepidochelys olivacea*) and (b) green (*Chelonia mydas*) sea turtles

Effect	Sum of squares	Degrees of freedom	*F*	*P*
a				
Season	1357.8	3	3.228	**0.033**
Year	7.3	1	0.052	0.820
El Niño	157.7	1	1.124	0.296
SCL	633.6	1	4.518	**0.040**
Residuals	5328.9	38		
b				
Season	191.72	3	2.287	0.120
Year	3.32	1	0.119	0.735
El Niño	16.45	1	0.589	0.455
SCL	169.09	1	6.052	**0.027**
Residuals	419.12	15		

A bold *P*-values indicate a statistically significant effect

Discussion

Our results of the frequency of occurrence of anthropogenic debris ingestion by green (91 %) and olive ridley (82 %) sea turtles are among the highest published values for sea turtles (Balazs 1985; Tourinho et al. 2010; Campani et al. 2013; Schuyler et al. 2013; Di Beneditto and Awabdi 2014; Hoarau et al. 2014; Ormedilla et al. 2014; da Silva Mendes et al. 2015; Guimarães Santos et al. 2015). The present study is the first published report of anthropogenic debris ingestion by olive ridleys in the Pacific, and only the second published report of anthropogenic debris ingestion for the species (Mascarenhas et al. 2004). While our loggerhead data are limited, both specimens consumed anthropogenic debris. The majority of anthropogenic debris ingested was plastic, both across all species and within each species. The prevalence of anthropogenic debris ingestion found in these sea turtles reflects the serious problem of anthropogenic debris accumulation in the North Pacific Ocean.

The current study supports the hypothesis that sea turtles (Carr 1987; Polovina et al. 2004; Parker et al. 2005) and anthropogenic debris (Moore et al. 2001; Pichel et al. 2007; Howell et al. 2012; Law et al. 2014) are commonly found near convergence zones (Fig. 1; Table 1). The North Pacific Subtropical Convergence Zone southern shift is similarly timed to seasonal movements of olive ridleys and loggerheads in the North Pacific Ocean, with loggerheads moving N to S and olive ridleys S to N (Polovina et al. 2004), bringing them each closer to the southern-shifted North Pacific Subtropical Convergence Zone. This could expose the sea turtles to the high concentrations of anthropogenic debris found in the convergence zone (Moore et al. 2001; Pichel et al. 2007; Howell et al. 2012; Law et al. 2014), thus contributing to the seasonal increase in anthropogenic debris ingestion by olive ridleys found in the present study. The seasonal effect on anthropogenic debris ingestion reported here (Fig. 4; Table 2) suggests that debris ingestion by olive ridley sea turtles was high in winter (relative to spring) but was not greater than the fall or summer months (Fig. 4; Table 2). The southern latitudinal shift of the North Pacific Subtropical Convergence Zone is thought to have contributed to the fatal ingestion of anthropogenic debris by two sperm whales (*Physeter macrocephalus*; Jacobsen et al. 2010). This shift of the North Pacific Subtropical Convergence Zone is further pronounced during El Niño years (Bograd et al. 2004; Pichel et al. 2007) and has been shown to increase the entanglement rates of critically endangered Hawaiian monk seals (*Monachus schauinslandi*; Donohue and Foley 2007). Although El Niño events occurred in 2002, 2004–2007, and 2009–2010 (Wang et al. 2012), we found no increase in ingestion of anthropogenic debris during those years (Table 2).

In our study, we found a significant positive correlation between SCL and percent by weight ($\%W_{iT}$) of

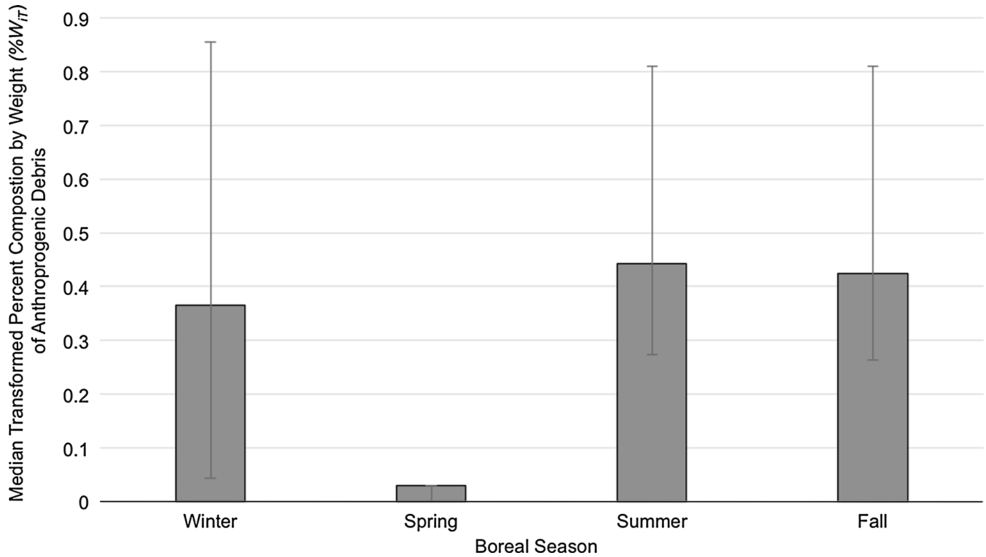

Fig. 4 Medians and adjusted nonparametric bootstrapped 99 % confidence intervals for transformed percent composition by weight of anthropogenic debris ($\%W_{iT}$) ingested by olive ridley sea turtles (*L. olivacea*) by boreal season (winter, December–February; spring, March–May; summer, June–August; fall, September–November)

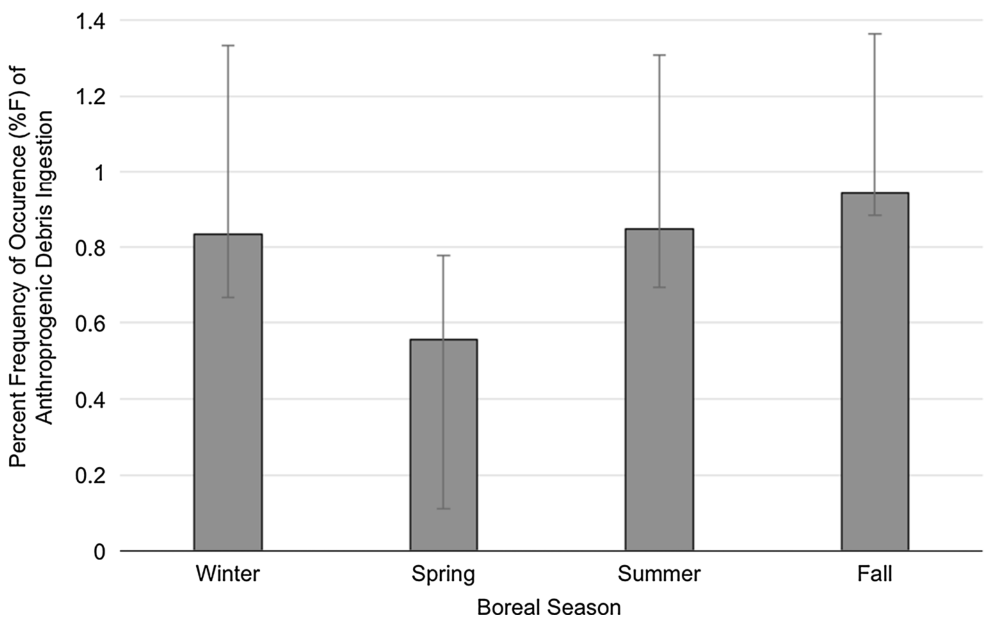

Fig. 5 Percent frequency of occurrence (%*F*) and adjusted nonparametric bootstrapped 99 % confidence intervals of anthropogenic debris ingested by olive ridley sea turtles (*L. olivacea*) by boreal season (winter, December–February; spring, March–May; summer, June–August; fall, September–November)

anthropogenic debris ingested for olive ridleys and a significant negative correlation for greens. To our knowledge, this is only the second study to report a positive correlation between sea turtle size and weight of anthropogenic debris ingested (Campani et al. 2013). Several publications have found no significant correlation between sea turtle size and weight of ingested anthropogenic debris (Bugoni et al. 2001; Tomás et al. 2002; Lazar and Gračan 2011; Hoarau et al. 2014). Two other studies have found negative correlations between these two factors, which are generally thought to be a result of older animals recruiting to neritic habitats and therefore being less exposed to anthropogenic debris than young oceanic sea turtles (Balazs 1985; Plotkin and Amos 1990), which could be the case here for our green sea turtles.

While our specimens did not die as a direct result of anthropogenic debris ingestion, a recent study suggested that death by anthropogenic debris ingestion is potentially underestimated (Guimarães Santos et al. 2015). Guimarães Santos et al. (2015) hypothesized that more immediate causes of death, like fisheries bycatch, may occur before the fatal effects of anthropogenic debris ingestion take their toll. Nearly half of the juvenile green turtles in the study by Guimarães Santos et al. (2015) died as a direct result of anthropogenic debris ingestion of less than 2.5 g of debris, with a critical amount of only 0.5 g enough to cause death by digestive tract blockage. Equally sized green turtles in our study, on average, had over two times that amount of anthropogenic debris ingestion with an average of 6.9 g,

Fig. 6 Anthropogenic debris ingestion by one loggerhead (*Caretta caretta*). The *picture* shows four sheets of A4 white paper (21 × 29.7 cm) covered in anthropogenic debris, which made up 78 % of this individual's diet (%W_i). Photograph: K.R. Wedemeyer-Strombel

Fig. 7 Anthropogenic debris ingestion by one green turtle (*Chelonia mydas*). The *picture* shows eight sheets of A4 white paper (21 × 29.7 cm) covered in plastic bags and small plastic pieces, which made up 75 % of the individual's diet (%W_i). Photograph: K.R. Wedemeyer-Strombel

which is 13.8 times the critical amount of 0.5 g to cause death by anthropogenic debris ingestion. Our olive ridleys and loggerheads had larger curved carapace lengths, on average, than the greens studied by Guimarães Santos et al. (2015), but were within the same size range. Our olive ridleys ingested an average of 3.8 g of anthropogenic debris, and one loggerhead in our study consumed 120.2 g (Fig. 2) of anthropogenic debris. Regardless of the loggerhead's larger size, that number is 48 times larger than the 2.5 g that killed nearly half of the green turtles in the study by Guimarães Santos et al. (2015), and 240 times larger than the critical value of 0.5 g.

Natural (non-anthropogenic debris) prey groups for all species analyzed were as expected (Table 1) and support results of previous studies on olive ridleys (Polovina et al. 2003; National Marine Fisheries Service and U.S. Fish and Wildlife Service 2007; Abreu-Grobois and Plotkin 2008; Plotkin 2010), greens (Arthur et al. 2008; Boyle and Limpus 2008; Jones and Seminoff 2013), loggerheads (Polovina et al. 2003; Polovina et al. 2004; Parker

Fig. 8 Anthropogenic debris ingestion by an olive ridley (*Lepidochelys olivacea*). The *picture* shows two sheets of A4 white paper (21 × 29.7 cm) covered in small plastic pieces and pieces of netting and rope, making up 48 % of the individual's diet (%W_i). Photograph: K.R. Wedemeyer-Strombel

et al. 2005; Kobayashi et al. 2008; Peckham et al. 2011), and leatherbacks (Lutcavage and Lutz 1986; Bjorndal 1997; Godley et al. 1998; Seminoff et al. 2012). Some of the natural prey, like *Lepas spp.*, are known to consume microplastics (Goldstein and Goodwin 2013) and colonize hard plastics (Parker et al. 2011), which could have incidentally contributed to the overall anthropogenic debris load of the sea turtles. The ingestion of multiple baitfish by several olive ridleys, greens, and by both loggerheads suggests they were feeding from one pelagic longline to another before capture. For loggerheads, this supports the hypothesis that they may ingest only injured or dead fish (Tomás et al. 2001; Parker et al. 2005), which could have been available on the longlines.

Opportunistically sampled sea turtles provided the opportunity to identify the diet contents of these oceanic animals and contribute to the critical conversation on sea turtle anthropogenic debris ingestion. Bycaught sea turtles may not be a complete representation of the whole population (Kaiser and Spencer 1994; Beukers-Stewart and Jones 2004; Lewison and Crowder 2007), could underrepresent healthy individuals (Forbes 1999), and could bias for seasonality, although the American Samoa fisheries effort (by number of sets) had consistent averages across all fishing quarters from 1997 to 2011(PIFSC Fisheries Research and Monitoring Division 2014). Diet content analysis in such sea turtles may overrepresent easy-to-identify and harder-/slower-to-digest items (e.g., anthropogenic debris) and opportunistic atypical prey (e.g., baitfish) (Bromley 1994; Kaiser and Spencer 1994; Bowen 1996). Such studies still provide a snapshot of what these sea turtles are eating (Bowen 1996; Forbes 1999), namely anthropogenic debris.

Conservation implications and future directions

The sublethal effects of anthropogenic debris ingestion are not well known for sea turtles or other species (Vegter et al. 2014). They are hypothesized to include dietary dilution, perforation and obstruction of gastrointestinal tract, and toxin absorption, all of which may impact development and reproductive output, thus lowering the organism's overall fitness (McCauley and Bjorndal 1999). More broadly, anthropogenic debris ingestion, especially that of plastics, affects several marine trophic levels, transferring organic pollutants throughout the food chain (Vegter et al. 2014). This is likely resulting in bioaccumulation of toxins within the marine ecosystem, which could influence ecosystem processes, but how and to what extent are still unknown (Vegter et al. 2014). The results from the present study emphasize the need for future research in this area and support species-level, population-level, and trophic linkage impacts of marine pollution on marine animals as top global research priorities (Vegter et al. 2014).

Combined with data on other protected species (critically endangered *Monachus schauinslandi*, Donohue and Foley 2007; vulnerable *Physeter macrocephalus*, Jacobsen et al. 2010; IUCN 2014), the present study lends support to the idea that seasonal physical oceanographic features may drive marine species–anthropogenic debris interactions. The continued monitoring of these protected populations, their seasonal movements, and their associations with physical oceanographic features and meteorological events are critical, as is the mitigation of anthropogenic debris pollution of the marine environment.

Acknowledgments We thank the Texas A&M University Marine Biology Graduate Interdisciplinary Program and the Texas A&M University Department of Biology for financial support for this research. This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-1252521. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Special thanks to Jeffrey Seminoff, Tarla Rai Peterson, Sarah Flanagan, Laura Edelstein, and Rachael Fajardo for guidance during the writing process, and Brittany Schwartzkopf, Charlayna Cammarata, and Samantha Trent for helpful comments on early versions of the manuscript. Thomas DeWitt and Gil Rosenthal provided usage of a drying oven, and Joseph Bernardo allowed access to dissection equipment. Thank you to Bryan Wallace, Barbara Santer, and our three reviewers, M. Frick, J. Senko and J. Tomás, for constructive comments on this manuscript, especially in reference to reexamining seasonality.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted. This article does not contain studies with human participants by any of the authors.

References

Abreu-Grobois A, Plotkin P (2008) IUCN red list for *Lepidochelys olivacea*

Arthur KE, Boyle MC, Limpus CJ (2008) Ontogenetic changes in diet and habitat use in green sea turtle (*Chelonia mydas*) life history. Mar Ecol Prog Ser 362:303–311. doi:10.3354/meps07440

Balazs GH (1985) Impact of ocean debris on marine turtles: entanglement and ingestion. In: Proceedings of the workshop on the fate and impact of marine debris US National Oceanic and Atmospheric Administration (NOAA) Technical memorandum 54. National Marine Fisheries Service, Honolulu, pp 387–429

Beukers-Stewart B, Jones G (2004) The influence of prey abundance on the feeding ecology of two piscivorous species of coral reef fish. J Exp Mar Biol Ecol 299:155–184. doi:10.1016/j.jembe.2003.08.015

Bjorndal KA (1997) Foraging ecology and nutrition of sea turtles. In: Lutz PL, Musick JA (eds) The biology of sea turtles. CRC Press, Boca Raton, pp 397–409

Bograd SJ, Foley DG, Schwing FB, Wilson C, Laurs RM, Polovina JJ, Howell EA, Brainard RE (2004) On the seasonal and interannual migrations of the transition zone chlorophyll front. Geophys Res Lett. doi:10.1029/2004gl020637

Bowen SH (1996) Quantitative description of the diet. Fisheries techniques, 2nd edn. American Fisheries Society, Bethesda, pp 513–532

Boyle MC, Limpus CJ (2008) The stomach contents of post-hatchling green and loggerhead sea turtles in the southwest Pacific: an insight into habitat association. Mar Biol 155:233–241. doi:10.1007/s00227-008-1022-z

Bromley PJ (1994) The role of gastric evacuation experiments in quantifying the feeding rates of predatory fish. Rev Fish Biol Fish 4:36–66. doi:10.1007/BF00043260

Bugoni L, Krause L, Petry V (2001) Marine debris and human impacts on sea turtles in Southern Brazil. Mar Pollut Bull 42:1330–1334. doi:10.1016/S0025-326X(01)00147-3

Campani T, Baini M, Giannetti M, Cancelli F, Mancusi C, Serena F, Marsili L, Casini S, Fossi MC (2013) Presence of plastic debris in loggerhead turtle stranded along the Tuscany coasts of the Pelagos Sanctuary for Mediterranean Marine Mammals (Italy). Mar Pollut Bull 74:225–230. doi:10.1016/j.marpolbul.2013.06.053

Carr A (1987) Impact of nondegradable marine debris on the ecology and survival outlook of sea turtles. Mar Pollut Bull 18:352–356. doi:10.1016/S0025-326X(87)80025-5

Conover WJ, Iman RL (1981) Rank transformations as a bridge between parametric and nonparametric statistics. Am Stat 35:124–129. doi:10.1080/00031305.1981.10479327

Cozar A, Echevarria F, Gonzalez-Gordillo JI, Irigoien X, Ubeda B, Hernandez-Leon S, Palma AT, Navarro S, Garcia-de-Lomas J, Ruiz A, Fernandez-de-Puelles ML, Duarte CM (2014) Plastic debris in the open ocean. PNAS 111:10239–10244. doi:10.1073/pnas.1314705111

da Silva Mendes S, de Carvalho RH, de Faria AF, de Sousa BM (2015) Marine debris ingestion by *Chelonia mydas* (Testudines: Cheloniidae) on the Brazilian coast. Mar Pollut Bull. doi:10.1016/j.marpolbul.2015.01.010

Dameron OJ, Parke M, Albins MA, Brainard R (2007) Marine debris accumulation in the Northwestern Hawaiian Islands: an examination of rates and processes. Mar Pollut Bull 54:423–433. doi:10.1016/j.marpolbul.2006.11.019

Derraik JGB (2002) The pollution of the marine environment by plastic debris: a review. Mar Pollut Bull 44:842–852. doi:10.1016/S0025-326X(02)00220-5

Development Core Team R (2014) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

Di Beneditto AP, Awabdi DR (2014) How marine debris ingestion differs among megafauna species in a tropical coastal area. Mar Pollut Bull 88:86–90. doi:10.1016/j.marpolbul.2014.09.020

Donohue M, Foley DG (2007) Remote sensing reveals links among the endangered hawaiian monk seal, Marine debris, and El Niño. Mar Mamm Sci 23:468–473. doi:10.1111/j.1748-7692.2007.00114.x

Forbes GA (1999) Diet sampling and diet component analysis. In: Eckert KL, Bjorndal KA, Abreu-Grobois FA, Donnelly M (eds) Research and management techniques for the conservation of sea turtles. IUCN/SSC Marine Turtle Specialist Group Publication No. 4

Gall SC, Thompson RC (2015) The impact of debris on marine life. Mar Pollut Bull. doi:10.1016/j.marpolbul.2014.12.041

Godley BJ, Thompson DR, Waldron S, Furness RW (1998) The trophic status of marine turtles as determined by stable isotope analysis. Mar Ecol Prog Ser 166:277–284. doi:10.3354/meps166277

Goldstein MC, Goodwin DS (2013) Gooseneck barnacles (*Lepas* spp.) ingest microplastic debris in the North Pacific subtropical gyre. Peer J 1:e184. doi:10.7717/peerj.184

Gregory MR (2009) Environmental implications of plastic debris in marine settings–entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos Trans R Soc Lond B Biol Sci 364:2013–2025. doi:10.1098/rstb.2008.0265

Guimarães Santos R, Andrades R, Altoé Boldrini M, Martins AS (2015) Debris ingestion by juvenile marine turtles: an underestimated problem. Mar Pollut Bull 93:37–43. doi:10.1016/j.marpolbul.2015.02.022

Hoarau L, Ainley L, Jean C, Ciccione S (2014) Ingestion and defecation of marine debris by loggerhead sea turtles, *Caretta caretta*, from by-catches in the South-West Indian Ocean. Mar Pollut Bull 84:90–96. doi:10.1016/j.marpolbul.2014.05.031

Howell EA, Bograd SJ, Morishige C, Seki MP, Polovina JJ (2012) On North Pacific circulation and associated marine debris concentration. Mar Pollut Bull 65:16–22. doi:10.1016/j.marpolbul.2011.04.034

IUCN (2014) 2014 IUCN Red List of threatened species. IUCN-SSC. http://www.iucnredlist.org

Jacobsen JK, Massey L, Gulland F (2010) Fatal ingestion of floating net debris by two sperm whales (*Physeter macrocephalus*). Mar Pollut Bull 60:765–767. doi:10.1016/j.marpolbul.2010.03.008

Jones TT, Seminoff JA (2013) Feeding biology, advances from field-based observations, physiological studies, and molecular techniques. In: Wyneken J, Lohmann KJ, Musick JA (eds) The biology of sea turtles, vol III. CRC Press, Boca Raton, pp 211–248

Kaiser M, Spencer B (1994) Fish scavenging behaviour in recently trawled areas. Mar Ecol Prog Ser 112:41–49. doi:10.3354/meps112041

Kobayashi DR, Polovina JJ, Parker DM, Kamezaki N, Cheng IJ, Uchida I, Dutton PH, Balazs GH (2008) Pelagic habitat characterization of loggerhead sea turtles, *Caretta caretta*, in the North Pacific Ocean (1997–2006): insights from satellite tag tracking and remotely sensed data. J Exp Mar Biol Ecol 356:96–114. doi:10.1016/j.jembe.2007.12.019

Korkmaz S, Goksuluk D (2014) MVN: multivariate normality tests R package version 34

Laist DW (1997) Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records marine debris. Springer, New York

Law KL, Moret-Ferguson SE, Goodwin DS, Zettler ER, Deforce E, Kukulka T, Proskurowski G (2014) Distribution of surface plastic debris in the Eastern Pacific Ocean from an 11-year data set. Environ Sci Technol 48:4732–4738. doi:10.1021/es4053076

Lazar B, Gračan R (2011) Ingestion of marine debris by loggerhead sea turtles, *Caretta caretta*, in the Adriatic Sea. Mar Pollut Bull 62:43–47. doi:10.1016/j.marpolbul.2010.09.013

Lewison RL, Crowder LB (2007) Putting longline bycatch of sea turtles into perspective. Conserv Biol 21:79–86. doi:10.1111/j.1523-1739.2006.00592.x

Lewison RL, Freeman SA, Crowder LB (2004) Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecol Lett 7:221–231. doi:10.1111/j.1461-0248.2004.00573.x

Lutcavage M, Lutz PL (1986) Metabolic rate and food energy requirements of the leatherback sea turtle, *Dermochelys coriacea*. Copeia 3:796–798. doi:10.2307/1444962

Mascarenhas R, Santos R, Zeppelini D (2004) Plastic debris ingestion by sea turtle in Paraíba, Brazil. Mar Pollut Bull 49:354–355. doi:10.1016/j.marpolbul.2004.05.006

McCauley SJ, Bjorndal KA (1999) Conservation implications of dietary dilution from debris ingestion: sublethal effects in post-hatchling loggerhead sea turtles. Conserv Biol 13:925–929

McCracken ML (2000) Estimation of sea turtle take and mortality in the Hawaiian longline fisheries. Southwest Fisheries Science Center Administrative Report H-00-06. National Marine Fisheries Service, NOAA, Honolulu, Hawaii

Moore C (2003) Trashed: across the Pacific Ocean, plastics, plastics everywhere. Nat Hist 112:46–51

Moore CJ (2008) Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. Environ Res 108:131–139. doi:10.1016/j.envres.2008.07.025

Moore CJ, Moore SL, Leecaster MK, Weisberg SB (2001) A comparison of plastic and plankton in the North Pacific central gyre. Mar Pollut Bull 42:1297–1300. doi:10.1016/S0025-326X(01)00114-X

Morishige C, Donohue MJ, Flint E, Swenson C, Woolaway C (2007) Factors affecting marine debris deposition at French Frigate Shoals, Northwestern Hawaiian Islands Marine National Monument, 1990–2006. Mar Pollut Bull 54:1162–1169. doi:10.1016/j.marpolbul.2007.04.014

National Marine Fisheries Service and U.S. Fish and Wildlife Service (2007) Olive ridley sea turtle (*Lepidochelys olivacea*) 5-year Review: Summary and Evaluation. U.S. Department of Commerce and the U.S. Department of the Interior

Oksanen J, Guillaume Blanchet F, Kindt R, Legendre P, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH, Wagner H (2013) vegan: community ecology package. R Package version 20-10

Ormedilla AC, Pereira TB, Monteiro MZ, Maranho A (2014) Analysis of anthropogenic waste found in the digestive tract of green turtles (*Chelonia mydas*). Unisanta BioScie 3:83–89

Parker DM, Cooke WJ, Balazs GH (2005) Diet of oceanic loggerhead sea turtles (*Caretta caretta*) in the central North Pacific. Fish Bull 103(142–152):0090–0656

Parker DM, Dutton PH, Balazs GH (2011) Oceanic diet and distribution of haplotypes for the green turtle, *Chelonia mydas*, in the Central North Pacific. Pac Sci 65:419–431. doi:10.2984/65.4.419

Peckham SH, Maldonado DD, Tremblay Y, Ochoa R, Polovina J, Balazs G, Dutton PH, Nichols WJ (2011) Demographic implications of alternative foraging strategies in juvenile loggerhead turtles *Caretta caretta* of the North Pacific Ocean. Mar Ecol Prog Ser 425:269–280. doi:10.3354/meps08995

Pichel WG, Churnside JH, Veenstra TS, Foley DG, Friedman KS, Brainard RE, Nicoll JB, Zheng Q, Clemente-Colon P (2007) Marine debris collects within the North Pacific Subtropical Convergence Zone. Mar Pollut Bull 54:1207–1211. doi:10.1016/j.marpolbul.2007.04.010

PIFSC Fisheries Research and Monitoring Division (2014) PIFSC report on the logbook program for the American Samoa longline fishery October–December 2013. Pacific Islands Fisheries Science Center, PIFSC Data Report DR-14-005

Plotkin PT (2010) Nomadic behaviour of the highly migratory olive ridley sea turtle *Lepidochelys olivacea* in the eastern tropical Pacific Ocean. Endanger Species Res 13:33–40. doi:10.3354/esr00314

Plotkin P, Amos AF (1990) Effects of anthropogenic debris on sea turtles in the Northwestern Gulf of Mexico. In: Shomura RS, Godfrey ML (eds) Conference on Marine Debris. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-SWFSC-154, Honolulu, Hawaii

Plotkin PT, Wicksten MK, Amos AF (1993) Feeding ecology of the loggerhead sea turtle *Caretta caretta* in the Northwestern Gulf of Mexico. Mar Biol 115:1–15. doi:10.1007/BF00349379

Polovina JJ, Howell E, Kobayashi DR, Seki MP (2001) The transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources. Prog Oceanogr 49:469–483. doi:10.1016/S0079-6611(01)00036-2

Polovina JJ, Howell E, Parker DM, Balazs GH (2003) Dive-depth distribution of loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*) sea turtles in the central North Pacific Ocean: might deep longline sets catch fewer turtles? Fish Bull 101(189–193):0090–0656

Polovina JJ, Balazs GH, Howell EA, Parker DM, Seki MP, Dutton PH (2004) Forage and migration habitat of loggerhead (*Caretta*

caretta) and olive ridley (*Lepidochelys olivacea*) sea turtles in the central North Pacific Ocean. Fish Oceanogr 13:36–51. doi:10.1046/j.1365-2419.2003.00270.x

Ribic CA, Sheavly SB, Rugg DJ, Erdmann ES (2012) Trends in marine debris along the U.S. Pacific Coast and Hawai'i 1998–2007. Mar Pollut Bull 64:994–1004. doi:10.1016/j.marpolbul.2012.02.008

Ryan PG, Moore CJ, van Franeker JA, Moloney CL (2009) Monitoring the abundance of plastic debris in the marine environment. Philos Trans R Soc Lond B Biol Sci 364:1999–2012. doi:10.1098/rstb.2008.0207

Schuyler Q, Hardesty BD, Wilcox C, Townsend K (2013) Global analysis of anthropogenic debris ingestion by sea turtles. Conserv Biol 28:129–139. doi:10.1111/cobi.12126

Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF (2012) Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions. Technical Series No. 67, 61 pages, Montreal

Seminoff JA, Resendiz A, Nichols WJ (2002) Diet of East Pacific Green turtles (*Chelonia mydas*) in the Central Gulf of California, Mexico. Herpetology 36:447–453. doi:10.1670/0022-1511(2002)036%5B0447:DOEPGT%5D2.0.CO;2

Seminoff JA, Benson SR, Arthur KE, Eguchi T, Dutton PH, Tapilatu RF, Popp BN (2012) Stable isotope tracking of endangered sea turtles: validation with satellite telemetry and delta15N analysis of amino acids. PLoS One 7:e37403. doi:10.1371/journal.pone.0037403

Sheavly SB, Register KM (2007) Marine debris and plastics: environmental concerns, sources, impacts and solutions. J Polym Environ 15:301–305

Sokal RR, Rohlf FJ (1994) Biometry: the principles and practices of statistics in biological research. Freeman, New York

Spear LB, Ainley DG, Ribic CA (1995) Incidence of plastic in seabirds from the tropical pacific, 1984–1991: relation with distribution of species, sex, age, season, year and body weight. Mar Environ Res 40:123–146. doi:10.1016/0141-1136(94)00140-K

Tomás J, Aznar F, Raga J (2001) Feeding ecology of the loggerhead turtle *Caretta caretta* in the western Mediterranean. J Zool 255:525–532. doi:10.1017/S0952836901001613

Tomás J, Guitart R, Mateo R, Raga JA (2002) Marine debris ingestion in loggerhead sea turtles, *Caretta caretta* from the Western Mediterranean. Mar Pollut Bull 44:211–216. doi:10.1016/S0025-326X(01)00236-3

Tourinho PS, Ivar do Sul JA, Fillmann G (2010) Is marine debris ingestion still a problem for the coastal marine biota of southern Brazil? Mar Pollut Bull 60:396–401. doi:10.1016/j.marpolbul.2009.10.013

Vegter AC, Barletta M, Beck C, Borrero J, Burton H, Campbell ML, Costa MF, Eriksen M, Eriksson C, Estrades A, Gilardi KVK, Hardesty BD, Ivar do Sul JA, Lavers JL, Lazar B, Lebreton L, Nichols WJ, Ribic CA, Ryan PG, Schuyler QA, Smith SDA, Takada H, Townsend KA, Wabnitz CCC, Wilcox C, Young LC, Hamann M (2014) Global research priorities to mitigate plastic pollution impacts on marine wildlife. Endanger Species Res 25:225–247. doi:10.3354/esr00623

Vilchis L, Ballance LT, Fiedler PC (2006) Pelagic habitat of seabirds in the eastern tropical Pacific: effects of foraging ecology on habitat selection. Mar Ecol Prog Ser 315:279–292. doi:10.3354/meps315279

Wallace BP, DiMatteo AD, Hurley BJ, Finkbeiner EM, Bolten AB, Chaloupka MY, Hutchinson BJ, Abreu-Grobois FA, Amorocho D, Bjorndal KA, Bourjea J, Bowen BW, Duenas RB, Casale P, Choudhury BC, Costa A, Dutton PH, Fallabrino A, Girard A, Girondot M, Godfrey MH, Hamann M, Lopez-Mendilaharsu M, Marcovaldi MA, Mortimer JA, Musick JA, Nel R, Pilcher NJ, Seminoff JA, Troeng S, Witherington B, Mast RB (2010) Regional management units for marine turtles: a novel framework for prioritizing conservation and research across multiple scales. PLoS One 5:e15465. doi:10.1371/journal.pone.0015465

Wang C, Deser C, Yu J-Y, DiNezio P, Clement A (2012) El Niño-Southern Oscillation (ENSO): a review. Coral Reefs of the Eastern Pacific. Springer, Berlin, pp 3–19