

Persistent macroplastics in the stomach contents of the green turtle *Chelonia mydas* (Linnaeus, 1758) on the northern coast of Peru

Macroplásticos persistentes en el contenido estomacal de la tortuga verde *Chelonia mydas* (Linnaeus, 1758) en la costa norte del Perú

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Abstract

This study analyses the diet composition and macroplastic ingestion in green turtles (*Chelonia mydas*) from Sechura Bay, northern Peru, based on digestive tract samples collected during two periods: 2001–2004 and 2013–2014. A total of 67 specimens were examined, revealing a significant increase in macroplastic ingestion over time, particularly among juvenile individuals. Dietary analysis showed a predominance of animal prey in the earlier period, with a negative correlation between animal prey and macroplastic occurrence. In contrast, algae consumption showed no significant relationship with macroplastic ingestion. Size composition analysis revealed a marked reduction in curved carapace length (CCL) in the second period, indicating a shift toward younger individuals. The presence of macroplastics was more frequent and diverse in recent samples, suggesting increased environmental exposure. These findings highlight Sechura Bay as a critical feeding ground for immature green turtles and underscore the growing impact of marine plastic pollution on vulnerable life stages. The study supports the hypothesis that macroplastic ingestion may be influenced by ecological interactions, such as biofouling and olfactory cues, rather than accidental intake alone. Conservation efforts should prioritize pollution control and habitat protection to mitigate long-term risks to green turtle populations in the Southeast Pacific.

Resumen

Este estudio analiza la composición de la dieta y la ingestión de macroplásticos por tortugas verdes (*Chelonia mydas*) de la bahía de Sechura, norte del Perú, a partir de muestras de tractos digestivos recolectadas en dos periodos: 2001–2004 y 2013–2014. Se examinaron un total de 67 especímenes, evidenciando un aumento significativo en la ingestión de macroplásticos a lo largo del tiempo, especialmente en individuos juveniles. El análisis mostró una predominancia de presas animales en el primer periodo, con una correlación negativa entre estas y la presencia de macroplásticos. En contraste, el consumo de algas no presentó relación significativa con la ingestión de plásticos. El análisis de la composición por tamaño reveló una reducción marcada en la longitud curva del caparazón (CCL) en el segundo periodo, indicando un predominio de individuos jóvenes. La presencia de macroplásticos fue más frecuente y diversa en las muestras recientes, lo que sugiere una mayor exposición ambiental. Estos hallazgos destacan a la bahía de Sechura como una zona crítica de alimentación para tortugas verdes inmaduras y evidencian el creciente impacto de la contaminación marina por plásticos. Se recomienda priorizar acciones de conservación enfocadas en el control de la contaminación y la protección del hábitat.

Keywords:

Juvenile green turtles, macroplastic ingestion, dietary analysis, marine pollution, *Chelonia mydas*.

Palabras clave:

Tortugas verdes juveniles, ingestión de macroplásticos, análisis de la dieta, contaminación marina, *Chelonia mydas*.

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Introduction

Marine turtles are highly migratory species, characterized by an extended pelagic stage during both immature and mature phases of their life cycle (Hirth 1997, Meylan & Meylan 2000, Vitt & Caldwell 2009), and by the use of terrestrial habitats during their earliest developmental stages (Bolten 2003). Of the seven recognized species of marine turtles, five have been documented along the Peruvian coast (Alfaro-Shigueto et al. 2011). The most abundant species in the Southeast Pacific is the green turtle, *Chelonia mydas* (Linnaeus, 1858) (Aranda & Chandler 1989, Frazier 2014).

The diet of *C. mydas* is highly diverse, encompassing sponges, jellyfish, corals, crustaceans, mollusks, tunicates, fish, algae, and seagrasses (Seminoff et al. 1999, 2002; Holloway-Adkins & Ehrhart 2004, Kelez et al. 2004, López-Mendilaharsu et al. 2006, Carrión-Cortez et al. 2010, Sampson et al. 2013, Delgado-Trejo et al. 2015). Since the 1970s, reports of macroplastic ingestion have increased significantly, particularly in green and leatherback turtles (Schuyler et al. 2013). The ingestion of macroplastics by marine turtles has been documented globally (Nichols 2003, Sako & Horikoshi 2003, Fahy 2006, Schuyler et al. 2012, Nicolau et al. 2015, Teryda et al. 2015, Yaghmour et al. 2018, Choi et al. 2021), with notable occurrences in the Pacific Ocean (Seminoff et al. 1999, 2002; Parra et al. 2011). Along the Peruvian coast, significant levels of macroplastic ingestion have been reported (Hays-Brown & Brown 1982, Kelez et al. 2004, Quiñones et al. 2015a, Jiménez et al. 2017, Quiñones et al. 2021), comparable to the consumption of other prey items such as fish (Hays-Brown & Brown 1982).

This study assesses temporal changes in size composition and macroplastic ingestion in green turtles (*Chelonia mydas*) from Sechura Bay. The comparison draws on data collected between 2001 and 2004 as part of a comprehensive study on the feeding ecology of green turtles in Sechura (Santillán 2008), and on records reported by Jiménez et al. (2017) for specimens sampled between 2013 and 2014, which include curved carapace length (CCL) and macroplastic ingestion. The objectives of this research are: (1) to evaluate temporal changes in size composition (based on CCL), and (2) to examine variation over time in macroplastic ingestion, identifying any increase or decrease between the two sampling periods.

Material and methods

Study area. The study was conducted in Sechura Bay, located in the department of Piura (05°20'S, 81°02'W) in northern Peru. Sechura Bay is the largest bay on the northern Peruvian coast and one of the largest along the entire Peruvian coastline.

Sample collection. Fieldwork was carried out between 2001 and 2004 as part of a monitoring program focused on small-scale fisheries in Sechura Bay. It was a passive monitoring where the researcher requested the fishermen their authorization to accompany them during their fishing activities. The researcher obtained informa-

tion about the fishing effort, the capture and the occurrence of bycatch of sea turtles. This information is part of the research on feeding ecology of green turtle (Santillán 2008). Additionally, data on curved carapace length (CCL) and macroplastic ingestion from the same area during the 2013–2014 period were obtained from Jiménez et al. (2017). The fishing area was the same for both periods, the Sechura bay in different locations, mainly in the southern section, close to the Virrilá estuary.

Diet analysis. Digestive tracts were collected from deceased specimens of *Chelonia mydas*. The contents of each tract were sieved using a 0.5 mm fine mesh to separate biological and non-biological components. Organic material was preserved in a 10% formaldehyde solution prepared with seawater (Work 2000), while macroplastic items were rinsed with clean water and air-dried.

This scientific note focuses on macroplastic elements occurrence, more than in a detailed feeding study. A detailed feeding ecology study was part of the master thesis of Santillán (2008). Biological items were not analyzed in detail but were used to assess general dietary preferences, categorized as: (i) dominance of carnivorous items or (ii) dominance of herbivorous items.

Frequency of Occurrence (%FO). Prey items were classified using the frequency of occurrence (%FO), a widely used metric in dietary studies of top predators (Hyslop 1980, García-Godos et al. 2007, Krishnan et al. 2008, Carrión-Cortez et al. 2010, Cisneros 2019). The %FO index quantifies the proportion of samples in which a given item appears, relative to the total number of samples analyzed. It is calculated using the following formula:

$$\%FO = \frac{\text{Number of stomach with } i \text{ component}}{\text{Total number of stomachs}} * 100$$

Classification of diet components. The component “i” in the %FO formula refers to the occurrence of animal prey (carnivorous items), algae (herbivorous items), or macroplastics. Species-level identification of prey items was not included in this study, as the objective was to categorize consumption into broader dietary types: carnivorous (when animal %FO was higher), herbivorous (when algae %FO was higher), and macroplastic ingestion.

Statistical analysis of diet composition. To assess the relationship between dietary type and macroplastic ingestion during the 2001–2004 period, we performed multiple Spearman correlation analyses (significance level: $P < 0.05$). Each dietary category was tested against macroplastic occurrence to identify potential associations.

Temporal variability in macroplastic ingestion. To evaluate temporal changes in macroplastic ingestion, we incorporated published data from Jiménez et al. (2017) corresponding to the 2013–2014 period. Macroplastic

occurrence was recorded as categorical data (presence/absence) in digestive tract samples. For comparative purposes, data were grouped into two periods:

– **Period 1:** 2001 – 2004

– **Period 2:** 2013 – 2014

The hypothesis that macroplastic occurrence varied between periods was tested using a chi-square (χ^2) goodness-of-fit test (confidence interval: 95%, $P < 0.05$). Prior to analysis, macroplastic items were classified into general categories based on particle type.

Size composition analysis. Curved carapace length (CCL) measurements were obtained from specimens collected during 2001 – 2004 and supplemented with

data from Jiménez et al. (2017) for the 2013 – 2014 period. To test the hypothesis that size composition did not differ between periods, we first assessed the normality of the CCL data distribution. Subsequently, a Pearson correlation test was conducted using a 95% confidence interval ($P < 0.05$).

Results

Sample overview. A total of 40 digestive tract samples were obtained during Period 1 (2001 – 2004), of which 18 specimens (45%) contained macroplastics (Table 1). Regarding dietary components, algae were absent in only three specimens, while animal prey was absent in just one. In contrast, macroplastics were present in all specimens analysed in Period 2 (Figure 1).

Table 1. Frequency of occurrence (FO) for type of consumption in turtles from period 1 (2001 – 2004).

Specimen code	FO (%) herbivore	FO (%) carnivore	FO (%) plastics
JAS-322	33.33	50.00	16.67
LAS-054	0.00	75.00	25.00
DMI-211	0.00	87.50	12.50
JAS-290	25.00	50.00	25.00
JAS-323	33.33	33.33	33.33
JAS-326	37.50	37.50	25.00
JAS-328	0.00	66.67	33.33
JAS-331	33.33	16.67	50.00
JAS-332	60.00	0.00	40.00
JAS-342	50.00	25.00	25.00
JAS-343	60.00	20.00	20.00
DMI-221	25.00	25.00	50.00
LAS-173	16.67	66.67	16.67
LAS-180	50.00	25.00	25.00
LAS-176	50.00	25.00	25.00
LAS-143	16.67	16.67	66.67
LAS-102	33.33	16.67	50.00
LAS-121	33.33	44.44	22.22

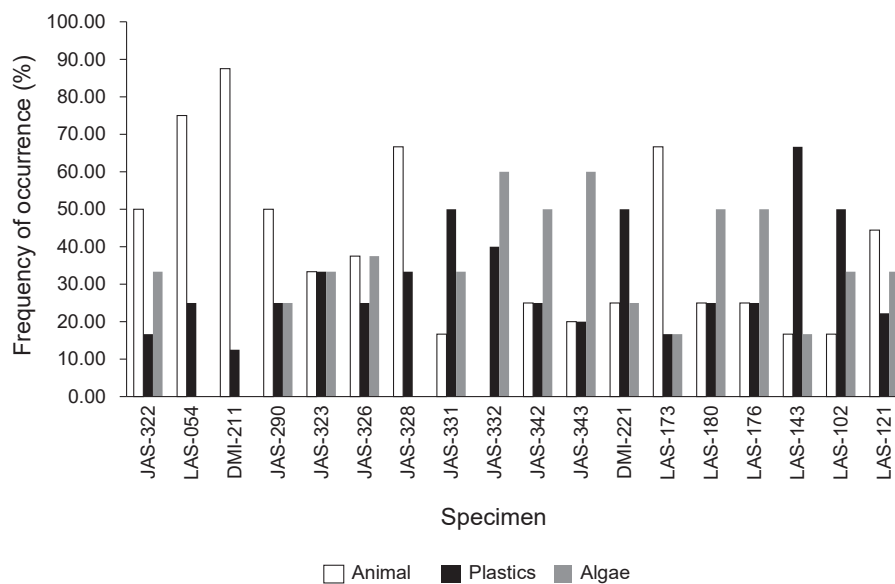


Figure 1. Frequency of occurrence of algae, animal and plastic items for period 1.

In Period 2 (2013–2014), 27 specimens were analysed, among them 15 individuals (55.6%) showed evidence of macroplastic ingestion.

Macroplastic consumption. *Comparison between periods.* Macroplastic ingestion was observed in 37.8% of specimens from Period 1 ($n = 18$) and in 55.6% of specimens from Period 2 ($n = 15$). Macroplastic items were classified into five categories: fibers, transparent plastics, fragments, colored plastics, and plastic cables (Table 2).

Table 2. Type of macroplastics observed in *Chelonia mydas* diet analysis.

Type	Sum of occurrence	
	Period 1	Period 2
Transparent plastic	5	10
Plastic fiber (fishing net)	2	4
Fragment	5	5
Coloured plastic	4	10
Plastic cable	3	0
Total	19	29

In Period 2, 60% of affected individuals contained two or more types of macroplastics, while only 13.3% had a single type. In contrast, during Period 1, 41.2% of cases involved only one type of macroplastic, and 17.6% involved two or more types.

Despite the increase in macroplastic ingestion in Period 2 —particularly transparent and coloured plastics— no statistically significant association was found between macroplastic type and sampling period ($\chi^2 = 6.086$, $P = 0.193$, $df = 4$).

Correlation between dietary components

Period 1. A significant negative correlation was found between animal prey and macroplastic ingestion ($n = 18$, Spearman $R^2 = -0.65343$, $P = 0.00327$), as well as

between animal and algae consumption ($n = 18$, Spearman $R^2 = -0.64148$, $P = 0.00411$). However, no significant correlation was observed between algae and macroplastic ingestion ($n = 18$, Spearman $R^2 = -0.002144$, $P = 0.99326$) (Table 3).

These results suggest that increased macroplastic ingestion is associated with decreased consumption of animal prey, and vice versa. Similarly, algae and animal prey show an inverse relationship. In contrast, algae and macroplastic consumption appear to occur independently.

Table 3. Spearman's correlation statistics among prey types in *Chelonia mydas* diet.

	Algae	Plastics	Animal
Algae		0.99326	0.0041123
Plastics	-0.002144		0.003274
Animal	-0.64148	-0.65343	

Size Distribution. Period 1. CCL data were available for 40 specimens from Period 1. Sizes ranged from 48 cm to 88 cm, with a modal range between 60 and 66 cm (Figure 2A). The variance was high ($s^2 = 102.24$), indicating substantial heterogeneity in size distribution, with both juvenile and adult individuals present.

Period 2. In Period 2, CCL data were available for 27 specimens. The size range was narrower, between 40 cm and 67 cm, with most individuals measuring between 48 and 60 cm (Figure 2B). Variance was lower ($s^2 = 40.65$), reflecting greater homogeneity and a predominance of smaller individuals (Table 4).

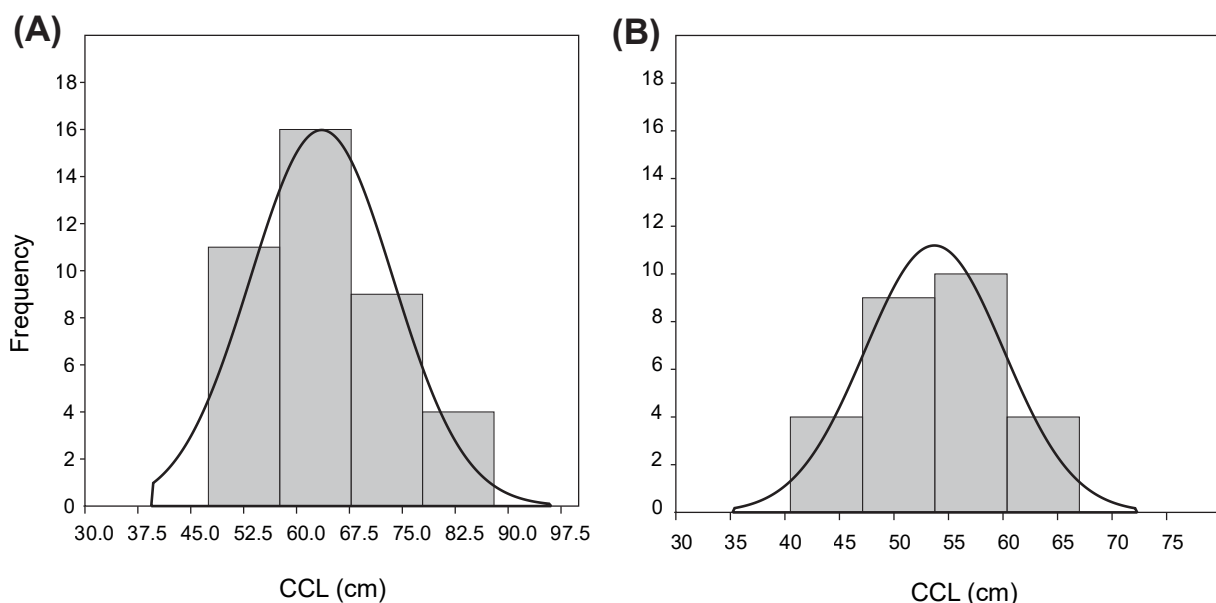


Figure 2. Histogram of distribution of specimens of *Chelonia mydas* according to the curve carapace length (CCL) for: (A) period 1 (2001 – 2004), (B) period 2 (2013 – 2014).

Table 4. Principal statistics of *Chelonia mydas* Curve Carapace Length (CCL).

Period I (2001 – 2004)		Period II (2013 – 2014)	
N:	40	N:	27
Mean:	63.568	Mean:	53.707
Var.:	102.24	Var.:	40.649

Comparative Analysis. Size variability was significantly greater in Period 1 than in Period 2, with a statistically significant difference in variance ($n = 40$, $t = 4.49$, $P = 0.0000294$). These results indicate a reduction in turtle size over time in Sechura Bay.

Relationship Between Size and Macroplastic Ingestion. A comparative plot of CCL and macroplastic occurrence is shown in Figure 3. Individuals from Period 1 (green bars) were generally larger than those from Period 2 (gray bars). Conversely, macroplastic ingestion was more prevalent in Period 2 (red line) than in Period 1 (dark blue line). These patterns suggest a temporal trend in Sechura Bay: decreasing turtle size accompanied by increasing macroplastic ingestion.

Relations between carapace length and plastic ingestion were CCL for period 1 is highly uncorrelated with plastic ingestion in period 2 (Table 5). Carapace length did not has high uncorrelation. However, the highest correlation is observed between carapace length in period 1 and plastic ingestion in period 2 (Figure 4) both data set show an increasing pattern, plastic ingestion in period 2 increased as well as the carapace length has high values in period 1.

Discussion

Several feeding grounds for marine turtles have been identified in the Southeast Pacific, particularly for green turtles (*Chelonia mydas*) (Aranda 1989, Aranda & Chandler 1989, Donoso et al. 2000, Donoso & Dut-ton 2002). In Peru, four major neritic aggregation areas have been documented: El Ñuro, Paracas Bay, Sechura Bay, and Lobos de Tierra Island (Hays-Brown & Hays 1982, de Paz & Alfaro-Shigueto 2008, Velez-Zuazo et al. 2014, Quiñones et al. 2015b). Sechura Bay hosts a significant aggregation of green turtles, most of which are below the reproductive size threshold established for nesting populations in the Galápagos Islands (Zárate et al. 2013).

Our results show that immature individuals dominated the population in both sampling periods. While a few mature turtles were present in Period 1, none were recorded in Period 2. The significant shift in size composition over time confirms that Sechura Bay remains an important feeding ground, but the average size of individuals has clearly declined.

Although *C. mydas* is generally considered herbivorous across various life stages (Seminoff et al. 1998, 1999, Seminoff 2000, López-Mendilaharsu et al. 2003, Arthur et al. 2009, Levinton 2014, Sampson et al. 2013, 2018), our study revealed a predominance of animal prey consumption (e.g., fish, mollusks, and other invertebrates), consistent with findings from Jiménez et al. (2017). In Period 1, animal prey intake showed a significant negative correlation with both algae and macroplastic ingestion, suggesting that increased consump-

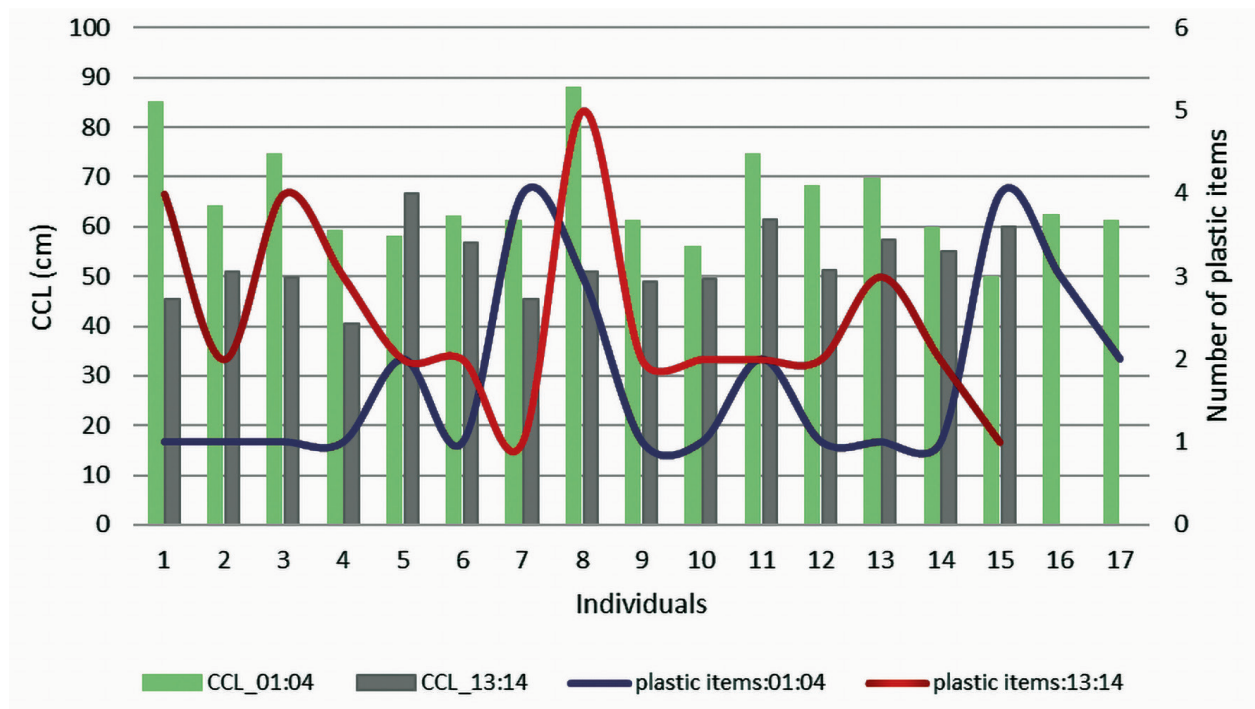
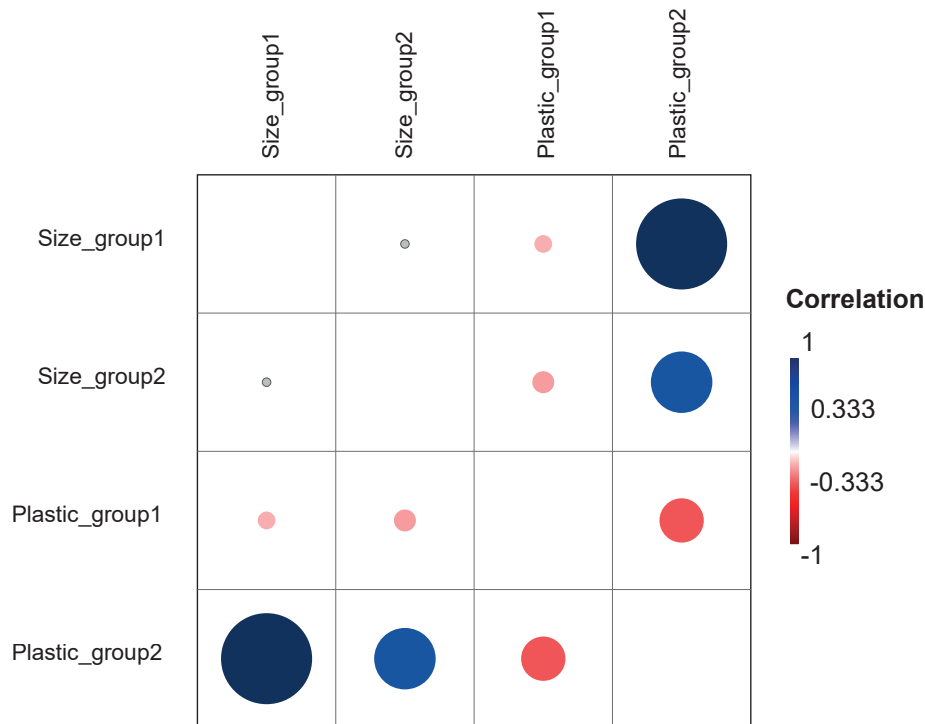


Figure 3. Size distribution (CCL) of *Chelonia mydas*, and plastic items consumption in periods 2001 – 2004 and 2013 – 2014. Green bars are CCL for specimens for period 2001 – 2004, gray bars are CCL for specimens for period 2013 – 2014, dark blue line is for plastic items in 2001 – 2004 and red line is for plastic items in 2013 – 2014.

Table 5. Spearman correlation between size of carapace (CCL) of *Chelonia mydas*, and plastic ingestion in both period 1 and period 2.

	CCL period 1	CCL period 2	Plastic period 1	Plastic period 2
CCL period 1		0.79378	0.58538	0.00084254
CCL period 2	0.79378		0.49803	0.043841
Plastic period 1	0.58538	0.49803		0.1607
Plastic period 2	0.00084254	0.043841	0.1607	

**Figure 4.** Graphical correlation with Pearson coefficients. Dark blue circles indicate positive correlation; red circles indicate negative correlations. Intensity of colors indicate higher (positive or negative) correlation.

tion of animal prey is associated with reduced ingestion of other items. However, algae and macroplastic consumption appeared to be independent of one another.

Seasonal variability in prey consumption has been documented in other studies and is often linked to fluctuations in prey availability (López-Mendilaharsu 2002, López-Mendilaharsu et al. 2003, Vitt & Caldwell 2009). In our temporal comparison, macroplastic ingestion increased notably from Period 1 to Period 2, likely reflecting the growing presence of plastic debris in the marine environment (PlasticEurope 2019). These findings suggest that macroplastics have become an increasingly common component of the green turtle diet in Sechura Bay.

Previous studies have reported plastic ingestion by green turtles along the Peruvian coast (Hays-Brown & Brown 1982, Kelez et al. 2004, Quiñones et al. 2015a). However, our data indicates a higher incidence in Sechura Bay. The bay is exposed to multiple pollution sources, including untreated sewage from fishmeal and fish oil factories, artisanal and industrial fisheries, local communities, and industrial facilities (IMARPE 2007). The lack of proper waste management likely contrib-

utes to the high prevalence of macroplastics in the marine environment, increasing the risk of incidental ingestion by turtles.

Similar trends have been observed along the Brazilian coast, where *C. mydas* is frequently affected by fishing-related debris such as nylon, ropes, and net fragments (Rodamilans et al. 2011, Henrique de Carvalho et al. 2015, Rizzi et al. 2019). In our study, macroplastic ingestion was recorded in 45% and 56% of specimens from Periods 1 and 2, respectively. Given the reduction in average CCL over time, juvenile turtles appear to be increasingly vulnerable to macroplastic pollution, raising concerns for the long-term health of the population in the Southeast Pacific. Similar findings were reported by Rice et al. (2021), who documented high macroplastic ingestion in neonates stranded in Florida.

One commonly cited explanation for plastic ingestion in turtles is the visual resemblance of floating plastics to jellyfish, a known prey item (Fukuoka et al. 2016). However, floating debris also attracts sessile organisms such as algae, which colonize inert substrates (Acleto 1986), forming microhabitats that attract fish and invertebrates. Marine microbiota often uses floating

items as substrates (Thiel & Gutow 2005, De-La-Torre et al. 2021), and Pfaller et al. (2020) proposed that olfactory cues from these communities may contribute to the attraction of turtles to plastics. These findings support the hypothesis that plastic ingestion may not be entirely accidental but rather influenced by ecological interactions with organisms colonizing the debris.

The ingestion of plastics can have severe physiological consequences. Bjørndal et al. (1996) and Parra et al. (2011) reported mortality due to digestive tract obstruction, even with small amounts of plastic. Although our samples were obtained from bycatch and not from necropsies, the frequent presence of macroplastics in digestive tracts suggests that such risks should not be underestimated.

In addition to physical harm, plastics can introduce chemical contaminants such as bisphenol A (BPA) and phthalates, known endocrine disruptors (Krishnan et al. 1993, Oehlmann et al. 2009, cited by Schuyler et al. 2013). Floating plastics can also absorb and release heavy metals and hydrocarbons into animal tissues (Teuten et al. 2009, cited by Schuyler et al. 2013), potentially leading to bioaccumulation and long-term health impacts.

Macroplastic ingestion has increased dramatically among marine megafauna, particularly seabirds and sea turtles (Gregory 2009, Tourinho et al. 2009, Kühn & van Franeker 2020). As migratory species, their ecological roles span multiple geographic regions, making the implications of plastic pollution a transboundary conservation concern.

The authors used Copilot as an AI assistant to correct and improve the grammatic and English style of the manuscript. The authors wrote entirely the manuscript in English before use the AI assistance.

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LS: Conceptualización, Análisis formal, Investigación, Escritura-preparación del borrador original, Redacción-revisión y edición.

AJ: Metodología, Investigación, Redacción-revisión y edición.

SP: Metodología, Investigación, Redacción-revisión y edición.

JA-S: Adquisición de fondos, Recursos, Administración del proyecto.

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Authors declare that they did not violate or omit ethical or legal norms in this research.

Marine turtles are protected by Peruvian national regulations; however, incidental captures are events that still occurs in the fishing activities in remote fishing areas. Our participation did not stimulate the capture of marine turtles but take information on fishing activities in a general view. We obtained material for this research from discarded animals found dead due to bycatch.

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