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RESEARCH

Epifaunal Communities in Floating Buoys on Gran Canaria (Canary Islands, NE Atlantic Ocean)

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Abstract

Ocean sprawl has become increasingly prevalent in marine environments. Artificial substrates, notably floating structures like buoys, have gained significant attention in recent years. They serve as valuable models for future studies aimed at understanding and mitigating the impacts of anthropogenic activities on marine ecosystems. We studied the epifauna from buoys at six different locations on the northern and southern coasts of the island of Gran Canaria (Canary Is., NE Atlantic Ocean). A total of 12,130 individuals belonging to 57 species were collected. The abundance of individuals was higher in the northern area, whereas the species richness was higher in the southern area. The n-MDS showed significant differences between localities, with Las Alcaravaneras being separated from the remaining ones. These dissimilarities were due to the differences in the abundances of the amphipods *P. gammaroides* and *A. rubricata*. The orientation was a pivotal factor in structuring these associated communities in floating buoys. As a preliminary approach, high biodiversity and species richness were observed in these buoys; hence, they have a high potential to be used as bioindicators of human disturbance.

Keywords Biodiversity Hotspot · Floating Devices · Artificial Substrates · Invertebrates · Amphipods · Associated Communities

Introduction

Human-driven perturbations are extensive all over the planet (Halpern et al. 2019). The main drivers of these changes include pollution, eutrophication, and deforestation (Nelson et al. 2006). Various activities in the ocean, such as fishing, aquaculture, and harbouring, contribute to these disturbances (Halpern et al. 2008). Artificial substrates are one of the major perturbations that show a steady increase in coastal areas (Ferrario et al. 2016). Extensive development and construction in marine and coastal systems contribute to a phenomenon called 'ocean sprawl'. This term describes the increasing dominance of man-made structures in marine and coastal environments due to continued population growth and the simultaneous development of coasts and offshore waterways (Ruiz et al. 2013). Ocean sprawl removes or transforms marine habitats by adding artificial structures (Heery et al. 2017). Artificial substrates include a variety of structures, such as groins, walls, breakwaters (Dugan et al. 2011), and floating devices, such as buoys, aquaculture farms, and nets (Heery et al. 2017).

Fouling refers to the growth of organisms on surfaces that are in contact with water (Ferrario et al. 2020). It involves the attachment and growth of microorganisms on submerged natural or human-made substrates (Ferrario et al. 2020). Fouling comprises algae and fauna, which are both sessile and mobile. Among the most abundant phyla in this type of epifauna are arthropods, mollusks, annelids, and echinoderms (Fortič et al. 2021; Castro et al. 2022). These taxonomic groups play a crucial role in coastal food webs and are intricately linked to benthic environments (Gagnon et al. 2021). The epifaunal community has been recognized as an effective indicator of changes in biodiversity and abundance (Pierri-Daunt and Tanaka 2014).

Floating devices such as buoys are objects that can be found in rivers, lakes, or seas and are anchored to the bottom

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(Bedard et al. 2010). Buoys are used for various purposes, including navigating boats through channels, marking shipping lanes, submerged objects or danger zones, and serving as weather stations (Templin et al. 2022). Studies on epifauna have often focused on floating objects such as buoys and ship hulls (Firth et al. 2016). Ship-mediated marine invasions are primarily caused by the transfer of organisms associated with ship hulls or ballast materials (e.g., Ruiz et al. 2013; Ros et al. 2020).

Maritime traffic can be affected by harmful plants and animals, creating complex communities, and contributing to material degradation (Murtaugh and Hernández 2014). The economic impact of biological pollution has affected countries striving for technological development (Coutts et al. 2010).

The Canary Islands, particularly the island of Gran Canaria, are of great ecological and marine importance (Riera and Delgado 2019). Gran Canaria is an island with a high population density and has Puerto de la Luz, an international maritime transport port (Tovar et al. 2015). A significant increase in the number of buoys in aquaculture, marinas, and beaches in Gran Canaria, effective marking strategies should be developed to ensure the safety of maritime activities while preserving marine ecosystems (Abramic et al. 2021).

The main aim of this study was to explore the epifauna community of the buoys on different beaches of the island of Gran Canaria and determine if orientation (North vs. South) is a pivotal factor in structuring these associated communities in floating buoys. This study hypothesized that the epifauna composition did not vary among the studied beaches neither North nor South areas.

Materials and Methods

Study Area

The Canary Islands is an archipelago in the Atlantic Ocean, which is located on the northwest coast of Africa, between 27° 37' and 29° 25' north latitude and 13°20' and 18° 10' west longitude (Fig. 1).

Samples were collected from beaches with buoys on Gran Canaria Island between March and April 2023 (Fig. 1). In a proactive survey carried out in February 2023, 15 beaches were sampled. However, due to the absence of buoys on some beaches during this period, sampling was limited to six specific beaches (Amadores, Inglés, Las Alcaravaneras, Las Nieves, Mogán and Puerto Rico). Table 1 provides an overview of the sampling areas and their characteristics.

Sampling Design

Ten samples were collected from each beach, using 25 × 25 cm quadrats, with each sample was equivalent to the measurements of two small yellow buoys (60 cm in diameter and 40 cm in height), making up a total of 60 samples (10 samples per beach x 6 studied beaches. At each beach, five

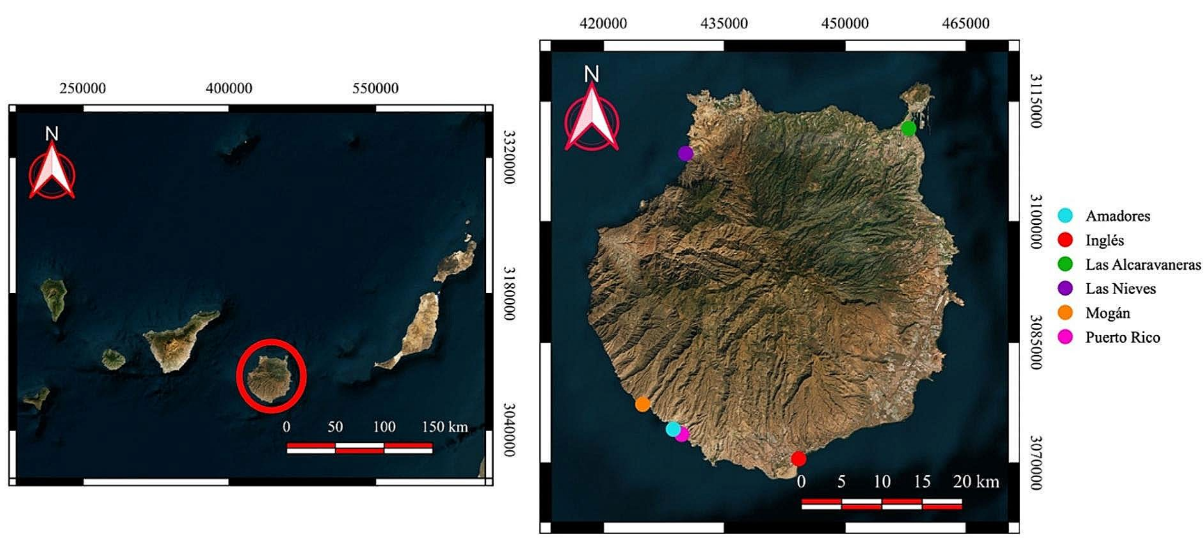


Fig. 1 Map of the study area, showing the sampled beaches on the island of Gran Canaria

Table 1 Characteristics of each sampling location

Sites / Beaches	Coordinates	Type of beach
AMADORES (South zone)	Latitude: 27°47’25.00"N Longitude: 15°43’27.14"W	Sand
INGLÉS (South zone)	Latitude: 27°45’29.34"N Longitude: 15°33’56.80"W	Sand
LAS ALCARAVANE-RAS (North zone)	Latitude: 28° 7’52.02"N Longitude: 15°25’44.77"W	Sand
LAS NIEVES (North zone)	Latitude: 28° 6’0.53"N Longitude: 15°42’37.80"W	Pebbles
MOGÁN (South zone)	Latitude: 27°49’5.22"N Longitude: 15°45’49.21"W	Sand
PUERTO RICO (South zone)	Latitude: 27°47’4.48"N Longitude: 15°42’48.82"W	Sand

buoys were selected randomly for sampling. The selected buoys had a similar fouling load, being left in the sea for a minimum of one year and a maximum of three years. The sampling procedure used a scraper to collect samples from the buoys, which was a destructive process. The collected samples were then preserved in marked zip bags and transported to the laboratory. To ensure preservation, a solution of seawater and 70% ethanol was added to the samples to facilitate identification in the laboratory. At the laboratory, the collected sample was carefully poured into a tray. A detailed sorting procedure was then carried out to sort the samples into different taxonomic groups. These groups were kept in vials to facilitate identification to the lowest taxonomic level, i.e. species. For species identification, taxonomic identification guides were used for the groups represented in the samples (e.g., Day 1968; Lincoln 1979; Riera et al. 2003).

Data Analysis

Statistical analyses were performed using the R software. Boxplot graphs were used to represent the distributions of species richness and individual abundance. In addition, it shows the median or second quartile, the distance between the third quartile and the first quartile, and the extreme values that cannot be explained by the distribution. The first quartile indicated that 25% of the values were equal to or less than this, and the third quartile had 75% of the values.

The non-metric multidimensional scaling (n-MDS) allows an analysis based on the ordination of the sampling points in a two-dimensional spatial system where the disparity or similarity of the points is noticeable. To do this, a code was created for the automatic selection of the lowest stress in 20 trials. The n-MDS shows the distribution of the different locations (10 beaches) and their respective orientation (North and South). Permutational Multivariate Analysis of Variance (PERMANOVA) allows analysis of a group of objects distributed or dispersed according to the factors considered. PERMANOVA was performed by considering the following factors: location and orientation. As a result, it is obtained the F value and the probability of F. The latter was required to be significant and must have a value of $p < 0.05$. Differences between localities in community descriptors (individual abundance and species richness) were analyzed by employing one-way analysis of variance (ANOVA), after verifying normality using the Shapiro test and Mann-Whitney test for homogeneity of variances.

The statistical analyses were performed using a set of R packages. The *vegan* (Oksanen et al. 2022) package contains the codes to perform n-MDS and PERMANOVA, and *ggplot2* (Wickham 2016) allows us to perform graphs, including the box plot. Other packages, such as *tidyverse (*Wickham et al. 2019), *janitor* (Firke 2023), *flextable* (Gohel and Skintzos 2023), and *readxl* (Wickham and Bryan 2022), were also used to read the data and create graphs and tables of higher quality.

Results

A total of 12,130 individuals were collected, belonging to 57 species, within five taxonomic groups (annelids, arthropods, chordates, echinoderms, and mollusks) (Table S1). Arthropoda was the most abundant group in the epifaunal community (11,007 individuals, 90.75% of the overall abundance), followed by annelids (1,078 ind., 8.89%), echinoderms (41 ind., 0.34%), mollusks (3 ind., 0.02%) and chordates (1 ind., 0.008%). The three most abundant species were amphipods, which stand out because of their dominance, namely, *Pleonexes gammaroides* (3,658 ind., 30.15%), *Ampithoe rubricata* (3,267 ind., 26.94%), and *Elasmopus rapax* (1,553 ind., 12.80%). Followed by the tanaid *Tanais dulongii* (608 ind., 5.01%), the sipunculid *Phascolosoma. (Phascolosoma) stephensoni* (593 ind., 4.89%), the amphipod *Stenothoe marina* (583 ind., 4.81%), the crustacean *Pachygrapsus transversus* (411 ind., 3.39%), the polychaete *Polyophthalmus pictus* (252 ind., 2.08%), the amphipods *Jassa marmorata* (236 ind., 1.95%) and *Apohyale perieri* (208 ind., 1.71%), and the crustacean *Pachygrapsus marmoratus* (204 ind., 1.68%).

As shown in Table 2, it was used different diversity indices at the localities to observe the changes at these sites. Mogán beach is the locality with the highest number of species in a community. In contrast, Las Nieves and Puerto Rico had the lowest species richness, although there was little difference between the localities in terms of species richness. Inglés beach had the highest Margalef index value, although all values were very low. Las Alcaravaneras and Las Nieves had the highest Simpson dominance index values. On the other hand, the Simpson diversity index value was higher

Table 2 Diversity indices of each sampling location

Diversity indices/ locations	Specific richness (S)	Margalef index	Simpson dominance index	Simpson diversity index	Shannon-wiener index (E)
AMADORES	25	0.0082	0.8359	0.1641	0.0590
INGLÉS	28	0.0283	0.6511	0.3489	0.1363
LAS ALCARAVANERAS	26	0.0080	0.9860	0.0140	0.0044
LAS NIEVES	23	0.0120	0.9806	0.0194	0.0064
MOGÁN	29	0.0137	0.6959	0.3041	0.1134
PUERTO RICO	23	0.0181	0.7017	0.2983	0.1192

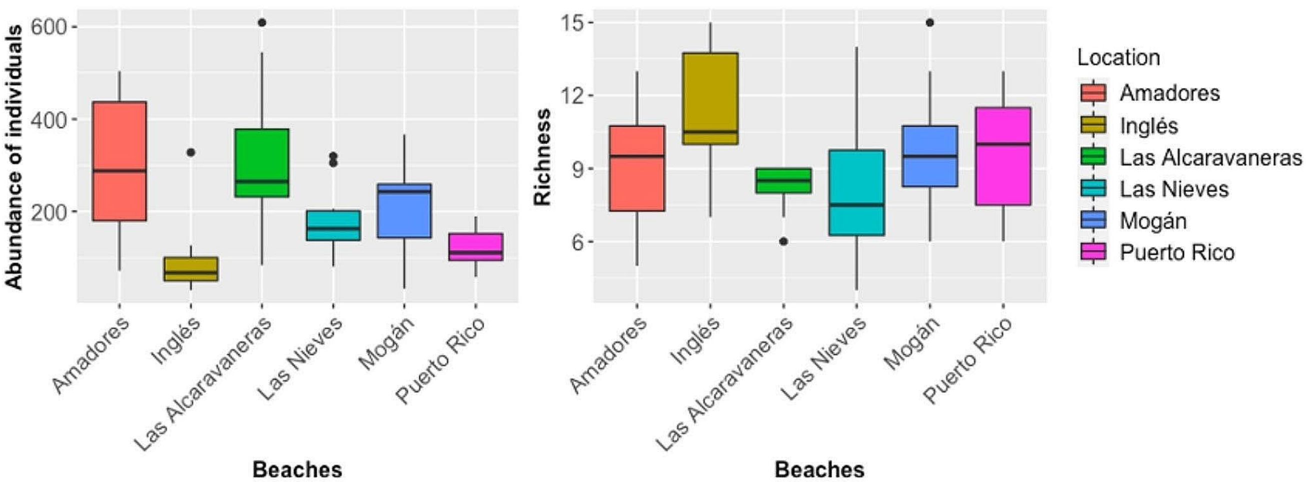


Fig. 2 Abundance and species richness of epifaunal communities at different sites

for Inglés beach and the Shannon–Wiener index value. Specific richness (One-way ANOVA, F = 0.599, p = 0.482) and the Margaleff index (F = 1.179, p = 0.339) showed that there were no significant differences in the diversity of individuals between northern and southern zones. In contrast, the Simpson dominance index (F = 19.18, p = 0.0119), Simpson diversity index (F = 19.18, p = 0.0119), and Shannon-Wiener index (F = 16.39, p = 0.0155) showed significant differences in the diversity of individuals. The values obtained when performing the PERMANOVA, considering the locations (F = 1.8789, p = 0.2444) and the orientation (F = 2.6759, p = 0.2) in both cases showed no significant differences.

Las Alcaravaneras (312.6 ± 162.30 ind.), and Amadores (293.9 ± 163.82 ind.) were the beaches with the highest abundances. On the other hand, abundances were lower in the remaining sampling areas, Inglés (95.4 ± 86.76 ind.), Las Nieves (183.8 ± 75.84 ind.), Mogán (204.8 ± 103.64 ind.) and Puerto Rico (122.4 ± 42.22 ind.). The number of species was similar in the studied beaches, mostly comprising 7 and 13 taxa, and Inglés beach (11.4 ± 2.5 spp.) showed the highest species richness, followed by Amadores (9.1 ± 2.60 spp.), Mogán (9.8 ± 2.70 spp.) and Puerto Rico (9.5 ± 2.51 spp.). In contrast, Las Nieves (8.0 ± 3.13 spp.) and Las Alcaravaneras (8.2 ± 1.03 spp.) had the lowest richness (Fig. 2).

The northern area, including the beaches of Las Alcaravaneras and Las Nieves, was the area with the highest abundance of individuals (248.20 ± 139.89 ind.). In contrast, the southern area, consisting of Inglés, Amadores, Mogán, and Puerto Rico (179.13 ± 130.35 ind.), showed lower abundances than the northern counterparts. In contrast, the southern (9.95 ± 2.63 spp.) was the richest area. The northern zone (8.10 ± 2.26 spp.) was also species-diverse, but less than the southern zone (Fig. 3). The differences in individual abundances between North and South areas were not significant (One-way ANOVA, F = 3.57, p = 0.0639), but the differences in species richness were highly significant between both areas (F = 7.19, p = 0.0095).

As shown in Fig. 4, the Alcaravaneras beach is different from the others, as it is concentrated on the left side of the ordination. The rest are grouped in the center and to the right of the figure. In addition, a high heterogeneity was observed in the Mogán samples compared to the other locations (Fig. 4). The stress of n-MDS was 0.24, a high number indicating the heterogeneity of the samples. The values obtained when performing the PERMANOVA, considering the beach (F = 7.10, p = 0.0001), the orientation (F = 6.62, p = 0.0001), and the interrelation with the factors (F = 15.571, p = 0.0001), in all cases showed highly significant differences. The epifauna communities were different

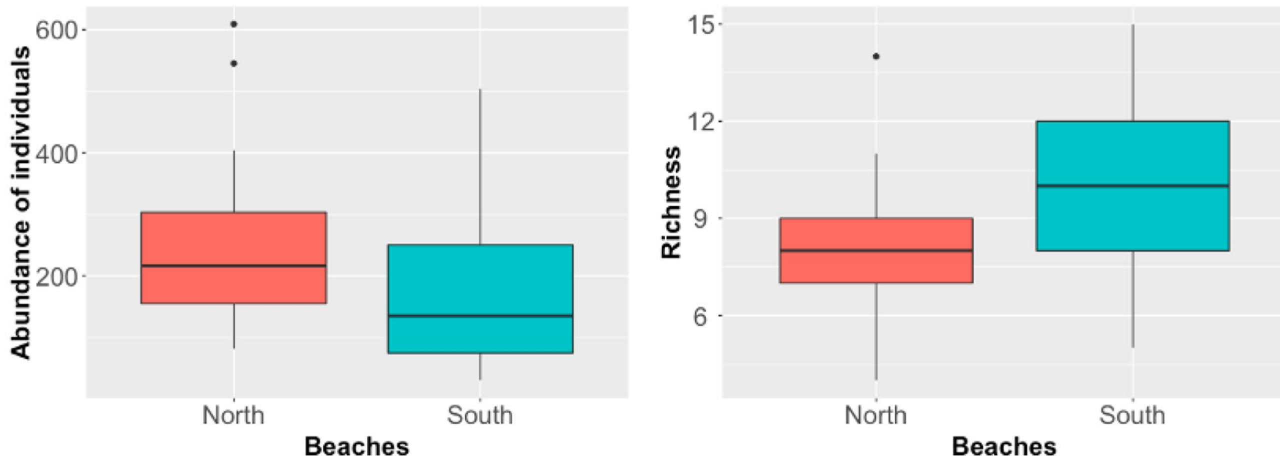
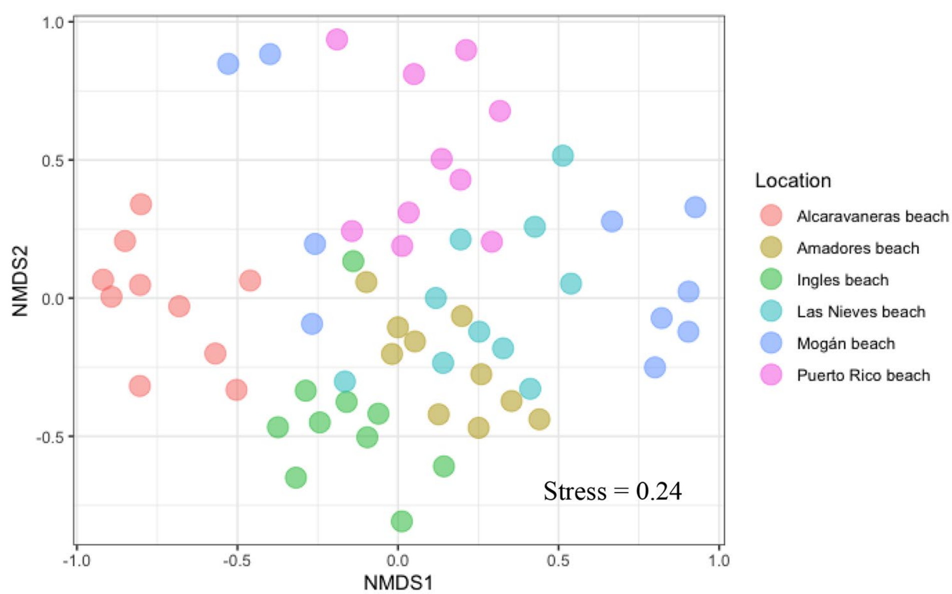


Fig. 3 Abundance and species richness of epifaunal communities in different orientations

Fig. 4 NMDS showing sampled beaches (Northern area: Alcaravaneras and Las Nieves; Southern area: Amadores, Inglés, Mogán and Puerto Rico)



among the studied beaches and between northern and southern locations.

The amphipod *A. rubricata* was the most important contributor to the similarity of epifauna community in Las Nieves (36.6%) and Amadores (50.9%), and contributed to Las Alcaravaneras, Inglés and Puerto Rico, with a percentage over 15% (15.4%, 20.6% and 15.9%, respectively). The amphipod *P. gammaroides* was the most abundant species in Las Alcaravaneras (47.9%), Inglés (28.0%), Puerto Rico (20.1%), and Mogán (38.3%) and contributed to Las Nieves (26.1%). Finally, there were specific species on the different beaches such as the amphipod *S. marina* in Las Alcaravaneras (15.7%), the polychaetes *P. dumerilii* (7.9%) *N. cirrosa* (4.4%), and *P. pictus* (4.1%) in Inglés, and the amphipod *A. stebbingi* (8.4%) and the tanaid *T. dulongii* (6,0%) in Puerto Rico (Table 3).

The amphipod *P. gammaroides* was the important contributor to establishing the dissimilarity between northern and southern locations (26.5%) and is found in greater abundance in the northern zone. This species was followed by the amphipod *A. rubricata* (25.9%), which peaked in the southern zone. The amphipods *E. rapax* (11.8%) and *S. marina* (5.6%), the sipunculid *P. (P.) stephensoni* (5.5%), and the tanaid *T. dulongii* (4.5%) were minor contributors. The species *E. rapax* and *P. (P.) stephensoni* were more abundant in the southern zone, whereas *S. marina* and *T. dulongii* were more abundant in the northern zone. Finally, the crustacean *P. transversus* (3.0%) was important in Amadores, and not in the remaining locations (Table 4).

Table 3 Percentage of species contribution at each sampled beach

Locations	Species	% Contribution	% Cum-sum
AMADORES	*Phascolosoma (Phascolosoma) stephensoni*	81.7	7.2
	Elasmopus rapax	74.5	23.6
	Ampithoe rubricata	68.7	50.9
INGLÉS	*Pachygrapsus marmoratus*	79.5	3.6
	Phascolosoma (Phascolosoma) stephensoni	75.9	3.9
	Polyophthalmus pictus	72.0	4.1
	Nephtys cirrosa	67.9	4.4
	Apohyale perieri	63.5	7.0
	Platynereis dumerilii	56.5	7.9
	Ampithoe rubricata	48.6	20.6
	Pleonexes gammaroides	28.0	28.0
LAS ALCARAVANERAS	*Ampithoe rubricata*	79.0	15.4
	Stenothoe marina	63.6	15.7
	Pleonexes gammaroides	47.9	47.9
LAS NIEVES	*Elasmopus rapax*	79.4	16.7
	Pleonexes gammaroides	62.7	26.1
	Ampithoe rubricata	36.6	36.6
MOGÁN	*Phascolosoma (Phascolosoma) stephensoni*	75.8	11.0
	Pachygrapsus marmoratus	64.8	11.0
	Elasmopus rapax	53.8	15.5
	Pleonexes gammaroides	38.3	38.3
PUERTO RICO	*Tanais dulongii*	81.1	6.0
	Apohyale stebbingi	75.1	8.4
	Elasmopus rapax	66.7	8.6
	Phascolosoma (Phascolosoma) stephensoni	58.1	11.0
	Apohyale perieri	47.1	11.1
	Ampithoe rubricata	36.0	15.9
	Pleonexes gammaroides	20.1	20.1

Table 4 Percentage of species contribution in North/South

Variable	Species	North ind.	South ind.	% Contribution	% Cum-sum
ORIENTATION (NORTH-SOUTH)	*Pachygrapsus transversus*	122 (29.68%)	289 (70.32%)	82.8	3.0
	Tanais dulongii	367 (60.36%)	241 (39.64%)	79.8	4.5
	Phascolosoma (Phascolosoma) stephensoni	2 (0.34%)	591 (99.66%)	75.3	5.5
	Stenothoe marina	565 (96.91%)	18 (3.09%)	69.8	5.6
	Elasmopus rapax	246 (15.84%)	1307 (84.16%)	64.2	11.8
	Ampithoe rubricata	1223 (37.43%)	2044 (62.57%)	52.4	25.9
	Pleonexes gammaroides	2067 (56.51%)	1591 (43.49%)	30.2	26.5

Discussion

In the present study, the orientation (North vs. South) played an important role in the structure of the epifaunal community. Mogán beach had the highest species diversity in the community. The Margalef index values consistently indicated low biodiversity across all locations. The Simpson's index values, which indicate the probability of two randomly selected individuals belonging to different species within a population of N individuals, suggest limited biodiversity. The southern zone has the highest species richness, while the northern area has the highest abundance of individuals. n-MDS analysis showed a high dissimilarity between the epifauna-associated communities between the sampling locations. The differences between northern and southern areas are mainly explained by differences in the densities of the most abundant species, i.e. the amphipods *P. gammaroides* and *A. rubricata*.

The presence of artificial structures on the coastal environment modifies the marine dynamics (currents, waves and connectivity of water masses), leading to changes in sedimentation patterns, beach erosion, larval dispersal and water mass transport (Sánchez-Jerez et al. 2002). This study indirectly considered several hydrodynamic effects at large, intermediate, and small spatial scales (Heery et al. 2017) by using orientation (North and South) as a proxy. Marine species often benefit from maritime traffic through ballast waters and hull biofouling (Castro et al. 2022), mechanisms that facilitate the transport and introduction of various organisms across different marine environments. The present study, focusing on the ecological dynamics of coastal regions, observed that amphipods were the most abundant group. This finding is significant given the pivotal role amphipods play in marine ecosystems as essential prey for other organisms and as primary and secondary consumers, thus showing their importance in sustaining aquatic food webs (Väinölä et al. 2008).

Amphipods are one of the most common species found in rocky and soft-bottom marine habitats (De-la-Ossa-Carretero et al. 2010) and in organisms that are attached to hard substrates (Çinar et al. 2020). In addition, they have been suggested as high-quality indicators of marine habitats (De-la-Ossa-Carretero et al. 2012) and human-made structures can affect the composition and traffic structure of an amphipod community, even if the algal substrates are the same (Sedano et al. 2020).

The results obtained are inconclusive due to the unavailability of buoys on other beaches during the prospective survey. The limitation of this work is that only beaches where buoys were available on the island of Gran Canaria were sampled. In addition, we were not able to obtain the same number of samples from the north and south of the island. For future research, it would be an asset to consider different factors such as temporal variation, that is, to sample the same buoys at different times of the year to know the temporal variability of the epifaunal community. Another factor to consider is the spatial variation, consisting of studying the epifauna on different beaches of Gran Canaria and placing them in different cardinal points (North, South, East, and West). In addition, it would be an asset to study epifauna on buoys or floating objects on other islands of the Canary Archipelago or in the Webbnesia ecoregion (Freitas et al. 2019).

For future research, it is essential to study the epifauna of other types of floating structures (signaling buoys, aquaculture leases, ports, and marinas), as they can be used as bio-indicators of pollution or anthropogenic activities, and thus provide insight into the state of the ecosystem where they are located. Different algae may be present on different floating structures, whether invasive/non-indigenous or native/indigenous. The presence of different types of algae can affect epifauna (Pereira et al. 2022).

This study shows that orientation is an important factor affecting the structure of the epifaunal community. Epifauna is a community of species found in the sampled buoys. It can be used as a reliable indicator of human-made disturbances because it is recorded at disturbed sites. Future research should focus on conducting more detailed studies on the epifauna of floating devices, particularly considering the spatial and temporal variabilities in these communities. Furthermore, increasing the sampling effort on the remaining islands of the Canary Islands and the adjacent archipelagos, i.e. Madeira, Azores, and Cape Verde may be important factors to be considered as medium- and long-term research objectives.

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Author Contributions AU-P collected samples, identify organisms, lead statistical analysis and write the first draft. RR develop the sampling design, revise taxonomic ID, support statistical analysis, and lead the revision of the first draft.

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Data Availability Data available upon request to the authors.

Declarations

Competing Interests The authors declare no competing interests.

Ethical Approval Not applicable.

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