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Copepod Diversity and Zooplankton Community Structure in a Coastal Special Area of Conservation (La Palma Island, Atlantic Ocean)

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Abstract: This study presents the first species-level assessment of zooplankton communities within a designated Special Area of Conservation (SAC, ES7020122) in the coastal waters of an oceanic island in the Atlantic Ocean, conducted in a previously under-sampled protected coastal region. Copepods emerged as the predominant taxa, offering key insights into early-stage community structure and potential indicators of ecological dynamics in marine ecosystems. Zooplankton biomass and abundance were primarily driven by organisms in the 200–500 µm size fraction, with spatial variation observed across latitudinal transects. A total of 44 copepods species were identified, including dominant genera (*Oncaea*, *Oithona*, and *Clausocalanus*) characteristic of subtropical Atlantic ecosystems. Several indicator species (e.g., *Candacia ethiopica* and *Oncaea scottodicarloi*) showed spatial patterns. While no direct impacts from the recent 2021 volcanic eruption were detected, the dominance of opportunistic copepods and the observed diversity suggest a potential adaptive response and resilience of the pelagic community to periodic geological disturbances. These results provide a valuable ecological baseline for future long-term monitoring under the Marine Strategy Framework Directive and underscore the importance of copepods as indicators of coastal ecosystem structure and variability.

Keywords: coastal environment; community structure; copepods; indicator species; zooplankton

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1. Introduction

Zooplankton are key components of marine ecosystems, playing a pivotal role in trophic dynamics by mediating energy transfer across food web levels [1]. Their short life cycles and high sensitivity to environmental variability make them excellent indicators of ecosystem change, particularly following natural disturbances such as volcanic activity or oceanographic anomalies [2,3].

In subtropical oceanic systems like the Canary Islands, volcanic and seismic events are recurrent phenomena with the potential to disrupt marine environmental conditions. Over the past two decades, the region has experienced heightened geophysical activity, including the 2011 submarine eruption off El Hierro and, more recently, the 2021 subaerial eruption of the Tajogaite Volcano on La Palma Island [4,5]. These events have been shown to induce significant alterations in the physical and chemical properties of the marine environment, such as anomalies in temperature, salinity, and carbon dynamics [6,7]. The Canary Islands represent a dynamic subtropical system with marked oceanographic variability and spatial heterogeneity. Zooplankton communities in this region are influenced by physical gradients, trophic interactions, and seasonal changes, making them valuable indicators for ecological assessments within marine conservation areas.

Although physical parameters such as temperature and salinity tend to recover relatively quickly after such events, the biological consequences, particularly on lower trophic levels, may persist and are less well documented [8,9]. Zooplankton, and copepods in particular, are among the first groups to respond to ecosystem shifts due to their ecological ubiquity and trophic relevance [10,11]. Understanding how these communities reorganize post-disturbance is critical for assessing both ecosystem resilience and the provision of marine ecosystem services [12,13].

Historically, research on zooplankton in the Canary Islands has focused predominantly on ecophysiological processes and biomass dynamics (e.g., [14,15]; see Supplementary Figure S1 and Supplementary Table S1), with fewer studies offering species-level insight into community structure [16,17]. Even fewer have examined how these communities vary spatially in response to natural disturbances, particularly in recently impacted areas such as La Palma. This gap limits our ability to detect ecological change in coastal systems, especially within areas of high conservation priority.

In this context, we present the first comprehensive, species-level assessment of zooplankton communities in a coastal Special Area of Conservation (SAC) off La Palma Island, an oceanic island in the Atlantic Ocean. This study focuses on characterizing the spatial variability of zooplankton biomass, abundance, and community composition in a dynamic coastal environment. Particular attention is given to copepods due to their ecological relevance and taxonomic richness in subtropical systems.

This research contributes essential baseline data on zooplankton community structure in a region of ecological importance and supports ongoing conservation and monitoring efforts under frameworks such as the EU Marine Strategy Framework Directive and UNESCO's Sustainable Development Goal 14 (Life Below Water). By focusing on a biologically responsive group, this study contributes to a broader understanding of spatial patterns and the taxonomic composition of zooplankton in subtropical coastal waters.

2. Material and Methods

2.1. Sampling

An oceanographic survey was conducted in January 2023 aboard the RV ACUIPALMA 5, as part of the MESVOL project, in the western coastal waters of La Palma Island (28°37′32.63″ N, 17°55′57.64″ W; Atlantic Ocean). The sampling targeted an area within the limits of a designated Special Area of Conservation (SAC; ES7020122), recently influenced by environmental changes associated with the 2021 volcanic eruption. Eight oceanographic stations were established along three coastal transects (Tr1, Tr2, and Tr3), arranged perpendicular to the shoreline to capture nearshore–offshore variation. Transects Tr1 and Tr2, located in the northern section of the study area, included three stations each (St1–St6), while the southernmost transect (Tr3) consisted of two stations (St7–St8) (Figure 1). The stations were spaced approximately 250–500 m apart, with placement determined by accessibility, proximity to key coastal areas under study, and the depth profiles of interest.

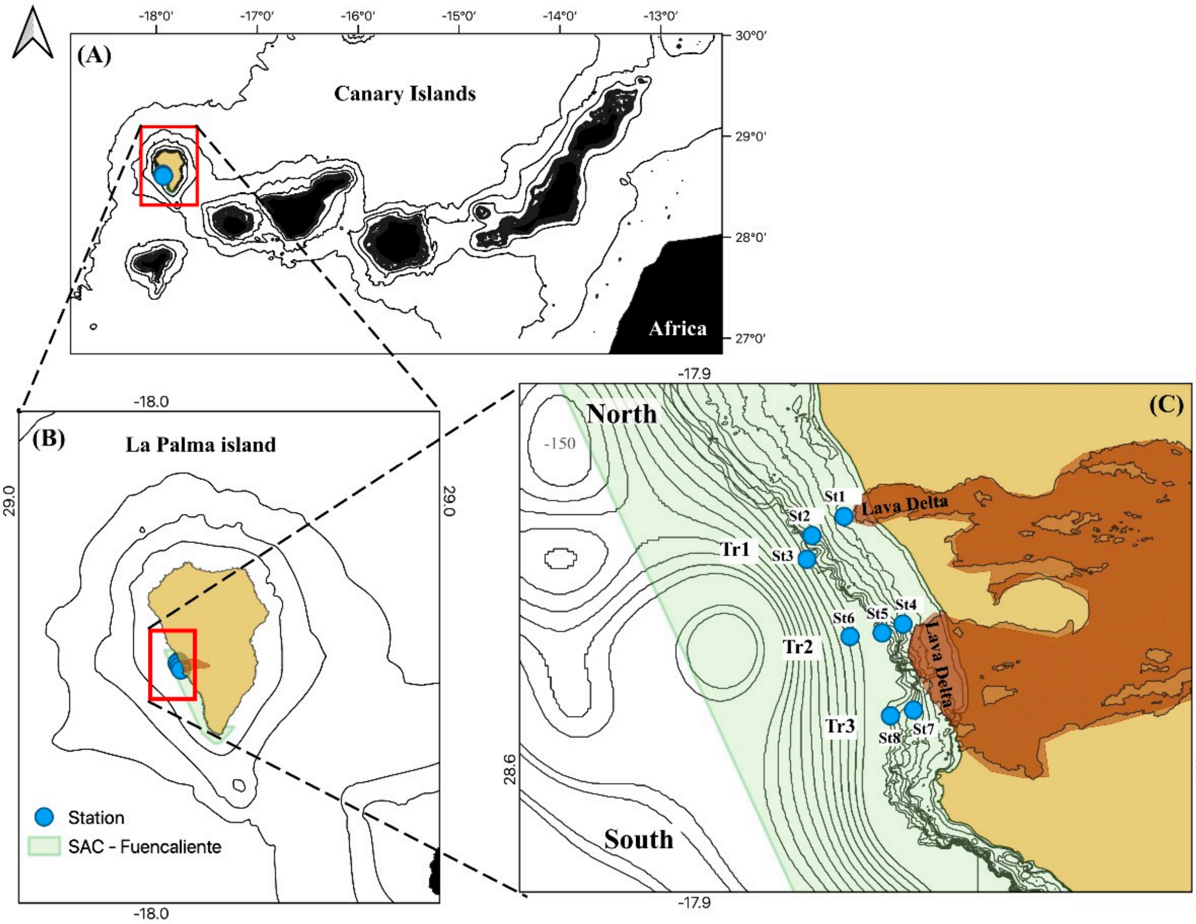

Figure 1. Study area off La Palma Island (Canary Islands), showing the location of transects and sampling stations: (**A**) geographic location of the Canary Islands; (**B**) detailed view of La Palma Island, including the SAC (in green); and (**C**) distribution of sampling stations (blue dots) along coastal transects.

2.2. Environmental and Biological Variables

Vertical profiles of potential temperature (°C) and salinity were obtained down to 60 m depth using a CTD profiler (Seabird 25 PLUS). Zooplankton samples were collected using a standard WP2 net (200 µm mesh size, 57 cm diameter, 0.25 m^2 mouth area, and 0.94 efficiency; [18]), which was vertically hauled from the bottom to the surface at a constant speed of 0.6 $m \cdot s^{-1}$. Sampling depths were set at 10, 30, and 50 m, corresponding to stations from the coastal zone to the open ocean.

On board, samples were split into two equal aliquots using a Folsom plankton splitter. One aliquot was used to determine dry weight biomass, and the other was preserved for taxonomic identification and abundance. Each aliquot was size-fractionated into three categories: 200–500 µm, 500–1000 µm, and >1000 µm.

In the laboratory, biomass was measured by drying the samples at 60 °C for 48 h and weighing them [19], with results expressed in milligrams of dry weight per cubic meter ($mg \cdot m^{-3}$). Abundance was calculated as individuals per cubic meter ($ind \cdot m^{-3}$) following identification under a Stemi DV4 stereomicroscope (Carl Zeiss AG, Oberkochen, Germany). Copepod specimens were further identified to the lowest possible taxonomic level using a stereomicroscope Olympus SZ61 and a compound microscope Olympus BX41 (Olympus Corporation, Hachioji, Tokyo, Japan). Taxonomic classification followed the guidelines established in the ICES Zooplankton Methodology Manual [20] and was conducted by OCEANSNELL S.L.

2.3. Data Analysis

Biomass (mg dry weight·m^{-3}) and abundance (ind·m^{-3}) were calculated for each station using the estimated filtered water volume m^3 considering the WP2 net mouth area (0.25 m^2), the net efficiency (0.94), and the sampling depth. Taxonomic groups contributing less than 0.5% of total abundance per station were grouped as either "Gelatinous" (including siphonophores and salps) or "Others" (including molluscs, polychaetes, amphipods, appendicularians, and fish larvae).

Spatial visualization of the study area was performed in QGIS (3.26.0-Buenos Aires), while environmental variables were visualized using Ocean Data View [21]. Statistical analyses were conducted using R software [22]. One-way analysis of variance (ANOVA) and Tukey's HSD post hoc tests were used to evaluate differences in biomass and abundance across transects. To explore community structure and indicator taxa, a SIMPER analysis and Indicator Value (IndVal) analysis were performed using PAST software (v4.10). IndVal analysis was based on [23], with statistical significance assessed through 9999 permutations.

3. Results

In this study, spatial variation in zooplankton community structure was analysed in relation to biomass, abundance, and taxonomic composition, with reference to environmental parameters. The results reflect distinct patterns in zooplankton distribution in the coastal waters of La Palma Island (Atlantic Ocean), a region recently affected by a natural disturbance within a Special Area of Conservation (SAC).

Vertical profiles of temperature and salinity (Figure 2) showed distinct patterns in the upper water column. In the first 10 m, both parameters observed variability: the temperature ranged from 21.4 to 21.7 °C, while the salinity fluctuated between 36.5 and 37.5. This heterogeneity could result from active ocean–atmosphere interactions, including wind mixing, evaporation, and localized precipitation, which can significantly influence surface water properties. Below this surface layer, the water column became increasingly homogeneous, with temperature and salinity stabilizing around mean values of 21.5 °C (±0.006 SE) and 37 (±0.021 SE), respectively.

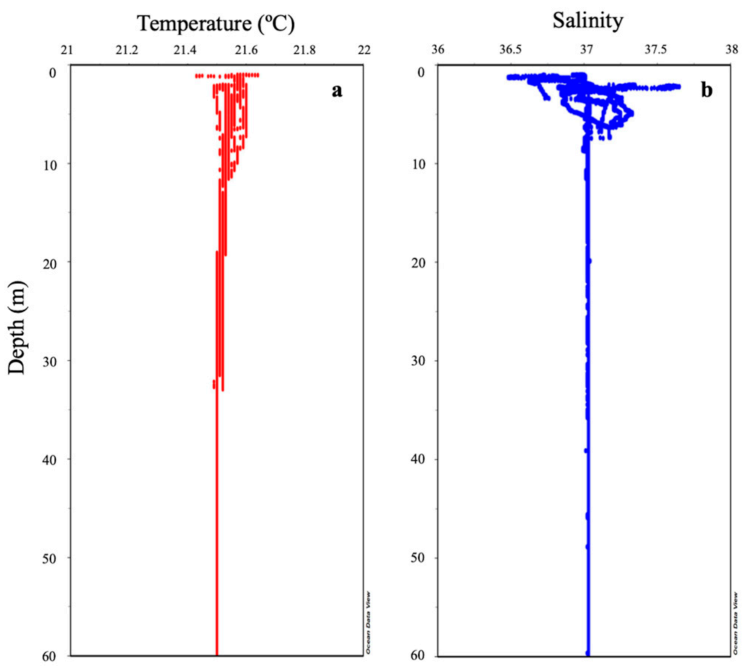

Figure 2. Vertical profiles of (**a**) temperature (°C) and (**b**) salinity for all eight sampled stations plotted together. Each line represents one station, showing variability across the coastal transects.

A total of 13,640 individuals belonging to 13 zooplankton taxonomic groups were observed in the disturbed coastal waters of La Palma Island. From the total abundance, the contribution of the different taxonomic groups was 82.1% Copepoda, 9.4% Crustacean eggs, 2.4% Gastropoda, 2.2% Chaetognatha, 1.3% Ostracoda, 1.1% Decapoda larvae, 0.5% Gelatinous organisms (siphonophores and salps), and 1% Others (other molluscs, polychaetes, amphipods, appendicularians, and fish larvae), as shown in Figure 3.

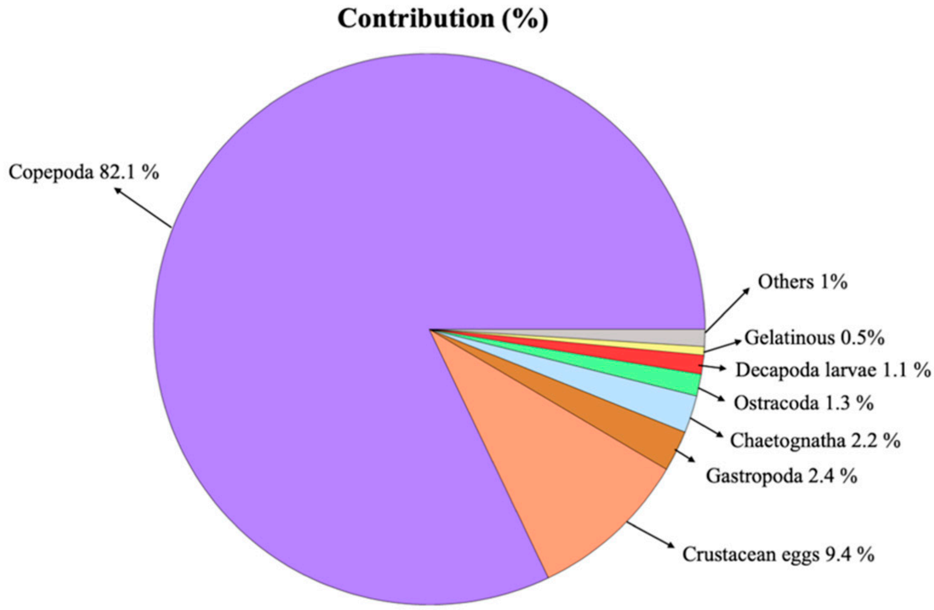

Figure 3. Relative contribution (%) of main zooplankton groups.

Zooplankton biomass and abundance exhibited clear patterns by size fraction and spatial variations across transects. Although total biomass showed a non-significant decreasing trend from the northern (Tr1) to the southernmost transect (Tr3), significant differences (ANOVA, Tukey's test, $p < 0.05$, Supplementary Table S2) were found in the 200−500 µm fraction, which contributed most to total biomass (Figure 4a).

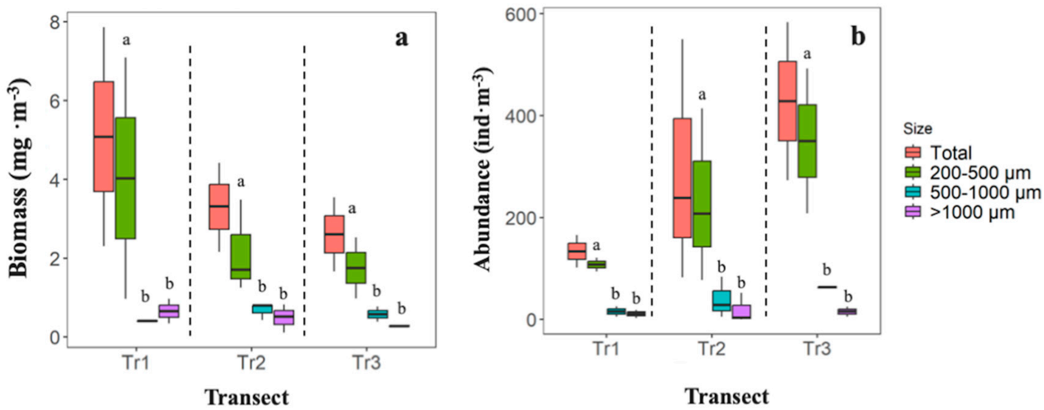

Figure 4. Boxplots of (**a**) zooplankton biomass (mg dry weight·m^{-3}) and (**b**) abundance (ind·m^{-3}) across transects (Tr1−Tr3) and size fractions (200−500, 500−1000, and >1000 µm). The "Total" category represents the sum across all size fractions. Letters above boxes indicate significant differences between size fractions within each transect based on Tukey's HSD post hoc test ($p < 0.05$).

Abundance patterns also varied significantly across transects ($p < 0.05$, Supplementary Table S2), with the 200−500 µm size fraction again showing the strongest contribution to differences (Figure 4b). No significant spatial differences were observed for the larger size fractions (500−1000 µm and >1000 µm), indicating that small zooplankton were key drivers of spatial variability.

The dominant copepods taxa as well as their contribution at the different spatial distributions across transects can be observed in Table 1. A total of 53 copepod taxa/groups were identified, comprising 44 copepod species, two main developmental stages (Copepodites and Nauplii), and seven genera identified at the lowest taxonomic level. The most abundant copepod taxa, accounting for the highest contributions, are as follows: Copepodites, *Acartia negligens*, *Oithona plumifera*, *Macrosetella gracilis*, *Farranula gracilis*, *Oncaea media*, *Clausocalanus paululus*, *Oncaea* sp., *Oncaea scottodicarloi*, *Clausocalanus furcatus*, *Calocalanus styliremis*, and *Calocalanus pavo* (Table 1). The remaining species contributed less than 1.5%.

Table 1. Most representative copepod taxa identified and their contribution (contribution %; SIMPER analysis) to dissimilarity among all samples selected by transect using Bray–Curtis similarity and abundance data (after square root transformation). Overall average dissimilarity per transect: 49.82.

Copepod Taxa	Transect—Contribution %
Copepodites	35.65
Acartia negligens	8.45
Oithona plumifera	6.30
Macrosetella gracilis	5.08
Farranula gracilis	4.71
Oncaea media	4.67
Clausocalanus paululus	4.23
Oncaea sp.	4.17
Oncaea scottodicarloi	2.91
Clausocalanus furcatus	2.72
Calocalanus styliremis	2.02
Calocalanus pavo	1.60
Paracalanus sp.	1.53
Clausocalanus arcuicornis	1.37
Mecynocera clausi	1.33
Calocalanus pavoninus	1.04
Oncaea venusta venella	0.95
Oithona setigera typica	0.90
Nauplius	0.86
Clausocalanus sp.	0.74
Farranula rostrata	0.65
Lucicutia flavicornis	0.62
Calocalanus plumulosus	0.54
Clausocalanus lividus	0.49
Agetus flaccus	0.48
Onychocorycaeus latus	0.48

Table 1. *Cont.*

Copepod Taxa	Transect—Contribution %
Calanoida	0.46
Lubbockia aculeata	0.36
Candacia bispinosa	0.34
Paracalanus aculeatus	0.32
Nannocalanus minor	0.32
Ctenocalanus vanus	0.31
Oncaea mediterranea	0.31
Calocalanus contractus	0.31
Acartia danae	0.29
Clausocalanus mastigophorus	0.28
Candacia ethiopica	0.27
Microsetella rosea	0.25
Corycaeus speciosus	0.20
Acartiidae	0.16
Copilia lata	0.14
Clausocalanus pergens	0.14
Cymbasoma rigidum	0.14
Calocalanus sp.	0.14
Sapphirina intestinata	0.11
Scolecithrix danae	0.10
Scolecitrichidae	0.09
Corycaeus clausi	0.09
Paracalanidae	0.09
Copilia mirabilis	0.09
Oncaea venusta venella	0.09
Calocalanus plumatus	0.09
Clytemnestra scutellata	0.08

The indicator species analysis (Figure 5) showed a total of 53 copepod taxa identified across the three coastal transects (Tr1, Tr2, and Tr3), revealing notable spatial differences in both species composition and relative abundance. Overall, copepod diversity and abundance increased from Tr1 to Tr3, with Tr3 (southern transect) exhibiting the highest species richness and a broader distribution of dominant taxa. Several genera, such as *Oithona*, *Oncaea*, *Clausocalanus*, and *Calocalanus*, were consistently present across all transects, although their relative abundance varied significantly between stations.

The dominance of specific taxa was more pronounced in Tr1, where certain species (e.g., *Candacia ethiopica*) appeared in high abundance (red zones in the heatmap), potentially indicating localized blooms or opportunistic responses to recent environmental disturbances. In contrast, Tr2 presented a more balanced community structure, with intermediate levels of abundance across multiple taxa. Tr3 exhibited the highest diversity, with several species showing elevated relative abundance, including *Lubbockia aculeta*, *Oithona setigera typica*, and *Oncaea scottodicarloi*). This trend suggests a shift toward a more stable and structured zooplankton community, potentially influenced by more favourable environmental conditions or reduced impact from recent perturbations.

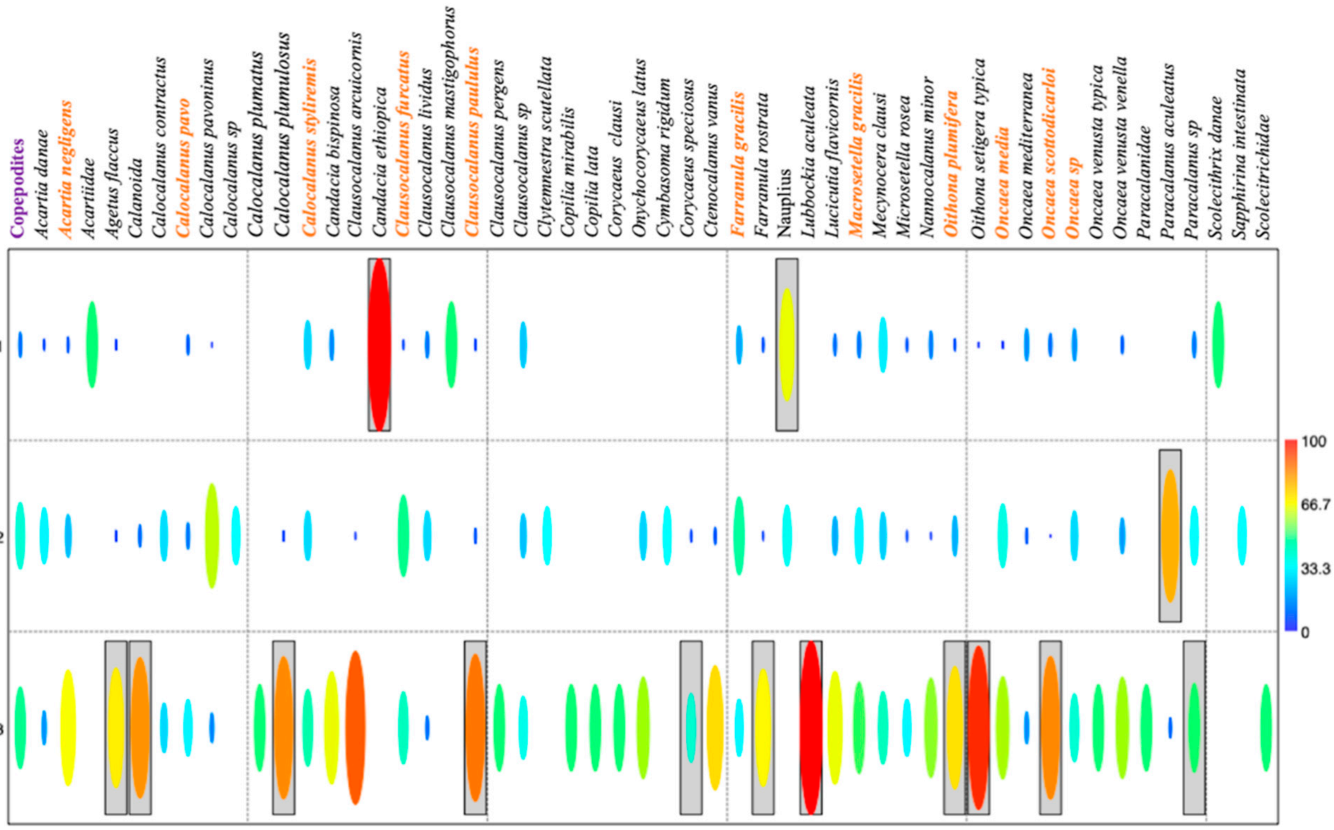

Figure 5. Indicator species in each station. The species highlighted with a box showed a significant p-value < 0.05. The colour scheme describes the individual value % of copepod taxa in the different transects. Violet shows the abundant copepod group "Copepodites". Brown shows the next abundant copepod species: *A. negligens*; *C. pavo*; *C. styliremis*; *C. furcatus*; *C. paululus*; *F. gracilis*; *M. gracilis*; *O. plumifera*; *O. media*; *O. scottodicarloi*; and *Oncaea* sp. Black shows the other copepod species identified.

In addition, distinct species assemblages were associated with each transect, reflecting the presence of spatial variations in environmental conditions. Some species appeared to be restricted to specific zones, which may serve as preliminary evidence of bioindicator potential in relation to recent coastal changes.

4. Discussion

The present study provides detailed records of zooplankton community structure in the coastal waters of an oceanic island in the Atlantic Ocean, within a designated Special Area of Conservation (SAC). Environmental parameters, specifically temperature and salinity, were similar to those observed during the winter season in previous studies conducted in the region [7]. However, these values were higher than long-term seasonal averages for Canary Island waters [24], aligning with regional warming trends observed over recent decades (+0.28 °C per decade; [25]. Such variations are known to influence zooplankton dynamics, particularly among taxa at the base of the marine food web [10].

Copepods were the dominant taxonomic group in the study area, contributing 82.1% of total zooplankton abundance. This aligns with previous research in the region, where copepod dominance typically ranges from 60% to 90% [26,27]. Crustacean eggs were the second most abundant group, consistent with more recent coastal studies [28,29] but differing from earlier research in the region, where appendicularians were commonly the second most abundant group [27,30]. This discrepancy is likely related to the spatial distribution of appendicularians, which are generally more abundant in deeper waters (100–200 m) and are influenced by the thermocline [31] rather than by nearshore coastal conditions [17,32].

Other contributing groups, including gastropods, chaetognaths, and ostracods, showed relative abundances consistent with prior studies across these subtropical waters [17,26,27,33]. Similarly, total biomass values matched historical records from both coastal [34] as well as other oceanic areas within the archipelago [16,17,35].

The 200–500 µm size fraction dominated the community, differing from previous oceanic studies that showed >1000 µm as the prevailing size fraction [35]. This may be attributed to (1) coastal proximity and shallow bathymetry favouring smaller taxa, (2) warmer temperatures observed during this study (>21 °C), which can accelerate the reproductive rates of small copepods, and (3) the reduced dry weight biomass contribution of gelatinous and larger predatory taxa, which often dominate the larger size fractions [36,37].

Zooplankton total abundance was comparable to other studies of dynamic oceanographic systems, including areas with seismic activity [17,38]. The contribution of the 200–500 µm size fraction, along with observed spatial variation along a latitudinal gradient, highlights the fine-scale ecological heterogeneity common in coastal zones. Such patterns may be influenced by physical variables such as stratification, mixing, and local circulation [39,40].

The copepod community in the dominant 200–500 µm size fraction was primarily composed of nauplius, copepodites, and adult stages of genera such as *Oncaea*, *Oithona*, and *Clausocalanus*, which are characteristic of zooplankton communities in the subtropical Atlantic Ocean [17,27,41]. The assemblage also included a mix of small calanoids (e.g., *Acartia*, *Clausocalanus*, *Paracalanus*, and *Calocalanus*) and non-calanoid taxa (e.g., *Oncaea*, *Oithona*, *Corycaeus*), reflecting the taxonomic diversity typically found in these waters.

These small copepod genera are known for traits such as short generation times, broad trophic plasticity, and tolerance to environmental variability [42,43], making them well-adapted to dynamic coastal environments, including recently disturbed zones. Their dominance in this study highlights their adaptability to nearshore environments, where hydrodynamic variability can influence distribution. In contrast, some calanoid copepods (e.g., *Candacia* and *Calocalanus*) with more specialized ecological requirements may exhibit sensitivity to environmental stressors, potentially explaining their spatially restricted distribution.

Indicator species analysis identified *Candacia*, *Oncaea*, *Calocalanus*, and *Oithona* as taxa with marked spatial patterns. While these genera have been linked to hydrographically variable environments [17,44], further research is needed to confirm their utility as spatial indicators in coastal SACs and to evaluate their responses across different seasons or oceanographic regimes.

The establishment of a species-level baseline within a protected zone where such inventories were previously lacking is a key contribution of this work. It provides a foundation for future biodiversity assessments, ecological monitoring, and marine conservation planning in the region.

Although no drastic differences in community structure could be directly attributed to the 2021 eruption, the dominance of opportunistic copepods such as *Oncaea* and *Oithona*, together with the diversity observed in Tr3, may suggest an adaptive response by pelagic communities. These results point to a potential structural resilience in an area exposed to periodic geological disturbances, as has also been observed in post-eruptive studies off El Hierro [17,38].

5. Conclusions

This study provides essential species-level information for understanding spatial variability in copepod-dominated zooplankton communities in coastal conservation areas. The dominance of copepods, the prominence of the 200–500 µm size fraction, and the spatial variability in community composition reflect the complexity of zooplankton dynamics in subtropical coastal waters.

By documenting fine-scale spatial patterns and taxonomic composition, this research contributes critical baseline knowledge for ongoing ecological monitoring under regional and international conservation frameworks. The results underscore the value of high-resolution taxonomic approaches in understanding zooplankton community structure and support the continued use of copepods as ecological indicators in marine biodiversity assessments.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jmse13061124/s1, Figure S1. Review of research studies carried out on zooplankton in the waters of the Canary Islands. showing the number of studies and their main characteristic (ecophysiology and/or composition and composition by zooplankton group or community). the grey lines represent transects. Table S1. Review of research studies carried out on zooplankton in the waters of the Canary Islands. including the information in relation to the study (year, island, area). Proximity to the coast and main characteristics (composition and/or ecophysiology). Table S2. Statistical using Tukey's variance test for Total Biomass and Total Abundance variables against different factors: Size (200–500, 500–1000, >1000 µm) and transects (Tr1, Tr2, Tr3). Refs [45–79] are cited in Supplementary Materials.

Author Contributions: Adrián Torres-Martínez collected and processed the samples, analysed the data, performed statistical analysis and graphics with R and ODV, and wrote the original draft (equal). Inma Herrera was responsible for conceptualization (lead) and supervision, collected and processed the samples, analysed the data, performed statistical analysis and graphics with QGis, Past4, and ODV, contributed to the funding, and reviewed and edited the article. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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