Phenological changes in seaweed community structure and the diversity of fish communities in seaweed ecosystems

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ABSTRACT

Seaweed communities in coastal areas serve as crucial habitat for many organisms and serve to maintain high levels of biodiversity in coastal ecosystems. However, the loss of these communities because of climate change and increasing levels of marine debris is leading to a decline of biodiversity and remains a significant concern. We studied the occurrence of fish species within seaweed communities formed in the subtidal zone. To observe changes in community structure of fish communities, we conducted the study throughout the year in the coastal waters of Arikawa Bay, Shin-Kamigoto Town, Nagasaki Prefecture, where there are significant seasonal changes in seaweed communities. We recorded species, height, and coverage of seaweeds, and the species and abundance of fish, water temperature, and salinity. We hypothesized that as the species diversity, height, and coverage of seaweed communities increase, the species diversity of and abundance of fish also increases. The seaweed coverage and height peaked during April to June. The number of fish species peaked during July to October, however the abundance decreased during this period; data analysis suggests a strong correlation between seaweed and fish communities. Omnivores and benthic feeders were positively correlated with species coverage and a Procrustes analysis also suggests a strong correlation between seaweed communities and fish communities. Analysis is underway to elucidate the impact of marine debris.

Keyword: Biodiversity/ Community/ Ecosystem engineer/ Habitat structure/ Marine debris/ Seaweed

1. INTRODUCTION

Kenyon and Kridler (1969) was one of the first to report the ingestion of plastic debris by birds (*Phoebastria immutabilis*) which led to increased mortality and demonstrated that 74% of chicks that died before fledging had plastic debris in their stomachs. However, records indicate that plastics were observed in birds collected in the early 1960s [2, 3]. Interest in plastic debris steadily increased due to the publication of two seminal papers on plastic debris in the oceans. These reports of marine plastic pollution described the occurrence of plastic pellets and spherules on the ocean surface [4, 5, 6]. Thereafter, plastics have been reported from coastal environments and were observed in bays and beaches [7, 8, 9]. Besides the ingestion of plastics, marine organisms were also observed to be entangled in plastic debris [10, 11, 12]. It is now clear that plastic debris is entering the food chain. One of the first reports suggests that plastic particles found in fur seal feces were originally ingested by their prey fish, *Electrona subaspera* [13]. Clearly, the continued mismanagement and discharge of plastic debris into the oceans will influence the abundance and biodiversity of marine species.

Although the largest amount of plastic waste entering the ocean occurs in East Asia [14] and is accumulating in coastal environments, the region is also experiencing the effects of climate change. Water temperatures are increasing, marine heat waves have been reported, and the subsequent impacts to coastal ecosystems have been reported [15]. As plastic debris accumulates and water temperatures rise, we hypothesize that this will negatively influence the biodiversity of marine organisms in the coastal environment, both directly by decreasing the fitness of marine organisms and increasing rates of mortality and indirectly through the loss and degradation of habitat.

Macroalgae and seagrasses can create large communities forming habitat for a wide variety of marine organisms. Besides providing vital habitat [16, 17], these communities also absorb carbon

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dioxide [18], purify water [19], and protect coastlines from erosion [20]. Fish, squid, crustaceans, and other organisms use seaweed and seagrass communities as a place to shelter from predators [16, 17], feed [21], and spawn [22]. Fish that inhabit seagrass beds can vary in their distributional patterns, which are linked to habitat structure [23]. However, studies have often been of short duration [24, 25, 26], and very few have observed the response patterns of fish communities to structural changes in seagrass communities over longer time scales [25]. This is important, since macroalgae communities undergo significant seasonal changes in structure and biodiversity; the ecological impact of changes in macroalgae biodiversity and community structure is an important factor influencing the biodiversity of organisms observed near seaweed communities.

In seagrass and seaweed ecosystems, suffocation and entanglement caused by marine debris, along with warming water temperatures, are expected to led to changes in the structure of the ecosystem, reduce biodiversity, and disruption traditional ecological relationships. These changes may have short term effects, or these changes may be long-lasting. We are currently investigating a coastal ecosystem in Arikawa Bay, which is a north-facing bay in Nakadori Island, Nagasaki, Japan. Here, we are examining the effect of marine debris and warming water temperatures on the biodiversity and abundance of seaweed, seagrass, and fish species. This paper addresses the first half of our study, providing the details of the biodiversity of fish and seaweed species from two sites in Arikawa Bay. The second half of our study, which examines the effects of marine debris on these two sites will begin in April 2025. Therefore, at this stage of our research, we simply examine the association between fish and seaweed species composition in two rocky shores in the bay.

2. METHODOLOGY

We observed the diversity of seaweed communities and surrounding fish communities in the subtidal area of Arikawa Bay, Nakadori Island, Nagasaki Prefecture, Japan, from June 2023 to May 2024 (Fig. 1). Two study sites were established at Yokoura and Naname shown in Fig. 1. Yokoura is adjacent to an area where fisherman dry and repair nets, whereas Naname is not located to any fisheries activity. The sites were chosen due to the relatively larger inflow of fisheries debris in Yokoura when compared to Naname. Each study site is denoted by the initial letter of the study site and the study station number (e.g., Naname Station 2, N2). A study site was defined as a circle with a radius of 2 m around the landmark. Water temperatures were also recorded, since water temperature is one of the most important variables affecting the ecology of marine organisms [1, 27] We placed data loggers (Tidbit V2, Onset) on the sea bottom of each study site and measurements were recorded at 10-minute intervals. Data collection and logger maintenance was carried out as appropriate.

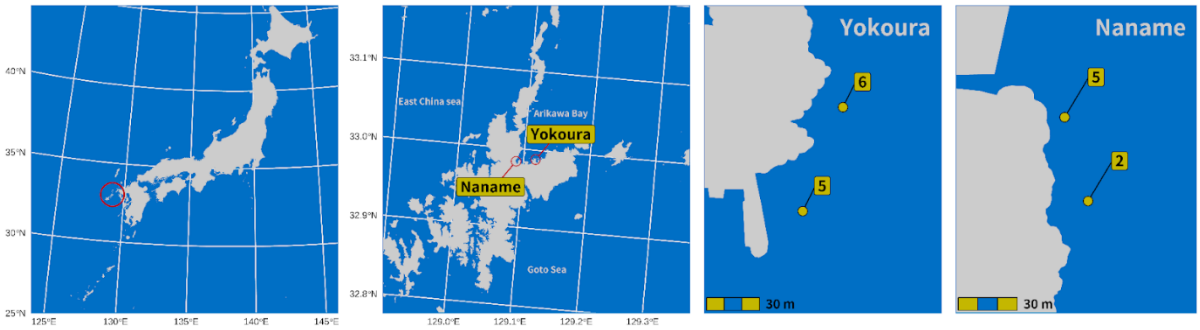

Figure 1. Study sites were located in Naname and Yokoura of Arikawa Bay, Nakadori Island, Nagasaki, Japan.

2.1 Fish communities

Observations of fish were made using time-lapse photography with underwater cameras. The recording interval was set at 10 minutes, and the cameras were recorded between 5 am and 8 pm in order to make observations during the bright hours between sunrise and sunset for about a week. From June 2023 to January 2024, the cameras were placed on the bottom once a month for one day and

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recorded for 24 hours. From March to May 2024, the cameras were floated 50 cm above the bottom, connected to weights on the bottom and recorded for about one week. The cameras were collected, and the data retrieved after recovery and the fish species that appeared were recorded. The species and number of appearances of individuals with whole bodies in the image were recorded. If species identification was difficult, genus or upper taxa were identified.

2.2 Seaweed communities

Observations of macroalgae species, height, and coverage were recorded. Macroalgae species and height were recorded with an underwater camera and visual inspection during skin diving. Every month from June 2023 to May 2024, macroalgae species were identified to the species level with images taken with a camera (TG-6, Olympus, Inc.). If species identification was difficult, individuals were identified to the family or genus level.

2.3 Statistical analysis

All statistical analyses were done using R version 4.4.1 [28]. The alpha diversity was determined for each site, station, and month by calculating the Shannon-Wiener index (1) [29] for fish and determining the species richness for both macroalgae and fish

Procrustes analysis [30] is a technique to measure morphological similarities and differences. It can also be used to estimate similarities in ordination-based matrices, such as those from a principal component analysis (PCA) [31]. Therefore, to determine the relationship between macroalgae communities and fish communities, first a PCA of the species richness for both the macroalgae and fish were determined. Next, the first two principal components of each PCA were used in the Procrustes analysis. A randomization test to examine the sum of residual deviations of the concordance matrix is used to test the statistical significance analysis at a level of 0.05 [25, 31].

$$H' = -\sum_{i=1}^{n} P_i \ln P_i \tag{1}$$

3. RESULTS AND DISCUSSION

During the study period we did not observe any fish communities in Y6 in June and September 2023, seaweed and fish communities or seaweed cover in December 2023 and February 2024 due to strong wind and wave effects and equipment trouble.

3.1 Fish communities

During the study period, we observed 31 species and 2300 individuals at station N2, 34 species and 3734 individuals at station N5, 44 species and 8763 individuals at station Y5, and 36 species and 6470 individuals at station Y6 (total 60 species and 21267 individuals). However, studies were not conducted at station Y6 in June and September 2023 due to poor weather. The species richness of the fish communities during the study was constant from 2023 July to 2024 January but increased from 2024 January to May at all study sites (Fig. 2).

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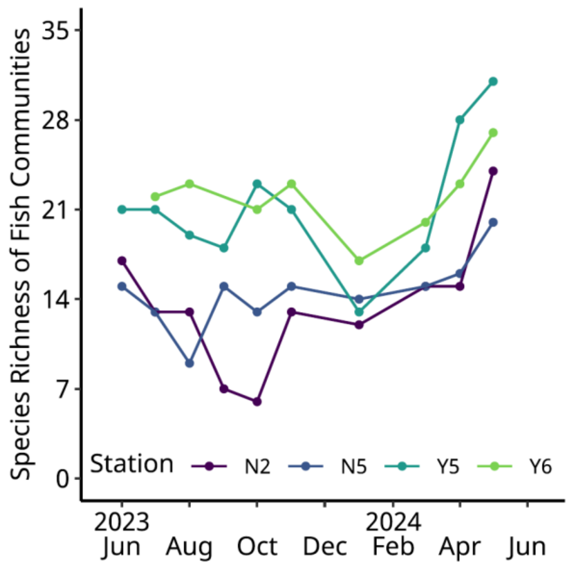

Figure 2. Species richness of fish communities determined from June 2023 to May 2024 at two stations in Naname (N) and two stations in Yokoura (Y) in Arikawa Bay, Nakadori Island, Nagasaki, Japan.

3.2 Seaweed communities

The species richness of the seaweed communities was 32 at station N2, 40 at station N5, 59 at station Y5 and 60 at station Y6 (84 species in total). Species richness at stations Y5 and Y6 appeared to decrease from the start of the study to a low during 2024 January and increase to a peak in 2024 April (Fig. 3). Species richness at stations N2 and N5 responded similarly (Fig. 3). Species richness generally decreased from June to October, which coincided with high water temperatures, and increased from January to April during the winter months (Fig. 3).

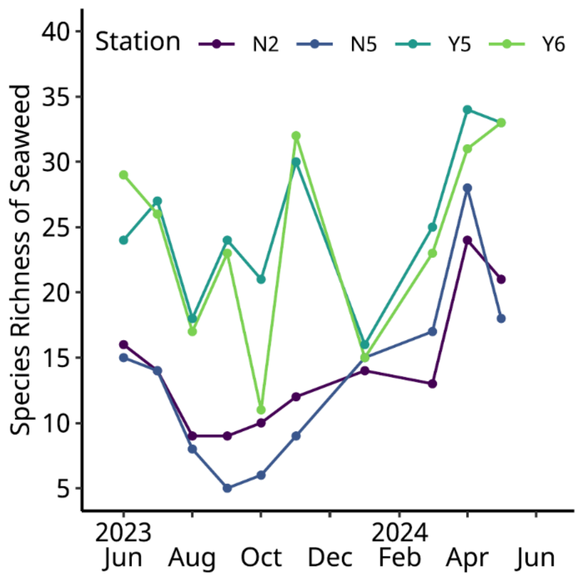

Figure 3. Species richness of seaweed communities determined from June 2023 to May 2024 at two stations in Naname (N) and two stations in Yokoura (Y) in Arikawa Bay, Nakadori Island, Nagasaki, Japan.

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3.3 Water temperature

During the study period, daily averages of water temperatures varied monthly (Fig. 4). The highest water temperatures were recorded in August in both Naname and Yokoura, with daily averages of 28.2°C in Naname and 27.8°C in Yokoura. In contrast, the daily average in February was 13.8°C in Naname and 14.7°C in Yokoura. Water temperature increased through August, decreased from September to February and increased again from March onwards. Although the sites were approximately 3 km in distance (straight-line distance), a small freshwater stream near the Naname site may have provided enough cold water to lower the water temperature at this site.

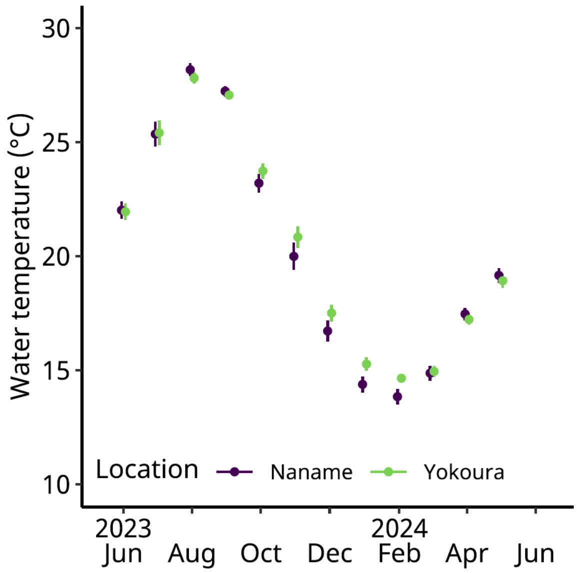

Figure 4. Average daily temperature and its 95% confidence interval determined from the Naname and Yokoura sites in Arikawa Bay, Nakadori Island, Nagasaki, Japan. Some error bars are smaller than the symbols.

3.4 Relationships between seaweed and fish communities

The species richness for fish and macroalgae communities were analyzed using principal components analysis (PCA). PCA is a technique to reduce the number of variables, to facilitate data interpretation. In the case where species abundance matrix is analyzed, PCA is used to reveal structure in the data. For the PCA of the fish community data, the first two principal components (PC) explained 36.7% of the variance revealing that the community can be roughly separated into two groups. Whereas in the macroalgae community, these components explained 30.7% of the variance (Fig. 5). The biplots of the PCA clearly shows separation among the communities observed at each station for either community.

The principal component space of the macroalgae and fish communities were subsequently analyzed using Procrustes analysis. Procrustes analysis indicated a strong correlation between the two communities, where the Procrustes sum of squares was 0.801 and the correlation coefficient was 0.446 ($P = 0.00075$). The projection of PC1 and PC2 also shows a distinct separation between the communities of both study sites (Fig. 6). However, the structure of the data suggests that the community composition of macroalgae and fish species were correlated. Similar correlations were observed in terrestrial ecosystems, where the species richness of animal communities was correlated with plant species richness [32]. Given that macroalgae provide shelter, food, and habitat to many fish species [33], animals inhabiting macroalgae communities likely served as prey for predatory fish species [34, 35, 36]. We hypothesize that the macroalgae communities examined in this study influenced the biodiversity of fish communities observed.

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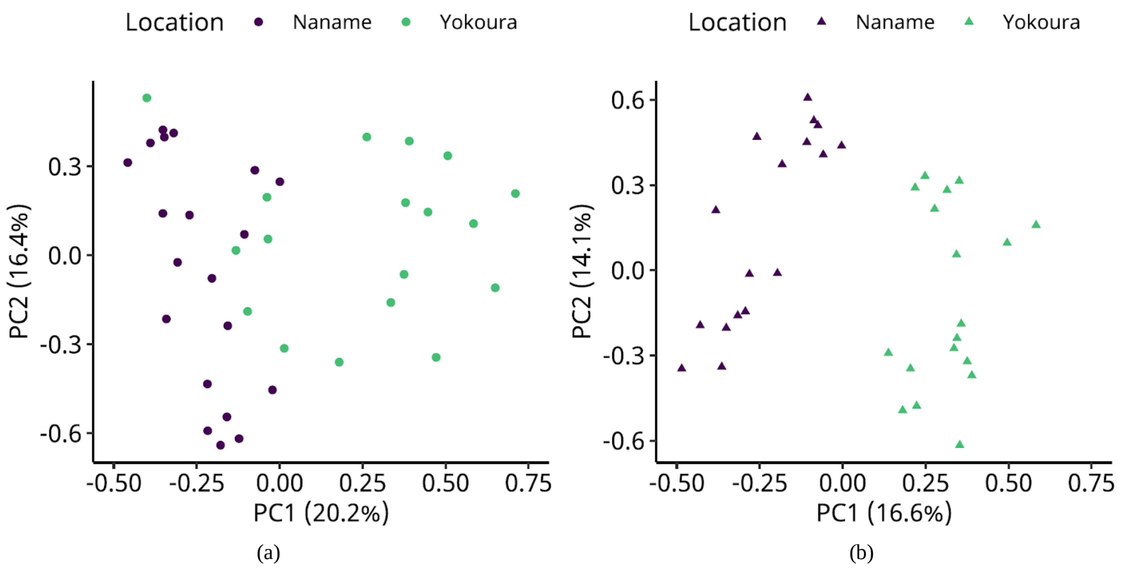

Figure 5. (a) The PCA results of fish communities, (b) The PCA results of seaweed communities.

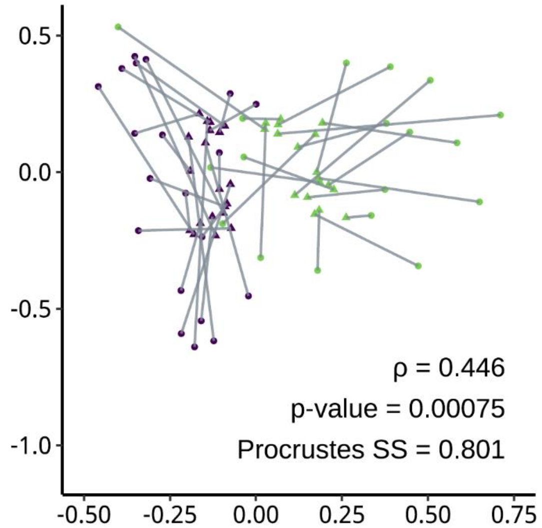

Figure 6. Procrustes Analysis with fish and seaweed communities.

4. CONCLUSIONS

The phenological response of macroalgae and fish species richness was clear in our observations. The Procrustean analysis also indicated that these communities were closely linked and were dissimilar across space. It is unclear as to what environmental variables drive the differences in these two sites, however we suggest that water temperature is one of the more important variables. Consider that the water temperatures during the winter were almost 1 °C colder at Naname compared to Yokoura. Such differences may have influenced the composition of both macroalgae and fish species.

Finally, as water temperature further increases because of climate change, more changes should be expected in patterns of species richness. Additionally, other environmental stressors will compound any effects of climate change. It is interesting to note that marine debris in coastal ecosystems are increasing in abundance and will compete for space with many sessile organisms. Coastal debris is increasing in abundance at Naname and Yokoura, and it remains to be revealed how this will affect the biodiversity of these areas in the near future.

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Reference

[1] Kenyon, K. W., & Kridler, E. (1969). Laysan Albatrosses swallow indigestible matter. *Auk,* 86, 339-343.

[2] Harper, P. C., & Fowler, J. A. (1987). Plastic pellets in New Zealand storm-killed prions (*Pachyptila* spp.).

[3] Rothstein, S. I. (1973). Plastic Particle Pollution of the Surface of the Atlantic Ocean: Evidence from a Seabird. *The Condor*, Vol 75, Issue 3, 344-345.

[4] Carpenter, E. J., Anderson, S. J., Harvey, G. R., Miklas, H. P., & Peck, B. B. (1972a). Polystyrene spherules in coastal waters. *Science,* 178: 749-750.

[5] Carpenter, E. J., Smith, K. J. Jr. (1972b). Plastics on the Sargasso Sea surface. *Science,* 175, 1240-1241.

[6] Colton, J. B. Jr, Knapp, F. D., & Burns, B. R. (1974). Plastic particles in surface water of the northwestern Atlantic.

[7] Cundell A. M. 1973. Plastic materials accumulating in Narragansett Bay. Marine Pollution Bulletin 4: 187 - 188.

[8] Cundell, A. M. (1974). Plastics in the Marine Environment. *Environmental Conservation*, 1(1):63-68.

[9] Gregory, M. R. (1977). Plastic pellets on New Zealand Beaches. *Marine Pollution Bulletin,* 8, 82-84.

[10] Fowler, C. W. (1987). Marine debris and northern fur seals: A case study. *Marine Pollution Bulletin,* 18: 326-335.

[11] Gochfeld, M. (1973). Effect of artefact pollution on the viability of seabird colonies on Long Island, New York. *Environmental Pollution,* 4: 1-6.

[12] Parslow, J. L. F., & Jefferies, D. J. (1973). Elastic thread pollution of puffins. *Marine Pollution Bulletin,* 3, 43-45.

[13] Eriksson, C., & Burton H. (2003). Origins and Biological Accumulation of Small Plastic Particles in Fur Seals from Macquarie Island," AMBIO: *A Journal of the Human Environment*, 32(6), 380-384.

[14] Jackson-Bué, M., Smale, D. A. King, N. G. Rushton, A. G. & Moore, P. J. (2023). Spatial variability in the structure of fish assemblages associated with *Laminaria hyperborea* forests in the NE Atlantic. *Journal of Experimental Marine Biology and Ecology*, Vol 564, 151899, ISSN 0022-0981.

[15] Suryan, R. M., Arimitsu, M. L., Coletti, H. A., Hopcroft, R. R., Lindeberg, M. R., Barbeaux, S. J., Batten, S. D., Burt, W. J., Bishop, M. A., Bodkin, J. L., Brenner, R., Campbell, R. W., Cushing, D. A., Danielson, S. L., Dorn, M. W., Drummond, B., Esler, D., Gelatt, T., Hanselman, D. H., Hatch, S. A., Haught, S., Holderied, K., Iken, K., Irons, D. B., & Zador, S. G. (2021). Ecosystem response persists after a prolonged marine heatwave. *Scientific Report* 11, 6235.

[16] Brandon, S. O'Brien., Kristen, M., Amber, L., & Jennifer, A. D. (2018). Seaweed structure shapes trophic interactions: A case study using a mid-trophic level fish species, *Journal of Experimental Marine Biology and Ecology*, Vol 506, 1-8, ISSN 0022-0981.

[17] Kordas, R. L., Harley, C. D.G., & O'Connor, M. I. (2011). Community ecology in a warming world: The influence of temperature on interspecific interactions in marine systems. *Journal of Experimental Marine Biology and Ecology*, Vol 400, Issues 1–2, 2011, 218-226, ISSN 0022-0981.

[18] Ortega, A., Geraldi, N. R., Alam, I., Kamau, A. A., Acinas, S. G., Logares, R., Gasol, J. M., Massana, R., Krause-Jensen, D., & Duarte, C. M. (2019). Important contribution of macroalgae to oceanic carbon sequestration. *Nature Geoscience*, 12, 748-754.

[19] Short., F. T. Short, C. A. (1984). THE SEAGRASS FILTER: PURIFICATION OF ESTUARINE AND COASTAL WATERS, Editor(s): VICTOR S. KENNEDY, *The Estuary As a Filter,* 395-413, ISBN 9780124050709,

[20] Gaylord, B., Rosman J. H., Reed D. C., Koseff J. R., Fram J., MacIntyre S., Arkema K., McDonald C., Brzezinski M. A., Largier J. L., Monismith S. G., Raimondi P. T., & Mardian B. (2007). Spatial patterns of flow and their modification within and around a giant kelp forest. *Limnology and Oceanography*, 52.

[21] McDonald, P. S., & Bingham, B. L. (2010). Comparing macroalgal food and habitat choice in sympatric, tube-building amphipods, *Ampithoe lacertosa* and *Peramphithoe humeralis*. *Marine Biology,* 157, 1513-1524.

[22] Balon, E. K. (1975). Reproductive Guilds of Fishes: A Proposal and Definition. *Journal of the Fisheries Research Board of Canada*, 32(6): 821-864.

[23] Srednick, G. S., & Steele, M. A. (2022). Macroalgal physical structure predicts variation in some attributes of temperate fish assemblages better than macroalgal species composition. *Marine Biology,* 169, 147.

[24] Evans, R. D., Wilson, S. K., Field, S. N., Moore, J. A. Y. (2014). Importance of macroalgal fields as coral reef fish nursery habitat in north-west Australia. *Marine Biology,* 161, 599-607.

[25] Jackson, D. A. (1995). PROTEST: A PROcrustean Randomization TEST of community environment concordance. *Ecoscience,* 2, 297-303.

[26] Wilson, S. K., Fulton, C.J., Depczynski, M., Holmes, T. H., Noble, M. M., Radford, B., & Tinkler, P. (2014). Seasonal changes in habitat structure underpin shifts in macroalgae-associated tropical fish communities. *Marine Biology,* 161, 2597-2607.

[27] Dell, A. I., Pawar, S., & Savage, van M. (2011). Systematic variation in the temperature dependenceof physiological and ecological traits. *Proceedings of the National Academy of Sciences*, 10591-10596, 108, 26.

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[28] R Core Team. (2024). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
[29] Shannon, C. E. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, vol. 27, no. 3, 379-423.
[30] Gower, J. C. (1971). A general coefficient of similarity and some of its properties. *Biometrics*, 27, 857-871.
[31] Peres-Neto, P. R., & Jackson, D. A. (2001). How well do multivariate data sets match? The advantages of a Procrustean superimposition approach over the Mantel test. *Oecologia*, 129, 169 - 178.
[32] Schuldt, A., Ebeling, A., Kunz, M., Staab, M., Guimarães-Steinicke, C., Bachmann, D., Buchmann, N., Durka, W., Fichtner, A., Fornoff, F., Härdtle, W., Hertzog, L. R., Klein, A. M., Roscher, C., Schaller, J., von Oheimb, G., Weigelt, A., Weisser, W., Wirth, C., Zhang, J., Bruelheide, H., & Eisenhauer, N. (2019). Multiple plant diversity components drive consumer communities across ecosystems. *Nature Communications*, 10, 1460.
[33] Christie, H., Norderhaug, K. M., & Fredriksen, S. (2009). Macrophytes as habitat for fauna. *Marine Ecology Progress Series*, 396, 221-234.
[34] Clifton, K. B., & Motta, P. J. (1998). Feeding Morphology, Diet, and Ecomorphological Relationships among Five Caribbean Labrids (Teleostei, Labridae). *Copeia*, (4), 953-966.
[35] Hajisamae, S., Chou, L. M., & Ibrahim, S. (2003). Feeding habits and trophic organization of the fish community in shallow waters of an impacted tropical habitat, Estuarine, *Coastal and Shelf Science*, Vol 58, Issue 1, 89-98, ISSN 0272-7714.
[36] Matsumoto, K., Kohda, M., & Yanagisawa, Y. (1999). Size-dependent feeding association of two wrasses (genus*Pseudolabrus*) with the morwong,*Goniistius zonatus*. *Ichthyological Research*, 46, 57-65.

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