Vertical distribution of macrobenthic communities from a shipwreck in the Strait of Magellan

Distribución vertical de comunidades macrobentónicas en un naufragio del Estrecho de Magallanes

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Abstract.- Shipwrecks are artificial reefs that can enhance local diversity. In this study, the macrobenthic community associated with a shipwreck in the Strait of Magellan, the DAP Mares, is described for the first time. Species richness and functional group richness were estimated, and general linear models were used to test the prediction that diversity varied systematically with depth. The most speciose and abundant groups were echinoderms, molluscs, sponges, and tunicates. The most abundant trophic type was suspension feeders. Species richness changed significantly with depth, being similar between the upper and middle zones but decreasing at the deepest zone. Neither functional group richness nor functional dispersion (Rao's quadratic entropy) varied with depth, suggesting that not all aspects of macrobenthic diversity respond equally to this variable. The biodiversity observed was consistent with that described for natural hard substrates in the Strait of Magellan. Thus, this vessel could represent a good model to study patterns of community structure.

Key words: Biodiversity, benthic communities, artificial reef, Patagonia

INTRODUCTION

Artificial reefs are formed by sunken structures in aquatic environments and for long periods they receive layers of biomass that successively colonize the structure (Amaral et al. 2010). Shipwrecks are a kind of artificial reefs, spatially complex habitats that can enhance local diversity (Walker et al. 2007, Balazy et al. 2019). Positive relationships between habitat complexity and species diversity have been evidenced by many authors (e.g., MacArthur & MacArthur 1961, Luckhurst & Luckhurst 1978, Dean & Connell 1987, Loke & Todd 2016). This occurs because habitat complexity generates an increased number of niches, higher food web productivity, stability, and protection from physical disturbances (reviewed by Kovalenko et al. 2012).

Due to the successive colonization of the hard substrata, often the abundance of species associated with shipwrecks is greater than the surrounding environment (Jensen 2002). Macrobenthic communities dominate in most artificial reefs, which provide food resources for consumers and secondary habitat for other invertebrates (e.g., Amaral et al. 2010). That is why shipwrecks and other artificial reefs serve as good model systems to study patterns of community succession and the response of epibiota to environmental clines over small spatial scales (Walker et al. 2007).

In addition to their ecological value, these sunken vessels are a relevant historic part of the Strait of Magellan, located in the Magellan Region in the southern part of the East Pacific. The Strait is a 560 km interoceanic route that connects the Pacific and Atlantic Oceans, being the main commercial route until the creation of the Panama Channel. So, it is not surprising that it harbors at least 134 shipwrecks since the 16th century, a number that it is most likely to be underestimated (Bascuñán et al. 2011). The Strait of Magellan encompasses a diversity of habitats, including subtidal rocky reefs, which are dominated by benthic invertebrates such as molluscs, echinoderms, ascidians, sponges, bryozoans and extensive kelp forests broadly distributed around the Southern Ocean, such as Macrocystis pyrifera (Newcombe & Cárdenas 2011,
Friedlander et al. (2018). These species coexist with endemic species originating from vicariant processes mainly during the Last Glacial Maximum (Aguilera et al. 2019). Sharp vertical abiotic environmental gradients can be observed in the Strait of Magellan. For example, photosynthetically active radiation (PAR) decreases to 10% at 15 m depth (Navarro et al. 2021). This could have important effects on biodiversity, leading to predictable vertical distribution patterns of species occurrences and abundances. At the Strait of Magellan and elsewhere, for example, subtidal vertical environmental gradients have been associated with a decrease in the abundance of macroalgae but an increase of invertebrates (Kotta & Witman 2009, Newcombe & Cárdenas 2011, Cárdenas & Montiel 2015, 2016; Villalobos et al. 2021).

In this study, the macrobenthic community associated with a shipwreck in the Strait of Magellan, the DAP Mares, is described for the first time. Since vertical environmental gradients might have deterministic effects on species diversity, species richness and trophic types were predicted to vary from shallow to deeper zones of the shipwreck.

**MATERIALS AND METHODS**

**STUDY SITE**

DAP Mares shipwreck is located 500 m from the coast in Tres Puentes, Punta Arenas City (53°7’24.406”S, 70°50’51.766”W). This vessel was a cargo ship built in 1970 in Spain. It was 76.5 m long and had 1,567 gross registered ton (GRT) (HISTARMAR).1 It was dedicated to Antarctic tourism and scientific logistic support until it ended up sinking on September 20th, 2006. Now the vessel is sunk in a semi-vertical position at the sandy bottom, between depths of 8 m (stem) and 20 m (bow).

A sampling of the shipwreck associated community was done between Feb-May 2018, twelve years after the ship’s sinking. The benthic community was sampled through 0.25 m² photo-quadrats at 8, 15, and 20 m on the outer walls of the ship. At each depth, ten photo-quadrats were obtained. The unit of replication was each quadrant (N = 30).

**DATA ANALYSIS**

The identification of all macrobenthic organisms (sessiles and mobiles > 1 cm) in the quadrants was done to the lowest taxonomic level possible (usually species), using specialized literature and field guides (Osorio et al. 1979, McLean 1984, Pastorino 2005, Häussermann & Försterra 2009). After the identification, the abundance of each species in each photo-quadrat was quantified with the software ‘Coral Point Count’ (Kohler & Gill 2006). One hundred distributed points were superimposed over each photo-quadrant image, and the identity of each taxon was recorded under each point. Species were quantified as counts (number of organisms).

Hill numbers were estimated at three scales of Rényi generalised entropy (Hill 1973):

\[ H_a = \left( \sum_{i=1}^{S} p_i^a \right)^{1/(1-a)} \]

Where \( a \) is the scale factor, \( S \) is the number of species, and \( p_i \) is the relative abundance of species \( i \). Hill numbers were calculated at \( a = 0 \) and \( a = 1 \), representing the effective number of species and exponent of Shannon diversity for each depth, respectively.

The trophic type of each species was defined as autotrophs, suspension feeders, herbivores, carnivores, or omnivores according with information from specialized literature, usually field guides (e.g., Häussermann & Försterra 2009). With these data, the functional group richness (FGR) for each depth was estimated as the number of trophic types, and Rao’s Quadratic Entropy (\( FD_Q \)). \( FD_Q \) is a suitable measure of functional diversity and combines both the abundance and the functional dissimilarity between species (Rao 1980).

General linear models (GLM and LM) were used to test the prediction that diversity, expressed as \( H_0 \), \( H_1 \), FGR, and \( FD_Q \) systematically varied with depth on the shipwreck’s outer walls. According to diagnostics of model residuals, Poisson models were used for \( H_0 \) and \( FGR \), a Gamma model was used for \( H_1 \), and a Gaussian model was used for \( FD_Q \). A “treatment” contrast was used, in which a reference level (8 m depth) is compared against each of the other levels of the factor (15 and 20 m depth). All analyses were conducted in the R statistical environment version 3.6.1. Tidyverse, vegan, cowplot, and FD R-packages were used to generate graphs.

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RESULTS AND DISCUSSION

A total of 36 species were found on the outer walls of the shipwreck (Table 1; Fig. 1). The groups with more species and individuals were echinoderms, molluscs, sponges, and tunicates, which are common in natural rocky substrata of the Strait of Magellan (Newcombe & Cárdenas 2011). The bivalve *Mytilus chilensis* dominated the shipwreck benthic community (N= 1,331), species that is also very abundant along the Strait of Magellan (Velasco-Charpentier et al. 2021). In addition, only two species of macroalgae were found, restricted to the upper depths of the shipwreck: *Macrocystis pyrifera* and *Lessonia flavicans*, which are dominant macroalgae in the Strait of Magellan (Newcombe et al. 2012, Friedlander et al. 2020). This highlights the role of shipwrecks as artificial reefs that foment recruitment and development of ecological communities (Scott et al. 2015).

Species richness changed significantly with depth (GLM pseudo-$R^2=0.25$; Fig. 2A), being similar between the upper and middle depths ($z=0.36$, $P=0.72$) but decreasing at 20 m ($z=-2.3$, $P=0.02$). On the other hand, the exponential Shannon diversity tended to increase at middle depth, 15 m ($t=2.1$, $P=0.05$; pseudo-$R^2=0.15$; Fig. 2B). Neither $FGR$ nor $FDQ$ varied systematically with depth ($P>0.05$; pseudo-$R^2=0.02$ and $R^2=0.05$, respectively). Our results are similar to Cárdenas & Montiel (2015), who described a significative effect of depth on species richness. The lower number of species in deeper zones contradicts what is described for other latitudes, where diversity tends to increase with depth (e.g., Logan et al. 1984).

Depth is relevant to the organization of rocky subtidal benthic communities since abiotic factors (such as light, sedimentation, temperature, and others) vary predictably with depth (Garrabou et al. 2002). The interaction between depth and substratum inclination strongly influences sessile communities in the Strait of Magellan (e.g., Cárdenas & Montiel 2015). Our results suggest that not all aspects of macrobenthic diversity respond equally to depth.

### Table 1. Taxonomic identities and trophic types found in the shipwreck DAP Mares. Numbers represent total abundance at each depth (m) / Identidades taxonómicas encontradas en el naufragio DAP Mares. Los números representan abundancia total a cada profundidad (m)

| Class / species | 8 m | 15 m | 20 m | Trophic type                          |
|-----------------|-----|------|------|---------------------------------------|
| Phaeophyceae     |     |      |      |                                       |
| *Macrocystis pyrifera* | 16  | 0    | 0    | Autotrophs                            |
| *Lessonia flavicans* | 28  | 0    | 0    | Autotrophs                            |
| Demospongiae     |     |      |      |                                       |
| *Mycale magellanica* | 72  | 24   | 21   | Suspension feeder                     |
| *Myxilla sp.*    | 40  | 53   | 60   | Suspension feeder                     |
| *Teudania sp.*   | 16  | 15   | 30   | Suspension feeder                     |
| *Halichroa sp.*  | 34  | 16   | 27   | Suspension feeder                     |
| *Demospongia sp.1* | 0   | 0    | 6    | Suspension feeder                     |
| Anthozoa         |     |      |      |                                       |
| *Metridium senile lobatum* | 6   | 15   | 0    | Suspension feeder                     |
| *Helicostylis pilatus* | 0   | 12   | 0    | Suspension feeder                     |
| *Thouarella sp.* | 20  | 45   | 24   | Suspension feeder                     |
| *Anthoella aechtes* | 0   | 0    | 3    | Suspension feeder                     |
| Polychaeta       |     |      |      |                                       |
| *Chaeopterus variegatus* | 70  | 129  | 30   | Suspension feeder                     |
| Echinidea        |     |      |      |                                       |
| *Arbacia dufresnii* | 6   | 3    | 1    | Herbivore/browser                     |
| *Pseudochima magellanicus* | 2   | 18   | 9    | Herbivore/browser                     |
| Asteroidea       |     |      |      |                                       |
| *Comasterias larida* | 4   | 3    | 9    | Carnivore                             |
| *Odontaster penicillatus* | 2   | 6    | 0    | Carnivore                             |
| *Labidiaster radawai* | 0   | 6    | 15   | Omnivore/opportunistic                |
| *Solaster regularis* | 2   | 0    | 0    | Carnivore                             |
| *Porania antarctica* | 4   | 9    | 7    | Omnivore/opportunistic                |
| *Eurydoides latreillii* | 0   | 3    | 0    | Omnivore/opportunistic                |
| *Muscula gregoria* | 26  | 30   | 39   | Omnivore/opportunistic                |
| *Pelurian spinosulum* | 3   | 1    | 0    | Omnivore/opportunistic                |
| Gasteropoda      |     |      |      |                                       |
| *Tritonia challengersana* | 2   | 6    | 0    | Carnivore                             |
| *Trophon sp.*    | 0   | 6    | 0    | Carnivore                             |
| *Acanthina monodon* | 4   | 3    | 0    | Carnivore                             |
| *Diodora sp.*    | 2   | 0    | 0    | Carnivore                             |
| *Fissurella sp.* | 2   | 3    | 1    | Herbivore/browser                     |
| Malacostraca     |     |      |      |                                       |
| *Euryplus laterilii* | 0   | 3    | 0    | Omnivore/opportunistic                |
| *Munida gregoria* | 26  | 30   | 39   | Omnivore/opportunistic                |
| *Pelturion spinosulum* | 3   | 1    | 0    | Omnivore/opportunistic                |
| Brachiopoda      |     |      |      |                                       |
| *Magellania venosa* | 18  | 42   | 0    | Suspension feeder                     |
Figure 1. Underwater photos from the shipwreck DAP Mares. The substrata are highly colonized by macrobenthic species, mainly sponges (A, B, D), echinoderms (B, C) and bivalves (B, D). Photo credits: Catalina Velasco-Charpentier / Fotos submarinas tomadas en el naufragio DAP Mares. Los sustratos se encuentran altamente colonizados por especies macrobentónicas, principalmente esponjas (A, B, D), equinodermos (B, C) y bivalvos (B, D). Créditos fotográficos: Catalina Velasco-Charpentier

Figure 2. Shipwreck DAP Mares at different depths: A) Species richness, B) Shannon diversity, C) Functional group richness considering the trophic type and D) Rao’s Quadratic Entropy. Points represent the mean values. Error bars represent the standard errors of the mean / Naufragio DAP Mares a diferentes profundidades: A) Riqueza de especies, B) Diversidad de Shannon, C) Riqueza funcional considerando el tipo trófico y D) Entropía de Rao (D). Los puntos representan el valor medio. Barras de error representan los errores estándar de la media
The most abundant trophic type was suspension feeders (Fig. 3). The abundances of primary producers and suspension feeders were significantly larger in shallow waters ($z = -4.50, P < 0.01$, pseudo-$R^2 = 0.78$ and $z = -17.7$ and -24.5, $P < 0.01$, pseudo-$R^2 = 0.97$, respectively). Herbivores significantly increased from shallow to 15 m depth ($z = 0.88, P = 0.02$, pseudo-$R^2 = 0.24$). Carnivores tended, non-significantly, to peak at 15 m depth ($z = 0.37, P = 0.06$, pseudo-$R^2 = 0.22$). Finally, omnivores monotonically increased with depth ($z = 2.35, P = 0.02$, pseudo-$R^2 = 0.34$). The squat lobster *Munida gregaria*, an abundant species in Patagonia fjords (Castro et al. 2021), accounted for most of the abundance of omnivore organisms (Table 1) (Pérez-Barros et al. 2010). In addition, the benthic life phase of *M. gregaria* seems to be unable to cope with low-salinity shallow waters in fjords, which could explain the patterns observed in this study (Betti et al. 2020). In the Magellan region, the dominant systematic group of shallow assemblages is mainly sessile suspension feeders (e.g., sponges, anthozoans, and bryozoans) (Gutt et al. 1999, Andrade et al. 2016, Friedlander et al. 2018). Suspension-feeding species dominate where environmental conditions are characterized by high water flux (Cattaneo-Vietti et al. 1999).

The biodiversity observed on the DAP Mares shipwreck was consistent with that described for natural hard substrates in the Strait of Magellan. Thus, this vessel-as other artificial reefs-could represent a good model to study patterns of community structure, succession, and the ecological response to environmental changes at a small spatial scale.
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