RESEARCH NOTE

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

Catalina Velasco-Charpentier [1,2*], **Felipe Pizarro-Mora[1], Nelso P. Navarro** [3,4,5], **Diego F. Morales-Torres** [6] **and Nelson Valdivia** [5,6]

[1]Fundación Mar y Ciencia, Santa Elena 161, Valparaíso, Chile
[2]Centro de Investigación Gaia Antártica, Universidad de Magallanes, Punta Arenas, Chile
[3]Laboratorio de Ecofisiología y Biotecnología de Algas (LEBA), Universidad de Magallanes, Punta Arenas, Chile
[4]Network for Extreme Environments Research, NEXER-Universidad de Magallanes, Punta Arenas, Chile
[5]Centro FONDAP de Investigación Dinámica de Ecosistemas Marinos de Altas Latitudes (IDEAL), Universidad Austral de Chile, Valdivia, Chile
[6]Instituto de Ciencias Marinas y Limnológicas, Facultad de Ciencias, Universidad Austral de Chile, Valdivia, Chile
*Corresponding author: cvelasco@umag.cl

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, wich are dominated by benthic invertebrates such as molluscs, echinoderms, ascidians, sponges, bryzoans 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 determistic 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 (stern) 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-quadrants 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.

---

[1] Historia y Arqueología Marítima. DAP Mares. Fundación HISTARMAR. Argentina.
<https://www.histarmar.com.ar/Naufragios/CostasdeChile/DAPMares.htm>

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 FD_Q 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	55	60	Suspension feeder
Tedania sp.	16	15	30	Suspension feeder
Haliclona sp.	34	0	0	Suspension feeder
Demospongiae sp.1	0	0	6	Suspension feeder
Anthozoa				-
Metridium senile lobatum	6	15	0	Suspension feeder
Halcurias pilatus	0	12	0	Suspension feeder
Thouarella sp.	20	45	24	Suspension feeder
Antholoba achates	0	0	3	Suspension feeder
Polychaeta				-
Chaetopterus variopedatus	70	129	30	Suspension feeder
Echinoidea				-
Arbacia dufresnii	6	3	1	Herbivore/browser
Pseudechinus magellanicus	2	18	9	Herbivore/browser
Asteroidea				-
Cosmasterias lurida	4	3	9	Carnivore
Odontaster penicillatus	2	6	0	Carnivore
Labidiaster radiosus	0	6	15	Omnivore/opportunistic
Solaster regularis	2	0	0	Carnivore
Porania antarctica	4	9	7	Omnivore/opportunistic
Eurypodius latreillii	0	3	0	Omnivore/opportunistic
Munida gregaria	26	30	39	Omnivore/opportunistic
Peltarion spinosulum	3	1	0	Omnivore/opportunistic

Class / species	8 m	15 m	20 m	Trophic type
Ascidiacea				-
Cnemidocarpa verrucosa	18	38	6	Suspension feeder
Corella eumyota	2	3	0	Suspension feeder
Paramolgula gregaria	4	3	0	Suspension feeder
Sycozoa sigillinoides	10	9	0	Suspension feeder
Polyzoa opuntia	0	0	3	Suspension feeder
Bivalvia				-
Mytilus chilensis	1067	180	84	Suspension feeder
Gaimardia trapesina	9	0	0	Suspension feeder
Gastropoda				-
Tritonia challengeriana	2	6	0	Carnivore
Trophon sp.	0	6	0	Carnivore
Acanthina monodon	4	3	0	Carnivore
Diadula sp.	2	0	0	Carnivore
Fissurella sp.	2	3	1	Herbivore/browser
Malacostraca				-
Eurypodius latreillii	0	3	0	Omnivore/opportunistic
Munida gregaria	26	30	39	Omnivore/opportunistic
Peltarion 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
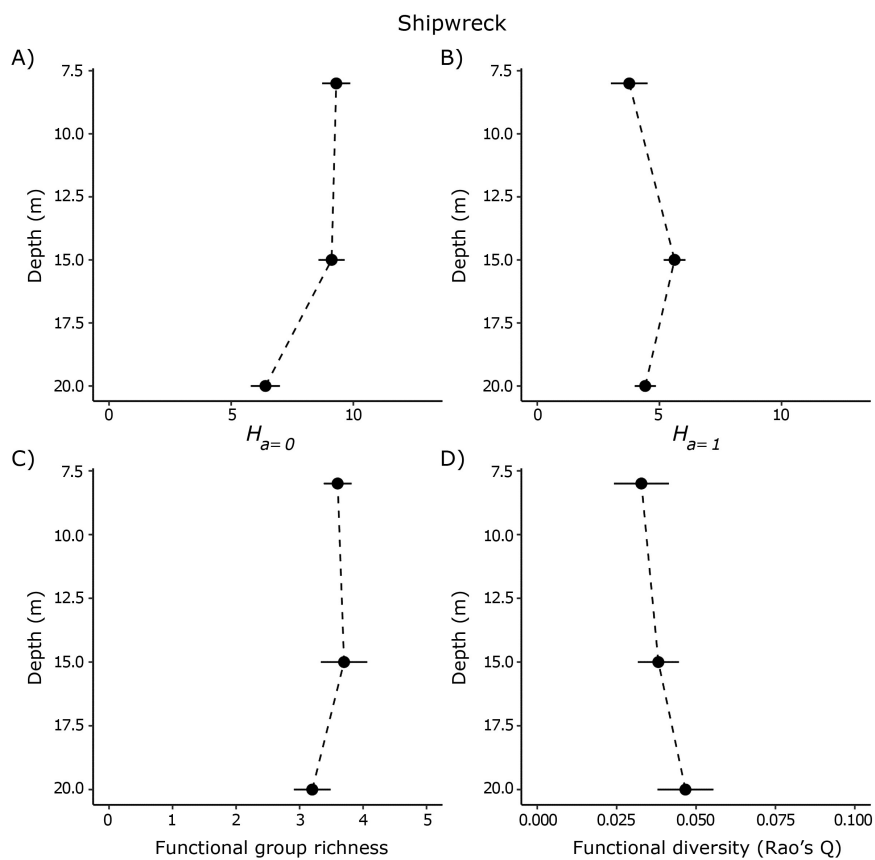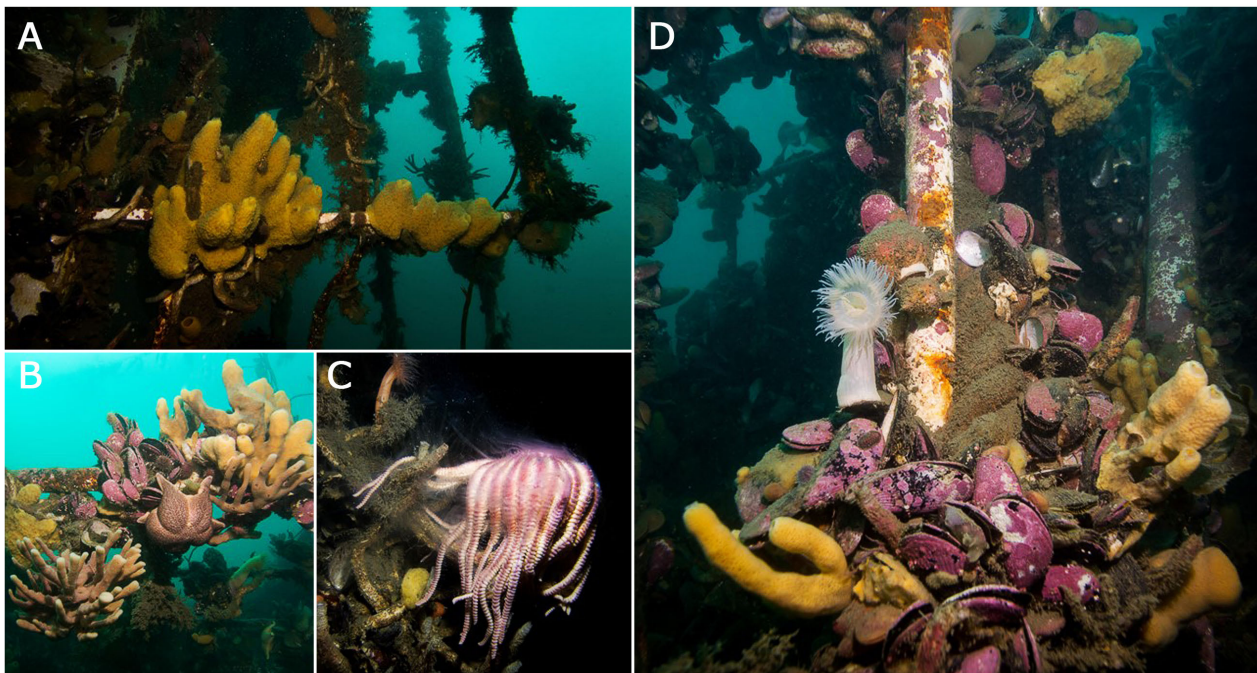

Figure 2. Shipwreck DAP Mares at different depths: A) Species richness, B) Shannon diversity, C) Functional group richness considering the trophic type and D) Rao's Quadratic Entropy. Points represent the mean values. Error bars represent the standard errors of the mean / Naufragio DAP Mares a diferentes 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.
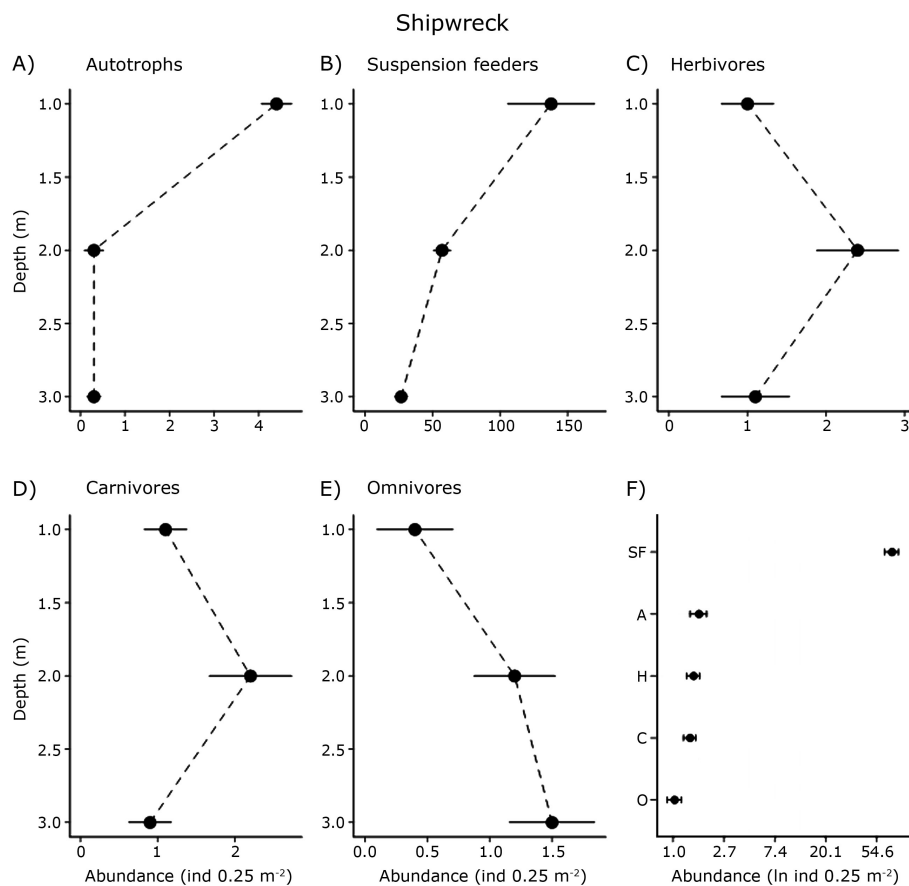

Figure 3. Vertical distribution of five trophic types (A-E) on the DAP Mares shipwreck, and the total abundance of trophic types (F) with the higher abundance for suspension feeders (SF). Points represent the mean values. Error bars represent the standard errors of the mean / Distribución vertical de cinco tipos tróficos (A-E) en el naufragio DAP Mares, y la abundancia total de tipos tróficos (F), con los suspensívoros (SF) en mayor abundancia. Los puntos representan el valor medio. Barras de error representan los errores estándar de la media

LITERATURE CITED

Aguilera M, J Aburto, L Bravo, B Broitman, R García, C Gaymer, S Gelcich, B López, V Montecino, A Pauchard, M Ramos, J Rutllant, C Sáez, N Valdivia & M Thiel. 2019. Chile: Environmental status and future perspectives. In: Sheppard C (ed). World seas: An environmental evaluation, pp. 673-702. Academic Press, New York.

Amaral F, C Farrapeira, S Lira, C Ramos & R Dom. 2010. Benthic macrofauna inventory of two shipwrecks from Pernambuco coast, northeastern of Brazil. Revista Nordestina de Zoologia 4(1): 24-41.

Andrade C, C Ríos, D Gerdes & T Brey. 2016. Trophic structure of shallow-water benthic communities in the sub-Antarctic Strait of Magellan. Polar Biology 39(12): 2281-2297.

Balazy P, U Copeland & A Sokołowski. 2019. Shipwrecks and underwater objects of the southern Baltic-Hard substrata islands in the brackish, soft bottom marine environment. Estuarine, Coastal and Shelf Science 225:106240. <10.1016/j.ecss.2019.05.022>

Bascuñán C, M Eichholz & F Hartwig. 2011. Naufragios en el Océano Pacífico Sur, tomo 1, 837 pp. Aguilar Chilena de Ediciones, Santiago.

Betti F, LR Castro, G Bavestrello, F Enrichetti & G Daneri. 2020. Distribution, abundance and ecological requirements of the benthic phase of *Munida gregaria* (Anomura; Munididae) in the Puyuhuapi Fjord (Chilean Patagonia). Regional Studies in Marine Science 40: 101534. <https://doi.org/10.1016/j.rsma.2020.101534>

Cárdenas CA & A Montiel. 2015. The influence of depth and substrate inclination on sessile assemblages in subantarctic rocky reefs (Magellan region). Polar Biology 38(10): 1631-1644.

Cárdenas CA & A Montiel. 2016. Coexistence in cold waters: Animal forests in seaweed-dominated habitats in southern high latitudes. In: Rossi S, L Bramanti, A Gori & C Orejas (eds). Marine animal forest, the ecology of benthic biodiversity hotspots, 1366 pp. Springer, Cham, Switzerland.

Castro LR, HE González, J Garcés-Vargas & P Barrientos. 2021. Separate feeding between the pelagic stage of the squat lobster *Munida gregaria* and the larger sized zooplankton crustacean groups in the Beagle Channel as revealed by stable isotopes. Frontiers in Marine Science 8: 635190. <doi: 10.3389/fmars.2021.635190>

Cattaneo-Vietti R, M Chiantore, C Misic, P Povero & M Fabiano. 1999. The role of pelagic-benthic coupling in structuring littoral benthic communities at Terra Nova Bay (Ross Sea) and in the Straits of Magellan. Scientia Marina 63(1): 113-121.

Dean R & J Connell. 1987. Marine invertebrates in an algal succession III. Mechanisms linking habitat complexity with diversity. Journal of Experimental Marine Biology and Ecology 109: 249-273.

Friedlander A, E Ballesteros, T Bell, J Giddens, B Henning, M Hüne, A Muñoz, P Salinas de León & E Sala. 2018. Marine biodiversity at the end of the world: Cape Horn and Diego Ramírez islands. PloS One 13(1): e0189930. <https://doi.org/10.1371/journal.pone.0189930>

Friedlander A, E Ballesteros, T Bell, J Caselle, C Campagna, W Goodell & P Dayton. 2020. Kelp forests at the end of the earth: 45 years later. PloS One 15: e0229259. <https://doi.org/10.1371/journal.pone.0229259>

Garrabou J, E Ballesteros & M Zabala. 2002. Structure and dynamics of north-western Mediterranean rocky benthic communities along a depth gradient. Estuarine, Coastal and Shelf Science 55(3): 493-508.

Gutt J, E Helsen, W Arntz & A Buschmann. 1999. Biodiversity and community structure of the mega-epibenthos in the Magellan area (South America). Scientia Marina 63(1): 155-170.

Häussermann V & G Försterra. 2009. Actiniaria-Anémonas de mar. En: Häussermann V & G Försterra (eds). Fauna marina bentónica de la Patagonia chilena, pp. 215-266. Nature in Focus, Santiago.

Hill M. 1973. Diversity and evenness: a unifying notation and its consequences. Ecology 54: 427-473.

Jensen A. 2002. Artificial reefs of Europe: perspective and future. ICES Journal of Marine Science 59: 3-13.

Kohler K & S Gill. 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. Computers & Geosciences 32(9): 1259-1269.

Kotta J & J Witman. 2009. Regional scale patterns. In: Wahl M (ed). Marine hard bottom communities: Patterns, dynamics, diversity and change, pp. 89-96. Springer-Verlag, Berlin.

Kovalenko K, S Thomaz & D Warfe. 2012. Habitat complexity: approaches and future directions. Hydrobiologia 685: 1-17.

Logan A, FH Page & MLH Thomas. 1984. Depth zonation of epibenthos on sublittoral hard substrates off Deer Island, Bay of Fundy, Canada. Estuarine, Coastal and Shelf Science 18(5): 571-592.

Loke L & P Todd. 2016. Structural complexity and component type increase intertidal biodiversity independently of area. Ecology 97: 383-393.

Luckhurst B & K Luckhurst. 1978. Analysis of the influence of substrate variables on coral reef fish communities. Marine Biology 49: 317-323.

MacArthur R & J MacArthur. 1961. On bird species diversity. Ecology 42: 594-598.

McLean J. 1984. Systematics of *Fissurella* in the Peruvian and Magellanic faunal provinces (Gastropoda: Prosobranchia). Contributions in Science, Natural History Museum of Los Angeles County 354: 1-70.

Navarro NP, P Huovinen, J Jofre & I Gómez. 2021. Ultraviolet radiation stress response of haploid and diploid spores of *Mazzaella laminarioides*: Do bio-optical traits matter? Algal Research 54: 102230. <https://doi.org/10.1016/j.algal.2021.102230>

Newcombe E & C Cárdenas. 2011. Rocky reef benthic assemblages in the Magellan Strait and the South Shetland Islands (Antarctica). Revista de Biología Marina y Oceanografía 46(2): 177-188.

Newcombe E, C Cárdenas & S Geange. 2012. Green sea urchins structure invertebrate and macroalgal communities in the Magellan Strait, southern Chile. Aquatic Biology 15: 135-144.

Osorio C, J Atria & S Mann. 1979. Moluscos marinos de importancia económica en Chile. Biología Pesquera, Chile 11: 3-47.

Pastorino G. 2005. A revision of the genus *Trophon* Montfort, 1810 (Gastropoda: Muricidae) from southern South America. The Nautilus 119: 55-82.

Pérez-Barros P, M Romero, J Calcagno & G Lovrich. 2010. Similar feeding habits of two morphs of *Munida gregaria* (Decapoda) evidence the lack of trophic polymorphism. Revista de Biología Marina y Oceanografía 45(3): 461-470.

Rao C. 1980. Diversity and dissimilarity coefficients: A unified approach. Theoretical Population Biology 21: 24-43.

Scott M, J Smith, M Lowry, M Taylor & I Suthers. 2015. The influence of an offshore artificial reef on the abundance of fish in the surrounding pelagic environment. Marine and Freshwater Research 66: 429-437.

Velasco-Charpentier C, F Pizarro-Mora, NP Navarro & N Valdivia. 2021. Disentangling the links between habitat complexity and biodiversity in a kelp-dominated subantarctic community. Ecology and Evolution 11(3): 1214-1224.

Villalobos VI, N Valdivia, G Försterra, S Ballyram, JP Espinoza, JL Wadham, K Burgos-Andrade & V Häussermann. 2021. Depth-dependent diversity patterns of rocky subtidal macrobenthic communities along a temperate fjord in Northern Chilean Patagonia. Frontiers in Marine Science 8: 635855. <doi: 10.3389/fmars.2021.635855>

Walker S, T Schlacher & M Schlacher-Hoenlinger. 2007. Spatial heterogeneity of epibenthos on artificial reefs: fouling communities in the early stages of colonization on an East Australian shipwreck. Marine Ecology 28: 435-445.