

Decapods associated with the Southern king crab (*Lithodes santolla*) fishery in  
central Patagonia (44° S, Chile).

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**Abstract:** The Southern king crab, *Lithodes santolla*, is an important fishery resource in the inner seas of Chilean Patagonia. The fishing gear used to catch Southern king crab (bait trap) and its operation at different depths over several months provide the opportunity to gather information about relative abundance. The aim of the present study was to analyze the information collected from the catches of Southern king crab and its associated fauna in the Magdalena Fjord to study the biodiversity and ecology of scavenging decapod crustaceans. Specifically, the study aimed to determine the bathymetric patterns of abundance by species, to model the abundance by season (winter and spring) and to determine the structuring pattern of scavenging decapods assemblage. Samples were collected between June and November 2019 by deploying traps in four bathymetric strata: 1 = 0–50 m; 2 = 51–100 m; 3 = 101–150 m; 4 = 151–200 m. We registered a total of 673 decapod specimens associated with the Southern king crab fishery, representing five species: *Lithodes santolla* (n = 96), *Libinia smithii* (n = 10), *Metacarcinus edwardsii* (n = 58), *Munida gregaria* (n = 507) and *Peltarion spinulosum* (n = 2). The abundance of decapod species varied by month and bathymetric strata. We found bathymetric patterns for *L. santolla* abundance, *M. gregaria*, *M. edwardsii*, and total species abundance. The most informative model to explain scavenging decapod abundance by GLM included species and season. The null model of species co-occurrence analysis revealed that all species associations during the sampled months were random. Our study is the first that provides evidence about patterns of bathymetrical and temporal variation of scavenging decapod abundance and expands the body of knowledge regarding the biodiversity of scavenger decapods in the Magdalena Sound, which currently is affected by multiple stressors such as climate change and anthropic activities (aquaculture and fisheries).

Keywords: *Lithodes santolla*, fisheries, Decapoda, bathymetric pattern, Patagonia

## 1. Introduction

There are few records of decapod fauna in Patagonian seas due to the geography, which is characterized by inner seas and islands that make the area difficult to access [1,2]. In the inner seas of Chilean Patagonia (from 41° to 55°S), one of the most important resources in crustacean fisheries is Southern king crab (*Lithodes santolla* Molina, 1782), with catches reported from 1940 (~ 500 t) to the present (~5000 t) [3]. From a biogeographical point of view, the decapod fauna in Patagonian inner seas is characterized by species found in sub-Antarctic and southern Atlantic seas [1].

The studies on decapod fauna are based mainly on the species records of scientific expeditions [4–9] that provide a basis for integrated biogeographical studies [1,8,9]. Nevertheless, ecological studies are scarce due to the difficulty of accessing southern Chilean Patagonia [2,10–12]. Previous studies were mainly conducted on intertidal and subtidal populations and communities in central and northern Patagonian inner seas [2,8,10] by studying the stomach contents of coastal fish for which decapods represent an important food source [10,13] as well as communities in deep seas [14]. Nevertheless, these studies were mainly based on first reports of decapod species and communities taken during short sampling periods.

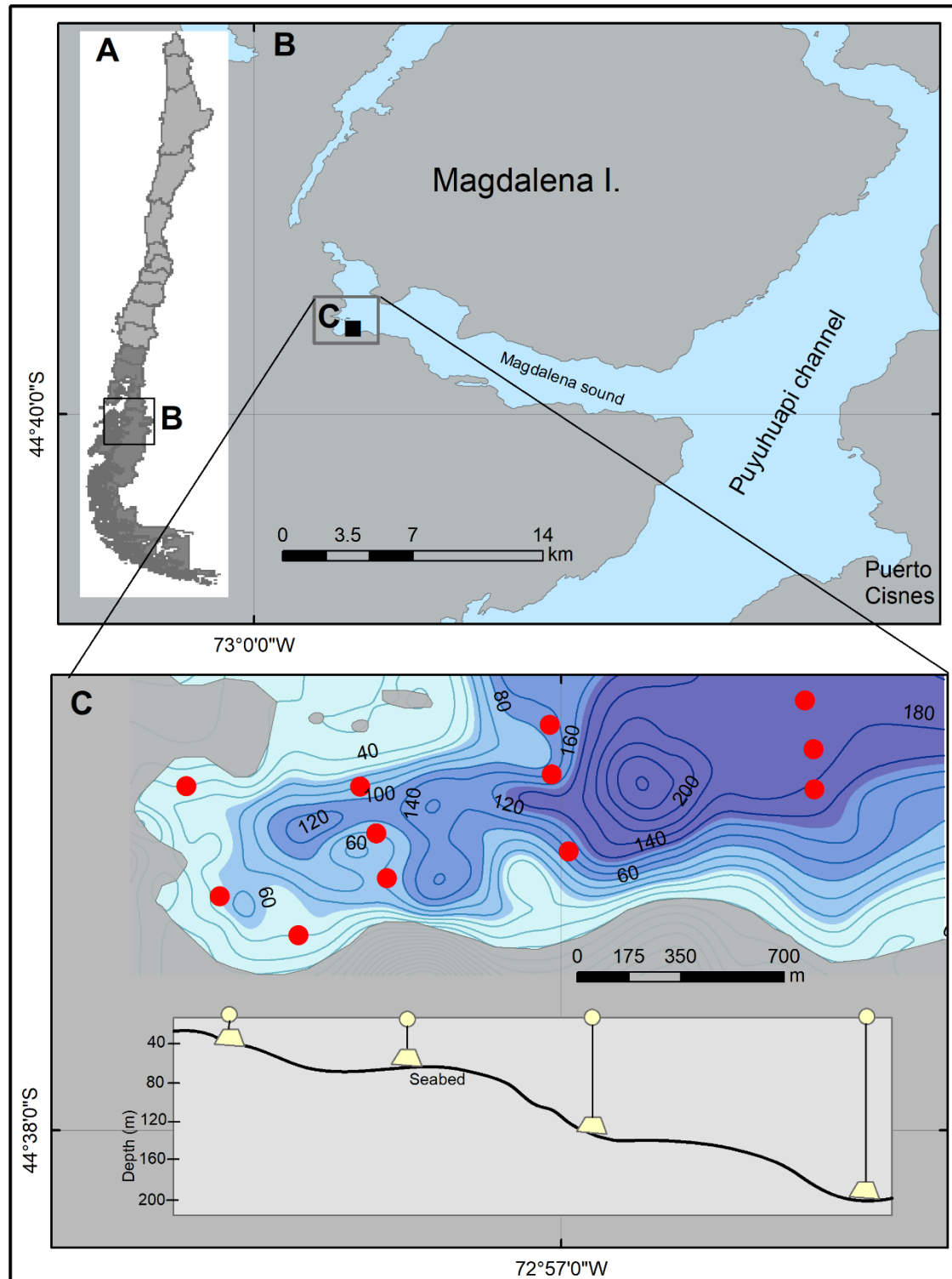
The fishing gear used to catch Southern king crab (bait trap) and its operation at different depths over several months [3] provides the opportunity to use the information collected (relative abundance) from the catches of both the target species and its associated

fauna to study the biodiversity and ecology of scavenging decapod crustaceans [14]. Additionally, due to the stratification and seasonal variations of the physicochemical parameters presented by the fjords of Patagonia [14,15], the relative abundance data obtained can be used to determine relevant ecological information such as bathymetric patterns of abundance by species, to model the abundance by season, and to determine the structuring pattern of the scavenging decapod crustacean assemblage.

The aim of the present study was to analyse the information from the catches of Southern king crab and its associated fauna in the Magdalena Fjord (44° S, Aysen region, southern Chile) to study the biodiversity and ecology of scavenging decapod crustaceans.

## **2. Materials and Methods**

*Study site:* The study was carried out in the Magdalena Sound, which is a fjord located in the Puyuhuapi Channel in the Aysén region of Chile (Figure 1). The Magdalena Sound is in front of the town of Puerto Cisnes on Magdalena Island, and is the deepest branch of the Puyuhuapi Channel, approximately 14 km long, 350 m deep and comprised mostly of vertical stone walls [14,15]. The area contains high amounts of dissolved organic matter, both of autochthonous (i.e., primary production) and allochthonous origin (i.e., discharge from rivers and aquaculture activities), and is influenced by the interaction of fresh water and seawater. This generates estuarine stratification, with the first layer (0–10 m deep) composed of brackish water and the deeper layers composed of seawater of sub-Antarctic origin [14,15].



**Figure 1.** Study area of Magdalena Sound in central Patagonia and schematic representation of bathymetric positioning of traps. Red circles represent the location of the Traps.

*Data collection:* In order to investigate the biodiversity and ecology of scavenging decapod crustaceans associated with the Southern king crab fishery, we analysed the catch data from individual traps (n = 12) distributed across the Magdalena Sound (Figure 1). Traps were positioned in four bathymetric strata (1 = 0–50 m; 2 = 51–100 m; 3 = 101–150 m; 4 = 151–200 m) (Figure 1), with three traps for each stratum. Catches were carried out monthly between June 2019 and November 2019, which represents austral winter and spring. The fishing gear used in the subtidal zone consisted of conical traps (1 m diameter, 0.7 m height, and a 0.25-m diameter opening at the top covered by a 2-cm weft net). All traps contained pieces of *Merluccius australis* (Hutton, 1872) as bait and were randomly distributed in the different bathymetric strata. Fishing time was standardized at 12 h (8:00 p.m.–8:00 a.m.). The specimens captured were counted and identified to the species level, then returned to their environment (except *L. santolla*).

*Data analysis:* Bathymetric patterns – The bathymetric patterns of abundance by species were analysed through a correlation analysis between depth strata and abundance of each species and total species [16,17]. Due to the nature of the data, a non-parametric Kendall correlation test was performed [18,19].

Modelling abundance – To model the seasonal (winter and spring) abundance of Southern king crab and decapod crustaceans associated with the fishery, a generalized linear model (GLM) approximation was performed due to the enormous number of 0 values in the catches [20]. The predicted variables were depth (four bathymetric stratum), season (winter and spring) and species (*L. santolla*; *Libidoclaea smithii* Miers, 1886; *Metacarcinus edwardsii* Bell, 1835; *Munida gregaria* Fabricius, 1793 and *Peltarion spinulosum* White, 1843). First, we only worked with the positive observations of abundance, and the models

that included all the predictor variables, but with different error distributions, were compared (i.e., Gaussian, gamma, Poisson, Quasi, Quasi-poisson and Negative binomial; Table 1). Second, model for the positive observations was selected (Delta-gamma [20]) using the lowest value of the Akaike information criterion (AIC). Third, the most influential predictor variables were species, season, and their interaction (Table 2). Fourth, we verified that the selected model met all assumptions. Fifth, the null values were included, generating a presence/absence matrix that was analysed as a dichotomous variable (0/1) in a GLM that included the same predictor variables (species and season) of the selected model for the positive observations. However, in this model, a binomial distribution of the error and a “logit-link” function were assumed [21]. Finally, the mean seasonal abundance of each species ( $\hat{S}_a$ ) was estimated by integrating the information from both models (positive and presence/absence of observation) in the most informative model corrected using the equation:  $\hat{S}_a = \hat{p} \cdot \widehat{SA}_p$ , where  $\hat{p}$  is the probability estimated by the GLM applied to presence/absence abundance data and,  $\widehat{SA}_p$  is the mean seasonal abundance estimated by GLM applied to positive abundance data. All GLMs were built and analysed using the “stats” and “car” packages in the software R.4.0 [22,23].

**Table 1.** Comparison of general linear models with different error distributions to model the positive abundance of decapod crustaceans.

Error distribution of models	Degrees of freedom	Residual deviance	Residual degrees of freedom	Deviance	AIC
Response variable: Positive abundance of decapod crustaceans					
Gaussian	81	5064.8	59	10869.5	618.8

Gamma	81	40.6	59	126.4	448.7
Poisson	81	334.7	59	952.18	646.9
Quasi	81	5064.8	59	10869.5	-
Quasi-poisson	81	334.72	59	952.2	-
Negative binomial	81	70.5	59	226.37	473.1

**Table 2.** Deviance analysis of predictor variables to model the positive abundance of decapod crustaceans.

	Degrees of freedom	Residual deviance	Residual degrees of freedom	Deviance	Pr(>x <sup>2</sup> )
Response variable: Positive abundance of decapod crustaceans					
Species	4	44.4	77	82.0	< 0.001
Season	1	9.5	76	72.5	< 0.001
Depth	3	0.417	73	72.1	0.85

Assemblage structure – To determine the assemblage structuring pattern of decapods associated with the Southern king crab fishery, null models of species co-occurrence were created [24]. The hypothesis of the null models corresponded to the absence of regulating factors in the assemblage structure [24]. A species presence/absence matrix was constructed, with the species in rows and the months in columns. First, we calculated a Checkerboard score (“C-score”), which is a quantitative index of occurrence that measures the extent to which species co-occur less frequently than expected by chance

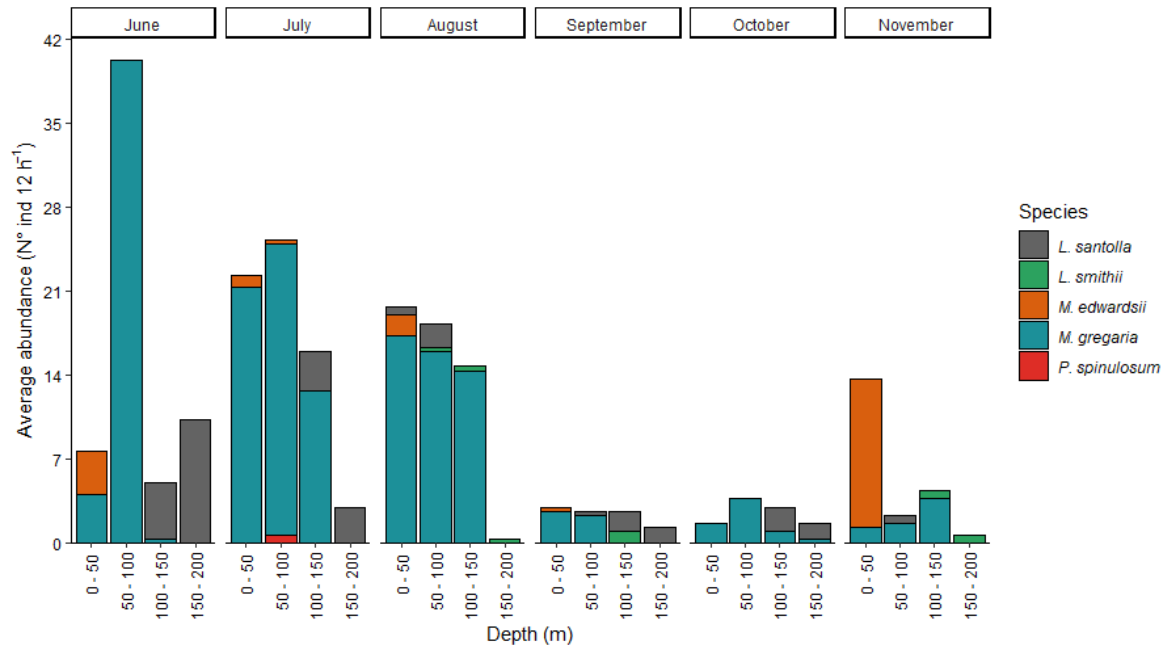


[25]. An assemblage is structured by competition when the C-score is significantly larger than expected by chance [25–26]. Co-occurrence patterns were compared with null expectations via simulation. Gotelli, 2000 [25] suggested statistical null models be Fixed-Fixed: in this model, the row and column sums of the matrix are preserved. Thus, each random assemblage contains the same number of species as the original assemblage (fixed column), and each species occurs with the same frequency as in the original assemblage (fixed row). The null model analyses were performed using the package EcosimR [26] and software R.4.0 [22].

### 3. Results

We registered a total of 673 decapod specimens associated with the Southern king crab fishery from the four bathymetric strata over six months. These specimens represented five species: *L. santolla* (n = 96), *L. smithii* (n = 10), *M. edwardsii* (n = 58), *M. gregaria* (n = 507) and *P. spinulosum* (n = 2) (Figure 2). *M. gregaria* was the most abundant species in June-October. In June, it was dominant in the second stratum (50-100 m), whereas in July and August it was dominant in the three most superficial strata (0-150 m depth, Figure 2) and in the September and October was dominant in the two most superficial strata (0-100 m depth, Figure 2). A different situation was reported for September and October, when the reported decapod abundance was very low compared to previous months. In November, the species abundances increased in comparison to September and October, and the most abundant species was *M. edwardsii* in the first bathymetric stratum (Figure 2). The presence of *L. santolla* and *L. smithii* were only recorded in the three deepest strata (50-200

m), while *M. edwardsii* and *P. spinulosum* were recorded in the two most superficial strata (0-100 m, Figure 2).



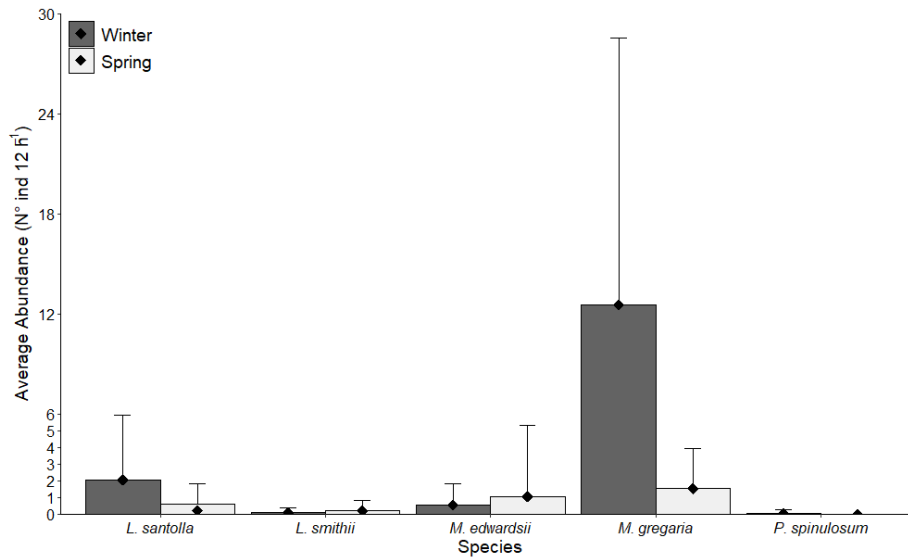
**Figure 2.** Monthly and bathymetric abundance of the decapods associated with the Southern king crab fishery.

The correlation analysis between depth and species abundances revealed a direct significant correlation between depth and *L. santolla* abundance, and significant inverse associations between depth and *M. gregaria*, *M. edwardsii*, and total species abundance (Table 3).

**Table 3.** Results of Kendall correlation analysis for decapod species reported and total decapod species reported and depth (“P” values lower than 0.05 denote significant correlations).

	<b>Tau</b>	<b>Z</b>	<b>P</b>
Depth – <i>Lithodes santolla</i>	0.399	3.871	< 0.001 *
Depth – <i>Metacarcinus edwardsii</i>	-0.530	-5.056	< 0.001 *
Depth – <i>Munida gregaria</i>	-0.299	-3.030	0.002 *
Depth – <i>Peltarion spinulosum</i>	-0.069	-0.636	0.524 n.s
Depth – <i>Libidoclaea smithii</i>	0.203	1.901	0.057 n.s
Depth – Total species	-0.184	-1.979	0.004 *

The GLMs show that the presence and abundance of decapods varied significantly due to the effect of species and season (Table 2). The mean abundance observed and estimated by the model for each species is presented in Figure 3. In general, the mean abundance estimate showed a good fit with respect to the mean abundance observed. The species *L. santolla*, *M. gregaria* and *P. spinulosum* showed higher abundances in winter than in spring; conversely, *L. smithii* and *M. edwardsii* showed higher abundances in spring than in winter (Figure 3).



**Figure 3.** Mean ( $\pm$  standard deviation) seasonal abundance of the decapods associated with the Southern king crab fishery. Black rhombuses correspond to the mean abundance estimated by GLM.

The null model of co-occurrence analysis showed index values close to 0 and did not detect statistically significant differences between the months (Table 4). The results revealed that all the species associations for the sampled months were random, which means that temporal species associations do not have a structured pattern (Table 4).

**Table 4.** Results of null model analysis by month sampled in the present study.

Results of species co-occurrence analysis				
	Observed index	Mean index	Variance	P
June	1.333	1.276	0.006	0.660
July	1.833	1.669	0.027	0.509
August	1.000	0.952	0.012	0.631

September	1.333	1.343	0.018	0.814
October	0.000	0.000	0.001	0.999
November	1.166	1.337	0.017	0.999

#### 4. Discussion

Using fishing gear to catch Southern king crab (bait trap) at different depths during several months our study provides evidence about patterns of bathymetrical and temporal variation of scavenging decapod abundance. We reported five decapod species, which corresponds to 6.7% (n = 75) of the species described in Patagonia between Guafo Bay and Cape Horn [9]. Furthermore, we reported two species (i.e., *L. smithii* and *P. spinulosum*) which were not previously recorded in the Magdalena Sound [14,15], thereby increasing the number of decapods species described in the Magdalena Sound to five, and crustacean species to 11 (Table 5). All decapods were found within the geographic and bathymetric ranges previously reported [9,14], which indicated that sampling method used is little effective to catch possible new or rare species, because it is restricted only to scavenging species.

**Table 5.** Crustacean species recorded in different bathymetric strata (1 = 0–50 m; 2 = 51–100 m; 3 = 101–150 m; 4 = 151–200 m) in the Magdalena Sound, in central Patagonia.

Taxa	Bathymetric strata				References
	1	2	3	4	
Decapoda					

<i>Lithodes santolla</i> (Molina, 1782)	X	X	X	X	[14, This study]
<i>Libidoclaea smithii</i> (Miers, 1886)		X	X	X	[This study]
<i>Metacarcinus edwardsii</i> (Bell, 1838)	X	X			[14, This study]
<i>Munida gregaria</i> (Fabricius, 1793)	X	X	X		[14,27, This study]
<i>Peltarion spinulosum</i> (White, 1843)		X			[This study]
<b>Amphipoda</b>					
<i>Pseudorchomene</i> sp.		X	X	X	[14]
<i>Orchomenella chilensis</i> (Heller, 1868)	X	X			[14]
<i>Uristes schellenbergi</i> (Lowry & Bullock, 1976)	X	X			[14]
<b>Isopoda</b>					
<i>Natatolana chilensis</i> (Menzies, 1962)	X	X		X	[14]
<b>Leptostraca</b>					
<i>Nebalia longicornis</i> (Thomson, 1879)	X				[14]
<b>Balanomorpha</b>					
<i>Balanus laevis</i> (Bruguère, 1789)	X				[15]

With respect to a separate study of decapod species abundances also recorded in the Magdalena Sound in different bathymetric strata in June 2019 [14], our results showed that the mean abundance of *M. edwardsii* recorded in the first stratum ( $3.67 \pm 1.53$  specimens  $12 \text{ h}^{-1}$ ) was slightly higher than recorded in the same stratum by the previous study ( $0.92 \pm 0.38$  specimens  $12 \text{ h}^{-1}$ ) [14]. The mean abundance of *L. santolla* recorded in the third and fourth strata ( $4.67 \pm 2.51$  and  $10.33 \pm 8.62$  specimens  $12 \text{ h}^{-1}$ , respectively) was

higher than that previously recorded in the same strata ( $1.17 \pm 0.63$  and  $2.58 \pm 2.16$  specimens  $12 \text{ h}^{-1}$ , respectively). The mean abundance of *M. gregaria* in the three most superficial strata ( $4.00 \pm 6.08$ ,  $40.33 \pm 10.70$  and  $0.33 \pm 0.58$  specimens  $12 \text{ h}^{-1}$ , respectively) was higher than that previously recorded in the same strata ( $1.00 \pm 0.52$ ,  $10.08 \pm 3.93$  and  $0.08 \pm 0.14$  specimens  $12 \text{ h}^{-1}$ , respectively). The high abundances of *M. gregaria* that we recorded in the most superficial strata in June-October are similar to those reported by Betti et al., 2020 [27] for the Puyuhuapi and Jacaf fjords, and show the importance of *M. gregaria* as a key species within the sub-Antarctic marine ecosystem of South America, representing a fundamental trophic link between the detritus-based food chains and higher-level predators [27].

At the species level, we found different bathymetric patterns. The abundance of *L. santolla* increased with depth, while the abundance of *M. gregaria* and *M. edwardsii* decreased with depth. The bathymetric pattern of abundance for *L. santolla* can be explained due to its ontogenetic migration to the depths and its physiological characteristics that allow it to inhabit hypoxic habitats such as deep fjords [14,15,28]. In addition, during winter and mid-spring the specimens mainly inhabit the deeper strata of the inner sea while during the summer they migrate toward shallower waters to reproduce [28]. With respect to the bathymetric pattern of abundance for *M. gregaria*, its higher abundance in the most superficial strata can be explained by the high supply of organic matter in these strata in fjords, provided by the rivers, which represent an important food source for *M. gregaria* [27]. With regard to the bathymetric pattern of abundance of *M. edwardsii*, our findings agree with those reported by Muñoz et al. 2006 [29] in the San Vicente Bay (Central Chile), and can be explained by physiological characteristics that allow it to inhabit areas with low

salinity (i.e., first bathymetric stratum influenced by estuarine stratification) [30] and the possible unavailability of soft bottom habitat in the depths of Magdalena Sound. At the assemblage level we found that species abundance and species richness decreased with the depth, which agrees with previous studies conducted in the Magdalena Sound [14,15] and are similar to the global trends of diversity and depth reported in the literature [15,31,32].

In decapods, seasonal variation in abundance has been well reported [29]. Low abundance in the winter (i.e., *M. edwardsii* and *L. smithii*) can be attributed to depth migration due to the higher incidence of storms [33]. Conversely, high abundance in the winter (i.e., *M. gregaria*) can be attributed to the high availability of organic matter provided by the rivers, which constitutes an important food source [27]. Furthermore, the seasonal variation in the physicochemical parameters of the Magdalena Sound, along with the physiological characteristics, intra-specific migration and feeding strategies of the recorded species can contribute to their seasonal variability in abundance.

The null model of species co-occurrence analysis revealed that all the species associations during the sampled months were random, which means that spatial and temporal species associations do not have a structured pattern (Table 4). This could be explained due to the low number of species reported and their repeated frequency per depth strata and sampling period. This may be the result of the type of fishing gear, because among its assumptions are: i) the bait attracts all species equally and, ii) the species are distributed randomly in the areas where the traps are located [29]. The pattern described is similar to that observed for intertidal crabs in northern Patagonian fjords [11]. The use of these kinds of null models in marine environments has not been recorded in Chilean marine ecosystems, and could be an important statistical tool for ecological studies.



Ecological information obtained from the operation of the Southern king crab fishery in the Magdalena Sound allows us to contribute to the body of knowledge regarding the biodiversity of scavenger decapods and complements existing biodiversity information [9,14,15]. Available information about high benthic biodiversity, ecology and the habitat use of the Magdalena Sound should be considered to increase the protection of this ecosystem due to the presence of multiple stressors such as climate change and anthropic activities (aquaculture and fisheries).

**Author Contributions:** Conceptualization: G.F.M., P.D.L.R. and M.D.; methodology: G.F.M., P.D.L.R and C.M.; investigation: G.F.M. and M.D.; writing-original draft preparation: G.F.M. and P.D.L.R.; writing-review and editing: All authors. All authors have read and agreed to the publishing version of the manuscript.

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**Institutional Review Board Statement:** Ethical review and approval are not necessary for this study because collected specimens come from fishing activities and have been treated ethically.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data will be made available on request.

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