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Roving Diver Survey as a Rapid and Cost-Effective Methodology to Register Species Richness in Sub-Antarctic Kelp Forests

Gonzalo Bravo [1,2,*,†], Julieta Kaminsky [3,*,†], María Bagur [3,*,†], Cecilia Paula Alonso [4], Mariano Rodríguez [4], Cintia Fraysse [3], Gustavo Lovrich [3] and Gregorio Bigatti [1,2,5]

1 Instituto de Biología de Organismos Marinos (IBIOMAR-CCTCONICET-CENPAT), Bvd. Brown 2825, Puerto Madryn U9120ACF, Argentina
2 Facultad de Ciencias Naturales, Universidad Nacional de la Patagonia San Juan Bosco (UNPSJB), Bvd. Brown 3051, Puerto Madryn U9120ACE, Argentina
3 Centro Austral de Investigaciones Científicas (CADIC-CONICET), Bernardo Houssay 200, Ushuaia V9410CAB, Argentina
4 Instituto de Ciencias Polares, Ambiente y Recursos Naturales, Universidad Nacional de Tierra del Fuego (ICPA-UNTDF), Fuegia Basket 251, Ushuaia V9410BXE, Argentina
5 Escuela de Ciencias Ambientales, Universidad de Especialidades Espíritu Santo, Av. Samborondón, Guayaquil 09230, Ecuador
* Correspondence: gonzalobravoargentina@gmail.com (G.B.); kaminsky.julieta@gmail.com (J.K.); mariabagur@conicet.gov.ar (M.B.)
† These authors contributed equally to this work.

Abstract: Underwater sampling needs to strike a balance between time-efficient and standardized data that allow comparison with different areas and times. The roving diver survey involves divers meandering and actively searching for species and has been useful for producing fish species lists but has seldom been implemented for benthic taxa. In this study, we used this non-destructive technique to register species associated with kelp forests at the sub-Antarctic Bécasses Island (Beagle Channel, Argentina), detecting numerous species while providing the first multi-taxa inventory for the area, including macroalgae, invertebrates, and fish, with supporting photographs of each observation hosted on the citizen science platform iNaturalist. This research established a timely and cost-effective methodology for surveys with scuba diving in cold waters, promoting the obtention of new records, data sharing, and transparency of the taxonomic curation. Overall, 160 taxa were found, including 41 not reported previously for this area and three records of southernmost distribution. Other studies in nearby areas with extensive sampling efforts arrived at similar richness estimations. Our findings reveal that the roving diver survey using photographs is a good approach for creating inventories of marine species, which will serve for a better understanding of underwater biodiversity and future long-term monitoring to assess the health of kelp environments.

Keywords: benthic species; scuba diving; Bécasses Islands; iNaturalist; Patagonia; underwater photography; biodiversity; rocky reefs

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1. Introduction

Making reliable and effective biodiversity surveys is crucial to evaluate the status of the marine environment and for conservation planning. Species richness is a key parameter used as basic information for community ecology and is considered among the biological and ecological essential ocean variables (EOVs, [1]). Monitoring the presence of marine species in space and time at local and global scales is necessary to reduce the knowledge gap in biodiversity, particularly in subtidal habitats. Furthermore, global platforms with open accessibility for uploading species occurrences, such as the Ocean Biogeographic Information System (OBIS) or the Global Biodiversity Information Facility (GBIF), provide databases to test ecological and biogeographic hypotheses. Recently, websites like iNaturalist.org enable shortcuts for adding observations to GBIF, and researchers have started integrating iNaturalist data in their studies [2–5].

Although there is an increase in underwater biodiversity studies, there are still gaps in the knowledge of benthic communities in the Southwest Atlantic [6,7], especially at shallow (<30 m) rocky shores in Atlantic Patagonia, Argentina. The Beagle Channel and the sub-Antarctic region, recognized as a conservation priority site for coastal biodiversity, houses the most southern *Macrocystis pyrifera* kelp forests globally [8]. These structurally complex and highly productive giant kelp forests provide habitat and food for marine mammals, seabirds, invertebrates, fish, and macroalgae, e.g., [9–13].

Previous studies in nearby areas have examined *M. pyrifera* kelp forest communities by using traditional underwater samplings such as transects, in situ quadrats, photoquadrats, or extractive samples, e.g., [14–22], that are difficult to perform due to weather conditions in these cold environments. Notwithstanding, many areas in this spatial and temporally heterogeneous region remain to be explored. With this in mind, we performed an active search photographic survey with the roving diver technique to investigate species richness associated with kelp forests at Bécasses Island. The roving diver survey involves divers meandering and actively searching for species [23] and has been useful for producing fish species lists in tropical seas, e.g., [24,25], but only seldom implemented for benthic taxa, e.g., [26,27]. This study constitutes a good example to establish a timely and cost-effective methodology for surveys with scuba diving in this area, characterized by strong winds and low water temperatures (average 6.8 °C [28]), especially during winter (minimum 5.1 °C, [28]). We created a species list and field photographic record of invertebrates, macroalgae, and fishes that occurred in kelp forests (2–30 m depth) at Bécasses Island, Beagle Channel, that will serve as a baseline of biodiversity and future monitoring to determine the health of sub-Antarctic kelp forests. Then, we discuss and compare our results to other approaches developed to study kelp forest communities in nearby areas.

2. Materials and Methods

2.1. Study Site

The Bécasses Islands are located at the eastern end of the Beagle Channel (Figure 1). They constitute a group of two main islands and a few islets, the larger one "Bécasses Island", also known as Septentrional Island, is approximately 750 m in length from north to south (Figure 1). Geomorphology in the Beagle Channel has been modeled during the Last Glacial Maximum previous to ca. 11,000 Ka [29], whereas the present fluvial and marine processes mainly have modeled coastal landscapes, e.g., cliffs, capes, and bays [30–32]. This natural Channel connects the Pacific and Atlantic Oceans with sub-Antarctic waters, particularly the Cape Horn Current, determining its hydrodynamics [33]. Oceanographic and meteorological conditions present a seasonal pattern in water and air temperatures and light and nutrient availability [28,34]. The Beagle Channel has subpolar wet weather, strong exposure to prevailing southwest winds, and a mixed semidiurnal tide regime with an average amplitude of 1.15 m [35,36]. During warmer months, freshwater inputs from glacial melting and river runoff reduce surface salinities, driving water column stratification and reducing light availability in the water column [33,37]. The Bécasses Islands are a nesting site for seabirds (*Phalacrocorax atriceps* and *P. magellanicus*, [38]) and marine mammals (*Otaria flavescens*, [39]).

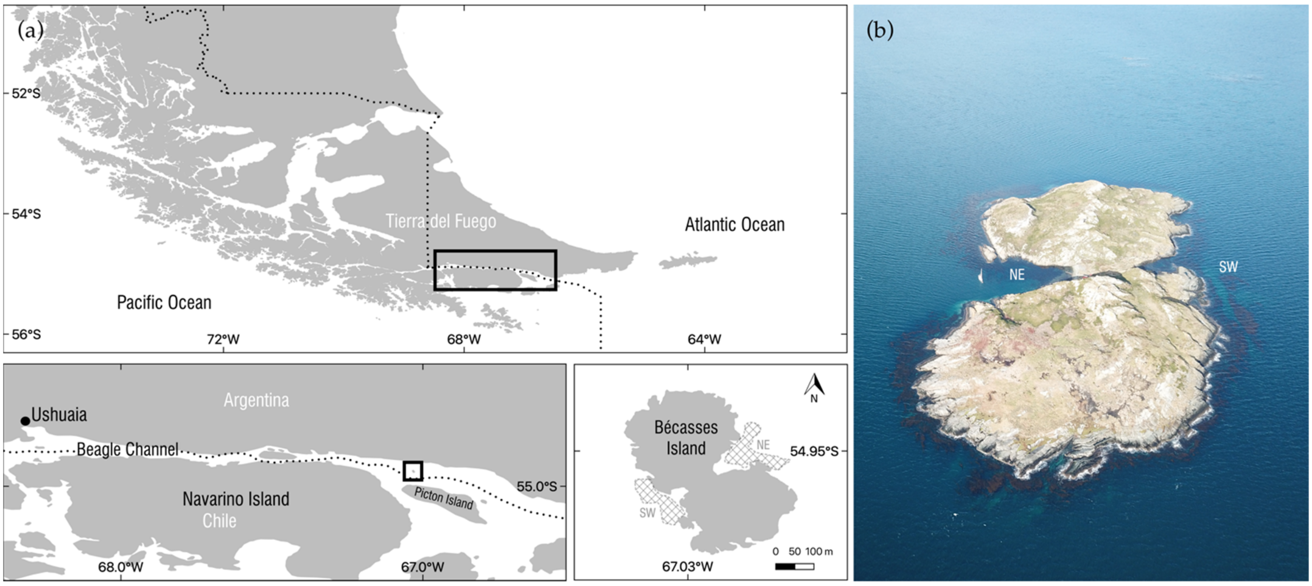

Figure 1. Bécasses Island location in the Beagle Channel, Tierra del Fuego, Argentina. (**a**) A map of the study area, the surveyed zones are indicated with grid lines (SW = Southwest and NE = Northeast). (**b**) Bécasses Island, photo acquired by a drone, survey zones marked with letters (SW and NE); and the sailboat "Kostat" is observed in the NE bay.

2.2. Survey Method

Bécasses Island was explored during a research cruise conducted in August 2021 (winter in the Southern Hemisphere) on board the sailboat "Kostat." An underwater roving diver survey [23] was conducted on the NE and SW subtidal areas of Bécasses Island (Figure 1) to create a benthic species inventory. The SW area is exposed to the dominant SW winds in the area. In both sampling areas, three to four dives were performed by 4–5 divers swimming freely for ~45 min and taking photos of each species they encountered, covering in total more than 700 min of diving and ~20,000 m^2. The diving range was 2–33 m in depth, and in each dive, more than 100 lineal meters were covered. Two-night dives were performed to record species with nocturnal behavior. Special attention was paid to taking good-quality photos of each specimen. Highly mobile and small-sized species (<1 cm) were not photographed. All divers participating in the surveys had marine biology backgrounds and knowledge of local species, which was relevant for finding rare or cryptic species. The cameras used for the survey were Olympus TG6 (Olympus corporation, Vietnam), Cannon SL1 (Canon, Taiwan, Republic of China), Sony Alpha 7S2 (Sony Corporation, Thailand), and Nikon Coolpix W300 (Nikon Corporation, Indonesia) with external lights or flashes. Only some individuals of specific groups (some macroalgae and sea stars) were collected by hand in order to confirm the species identification under a stereoscopic microscope.

2.3. Data Preparation and Quality Control

All the photos (n = 672) were uploaded to an iNaturalist project [40] that only includes observations of divers in this expedition. The open platform iNaturalist (launched in 2008) allows users to submit species observations along with images and GPS coordinates. Once submitted, the observations were identified by the community and vetted by specialists (curators). In our case, we request local taxonomists to review the observations of this project in order to improve the taxonomic resolution (see Acknowledgments). Higher taxonomic levels as genus or family were only used when the photograph was not clear enough, or the specimen did not show the taxonomic features needed for specific identification. All these observations identified to species level and accepted by two or more iNaturalist users ("Research Grade") were automatically uploaded to GBIF by the platform.

Our sampling method was compared with previous studies involving diving surveys and reporting marine species in the nearby areas (50° S to 56° S) with similar subtidal environments, hence we created a list combining all species (Supplementary Material Table S1). Only studies involving communities sampled through transects or quadrats were selected instead of detailed extractive samplings, e.g., analysis of the macrofauna inhabiting kelp holdfasts [10,22] was not selected because of species sizes and sampling effort differences. All the taxonomic names recovered by this list were verified using the Taxon Match tool [41] of the World Register of Marine Species (WoRMS) in December 2022, to prevent the inflation of taxa richness by synonyms, unaccepted or non-updated names. The websites AlgaeBase [42] and FishBase [43] were also used to check the accepted names of macroalgae and fishes, respectively. Due to some invalid taxonomic names that drive inconsistencies (e.g., Porifera sp. 1, Porifera sp. 2, Porifera sp. 3, etc.), the total number of species reported by each study was calculated using this list instead of using the numbers presented in the original articles. In order to compare the richness variation among the different studies and for each group of taxa, the coefficient of variation (CV = standard deviation divided by the mean) was calculated. Additionally, a presence–absence table was constructed to find "unique" species in each of the studies, i.e., species only present in one of the studies and absent in all others (Supplementary Material Table S2).

3. Results

3.1. Environment

Kelps widely colonized subtidal environments in Bécasses Island where the water temperature was 7 °C during the samplings. In the upper subtidal, down to 2 m of depth, kelp forests were mainly dominated by *Lessonia flavicans*, whereas *Macrocystis pyrifera* and *Lessonia searlesiana* formed dense, mixed forests between 2 and 20 m depth. *Lessonia searlesiana* was also found down to 30 m depth. The underwater landscape presented visual differences between NE and SW coasts: the former, the windward side, with a stepped topography with flat bedrock reaching more than 30 m deep, whereas the SW coast was shallower (13 m maximum deep) and presented bedrock with boulders surrounded by sand patches.

3.2. Bécasses Checklist

A total of 160 taxa were recorded by the roving diver survey at the two zones sampled (see Figure 1) at Bécasses Island, including 121 invertebrates, 7 fishes, and 32 macroalgae (Table 1). Invertebrates were dominated by Mollusca (40 taxa), followed by Echinodermata (27), Cnidaria (14), Arthropoda (13), Tunicata (10), Annelida (7), Bryozoa (5), and Porifera (4). Most species of fish belonged to the Nototheniidae family. Regarding macroalgae, 19 Rhodophyta, 10 Ochrophyta, and 3 Chlorophyta species were found. All observations are publicly available at iNaturalist (see Section 2).

3.3. Comparison with Other Studies

In order to compare the species richness obtained with our photographic survey method with traditional methods performed in nearby areas (such as transects and photo-quadrats), seven articles were selected (Table 2). One paper studies only the understory macroalgae community in nearby kelp forests [9], another studies only the fishes community [11], and the rest investigate the invertebrate community only [18,20], or together with fish [17,19,21]. Careful data control was taken to avoid species name artifacts (see Section 2 and Supplementary Material Table S1) as inputs for Tables 1 and 2.

Table 1. List of marine species found during this study with indication of the number of observations (N) with associated photograph and those taxa recorded by other studies in the region (*). Bold letter indicates "unique" records (family, genus, or species) found in our study. N for taxa higher than species corresponds to specimens not possible to be determined to specific level.

Phylum	Class	Order	Family	Genus	Species	N (this study)	Beaton et al. 2020 [18]	Cárdenas and Montiel 2015 [20]	Friedlander et al. 2018 [17]	Friedlander et al. 2020 [19]	Friedlander et al. 2021 [21]	Santelices and Ojeda 1984 [9]	Vanella et al. 2007 [11]
Porifera	Calcarea	Leucosolenida	Syconidae	Sycon		2			*	*	*		
	Demospongiae					2							
		Haplosclerida	Chalinidae	Haliclona		1		*	*	*	*		
		Poecilosclerida	Hymedesmiidae	Phorbas	*Phorbas ferrugineus*	9				*	*		
Cnidaria	Anthozoa	Actiniaria				2		*	*				
			Actiniidae	Bunodactis	*Bunodactis octoradiata*	1	*	*	*	*	*		
			Actinostolidae	Actinostola		3							
			Actinostolidae	Antholoba	*Antholoba achates*	4	*			*	*		
			Halcuriidae	**Halcurias**		**4**							
			Isanthidae	Isoparactis	***Isoparactis fionae***	**1**							
			Metridiidae	Metridium	*Metridium senile*	24			*		*		
			Preactiniidae	Dactylanthus	***Dactylanthus antarcticus***	**4**							
		Alcyonacea	Alcyoniidae	Alcyonium	***Alcyonium haddoni***	**6**							
			Clavulariidae	Incrustatus		1							
			Primnoidae	Primnoella		4							
			Primnoidae	Primnoella	*Primnoella chilensis*	1		*			*		
	Hydrozoa	Leptothecata	Campanulariidae	Obelia	*Obelia geniculata*	2			*	*	*		
	Staurozoa	Stauromedusae	Haliclystidae	Haliclystus	*Haliclystus antarcticus*	1	*						
Annelida	Polychaeta		Chaetopteridae	Chaetopterus		1							
			Chaetopteridae	Chaetopterus	*Chaetopterus variopedatus*	1	*	*	*	*	*		
		Phyllodocida	Nereididae			1							
			Phyllodocidae	Eulalia		1					*		
			Phyllodocidae			3							
			Polynoidae			1							
		Terebellida	**Cirratulidae**			1							
Mollusca	Bivalvia	Mytilida	Mytilidae	Aulacomya	*Aulacomya atra*	3		*			*		
		Pectinida	Pectinidae	Austrochlamys	***Austrochlamys natans***	**2**							
	Cephalopoda	Myopsida	Loliginidae	Doryteuthis	***Doryteuthis gahi***	**10**							
		Octopoda	Enteroctopodidae	Enteroctopus	***Enteroctopus megalocyathus***	**4**							
	Gastropoda		Limapontiidae	Placida	***Placida sudamericana***	**1**							
			Nacellidae	Nacella		2			*				
			Nacellidae	Nacella	***Nacella deaurata***	**2**							
			Nacellidae	Nacella	*Nacella mytilina*	3	*		*	*	*		
			Plakobranchidae	Elysia	***Elysia patagonica***	**2**							
		Lepetellida	Fissurellidae	Fissurella		1			*	*	*		
			Fissurellidae	Fissurella	*Fissurella oriens*	4	*						
			Fissurellidae	Fissurella	***Fissurella picta***	**1**							
		Littorinimorpha	Calyptraeidae	**Crepidula**		**1**							
			Calyptraeidae	Crepipatella	*Crepipatella dilatata*	2				*	*		
			Cymatiidae	Fusitriton	*Fusitriton magellanicus*	9			*	*	*		
			Velutinidae	Lamellaria		1				*	*		
		Neogastropoda	Cominellidae	Pareuthria	*Pareuthria fuscata*	1	*		*	*	*		
			Muricidae			1							
			Muricidae	Acanthina	*Acanthina monodon*	1	*			*	*		
			Muricidae	Trophon	*Trophon geversianus*	1	*		*	*	*		
			Volutidae	Adelomelon	*Adelomelon ancilla*	6			*	*	*		
			Volutidae	Odontocymbiola	*Odontocymbiola magellanica*	6	*						
		Nudibranchia	Chromodorididae	Tyrinna	*Tyrinna delicata*	3			*		*		

Table 1. *Cont.*

Phylum	Class	Order	Family	Genus	Species	N (this study)	Beaton et al. 2020 [18]	Cárdenas and Montiel 2015 [20]	Friedlander et al. 2018 [17]	Friedlander et al. 2020 [19]	Friedlander et al. 2021 [21]	Santelices and Ojeda 1984 [9]	Vanella et al. 2007 [11]
			Coryphellidae	Coryphella	*Coryphella falklandica*	5					*		
			Discodorididae	Diaulula	*Diaulula hispida*	1			*	*	*		
			Discodorididae	Diaulula	*Diaulula punctuolata*	2			*	*	*		
			Dorididae	Doris	*Doris fontainii*	3			*	*	*		
			Polyceridae	Thecacera	*Thecacera darwini*	4			*	*	*		
			Tritoniidae	Tritonia	*Tritonia challengeriana*	10			*		*		
			Tritoniidae	Tritonia	***Tritonia odhneri***	**3**							
			Tritoniidae	Tritonia	***Tritonia vorax***	**1**							
		Pleurobranchida	Pleurobranchidae	Berthella	*Berthella platei*	4					*		
		Trochida				1							
			Calliostomatidae	**Calliostoma**		1							
			Calliostomatidae	Margarella	*Margarella violacea*	3	*		*	*	*		
	Polyplacophora	Chitonida	Chitonidae	Tonicia		8				*	*		
			Chitonidae	Chiton	*Chiton magnificus*	3			*	*	*		
			Chitonidae	Tonicia	*Tonicia chilensis*	1			*				
			Chitonidae	Tonicia	*Tonicia disjuncta*	5	*						
			Mopaliidae	Plaxiphora	*Plaxiphora aurata*	2	*		*	*	*		
Arthropoda	Hexanauplia					2	*	*					
		Balanomorpha	Balanidae	Austromegabalanus	*Austromegabalanus psittacus*	4	*		*	*	*		
	Malacostraca	Amphipoda	**Ampithoidae**			**1**							
			Gammarellidae	**cf. Austroregia**		**2**							
			cf. Gammarellidae			2							
		Decapoda	Campylonotidae	Campylonotus	*Campylonotus vagans*	11			*	*	*		
			Hippolytidae	Nauticaris	*Nauticaris magellanica*	5	*		*	*	*		
			Hymenosomatidae	Halicarcinus	*Halicarcinus planatus*	2	*		*	*	*		
			Inachidae	Eurypodius	***Eurypodius longirostris***	**7**							
			Lithodidae	Paralomis	*Paralomis granulosa*	10	*		*	*	*		
			Munididae	Grimothea	*Grimothea gregaria*	7			*	*	*		
			Paguridae	Pagurus	*Pagurus comptus*	2	*		*	*	*		
			Trichopeltariidae	Peltarion	*Peltarion spinulosum*	1			*	*	*		
Brachiopoda	Rhynchonellata	Terebratulida	Terebratellidae	Magellania	*Magellania venosa*	3	*		*	*	*		
Bryozoa						4	*	*	*	*	*		
	Gymnolaemata	Cheilostomatida	Beaniidae	Beania	*Beania magellanica*	1		*	*	*	*		
			Cellariidae	Cellaria	*Cellaria malvinensis*	2	*	*	*	*	*		
			Alcyonidiidae	Alcyonidium	*Alcyonidium australe*	1		*					
	Stenolaemata	Cyclostomatida	Crisiidae	Crisia		3			*		*		
Echinodermata	Asteroidea	Forcipulatida	Asteriidae			1							
			Asteriidae	Anasterias	*Anasterias antarctica*	4	*		*	*	*		
			Asteriidae	Diplasterias	***Diplasterias brandti***	**12**							
			Heliasteridae	Labidiaster	*Labidiaster radiosus*	21	*		*	*	*		
			Stichasteridae	Allostichaster	***Allostichaster capensis***	**1**							
			Stichasteridae	Cosmasterias	*Cosmasterias lurida*	16	*		*	*	*		
		Spinulosida	Echinasteridae	Henricia	*Henricia obesa*	4			*	*	*		
		Valvatida				1							
			Asterinidae	Asterina	*Asterina fimbriata*	1	*		*	*	*		
			Asterinidae	Cycethra	*Cycethra verrucosa*	8	*		*	*	*		
			Asterinidae	Ganeria	*Ganeria falklandica*	9	*			*	*		
			Odontasteridae			2							

Table 1. *Cont.*

Phylum	Class	Order	Family	Genus	Species	N (this study)	Beaton et al. 2020 [18]	Cárdenas and Montiel 2015 [20]	Friedlander et al. 2018 [17]	Friedlander et al. 2020 [19]	Friedlander et al. 2021 [21]	Santelices and Ojeda 1984 [9]	Vanella et al. 2007 [11]
			Odontasteridae	Diplodontias	*Diplodontias singularis*	3				*	*		
			Odontasteridae	Odontaster	*Odontaster penicillatus*	4	*		*	*	*		
			Poraniidae	Glabraster	*Glabraster antarctica*	25	*		*		*		
			Poraniidae	Poraniopsis	*Poraniopsis echinaster*	6			*		*		
	Echinoidea	Arbacioida	Arbaciidae	Arbacia	*Arbacia dufresnii*	23	*		*	*	*		
		Camarodonta	Parechinidae	Loxechinus	*Loxechinus albus*	24	*		*	*	*		
			Temnopleuridae	Pseudechinus	*Pseudechinus magellanicus*	11	*		*	*	*		
	Holothuroidea	Apodida	Chiridotidae	Chiridota	*Chiridota pisanii*	2				*	*		
		Dendrochirotida	Cucumariidae	Cladodactyla	*Cladodactyla crocea*	4	*						
			Cucumariidae	Trachythyone	***Trachythyone lechleri***	**1**							
			Psolidae	Psolus	*Psolus patagonicus*	2					*		
	Ophiuroidea	Amphilepidida	Amphiuridae	Ophiophragmus	***Ophiophragmus chilensis***	**1**							
			Ophiactidae	Ophiactis	*Ophiactis asperula*	3	*		*	*	*		
		Euryalida	Gorgonocephalidae	Gorgonocephalus	***Gorgonocephalus chilensis***	**16**							
		Ophiacanthida	Ophiomyxidae	Ophiomyxa	*Ophiomyxa vivipara*	1	*		*	*	*		
Chordata	Actinopterygii	Perciformes	Bovichtidae	Cottoperca	*Cottoperca trigloides*	2			*	*	*		
			Harpagiferidae	Harpagifer	*Harpagifer bispinis*	1				*	*		
			Liparidae	Careproctus	*Careproctus pallidus*	1					*		*
			Nototheniidae	Patagonotothen		9			*	*	*		
			Nototheniidae	Paranotothenia	*Paranotothenia magellanica*	2			*	*	*		*
			Nototheniidae	Patagonotothen	*Patagonotothen tessellata*	1			*	*	*		*
			Zoarcidae	Dadyanos	*Dadyanos insignis*	3					*		
	Ascidiacea					3	*				*		
		Aplousobranchia	Didemnidae			3	*						
			Holozoidae	Sycozoa	*Sycozoa gaimardi*	2	*		*	*	*		
			Polyclinidae	Aplidium		3	*	*	*	*			
			Polyclinidae	Aplidium	*Aplidium fuegiense*	5		*	*	*	*		
		Stolidobranchia	Molgulidae	Paramolgula	*Paramolgula gregaria*	1	*						
			Pyuridae	Pyura	*Pyura legumen*	3	*		*	*	*		
			Styelidae	Cnemidocarpa		1			*	*	*		
			Styelidae	Cnemidocarpa	*Cnemidocarpa verrucosa*	1			*	*	*		
			Styelidae	Polyzoa	*Polyzoa opuntia*	6			*	*	*		
Rhodophyta	Florideophyceae	Balliales	Balliaceae	Ballia	*Ballia callitricha*	3		*				*	
		Bonnemaisoniales	Bonnemaisoniaceae	Ptilonia	*Ptilonia magellanica*	9		*					
		Ceramiales	Delesseriaceae	**Paraglossum**		**1**							
			Delesseriaceae	Cladodonta	***Cladodonta lyallii***	**1**							
			Delesseriaceae	Hymenena	***Hymenena falklandica***	**2**							
			Delesseriaceae	Pseudophycodrys	***Pseudophycodrys phyllophora***	**6**							
			Rhodomelaceae	Lophurella	***Lophurella hookeriana***	**1**							
			Rhodomelaceae	Picconiella	***Picconiella pectinata***	**4**							
			Wrangeliaceae	Griffithsia		1						*	
		Corallinales				3							
			Corallinaceae	Ellisolandia	***Ellisolandia elongata***	**1**							
		Gigartinales				1							

Table 1. *Cont.*

Phylum	Class	Order	Family	Genus	Species	N (this study)	Beaton et al. 2020 [18]	Cárdenas and Montiel 2015 [20]	Friedlander et al. 2018 [17]	Friedlander et al. 2020 [19]	Friedlander et al. 2021 [21]	Santelices and Ojeda 1984 [9]	Vanella et al. 2007 [11]
			Gigartinaceae	Sarcopeltis	*Sarcopeltis skottsbergii*	11		*				*	
			Kallymeniaceae	Callophyllis	***Callophyllis atrosanguinea***	**5**							
			Kallymeniaceae	Callophyllis	*Callophyllis variegata*	2						*	
		Hildenbrandiales	Hildenbrandiaceae	**Hildenbrandia**		**3**							
		Plocamiales	Plocamiaceae	Plocamium	*Plocamium secundatum*	1						*	
		Rhodymeniales	Rhodymeniaceae	Rhodymenia	***Rhodymenia coccocarpa***	**2**							
			Rhodymeniaceae	Rhodymenia	*Rhodymenia falklandica*	1						*	
Ochrophyta	Phaeophyceae	Desmarestiales	Desmarestiaceae	Desmarestia		5							
		Dictyotales	Dictyotaceae	Dictyota	***Dictyota falklandica***	**5**							
		Ectocarpales	Adenocystaceae	Adenocystis	*Adenocystis utricularis*	1		*				*	
			Adenocystaceae	Caepidium	*Caepidium antarcticum*	2		*					
			Scytosiphonaceae	**Colpomenia**		**1**							
		Laminariales	Laminariaceae	Macrocystis	*Macrocystis pyrifera*	9	*	*	*	*	*	*	
			Lessoniaceae	Lessonia	*Lessonia flavicans*	9				*		*	
			Lessoniaceae	Lessonia	***Lessonia searlesiana***	**4**							
		Sphacelariales	Stypocaulaceae	Halopteris		1							
		Syringodermatales	Syringodermataceae	Microzonia	***Microzonia velutina***	**3**							
Chlorophyta	Ulvophyceae	Bryopsidales	Bryopsidaceae	**Bryopsis**		1							
			Codiaceae	Codium	***Codium subantarcticum***	**8**							
		Ulvales	Ulvaceae	Ulva		4		*					

The number of taxa reported in this study reached similar values to previous studies and the overall CV (31%) was low (Table 2). Comparisons of the number of taxa for each taxonomic group revealed that our estimations had similar values to other studies for most of the groups, except for Porifera, Bryozoa, and fishes. The highest number of taxa (n = 196) was found by Friedlander et al. [21] at the Kawésqar Reserve, Chile. The closest area to our study, Peninsula Mitre, and Isla de los Estados, was surveyed by Friedlander et al. [19], where they recorded 162 taxa in a broader area. Santelices and Ojeda [9] for macroalgae and Vanella et al. [11] for fish, using extractive sampling (no other option available for comparison), found similar species richness estimations compared with our photo surveys (Table 2). *Bunodactis octoradiata*, *Chaetopterus variopedatus*, *Cellaria malvinensis*, *Macrocystis pyrifera*, and *Lessonia* spp. constitute common species recorded by all the studies (Table 1).

From the overall number of taxa found in this work, 41 (30 species, eight genera, and three families) were not reported in previous studies and therefore here considered as "unique" species (Table 1, see names in bold). This number represented the highest as compared to other studies (between 2 and 28 species, see Supplementary Material Table S2). Three of these "unique" species represented the southernmost record of the species (checked in GBIF and local references): the seastar *Allostichaster capensis*, and the molluscs *Elysia patagonica* and *Placida sudamericana* (Figure 2a,c,d).

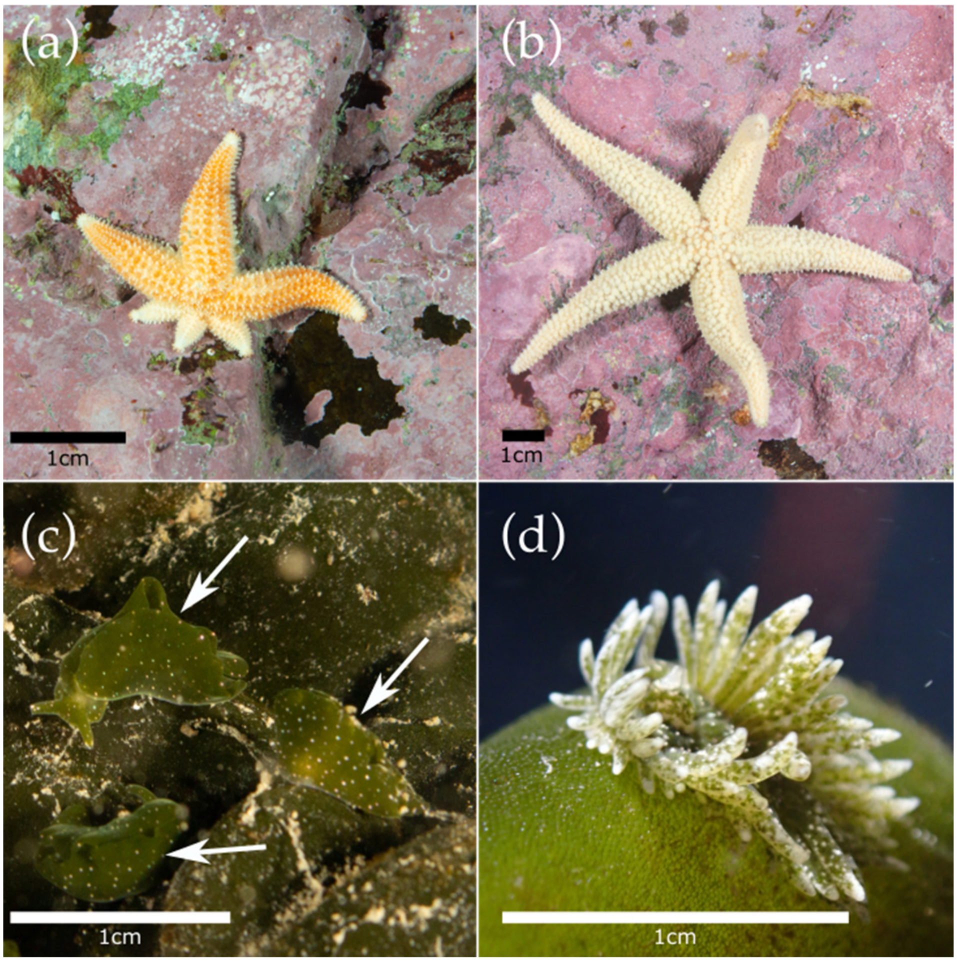

Figure 2. Field photos of those species that represented first photographic record for the area or southernmost record: (**a**) *Allostichaster capensis* (southernmost record); (**b**) *Diplasterias brandti* (first photo record for Beagle Channel); (**c**) *Elysia patagonica* (southernmost record), arrow indicates specimens; (**d**) *Placida Sudamericana* (southernmost record).

Table 2. List of studies in the nearby areas with information of the type of methodology, the depth range, and the number of taxa found by taxonomic groups. SD = standard deviation and CV = coefficient of variation.

Study	Geographic Area	Method	Depth Range (m)	Porifera	Cnidaria	Annelida	Mollusca	Arthropoda	Bryozoa	Echinodermata	Tunicates	others invertebrates	Fish	Macroalgae	Total
Santelices and Ojeda 1984 [9]	Puerto Toro, Navarino Island, Chile (55°)	Extractive quadrat in transects	4–10											39	39 *
Vanella et al. 2007 [11]	Despard Island, Beagle Channel, Argentina (54°)	Trammel nets and holdfast removal	6										11		11 *
Cárdenas and Montiel 2015 [20]	Santa Ana, Magellan Strait, Chile (53°)	Photoquadrats in vertical walls	0–30	5	5	3	3	2	9	2	6	1		31	67
Friedlander et al. 2018 [17]	Francisco Coloane Reserve, Cape Horn, Diego Ramirez, Chile (53°–56°)	Visual transect survey	7–15	13	12	2	31	15	8	20	11	2	14	2 *	130
Friedlander et al. 2020 [19]	Península Mitre and Isla de los Estados, Argentina (54°)	Visual transect survey	3.7–17	20	14	4	33	14	10	28	14	1	21	3 *	162
Friedlander et al. 2021 [21]	Kawésqar Reserve, Chile (50°–54°)	Visual transect survey	3.5–10	19	20	6	43	18	13	32	19	4	19	2 *	195
Beaton et al. 2020 [18]	Malvinas Islands, Argentina (51°)	Photoquadrats along transects	5–20	19	11	8	31	9	2	21	13	2		2 *	118
This study	Bécasses Island, Argentina (54°)	Roving diver survey	2–33	4	14	7	40	13	5	27	10	1	7	32	160
		SD		7.28	4.89	2.37	14.2	5.64	3.87	10.63	4.36	1.17	5.73	4.36	44.3
		CV		54.64	38.57	47.33	47.09	47.63	49.39	49.08	35.8	63.77	39.77	12.82	31.95

* Not considered for SD and CV calculation. Only those studies that sampled the overall community were taken into account.

4. Discussion

The results of this study provide an updated checklist of marine taxa for Bécasses Island, a location on the eastern Beagle Channel, including several new records for nearby areas. We listed 160 taxa, this study being the first to compile with photographic support invertebrates, fish, and macroalgae species for the Beagle Channel. We stored the photos with geographic positions on the iNaturalist platform. The most powerful benefits of using a citizen science platform as iNaturalist were: (a) the photos of the taxa remain with public access, (b) verified observations were uploaded to GBIF, and (c) the digital collection could serve as an identification guide for other studies, whereas some observations already had additional scientific importance. For example, our observations of *Metridium senile* were used as input on a scientific note aiming to track the movement of this invasive anemone in the last ten years [44]. We also registered the southernmost occurrence of three species (*Allostichaster capensis*, *Elysia patagonica*, and *Placida sudamericana*) and the first record with an in situ field photo of the seastar *Diplasterias brandti* for the Beagle Channel (Figure 2b). The latter is important since previous records were deeper or closer to the Beagle Channel's eastern entrance with Atlantic waters influence [45].

Most of the studies analyzed in Table 2 showed similar species richness compared to our survey, meaning the roving diver survey succeeded in characterizing the local species richness. Compared to our study, the greater number of species recorded by Friedlander et al. [17,21] could be related to their sampling effort and broader survey areas. However, we also notice a high estimation of sponges, bryozoans, and some sea star species that is too detailed for a visual survey without sample extraction and dissection. Sponges of the same species typically vary in color and shape; therefore, identification requires the study of the morphology and size of spicules [46]. This is similar for bryozoans since microscopical analysis might be needed. Fraysse et al. [45] identified 22 sea star species along the Beagle Channel, but some of them are cryptic species that can only be identified under a stereoscopic microscope. With this in mind, we decided to be conservative in identifying these taxa by photos, resulting in fewer species. Although Friedlander et al. [17,19,21] might have overestimated these groups, we probably underestimated them.

For macroalgae, it is often necessary to collect samples and dissect them under a microscope for proper identification. Moreover, at the Beagle Channel, macroalgae communities commonly show variations in composition and biomass between seasons, spring and summer being the seasons with higher abundances [47]. Notwithstanding, we could identify by field photos (using macro lenses in many cases and collecting small samples in a few others) as many as 32 different macroalgae. This richness is similar to that reported by Santelices and Ojeda [9], see Table 2) in the nearby Puerto Toro by means of extractive sampling. Furthermore, in a one-year seasonal extractive sampling conducted in two different kelp forests of the Beagle Channel, we found around 60 macroalgae species [48], double what we found in winter in Bécasses Island with the roving diver survey. Therefore, we believe this kind of survey is a good method for registering macroalgae as an initial monitoring method, which can be complemented later with extractive samplings for more detailed information. Most of the common macroalgae can be identified through pictures by a trained diver. However, small-sized species or specific groups still need collection and processing in the lab. For example, Mendoza [49] found 17 species of Corallinales for Tierra del Fuego, most of them impossible to identify in the field.

4.1. Limitations of the Roving Diver Survey Methodology

Because richness estimates are dependent on the sample design and sampling effort, the comparisons with other studies found here should be considered only qualitative. However, based on the low number of dives employed and the high number of species reported only by this study, we suggest that the roving diver survey should be considered a good method to complement richness estimates. The weakness of this type of survey is that density and cover cannot be estimated, and it is well-known that this information is important for biodiversity studies [50]. However, species richness data and taxa geographic distribution could serve as input for future studies, biodiversity monitoring, and species distribution modeling [51].

Although some small-sized species could be photographed and added to the list (e.g., polychaetes and small crustaceans), the roving diver survey is not recommended for highly mobile and small species (<1 cm). These kinds of organisms need extracting sampling methods (e.g., drags, nets, etc.), with adequate processing (e.g., sieves) and conservation depending on the taxa, in order to identify the species and count individuals. For example, 36 amphipod species have been found with extractive methods associated with the kelp *Macrocystis pyrifera* at the Beagle Channel [52]. However, we only photographed three of the largest species (Table 1).

4.2. Why Have We Found More "Unique" Species Than in Previous Studies?

Several reasons can explain the presence of a higher number of "unique" species when comparing the roving diver survey with more traditional surveys. This method allows the diver to explore a vast area and "free their eyes of other tasks" (e.g., counting and writing down species numbers), gaining time to search for "unique" species. Particularly the following reasons can be explained by examples from this study:

Deep species: The roving diver survey allows for freely exploring a broader area, whereas traditional sampling methods have been conducted in shallow waters (see Table 2) and were mostly restricted to kelp forests. Below 18 m, we found some species normally present at depth ranges of 15–900 m. Examples are the gorgonian-feeding anemone *Dactylanthus antarcticus* (Figure 3b), the orange deep-water anemone *Actinostola* sp. (Figure 3c), the basket star *Gorgonocephalus chilensis* (Figure 3d) and the nudibranchs *Tritonia vorax* (Figure 3f) and *Tritonia odhneri* (Figure 3e) [53].

Small/cryptic species: Small-sized (2–4 cm) and cryptic species are frequently not included (intentionally or not) in traditional samplings such as bottom transects or quadrats. The roving diver survey allows including these kinds of species, by using macro lenses in cameras (to obtain quality pictures of small species) and fundamentally by carefully exploring different types of habitats, which are normally restricted in traditional samplings (e.g., vertical or overhanging surfaces, crevices, species under rocks, biological habitats such as algae, sponges, or shells). The "good eye" and local biodiversity knowledge of biodiversity by the survey divers are also important factors. In this survey, we can mention as this type of "unique" species some polychaetes and small crustaceans (mainly amphipods and isopods), the octopus *Enteroctopus megalocyathus* (Figure 3g), the heterobranch sea slugs *Elysia patagonica* (Figure 2c), and *Placida sudamericana* (Figure 2d). The octopus was hiding in a crevice and the sea slugs were associated with the green algae *Codium subantarcticum*. These sea slugs were 10–20 mm in size and the same color as the algae (see Figure 2c,d); therefore, a careful look was fundamental to find them. On the other hand, small highly mobile species are still very difficult to detect with the roving diver survey and should not be considered when estimating richness. We could easily photograph small sea slugs because they are slow, but highly mobile species such as shrimps are too difficult to photograph, and not because they are necessarily cryptic but because of their exhaust speed.

Rare species: Infrequent species (because of their low density or infrequent presence in one particular environment) could be challenging to detect with traditional methods such as transects or quadrats. As the roving diver survey commonly explores a broader area, the chances to find rare species increase. The possibility of freely exploring different habitats and not being restricted to swimming following a line increases the chances even more. For example, only a few individuals of the sea stars *Allostichaster capensis* and *Diplasterias brandti* (see Figure 2a,b) were photographed during the roving diver survey. However, these records were scientifically important because they constitute the southernmost record for *A. capensis* [54] and the first record with an in situ field photo of *D. brandti* for the Beagle Channel.

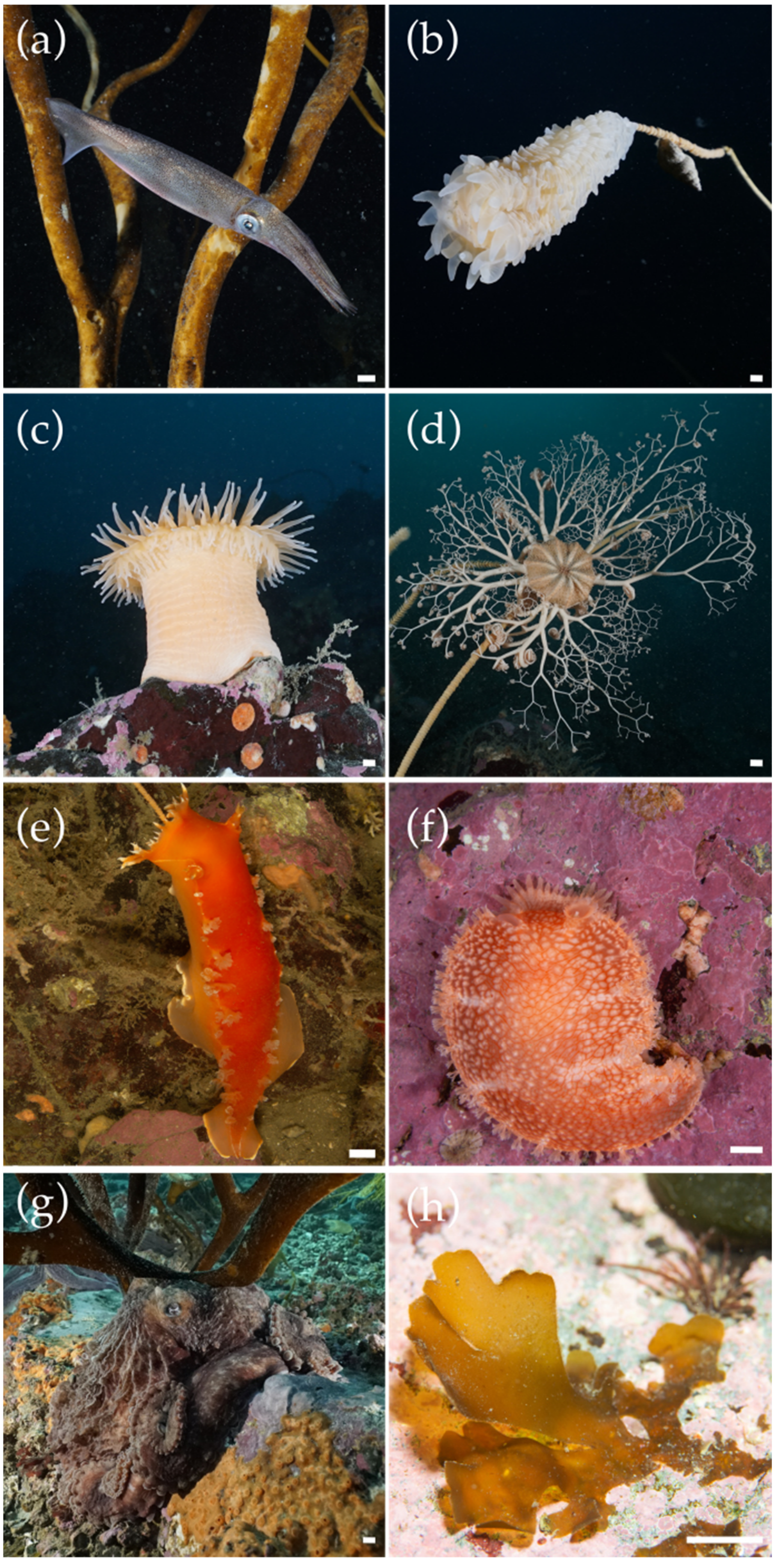

Figure 3. Some interesting species recorded in the field. (**a**) *Doryteuthis gahi*; (**b**) *Dactylanthus antarcticus*; (**c**) *Actinostola* sp.; (**d**) *Gorgonocephalus chilensis*; (**e**) *Tritonia odhneri*; (**f**) *Tritonia vorax*; (**g**) *Enteroctopus megalocyathus*; (**h**) *Dictyota falklandica*. The scale bars correspond to 1 cm.

Pelagic/nocturnal species: In contrast with traditional surveys where the focus is generally on benthic species, the roving diver method allows also registering pelagic species (e.g., jellyfish), occasional visitors (e.g., sea lions), and epibenthic species that can be climbing or attached to the kelp at different depths in the water column. Many of these species can also have nocturnal behavior; therefore, it is important to conduct the survey during the day and night. For example, we have registered the squid *Doryteuthis gahi* (Figure 3a). It is common to find egg masses of this species attached to kelp stipes and blades [55], but squids are generally difficult to see.

New species/taxonomic problematic species: Finally, and in this case not concerning the roving diver survey, we have found more "unique" species in comparison with other published studies, simply because new species have been discovered and described in the last few years. Taxonomy is constantly changing, and new species may have been confused with other known species, especially if samples of individuals were not collected and no field pictures were available. As examples, we can mention three new species found on Bécasses Island that were described in the last four years: the macroalgae *Dictyota falklandica* (Figure 3h) [56], the sea anemone *Isoparactis fionae* [57], and the heterobranch sea slug *Placida sudamericana* [58]. Species with taxonomic problems or that are difficult to identify in the field (name in revision, sibling species, etc.) often lead to misinterpretations. In this last category is the kelp *Lessonia searlesiana*, which has often been confused in the selected studies with *Lessonia vadosa* or *L. flavicans*. The genus *Lessonia* is actually under revision. Following Asensi and de Reviers [59], we detected differences in blades and stipes morphology between *L. searlesiana* and *L. flavicans*. Particularly, for these species, we collected some samples and looked for the presence/absence of lagoons in blades through microscope view: *L. flavicans* presented lagoons, whereas the absence was detected in *L. searlesiana*. As mentioned above, the spatial distribution also differed between these species. *Lessonia flavicans* was found in the upper subtidal, whereas *L. searlesiana* was observed at intermediate and deeper subtidal zones, even at 30 m.

4.3. Recommendations for Applying the Roving Diver Survey

The roving diver survey applied in this study has been useful in obtaining a complete checklist of macroalgae, invertebrates, and fish in a fast and easy way in an extreme subtidal environment. Divers optimize their time under the water by freely swimming to wherever they like and searching for species in special habitats (e.g., searching for cryptic species). This method also avoids spending time and effort in carrying and deploying extra equipment, such as transect lines or quadrats. We recommend the roving diver survey for checklist studies by the presence–absence of species, in places difficult to sample due to extreme conditions, and when human resources and equipment are scarce (e.g., when comparing many sites for a marine baseline study).

Marine biodiversity knowledge is an important factor for the roving diver survey. Local knowledge of the diving sites and their fauna will allow scientific divers to easily obtain data on the common species and to search for rare species in specific habitats. An inexperienced diver could easily misidentify or lose cryptic species, while a trained diver is less likely to do so. To avoid confusion and misinterpretations, we strongly recommend using underwater cameras and external light to back up the species identification. A known-species checklist could be filled while diving, but the photos must accompany the checklist. We found it very useful to upload the photos later to the iNaturalist platform, and we encourage researchers and other divers to do this for data validation transparency and accessibility of the community.

In order to improve the survey, an underwater position system that allows errant swimming of divers between kelp forests, e.g., [60], could be used to record the dive trajectory and estimate the density of species with precision. Another option, which does not require additional technology, is to use the SACFOR scale (Superabundant; Abundant; Common; Frequent; Occasional; Rare) (see [61]), where species are recorded, either in terms of percentage cover or density in six logarithmic steps. This scale is quicker, compared to more time-consuming density estimation methods such as quadrats or transects.

In conclusion, our findings reveal that the roving diver survey using photographs is a good approach for creating inventories of subaquatic species in a timely and cost-effective way. This method is very recommendable for kelp forests, where minimum equipment and trajectory freedom help to avoid frequent entanglements, and optimization of the time when diving in extreme environments such as sub-Antarctic cold waters is especially important. We encourage scientific and recreational divers to try this non-destructive method and enjoy the freedom of exploring in every dive. As it has been proven in other parts of the world, the roving diver survey can be easily adapted for citizen science programs in different environments, e.g., Reef Environmental Education Foundation (REEF) Fish Survey Project, and has provided valuable data for scientific research [62,63]. At the same time, unstructured citizen science data stored on iNaturalist can increase the species richness records, especially in those areas where recreational diving is popular [64]. Comparing the species richness obtained in the same site by different sampling methods (e.g., transects vs. roving diver survey) could be a way to improve and optimize the roving diver survey. We hope this proposed method will serve for a better understanding of underwater biodiversity and be implemented for monitoring programs, aiming at the conservation of marine habitats.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d15030354/s1, Table S1: overall list of species from all the studies used for comparison; Table S2: unique species: species only present in one of the studies and absent in all others. Videos S1: https://youtu.be/Uvi083RWEz8, https://youtu.be/ZQUlATCEfkY: sailing and underwater images from the August 2021 Bécasses campaign.

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Data Availability Statement: Publicly available datasets were analyzed in this study. This data can be found here: https://www.inaturalist.org/projects/biodiversidad-submarina-islas-becasses, accessed on 10 December 2022.

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