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Nimble vessel cruises as a complementary platform for Southern Ocean biodiversity research: concept and preliminary results from the Belgica 121 expedition

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Abstract: The western Antarctic Peninsula is facing rapid environmental changes and many recent publications stress the need to gain new knowledge regarding ecosystems responses to these changes. In the framework of the Belgica 121 expedition, we tested the use of a nimble vessel with a moderate environmental footprint as an approach to tackle the urgent needs of the Southern Ocean research community in terms of knowledge regarding the levels of marine biodiversity in shallow areas and the potential impacts of retreating glaciers on this biodiversity in combination with increasing tourism pressure. We discuss the strengths and drawbacks of using a 75' (23 m) sailboat in this research framework, as well as its sampling and environmental efficiency. We propose that the scientific community considers this approach to 1) fill specific knowledge gaps and 2) improve the general coherence of the research objectives of the Antarctic scientific community in terms of biodiversity conservation and the image that such conservation conveys to the general public.

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The Southern Ocean is undergoing environmental change

The Southern Ocean (SO) ecosystems are exposed to a range of environmental stressors that act together and materialize as seawater temperature increases, salinity decreases, seawater acidification, UV-B radiation increases, sea-ice regime changes, ice-shelf collapses and coastal glacier retreat (Fabry *et al.* 2009, Reygondeau & Huettmann 2014, Gutt *et al.* 2015, Menezes *et al.* 2017, Etourneau *et al.* 2019). The intensity and pace of environmental change are not homogeneous across the whole SO: the western Antarctic Peninsula (WAP), for instance, is enduring the most intense changes (Kerr *et al.* 2018, Siegert *et al.* 2019). This has a potentially strong impact on the marine ecosystems of this region, as they are also facing direct anthropogenic disturbances such as through fisheries, tourism and scientific activities (Lenihan & Oliver 1995, Aronson *et al.* 2011, McCarthy *et al.* 2019). There is, however, a general consensus regarding a number of unique physiological characteristics and life-history traits found in these organisms, including high levels of endemism (Griffiths *et al.* 2009, Kaiser *et al.* 2013, Saucede *et al.* 2014), high sensitivity to temperature increases (Cheng & William 2007, Pörtner *et al.* 2007, Peck 2016, 2018) and the relative importance of brooding as a reproductive strategy (David & Mooi 1990, Hunter & Halanych 2008, Sewell & Hofmann 2011, Moreau *et al.* 2017). Altogether, these characteristics are thought to contribute to the potential vulnerability of SO organisms, populations and ecosystems (Peck 2005, Peck *et al.* 2004, 2010, Ingels *et al.* 2012, Lohrer *et al.* 2013, Guillaumot *et al.* 2018b). Despite intense research efforts to gather the data required to understand ecosystem responses to environmental stressors, our knowledge of these responses remains patchy and so further investigation is required (Sen Gupta *et al.* 2009, Constable *et al.* 2014, Reygondeau & Huettmann 2014, Bonsell & Dunton 2018, Le Guen *et al.* 2018, Rogers *et al.* 2020).

Southern Ocean biodiversity and sampling

Many knowledge gaps (in terms of spatial and/or temporal coverage) regarding biodiversity in the SO remain (e.g. Hogg *et al.* 2011, Schiaparelli *et al.* 2013). Various meta-analyses have revealed that published Antarctic biodiversity data are highly heterogeneous, with many sampling hotspots but also vastly under-sampled areas and life-forms (Barry & Elith 2006, Griffiths *et al.* 2011, Guillaumot *et al.* 2018a, 2019). Furthermore, the bulk of this biodiversity data concentrates on offshore collections from the Antarctic shelf gathered using large research vessels and on bird and marine mammal observations or tracking data (Griffiths *et al.* 2014). Except in the direct vicinity of research stations, the paucity of detailed data from shallow, coastal areas (> 100 m depth) persists, including for the intertidal zone, which is an ecologically complex area at the interface between multiple terrestrial and marine processes and is directly exposed to changes induced by glacier retreat (Griffiths & Waller 2016). Such biases highlight the need for complementary fieldwork approaches in order to address sampling gaps and to provide much-needed biodiversity data at a pace matching the rapid environmental changes occurring along the WAP.

An element of the solution: a nimble research platform

We propose that the use of nimble vessels with moderate environmental footprints (e.g. in terms of greenhouse gasses, microplastics or exotic propagule emissions) is a valuable approach to tackling the urgent knowledge needs of the SO research community in a complementary manner. In fact, some early Antarctic expeditions used nimble vessels very successfully for biological research at the Antarctic Peninsula, assembling the first biodiversity inventories for the area (Bagshawe 1938). Recent research has also employed nimble vessels, particularly for the study of Antarctic birds at the WAP and in the Scotia Sea (e.g. Lynch *et al.* 2016, Borowicz *et al.* 2018). However, there is still untapped potential in the use of nimble vessels for Antarctic research, including marine biology operations at sea (e.g. dredge or SCUBA diving activities within no decompression limits). We therefore explore in this paper the concept of using a small research vessel for multifaceted, agile marine biodiversity research. More specifically, we tested the use of such a platform to focus on quantifying the levels of marine biodiversity in the shallows and the potential impacts of retreating glaciers on this biodiversity in combination with increasing tourism pressure.

While there are many advantages to expeditions that are carried out on large icebreaking research vessels (including ample laboratory space, the availability of heavy sampling machinery, ice-breaking capability and deep-sea sampling), there are also some limitations due to their cost and size, their substantial environmental footprint and sampling often being restricted to relatively deep, offshore waters. Furthermore, while large research teams on board icebreakers represent a great diversity of expertise and skill sets, ship-time allocation between projects can become a delicate matter. In this context, the Belgica 121 expedition (B121) commissioned the RV *Australis*, a fully rigged 75' (23 m) motor sailor (Ocean Expeditions 2019) that can accommodate a small scientific team (nine individuals) together with the vessel's crew (three individuals). Small-scale expeditions may specifically target under-sampled areas and can access remote places distant from research stations where shallow-water environments have been little if ever explored. Furthermore, a collaborative research team focusing on a unique overarching project (in this case, a biodiversity census) with diverse subprojects may function very efficiently thanks to the mutual inclusiveness of the research activities. Finally, gaining access to large national oceanographic vessels is often a lengthy, competitive process. B121 was small and comparatively cheap and easy to organize and therefore our approach could help address urgent research needs in a timely fashion.

Aims of the Belgica 121 expedition

The aims of our study were two-fold:

1) A logistics-orientated facet focused on assessing the suitability, advantages and efficiency of a nimble research platform for complementing traditional approaches to conducting biodiversity research in the SO;
2) A scientific facet focused on carrying out a detailed biodiversity census near selected stations in the WAP using a wide variety of qualitative and quantitative methods.

Our expedition aimed to gather samples and data in order to establish baseline information on biodiversity so as to better understand the responses of such biodiversity to fast-paced environmental change. The expedition used an integrative approach including oceanographic measurements, habitat mapping, a biodiversity census, genomics, environmental DNA surveys and trophic ecology. Here, we describe the concept of our sampling approach with a particular focus on assessing its sampling potential and efficiency and its environmental impact.

Belgica 121 efficiency

The expedition took place on the RV *Australis*, a vessel that can accommodate nine scientists and three crew

Table I. Overview of the expedition sampling and operations at the different stations. A few examples of counts for gear deployment are provided (a full account is available from the cruise report; see Danis *et al.* 2019).

Station name	Acronym	Samples	Operations	Dives	Dredges, grabs	Nets	Traps	Intertidal
Melchior Island	MI	310	36	8	7	2	1	4
Metchnikov Point	MP	2	2	0	0	0	0	0
Neko Harbor	NH	168	29	3	4	2	1	2
SeaMount	SM	17	2	0	1	0	0	0
Useful Island	UI	278	18	4	2	1	1	2
Skontorp Cove	SK	201	24	3	2	3	1	2
Alvaro Cove	AC	8	4	0	1	0	0	0
Hovgaard Islands	HI	212	25	5	5	1	1	2
Berthelot Islands	BI	54	9	2	1	0	1	0
Vernadsky Station	VS	14	2	0	0	0	0	0
Cape Tuxen	CT	2	2	0	0	0	0	0
Green Reef	GR	142	22	5	3	1	1	2
Arctowski Peninsula	AP	9	1	0	0	0	0	0
Foyn Harbour	FH	201	24	4	3	4	1	3
Enterprise Islands	EI	1	1	1	0	0	0	0

members and is equipped with two tenders (Ocean Expeditions 2019). Despite the relatively limited space available, the RV *Australis* can accommodate various sampling activities from gear deployment to sample processing (for details, see Danis *et al.* 2019). The B121 expedition lasted for a total of 28 days, with a total of 22 days spent sampling and 6 days devoted to crossing the Drake Passage. Sampling operations are detailed in Table I and a comprehensive description of each method has been published in the B121 cruise report (Danis *et al.* 2019). In total, we investigated 15 stations of which 7 were more comprehensively sampled (Fig. 1). In total, 51,210 organisms were collected from 201 gear deployments, which is comparable to some expeditions conducted from research icebreakers (Tables II & III). Over the course of the expedition, 3.56 T of fuel were consumed (including from steaming, energy generators and tenders; Table II), which is comparatively low-level fuel consumption (e.g. 54 T day^{-1} for a polar-class icebreaker sailing in open waters and 15 T day^{-1} when stationary in the case of the RV *Polarstern*; see, e.g., https://www.mosaic-expedition.org/wp-content/uploads/2019/09/mosaic-factsheet-facts-on-sustainability.pdf). The average total operating cost of the vessel per day came to €4570 (Table III).

Strengths and drawbacks of a small sampling platform

In general, we found this expedition to be highly efficient and extremely versatile (Table I). Nine scientists were able to work in parallel thanks to a well-organized research plan, a careful design of workspaces by the RV *Australis* skipper and also the complementary design of the research (sub)projects (for a comprehensive description, see Danis *et al.* 2019).

Strengths

The greatest strength of this research approach is its ability to investigate shallow and nearshore areas away from scientific bases. We were able to anchor in waters as shallow as 5 m depth where we could work from the ship or from any of the two tenders. This gave us easy access to many areas that are difficult or even impossible to reach from larger oceanographic vessels or established bases (which would always at least involve an extra trip by tender). This proved particularly convenient for conducting SCUBA diving operations in waters shallower than 20 m, as large vessels are not ideal for scientific diving. The flexibility of being able to start working or continue working into the night without hindering any other projects was a great advantage and a major contributor to the success of the expedition. Another strength of our approach was the great amount of control we had over ship time. A coherent research design allowed for adapting our sampling efforts to weather conditions as they changed during the expedition. Having a small team allowed for the selection of research projects that complemented each other and accommodated parallel sampling. This means that while on site each team member was constantly busy, with no single subproject hampering the progress of others. Another positive aspect of this expedition was its low cost and moderate environmental impact. During the International Polar Year that ran from March 2007 to March 2009, many research projects were under threat because of the steep rise in marine fuel costs, which had increased five-fold during the planning period between 2003 and 2007 (Schiermeier 2008). Even though large oceanographic vessels can have > 50 scientists on board (and therefore potentially have a five-fold greater output capacity per day compared to our expedition), our total fuel

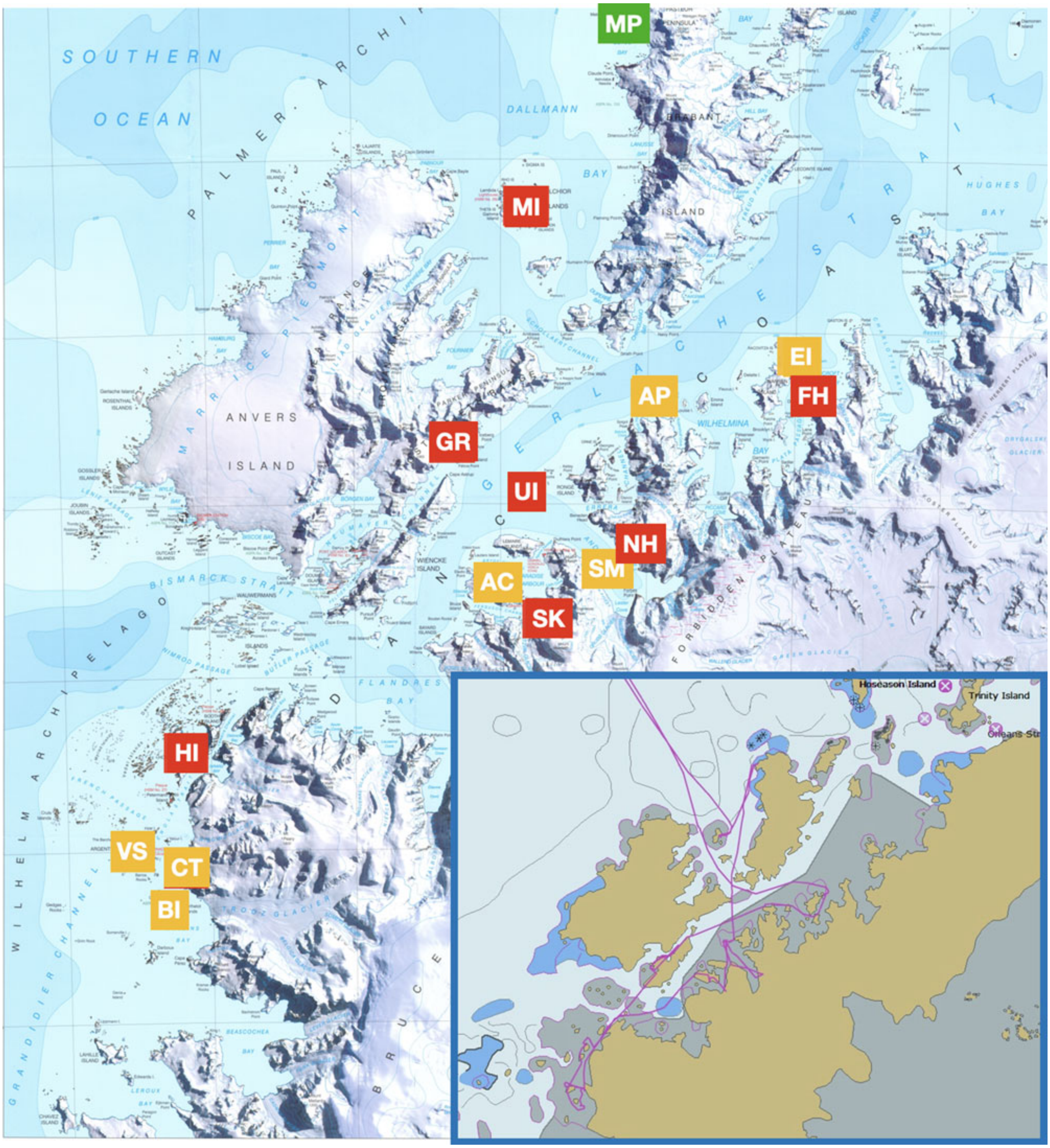

Fig. 1. General map of the sampling area in the western Antarctic Peninsula. Red rectangles: complete stations (all sampling gear deployed); orange rectangles: partial stations; green rectangle: historical monument visit. See Danis *et al.* (2019) for details. For station acronym definitions, see Table I. Modified after map 'Brabant Islands to Argentine Islands', British Antarctic Survey, Edition 1, 2008. The insert displays the RV *Australis* track while in the Antarctic Peninsula.

consumption over the whole expedition represented a small fraction of the daily fuel consumption of a large vessel at sea. This is also embodied in the economic cost of the 32 day expedition being far less than the operating cost of a polar-class icebreaker for 2 days. This reduced economic cost represents an opportunity for countries or institutes with limited budgets to be involved in Antarctic science without the necessity of building infrastructure on land or being a part of large expeditions led by other countries.

Table II. Non-exhaustive comparative list of research activities (as number of deployments of scientific gear) conducted during some recent Antarctic research expeditions on different platforms. Note that it is virtually impossible to fully quantify successful research activities.

Expedition	Platform	Sampling days (*n*)	Deployments (*n*)	Deployments per day
JR15005	RRS *James Clark Ross*	24	183	7.6
PS96	RV *Polarstern*	49	316	6.5
Belgica 121	RV *Australis*	22	201	9.1

Drawbacks

We have experienced strong weather dependency during B121 regarding both the crossing of the Drake Passage and during our sampling time. While we consider ourselves to be extremely lucky not to have experienced any storms during the whole expedition, we acknowledge that adverse weather conditions could greatly hamper the work power of such an expedition. Furthermore, the indoor working space is limited, especially for wet sampling, and bad weather could significantly slow down the processing of samples. In contrast, larger ships and stations are less affected by the weather in terms of both transit time and the availability of indoor laboratories. In addition, the feasibility of using small vessels is dependent on the geographical area being considered. For example, areas such as the sub-Antarctic islands, South Georgia or the WAP are very appropriate for such vessels due to the absence or reduced ice cover in these areas during the summer months and the possibilities for shelter. In contrast, considering the very limited ice-breaking capacity of yachts, very remote Antarctic locations (e.g. Weddell Sea, Ross Sea) would inappropriate for such expeditions. The lack of heavy equipment on these vessels is another significant limiting factor. While this did not affect our type of research, it could restrict the kinds of projects that could be pursued on such a research vessel. Although we successfully deployed a conductivity-temperature-depth (CTD) sensor) and a Niskin bottle (for plankton and environmental DNA sampling) at 400 m depth, sampling at any greater depth would become impractical without larger winches. Furthermore, the inability to trawl and take advantage of dynamic positioning (for deployments deeper than 500 m) also shapes the kind of research that can be carried out.

Table III. Overview of the expedition efficiency. Total and daily figures provided for sampling efforts (number of stations visited, organisms sampled, gear deployments) compared to the time, fuel consumption and overall cost of the expedition.

Activity		Total	Average per day
Station	Full stations	7	0.3
	All stations	15	0.7
Organisms (*n*)		51,210	2227
Deployments (*n*)		201	-
Total expedition duration in days		28	-
Days in Drake Passage		6	-
Sampling days		22	-
Fuel consumption (tons)		3.56	0.127
Nautical miles covered		1727	54
Cost (euros)		128,000	4570

Relevance of the concept

Using a nimble research platform for marine biodiversity studies in the shallow waters of the SO has proven to be efficient in terms of filling targeted knowledge gaps and being environmentally friendly and cost effective. Based on our experience, we would like to call for a more general mobilization of such platforms not as replacements for traditional oceanographic vessels or local sampling from research stations, but rather as a targeted effort to rapidly fill knowledge gaps from under-sampled areas, such as remote nearshore and shallow (< 100 m) shelf areas away from research bases. In terms of the potential for using other types of gear from a nimble platform, there is clearly a possibility for using remotely operated vehicles and autonomous underwater vehicles (for detailed habitat mapping and/or photogrammetry) and other types of equipment to carry out work on sea ice, oceanography, etc., providing that the vessel is adapted appropriately and in advance. We believe that special attention should be devoted to the intertidal zone, which is currently expanding due to glacier retreat and is bound to offer vacant ecological niches to potential invasive species in an area exposed to intense maritime traffic. More regular use of nimble vessels would also benefit from a concerted effort to develop standardized rapid assessment protocols, similar to the vision developed by the Scientific Committee on Antarctic Research Antarctic Near-Shore and Terrestrial Observation System (SCAR-ANTOS). Several nimble vessel options exist for scientific expeditions in the SO. For example, it was estimated that ~50 yachts sailed to Antarctica from 2018 to 2019 and 43 did so from 2019 to 2020 (IAATO 2021). Not all of these vessels may be amenable to all types of research, but given the proof of concept presented here and other successful examples (e.g. Lynch *et al.* 2016, Borowicz *et al.* 2018) it seems worthwhile for the scientific community to explore these alternatives more often. In the context of the B121, we have found that using a nimble research platform can yield large amounts of new knowledge and samples at a low cost and having only a moderate environmental impact. Finally, we believe that the Antarctic research community should also consider using nimble research platforms whenever possible to improve the general coherence of the ultimate research objectives of the Antarctic scientific community in terms of biodiversity conservation and the image that such conservation conveys to stakeholders and the general public.

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Author contributions

BD led the Belgica 121 expedition, developed the expedition concept, performed data preparation and edited the manuscript prior to submission; BW skipped the RV *Australis*, developed the expedition concept and edited the manuscript prior to submission; CG collected subtidal (SCUBA) samples, performed data analysis and edited the manuscript prior to submission; CM collected intertidal samples, identified organisms, performed data analysis and edited the manuscript prior to submission; FP collected subtidal samples (SCUBA), performed data analysis and edited the manuscript prior to submission; FMH collected samples, performed data analysis and prepared and edited the manuscript prior to submission; HR collected samples, performed data analysis and prepared and edited the manuscript prior to submission; HC collected samples, performed data analysis and edited the manuscript prior to submission; QJ collected intertidal samples, identified organisms, performed data analysis and edited the manuscript prior to submission; TS developed the expedition concept, collected subtidal (SCUBA) samples, performed data analysis and edited the manuscript prior to submission.

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Permits

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