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Byers Peninsula: A reference site for coastal, terrestrial and limnetic ecosystem studies in maritime Antarctica

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Abstract

This article describes the development of an international and multidisciplinary project funded by the Spanish Polar Programme on Byers Peninsula (Livingston Island, South Shetlands). The project adopted Byers Peninsula as an international reference site for coastal and terrestrial (including inland waters) research within the framework of the International Polar Year initiative. Over 30 scientists from 12 countries and 26 institutions participated in the field work, and many others participated in the processing of the samples. The main themes investigated were: Holocene changes in climate, using both lacustrine sediment cores and palaeo-nests of penguins; limnology of the lakes, ponds, rivers and wetlands; microbiology of microbial mats, ecology of microbial food webs and viral effects on aquatic ecosystems; ornithology, with investigations on a Gentoo penguin rookery (*Pygoscelis papua*) as well as the flying ornithofauna; biocomplexity and life cycles of species from different taxonomic groups; analysis of a complete watershed unit from a landscape perspective; and human impacts, specifically the effect of trampling on soil characteristics and biota.

Byers Peninsula offers many features as an international reference site given it is one of the largest ice-free areas in the Antarctic Peninsula region, it has a variety of different landscape units, and it hosts diverse aquatic ecosystems. Moreover, the Byers Peninsula is a hotspot for Antarctic biodiversity, and because of its high level of environmental protection, it has been very little affected by human activities. Finally, the proximity to the Spanish polar installations on Livingston Island and the experience derived from previous expeditions to the site make it logistically feasible as a site for ongoing monitoring and research.

Keywords: Lakes; Limnology; Limnopolar; Byers peninsula; Terrestrial ecosystems

1. Introduction

Byers Peninsula (latitude 62° 34′–62° 40′ S, longitude 60° 54′–61° 13′ W; Livingston Island, South Shetlands Islands, Antarctica; Fig. 1) is one of the largest ice-free areas of the maritime Antarctica (Thomson and López-Martínez, 1996) in summer, and holds a high number of inland aquatic ecosystems: over 60 lakes and ponds and many streams (Toro et al., 2007). Byers Peninsula has a special protection regime, as the Antarctic Specially Protected Area No. 126, in which entrance is only granted under explicit permission of each country's Polar Authorities. No vehicles can circulate, aircraft landings are limited to certain areas and no tourism is allowed in this area (SCAR, 2003).

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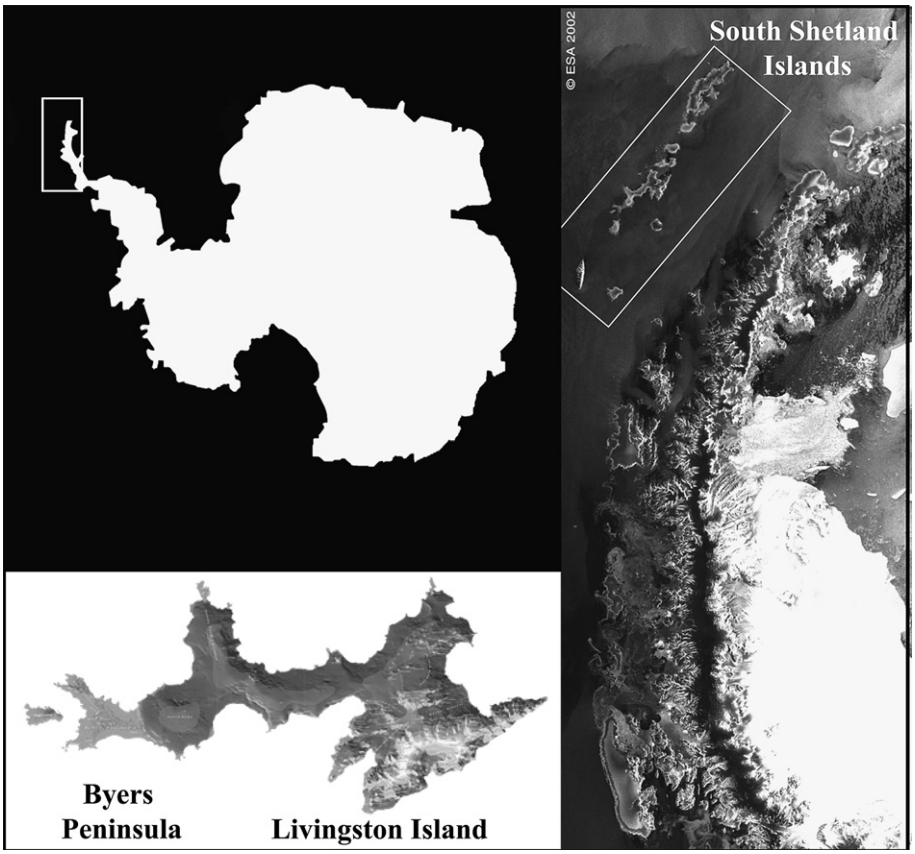

Fig. 1. Location of Byers Peninsula (Livingston Island) in the Antarctic Peninsula region. Satellite picture obtained by ESA, and reproduced here by permission.

This area was previously investigated from a geological and palaeontological point of view, and some preliminary studies were also conducted on the palaeolimnology, limnology, zoology and botany from late 1980s to 1990s. During the last eight Antarctic summer seasons our team has been investigating the non-marine aquatic ecosystems in Byers Peninsula within the LIMNOPOLAR project funded by the Spanish Polar Programme. The aim of that project was to evaluate the role of lakes and other non-marine aquatic ecosystems as sentinels of global change in polar regions. The main hypothesis was that non-marine aquatic ecosystems are strongly influenced by the physical environment, notably temperature, and light, and that changes in these and other environmental variables can modify ecosystem functioning, both by direct effects and by indirect changes occurring within the catchments (Camacho, 2006). Thus, when the functional ecology of these ecosystems is investigated in a latitudinal gradient one can estimate how a latitudinal degree modifies the functional ecology of the ecosystems, and thus the response of ecosystems may be forecasted under different scenarios of global change.

Meteorological (Bañón, 2004) and impact assessment studies (Tejedo et al., 2005, 2009) have also been conducted during these years. All this previous research conducted in Byers Peninsula represents relevant background information for evaluating hypotheses, elaborated for the international expedition (November 2008–March 2009), within the International Polar Year context.

Our studies on Byers Peninsula indicate that the site is a unique location that deserves special attention. It is a pristine area within the South Shetland Islands, little impacted by tourism or research stations. Byers Peninsula is, thus, a highly appropriate location to carry out comparative studies with the rest of the maritime Antarctic region. Moreover, it is considered a hot spot in terms of biodiversity, with many more species present than in other locations in the proximity (Convey et al., 1996; Rodríguez and Rico, 2008; Toro et al., 2007; Van de Vijver et al., in press). This large diversity could be due to the mild environmental

conditions of the area but also to the proximity of South America and the potential transportation of propagules by the dominant winds. For these reasons this location may be considered as an important site for studying the invasion of new species in the context of climate change. Less restrictive conditions for life are expected to occur within this area as a consequence of regional warming (Quayle et al., 2002).

The relevance of this area as an international reference site is also supported because it is an ideal site for studying natural processes at landscape scale, with a great diversity of periglacial, geomorphological features interacting with hydrological and biological processes. This area represents probably the most complete example of Antarctic ice-free landscapes.

An international and multidisciplinary project was organized at Byers Peninsula within the framework of the International Polar Year (IPY), with close scientific links established via several IPY projects: MERGE (IPY endorsed activity number 55), EBA (IPY endorsed activity number 137) and TARANTELLA (IPY endorsed activity number 59). The Byers project was well positioned with the main themes of IPY: (1) to determine the present environmental status of the polar regions; (2) to quantify and understand past and present natural environmental change in the polar regions, and to improve projections of future change; (3) to advance our understanding at all scales of the links and interactions between polar regions and the rest of the globe; and (4) to investigate the frontiers of science in the polar regions. IPY provided a unique framework to obtain funding for an international, multidisciplinary initiative of this type.

The main aim of this project was to study and define Byers Peninsula as an International Site of Reference for Coastal and Terrestrial/Limnetic research, in a similar way to previously designated locations such as the McMurdo Dry Valleys in Victoria Land (Priscu, 1998) or the Vestfold Hills in East Antarctica (Pickard, 1986). These other areas are being investigated very intensively by several polar research groups (Vincent and Laybourn-Parry, 2008). The results obtained are considered as the most comprehensive data set available about non-marine Antarctic ecosystems and are crucial for comparing the ecological effects of future environmental changes (Quesada et al., 2006). Global change is strongly affecting the maritime Antarctica region (Hansen and Sato, 2001; Quayle et al., 2002), and ice-free areas are likely to be strongly impacted by this change (Quesada et al., 2006; and references therein). A deep knowledge about the present-day status of the different ecosystems on Byers Peninsula will provide a valuable baseline for evaluating the changes in the coming years and understanding the processes and the interrelationships amongst them within a global change perspective. It is also necessary to set a multidisciplinary reference point in this area for comparison with other Antarctic regions (see Vincent and Laybourn-Parry, 2008) and with other places on Earth.

2. Development of the project

The Spanish Polar Program, as many other polar programmes, launched an ad-hoc call for projects related to the International Polar year in 2006, which increased three-fold the typical budget for national research projects on polar areas. A wide range of Spanish researchers covering different disciplines, but with a strong focus on biological sciences, agreed to prepare and submit a proposal for this special call. In this proposal our particular aim was to define Byers Peninsula as an international reference site for coastal and terrestrial (including inland waters) research, supported by an interdisciplinary research effort.

The project was submitted to the Spanish Polar Programme requesting mainly logistic support and basic equipment for doing research in the non-permanent Byers Peninsula camp. The project would not fund science costs that would be covered by participants' own projects. The proposal was accepted and funded. An international call was then open and advertised at international level for all scientists interested in doing research in Byers Peninsula on one of the five themes suggested: global climate change; increase in UVB radiation; Antarctic biodiversity and interactions between organisms; Environmental impact due to research or tourism; palaeoecology. This call was advertised in the IPY webpage, through the coordinators of the potentially interested IPY projects and by direct mailing to institutions, Polar institutes and individuals that could be interested.

Many research groups attended the call and submitted their expression of interest (EoI) that were evaluated and prioritized by a National Committee composed by a multidisciplinary group of researchers, related to the priority themes of the project, and the Head of the Spanish Polar Research Programme. The projects were scored by that committee according to their scientific merit, the potential relationship with Spanish research groups and the feasibility of the projects. Then, the approved EoIs were considered according to the logistic limitations and the peculiar characteristics of Byers Peninsula.

Since one of the main goals of the project is the environmental protection of this ASPA, we decided to

keep the size of the camp with a maximum of seven scientists and one field assistant. A small camp allows the infrastructure to be kept to the minimum and reducing the fuel consumption, minimises the spill risks and the negative impact on the zone, while dedicating most time and effort to science. These environmental restrictions precluded all the EoIs to deploy their complete teams to the field, but as we worked in very tight collaboration, when possible, some scientists collected samples for other teams not participating in the field expedition. The overall philosophy of the project is based on close collaboration between projects and individuals in order to obtain a real multidisciplinary perspective of the different ecosystems under study. The Spanish Polar Programme logistics provided a number of entries to the area, and we were able to organize six time periods in which six different groups of scientists visited and worked in the area for a period of 2 weeks. As the groups were multidisciplinary, all the scientists travelling to Byers Peninsula accepted collaborating in others' projects, to provide a real interaction between the different disciplines. Over 30 scientists from 12 countries and 26 institutions participated in the field work, and many other scientists continue to participate in processing the collected samples.

The main research topics were as follows:

(a) Study of the Holocene changes in climatic conditions. The main aim of this topic was to investigate the variations of climatic and ecological characteristics in the area for the last thousands of years. For this purpose a group of scientists investigated the variations in the lake environment by palaeolimnological studies. Multiple biological proxies such as diatoms frustules, invertebrate remains and biological pigments provided information about the changes experienced by the terrestrial/inland waters ecosystems in the last thousands of years. Other researchers in this theme studied the palaeonests of penguins or the remains of marine mammals to understand variations in the marine environment (Emslie and Patterson, 2007).

(b) Study of the limnology of the area, including all kinds of inland ecosystems (lakes, ponds and streams), and considering also the hydrology of the systems (permafrost water supply, snow cover and the elements movement within the water catchment). The limnological research encompassed studies on the interactions between organisms in the aquatic ecosystems (trophic ecology) as well as the effects of a potential increase of nutrient loads and biological interactions in a global change scenario. The benthic communities, both aquatic mosses and microbial mats, represent an important fraction of the total biomass and activity of these lacustrine ecosystems. These communities were investigated with the help of divers, with in situ measurements of biological activities, greatly extending earlier work on the knowledge of the inland ecosystems of maritime Antarctica (Priddle, 1980; Vincent and Laybourn-Parry, 2008). Biological interactions of the top consumers in the lakes (copepods and anostraca), as well as their role as nutrient carriers, were also been investigated.

(c) Microbiological studies focused on the microbial communities that form the largest biomass in the non-marine ecosystems. Microbial mats, bacteria and viruses were investigated in detail, both through the description of the community structure and functional approaches, since an important fraction of the biological activity is due to microorganisms. Microbial mats are communities of special interest and are considered to be the largest non-marine biomass present in polar regions (Quesada et al., 2008; Vincent, 2000), and cover wide zones of lake catchments in Byers Peninsula (Fernández-Valiente et al., 2007). The knowledge about these communities is improving and important advances have recently allowed a better description on their taxonomical composition using genetic tools (Taton et al., 2003). However, other aspects such as seasonal succession or trophic structure within the microbial mat have only been studied slightly and in the Byers IPY project addressed some of these gaps. Bacterial assemblages in different habitats were also investigated, with a special focus on euryhaline halophiles found in diverse environments on Byers Peninsula. Microbial interactions involving bacteria, protozoa and copepods, which can be responsible for a large part of energy transfer within the planktonic systems (Camacho, 2006), and can be enhanced by regional warming, were studied. Viruses can be important in controlling aquatic ecosystems in which the microbial loop dominates the energy and C cycles (Säwström et al., 2008). We have taken samples to analyse their diversity and their ecological role in these ecosystems.

(d) Ornithology. Byers Peninsula is well known for its ornithological diversity with nesting colonies of many different bird species. We have studied both Gentoo penguin rookery (*Pygoscelis papua*) and the flying ornithofauna from the area. The colonies have

been described and a number of individuals of the most prominent species have been captured to study the presence of ecto- and endo-parasites, as well as the presence of bacterial infections or the presence of pesticides and other chemicals in their blood plasma. The penguin rookery will be used as a control to compare the effects of tourism in other rookeries frequently visited, since the rookery in Byers has not been exposed to any tourism pressure. Also, the role of birds as providers of matter to lakes, as well as their possible predator effects on lake fauna were investigated. A census of the nesting bird species in Byers Peninsula was also completed.

(e) Biocomplexity and life cycles. Byers Peninsula is considered as a biodiversity hot spot (Convey et al., 1996; Toro et al., 2007), with the presence of a large number of species from different taxonomical groups. For instance, it is one of the few places in Antarctica where two insect species (*Belgica antarctica* and *Parochlus steinenii*) coexist (Convey and Block, 1996). Recently, our research group has described a new oligochaete from Byers Peninsula (Rodríguez and Rico, 2008), as well as a new diatom species (Van de Vijver et al., In press), and a large number of ciliate species have also been found in Byers Peninsula (Petz et al., 2007). Considerable effort has been dedicated to obtain samples from many different habitats for the taxonomic description of the organisms present, using both morphology and genetic tools. In relation to this activity we have also been investigating the temperature adaptation and the life cycles of different species through observations and experiments run in the field during the summer season.

(f) Taking advantage of the presence of such a diverse group of scientists we have designed an experimental activity that required the participation of many researchers. This experimental activity was aimed at studying the functioning of a complete watershed unit from a landscape perspective, including the geomorphology, geochemistry, hydrology, permafrost, vegetation, microbiology, limnology and biological activities. In a scenario of global change each element of the watershed will be altered, but probably at a low magnitude at the first stages of the change. We hypothesize that lakes may act as integrators (Quesada et al., 2006) of all effects taking place in the watershed, and thus may be monitored as sentinels of global change. With this activity we intended to model the watershed functioning in terms of water, matter and energy flows in the way that we can estimate the magnitude of each flow and forecast the effects of global change in the complete terrestrial/limnetic ecosystem.

(g) Finally we have investigated the impact of the researchers trampling in this polar ice-free region, continuing the studies previously published by our group (Tejedo et al., 2005, 2009). In particular, the recovery rate of previous impacts has been investigated, and also the relationships between the impact and recovery and the environmental characteristics of the soil.

3. Links with other international projects

Because of the international and multidisciplinary character of this project there are numerous links with other international projects both within and out of the International Polar Year initiative. Within the IPY three main projects are directly linked to this Byers Peninsula project: MERGE, EBA and TARANTELA to a lesser extent. The international project 'Predicting biocomplexity in the Dry Valleys system' from New Zealand, has similar objectives than ours but at larger scale, using several watersheds in the McMurdo Dry Valleys. Both projects have linked directly, with meetings, methodological and personnel exchange. Our project is also closely connected to the international Latitudinal Gradient Project (LGP) of Victoria Land, and the MERGE-Canada research program in the Canadian High Arctic (NEIGE: Northern Ellesmere Island in the Global Environment).

4. Perspectives

In addition to establishing Byers Peninsula as an International Reference Site the results obtained through this project will describe in detail many aspects of the recent past of the South Shetland Islands: the palaeo-limnological work, the study of the vertebrate remains in the penguin rookeries and the current ecology of an ice-free area from a polar region. Several new species from different groups are likely to be formally described and the presence of known species will be described for the first time in Antarctica using both morphological and genetic tools. This will be an important dataset for taxonomy, biodiversity and biogeography studies.

The holistic study on the water catchment will allow understanding the water, elements and energy cycles in a complete catchment. As far as we know this is the first time that this kind of approach at a landscape level has been proposed in maritime Antarctica. The interaction between the hydrology, mineral weathering and

transport rates and biological activities in the watershed and within the model lakes will represent an important contribution to the general ecological knowledge, connecting limnology and terrestrial ecology. The modelling efforts dedicated to explore the relationships between the lake functioning and the contribution from the terrestrial environment will provide unique information to interpret landscape-lake interactions, and to evaluate the utility of these lakes as sentinels of Global Change.

The detailed aquatic research program at Byers Peninsula is providing an important contribution to the limnological knowledge of maritime Antarctica. It is yielding basic and continuous data, through the automatic limnological station installed in Lake Limnopolar, and experimental results for microbial and predation processes. Similarly the role of viruses in modulating carbon and energy cycles will be evaluated, and linked the general limnological knowledge. The studies on microbial mats will complete the previous extensive works made on this largest component of non-marine Antarctic biomass. Studies on the trophic interactions and ecological controlling factors of the different biological elements of the community will provide more elements for describing the general functioning of the microbial mats. The study of the life cycles and the behaviour of the main consumers of these ecosystems will also be useful to evaluate ecological and evolutionary hypotheses.

Although each researcher will publish their own results in the journals they consider appropriate, the aim is to produce a special issue of an international journal dedicated to Byers Peninsula Project within the IPY initiative as a compilation of some of the most relevant results obtained in this project.

5. Conclusions

Byers Peninsula is proposed as an international site of reference for terrestrial/limnetic and coastal studies because: (i) it is one of the largest ice-free areas in maritime Antarctica; (ii) includes one of the most complete sets of landscape units for Antarctica with multiple geological/hydrological/biological interactions; (iii) it is one of the most pristine areas in the region; (iv) it is a hotspot of Antarctic biodiversity; and (v) it is located in one of the areas on Earth in which climate change is producing the most striking effects.

During this ambitious project we will provide to the international community one of the most complete datasets from the maritime Antarctic region. This will constitute a regional baseline for climate change research, and it will contribute fundamental new knowledge about the Antarctic environment. Our project includes holistic studies of complete, couple land water systems, as well as exploration of the effects of environmental characteristics on ecosystem biocomplexity, and the formulation of models to generate prognoses of future change. The diverse, international, multidisciplinary studies within the Byers Peninsula IPY project will likely yield many new insights into the structure and functioning of Antarctic geosystems and ecosystems.

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