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Multidisciplinary research on Byers Peninsula, Livingston Island: a future benchmark for change in Maritime Antarctica

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Introduction

The inspiration for the LIMNOPOLAR Project came from the polar gradients concept originating in the mid 1990s, especially through several international initiatives such as Regional Sensitivity to Climate Change (RiSCC) under the SCAR umbrella (Huiskes & Quesada 2002) and the Victoria Land Transect in the Latitudinal Gradients Project (LGP) organized by New Zealand (Howard-Williams *et al.* 2010). We recognized that there was an important bias in the available limnological information in the Antarctic scientific literature, in that the McMurdo region and parts of the Australian sector were better researched and understood than the Maritime Antarctic. With the exception of work published on the South Orkney Islands there was little on the Maritime Antarctic freshwater systems and this was particularly true for the South Shetland Islands. It was obvious that the South Shetland Islands region could provide another data point in the Antarctic Gradient conceptual framework. A second reason for targeting this area was the strong signal of climate warming in the Maritime Antarctic (Quayle *et al.* 2002), which suggested that the South Shetland Islands were well positioned to provide a suitable field laboratory where the effects of climate change on Antarctic ecosystems could be studied. Byers Peninsula, on Livingston Island, had been rediscovered and described in the early 1990s as a relevant limnological site, ice-free in summer with numerous waterbodies of considerable interest (Ellis-Evans 1996). Fortunately, this location was relatively near the Spanish station Juan Carlos I, and it was accessible with the help of Spanish logistics. A non-permanent facility was established in 2001 during the summer on South Beaches, mainly consisting of a tented field camp and two glass-fibre huts. The area is an Antarctic Specially Protected Area (ATCM 2011) with a management plan highlighting the importance of its waterbodies and vegetation. The Spanish LIMNOPOLAR project, beginning in 2000, had as the main aims to describe the terrestrial and limnetic ecosystems on Byers Peninsula, to compare these with other Antarctic regions, and to develop an understanding of how this point on the polar latitudinal gradient might be affected by climate change.

The LIMNOPOLAR project was conceived as a multidisciplinary and international approach aiming to cover most aspects of limnetic ecosystems, including watersheds, mainly of Byers Peninsula. This allowed the participation of many scientists covering a wide range of biophysical and earth sciences, from meteorology to virology. Since the initial expedition in 2001 scientists from many nationalities have contributed to the project, providing expertise and comparisons with other polar locations, in both the Arctic and Antarctic.

The International Polar Year

The scientists involved in the LIMNOPOLAR project used the International Polar Year as a springboard to recruit suitable specialists for work on Byers Peninsula from across the Antarctic community. There was an open call to submit Expressions of Interest to participate in the IPY-LIMNOPOLAR project, and a large number of members of the polar community submitted their proposals, most of which were accepted by a multidisciplinary committee, allowing them to participate in the fieldwork. Since Byers Peninsula is a protected area requiring a permit for entry it had been little visited in the past and was little affected by human activities. Tejedo *et al.* (2009) showed that the soils in Byers Peninsula were quite sensitive to trampling and as few as 200 steps on a specific site could produce an effect. To minimize the impacts on the peninsula we decided to keep the number of people in the camp to the minimum, with a limit of ten people at any one time, as we had done in the previous expeditions. This implied a complicated logistics operation with multiple entries and exits and a relatively limited time in the field, in most cases just enough to run precise measurements or experiments. In total this project comprised over 30 scientists from 14 countries and 26 different institutions. This Special Issue is a collection of papers on the data obtained mostly during this expedition, although in some cases data were complemented with those obtained in previous expeditions.

The site

Byers Peninsula has been described as a polar hot spot of biological diversity (Rautio *et al.* 2008) because of the relatively mild conditions (annual mean temperature of -2.8°C), high precipitation and a geographical position midway between South America and the Antarctic continent. Byers Peninsula does indeed contain very high biological diversity of many different taxa such as viruses (López-Bueno *et al.* 2009), bacteria (Villaescusa *et al.* 2010), cyanobacteria (Fernandez-Valiente *et al.* 2007), ciliates (Petz *et al.* 2007), diatoms (Kopalová & Van der Vijver 2013), invertebrates (Convey *et al.* 1996, Rodríguez & Rico 2008), lichens and mosses (Sancho *et al.* 1999), and birds (Gil-Delgado *et al.* 2013).

One of the more immediate and relevant contributions from the LIMNOPOLAR project, besides the numerous scientific findings and publications, has been our participation in the recently approved new Management Plan for Byers Peninsula agreed by the Antarctic Treaty. For this plan abundant new data have been provided on the organisms inhabiting the site and the ecological values of this area, as well as on the environmental impact of scientific activities.

This Special Issue

This Special Issue is intended to provide the baseline information on different aspects of the ecosystems on Byers Peninsula in order that the future effects of climate change can be measured in one of the areas of the world where temperature has increased the most in recent decades (Quayle *et al.* 2002). In addition it provides a uniquely well-documented description of an Antarctic Specially Protected Area in a way that nobody has attempted before.

The first stage was to establish what was already known about the Byers Peninsula through an especially thorough literature review, using the latest bibliometric methodologies (Benayas *et al.* 2013). The remainder of the contributions on new science are then organized in four different sections: abiotic aspects of the Byers Peninsula ecosystems, the recent history of the area with two contributions on palaeoecology of both terrestrial and marine ecosystems, the science of the various taxonomic groups from microbial communities to birds, and finally a section on human impacts on these polar ecosystems.

The first section starts with a meteorological description of Byers Peninsula (Bañón *et al.* 2013), showing that this site is somehow colder than other nearby stations such as Juan Carlos I Station (also on Livingston Island), Deception Island or Bellinghausen Station (King George Island). In any case the mild temperatures found in the South Shetland Islands contrast markedly with those of the continent, with a mean annual temperature around -3°C and an absolute minimum temperature warmer than -30°C. This paper investigates some critical aspects of climate that directly affect ecosystems functioning such as lake ice-cover, and the accumulation of snow. Fassnacht *et al.* (2013) demonstrates that wind related variables determine both the presence of snow and its depth with profiles of the snowpack in spring of 2008 indicating that the density of the snow was similar from location to location during the times of peak snow accumulation. This has a direct affect on the permafrost and De Pablo *et al.* (2013) report on a newly established CALM site in the Limnopolar Lake basin and present three years of observations (2009–11). These show that the mean active layer thickness was 44 cm, but with a range of ~92 cm, and the active layer thickness depended upon variables such as air temperature and snow cover depth. Extensive studies on the geochemistry of a number of streams on the peninsula by Lyons *et al.* (2013) was a follow up to the earlier work of Toro *et al.* (2007). Oxygen isotopic measurements of both precipitation and stream waters indicate that the watersheds rapidly integrate snowmelt with seasonal precipitation with small variations in the streams compared to the precipitation. This precipitation produced higher than expected short-term chemical weathering rates within a number of watersheds. To supplement this, Velazquez *et al.* (2013) conducted a whole watershed study. They chose the Limnopolar Lake watershed because it is small ($< 1\,km^2$) and it is well documented. Their aim was to measure all macroscopic biomass in the watershed (mosses, lichens and cyanobacterial mats) and analyse their C, N and P to evaluate the nutrient stock and the interactions between the different ecosystems in the watershed. Their findings indicate that mosses (both aquatic and terrestrial) represent the maximum biomass with 79% of the C in the watershed. Cyanobacterial mats are also important and represent about 19% of the C in the watershed. There is a clear difference in the other nutrients between the compartments, while 43.5% of the organic N in the biomass is retained in the microbial mats, more than 90% of P is found within the moss carpets. They found that this watershed is extremely poor in P, which is most probably the most limiting element for growth. These patterns of distribution may have profound implications for the ecological functionality of the different ecosystems within the watershed, with small variations in the P input being able to shift the nutrient balance and thus the organism distribution and abundance.

The palaeoecology section covers two different aspects of the Holocene environmental conditions, palaeolimnology, and past food conditions in marine ecosystems. Toro *et al.* (2013) explain the complete history of Limnopolar Lake, reaching the diamicton, and doubling the previous estimated age for deglaciation in the Peninsula from 4000 to over 8000 years. This important result has profound implications for the Holocene history of the region. Moreover, these authors found heterogeneities in the sediment record that can be attributed to climate changes, and can be used as a proxy for estimating the effects of recent climate changes in the 'Anthropocene'. The abundance of the C and N stable isotopes in gentoo penguins' (*Pygoscelis papua* Forster) egg membrane has been used by Emslie *et al.* (2013) to estimate changes in the penguin diet, related to shifts in prey abundance. They found a significant decrease in the natural abundance of these heavier isotopes in modern tissues by comparison with older remains. This difference could be related to changes in the diet, perhaps due to direct or indirect human impacts.

The section dedicated to biodiversity covers a wide range of organisms: bacteria, cyanobacteria, diatoms, vascular plants, chironomids and birds. Among bacteria, Nakai *et al.* (2013) performed a study on ultramicrobacteria, paying special attention to *Rhizobiales*, occurring on Byers Peninsula and within the cryospheric regions from both poles, which are compared to those from other locations worldwide. Villaescusa *et al.* (2013) built 16S rRNA gene clone libraries from bacterioplankton samples from Lake Limnopolar, and, in spite of the physical-chemical homogeneity, demonstrate remarkable vertical differences in the composition of the bacterioplankton assemblages, that are mostly mediated by biological processes. The diatom community in Byers Peninsula's freshwater ecosystems (streams, lakes and pools) was investigated by Kopalová & Van de Vijver (2013), who found over 140 taxa, of which 55% had a restricted Antarctic distribution. By analysing the environmental conditions in relation to biodiversity the authors demonstrate that conductivity and nutrients were the main variables explaining a high proportion of the diversity variance. Also on diatoms, Pla-Rabes *et al.* (2013) investigate the ecological succession in the different substrata of a stream at high temporal resolution, and clearly identify the level and type of disturbance as the factor triggering succession. The authors also noted that the epilithic stream communities acted as a reservoir of Antarctic endemic diatoms. In Maritime Antarctica, as in other polar regions, microbial mats dominate terrestrial biological communities in wet areas. The fine structure of these microbial mats dominated by cyanobacteria is described and discussed by Rochera *et al.* (2013a). This paper shows the differences in pigment contents and chemical constituents between the surface and the bottom layers of the mat, indicating that the upper layer may act as a photoprotective shield with accumulation of non-active biological matter, the most active photosynthetic biota is found while in the bottom layer. Rochera *et al.* (2013a) describe cyanobacterial mats as a physiologically coherent micro-ecosystem in which the perfect match between elements allows the survival of both components in this harsh environment. Lakes as whole ecosystems are also covered as one of the most important non-marine ecosystems in Byers Peninsula, with very numerous waterbodies. The chemical characteristics, trophic structure and the relative relevance of benthic and planktonic communities of a number of lakes are studied in a second paper by Rochera *et al.* (2013b). The authors conclude that a lake's morphology and proximity to the sea influence the relative contribution and the abundance of the benthic and planktonic compartments by determining the trophic status of these waterbodies.

Byers Peninsula is an area where the only two native Antarctic insect species coexist. These are two chironomids, *Parochlus steinenii* (Gerke), also present in South America, and the Antarctic endemic *Belgica antarctica* Jacobs. Rico & Quesada (2013) describe the chironomid populations in Byers Peninsula and suggest relevant ecological patterns, finding the *Parochlus steinenii* populations mainly in lacustrine habitats but with a relative high dispersive capability able to invade streams and form both stable and unstable populations there. These authors also suggest different feeding habits of both species depending on the ecosystems they inhabit. They also show, for the first time, how the drift cycle of *Belgica antarctica* is governed by the irradiance, but contrary to temperate aquatic ecosystems, maximum drift takes place at the maximum irradiance period. In streams and rivers in temperate climates the drift pattern of chironomids tends to be maximum at night and this is argued to be a defence mechanism to reduce predation. The differences could be due to the lack of predators on these animals in Antarctica.

Vegetation on Byers Peninsula is quite luxuriant compared with most Antarctic locations. On Byers Peninsula, the only two native vascular plant species from Antarctica (*Deschampsia antarctica* Desv. and *Collobanthus quitensis* (Kunth) Bartl.) spread out over lowland areas. Vera *et al.* (2013) show the precise distribution of both plants on extensive areas of the peninsula providing a crucial dataset for future studies of the changes in the distribution of populations of both plants. Moreover, these authors investigate the biological traits of both species and compare their performance with populations of nearby regions. They find that on Byers Peninsula *D. antarctica* produces more viable seeds than *C. quitensis*. In fact the seed production of this latter species was lower than in nearby locations. Using the size of *C. quitensis* stands as a proxy of the age of the plant, the authors suggest that the populations of this plant may have established there about 50 years ago. The study provides data indicating that both plants could be spreading, as the finding of seedlings and young plants may demonstrate. In fact the authors suggest also a potential spreading of these plants (mainly *D. antarctica*) by seeds.

Bird censuses are extremely important in polar regions since they are considered very good estimators of environmental conditions as well as of human pressure (Gibbs 2000). Information about the breeding population on Byers Peninsula is quite scarce and a few decades old. The paper by Gil-Delgado *et al.* (2013) brings recent and robust data on the size and location of the breeding populations of the most abundant bird species: *Sterna vitata* Gmelin, *Larus dominicanus* Lichtenstein, *Catharacta antarctica* Lesson, *Pygoscelis antarctica* Forster, *P. papua* Forster and *Macronectes giganteus* (Gmelin). Their results indicate that some species such as gentoo penguins may have increased, some such as chinstrap penguins have decreased, but populations of the other principal species - terns, kelp gull and southern giant petrel - seem to be stable or have increased only slightly.

In the last section, devoted to the human impacts on Byers Peninsula, four contributions are included. For the first time in the South Shetland Islands Pertierra *et al.* (2013a) made a careful estimation of the potential impacts of researchers and research on ice-free Antarctic ecosystems. The authors examine the pollution and other impacts generated by the scientific research in Byers Peninsula during the ten years of activity. The greenhouse gas emissions represented about 58 t of CO_2 equivalent per researcher, including the researcher and cargo transportation to the site. This study presents important data to make Antarctic research more sustainable and provides advice to minimize environmental impacts. The cumulative effects of trampling on soils and edaphic communities are also investigated in a second paper by Pertierra *et al.* (2013b). Mosses are considered a sensitive community with respect to environmental variations, and in fact are known to be very sensitive to trampling pressure in temperate areas. However, information regarding Antarctic communities was lacking until this paper, which experimentally quantifies the effects of trampling in three different cryptogamic communities. The investigated communities proved extremely sensitive to trampling and any community kept only 50% initial cover after as few as 200 passes. The lichen dominated community on dry soils was the most susceptible to trampling and with as few as 10 passes the effects were visible. In this article the authors suggest different strategies to minimize the effects of trampling on the cryptogamic consortia.

The almost-pristine nature of Byers Peninsula's ecosystems makes it a perfect site to compare the effects of human disturbances on the biological elements with other sites more exposed to human impacts. An example is found in Barbosa *et al.* (2013) where one of the gentoo penguin colonies was used as an unexposed population and compared with the populations of this species in Hannah Point, also on Livingston Island, which have been regularly exposed to the tourists' visits. Barbosa *et al.* (2013) investigated the heavy metal presence in both populations and also some physiological markers of pollution and stress, such as erythrocytic abnormalities and immunological parameters. Their results indicate a significantly higher concentration of heavy metals and a higher proportion of nuclear erythrocytic abnormalities in the visited population in comparison with the Byers Peninsula population. However, the immunological response did not provide a clear pattern and some of the stress markers seemed to be higher in the Byers Peninsula population suggesting habituation to the human presence in the Hannah Point population.

The article by Abad *et al.* (2013) presents the data obtained on the presence of Avian Influenza A virus in sub-Antarctic and Antarctic penguins. They compare the evidence for previous exposure to this virus in animals from different locations on sub-Antarctic islands and on Byers Peninsula communities, and find that while a significant proportion of the animals analysed from the sub-Antarctic had been exposed to this virus, all the animals from Byers Peninsula were seronegative, indicating that the virus had been circulating through sub-Antarctic regions, but it had not reached the Antarctic locations investigated. The virus itself was not found in any of the 140 analysed samples in the study.

Clearly this multidisciplinary and international investigation during IPY, supported by the Spanish Antarctic Programme, and previous work by Spanish expeditions, will serve as a very important baseline in the quest to benchmark future environmental change in the Maritime Antarctic region. This group of scientists has not only contributed considerable new knowledge on ecosystems in the South Shetland Islands but has also posed new questions for polar sciences in the 21st century.

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