Colonisation of stranded whale bones by lichens and mosses at Hennequin Point, King George Island, Antarctica

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Received October 2017; first published online 14 March 2018

ABSTRACT. This paper presents the details of lichens and mosses found on whale vertebrae substratum in the Admiralty Bay area, King George Island, Antarctica. Samples were taken in the coastal area at Hennequin Point, a relict of the Antarctic whaling era. The samples were collected from the upper surface of the whale bones found in the study area during the austral summer 2010–2011. A total of 15 lichen and two moss species were found. All species sampled are known in the Admiralty Bay area, both as pioneers and in more advanced succession stages in ice-free areas. These results suggest that the colonisation of whale bones is not new for Antarctic plants, but it is an additional substrate on which these plants can develop. A map showing the distribution of colonised bones and details of the usual substrata for the lichens and mosses found in this study are provided.

Introduction

In the beginning of the twentieth century, whale hunters intensively used the maritime Antarctic and South Shetland Island Archipelago (Tønnessen & Johnsen, 1982). Admiralty Bay, inner King George Island, is an area of outstanding environmental, historical and scientific interest where remnants of former sealing and whaling activities still remain. Sheltered harbours and accessible beaches enabled an early start to whaling activities in Admiralty Bay. The bay offered protection for ships during the nineteenth and early twentieth century hunting seasons, and the ruins of installations from the latter period still remain (Rakusa-Suszczewski, 1998).

Humpback whales (*Megaptera novaeangliae* Borowski) were the most intensively captured, and after ca. 1914, fin whales (*Balaenoptera physalus* L.), blue whales (*Balaenoptera musculus* L.) and, to a lesser extent, sei whales (*Baleanoptera borealis* Lesson) were also captured. According to data from International Whaling Statistics (1931), 183, 791, 930 and 1743 whales were captured in the South Shetland Islands region in 1906, 1907, 1908 and 1909, respectively (Rakusa-Suszczewski, 1998). The activity on the islands remained substantial until ca. 1960 when Norwegian–British Antarctic whaling came to an end (Proulx, 1986). In the Admiralty Bay area, the modern whaling industry began in 1906, when this area was used as a harbour for whale-catchers and factory ships until 1931. Evidence of the industry remains in the form of whale vertebrae present on many of the beaches (Miller, 2007). These bones remain as heritage of the whaling period, together with buildings and wooden and metal objects.

Kittel (2001) catalogued the whaling objects in the Admiralty Bay area and mapped the bones found on the beaches and surrounding areas. The largest accumulations of whale bones, mainly vertebrae, ribs and small fragments of other bones, are found at Hennequin Point, Keller Peninsula (near the Brazilian station) and near the Arctowski Station (Poland) (Fig. 1a). In the last decade, several research groups have visited Hennequin Point (62°03′40″–62°05′40″S and 58°23′30″–58°24′30″W), most have been Brazilian researchers studying vegetation and seabird diversity (Victoria et al., 2013).

The Antarctic flora is composed mainly of bryophytes and lichen species adapted to harsh conditions, including low temperatures and a short photoperiod. The flora

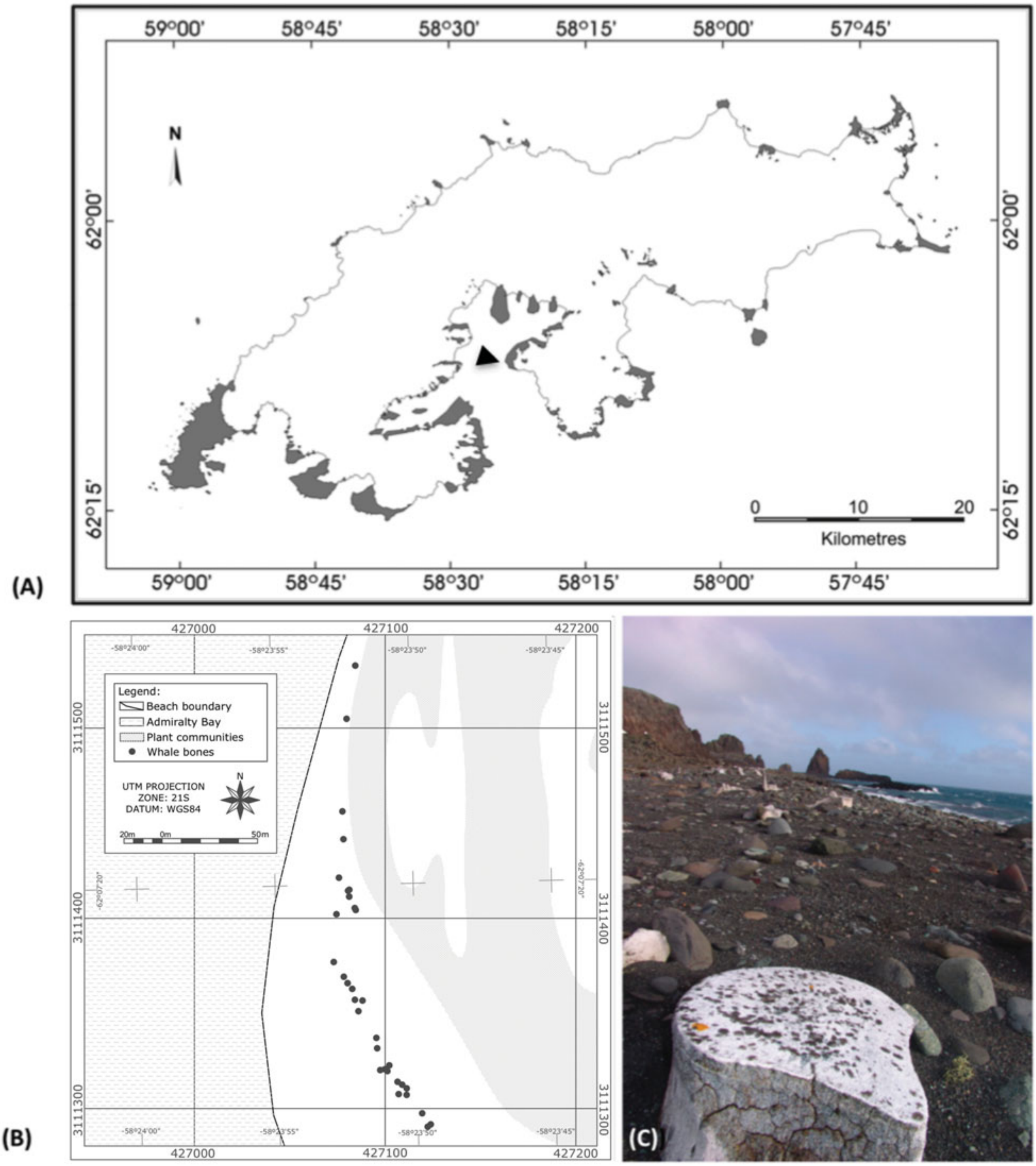

Fig. 1. a. King George Island, Antarctic, showing Hennequin Point (arrow), Admiralty Bay, where lichen and moss species were sampled from whale vertebrae. b. Distribution map of vertebrae (black dots) on the raised beaches typical of the study area. c. Photographs of the study area presenting an example of a whale vertebra, in the foreground, with notable colonisation by multiple lichens.

comprises 111 moss species and 360 lichen species (Ochyra et al., 2008; Øvstedal & Smith, 2004); however, recent studies suggest that lichen numbers may reach 500 species (Øvstedal & Schaefer, 2013). There are only two species of native angiosperms described from Antarctica, *Deschampsia antarctica* Desv. and *Colobanthus quitensis* (Kunth.) Bartl. (Smith, 1984). Plants are limited by low water availability and low temperature ranges (Gignac, 2001; Longton, 1982). Since ice-free areas are scarce and growth conditions are restrictive, the area around Admiralty Bay is a useful model for monitoring changes in environmental conditions.

Lichens are the dominant species in most habitats of the Antarctic biome, with a few exceptions. However, their occurrence and development are restricted by local environmental conditions, such as substratum instability,

https://doi.org/10.1017/S0032247418000062 Published online by Cambridge University Press

rock type and surface texture, permanent shading from direct solar radiation, excessive exposure to strong and abrasive wind action, mineral particles and ice crystals and, in the close proximity of bird colonies, the impact of disturbance and toxic levels of certain chemical elements (Smith, 2007). Some species are abundant and form distinct communities in habitats receiving nutrient enrichment (especially from nitrogenous compounds in meltwater run-off and in aerosol form) from seabird colonies (Jablonski, 1986); although lichens may develop dense stands even in some nutrient-deficient habitats (Albuquerque et al., 2012).

The relationship between mechanical, chemical and mineralogical soil properties and the type of substratum are likely to influence lichen distribution. Substrate pH changes may also affect the formation of lichen stems. Garty et al. (1974) found that *Squamarina* species were located on soils with low shrinkage rates, but when the shrinkage rate increased above five per cent the lichens colonised rock and moss instead. Gaio-Oliveira et al. (2005) found that, in non-polar environments, changes in nitrogen concentrations had significant effects on the thallus development of *Xanthoria parietina*. (L.) Th. Fr. Armstrong (1990) used the same species in an experiment to evaluate the effect of pH change on growth by exposing samples to droppings from a variety of birds. Treatment with bird droppings was essential for the survival of *X. parietina* thalli on siliceous rock away from the sea, suggesting that this species may be more responsive to changes in pH than nitrogen concentration. In any areas of land where ideal growing conditions do not exist, whale bones may support species establishment.

The most important substrata for the development of native apophytic flora are whale bones, especially vertebrae (Olech, 1996). The occurrence of flora on whale vertebrae is related to microclimate conditions and nutrients retained in the bone pores (Olech, 1996). However, detailed information about which species can colonise this type of substrate are lacking. Are all species of lichen able to grow on whale bones deposited on the shores of the Antarctic ice-free areas? Does this new substrate represent a possibility for an expansion of plant communities or only a small group of species?

With increased human activity in Antarctica, anthropogenic impacts on terrestrial ecosystems may become a reality, as shown in other ecosystems already affected by human activity. Some of these changes are increasingly visible, especially by changes in vegetation and geographical scale due to the introduction of non-native species, such as *Poa annua* L. (Olech, 1996). The whale bone remnants of the Antarctic hunting era could be considered an important substrate which affects the distribution of mosses and lichens in the Antarctic environment.

The aim of this study was to identify lichen and plant species growing on whale bones at Hennequin Point and to compare the results with similar approaches in other areas of maritime Antarctica.

Materials and methods

Sample collections

Seventy (70) whale vertebrae on the beach at Hennequin Point, King George Island, Antarctica, were sampled (Fig. 1b) during the austral summer 2010–2011. The bones sampled were previously mapped by Kittel (2001). The upper surface of each vertebra was analysed to verify the presence of lichens and mosses (Fig. 1c). Photographs were taken of each visible plant or lichen found growing on the bones. Small samples were collected, especially for those species that require microscopic analysis for identification, from each bone using a knife or chisel. The specimens found were identified based on specialist literature: bryophyte identification was based on Ochyra (1998) and Ochyra et al. (2008), and lichen identification was based on Øvstedal & Smith (2001) and Redon (1985). The findings were compared with other reports of lichen and moss occurrences on whale bones available in the published literature (Kim et al., 2006; Olech, 1996).

In order to represent the complexity of the surface of the whale bones and to estimate its microtopography, a photographic survey was carried out. Each whale vertebrae sampled in Hennequin Point was photographed to determine the percentage of lichen or moss coverage (referred to hereafter as plant coverage [PC]). For this analysis, two bones with high density coverage and two with low density coverage were selected. Each image was submitted to a treatment where an average value was computed for each pixel. To calculate an average value, the wavelengths in the visible band, R, G and B, were divided by three using the Geographic Information System (GIS) of the QGIS software; the resultant image formed is called the simple band image (ImgS). To determine percentage of exposed bone, manual contour and creation of a vector layer of the bone (Lim) was performed, in which only bone was contained in the image. With the ImgS for each bone and its Lim vector layer, a cut was made using the trimming tool from the same program, to obtain an image of the inner part of the bone (ImgEX).

To distinguish the surface of the bone from the surface covered with lichen or moss, a script was created in the R program (R Core Team, 2017). The main package used in this script was 'raster' (Robert, 2015). The 'K-means' tool (R Core Team, 2017) was used to group the reflectance values for each pixel of each ImgEX in order to differentiate between PC and bone (clusters 1 and 2, respectively). The number of pixels representing each of the two clusters was calculated and their percentages obtained. Finally, for visual exemplification, an image was generated showing the clusters obtained.

Results

Species composition and richness on whale vertebrae

Fifteen lichen and two moss species were identified growing on the whale vertebrae found on the beaches at Hennequin Point, King George Island. Olech (1996) and Kim et al. (2006) found 19 lichen and two moss species

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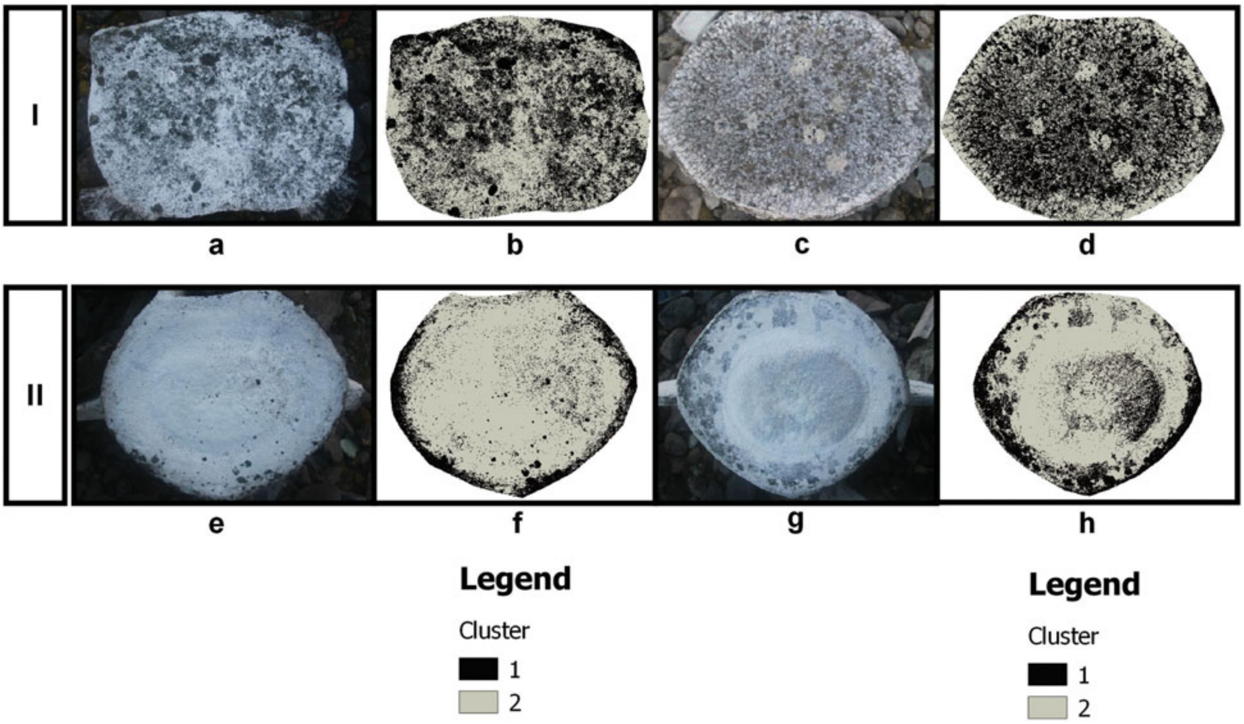

Fig. 2. Photographs of whale bones (a., c., e. and g.) showing plant colonisation and ImgEX images showing the respective cluster patterns (b., d., f. and h.). Class I, high density plant coverage (PC); class II, low density PC. Cluster 1, standard PC; cluster 2, bone surface.

on whale bone substrata. These papers also reported algae species growth on these substrata, but these are not evaluated in the present work.

The richest and most diverse flora compositions were found on the bones compared with the immediate surrounding areas on the beaches. Species observed in the surrounding areas were predominantly epilithic found on sea cliffs. Many species that occur preferentially in sites at much higher elevations relative to the sea level (15–300 m above sea level, for example) are growing on the whale bones on the beaches, suggesting that this alternative substrate enables the emergence of these species closer to the sea.

Fig. 2 shows the four bones selected for further analysis and the cluster patterns obtained. Two bones had high density PC (class I; Fig. 2a,c) and two had low density coverage (class II; Fig. 2e,g). The pattern of surface roughness is quite different between the class I and class II bones. Class I bones have a higher apparent roughness (Fig. 2a–d) than class II, which have a smoother surface with rough edges (Fig. 2e–h). PC is a function of the bone reflectance pattern at wavelengths in the visible band (R, G and B), whereby the PC increases with the roughness of the bone surface (Table 2). In summary, these patterns demonstrate that more complex bone surfaces favour plant growth.

The most common plant communities established on beaches in the maritime Antarctic that are associated with pebbles and fragmented rocks, such as moss carpet formations and fruticose and crustose lichen formations, were both found in the Hennequin Point area in the 2004–2005 austral summer (Victoria et al., 2013). In fact, the latter community (invariably with *Buellia* spp., and usually *Lecidea cancriformis* C. W. Dodge & G. E. Baker, *Rhizoplaca aspidophora* (DC.) Leuckert & Poelt., *Pleopsidium chlorophanum* (Wahlenb.) Zopf., *Carbonea* spp., *Acarospor*a spp. and several other crustose species) is less frequent and has been replaced by moss carpets of *Sanionia uncinata* (Hedw.) Loeske observed in the 2010–2011 austral summer.

Discussion

Of the species identified on whale bones by Olech (1996) and Kim et al. (2006), *Acarospora macrocyclos* Vain., *Lecania brialmontii* (Vain.) Zahlbr., *Rhizoplaca melanophthalma* (DC.) Leuckert & Poelt., *Syntrichia magellanica* (Mont.) R.H. Zander (cited as *Tortula grossiretis* Cardot) were also found in the present study. The moss *S. magellanica* and the lichens *Caloplaca* sp. and *Buellia anisomera* were the most frequent species found on the whale vertebrae sampled. These species are the most common in the maritime Antarctic plant communities and are recognised as pioneer species in non-vegetated sites (Victoria et al., 2009b), probably because of their ideal growing condition (Olech, 2004).

The moss species *Hennediella heimii* (Hedwig) R. H. Zander and the lichens *Bacidia stipata* I. M. Lamb., *Buellia anisomera* Vain., *Cystocoleus ebeneus* (Dillwyn) Thwaites, *Huea cerussata* (Hue) C. W. Dodge & G. E. Baker, *Lecidea sciatropha* sciatrapha Hue, *Ochrolechia parella* (L.) A.Massal., *Parmelia saxatilis* (L.) Ach. and *Psoroma cinnamomeum* Malme were found growing on

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Table 1. Lichen and moss species identified on whale bone substratum at Hennequin Point. Also presented are the most common substrata and localities relative to sea level for each species.

Species	Number of colonies	Common substrata	Common locality (m above sea level)
Acarospora macrocyclos Vain.	1	Coastal rocks	2–395
Bacidia stipata I. M. Lamb.	4	Moist rocks	2–335
Buellia anisomera Vain.	12	Coastal rocks	2–200
Caloplaca sp.*	13	–	–
Cystocoleus ebeneus (Dillwyn) Thwaites	2	Dry soils Bryophytes in rocks	5–300
Hennediella heimii (Hedwig) R. H. Zander	2	Moist rocky soil	2–150
Huea cerussata (Hue) C. W. Dodge & G. E. Baker	1	Coastal rocks	2–80
Lecania brialmontii (Vain.) Zahlbr.	2	Moist rocks	1–75
Lecidea sciatropha sciatrapha Hue	3	–	15–300
Ochrolechia parella (L.) A.Massal.	1	Dry exposed rocks	2–280
Parmelia saxatilis (L.) Ach.	4	Dry to moist rock faces Stony soil Bryophytes	2–250
Psoroma cinnamomeum Malme	1	Dry and moist soil Bryophytes	2–250
Rhizocarpum spp.*	6	Rocks	–
Rhizoplaca melanophthalma (DC.) Leuckert & Poelt.	4	Rocks and stones	10–250
Syntrichia magellanica (Mont.) R.H. Zander	7	Rocks, dry and moist soil under ornithogenic soils	1–2
Verrucaria psicrophyla Verrucaria psychrophila I. M. Lamb.	6	Intertidal rocks	1–2

*Non-fertile specimens.

Table 2. The number of pixels analysed for each bone and percentage plant coverage (PC) for each sample.

	Pixels				
	Total	Bone	PC	Bone	PC
ImgEX	*n*	*n*	*n*	%	%
b	9,540,035	5,162,126	4,377,909	54.11	45.89
d	7,810,008	3,512,568	4,297,440	44.98	55.02
f	7,758,765	6,372,539	1,386,226	82.13	17.87
h	6,929,165	5,014,542	1,914,623	72.37	27.63

b, d, f and g represent part labels in Fig. 2.

whale bones for the first time. *Psoroma cinnamomeum*, considered a muscicolous species, was recently documented on King George Island (Olech, 2004). *Ochrolechia parella* has only been reported at one site at Hennequin Point up to 50 m above sea level and it occurs mainly on inland hills in other areas of Admiralty Bay (Olech, 2004); this occurrence near the shore was unexpected. In contrast, the moss *Hennediella heimii* is commonly found in areas of salt spray deposition (Ochyra et al., 2008), such as where the whale vertebrae surveyed in the present study often occur. Some species identified by Kim et al. (2006) on whale bones were not found in the present survey.

We observed that saxicolous species found growing on the whale vertebrae were not found on the surrounding pebbles on the beach. Plant growth limited to bones is probably related to the rich mineral content of the whale bones and the establishment of bird foraging/resting areas around the intertidal zone (Albuquerque et al., 2012). Skuas and sea gulls nesting near the whale bones could increase nutrient composition, mainly nitrates derived from guano. The whale vertebrae act as alternative substrates for the Antarctic plant communities, since all species found in the present work are usually epilithic (Olech, 2004; Øvstedal & Smith, 2001).

For bones with much more complex surface roughness and microtopography patterns almost half of the surface was covered with lichens or mosses (Fig. 2e–h). PC was much higher for these bones even when they were located in the same area as a bone with a class II pattern. The smoother surface of the class II bones is possibly a disadvantage for colonisation of plants (Fig. 2f,h), with a percentage coverage of 17.87–27.63% (Table 2). It can be clearly observed in these examples that a greater roughness at the edges favoured plant colonisation. The surface roughness may be associated with bone density.

One theory that gains strength from this analysis is that greater roughness would favour the presence of plant tissues in deeper parts of the bones. However, to prove this hypothesis a bone profile analysis would be required, which was not performed in the present study. In summary, greater surface roughness and complexity in the microtopography influences lichen and moss colonisation of whale bones.

Considering the physiognomy and floral composition of the plant communities of ice-free areas in Admiralty Bay, evidence shows that these communities differ from those found on other islands of maritime Antarctic, probably because of the concentration of birds in the area and the distinct topography (Victoria et al., 2013). Moss formations are more expressive and complex in ice-free areas, and they occur mainly in tufts and carpets in lower areas such as on beaches and drainage lines (Victoria et al., 2009a). However, moss cushions can be found in rocky outcrops of marine raised beaches and/or rock platforms and on rocks next to bird colonies (Jablonski, 1986; Pereira & Putzke, 1994). Studies show that lichens and mosses grow relatively slowly in polar regions compared with other environments (Havström et al., 1995; Scott, 1990; Seppelt, 2011); however, Sancho et al. (2007) observed the fastest reported growth rates for crustose lichens species in the Dry Valleys, with 100-fold higher rates than previously reported globally. Therefore, studies on the growth rate of lichens on alternative substrates are needed. The stable environment inside the bone is suitable for the growth of numerous organisms, including cyanobacteria and fungi (Raabová & Kovácik, 2013). These microenvironments may contribute to lichen and moss colonisation by acting as a trap for propagules and helping them to avoid abiotic stress; however, this assumption needs to be evaluated in further studies.

Evidence shows that whale carcasses act as dispersal and evolutionary stepping-stones between marine habitats (Distel et al., 2000; Smith et al., 1989), but whale bones deposited on beaches have not been evaluated in this regard. Specific studies are required to assess whether bones may also contribute to species dispersal in terrestrial environments.

Comparisons with previous surveys show an increase in the number of species growing on whale bones, with seven new lichen species identified. A long-term monitoring study is necessary to clarify the changes in diversity of plant colonisation of this substratum. Bone remnants are ecologically important and impact nutrient cycling in nature.

Acknowledgements

This work was supported by the Brazilian Antarctic Program through the National Council for Research and Development (CNPq; process no. 574018/2008), Research Foundation of the State of Rio de Janeiro (FAPERJ; process E-26/170.023/2008), Ministry of Environment (MMA), Ministry of Science and Technology (MCT) and Interministerial Commission for Sea Resources (CIRM), whom the authors thank for the financial and logistic support needed to perform this study.

References

Albuquerque, M. P., Victoria, F. C., Schunemann, A. L., Putzke, J., Gunski, R. J., Seibert, S., . . . Pereira, A. B. (2012). Plant composition of skuas nests at Hennequin Point, King George Island, Antarctica. *American Journal of Plant Sciences*, *3*, 688–692.

Armstrong, R. A. (1990b). The influence of calcium and magnesium on the growth of the lichens. Xanthoria parietina and Parmelia saxatilis. *Env Exp Bot*, *30*, 51–57.

Distel, D., Baco, A., Chuang, E., Morrill, W., Cavanaugh, C. & Smith, C. (2000) Marine ecology: do mussels take wooden steps to deep-sea vents? *Nature*, *403*, 725–726.

Gignac, L. D. (2001). Bryophytes as indicators of climate change. *The Bryologist*, *104*, 410–420.

Gaio-Oliveira, G., Dahlman, Palmqvist, K. & Maguas, C. (2005). Responses of the lichen Xanthoria parietina (L.) Th. Fr. to varying nitrogen concentrations. *Lichenologist*, *37*, 171–179.

Garty, J., Gal, M. & Galun, M. (1974). The relationship between physiochemical soil properties and substrate choice of 'multisubstrate' lichen species. *Lichenologist*, *6*, 146–150.

Havström, M., Callaghan, T. V., Jonasson, S. & Svoboda, J. (1995). Little Ice Age temperature estimated by growth and flowering differences between subfossil and extant shoots of *Cassiope tetragona*, an Arctic heather. *Functional Ecology*, *9*, 650–654.

Jablonski, B. (1986). Distribution, abundance and biomass of a summer community of birds in the region of the Admiralty Bay (King George Island, South Shetland Islands, Antarctica) in 1978/1979. *Polish Polar Research*, *7*, 217–260.

Kim, J. H., Ahn, I. Y., Hong, S. G., Andreev, M., Lim, K. M., Oh, M. J., . . . Hur, S. J. (2006). Lichen flora around the Korean Antarctic Scientific Station, King George Island, Antarctic. *The Journal of Microbiology*, *44*, 480–491.

Kittel, P. (2001). Inventory of whaling objects on the Admiralty shores (King George Island, South Shetland Islands) in the years 1996–1998. *Polish Polar Research*, *22*, 45–70.

Longton, R. E. (1982). Physiological ecology of mosses. In: Taylor R. J. & Leviton A. E. (Eds.). *The mosses of North America*. San Francisco, CA: Pacific Division of the American Association for the Advancement of Science.

Miller, G. D. (2007). King Geroge Island. In: Riffenburgh, B. 2007. Encyclopedia of Antarrctic. Volume 1.Taylor & Francis, New York. 577–578pp.

Ochyra, R. (1998). *The moss flora of King George Island Antarctica*. Kraków: Polish Academy of Sciences.

Ochyra, R., Smith, R. I. L. & Bednarek-Ochyra, H. (2008). *The illustrated moss flora of Antarctica*. Cambridge: Cambridge University Press.

Olech, M. (1996). Human impact on terrestrial ecosystems in west Antarctica. *Proceedings of the NIPR Symposium on Polar Biology*, *9*, 299–306.

Olech, M. (2004). *Lichens of King George Island, Antarctica*. Kraków: Institute of Botany, Jagiellonian University.

Øvstedal, D. O. & Smith, R. I. L. (2001). *Lichens of Antarctica and South Georgia – A guide to their identification and ecology*. Cambridge: Studies in Polar Research, Cambridge University Press.

Øvstedal, D. O. & Smith, R. I. L. (2004). Additions and corrections to the lichens of Antarctica and South Georgia. *Cryptogamie, Mycologie*, *25*, 323–331.

https://doi.org/10.1017/S0032247418000062 Published online by Cambridge University Press

Øvstedal, D. O & Schaefer, C. E. G. R. (2013). A new lichen species from the Heritage Range, Ellsworth Mountains, Antarctica. *Hoehnea*, *40*, 361–364.

Proulx, J. (1986). Whaling in the North Atlantic: From Earliest Times to the Mid-19th Century.

Pereira, A. B. & Putzke, J. (1994). Floristic composition of Stinker Point. Elephant Island, Antarctica. *Korean Journal of Polar Research*, *5*, 37–47.

R Core Team. (2017). *R: a language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/.

Rakusa-Suszczewski, S. (1998). The past and present of King George Island (South Shetland Islands, Antarctica). *Polish Polar Research*, *19*, 249–252.

Raabová, L. & Kovácik, L. (2013). Four aeroterrestrial algae grow at a special substrate of de-glaciated coastal areas of Petuniabukta, Svalbard. *Czech Polar Reports*, *3*, 157–162.

Redon, J. (1985). *Liquenes Antarticos*. Santiago de Chile: Publicação do Instituto Antártico Chileno.

Robert, J. H. (2015). *raster: geographic data analysis and modeling*. R package version 2.4-20. Retrieved from http://CRAN.R-project.org/package=raster.

Sancho, L. G., Green, A. & Pintado, A. (2007). Lichen growth. Slowest to fastest: extreme range in lichen growth rates supports their use as an indicator of climate change in Antarctica. *Flora*, *202*, 667–673.

Scott, J. J. (1990). Changes in vegetation on Heard Island 1947–1987. In: Kerry K. R. & Hempel G. (Eds.). *Antarctic ecosystems. Ecological change and conservation* (pp. 61–76). Berlin: Springer.

Seppelt, R. (2011). Bryophytes and lichens in a changing climate. An Antarctic perspective. In: Zoltan T., Nancy G. S. & Lloyd R. S. (Eds.). *Bryophyte ecology and climate change* (pp 251–276.). Cambridge: Cambridge University Press.

Smith, C., Kukert, H., Wheatcroft, R., Jumars, P. & Deming, J. (1989). Vent fauna on whale remains. *Nature*, *341*, 27–28.

Smith, R. I. L. (1984). Terrestrial plant biology of the sub-Antarctic and Antarctic. In: Laws R. M. (Ed.). *Antarctic ecology* (pp. 61–162). London: Academic Press.

Smith, R. I. L. (2007). Lichens. In: Riffenburgh, B. *Encyclopedia of Antarctic* (Volume 1). New York, NY: Taylor & Francis.

Tønnessen, J. & Johnsen, O. (1982). *The history of modern whaling*. London, Canberra: C. Hurst & Company, Australian National University Press.

The committee for whaling statistics. (ed.). 1931. International whaling statistics II. Steenske Boktrykkeri Johannes Bjørnstad A/S, Oslo. 68pp.

Victoria, F. C., Albuquerque, M. P., Pereira, A. B., Simas, F. N. B., Spielmann, A. F. & Schaefer, C. E. G. R. (2013). Characterization and mapping of plant communities at Hennequin Point, King George Island, Antarctica. *Polar Research*, *32*, 1–10.

Victoria, F. C., Costa, D. P. & Pereira, A. B. (2009a). Life-forms of moss species in defrosting areas of king George island, South Shetland Islands, Antarctica. *Bioscience Journal*, *25*, 151–160.

Victoria, F. C., Pereira, A. B. & Costa, D. P. (2009b). Composition and distribution of moss formation in the ice-free areas adjoining the Arctowski region, Admiralty Bay, King George Island, Antarctica. *Iheringia, Série Botânica*, *64*, 8–91.