Available online at www.sciencedirect.com
ScienceDirect
Journal of Environmental Sciences 2011, 23(9) 1431–1436
JOURNAL OF ENVIRONMENTAL SCIENCES
ISSN 1001-0742
CN 11-2629/X
www.jesc.ac.cn

Ecosystem evolution of seal colony and the influencing factors in the 20th century on Fildes Peninsula, West Antarctica

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Received 10 November 2010; revised 08 March 2011; accepted 23 March 2011

Abstract

As the topmost predator in Antarctica, the seal is a unique indicator of Antarctic environment and climate changes. In this study, we collected a sediment core from the Fildes Peninsula of West Antarctica, and used cholesterol, cholestanol, epicoprostanol, coprostanol, and seal hair numbers as the proxy indicators of seal population size and phytol as of general vegetation, and we reconstructed the 20th century history of variation of the seal population and vegetation abundance on this island. The sealing industry in the early 20th century caused the dramatic decline of seal population, and the ban of seal hunting since the 1960s led to its recovery of seal population. The seal population during the past century was primarily controlled by human activities and krill density. The reconstructed relation between seal population and vegetation abundance may offer new insights into Antarctic environment and ecology.

Key words: fecal sediment; molecular marker; human culture; seal ecosystem; climate

DOI: 10.1016/S1001-0742(10)60601-8

Citation: Huang J, Sun L G , Wang X M, Wang Y H, Huang T, 2011. Ecosystem evolution of seal colony and the influencing factors in the 20th century on Fildes Peninsula, West Antarctica. Journal of Environmental Sciences, 23(9): 1431–1436

Introduction

Antarctica, due to its distance from human-active areas and its unique ecosystem, is an ideal place to study global climate and environment changes and ecological responses to human activities (Yin et al., 2007). In the marine ecosystem of Western Antarctica, Southern Ocean, the seal is the top predator whose demography and population are directly influenced by the availability of its prey mainly krill (Croxall et al., 1999), which is itself influenced by abiotic components (Mangel and Nicol, 2000). Due to its sensitivity, the seal is an optimal indicator for environment and ecosystem changes of the Southern Ocean (Costa et al., 2008; Curtis et al., 2009; Learmonth et al., 2006; Sun et al., 2004).

The Antarctic Peninsula is one of the three areas that are experiencing the fastest climate changes on earth (King, 1994; Smith et al., 1996; King and Harangozo, 1998; Vaughan et al., 2003), and its mean annual temperature has increased by more than 1.5°C, compared to the global mean increase of 0.5°C since 1950 (Folland et al., 2002). The third Intergovernmental Panel on Climate Change assessment report (Folland et al., 2002) confirmed that this area warmed rapidly in the period 1976–2000. Fildes Peninsula is the largest oasis in King George Island, Antarctic Peninsula, West Antarctica. Because of its sensitive responses to climate changes and rich diversity of living organisms, Fildes Peninsula has become a hotspot for ecological research (Smith, 1990; Zhao, 2002). There are several science research stations of Russia, Chile and other countries, some Antarctic Specially Protected Areas, and International Space Science Institutes. Various methods have been utilized to study the evolution of climate and environment in West Antarctica (Barlow et al., 2002; Casaux et al., 2006, 2009; Corsolini, 2009; Curtis et al., 2009; Hodgson et al., 1998; Learmonth et al., 2006; Miranda et al., 2007; Sun et al., 2000, 2004, 2006; Tao et al., 2006; Tollit et al., 2007; Yin et al., 2007); the use of organic molecular markers in the ecological studies of seal colonies, however, is very limited (Wang et al., 2007; Huang et al., 2010).

In this study, we performed organic geochemical analysis on a sediment core from Fildes Peninsula in King George Island, West Antarctica, and reconstructed the ecosystem history of this area for the last century. We also examined the impact of human activities and climate changes on the ecosystem of Southern Ocean.

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1 Materials and methods

1.1 Study site and sample collection

Fildes Peninsula locates in the southwest of King George Island with a total area of 38 km^2 (8 km × 2.5–4.5 km, Fig. 1) (Sun et al., 2006). In this study, we collected a sediment core HN1 (35.5 cm long) from a terrestrial catchment (62°11′57″S, 59°58′48″W, and an altitude of 2 m) of a depositional basin in the first marine terrace on the Fildes Peninsula (Fig. 1). During the field investigation, a PVC pipe of a diameter of 12 cm was pushed vertically into the catchment center to excavate the sediment core. After the PVC pipe was retrieved, both ends were hermetically sealed.

1.2 Sample analysis

The HN1 sediment core was sliced at 0.5 cm intervals and several samples were selected based on the work of Yang et al. (2010). The top 25.5 cm of HN1 was identified as seal excrement deposition (Table 1). The samples were freeze-dried prior to analysis. The detailed analytical procedures were described previously in Wang et al. (2007). Briefly, sediment samples were Soxhlet extracted with 2:1 (*V*/*V*) dichloromethane/methanol for 72 hr. The extracts were concentrated by rotary evaporation and then saponified using 0.5 mol/L KOH/MeOH. Neutral lipids were partitioned out of the basic solution with hexane. The pH of the saponified extract was then adjusted to 2 with 6 mol/L HCl and acidic lipids were extracted with 20% dichloromethane in hexane. Acidic lipids were allowed to sit in the presence of anhydrous Na_2SO_4 overnight to remove trace water. Neutral lipids were further separated on 5% deactivated silica gel column chromatography using solvents of increasing polarity from hexane through methylene chloride. The fractions containing hydrocarbons (eluted with hexane) and *n*-alkanols/sterols (eluted with methylene chloride) were collected separately. The alcohol and acid fractions were treated with BSTFA (*N*,*O*-bis-trimethylsilyltriXuoroacetamide) to form trimethylsilyl (TMS)-ether derivatives, and then analyzed in SCAN model by a HP 5972 gas chromatography-mass selective detector (GC-MSD). The analytes were separated using a Agilent DB-5 capillary column (50 m × 0.32 mm i.d. × 0.17 μm film thickness). All sample analysis was performed in the State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Science (CAS).

Table 1 Sample numbers and the depth of HN1

Sample number	Depth (cm)	Sample number	Depth (cm)
HN1-23	24.5	HN1-48	12
HN1-26	23	HN1-49	11.5
HN1-32	20	HN1-52	10
HN1-37	17.5	HN1-57	7.5
HN1-42	15	HN1-62	5
HN1-46	13	HN1-67	2.5
HN1-47	12.5	HN1-71	0.5

1.3 Dating

The detailed chronology of HN1 was previously reported by Yang et al. (2010). The depth of 11.5, 8.5, and 4.5 cm corresponded to the year of 1965, 1977, and 1988, respectively; the sample at the depth of 25.5 cm had the maximum age of 1926 AD. Linear interpolation was used to interpolate the ages at depth between 0 and 25.5 cm.

2 Results

Phytol derives from the side chain of chlorophyll (Rontani and Volkman, 2003) and frequently appears as the main peak of alcohols in Antarctic lake sediments. As shown in Fig. 2, phytol has an extremely high level in HN1, indicating that it is well preserved in the low-temperature environment of Antarctica. Because phytol is ubiquitously found in all green plants, it is used as a proxy indicator of overall vegetation. Previous studies (Wang et al., 2007;

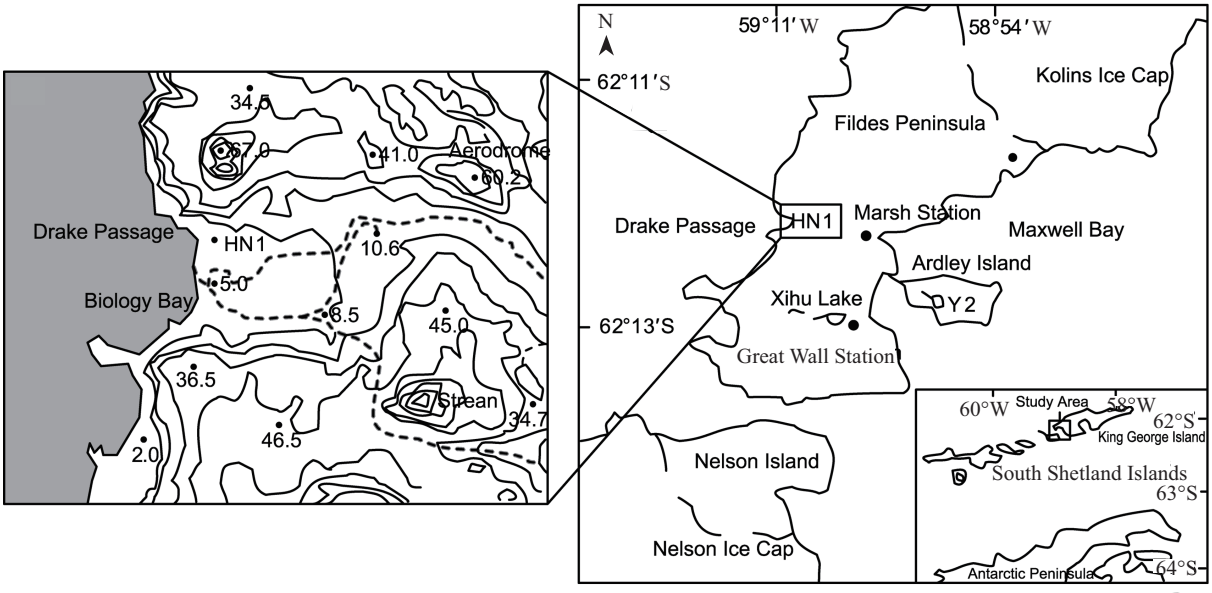

Fig. 1 Map of Fildes Peninsula showing the HN1 sampling site.

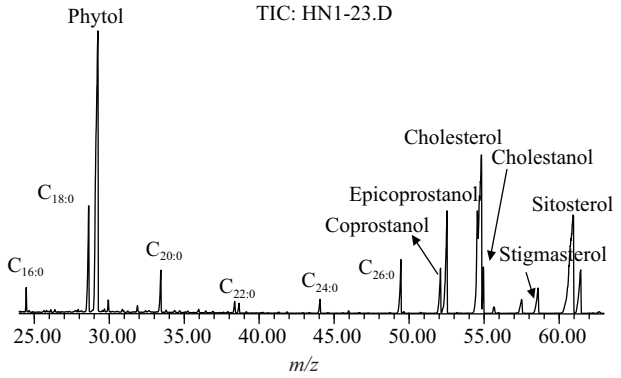

Fig. 2 Alcohol composition of the sediment core HN1 at depth of 23 cm.

Huang et al., 2010) used phytol and reconstructed the historical changes of vegetation abundance in penguin colonies.

Coprostanol, epicoprostanol, cholesterol, and cholestanol are common fecal sterols. They are used to indicate fecal contamination and distinguish animal dung among different species. Considering the sampling site and abundant seal hairs in the samples, we assume that the sterols come from seal excrements. Venkatesan and Santiago (1989) reported that seals and sea lions excrements contained very low level of coprostanol and no epicoprostanol. But Martins et al. (2002) noted that in all the Antarctic sediments, epicoprostanol dominated over coprostanol, likely due to the conversion of coprostanol to epicoprostanol by some natural anaerobic bacteria (McCalley et al., 1981). Martins et al. (2002) also concluded that cholesterol typically accounted for more than 90% of the sterols in the fresh feces of *Leptonychotes weddellii*, *Mirounga leonine* (elephant seal, the main seal species on the Fildes Peninsula), *Hudrurga leptonyx*, and *Arctocephalus gazella*. Our study site and samples are similar to theirs, whereas the proportion of cholesterol in sterols of HN1 is only 50% (Venkatesan and Santiago, 1989; Martins et al., 2002). This difference is likely caused by the abundant bacteria. As shown in Fig. 3, the level of hop-17-en and hop-22-en, which are indicators of bacteria activity, are high in the HN1 core. Bull et al. (2002) proposed that cholestanol found in sediments was likely due to natural hydrogenation of cholesterol. Therefore, epicoprostanol and cholestanol are probably derived separately, from coprostanol and cholesterol and they are bacterial byproducts of the corresponding biomarkers. Because these four types of sterols come directly or indirectly from seals, their fluctuations reflect the variation in seal numbers. As a result, we could use the total fecal sterols (cholesterol+cholestanol+coprostanol+epicoprostanol) as a proxy indicator of historic seal population.

3 Discussion

By using the two molecular markers (cholesterol+cholestanol+coprostanol+epicoprostanol and phytol) for seal population and vegetation abundance in the sediment core HN1, we reconstructed the ecosystem history of the studied seal colony on Fildes Peninsula in 20th century. The content versus depth profiles of total fecal sterols (cholesterol+cholestanol +coprostanol+epicoprostanol), phytol, TOC (Yang et al., 2010), and seal hair numbers in HN1 are shown in Fig. 4 together with the reported mean annual temperatures in King George Island during 1947 to 1995 years (Ferron et al., 2004). As discussed above, fecal sterols and seal hair numbers are used as proxy indicators of historical seal population and phytol of overall vegetation. For convenience of discussion, we divide the last century into three time periods mainly according to fluctuations of these molecular markers and mean annual temperature.

Period I: 1926–1962 AD. During this period, the level of total fecal sterols and the seal hair numbers declined sharply, indicating a significant drop in seal population (Fig. 4). In this period, there was no climate anomaly (Vaughan et al., 2003). Therefore, the population drop was unlikely caused by climate changes. We examined the sealing and whaling history in the Fildes Peninsula. The sealing activity started in the 19th century on South Georgia, became restricted in 1910 (54°S–55°S, 36°W–38°W), and was terminated in 1964 (Croxall, 1992). The seal population changes were influenced by not only environmental factors, but also human sealing and whaling activities (Hodgson et al., 1998). Geographically, Fildes Peninsula is near South Georgia; thus the changes in sealing activity could be the main factor for the seal population changes on the Fildes Peninsula in this period.

With the declined seal population, seal-derived nutrition and seal's impact on the terrestrial and freshwater ecosystems became reduced; consequently vegetation abundance decreased markedly and stayed stable, as indicated by the changes in phytol (Fig. 4).

Period II: 1962–1970 AD. The levels of molecular markers in this time period were marked by a fluctuating rise (Fig. 4). Started in 1922, whaling and sealing industry dramatically reduced the whale and seal numbers in the Southern Ocean and increased the abundance of krill, which is the main food of whale and some seal species (Croxall and Prince, 1979; Laws, 1985). When the sealing was totally banned in 1964, the seal population recovered. In this period, a substantial decline in sea-ice extent started in the mid 1950s, and it was largely complete by 1973 (Park et al., 1998; Simões et al., 1999). As climate became warmer and floating ices were reduced, krill population and thus seal population were expected to decline (Hegseth and Von Quillfeldt, 2002). Therefore the sharp rise of seal population in this period (Fig. 4) indicated that human activities had more influence on the seal population than natural factors.

In this period, phytol level and thus vegetation abundance had a large increase, very likely due to the increased input of nutrients from enlarged seal population. In seal colonies, seals provided nutrition for vegetation; but at the same time they could also cause physical damages such as trampling (Smith, 1988, 1997; Butler, 1999; Yves et al., 2005).

Period III: 1970–2002 AD. The level of total fecal

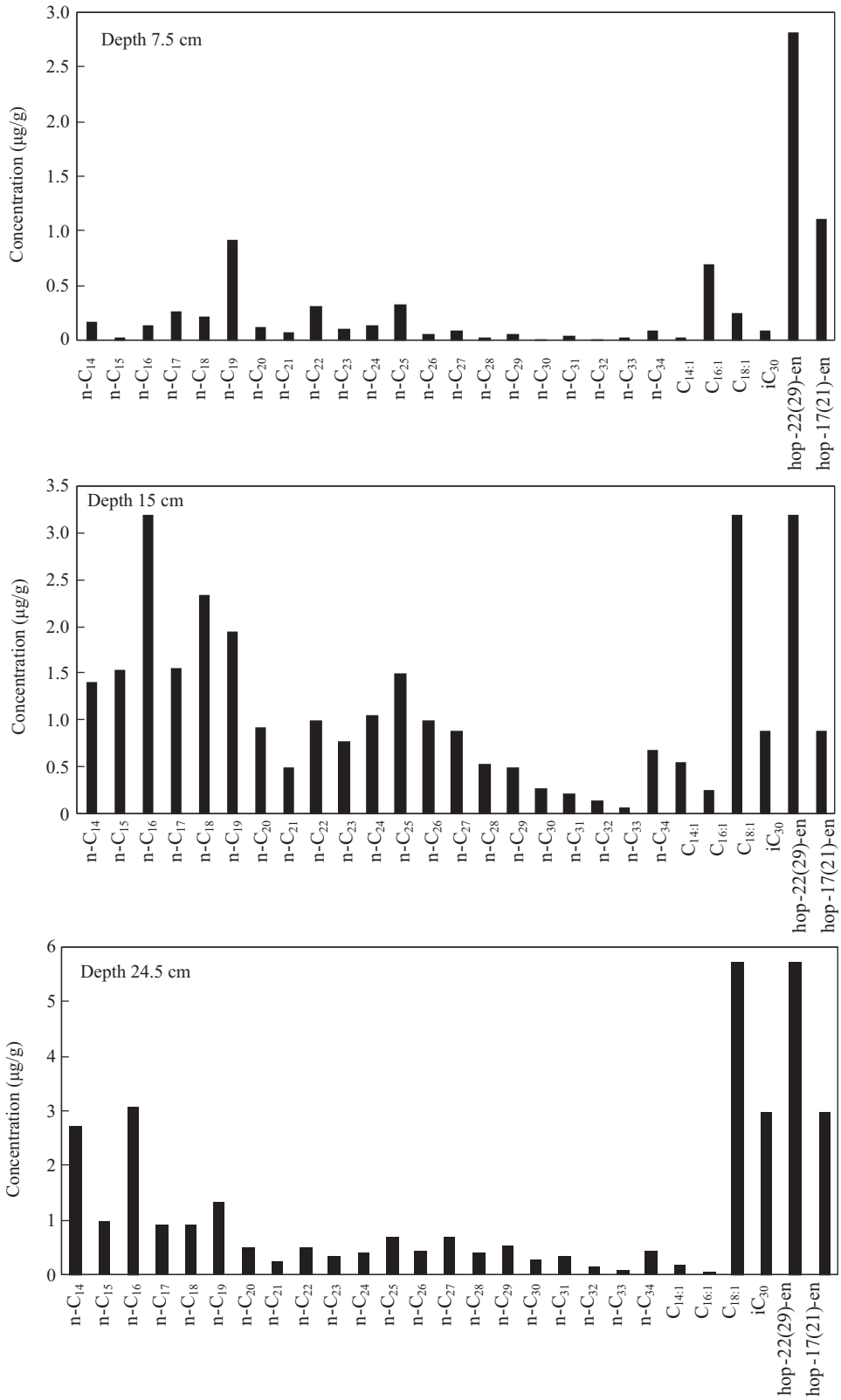

Fig. 3 Alkane composition and concentration of the sediment core HN1 at three depths of 7.5, 15 and 24.5 cm.

sterols rose first and then declined (Fig. 4), and it is similar to the changes of seal hair numbers. Although the climate warmed after the sealing ban in the 1960s (Fraser and Trivelpiece, 1996; Fraser et al., 1992), krill was still abundant and thus the seal population was rapidly expanding. The persistent warming in Antarctica since 1970s (Skvarca et al., 1999; Vaughan and Doake, 1996) and the preying by seals and other animals, however, started to affect and reduce the krill and the seal populations. The seal population mainly depends upon krill biomass. Atkinson et al. (2004) reported similar krill and the seal population changes in this time period. Boyd (1993) reported that seal population on South Georgia (near our study site) in 1990–1991 was less than that in 1950–1960.

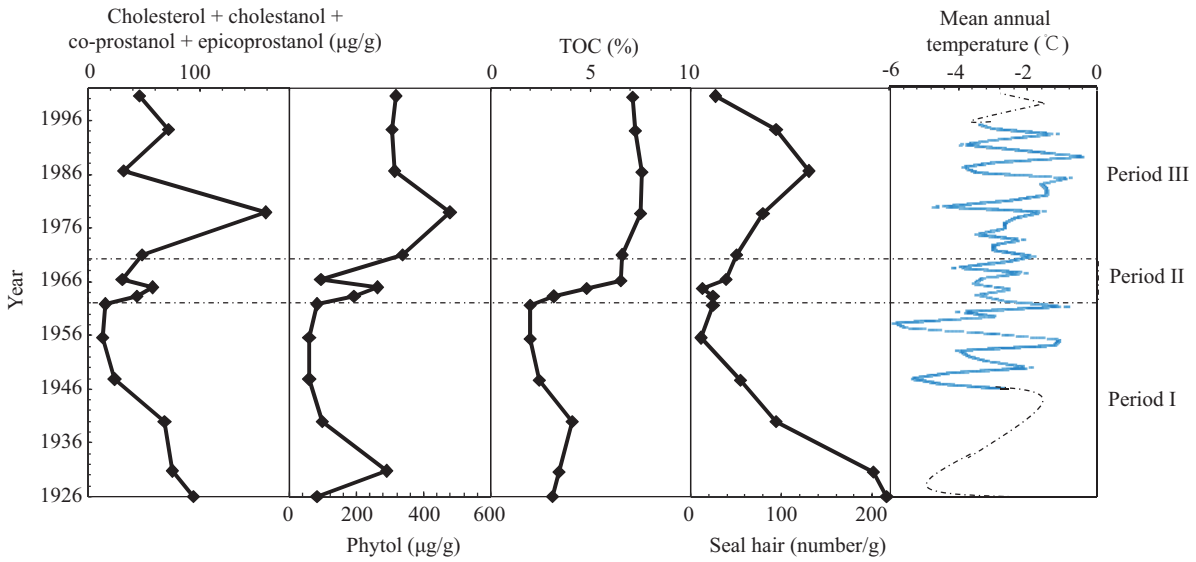

Fig. 4 Content versus ages profiles of molecular markers in the sediment core HN1.

During this time period, the phytol content declined first and finally stayed stable at a high level. The blooming vegetation around the studied seal colony was very likely caused by the abnormal climate warming.

4 Conclusions

From the profiles of organic molecular markers in the sediment core HN1, we reconstructed the history of seal population and vegetation abundance changes in Fildes Peninsula for the 20th century and examined the influencing factors. The Antarctic seal population is likely affected more by anthropogenic activities than by climate changes. The sealing industry from the 1920s to the 1950s dramatically reduced the seal populations in Fildes Peninsula, and the seal hunting ban since the 1960s led to the recovery of seal populations. Vegetation abundance change is mostly consistent with seal population variation, indicating the nutrient from seals is crucial for plant growth. Since 1980s, the rapid warming of climate has reduced krill supply and thus seal population; but the warming seems to be beneficial for vegetation.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (No. 40730107), the National Key Technology R&D Program of China (No. 2006BAB18B07), the National Basic Research Program of China (No. 2009CB42160X) and the State Key Laboratory of Organic Geochemistry Foundation (No. OGL-200606). We thank the Chinese Arctic and Antarctic Administration, CHINARE18 team in Changcheng Station and assistance in the field working. We thank Prof. Renbin Zhu for sample collection.

References

Atkinson A, Siegel V, Pakhomov E, Rothery P, 2004. Long-term decline in krill stock and increase in salps within the Southern Ocean. *Nature*, 432: 100–103.

Barlow K E, Boyd I L, Croxall J P, Reid K, Staniland I J, Brierley A S, 2002. Are penguins and seals in competition for Antarctic krill at South Georgia? *Marine Biology*, 140(2): 205–213.

Boyd I L, 1993. Pup production and distribution of breeding Antarctic fur seals (*Arctocephalus gazella*) at South Georgia. *Antarctic Science*, 5(1): 17–24.

Bull I D, Lockheart M J, Elhmmali M M, Roberts D J, Evershed R P, 2002. The origin of faeces by means of biomarker detection. *Environment International*, 27(8): 647–654.

Butler H G, 1999. Seasonal dynamics of the planktonic microbial community in a maritime Antarctic lake undergoing eutrophication. *Journal of Plankton Research*, 21(12): 2393–2419.

Croxall J P, Reid K, Prince P A, 1999. Diet, provisioning and productivity responses of marine predators to differences in availability of Antarctic krill. *Marine Ecology Progress Series*, 177: 115–131.

Casaux R, Baroni A, Ramon A, 2006. The diet of the weddell seal *Leptonychotes weddellii* at the Danco Coast, Antarctic Peninsula. *Polar Biology*, 29(4): 257–262.

Casaux R, Carlini A, Corbalan A, Bertolin L, DiPrinzio C Y, 2009. The diet of the Weddell seal Leptonychotes weddellii at Laurie Island, South Orkney Islands. *Polar Biology*, 32(6): 833–838.

Corsolini S, 2009. Industrial contaminants in Antarctic biota. *Journal of Chromatography A*, 1216(3): 598–612.

Croxall J P, 1992. Southern ocean environmental changes: effects on seabird, seal and whale populations. *Philosophical Transactions: Biological Sciences*, 338: 319–328.

Croxall J P, Prince P A, 1979. Antarctic seabird and seal monitoring studies. *Polar Record*, 19: 573–595.

Curtis C, Stewart B S, Karl S A, 2009. Pleistocene population expansions of Antarctic seals. *Molecular Ecology*, 18(10): 2112–2121.

Ferron F A, Simões J C, Aquino F E, Setzer A W, 2004. Air temperature time series for King George Island, Antarctica. *Brazilian Antarctic Research*, 4: 155–169.

Folland C K, Karl T R, Salinger M J, 2002. Observed climate variability and change. *Weather*, 57(8): 269–278.

Fraser W R, Trivelpiece W Z, 1996. Factors controlling the distribution of seabirds: winter-summer heterogeneity in the

distribution of Adéie penguin populations. In: Foundations for Ecological ResearchWest of the Antarctic Peninsula (Robin M R, Eileen E H, Langdon B Q, eds.). American Geophysical Union, Washington. 257–272. Antarctic Research Series, Vol. 70.

Fraser W R, Trivelpiece W Z, Ainely D G, Trivelpiece S G, 1992. Increases in Antarctic penguin populations: reduced competition with whales or a loss of sea ice due to global warming? *Polar Biology*, 11(8): 525–531.

Hegseth E N, Von Quillfeldt C H, 2002. Low phytoplankton biomass and ice algal blooms in the Weddell Sea during the ice-filled summer of 1997. *Antarctic Science*, 14(3): 231–243.

Hodgson D A, Johnston N M, Caulkett A P, Jones V J, 1998. Palaeolimnology of Antarctica fur seal *Arctocephalus gazella* populations and implications for *Antarctic management*. *Biological Conservation*, 83(2): 145–154.

Huang J, Sun L G, Huang W, Wang X M, Wang Y H, 2010. The ecosystem evolution of penguin colonies in the past 8,500 years on Vestfold Hills, East Antarctica. *Polar Biology*, 33(10): 1399–1406.

King J C, 1994. Recent climate variability in the vicinity of the Antarctic Peninsula. *International Journal of Climatology*, 14(4): 357–369.

King J C, Harangozo S A, 1998. Climate change in the western Antarctic Peninsula since 1945: observations and possible causes. *Annals of Glaciology*, 27: 571–575.

Laws R M, 1985. The ecology of the Southern Ocean. *American Scientist*, 73(1): 26–40.

Learmonth J A, MacLeod C D, Santos M B, Pierce G J, Crick H Q P, Robinson R A, 2006. Potential effects of climate change on marine mammals. *Oceanography and Marine Biology: an Annual Review*, 44: 431–464.

Martins C C, Venkatesan M I, Montone R C, 2002. Sterols and linear alkylbenzenes in marine sediments from Admiralty Bay, King George Island, South Shetland Islands Antarctic. *Science*, 14(3): 244–252.

McCalley D V, Cooke M, Nickless G, 1981. Effect of sewage treatment on faecal sterols. *Water Research*, 15(8): 1019–1025.

Miranda K C, Metcalfe T L, Metcalfe C D, Robaldo R B, Muelbert M M C, Colares E P et al., 2007. Residues of persistent organochlorine contaminants in Southern elephant seals (*Mirounga leonina*) from Elephant Island, Antarctica. *Environmental Science & Technology*, 41(11): 3829–3835.

Mangel M, Nicol S, 2000. Krill and the unity of biology. *Canadian Journal of Fisheries and Aquatic Sciences*, 57(3): 1–5.

Park B K, Chang S K, Yoo H I, Chung H, 1998. Recent retreat of ice cliffs, King George Island, South Shetland Islands, Antarctic Peninsula. *Annals of Glaciology*, 27: 633–635.

Rontani J F, Volkman J K, 2003. Phytol degradation products as biogeochemical tracers in aquatic environments. *Organic Geochemistry*, 34(1): 1–35.

Simõs J C, Bremer U F, Aquino F E, Ferron F A, 1999. Morphology and variations of glacial drainage basins in the King George Island ice field, Antarctica. *Annals of Glaciology*, 29: 220–224.

Skvarca P, Rack W, Rott H, Donangelo T I Y, 1999. Climatic trend and the retreat and disintegration of ice shelves on the Antarctic Peninsula: an overview. *Polar Research*, 18(2): 151–157.

Smith R C, Stammerjohn S E, Baker K S, 1996. Surface air temperature variations in the western Antarctic Peninsula region. In: Foundations for Ecological Researchwest of the Antarctic Peninsula (Ross R M, Hofmann E E, Quetin L B, eds.). American Geophysical Union Press, Washington DC. 105–121. Antarctic Research Series, Vol. 70.

Smith R I L, 1988. Destruction of Antarctic terrestrial ecosystems by a rapidly increasing fur seal population. *Biological Conservation*, 45(1): 55–72.

Smith R I L, 1990. Signy Island as a paradigm of biological and environmental change in Antarctic terrestrial ecosystems. In: Antarctic Ecosystems, Ecological Change and Conservation (Kerry K R, Hempel G, eds.). Springer-Verlag Press, Berlin. 32–50.

Smith R I L, 1997. Impact of an increasing fur seal population on Antarctic plant communities: resilience and recovery. In: Antarctic Communities: Species, Structure and Survival (Battaglia B, Valencia J, Walton D W H, eds.). Cambridge University Press, UK. 432–436.

Sun L G, Liu X D, Yin X B, Zhu R B, Xie Z Q, Wang Y H, 2004. A 1,500-year record of Antarctic seal populations in response to climate change. *Polar Biology*, 27(8): 495–501.

Sun L G, Xie Z Q, Zhao J L, 2000. Palaeoecology – A 3,000-year record of penguin populations. *Nature*, 407: 858–858

Sun L G, Yin X B, Liu X D, Zhu R B, Xie Z Q, Wang Y H, 2006. A 2000-year record of mercury and ancient civilizations in seal hairs from King George Island, West Antarctica. *Science of the Total Environment*, 368(1): 236–247.

Tao L, Kannan K, Kajiwara N, Costa M M, Fillmann G, Takahashi S et al., 2006. Perfluorooctanesulfonate and related fluorochemicals in albatrosses, elephant seals, penguins, and Polar Skuas from the Southern Ocean. *Environmental Science & Technology*, 40(24): 7642–7648.

Tollit D J, Heaslip S G, Barrick R L, Trites A W, 2007. Impact of diet-index selection and the digestion of prey hard remains on determining the diet of the Steller sea lion (*Eumetopias jubatus*). *Canadian Journal of Zoology-Revue Canadienne De Zoologie*, 85(1): 1–15.

Vaughan D G, Doake C S M, 1996. Recent atmospheric warming and retreat of ice shelves on the Antarctic Peninsula. *Nature*, 379: 328–331.

Vaughan D G, Marshall G J, Connolley W M, Parkinson C, Mulvaney R, Hodgson D A et al., 2003. Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change*, 60(3): 243–274.

Venkatesan M I, Santiago C A, 1989. Sterols in ocean sediments: novel tracers to examine habitats of cetaceans, pinnipeds, penguins and humans. *Marine Biology*, 102: 431–437.

Wang J J, Wang Y H, Wang X M, Sun L G, 2007. Penguins and vegetations on Ardley Island, Antarctica: evolution in the past 2,400 years. *Polar Biology*, 30(11): 1475–1481.

Yang Q C, Sun L G, Kong D M, Huang T, Wang Y H, 2010. Variation of Antarctic seal population in response to human activities in the 20th entury. *Chinese Science Bulletin*, 55(11): 1084–1087.

Yin X B, Sun L G, Zhu R B, Liu X D, Ruan D Y, Wang Y H, 2007. Mercury-selenium association in antarctic seal hairs and animal excrements over the past 1,500 years. *Environmental Toxicology and Chemistry*, 26(3): 381–386.

Yves F, Steven L C, Jennie W, Patricia M S, Peter C, Mary S et al., 2005. Biological invasions in the Antarctic: extent, impacts and implications. *Biological Reviews*, 80(1): 45–72.

Zhao Y, 2002. Late holocene sea-level changes in fildes peninsula, Antarctica. *Earth Science Frontiers*, 9: 137–142.