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Impact of a newly-formed periglacial environment and other factors on fresh water chemistry at the western shore of Admiralty Bay in the summer of 2016 (King George Island, Maritime Antarctica)

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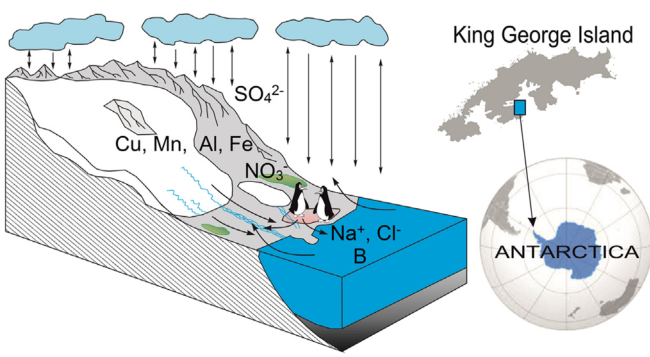
HIGHLIGHTS

- Water chemistry in zones recently and historically uncovered by glaciers differs
- PCA analysis covers aerosol influence and chemical weathering.
- Ornithologists and Moss Creek waters influenced by biological factors (higher PO43 −, NO3 −, NH4 +)
- Anthropogenic influence needs monitoring, esp. in terms of heavy metals occurrence.

GRAPHICAL ABSTRACT



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ABSTRACT

This study provides a comprehensive analysis of the inorganic chemistry of flowing water at the western shore of Admiralty Bay. In the water samples, ions, and major and trace metals (and B) were detected and quantified. Additionally, the parameters of pH, specific electrolytic conductivity (SEC_{25}) and total organic carbon (TOC) were determined. Moreover, multivariate data set was created and Principal Component Analysis (PCA) was performed. Generally, the water has low total content of the measured mineral constituents < 100 mg L^{-1}. PCA analysis we distinguished two groups of chemical variables shaping water chemistry in the investigated creeks: I – components of marine aerosol origin (presence of Na^+, Cl^- and B) and II – those associated with chemical weathering processes (presence of Al and Fe). Furthermore, the results showed that the flowing water in the newly-formed periglacial areas (formed over the last 30 years) are rich in easily soluble Al and Fe and have lower total measured contents of mineral constituents during the summer period than creeks in non-glacial catchments. Permafrost influence on water chemistry is difficult to identify. The rather insignificant difference between TOC concentrations in waters during summer indicates that permafrost is not a store of organic matter in the studied area. Moreover, local biological factors (lichens and mosses) and those limited to the sea-shore

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vicinity (seabirds and mammals activity) are significant sources of PO_4^{3-}, NO_3^-, and NH_4^+. Despite the described geological and biological features influencing water chemistry, the impact of anthropogenic activity still needs to be verified, especially in terms of heavy metal concentrations.

1. Introduction

Various effects of climate changes (e.g. retreat of glaciers, permafrost degradation) have been observed in recent decades in the Antarctic Peninsula (Guglielmin and Vieira, 2014; Kejna, 1999; Kejna et al., 2013a). This area has been subject to one of the most rapid warming phases on Earth in the last few decades (Vaughan et al., 2003; Turner et al., 2005; Vieira et al., 2008; Mulvaney et al., 2012; Bockheim et al., 2013) and provides a unique opportunity to better understand the impact of global climate on glaciers and permafrost, as well as on related ecosystems (Guglielmin, 2011; Bargagli, 2008).

In the research area, hydrological changes directly related to deglaciation strongly influence the conditions of life, while bedload transport alters the geomorphology of the place. Since its establishment in 1979, the area has undergone a number of changes, in which the process of deglaciation has played an important role. For instance, Simões et al. (1999) suggested that King George Island has lost about 7% of its original ice cover. The distribution of glaciers on the western shore of Admiralty Bay makes this region very interesting (Fig. 1). The glaciers located at the Warsaw Icefield are diverse in terms of the glacial deposits they supply and the intensities of their sediment transport. The following glaciers are located in the area of interest: Ecology, flowing into Suszczewski Bay; Sphinx, whose forehead has rested on flat land since 1977; and the Tower and Windy glaciers on the border of the study site, and from which fresh water flows down a steep slope into the Bransfield Strait. Finally, there is also the Baranowski glacier, until recently a tidewater glacier, whose recession uncovered almost 0.73 km^2 of surface area, establishing many new riverbeds in the process (see Sziło and Bialik, 2017). The observed retreat of glaciers (Birkenmajer, 2002; Cook et al., 2005; Rückamp et al., 2011; Sobota et al., 2015; Oliva and Ruiz-Fernández, 2016; Pętlicki et al., 2017; Sziło and Bialik, 2017) gives rise to new ice-free areas with intense inflow of glacier meltwater and considerably dynamic geomorphological processes (Oliva and Ruiz-Fernández, 2015, 2016) which is associated with, among others, the formation of drainage networks (Mink et al., 2014; Fountain et al., 2014). The processes in question affect not only the hydrological status of water, but may also constitute a cause for changes in water chemistry. Thus, changes in the chemical composition of water may be seen as a direct indicator of transformations occurring within the cryosphere (e.g. glaciers and permafrost). On the recently deglaciated terrain, weathering processes may be observed. Anderson et al. (2000) pointed out that studies of chemical denudation of glaciated basins indicate that solute fluxes in those areas are above the global mean rate. Chemical weathering in glacial environments causes an increase in bioavailable nutrients in water, e.g. P and Fe, that can be readily used by organisms in downstream environments (Tranter and Wadham, 2014), which may in turn cause changes in biodiversity in freshwater and marine ecosystems.

The factors changing the water chemistry characteristics are complex. Moreover, the source of the chemical composition within the streams is unclear. Unfortunately, water chemistry remains the least studied element of the ice-free area in the Antarctic Peninsula region (i.e. King George Island, KGI). Studies on the chemical composition of fresh water are limited to only a few publications focused primarily on James Ross Island (Hawes and Brazier, 1991), Livingston Island (Toro et al., 2007) and the western shore of Admiralty Bay (inter alia Wojtuń and Fabiszewski, 1999; Juchnowicz-Bierbasz, 1999; Nędzarek and Pociecha, 2010; Nędzarek et al., 2014, 2015; Zwoliński et al., 2016). Typical analyses of the results tend to be limited to selected parts of water chemistry description (ion, metal concentration, organic composition) and are discussed separately. The available studies concerning freshwater in Antarctica do not seek to interpret the results of comprehensive analyses of water chemistry performed using, for instance, chemometric tools for multivariate data processing.

The main objective of this paper is to identify the factors which shape the water chemistry of the creeks located in the western shore of Admiralty Bay and to determine the potential influence of chemical components on ice-free areas and, consequently, on near-shore marine ecosystems also. Hence, this paper aims to provide an interpretation of the multivariate data base of freshwater samples (ions, metal, TOC, pH, specific electrolytic conductivity). Data evaluation involves both the separate interpretation of specific groups of compounds and the use of state-of-the-art tools for multivariate data analysis (e.g. Principal Component Analysis, PCA). Using such a comprehensive approach allowed water composition to be analysed not only in relation to the location of sampling sites, but also with regard to the impact of various factors altering water composition. The studied environment is one of the most sensitive in the world, which is why description of each factor is important, especially description of naturally occurring factors (periglacial environment) vs. anthropogenic factors. This analysis may help to distinguish the sources of each chemical component between soil background (geochemical factor), marine aerosols, glacier retreat, meteorological conditions and transport of nutrients by biovectors e.g. penguins, and the anthropogenic factor.

2. Materials and methods

2.1. Study area

The study area is located on the western shore of Admiralty Bay (King George Island, South Shetland Islands, Antarctic Peninsula, Fig. 1), which belongs to Antarctic Specially Protected Area 128 (ASPA No. 128). ASPA No. 128 was established in order to protect areas featuring important or unusual assemblages of species, including major colonies of breeding native birds or mammals, against unforeseen and potentially hazardous human activity. King George Island, the largest of the South Shetland Islands, has a surface area of approximately 1310 km^2, 90% of which is permanently glaciated (Birkenmajer, 2002). The ice-free area has conditions favourable to permafrost processes. Discontinuous permafrost occurs on King George Island as ice-cored moraines, rock glaciers and ice- and sand-wedge polygons at an altitudinal range exceeding 15 m a.s.l. (Bockheim et al., 2013). Permafrost thickness ranges from 20 to 100 cm, whereas the active layer depth is from 50 to 180 cm. Recent studies on the South Shetland Islands show that the permafrost and active layer geomorphic system is most common in the ice-free areas of maritime Antarctica (López-Martínez et al., 2012).

Research was conducted on eight streams flowing in one of the largest ice-free areas on the western shore of Admiralty Bay (Figs. 1, 2). The first three watercourses (Petrified Forest Creek 1.62 km in length, Moss Creek – 0.91 km and Ornithologists Creek – 0.90 km, areas I–III) drain the ice-free area to the south-west and south of the Henryk Arctowski Polish Antarctic Station (Fig. 1). The other studied streams drain the immediate forefield of the Sphinx Glacier – area IV (Sphinx 1 Creek – 0.51 km, Sphinx 2 Creek – 0.65 km, Seal Creek – 0.85 km) and the Baranowski Glacier – area V (Siodlo Creek – 0.31 km). The main geographical features of the investigated sites are presented in the Table 1. The most important differences between the studied areas include the presence of permafrost in the catchments of Petrified Forest