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Pharmaceutical and personal care products in Antarctic wastewater effluent – impacts and regulation.

Olivia Pointon

31023423

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Abstract/executive summary (ca. 200 words):

Contaminants of emerging concern (CECs) are a growing category of environmental contaminants. Pharmaceuticals and Personal Care Products (PPCPs) are a group of compounds classified as CECs that have a growing reputation as potential dangers to organisms and the environment. A key source of PPCP contamination in Antarctica is through wastewater discharge as the treatment requirements as outlined in the Environment Protocol are minimal. This report outlines the presence of PPCPs in the Antarctic environment and some of the potential risks to biota. It then details current wastewater management systems in Antarctica and potential improvements to treatment facilities drawing on examples from the Arctic. Finally, key recommendations are briefly outlined as to future regulation of PPCPs in the Antarctic environment.

Contents

Introduction

Contamination of the environment from wastewater and sewage discharge is a global concern. It is widely understood that wastewater discharge can release a number of potentially harmful chemicals and pathogens to the environment (Bargagli, 2008). With advances in analytical chemistry in recent decades, a vast range of compounds are now able to be detected in wastewater discharge even at low concentrations (Esteban et al., 2016). An area of recent growth in environmental contaminant research is the category of emerging contaminants. Emerging contaminants, or contaminants of emerging concern (CECs), are broadly defined by the US Geological Survey as "any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause known or suspected adverse ecological and(or) human health effects" (U.S. Geological Survey [USGS], 2016). The US Environmental protection agency has identified a large list of emerging contaminants ranging from plasticisers and pesticides, to pharmaceuticals and flame retardants (US EPA, 2009). This report will focus on one category of CECs, pharmaceutical and personal care products (PPCPs) and their implications in the Antarctic environment.

PPCPs encompass a large range of organic compounds. They can range from prescription drugs such as antibiotics and oral contraceptive medication, to soaps, lotions and fragrances (Murdoch, 2015). These products are used around the world in large quantities daily and concern is growing over their presence in the environment and the potential impacts they may have. As they have only recently been identified as potential cause for concern, very little research has been conducted especially with regard to the Antarctic environment. PPCPs are released into the Antarctic environment through wastewater discharge, which often has had little or no treatment applied (Esteban et al., 2016). This is cause for concern as Antarctic organisms may be more vulnerable to any toxic effects than temperate species and the marine biota near wastewater outfalls may be experiencing detrimental effects (Gunnarsdóttir, Jenssen, Erland Jensen, Villumsen, & Kallenborn, 2013).

This report will highlight some examples of PPCPs that have been detected in the Antarctic and assess the risks to Antarctic biota. It will also present recommendations and possible improvements to Antarctic wastewater treatment and discharge regulation in order to minimise impacts of emerging contaminants like PPCPs.

PPCPs in Antarctica

PPCPs encompass a wide range of compounds and consumer products. They have been classified as emerging contaminants due to their resilience to degradation, potential for accumulation in the environment and some have been shown to have toxic effects to marine organisms even at low doses (NIWA, 2011). Their emergence has been made feasible by advancements in analytical technology and information on PPCPs in different environments is rapidly growing. Because of the extremely dry Antarctic environment and intense UV light conditions, PPCPs such as sunscreens and moisturisers are very common and used frequently (Emnet, Gaw, Northcott, Storey, & Graham, 2015). Additionally, soaps, shampoos and cleaning disinfectants are also used in large quantities to minimise the risk of illness at bases. As most of these products are designed for external use, they may not undergo any metabolic changes before entering wastewater systems when washed off (Emnet et al., 2015; Ternes, Joss, & Siegrist, 2004). Wastewater systems are not usually designed to remove compounds like PPCPs and removal rates can be highly variable (Esteban et al., 2016). As a result, large quantities may be present in wastewater effluent that is discharged to the Antarctic marine environment.

Several studies have been conducted in Antarctica analysing potential emerging contaminants in the environment and wastewaters. A range of potentially toxic contaminants have been found including UV filters, parabens, antimicrobial compounds, plasticisers and pharmaceutical residues like estrogen steroid hormones (Emnet et al., 2015; Esteban et al., 2016). Emnet et al. (2015) conducted a comprehensive study of PPCPs in the wastewater effluent and surrounding marine environments of McMurdo Station and Scott Base. A wide range of PPCPs was detected in the wastewater effluent of both bases including several UV filters, four types of paraben preservatives, and natural and synthetic estrogen hormones. The concentrations of several compounds analysed in Scott Base wastewater effluent were close to maximum concentrations observed internationally. These were the UV filter 4-methyl-benzylidene camphor, the antimicrobial agent methyl-triclosan and the alkylphenol 4-*t*-octylphenol (Emnet et al., 2015).

Esteban et al. (2016) carried out a similar in the Northern Antarctic Peninsula region and detected many of the same compounds and at similar concentrations to other studies completed in other parts of the world. They sampled several different freshwater environments and one wastewater discharge effluent. The wastewater discharge showed high levels of methyl-paraben, and significant levels of nonylphenol and its derivatives.

Impacts on biota and ecosystems

The significance of products like PPCPs in the Antarctic environment is still to be determined but many of the mechanisms by which pharmaceuticals and PCPs interact in human systems are conserved across a diverse range of organisms, so the potential effects of PPCPs in non-target species that are exposed is of significant interest (Gunnarsson, Jauhiainen, Kristiansson, Nerman, & Larsson, 2008; Murdoch, 2015).

Antarctic biota are slow growing, have slow metabolic rates and slow reproduction (Peck, 2002), so their ability to excrete harmful chemicals may be reduced and they may be exposed to toxic effects for longer periods. Their slow growth also means longer periods of critical development phases during which PPCPs could interfere (Emnet et al., 2015).

A further concern regarding the discharge of PPCPs is their potential to cause endocrine disrupting effects (Esteban et al., 2016). Endocrine disruptors are chemicals that interfere with the endocrine or hormone system of an organism, they can cause reproductive issues and developmental problems in specific organisms and indirectly lead to disruption of the ecosystem balance (Murdoch, 2015; National Institute of Environmental Health Sciences, 2017). Many known or suspected endocrine disrupting chemicals are present in the category of PPCPs and may exert biological effects at very low concentrations, which when compounded with the unique nature of Antarctic biota could have profound effects on the marine ecosystem.

Routledge et al. (1998) performed *in vivo* experiments on species of adult male rainbow trout (*Oncorhynchus mykiss*) to assess the responses of the organisms when exposed to estrogens. They found that exposure at concentrations similar to that discharged from municipal wastewater treatment plants were sufficient to induce vitellogenin synthesis (female egg yolk protein) in the male fish. Many other toxicity studies have been conducted on biota in temperate regions and have shown detrimental effects to organisms when exposed to environmental levels of PPCPs. For example, Dann and Hontela (2011) found the disinfectant triclosan and its metabolites can bioaccumulate to high levels in some species of algae, invertebrates and fish.

However, there have been very few studies conducted in the Antarctic on polar organisms, which means that it is difficult to determine if a species in Antarctica is likely to be more or less sensitive to a contaminant than a temperate species. It is also difficult to establish whether the relationship between the environmental concentration and any observed biological impacts in temperate species can be directly applied to high latitude organisms (Poland, Riddle, & Zeeb, 2003). For example, a key adaptation to the cold in a number of Antarctic organisms is the use of fat. But large quantities of fats could allow greater bioaccumulation of PPCPs as many are lipid and fat soluble, and this could lead to bio-magnification up the food chain to a greater extent than in temperate species (Brausch & Rand, 2011; Poland et al., 2003).

Another concern is that the presence of low doses of antibiotics in wastewater effluent has been shown to promote antibiotic resistance in receiving microbial communities. This could be detrimental to native Antarctic microorganisms and contribute to subtle changes in ecosystems (Murdoch, 2015).

Based on assessments of acceptable daily intakes and the concentrations of emerging contaminants in freshwater, Murray, Thomas, and Bodour (2010) reported that PPCPs should be regarded as high priority emerging contaminants. Disruption to the bottom of the food web such as to keystone algae species would cause a ripple effect across many trophic functions and alter the ecosystem dramatically.

Environmental degradation

In temperate climates, most PPCPs can degrade relatively quickly in the environment through photo-degradation, hydrolysis and microbial processes. Because of this, they are not classified as persistent contaminants in the environment but daily use of PPCPs and the large range of products means they are being continually released and can become - 'pseudo-persistent' (Daughton & Ternes, 1999; Muñoz et al., 2008). In Antarctica, the extremely cold temperatures, long periods of darkness, and sea ice covering coastal waters can significantly reduce the rate of degradation of PPCPs (Emnet et al., 2015). Additionally, wastewater discharge in Antarctica tends to be more concentrated and more variable than urban wastewater effluents due to the limited water supply and large seasonal fluxes in population (Stark et al., 2015). This means they may persist in the environment for longer and potentially cause more adverse effects on organisms in these areas.

Another factor of environmental contamination in Antarctica is the possibility for PPCPs to become trapped in sea-ice as it forms each autumn. Contaminants would remain in the ice until the following summer when the sea-ice begins to break out and melt. As the ice breaks out and floats away on currents, PPCPs could be transported to otherwise non-impacted marine areas leading to isolated areas experiencing 'pulses' of PPCP contamination in the water (Emnet et al., 2015)

Current wastewater treatment systems

In 1991 the Protocol on Environmental Protection the Antarctic Treaty (Environment Protocol) was established (Antarctic Treaty Consultative Parties [ATCP], 1991). The Environment Protocol and its six Annexes aimed to provide a framework for Antarctic Treaty Parties to develop environmental management processes for their activities on the continent. Annex III addresses waste disposal and the minimum requirements for sewage and wastewater discharge. Article 2.2 states the requirement that any waste should "to the maximum extent practicable, be removed from the Antarctic Treaty area by the generator of such wastes". Article 5 however allows direct discharge of waste into the sea provided that "conditions exist for initial dilution and rapid dispersal" and that larger quantities of waste (from greater than 30 individuals) "shall be treated at least by maceration" (Environment Protocol, 1991).

The Environment Protocol should ensure common standards and environmental practices for all Antarctic activities but ambiguity and unclear definitions of key terms in the documents has led to independent interpretations and inconsistencies in practice. Presently, Treaty Parties all have varying methods of wastewater treatment. Gröndahl, Sidenmark, and Thomsen (2009) found that 52% of the 71 stations in Antarctica have no treatment system at all. Also, a number of stations with treatment operations have issues with their wastewater systems or are unsure of their efficiency (Gröndahl et al., 2009).

Halton and Nehlsen (1968) recommended that all sewage be treated before discharge into a polar environment. In the 50 years since the publishing of this paper, over a third of Antarctic stations still have no form of wastewater treatment (Gröndahl et al., 2009).
A lack of wastewater treatment or inefficient systems means significant levels of PPCPs as well as other contaminants will be discharged into the coastal Antarctic waters year round. The cumulative environmental impact of non-treated wastewater discharge around the continent – particularly in the summer season – could be significant.
A study by Stark et al. (2015) investigated the impacts of a non-operational wastewater treatment system at Davis station in East Antarctica. Wastewater and sewage was being macerated before discharge which was still within the bounds of the Environment Protocol but there was no other form of treatment. The study showed that the Davis station wastewater effluent was toxic to marine organisms at low concentrations. During the summer, wastewater was retained around the outfall site with little dilution. Wildlife around the outfall were being exposed to high levels of bacteria associated with sewage and there was accumulation of other contaminants such as hydrocarbons and metals. Although PPCPs were not included in this study, the poor wastewater dilution would be expected to have potentially significant levels of PPCPs. In the winter with sea-ice present, dilution and dispersal is likely to be further reduced. Davis station has a winter over staff of approximately 20 people and a summer season maximum of 100 people. The size, wastewater treatment type, and coastal conditions are broadly representative of many coastal Antarctic stations so it is likely that the results of this can study can be broadly extrapolated to other stations around the continent (Stark et al., 2016).

Improving wastewater treatment systems

Finding ways to deal with wastewater and sewage in Antarctica faces many constraints. Designs and technologies employed in wastewater treatment plants elsewhere are not suitable for Antarctica and need to be adapted for functionality in the extreme environment (Stark et al., 2015). Treatment facilities including pipes, holding tanks and pumps need to be able to cope with the extremely low temperatures which requires large amounts of energy that may be costly to run. They also need to be able work with limited quantities of water and be able to adapt to large fluctuations in load inputs without operational issues (Gunnarsdóttir et al., 2013; Stark et al., 2015). New Zealand's treatment system at Scott Base can get overloaded with the influx of personnel over the summer months, and Australia and the US have struggled with operational issues in their plants (Gröndahl et al., 2009).

There are further operational limitations as technical help and repair support is not always readily available if problems do arise. Any potential replacement parts and tools as well as personnel with the right expertise need to be on hand.

Gunnarsdóttir et al. (2013) conducted a comprehensive review of wastewater handling in the Arctic and proposed several methods of wastewater treatment improvements that have the potential to also be utilised in Antarctic conditions. One of these was composting of human waste which has already been trialled at the Norwegian Antarctic research station where they used composting toilets (Hanssen, Paruch, & Jenssen, 2005). Although composting in an extremely cold climate has its challenges, the use of efficient insulation and solar heating during the summer months to enhance biodegradation could make composting a feasible treatment idea for smaller summer only stations. The critical issue of removing PPCPs from the wastewater effluent has proven a difficult challenge, but the use of thermophilic composting could allow for better breakdown and removal of PPCP residues than what may occur in conventional wastewater treatment plants (Gunnarsdóttir et al., 2013).

There is still a lack of research on the behaviour of PPCPs in wastewater effluent and the variation between results of studies analysing how well they can be removed presents a challenge. Improvements in technology and the development of new 'hybrid' processes may mean that effective wastewater treatment in Antarctica could soon be feasible for the majority of research stations and reduce contamination of the marine coastal environment (Grandclément et al., 2017).

Recommendations

- Development of monitoring frameworks is important to establish a sound knowledge base for impacts of PPCPs in Antarctica and on the biota. It would also allow for high risk contamination locations to be determined and the most risk organisms.
- Implement restrictions or guidelines on PCPs entering the environment. Nordic European countries have trialled an eco-labelling system which aims to provide consumers information on the ingredients in a range of personal care products and allow more environmentally friendly products to be easily recognisable and identifiable (Joss et al., 2006). A similar system could be utilised in recommending or restricting particular products for use in Antarctica.
- Catalyse discussions within the Antarctic Treaty System on environmental contamination from wastewater in order to update minimum requirements on wastewater treatment at research stations.

Conclusion

At present, very few regulations or guidelines are in place to address PPCPs in the Antarctic environment. There are still large knowledge gaps in research particularly with regard to long term effects and the 'cocktail effect' of mixtures of PPCPs in the environment. Chemicals may act synergistically and compound the effects of seemingly low doses. With more awareness on emerging contaminants and PPCPs it will be possible to improve the monitoring and regulation of these compounds. Very little is known about what kinds of products personnel take with them to the Ice and the range of products available means that it is highly likely that most wastewater effluents in Antarctica will contain a variety of different PPCPs. It is the responsibility of individual Treaty Parties to uphold their obligations to the Environment Protocol and aim to ensure that best practice is followed when it comes to environmental contamination, but the minimum environmental standards outlined in the Environment Protocol should be updated to reflect the present knowledge and technology available.

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