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Plants in Antarctica: Current and Future Phytoremediation Potential

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Graphical abstract

Abstract

As an extremely cold, dry and windy part of the world, Antarctica is a unique continent that can only be inhabit by limited number of organisms. For a long time, Antarctica was a pristine area. But nowadays, it has been invaded with many kinds of pollutants derived from human activities such as solid, liquid and metal wastes. To prevent further deterioration in Antarctic environment, remediation process is strongly needed. Phytoremediation is an environmentally clean technique to remove pollutants using plants. This is an alternative to the current physical and chemical remediation method. The success of phytoremediation technique is influenced by plant species and various environmental parameters. Unlike in the temperate and tropical region, an extremely low temperature in Antarctica does not permit the growth of many types of vegetations. Thus, phytoremediation process is scarce. Despite this limitation, there are growing interests among scientists to investigate the potential of phytoremediation to occur in tremendously harsh condition. This paper reviews current pollution problems in the Antarctic region and the possibility of phytoremediation technique to be implemented in this continent.

Keywords: Antarctica; pollution; phytoremediation

Abstrak

Sebagai kawasan yang amat sejuk, kering dan berangin, Antartika adalah benua unik yang boleh menampung kehidupan sebilangan organisma. Kawasannya yang dahulu bebas daripada pencemaran telah dirosakkan dengan pelbagai jenis bahan pencemar dari aktiviti manusia termasuk sisa pepejal, cecair dan logam. Bagi mengelakkan kerosakan berterusan terhadap kawasan Antartika, proses pemulihan perlu dijalankan. Fitoremediasi adalah teknik pemulihan menggunakan tumbuh-tumbuhan yang mesra alam. Ia menjadi alternatif kepada teknik yang digunakan sekarang iaitu pemulihan secara fizikal dan penggunaan bahan kimia. Kejayaan proses ini adalah bergantung kepada spesis tumbuhan tersebut dan pelbagai faktor alam sekitar yang lain. Tidak seperti di kawasan beriklim sederhana dan kawasan tropika, suhu sejuk melampau di Antartika tidak mengizinkan pertumbuhan pelbagai jenis pokok. Maka fitoremediasi tidak begitu menonjol. Namun begitu, minat mendalam para saintis untuk mengetahui potensi fitoremediasi di kawasan ekstrim ini telah meningkat. Artikel ini membincangkan tentang masalah pencemaran di Antartika dan potensi untuk membangunkan fitoremediasi di kawasan ini.

Kata kunci: Antartika; pencemaran; fitoremediasi

1.0 INTRODUCTION

Located at the most southern part of the world, the Antarctic continent is mainly covered with ice. There is just a small amount of ice-free area, hence only several robust vegetations are able to colonize this continent. Geographically, there are two distinct regions in the Antarctic, categorized by the climatic profiles. In the western side, it is known as "The Maritime Antarctic" and in the Eastern Antarctic Peninsula, it is known as "Continental Antarctic" (Figure 1). The Maritime Antarctic has milder temperatures and received more rain during summer, thus being a preferred home for terrestrial plants and small animals.

A unique and mysterious condition of the Antarctica has increased human's interests to visit and conduct various explorations here. Unfortunately, rising number of visitors has slowly threatened the environmental cleanliness in the Antarctic, on top of the natural processes and the effects of global climate change that generate different kinds of pollutants in this area.

Figure 1 Map of the Antarctica adapted from NERC Science of the Environment [1]

To prevent further disruption and to conserve the environment in the Antartica, pollutant clean up is needed. Although the physical and chemical techniques are currently available, these approaches are often very costly. In addition, the use of chemicals will expose the environment to a lot of harmful effects. As an alternative, phytoremediation as a tool for the removal of pollutants is preferred since it is proved to be economical and environmental-friendly.

In this review, current pollution issues in the Antarctic are discussed, and plants that are potentially used for phytoremediation in this continent were identified based on several main biomonitoring programmes conducted by previous researchers. The potential of these plants to be used as phytoremediation agent is assessed by taking into consideration various challenges and limitations for these plants to survive harsh environment.

2.0 PLANTS IN ANTARCTICA

There are limited vegetations in the Antarctic. Only competent organisms that can tolerate extremely cold temperature, dehydration and windy conditions such as certain species of mosses, liverwort, and lichens can endure in this environment. Table 1 shows approximate number of species for each type of vegetation that have been identified in the Antarctica [2].

Table 1 Approximate number of plant species in Antarctica

Vegetation	Approximate number of species
Lichens	350
Mosses	100
Liverworts	25
Microfungi	20
Algae	>300
Vascular plants	40

Amongst all, lichen constitutes the biggest population of vegetations in the Antarctica. Lichens are unique organisms with symbiotic blend of fungi and algae, thus giving them the ability to survive in most extreme conditions. *Usnea antarctica* and *Usnea aurantiacoatra* are the species of lichens commonly found from rocks in Antarctica [3].

Besides that, other lower vegetations largely available in Antarctica are mosses [4]. Mosses are small, soft leafy plants without flowers or seeds that grow in clumps. Mosses need damp and shady area to flourish. *Polytrichastrum alpinum, Sanionia georgico-uncinata, Bryum urbanskyi, Bryum pseudotriquetrum,* and *Pohlia cruda* are common species of mosses in the Antarctic. In addition, more than 350 different species with about 700 taxa of marine and non-marine algae were identified in this continent [5].

Unlike lower vegetations, vascular plants are less abundant. Along the western side of Antarctic peninsula, warmer and wetter conditions permit the growth of two higher flowering species from the carnation family known as Antarctic hair grass (*Deschampsia Antarctica*) and Antarctic pearlwort (*Colobanthus quitensis*). These two species are the only vascular plants indigenously inhabit Antarctica. In the area of South Georgia, about 40 types of flora including alien species were identified [2]. Alien species mostly dominated by angiosperms [6] that grow from natural processes such as pollination or from the seeds transferred by animals. However, the presence of alien species via human who carry the seeds either intentionally or accidentally is more obvious [7]. Under conducive environment, the seeds of these alien vascular species would successfully colonize both Maritime and Continental Antarctic.

Due to the presence of alien species, number of plants in Antarctica is expected to increase. As an example, *Poa annua* is a non-indigenous vascular plant species widely found in this continent. Due to its extensive distribution, scientists have tried to determine the origin of the species using different approaches including the molecular techniques [8, 9]. Recently, flowering species originated from the mountain area of Fuegian have been found at Deception Island, Antarctic [10].

The introduction of new species has increased people's concerns on biodiversity and conservation issues [11]. To date, the pros and cons of introducing foreign plants to the Antarctica continent is still being debated. In a review by Robinson, 2003 [12], plant distributions in the Maritime Antarctic and Continental Antarctic were highlighted, and alteration of biodiversity due to global changes were discussed [12]. Although plant diversities in Antarctica could be improved by non-indigenous species, their presence might disturb the local ecosystem in the Antarctic due to increasing competition of nutrients and other requirements for survival [11, 13, 14].

3.0 POLLUTION IN ANTARCTICA

Environmental pollution is a worldwide problem and nowadays Antarctica region is not excluded. As an indicator of global climate change, the effects of pollution that mounting in other regions around the world could be monitored by changes in Antarctica environment. However, impacts on the Antarctic environment are not just due to global, but also local pollution. In the past, Antarctica continent might be contaminated by pollutants from natural processes. But currently, human activities have mainly contributed to its environmental destruction.

This is partly verified by increasing number of visitors to Antarctica year by year. According to the International Association of Antarctica Tour Operators (IAATO), visitors normally come to this continent during summer time which is between November to March [15], for different reasons. Specific for research purposes, there are approximately 100 stations operating under the National Antarctic Program in the Antarctic Treaty Area, involving various research and explorations of about 30 countries, as in April 2012 [16].

Due to human activities, contaminants and wastes have been actively produced. These compounds are highly localized to the area near the buildup stations. Previously, human generated wastes were disposed in the form of snow pits, waste dumps, and open pit burning, while untreated sewage was discharged into the ocean. Hence, various organic and inorganic pollutants were detected in Antarctica atmosphere, snow, water and soil.

The cleanliness of Antarctic atmosphere has been fouled with contaminants from emission of soot, noxious gaseous, heavy metals and organic compounds. These contaminants are usually generated from wastes of fuel burning activities [17]. Contamination from fuel is common with increasing shipping activities in the Antarctic. Thus more toxic and persistent organic pollutants including polychlorinated biphenyls (PCB) and chlorinated hydrocarbon were detected in Antarctica atmosphere. Recently, a group of researchers have measured PCB and polybrominated diphenyl ethers (PBDEs) by passive air samplers using polyurethane foam (PUF)-disk based in King George Island [18]. Emission without control, in addition to the effect of windy condition in Antarctica has possibly spread these pollutants to adjacent areas.

Besides that, land contamination has been detected many decades ago, mainly with the presence of heavy metals. In the beginning, only natural events such as volcanic and marine biogenic process contribute to the presence of heavy metals in the environment. Slowly, human activities in nearby region such as smelting have endowed to above background level of cadmium, copper and zinc [19]. Monitoring programmes revealed the presence of more elements including vanadium and uranium, for instance in Coat Land area [20]. In the study of Planchon and co-workers, comparison of heavy metals presence in Coat Land from mid 19-th to the late 20-th century were highlighted [20]. The occurrence of certain metal elements is currently reached alarming levels due to their quantities and potential of leaching to nearby vicinity [21].

Besides heavy metals, soil in Antarctica also has been contaminated with various organic pollutants, from locals or being transported from other parts of the world. Organic compounds derived from natural occasion such as volcanic eruption and forest fire, also combustion of fuel component and industrial wastes. The presence of compounds from other places outside the Antarctic such as traces of pesticides in snow [22] is also an alarming sign that the world pollution problem is getting worse.

As for water bodies, marine pollution is critical. It occurs due to disposing raw sewage into the sea. This promotes higher level of nitrogen and phosphorus, thus increase the possibility of eutrophication [23]. In Terra Nova Bay (Ross Sea), fecal pollution was detected near to the outfall of the sewage disposal plant [24].

In addition, human settlement, for example at the McMurdoch Station that are equipped with facilities such as docks for ships has increase the amount of tarry materials and chlorinated biphenyls in the sediments [25].

Vigorous oil spillage in Antarctica has contaminates water bodies with hydrocarbon compounds. These incidents were reported in many parts of the Antarctic continents including in Ross Dependency [26] and Scott Based area [27].

These are some of the cases that have been highlighted to at least, give an indication on environmental status in the Antarctica. Importantly, the consequences of this contaminated environment are very much concerned and mitigation of the pollution problem in this continent is needed.

Currently, the Protocol on Environmental Protection is implemented for the Antarctic treaty regulatory. In this protocol, work sites cleaned up is required unless the pollutant removal caused further environmental deterioration. One of the initiatives that have been implemented by the Australian Antarctic Division is the establishment of a taskforce at the sites to assess and suggest better approaches to manage pollutants, specifically in Casey Station. This provides transition from previous waste-management practices such as disposal to tips, sea-icing and open burning to suitable clean-up options [28].

■4.0 PLANTS FOR BIOMONITORING AND BIOREMEDIATION OF POLLUTANT

Literature to date reported quite a number of biomonitoring programmes in Antarctica. These programmes normally involve monitoring the level of pollutants in living organisms including plants to signify the severity of the polluted condition, the duration of these pollutants settled in the Antarctic and the means of these pollutants being transported or travelled through atmosphere, soil and water. In the temperate region, one of the strategies to monitor the level of pollutants is through biomonitoring using vascular plants. These plants have roots, leaf, stems and other parts that probably accumulate different level of pollutants.

Although flowering plants are good bioindicators for regional warming [29], the presence of these species in the Antarctic are rare, thus reports on higher plants for phytoremediation and biomonitoring is lacking. Accordingly, lower vegetations such as lichen and mosses have been widely used as biomonitoring agents in this continent. In fact, low amount of toxic substances can be concentrated by both mosses and lichens [30] due to their unique accumulating capacity.

The nature of lichens with no roots permits nutrients absorption from surrounding air to the thallus. Simultaneously, contaminants from environs will be absorbed together with nutrients. Thus, lichens are suitable for biomonitoring of atmospheric pollutions especially heavy metals [31]. To date, advanced equipment such as Graphite Furnace Atomic Absorption Spectrometry (GFAAS) or Inductively Coupled Plasma Mass Spectrometry (ICP-MS) have been used to determine the level of pollutant, especially heavy metals in lichen matrix [32].

For mosses, the rhizoid structure will provide them with moisture and nutrients. Nutrient uptake from atmosphere is promoted by weakly developed cuticle and the presence of vascular bundles, hence allows better adsorption than vascular plants. Mosses are suitable for biomonitoring purposes as they could accumulate pollutants during their slow growth rate and minimal morphological changes during lifetime [33]. Mosses also have high cation exchange capacity to allow trace elements to be accumulated.

In addition, shorter length of biomonitoring programme can be conducted using algae, taking advantage of algae short life cycle and rapid reproduction system [34]. In the temperate region, algae have been extensively used for biomonitoring of stream water [35,36], lake [37], and estuaries [38].

In the temperate and tropical region, many higher plant species are pollutant-tolerate, and some are hyperaccumulators that have the ability to take up unusual amount of pollutants. Among the common species with this capacity are *Phaseolus vulgaris*, *Brassica juncea*, and *Thlapsi caerulescens* [39].

However, phytoremediation process in the tropics could be different from the one in the Antarctic due to distinct environmental conditions. This aspect is discussed further in the next section of this review. Focusing on biomonitoring in Antarctica, several studies showing the capabilities of Antarctica vegetations to accumulate pollutants were highlighted in Table 2.

Table 2 Antartica vegetation and detection of pollutants

Types	Species	Pollutants	Area	Remarks	Reference
Lichen	*Usnea aurantiacoatra*	Heavy metal (Pb)	Barton Peninsula, King George Island	• Higher amount of Pb accumulated in lichens collected near the research station • More Pb accumulated in the upper part of lichens	[40]
Lichen	*Usnea aurantiacoatra* *Usnea antartica*	Heavy metals (Zn, Cu,Fe, Cd, Mn)	Shetland Islands	Metal content in lichens has been an indicator of pollutant transported in the atmosphere	[41]
Mosses	Species non-specified	Polychlorinated biphenyls	Fildes Peninsula	Detection of dioxin-like polychlorinated biphenyls	[42]
Mosses	*Bryum argenteum* *Pottia heimii* *Ceratodon purpureus*	Organochlorine	Victoria Land	Polychlorobiphenyls was dominant in moss compared to other organochlorine assessed.	[43]
Mosses	*Potia heimii* *Bryum argentums* *Byrum pseudotriquetru* *Ceratodon purpureus*	Hg, Cd, Pb	Edmonson Point, Northern Victoria Land	• Metals were absorbed in mosses by atmospheric deposition and evapotranspiration • Hg and Cd were higher in mosses compared to Pb	[44]
Lichen	*Usnea antartica*	Organochlorine	Kay Island Ross Sea	Data were compared to the same species collected from Antarctic Peninsula	[45]
Mosses	*Byrum Sp*				
Algae, mosses, lichen	Species non-specified	Metal elements	Terra Nova Bay	• Algae absorbed more elements compared to mosses • Macronutrients such as Ca, K and Mg were highly detected, followed by Na and Fe • Low concentration of Pb, Cu, Zn, Cd and Mo were detected	[46]
Lichen	*Lecanora aspidophora* *Mbilicaria propagulifera* *Stereocaulon glabrum* *Usnes sulphurea*	Chlorinated hydrocarbon (HCB, HCH isomers, DDT, DDE, PCB)	Antarctic Peninsula	Early studies to evaluate the level of tropospheric contamination in Antarctica	[47]
Moss	*Bryum algens* *Drepanocladus uncinatus* *Andreaea regularis*				
Lichen	*Usnea antarctica* *Usnea aurantiaco-atra*	PBDE	King George Island, Maritime Antarctica	Lichen and mosses accumulate similar amount of PBDE	[48]
Mosses	*Sanionia uncinata*				
Macroalgae	*Monostroma hariotii* *Phaeurus antarticus*	Metal elements	Potter Cove, King Goerge Island	Optimized technique using Inductively coupled plasma optical emission spectroscopy microvawe-assisted digestion procedure to identify potential species for biomonitoring was achieved	[49]

5.0 LIMITATIONS AND FUTURE PERSPECTIVES

In general, plants remove pollutants *via* rhizofiltration, phytostabilization, phytoextraction, or phytovolatilization. However, the success of phytoremediation process is determined by various factors, including plant species and the surrounding conditions.

Currently, studies focusing on phytoremediation in the Antarctic are scarce. However, the use of plants in various biomonitoring programmes in this continent has given positive indications on the potential of phytoremediation process to occur. As such, further investigation is needed to determine if vegetations in the Antarctic have the ability to convert pollutants into harmless compounds.

Phytoremediation process in the Antartic is limited mainly due to extreme surroundings and limited vegetations. Phytoremediation could be slower under certain circumstances and one of the factors is cold condition [50]. This is supported by Wright and co-workers who found that limited phytoremediation in low temperature can be enhanced at warmer temperature [51]. For plants, their root morphology could be influenced by soil temperature [52] hence their potential in bioremediation is compromized.

The behavior of compounds also depends on environmental condition. Under cold temperature, compounds such as petroleum can be easily solubilized in water and slowly evaporated [53]. Thus, the capabilities of microbes or plant-associated microbes to come into contact with these compounds are restricted. However, there are also some hydrocarbons that become less soluble in water at lower temperatures. Thus, greater biodegradation could be achieved due to less toxicity effects of these compounds with microbes in that area [54].

Advancement in microbial technologies offers alternatives for the microbial community to be applied in bioremediation. Microbes are more diverse in species and are adaptable to survive in extreme environment. It should be noted that phytoremediation process often includes microbes that are associated with plants. Vascular species have their own rhizosphere that anchors plant roots and soil to help in phytoextraction process. As in the temperate and the tropical region, Antarctica rhizosphere could be diverging from the rest of the soil. Rhizospheric bacteria have been isolated and identified from Antarctica flowering plant *Deschampsia antarctica Desv*. [55]. These microbial communities conceivably have certain capacity in phytoremediation, although further investigation is needed.

Besides microbial assistance, addition of certain non-harmful chemicals is another way to improve phytoremediation process. As an example, the capacity of plants to absorb metals is decreasing at higher metal concentrations due to the saturation of metal binding sites [56]. In this case, metal chelation could be improved by applying suitable pretreatment with chemicals that help to increase biosorption capacity of metal ion [57, 58]. Kumar and Gaur (2011) in their work also proved that chemical pretreatment increase metal binding capacity due to increasing crosslinking between polymer chain of the exopolysaccharides [59]. Not only alkaline solution, acidification using HCl could also increase metal chelating capacity [60, 61]. This is however, required further investigations as the methods are currently applicable to phytoremediation using plants in the temperate region.

Differences in mechanisms of pollutant uptake for vegetations in harsh condition and temperate region create huge challenges for researchers to understand the issues. Nonetheless, it is interesting to explore the pathways involved using various molecular and biochemistry techniques. Available basic information from phytoremediation studies conducted in temperate region could act as the step-stones for better approach to be used in the Antarctic. In future, suitable genes or enzymes for pollution remediation, whether from the tropics to cold temperature area or vice versa could probably be transferred via advanced techniques to improve the vegetations for phytoremediation purposes.

Due to the survival of several alien species in the Antarctic, the introduction of non-indigenous plants to colonize this vicinity might help in phytoremediation. However, this is subjected to the suitability and regulations as non-indigineous species and transgenic plants might cause negative impacts to the present environment. Overall, collaboration among scientists with various expertise including geologists, ecologist, biologist, chemist and other related field is required.

6.0 CONCLUSION

To conclude, more studies are needed for phytoremediation technique to be effectively implemented in this continent. If this is a success, it will benefit human and the environment as pollutants can be removed in cleaner and cheaper way. Taken as a whole, prevention is always better than cure. Perhaps rules and regulations on environmental issues need to be strengthened to ensure Antarctica will not be further deteriorated with pollutants from its locality or other parts of the world.

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