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Oil Pollution in the Antarctic Terrestrial Environment

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Abstract: Fuel oil has been extensively relied upon as an energy source since the earliest discovery and exploration of Antarctica. During this time oil spills have occurred, particularly around established research stations, which have had a negative impact on the terrestrial environment. Recently developed bioremediative technology, using indigenous Antarctic hydrocarbon-degrading bacteria, may be used to assist in cleaning up existing oil-contaminated land.

Zusammenfassung: Seit der frühesten Entdeckung und Erforschung der Antarktis sind Öltreibstoffe die am häufigsten genutzte Energiequelle. Während dieser Zeit sind Ölunfälle mit negativem Effekt für die terrestrische Umwelt immer wieder passiert, besonders im Umfeld der Forschungsstationen. In jüngerer Zeit entwickelte Sanierungstechnologien unter Verwendung Kohlenwasserstoffe abbauender antarktischer Bakterien können bei der Reinigung Öl kontaminierter terrestrischer Bereiche eingesetzt werden.

INTRODUCTION

Throughout the last century, fuel oil has been the dominant natural energy resource responsible for man's survival, successful exploration and scientific discovery in Antarctica (PLATT et al. 1981). Oil permits efficient transport to and within Antarctica, facilitates the construction and maintenance of research stations run by national operators and, either directly or indirectly, powers the scientific equipment used by researchers. Land-based tourism has increased in recent years, and the infrastructure provided by Antarctic tourism companies also depends on oil. As human presence increases in the Antarctic terrestrial environment, so does the opportunity for oil spills. When oil spills occur, whether in the form of diesel (marine diesel oil), paraffin, avtur, petrol, engine oils or lubricants, the pristine and often barren nature of the Antarctic terrestrial environment makes the pollution even more noticeable.

This paper provides a brief introduction to oil pollution in Antarctica and describes recent bioremediation research which could be used to clean up polar oil-spills.

OIL SPILLS IN ANTARCTIC TERRESTRIAL ENVIRONMENTS

Oil can have negative impacts on the local environment if it is not adequately contained and managed. The impact will depend mainly on the size of the spill:

• Minor spills (<1 litre) are common throughout Antarctica during vehicle and aircraft refuelling. Often these spills are unnecessary and could be avoided if operators were more careful.

• Medium size spills, though less common, may be caused by puncture or corrosion of 200 litre fuel drums, fuel leaks from vehicles or spills during bulk fuel tank refilling (KERRY 1993).

• Large spills are comparatively rare in Antarctica. The largest spill reported in Antarctica occurred as a result of the sinking of the "Bahia-Pariaso" (KARL 1992, JANIOT et al. 2003). During this time 600,000 litres of petroleum were released into the sea at Arthur Harbour. In 1989, a spill occurred on Williams Field on the Ross Ice Shelf, 13 km from McMurdo station (WILKNESS 1990). Fuel in several bladders leaked due to valve failure resulting in a spill of 260,000 litres. During the subsequent clean up, 100,000 litres of fuel were recovered, with the rest soaking into the snow and ice and eventually calving off into the sea. Large-scale oils spills in the Antarctic terrestrial environment are rare. However, as the numbers of people visiting and working in Antarctica increase, and associated energy requirements also increase, oil spills may become more common.

Spills in different terrestrial environments

The majority of Antarctic research stations are situated on ice-free coastal areas to allow for easier station construction and re-supply by ship. Terrestrial oil spills tend to be found at sites of significant human activity, either currently or in the past (CRIPPS & SHEARS 1997). Some research stations have been continuously occupied for more than 50 years (e.g. McMurdo Station). Oil spilled during that time may accumulate to produce significant impacts on terrestrial ecosystems. Most research has focused on bacterial populations, whose numbers may increase with the addition of hydrocarbons, but overall microbial biodiversity may decline (SAUL et al. 2005). Hydrocarbon spills may also alter fungal diversity. KERRY (1990) found that *Hormoconis resinae* was only found associated with sites of recent oil spills, while *Geomyces pannorum* and *Thelebolus microsporus* were less common in contaminated soils. Little information exists on the impact of hydrocarbon contamination on terrestrial Antarctic plant, micro-invertebrate, algal and protist communities.

Following an oil spill, the low molecular weight volatile fractions quickly evaporate, leaving high molecular weight aliphatic, aromatic and poly-aromatic hydrocarbons (PAHs) (GREEN et al. 1992, AISLABIE et al. 1999). This heavier fraction may stain the rock and soil or sink below the ground surface and pool in depressions above the permafrost. Annual flushing of the soil by melt water may remove some of this residue, but this effect is unlikely to be uniform, resulting in variable oil contamination across an impacted site (PETTERSSON & NOBES 2003).

A small number of stations are constructed on ice shelves

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(e.g., Halley and Neumayer research stations) or on the polar ice cap (e.g., Vostoc or Amundsen-Scott station). If oil spills occur in these areas, the oil may sink through the surface snow or through fissues in the ice making recovery or clean up impossible.

Oil spill prevention and clean up

Under the Protocol on Environmental Protection to the Antarctic Treaty operators are obliged to clean up contaminated sites (ATCP 1991, Antarctic Treaty Consultative Parties, Annex III to the Protocol on Environmental Protection to the Antarctic Treaty,). However, it is less expensive - and better for the environment - to prevent oil spills in the first place, rather than undertake costly oil spill remediation. Steps may include:

- adequate bunding of fuel tanks;
- good levels of staff training (most oil spills are a direct result of human error);
- the production of emergency oil spill protocols;
- good maintenance of oil storage facilities;
- increased energy efficiency in research stations, thereby reducing the requirement to store large quantities of oil in Antarctica;
- better use of technology, so that more science can be performed by fewer people, thereby allowing research stations to be smaller or shared by nations.

Regrettably, even thorough precautions fail and oil spills do occur in Antarctica. Physical methods to clean up terrestrial spills include the use of absorbent pads (for small spills) and the containment and removal of contaminated soil. Removal of oil-contaminated snow is technically difficult and prohibitively expensive due to the remote location of stations constructed on snow and ice (Aislabie et al. 2004). In addition, annual snow accumulation often results in fuel storage tanks being buried beneath the snow surface. In these confined spaces, any spills may be difficult or dangerous to access for clean-up purposes. Polluted ice and snow may be put into containers and, following melting, the oil may be decanted off. Cleaning up oil spills is hazardous work and can result in inhalation of hydrocarbon fumes and skin irritation; appropriate personal protective equipment is required. Equally hazardous is the risk of combustion, which may be a greater danger in poorly ventilated areas.

The British Antarctic Survey co-ordinates an annual oil spill response course open to personnel from other Antarctic Treaty nations. This has been running since 1992, and has been attended by representatives from nine different nations.

The environmental impact of terrestrial oil spills

When oil is spilled in terrestrial environments it can affect the soil physical properties, chemistry and biology.

Physical properties

Oil-contaminated surface soils can trap more heat (due to decreased surface albedo) and may display greater hydrophobic properties than non-polluted soils (Balks et al. 2002).

Chemistry

Antarctic soils generally contain low amounts of organic carbon (Arnold et al. 2003) and oil contamination can increase the levels. However, while attempting to degrade hydrocarbons, indigenous oil-degrading microorganisms may deplete the soil of other nutrients, such as nitrate (Stallwood et al. 2005).

Biology

Oil spills generally have a negative impact on soil biodiversity. Nevertheless, most soils, including those in Antarctica, contain bacteria that can tolerate high concentration of hydrocarbons and some may even be able to degrade aliphatic and aromatic hydrocarbons (Aislabie et al. 1998). Following an oil spill, hydrocarbon-degrading bacteria may increase dramatically in number, and may become a major proportion of the total culturable microbial population (Delille 2000). Despite this, natural remediation by Antarctic soil microorganisms is slow due to low availability of liquid water, lack of nutrients to support microbial growth and low temperatures that reduce bacterial metabolic rates (Ferguson et al. 2003a,b). Nevertheless, indigenous Antarctic hydrocarbon-degrading microorganisms are often the best adapted to the environmental conditions. As such they may be good candidates for human-assisted microbiological clean up of oil spills (bioremediation). In addition, the Antarctic Treaty legislates against the introduction or release of non-indigenous species, therefore commercially available bioremediation bacteria isolated from other locations cannot be used in Antarctica (ATCP 1991, Annex II to the Protocol on Environmental Protection to the Antarctic Treaty).

BIOREMEDIATION

Following an oil spill, several options are available to increase rates of in situ bioremediation of oil spills:

- Hydration: addition of liquid water to facilitate increased microbial metabolic activity;
- Biostimulation: addition of fertilisers to increase the assimilation and mineralisation of oil-derived organic carbon by microorganisms;
- Bioaugmentation: addition of specifically isolated hydrocarbon-degrading bacteria that have been cultured in the laboratory *ex situ.*

To use microorganisms to remediate oil spills requires a detailed knowledge of local soil moisture, hydrophobicity, temperature and microbial activity (Aislabie et al. 2001). Pristine Antarctic soils generally contain low numbers of hydrocarbon-degrading bacteria within the natural soil community (Bej et al. 2000, Baraniecki et al. 2002, Delille et al. 2004). Preliminary experiments, performed in the laboratory by Stallwood et al. (2005), have shown the potential benefits of human intervention in increasing hydrocarbon degradation rates in Antarctic soils through hydration, biostimulation and bioaugmentation. Oil was added to aseptically sampled pristine Antarctic soil from Signy Island, South Orkney Islands (60°45’ S, 45°36’ W) and the rate of hydrocarbon degradation (C16–C20), relative to phytane, was monitored using gas chromatography and mass spectroscopy over an 18 weeks period (Fig. 1). The experiment was performed at 4 °C, which is a typical summer air temperature in maritime

Antarctica (ARNOLD et al. 2003):

- When only oil and soil were combined, no significant oil degradation was observed over the 18-week period of the experiment (data not shown).
- Addition of water to the soil and oil (Fig. 1a: hydration) caused a ~25 % reduction in hydrocarbon concentration, although this took more than seven weeks to become evident. The water may have facilitated metabolic activity and reproduction of the hydrocarbon-degrading bacteria already in the soil. Bacterial numbers may only have increased enough to cause a significant degree of hydrocarbon degradation after seven weeks. Hydrocarbon degradation may have effectively stopped after this time due to a lack of nutrients (e.g., bioavailable nitrogen or phosphorous).

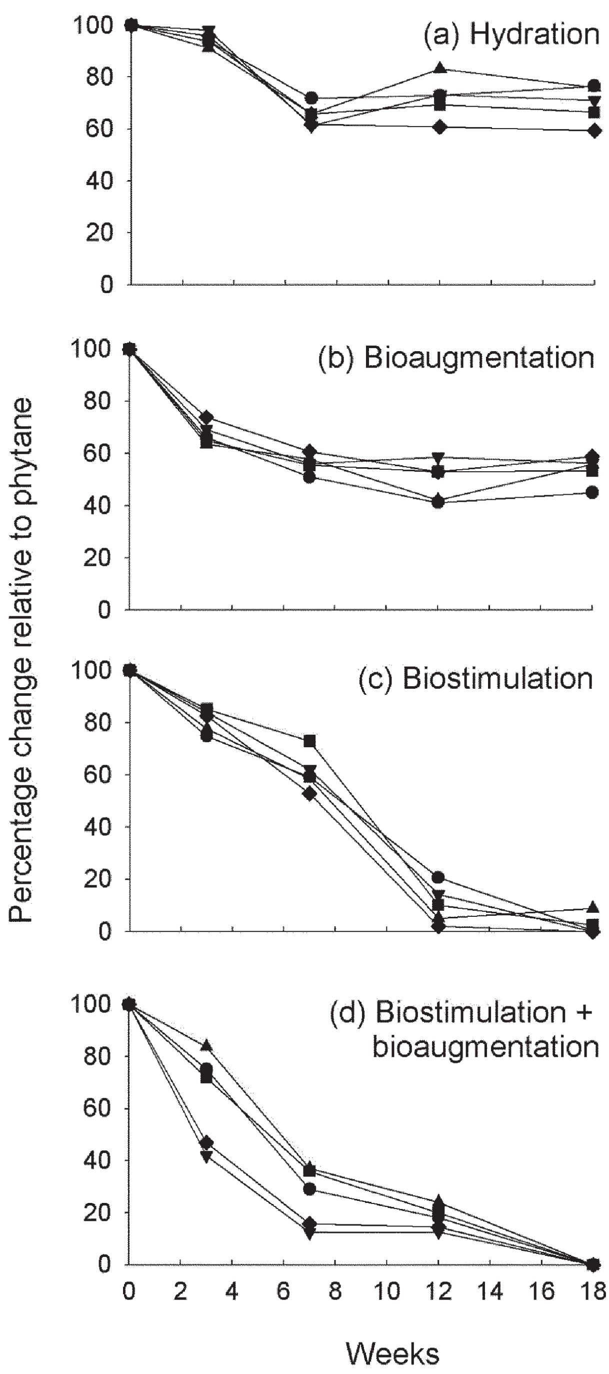

Fig. 1: Changes in alkanes C16 (●), C17 (■), C18 (▲), C19 (▼) and C20 (◆) relative to phytane (100 %) in soil microcosm experiments under different treatments: (a) hydration (oil plus water), (b) bioaugmentation (oil plus *Pseudomonas* ST41), (c) biostimulation (oil plus nutrients) and (d) biostimulation and bioaugmentation (oil, nutrients and *Pseudomonas* ST41). The ratio at time 0 was taken to be 100 %.

Abb. 1: Veränderungen der Alkane C16 (●), C17 (■), C18 (▲), C19 (▼) und C20 (◆) relative zu Phytan (100 %) in boden-mikrobiologischen Experimenten bei unterschiedlicher Behandlung: (a) = Öl + Wasser, (b) Öl + *Pseudomonas* ST41, (c) = Öl + Nährstoffe und (d) = Öl + Nährstoffe + *Pseudomonas* ST41. Das Verhältnis zum Zeitpunkt 0 wurde als 100 % definiert.

- During previous work, Signy soil was screened for hydrocarbon-degrading microorganisms. A *Pseudomonas* strain (ST41) was isolated that could degrade a wide range of hydrocarbons at 4 °C, including naphthalene and phenol. Addition of laboratory cultured *Pseudomonas* ST41 (bioaugmentation) to the soil and oil caused a ~45 % decline in hydrocarbon concentration. The initial rate of oil degradation was faster than the hydration treatment (Fig. 1a) due to the higher number of hydrocarbon bacteria (i.e. the small number of indigenous soil bacteria, plus the added cultured *Pseudomonas* ST41) available to degrade the oil. However, as with the hydration treatment, oil degradation effectively halted after seven weeks, again probably due to a lack of nutrients.
- The effect of adding nutrients (biostimulation) to the soil and oil can be seen in Figure 1c. The initial rate of oil degradation was low, probably due to the small numbers of hydrocarbon-degrading bacteria in the soil, but after 18 weeks the oil had been almost completely degraded. It took more than three weeks for the indigenous hydrocarbon degrading bacterial population to reproduce to a level where significant oil degradation could occur. However, after this, the nutrients facilitated almost complete assimilation of the C16-C20 hydrocarbons by the indigenous soil bacteria.
- Figure 1d shows the effect of combining bioaugmentation and biostimulation on hydrocarbon degradation. Combining the treatments produced the most rapid and complete degradation of the oil. The addition of *Pseudomonas* ST41 allowed rapid degradation to occur almost immediately, which was enhanced by the presence of sufficient nutrients to permit complete oil degradation by week 18.

This work shows that in the future, the use of bioremediative techniques, where nutrients and known hydrocarbon-degrading micro-organisms are added to contaminated soil, may be more efficient and cost-effective at clean up oil-contaminated land than more expensive and disruptive removal strategies.

SUMMARY

- The energy required for the majority of man's activities in Antarctica are supplied by combustion of fuels derived from oil.
- Oil spills in the terrestrial environment can have significant impacts on the physical and chemical properties of Antarctic soils and have long-term negative impacts on soil biological ecosystems.
- Oil spills are preventable and many steps can be taken to reduce the likelihood and environmental impact of spills. Generally, it is less expensive, and better for the environment, to prevent oil spills in the first place, rather than undertake costly oil spill remediation.
- Despite precautions, oil spills do occur, often leading to

long-term contamination of terrestrial and marine environments.

- Antarctic hydrocarbon-degrading bacteria have the potential to be used in bioremediation of oil-contaminated land.

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