ECOLOGICAL RISK ASSESSMENT AT A NORTHERN HISTORICAL SITE – FORT CONGER, ELLESMERE ISLAND

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ABSTRACT

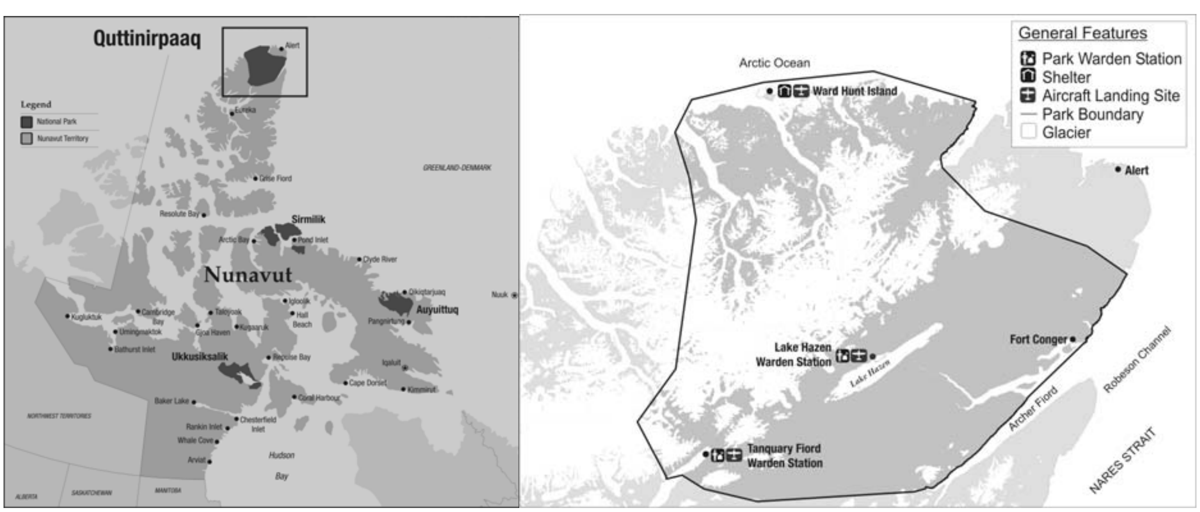
Fort Conger is located on the shores of Discovery Harbour in Quttinirpaaq National Park (QNP) on northeastern Ellesmere Island. Historically, the site was used as a base by a number of Arctic expeditions and is an important cultural resource. Building remains and artifacts from the exploration era are still found on site. However, environmental site investigations have identified surprisingly high levels of inorganic contamination, with the most widespread contaminants being arsenic, copper, lead and zinc. Likely sources of these contaminants include arsenic trioxide used to preserve natural history specimens; mercury from weather recording instruments; lead from tin can solder; and copper and zinc from batteries.

The Environmental Sciences Group is working with Parks Canada staff to develop a remediation plan for the site that is protective of the environment, but also takes into consideration the historical significance of the site. This paper will discuss legacy issues potentially associated with historical sites, and the approach used at Fort Conger to determine remediation targets. The challenges of conducting an ecological risk assessment at a unique arsenic-contaminated Arctic site will also be discussed as will the inclusion of novel risk assessment approaches (bioaccessibility).

SITE DESCRIPTION AND BACKGROUND

Fort Conger is located in Quttinirpaaq National Park on northeastern Ellesmere Island at latitude N 81˚ 45.13' and longitude W 64˚ 49.56' (Figure 1). The nearest community on Ellesmere Island (Grise Fiord) is located more than 800 km to the south, while Canadian Forces Station Alert is approximately 100 km to the northeast. Fort Conger is situated approximately 10 m from the ocean on the east side of Discovery Harbour, with a steep bank (2.5 m high) leading from the site to the ocean. Access is generally only possible by helicopter or by Twin Otter, with a landing strip located about a kilometre from the site. Due to the extreme remoteness of the site, human visitors are rare.

Figure 1: Map of Quttinirpaaq National Park, located on the northeastern tip of Ellesmere Island in the Canadian Arctic.



Climatically, Fort Conger is located in a polar desert, with low annual precipitation (60 mm) and low temperatures year round. The mean daily temperature for January through March at nearby Alert is -33˚C, with a record low of -50˚C (EC 2005). In July, the mean daily maximum temperature is 6˚C with a record high of 20˚C; Alert has only 20 to 30 frost-free days per year. Permafrost studies at Alert have shown that permanently frozen ground exists to a depth of at least 480 m below the ground surface (Gray 1997). The active layer, which is the layer of surface soil that thaws each summer, is less than 1 m deep in most places. The bank adjacent to the Fort Conger site is actively eroding due to permafrost degradation processes and tidal activity.

Historical activities at Fort Conger have led to a rich heritage of cultural resources at the site. Fort Conger was used as an over-wintering base by a number of Arctic expeditions, most notably the Greely expedition (Lady Franklin Bay Expedition), which established a semi-permanent scientific research camp here from 1881 to 1883. The foundations of a house built by the Greely expedition, as well as artifacts and debris from this era, may still be found on the site (Figure 2). Three wooden huts constructed from the materials of the Greely house by explorer Robert Peary in 1900 are still standing (Figure 2). Because of its historical significance and wealth of artifacts, Fort Conger is protected and monitored by Parks Canada.

Significant contamination by inorganic elements (especially arsenic, copper, lead, and zinc) and PAHs (polycyclic aromatic hydrocarbons) exists at Fort Conger (ESG 2006). Contamination by inorganic elements is widespread and focussed mainly on the area around the Greely house foundations. There is clear evidence for uptake of inorganic contaminants (arsenic, copper, lead, and zinc) into plants growing on the site. In 2006, deposits of pure arsenic trioxide powder were found on site. This is a highly toxic and soluble form of arsenic that appears to have disseminated widely around the site through dust transport, leading to a footprint of arsenic contamination centred on the Greely house foundation. The pure arsenic powder was excavated and containerized in 2007, but several hotspots of highly arsenic-contaminated soils remain.

The significant pattern of contamination found at Fort Conger was initially unexpected, but illustrative of legacy issues that may be associated with a historical site. The presence of pure arsenic trioxide is unusual and appears to have led to some unique patterns of contaminant distribution at the site. Arsenic trioxide and mercury were likely used as preservatives for natural history specimens that were collected by the Greely expedition, as this was common practice at the time. High levels of copper are associated with blue stained areas on site consistent with a liquid source, and may have been from early battery prototypes used on site. The highest levels of lead were found adjacent to tin can debris and are suspected to have originated from lead solder used in the cans. Tar paper used to cover the Greely House and Peary cabins appears to be the main source of PAH contamination.

Figure 2: Aerial photograph of Fort Conger, showing the Greely house foundation (left) and Peary huts (upper right). (Photo credit: Tim Christie)

FORT CONGER: CHALLENGES AND APPROACH FOR MANAGEMENT

Fort Conger is a unique site with two guiding principles for management that must be balanced: the need to preserve ecological integrity while also minimizing disturbance to cultural resources. Given this and limited human presence at the site, a main objective for remediation plan development is to identify the minimum area of the site requiring remediation.

Managing the Fort Conger site will require an innovative and collaborative approach. In order to meet these challenges, a remediation working group composed of archaeologists, contaminants experts, and Parks Canada staff will guide decision-making. The group decided that a first step was to carry out an ecological risk assessment (ERA) for the site to identify the "hotspots" that must be remediated to protect its ecological integrity. Such an approach allows for identification of the minimum area on site for remediation; it is protective of the environment but minimizes site disturbance. Once the hotspots on site requiring remediation have been identified, it is anticipated that site remediation will occur in conjunction with an archaeological investigation to document cultural resources. Creating a virtual site record through laser scanning before any further ground surface alteration occurs is being considered.

A further challenge for management is the fact that the bank next to the Fort Conger site is actively eroding. Historical rates of bank erosion are being determined through air and satellite photo review, as well as previous records from the site. A monitoring program for bank erosion has also been established. The information from these studies will be used to determine which portion of the site may be at risk of erosion. The results from this program will be incorporated into remediation decisions.

ECOLOGICAL RISK ASSESSMENT

Receptor selection was based on several important factors. Because the nearest community, Grise Fiord, is more than 800 km away and harvesting activities are negligible, the cultural and economic significance of the receptors was not taken into account. As a result, selection of receptors was based on the following criteria:

- presence (abundance) on-site
- importance to the overall ecosystem (e.g. keystone species, rare species)
- susceptibility to potential contaminant pathways
- representation of a number of trophic levels.

Based on these criteria, the ecological receptors chosen were the collared lemming (*Dicrostynux groenlandicus*), Snowy Owl (*Bubo scandiacus*), Long-tailed Jaeger (*Stercorarius longicaudus*) and arctic fox (*Alopex lagopus*).

Arctic receptor sensitivity information is extremely limited. Because of this, receptor species were chosen based on their ecological significance and trophic level. Collared lemmings are a keystone species within QNP, as they are extremely important within the trophic dynamics of Ellesmere Island. In addition, as a primary consumer of plants, they are considered to be highly susceptible to contamination at Fort Conger. As secondary consumers, Snowy Owl, Long-tailed Jaeger and arctic fox represent higher trophic levels that are exposed to contamination via prey. Selection of these four receptors allows for an ERA that is representative of the risk that contamination at Fort Conger poses to the surrounding ecosystem.

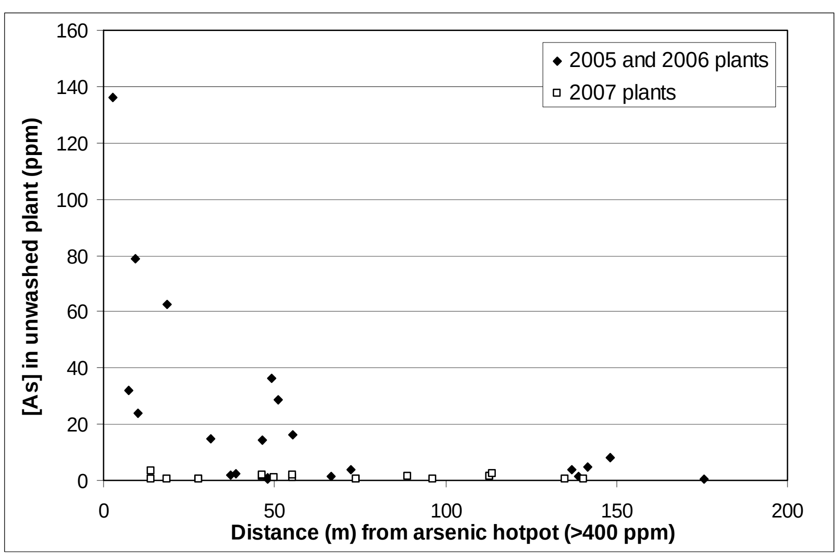
The presence of pure arsenic trioxide on the Fort Conger site, as well as naturally elevated background arsenic levels, gives rise to several challenges in determining realistic measures of ecological risk. Risk assessments have traditionally assumed that 100% of a contaminant ingested by a receptor is taken up by the receptor. However, this assumption is overly conservative: for example, previous studies in our group indicate that the bioaccessibility of arsenic from soil (i.e., the fraction liberated from soil passing through the digestive system) is typically less than 30% (Ollson, 2003; Reimer *et al.*, 2003). For Fort Conger, if it is assumed that 100% of the arsenic in soil and plant samples is taken up by receptors, both the background and site soil concentrations would be calculated as posing a risk to lemmings. In reality, bioaccessibility analyses for soil and plant samples from the site indicate that arsenic bioacessibility varies greatly depending on the arsenic form. For example, soil samples collected from close to the arsenic trioxide source had bioaccessibility levels averaging 61%, with a bioaccessibility of 100% for the arsenic trioxide source. Soil samples across the rest of the site were generally lower, with background soil samples showing a mean bioaccessibility of approximately 13%. Incorporation of bioaccessibility measures into risk assessments allows for a more realistic calculation of risk (see also Lord-Hoyle *et al.*, this issue).

Secondly, the arsenic trioxide source at Fort Conger appears to have spread across the site through dust transport. This has important implications for the calculation of current ecological risk through influencing contaminant concentrations in plants (the main component of a lemming diet and therefore the main determinant of ecological risk). The contribution of the arsenic trioxide dust source to arsenic concentrations in site plants was evaluated by dividing a plant shoot in two, washing one portion, and comparing arsenic concentrations in the unwashed and washed plant portions. Arsenic concentrations in unwashed plants growing close to the arsenic trioxide source were an order of magnitude higher than the washed plant portion. However, comparison of the arsenic concentrations in unwashed plants from 2005 and 2006 (collected in mid-season) with 2007 unwashed plants (collected in early season soon after snow melt; Figure 3) suggests that seasonal conditions influence dust transport and hence plant arsenic concentrations. These data suggest that arsenic plant concentrations will decline rapidly following the removal of the arsenic trioxide source, and that washed plant concentrations are appropriate for calculating future ecological risk.

A conventional risk assessment for Fort Conger based on soils and plants subjected to contaminant analysis indicates that copper and arsenic pose the greatest risk to lemmings (deemed the most sensitive ecological receptor), while nickel and mercury also show potential risk. Chromium, lead, zinc, and cadmium contamination on site do not appear to pose risk to lemming receptors. Organisms higher in the food chain, such as arctic fox, Snowy Owls, or Long-tailed Jaegers, also do not appear to be at risk from contaminants at Fort Conger given their large home ranges. Remediation is necessary because of the risk posed by some contaminants, the uptake of these contaminants into the terrestrial food chain, and the highly toxic form of arsenic present at Fort Conger.

A main objective for site management was to identify the minimum area of the site requiring remediation, as remedial activities will lead to irrevocable loss of cultural resources at Fort Conger. Spatial modeling was used to examine the effects of sequential removal of hotspots of contamination on ecological risk, following an approach used by Bennett *et al.* (2007). Incorporating spatial modelling into the risk assessment indicates that remediation of the two arsenic hotspots of soil >400 ppm would reduce ecological risk to acceptable levels. Because the highly elevated copper concentrations (>5000 ppm) are confined mostly to small stains, these soils may be left in place without significant ecological effects on lemming receptors, which are assumed to forage equally throughout their home range.

Figure 3: Arsenic concentrations in unwashed plant shoots with distance from arsenic source.



Spatial modelling results in a more realistic measure of ecological risk compared with conventional methods, as it takes into account variability in soil concentrations throughout a receptor home range. An advantage of this technique is that it can be used to identify a minimum area of the site for remediation. This is important at a site such as Fort Conger, where minimizing disturbance is crucial to preserve cultural resources, and where logistical and cost constraints greatly limit site remediation activities. However, a trade-off of the spatial modelling approach is that it requires intensive sampling and analysis to provide good spatial coverage of soil and plant contaminant concentrations across the site. This level of effort may not be justified at many sites, where a conventional risk assessment may be adequate.

CONCLUSIONS

Site investigation work at Fort Conger highlights the fact that historical sites may have a significant legacy of associated contamination. The unique features of Fort Conger, particularly the presence of arsenic trioxide, have led to an unusual pattern of contamination around the site that provides challenges for risk assessment. Novel approaches such as incorporating bioaccessibility and spatial modeling into the risk assessment enable a more realistic measure of ecological risk.

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