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Assessment of risks from environmental contamination to endangered species at remote lightstations along the Pacific coast of Canada.

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Abstract

The Canadian Coast Guard is assessing the potential environmental impacts of contamination at 27 remote lightstations on the British Columbia coast. British Columbia has about 25,000 km of shoreline including thousands of islands, most of which are accessible only by boat or helicopter. The lightstations, which have been in use for up to 140 years, essentially consist of industrial installations maintained by resident lightkeepers in settings of otherwise pristine coastal wilderness. The region is a hotspot of biological diversity. Previous studies had shown that heavy metals and petroleum hydrocarbon concentrations in surface soils exceeded provincial and federal environmental standards and guidelines at these stations. Contaminant sources include the historical use, degradation and dispersion of heavy metals based paints, waste dumping and incineration, and bulk petroleum hydrocarbon storage and transfer. This paper presents a study used for assessing potential impacts to endangered species and habitat elements from direct (contact) and indirect (food chain) exposure to the environmental contamination.

An initial search of endangered species and habitat element records identified over 300 occurrences in marine and terrestrial environments among the sites. Variability in the extent and magnitude of contamination, anticipated transport and fate of contamination, and the distribution of sensitive receiving environments, including the presence of rare species, provided a basis to prioritise 14 lightstations for field study. The subsequent field investigations consisted of a qualitative habitat survey and collection of environmental samples of relevant exposure media (e.g., soil, plant tissue, soil invertebrate tissue, groundwater, surface water, and mussel tissue) for chemical analysis. Measured concentrations in exposure media were then input into a food chain

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model to determine the probable degree of contaminant exposure for a range of indicator species. The results of the qualitative field surveys and modeling were incorporated into an ecological risk assessment. The assessment concluded no risks for rare plant species and potential risks for only one rare animal, a subspecies of ermine. Populations of common insectivorous birds and small mammals may also be at risk. These risks are predicted using conservative model parameters and further studies are planned to quantify risks.

1 Introduction

The Canadian Coast Guard is assessing the potential environ-mental impacts of contamination at its lightstation properties along the British Columbia coastline (Mann et al., 2001[1]). This study, known as an ecological risk assessment, required a review of rare and endangered species and habitat elements in or near the subject sites. The assessment includes species and subspecies on provincial red, blue or yellow lists (see Methods), and certain rare natural features such as plant communities and record-sized trees; for convenience, these are collectively referred to herein as simply "rare species."

Twenty-seven staffed lightstations (a number of others have been automated) are spread out along 25,711 kilometers of shoreline (Figure 1). The sites are the focus of capital upgrading, including addressing environmental liabilities, by the Coast Guard.

Previous investigations had revealed the following common environmental contamination issues:

- dispersed heavy metals with no specific locus, mainly from historical use, abrasive blasting, natural degradation, and dispersion of heavy metals based paints,;
- heavy metals and/or petroleum hydrocarbons associated with waste incineration and dumps; and,
- petroleum hydrocarbons associated with leaks and spills from bulk fuel storage and transfer.

Given the high cost of clean-up at these remote locations and their sensitive environmental setting, an ecological risk assessment was undertaken to determine the potential effects of contamination on the natural environment (a separate project dealt with related human health concerns).

In this phase of the project we:

1. inventoried and mapped rare species that occur near staffed lightstations;
2. ranked the rare species according to their conservation status and vulnerability to contaminants at the lightstations;
3. ranked the lightstations according to the severity of contamination and vulnerability of rare species;
4. surveyed the top 14-ranked lightstations to (a) make qualitative observations of marine and terrestrial communities and habitat, (b) verify the presence, within reasonable exposure routes, of rare

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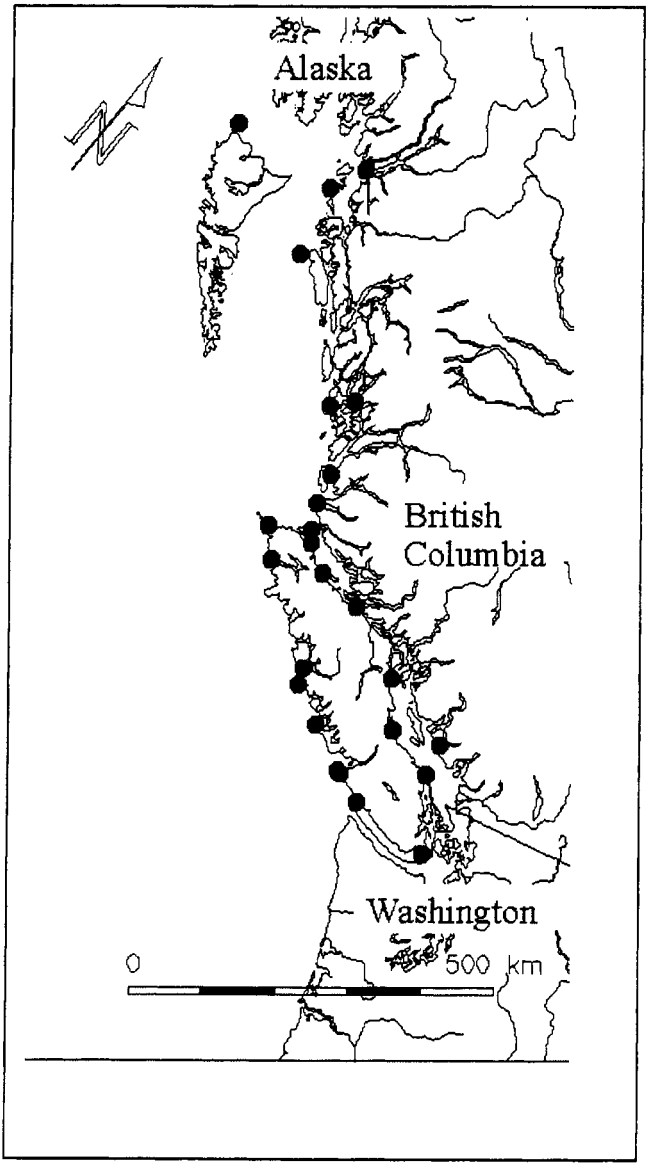
species and (c) collect samples of environmental media and food items along potential exposure routes; and,

5. modeled contaminant uptake to (a) eliminate those rare species that are not reasonably vulnerable to toxicity associated with exposure and (b) identify those rare species/contaminant issue/lightstation combinations where remedial action may be considered.



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2 Study Area

The coastal region is a North American center of biological diversity (Harding and McCullum, 1994[2]). From just beyond the city of Vancouver to Alaska – about 840 km in a straight line but encompassing 25,711 km of coastline, including islands – only three roads reach the mainland coast. The mainland contains the largest blocks of unlogged temperate, old-growth forest on the planet. The mainland and the larger islands are home to grizzly bears (*Ursus arctos*), rare blue and white varieties of black bear (*Ursus americanus*), rare subspecies of wolves (*Canis lupus*) and the densest population of cougars (*Puma concolor*) anywhere. The marine waters are oxygen- and nutrient rich. The tidal surges at the numerous narrow fjord entrances and between islands encourage the development of extremely diverse and abundant attached invertebrate and benthic invertebrate communities. The largest octopus species and the largest sea star species in the world occur here. The productive marine environment supports and provides refuge for vertebrates including gray, killer, humpback and other whales; sea lions and seals; sea otters; and millions of colony-nesting seabirds. The estuaries support shorebird populations of hemispheric importance during migration. Much of the area is biologically unknown; nearly every botanical and zoological survey reveals new species.

3 Methods

3.1 Inventory of rare and endangered species and habitat elements

The Conservation Data Centre (CDC) of the British Columbia government maintains a database of all known occurrences of rare and endangered species and rare habitat elements throughout the province. The conservation status assignments, based on standard criteria developed by The Nature Conservancy and the Association for Biodiversity, considers both global and provincial rarity. The assignments result in red (extirpated, endangered, or threatened), blue (vulnerable to becoming red-listed if the factors causing their decline or low numbers are not reversed) and yellow (neither red nor blue listed but of special management concern) lists.

Using a GIS, CDC staff provided us with maps and a database of all known occurrences within 10 km of each of the 27 lightstations. These records were cross-referenced with complete provincial red and blue lists and the federal COSEWIC (Committee on Status of Endangered Wildlife in Canada) list and supplemented with reference to the literature on certain insular species and subspecies distributions to make a complete list of possible occurrences on or near lightstation properties.

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3.2 Prioritization and development of conceptual exposure model

3.2.1 Prioritizing rare species

Rare species occurrences at the lightstations were prioritized on the basis of:

1. High: Red-listed and occurs on or adjacent to the property.
2. Medium: Red-listed and occurs within 10 kilometre of the lightstation; or blue-listed and occurs on or adjacent to the property.
3. Low: Blue-listed, occurs within 10 kilometre of the lightstation; or not listed but of special management concern and occurs within 10 kilometre of the lightstation.

3.2.2 Development of conceptual exposure model

We developed conceptual exposure models to describe potential sources, exposure pathways and receptors at the lightstations. Examples include:

- contaminants in soil ⇒ soil invertebrates ⇒ insectivorous birds and mammals ⇒ predaceous birds and mammals;
- contaminants in soil ⇒ plants (berries and grass) ⇒ herbivorous birds and mammals ⇒ predaceous birds and mammals; and,
- contaminants in soil ⇒ groundwater ⇒ marine surface water ⇒ mussels ⇒ predaceous birds and mammals.

The conceptual exposure model was used to plan and focus future assessment efforts.

3.2.3 Prioritizing the lightstations

Using both the large-scale maps of rare species occurrences and the small scale site plans of contaminant distribution at each lightstation, we prioritized the stations for on-site investigation. The prioritization was based on the presence of rare species, severity of heavy metal and petroleum hydrocarbon contamination and the existence of probable exposure pathways. Evaluation of exposure pathways included a consideration of physico-chemical properties of each contaminant, physical features of the sites in relation to contaminant loci, biological transformation processes, and food chains. This resulted in a list of 14 lightstations for on-site investigations.

3.3 Field investigations

At each of the 14 lightstations, we searched the property and adjacent forest and intertidal environments in the areas of contaminant loci and physical dispersal pathways (such as obvious watercourse, subsurface water percolation, downwind of paint chip sources) to (a) make qualitative observation of community fitness, (b) identify any rare species or their habitats, and (c) identify (or further refine) exposure pathways such as surface drainages and seepages. In terrestrial environments, we collected samples of soil, grass

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clippings, earthworms and berries from previously identified contaminated areas. In marine environments, we collected mussel (*Mytilus californianus*) samples at locations of surface runoff or subsurface seepage in intertidal zones below previously identified contaminated areas. Mussel samples were also collected from a suitable reference location. The samples were submitted to a laboratory for chemical analysis.

3.4 Modeling contaminant pathways, uptake and potential toxicity to indicator species

Laboratory analysis quantified contaminant concentrations in food items. These data were used in a food chain model to predict potential adverse effects to higher trophic level organisms. As with other aspects of ecological risk assessment, food chain models are constructed iteratively. Models are initially parameterized making conservative assumptions and refined when unacceptable risk is predicted. The model presented is primarily a screening level model. Areas of possible refinement will be identified and recommended.

The model calculations follow the Oakridge National Laboratory (ORNL) approach (Sample et al. 1994[3], 1996[4] and 1998[5]). Most of the input parameters were derived from the ORNL guidance, the wildlife exposures handbook (USEPA 1993[6]) and ATSDR web page (ATSDR 2002[7]); however primary literature was also consulted when required. The model algorithms were constructed in Excel using multiple worksheets to organize and differentiate input parameters and formulae.

The model uses literature-based life history parameters and site-specific concentrations of heavy metals and metalloids and petroleum hydrocarbons in various environmental compartments (soil, soil invertebrates, grass and berries) to estimate contaminant uptake for a suite of selected indicator species. The primary life history parameters used in the model, which are adjustable to account for known site- or species-specific differences, are:

- Dietary preferences (percent of grass, berries, invertebrates, small mammals and bivalves); and,
- Receptor-specific data including body weight; ingestion rates for water, soil and food; and foraging range.

The indicator species used in the model were selected as surrogates to represent common trophic level/habitat/taxonomic group combinations along potential contaminant pathways, rather than specific species *per se*. The indicator species are often used in food chain modeling on the basis of their wide distribution in North America, their known biology and a greater availability of toxicological literature on closely-related taxa. The indicator species selected for terrestrial environments were:

- White-footed mouse, *Peromyscus* spp., represents herbivorous small mammals of wooded habitats

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- Short-tailed shrew, *Blarina* spp., represents insectivorous small mammals
- Meadow vole, *Microtus pensylvanicu*, represents herbivorous small mammals of meadow habitats
- Cougar, *Puma concolor*, represents large carnivores that, in the study area, prey primarily on deer
- Red fox, *Vulpes fulva*, represents medium-sized carnivores that prey on small mammals
- White-tailed deer, *Odocoileus virginianus*, represents medium-sized herbivores.
- Red-tailed hawk, *Buteo jamaicensis*, represents avian predators of small mammals
- American robin, *Turdus migratorius,* represents insectivorous birds that prey on earthworms in lawns and other open habitats

For marine environments, the indicator species selected were:

- River otter, *Lutra canadensis*, represents mammalian carnivores that prey on fish and intertidal organisms
- Black oystercatcher, *Haematopus palliatus*, represents avian carnivores that prey on intertidal organisms, mainly mussels

The model outputs intermediate calculation results and final hazard quotients (HQs). HQs are quantitative estimates of the relative magnitude of potential ecological risks. HQs were calculated by dividing the modeled exposure (or dose) by a toxicity reference value (TRV): the maximum dose not associated with unacceptable adverse effects. Two TRVs were calculated for each contaminant/indicator species pair: (1) the lowest observed adverse effects level (LOAEL), which represents the lowest concentration at which adverse effects were observed in the database of chronic, sublethal toxicity assays; and (2) the no observed adverse effects level (NOAEL), which represents the highest concentration at which no adverse effects were observed in any chronic, sublethal toxicity study. LOAEL-based TRVs are considered appropriate for protection of populations of organisms against significant toxicological impacts; this benchmark is considered an appropriate level of protection for non-threatened species. NOAEL-based TRVs are considered appropriate for protection of individual organisms against significant toxicological impacts; this benchmark is considered an appropriate protection level for rare species. Ecological risks are considered acceptable when the HQ is one or less, risks are considered low when the HQ is one to ten, and risks are considered moderate to severe when the HQ is over ten.

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4 Results

4.1 Rare and endangered species identified through the CDC database

The Conservation Data Center identified 321 rare species occurrences at 24 of the 27 lightstations including vertebrate animals, invertebrate animals, plant associations, and habitat elements in marine and terrestrial environments. The 321 occurrences included multiple occurrences of several species. The rare species and habitat elements identified included:

- In terrestrial environments including aquatic habitats: 11 rare plant communities, 4 record-sized trees, 55 vascular plant species or subspecies and 6 vertebrate species or subspecies.
- In marine environments including on-land nests or haul-outs of species that feed in marine environments: 14 invertebrate species or subspecies, 24 non-vascular plant species or subspecies and 10 vertebrate species or subspecies.

They were ranked as follows:

1. 23 rare species or plant associations that occur at 10 lightstations were provisionally designated as **HIGH** priority because they are red-listed and occur on or adjacent to the properties.
2. 12 rare species that occur at 8 lightstations were provisionally designated as **MEDIUM** priority because they are blue-listed and occur on or adjacent to the properties.
3. 166 rare species and plant associations are provisionally designated as **MEDIUM** priority because they are red-listed and occur within 10 kilometres of the lightstations.

The other 119 species and plant associations are considered **LOW** priority (blue-listed and not on or near the properties; or yellow-listed and either not on the property, or in a location that is not subject to exposure pathways). Low priority species were not considered further unless they were found, during on-site investigations, to be on the properties or near enough to be potentially exposed to contaminants.

4.2 Results of field investigations

Despite the number of potentially exposed rare species, few were identified whose physical distribution or habitats at the lightstations could make them actually vulnerable to contaminant exposure pathways. In terrestrial environments of the lightstations, the only species considered potentially exposed to contamination were:

- A rare subspecies of peregrine falcon (*Falco peregrinus pealei*) nested near two lightstations. These falcons

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occasionally prey on small birds of lawn/shrub environments, although their main prey is marine birds.

- Bald eagles (*Haliaeetus leucocephalus*) were nesting near most of the lightstations. Bald eagles may scavenge terrestrial carrion or garbage around lightstations, although they mainly use marine resources.
- A rare subspecies of ermine (*Mustela erminea anguinae*) occurred at one lightstation.
- Rare vascular plants occurred at several lightstations.

In marine environments, the species identified on site or along possible exposure pathways included:

- Peregrine falcons as noted above.
- Bald eagles as noted above.
- Colonies of rare species or subspecies of seabirds and cormorants (*Phalacrocorax spp.*) nested at several of the lightstations.
- Rare marine mammals including Stellar's sea lion (*Eumetopias jubatus*), sea otter (*Enhydra lutris*), gray whale (*Eschrichtius robustus*) and humpback whale (*Megaptera novaeangliae*) occurred at several of the lightstations.
- Rare marine algae (seeweeds) occurred at several lightstations.
- Rare marine invertebrates occurred at several lightstations.

These investigations documented previously unpublished range extensions both northward and southward of breeding colonies of sea otters and a range extension of a rare shrub (California wax-myrtle, *Myrica californiana*). It also resulted in new occurrence records of a number of rare marine mammals species (e.g., Stellar's sea lion, elephant seal [*Miraunga angustirostris*], gray whale and humpback whale) at certain lightstations where they had not been previously documented, but within their known ranges.

Results of chemical analysis for petroleum hydrocarbons had not been received at this writing and are not discussed further. Results of chemical analysis for heavy metals and metalloids in terrestrial and marine food items were input to the model.

4.3 Results of modeling

The results of the food chain model provide a basis to estimate the overall risks for each receptor/contaminant combination. In the terrestrial environment, heavy metals of concern with hazard quotients HQs>1 using the LOAEL-based TRVs were found for the following receptor/contaminant combinations:

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- American robin for chromium, cobalt, lead, mercury, selenium and zinc;
- Short-tailed shrew for arsenic, lead, mercury and selenium;
- White-footed mouse for arsenic and mercury

Based on these results, two key factors were identified as driving the risks to terrestrial receptors: 1) lead and mercury were found to pose substantially higher potential risks to receptors than any other contaminants; and 2) the overwhelmingly dominant exposure pathway contributing to potential risks was through the consumption of soil invertebrates - represented in the risk assessment by earthworms.

In the marine environment, heavy metal concentrations in mussels were not high enough to generate positive hazard quotients for the two indicator species (i.e., river otter and black oystercatcher).

4.4 Implications for rare and endangered species at lightstations

Of the 321 rare species occurrences identified, only one animal – the ermine subspecies – is on a contaminant uptake pathway, where the modeled contaminant exposure could make it vulnerable to heavy metal toxicity. This is because it preys partially on small mammals that may be accumulating mercury and arsenic at toxicologically relevant levels from soil invertebrates, grasses and berries. However, the current model does not include a surrogate receptor species that closely matches the ermine. If the fox model is used to assess risks to the ermine, no adverse effects are predicted. If the shrew model is used to assess potential risk to the ermine, potential adverse effects are predicted. A study of the impact of contaminants and potential soil remediation options on this weasel was recommended.

Other listed species occurring at or near the lightstations are not thought to be vulnerable to exposure for various reasons of habitat and food sources. Examples include the peregrine falcons, bald eagles and Rhinoceros auklets (*Cerorhynca momocerata*). These species nest near enough to known areas of contamination to be possibly exposed, but that feed exclusively, or nearly so, in the marine environment, eliminating the possibility of exposure through ingestion of grasses, seeds or soil invertebrates. Some rare plants are also present (e.g., California wax-myrtle); potential effects of contamination on plants were assessed qualitatively using habitat surveys. The qualitative habitat surveys revealed no observable signs of toxicity to marine intertidal and terrestrial plant communities. However, the presence of rare plants would be of particular importance for the consideration of various remediation options.

In addition to officially listed rare species, we identified a few other species or subspecies that are also of conservation concern. They include a number of insular and endemic small mammals whose taxonomy and distribution are

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poorly known and may be placed on endangered species lists when their taxonomic status is clarified. Insular and endemic species are more at risk to contaminants than widespread species because, in the case of a contaminant source on a small island, a much larger proportion of the population – or even the entire population – could be exposed.

5 Discussion

The results of the food chain model suggest lead and mercury contamination may result in potential adverse effects for populations of insectivorous birds and small mammals. Of the 321 rare species occurrences recorded, the study suggests that one animal, the ermine subspecies, may be affected. Further study will be required to validate or refute the model predictions.

Environmental risk assessment is an inherently iterative exercise. Conservative assumptions are used in the initial rounds of assessment. This is done to minimize the possibility of underestimating risk. As the scope of potential risk is reduced, additional data is collected to reduce the assessment uncertainty and the consequent need to rely on conservative assumptions. The results of this study have allowed us to rule out risks from environmental contamination to the vast majority of plants and animals at the Coast Guard lightstations. For those animals that are still in question, the study has allowed us to focus future work on the key drivers of potential risk – consumption of lead and mercury contaminated soil invertebrates by small mammals and birds. If future studies conclude that the contamination is having toxic effects on these animals, the impacts of these effects will have to be considered in the context of potential impacts to the natural environment from clean-up activities.

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