

Animals as Sentinels for Public Health Risks Associated with Oil and Gas Development

A Primer for Environmental Health Professionals

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Executive Summary

Forecasted growth in Canada's oil and gas production and accompanying public concern is creating a need to better understand the health impacts of this industry. Inconsistent evidence, uncoordinated surveillance and ecological complexity complicate detection and assessment of public health risks. Animal sentinels (domestic or wildlife, terrestrial or aquatic) may help to better understand the pathways and effects of exposure to the various chemicals associated with this sector. In this report, we summarize known animal health outcomes and current capacity in Canada to detect and assess these outcomes and evaluate the possible use of animals as sentinels of public health risk under normal production and environmental conditions of the oil and gas sector.

We used a rapid scoping review to identify trends, gaps and emerging themes in literature and online. A brief review of the oil and gas sectors, including exploration, development, transport and refinement activities, public health concerns, and criteria for effective sentinels is provided in the Background sections. In Section 1, we describe the expected hazards and exposures to those hazards as a result of oil and gas exploration and development. A review of the observed health impacts on animals is provided in Section 2, and in Section 3 we discuss Canada's capacity to detect, assess and communicate animal health sentinel events. Section 4 provides conclusions and Section 5 recommendations.

Oil and gas products and components have been shown under field and laboratory settings to cause measurable, adverse health outcomes in many animal species ranging from mild debilitation through to death. Health effects may be as a result of direct exposure and acute toxicity, or indirect as a result of environmental changes or increased physiological stress. Health impacts vary by the species, duration or route of exposure, and the chemical composition of the substance under study but many are meaningful from a human health impact perspective. Cause-effect evidence is stronger with experimental and acute exposures to specific compounds than for chronic exposures under natural conditions. There is controversy as to the frequency or magnitude of effects of exposures outside of experimental settings and, thus, questions about the specificity and reliability of animal data for human health risk assessment.

General diagnostic and field investigation services have been central to identifying new and emerging health impacts from environmental pollution, and have been effectively deployed to assess die-offs, outbreaks and unusual pathology or productivity in animals. We found no ongoing, systematic

approach to integrating animal health information and assessing it from a public health perspective. Federal and industry-led initiatives are focussing on sampling animals for the presence of chemical contaminants in and around oil and gas development sites. There is capacity to investigate animal health outcomes of greatest concern to the public but economic barriers often result in insufficient numbers being submitted to diagnostic laboratories to estimate prevalence or do statistical trend analysis. Cost also limits toxicology testing at diagnostic facilities. Private, public and university laboratories across Canada routinely receive diagnostic samples from wildlife and domestic animals that inhabit areas nearby oil or gas production, transportation or refinement sites. These laboratories provide rigour and response that can rule-out public concern by determining when the specific cause of death is due to something other than oil and gas associated hazards.

Most evidence has focused on conventional oil spills and, more recently, oil sands with much less on other sectors or other chemicals associated with extraction and refinement. This limits the use of animals as sentinels to a sub-set of settings and hazards. The interaction of different chemical compounds with environmental and ecological variables results in a highly variable system that could result in a diversity of impacts in a variety of species. Although efforts have been made to relate oil and gas exposures to specific effects in fish, cattle and some wildlife species, there remains no single “right” sentinel species or sentinel lesion to track. The available science is not yet able to identify specific animal outcomes, prevalence or intensity that could be a direct measure of human health risk. Additional research would be required to determine their utility across the oil and gas industries.

We recommend the development of an animal health observatory for oil and gas, with a mandate to synthesize data and target specific areas for data collection to highlight health issues and inform policies and actions. The observatory could have the dual responsibility of knowledge synthesis and mobilization, and could support standardization of data generation and collection to facilitate research synthesis and monitoring outputs. It would be useful to extend the One Health philosophy to environmental contaminants, to further dialogue on how to collect, integrate and interpret animal, environmental and human health data with respect to oil and gas. We advise supporting more systematic surveillance with enhanced response and investigative capacity to help rule out oil and gas pollutant effects where appropriate and to more systematically identify signals of emerging impacts. There needs to be more explicit links between animal and human health monitoring in exposure areas. Research rather than surveillance is needed to clarify cause-and-effect relationships and cumulative effects on health outcomes from oil and gas exposure.

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Key Points

- Chemicals exposures associated with the oil and gas industry have been shown under field and laboratory settings to cause measurable, adverse health outcomes in many animal species ranging from mild debilitation to death.
- There is no single “right” sentinel species or sentinel lesion to track because of the complexity and variability of the risk settings. Although efforts have been made to relate oil and gas industry exposures to effects in fish, cattle and certain wildlife species, the available science is not yet able to identify specific animal outcomes, prevalence or intensity that could directly estimate human health risk.
- There is no ongoing, systematic surveillance of animal health for public health risk detection and assessment associated with the oil and gas industry.
- General veterinary diagnostic and field investigation services have been central to identifying new and emerging health impacts from environmental pollution, and have been effectively deployed to assess die-offs, outbreaks and unusual pathology or productivity in animals but economic barriers reduce their utility for oil and gas industry surveillance.
- Research rather than surveillance is needed to clarify cause-and-effect relationships and cumulative effects on health outcomes from oil and gas exposure.
- The creation of animal health observatories and removal of barriers to submissions to diagnostic laboratories would provide public assurance and to increase the likelihood that animals will be useful sentinels of emerging risks to public health.

Target Audience

This paper is intended for public health practitioners who are curious as to how animal health information can be used to influence risk detection and assessment in the oil and gas industries. The paper takes a Canadian perspective and strives to provide a foundational understanding of the potential utility of animals as sentinels for public health in the context of oil and gas exploration, development, transport and refinement.

Purpose

The National Energy Board forecasts substantial future growth in total Canadian oil and gas production (2013). The speed and potential magnitude of this development has created public concern as the rapid growth of the oil and gas industry has outpaced our understanding of possible health and safety impacts. In a 2012-13 survey conducted by the National Collaborating Centre for Environmental Health, oil and gas was ranked as the third most important area with environmental health needs and gaps (particularly the health impacts of hydraulic fracturing, National Collaborating Centre for Environmental Health, 2013). Environmental health managers tasked with assessing public health impacts face challenges in accessing the necessary data, accounting for cumulative effects of interacting environmental hazards, dealing with ecological complexity, and inconsistent evidence.

Animal sentinels may help to better understand pathways and effects of exposure to chemicals associated with the oil and gas sector (Cruz-Martinez & Smits, 2012). Reports of animal disease, death or deformity come to the attention of regulators from community members concerned with adverse impacts of industrial activities. Hunters and fishers have expressed concerns over the safety of food gathered in and around the oil and gas industry. The toxicity of various chemicals is often established through animal experiments. Animal tissues have been analyzed to trace the distribution of contaminants in the environment. In this paper, we will synthesize the lessons learned at the interface of people with aquatic and terrestrial (domestic and wildlife) animals to examine if animal health data can be used to expand our understanding of, and inform our responses to, environmental health concerns associated with the oil and gas industry in Canada.

This paper provides background for public health workers by (i) discussing the types of animal health outcomes that have been associated with the oil and gas industry, (ii) describing current capacity to use animals for early warning or risk assessment purposes, and (iii) assessing if animals fit criteria for effective sentinels. It is not a complete inventory of all possible animal health outcomes from all possible hazards associated with the oil and gas sector. Nor is there an assessment of all public health risks and benefits from the oil and gas industries. Rather, it is our intention to assess the potential value of animals as sentinels for human health risk associated with these industries.

A sentinel is an individual or part of a population susceptible to a hazard that is being monitored for the hazard or for evidence of an impact from that hazard. This paper focuses on information related to the possible use of animals as sentinels under normal oil and gas production and environmental

conditions rather than detailing research relating to their role as experimental models or subjects for toxicity testing. It does not assess animal health outcomes that directly impact determinants of health through impacts on food safety or social welfare linked to animal use. Our goal is to make recommendations on whether or not Canada needs to invest in enhanced animal health surveillance around energy developments to provide public health early warning of impending risks to people.

Methods

A scoping review was conducted between January and February, 2014 to explore the breadth of the available literature regarding animals as sentinels for public health effects of the oil and gas industry in Canada. Scoping reviews provide an overview of the type, extent and quantity of research available on a given topic with the aim of identifying trends, gaps and emerging themes.

We identified papers of interest through a combination of Google Scholar, Canary Database (canarydatabase.org), JSTOR, Web of Science, BioOne and PubMed database searches. The majority of relevant papers were found either through Web of Science forward citation searches or reviews of cited references from papers identified through the aforementioned web-based, website and digital library searches. Key words that identified the most promising literature included combinations of phrases such as “animal”, “health”, “health outcomes”, “disease”, “pathology”, “toxicity”, “oil and gas”, “petroleum” and “hydrocarbon”. Appendix 1 provides details of the search strategy. Grey literature and technical reports were found using Google searches with similar key words. An emphasis was placed on finding review articles in specific topic areas, past risk assessments or technical reports that synthesized other reports and papers. We excluded papers with a focus on environmental fate and contamination from oil and gas associated chemicals.

We also identified and interviewed experts in animal health effects and oil and gas, who kindly provided us with additional citations and opinions. Experts were members of the Canadian Wildlife Health Cooperative; British Columbia Ministry of Forests, Lands and Natural Resource Management Operations; Western Interprovincial Scientific Study Association Advisory Panel; and Alberta Environment and Sustainable Resource Development, Government of Alberta.

Background

Overview of the Oil and Gas Sectors

Appendix 2 provides details of the oil and gas sector and describes where in the process of exploration, extraction and transportation hazards may be present. A summary is provided here.

Crude oil is a hydrocarbon based liquid located in underground reservoirs that are accessed either from land, sea or lakes.

Conventional oil is extracted through drilling and pumping oil that is free flowing.

Unconventional oil involves mining or drilling for bitumen, a semi-solid petroleum that along with sandstone, sand, clay, and water make up what is known as the oil sands.

Natural gas is a combustible fossil fuel that is composed of hydrocarbons, primarily methane. It is found underground in pressurized reservoirs trapped between layers of rock or in low permeability rock formations (Government of Alberta, 2013).

Conventional gas is extracted by perforating free gas reservoirs in porous zones of

carbonate, sandstone, and siltstone formations. Unconventional gas does not flow freely through the rock like conventional gas so the process of hydraulic fracturing (fracking) is used to allow access to the gas. This process uses pressurized fluids to fracture rock and allow gas to move towards wells for collection.

To a large degree, oil and gas development is and will largely be a western Canada issue with oil sands development dominating future production (Carey, 2009). Oil sands account for 97 percent of Canada's total oil reserves and is expected to account for up to 90% of Canadian crude oil production by 2030 (Natural Resources Canada [NRC], 2014). Overall, Canada's oil sands production could more than triple by 2030. Alberta, Saskatchewan and Newfoundland and Labrador are currently the top producers

Box 1: Differentiating crude oil from natural gas

Crude Oil

- Hydrocarbon based liquid fossil fuel
- Located in underground reservoirs
- Conventional Oil
 - Freely flowing, easily pumped out of the ground
- Unconventional Oil
 - Semi-solid "bitumen" that first needs to be extracted from the sandstone, sand and clay to which it is bound

Natural Gas

- Combustible hydrocarbon fossil fuel
- Found in pressurized reservoirs trapped between layers of rock or in low permeability rock formations
- Conventional Gas
 - Freely flowing once the reservoirs have been perforated
- Unconventional Oil
 - Does not flow easily, requires hydraulic fracturing of rock to gain access to gas deposits

of conventional oil in Canada with lesser amounts in British Columbia, the Territories and Manitoba (Carey, 2009). Offshore oil production is centered in the Atlantic Provinces (Nova Scotia and Newfoundland and Labrador). There continues to be a moratorium against exploration and development of offshore supplies in British Columbia.

Canadian natural gas production is expected to rise slowly after 2014, due to the development of unconventional gas (NRCAN, 2011). Natural gas production is currently dominated by Alberta with lesser amounts in British Columbia, Saskatchewan and Nova Scotia, although development of shale gas in northeast British Columbia will increase that province's contribution. Potential and producing shale gas resources are found in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick and Nova Scotia. Most of the current drilling and production activities are occurring in northeast British Columbia (NRC, 2011).

The Canadian Association of Petroleum Producers reported that in 2012, Canada produced 1.31 million barrels of conventional oil per day, 1.7 million barrels per day of oil sands and 13.7 billion cubic feet per day of natural gas (Canadian Association of Petroleum Producers [CAPP], 2012).

Overview of public health concerns

There is a range of potential public health concerns linked to the oil and gas sector in Canada (Fraser Basin Council, 2012; Medd & Bush, Unknown; Vlavianos, 2006). Some are direct health outcomes such as cancers, respiratory and cardiac disease, and reproductive health effects. Others are related to a loss of confidence in the safety of food and water supplies. Social and community health impacts ranging from accidents to substance abuse and violence are concerns of the public health community, but the media and general public seem more interested in the effects of chemical compounds associated with the industry (Government of New Brunswick, 2012). There currently seems to be better evidence for social harms than harms from chemical pollutants.

Identifying an undisputed causal link between public health outcomes and oil and gas exploration, extraction, refinement or shipping is complicated when one takes a cumulative effects perspective or considers the long term risks over the life time of the industry. In a number of jurisdictions, especially those undergoing new development, there is a lack of health status monitoring systems in place (Government of New Brunswick, 2012). When coupled with the lack of information on the specific chemical composition of the petroleum products, or of the products used in petroleum

extraction and refinement, this lack of ongoing monitoring hinders routine surveillance and creates the need for special studies to investigate and identify possible risks to health.

Animal health as a sentinel of public health risk

Under the right conditions, domestic and wild animals can reveal the presence of unknown environmental harms before they affect people. Animals (wild or domestic, terrestrial or aquatic) may also help identify exposure pathways since they can share the same exposures to pollutants as people (National Research Council, 1991). Animals are more likely to inadvertently consume contaminated water and feedstuffs, and unlike humans may not be able to remove themselves from the contaminated environment, allowing for more intimate exposures to toxins. Their shorter life spans and more frequent reproductive cycles compared to humans allows for more opportunities to see individual and hereditary impacts. Some of the uncertainty in predicting risk for people from exposure to toxic substances can be reduced by considering the presence of toxins and toxic effects in animals to document environmental exposures (National Research Council, 1991).

Pets, agricultural species and wildlife have been used purposely or incidentally as sentinels for human environmental health risks for over a century. The use of mice and birds in early 1900's coal mines to detect carbon monoxide is one of the earliest examples of the planned use of animals to forewarn of environmental hazards to people: the proverbial canaries in a coal mine. Clinical signs in animals foreshadowed Minamata disease (mercury), West Nile virus incursion, carcinogenic risk from pesticides, asbestos and other materials, respiratory effects of urban air pollution, immunological and hormone mimicking effects of a variety of industrial and pharmaceutical pollutants, and more (Reif, 2011).

Animal studies have also helped to document the distribution and persistence of pollutants in nature. For instance, laboratory studies remain a standard for establishing the toxicity of various substances, including oil and gas associated chemicals. Extensive investment has been made in outbreak investigations or targeted monitoring programs in domestic animals to assess risks and impacts of oil and gas (Scott et al., 2003a,b; Waldner, 2001b, 2008a, 2009; Western College of Veterinary Medicine, 2001). Cruz-Martinez & Smits (2012) concluded that wildlife species can provide early warning and predictive information regarding exposure and effects of contaminants from oil sands activities that would complement the ongoing investment into air and water monitoring systems.

Animal populations can provide several advantages as environmental health sentinels (Stephen & Ribble, 2001). First, many species have pathophysiological mechanisms similar to people, allowing for meaningful interpretations of how biological responses in animals could reflect human health risk. Second, some species have immediate and dependent relationships with their surroundings, making it easier to link local environmental changes with health effects. Third, several levels of biological impacts – such as species distribution, reproductive success, immune function and rates of infectious, neoplastic and other diseases – can be observed more readily in animal populations in response to environmental change. Finally, ethical and practical considerations make it easier to collect data from animal populations.

There are no standard criteria for evaluating animal sentinels, making their selection and assessment *ad hoc* or on a case-by-case basis (Halliday, 2007). To be an effective sentinel an animal must be sensitive to the hazard of concern; demonstrate measurable, interpretable and relevant health outcomes that have reasonable predictive value for effects on people; reveal those changes before effects are seen in people; be effected at levels of exposure that are relevant to the risk setting; be in the same place as people to prevent the need to extrapolate effects from elsewhere to the immediate surroundings; and produce information that is convincing to decision makers (Halliday et al., 2007; Stephen & Ribble, 2001). The biology of the sentinel animals, including their home range and movements, should be known, they must be tolerant to capture, sampling and handling, it must be

Box 2: Features of animal sentinels

- Sensitive to the hazard of concern
- Demonstrates measurable, interpretable and relevant impacts on health outcomes
- Demonstrates health outcomes in animals before these effects are seen in humans
- Affected at exposure levels that are relevant to the risk setting
- Geographic and temporal overlap for extrapolation from the sentinel population to human populations
- Produces information that is convincing to decision-makers

practical and cost-effective to sample them, and the results must be of interest to the people responsible for making changes (Cruz-Martinez & Smits, 2012). Sentinel populations should enhance the detection of hazards or outcomes and/or improve the effectiveness and efficiency of surveillance and monitoring activities.

Despite their potential advantages, animal sentinels are not widely used in environmental health practice. There are few clear guidelines for their use in human health decision making (Rabinowitz et al., 2005). In some cases, this is due to a lack of understanding of the relationship

between animal and human health. In other cases, there are limitations in study methods and a lack of clear links to human health (Rabinowitz et al., 2005). Public health practitioners can be unaware of, or lack access to, information animals (Stephen and Ribble, 2001). While there is widespread agreement that animals have proven useful as sentinels, there are disagreements about the use of 'natural experiments' associating animal health outcomes with pollutants as the basis for causal conclusions (Cruz-Martinez & Smits, 2012). Often, it is simply too difficult to form the appropriate linkages between data, programs and people to incorporate animal health into a public health surveillance program.

Section 1: Hazards and exposure assessments

It would be short-sighted to conceive of the oil and gas industry as a single industry. Rather, the different production systems, varying exposure routes and multiple interacting hazards result in a highly variable risk setting. It is unlikely that the specific combination of exposure routes and hazards that exist at one site will be the same as another site. Production methods, human and animal ecologies and environmental factors vary between sites. It is reasonable, however, to say that oil and gas exploration, development, production, refinement and transportation can cause considerable changes to the environment. Direct or indirect environmental change can result from the construction of new infrastructure, product extraction, waste and emissions production, and accidents or spills. Opportunities for human exposure could come from occupational settings, through impacts on shared airsheds and watersheds, effects on soil quality and land, and through secondary exposure via the consumption of contaminated foodstuffs. These same routes exist for animals if we replace occupational exposure with exposures to spills and leaks.

Hazards

The oil and gas industry faces a number of operational constraints that make it difficult to eliminate the production and release of a variety of hazards. These hazards fit into four general categories. First, there are physical disruptions to the environment that result from the development of infrastructure for exploration, extraction, transportation and refinement. Habitat is cleared, roads are constructed and obstacles created that can affect animal movements and the incursion of people into 'virgin' habitat. Work in more tropical climates have associated such activities with increased risk for emerging infectious diseases due to novel or altered contacts between people, wildlife and vectors, but little has been written on this risk in temperate forests (Patz et al., 2004). Associated with these activities are noises and seismic activity that may interfere with animal behaviour (Bradshaw, Boutin, and Hebert, 1997; Gordon et al., 2003).

Second, petroleum and gas products are a mix of compounds, the combination and proportions of which may vary between and within gas or oil processes (National Oceanic and Atmospheric Administration [NOAA], 2014). Natural gas is a simple hydrocarbon mix made up primarily of methane with smaller amounts of ethane, propane, butane and pentane (Enbridge, 2012). A material safety data sheet for natural gas states that it is a simple asphyxiant that displaces oxygen in the air but has no known mutagenic, carcinogenic, teratogenic or reproductive effects (Enbridge, 2012). Crude oil is a

mixture of paraffinic, naphthenic and aromatic hydrocarbons plus varying amounts of nitrogen, oxygen, and sulfur compounds, organometallic complexes (notably of sulfur and vanadium), dissolved gases such as hydrogen sulfide, heteroatoms (e.g., nitrogen- and oxygen containing hydrocarbon analogs) and asphaltenes (Environmental Protection Agency [EPA], 2011b). The properties of petroleum (crude oil) vary between and within oilfields.

Third, mining, drilling and extraction all require the use of chemical products. The specific chemicals used by industry will vary with production type and location. For example, the drilling process requires the addition of drilling fluid comprised of compressed air, water, barite, clay, and chemical additives that assists in cutting the hole and lubricating the drill. Hot water, caustic soda and diluents, such as naphthenic and paraffinic acids are used to separate bitumen from the sand (Siwik, Van Meer, MacKinnon, & Paszkowski, 2000). Large volumes of ground or surface water, 7 to 19 million liters per well, is used in the hydrofracturing process (EPA, 2014). Chemical additives and proppants (solid material designed to keep an induced hydraulic fracture open) are added to the water. The chemical formulations of the hydrofracture fluid are proprietary and closely guarded. Toxicological information can be lacking or limited to only a sub-set of chemicals.

Fourth, toxic wastes and emissions generated in the extraction and refinement process must be disposed of, reused, recycled or contained. These wastes contain various additives, fluids and other compounds, that are not always fully characterized and that can be quite variable between sectors and locations (Government of New Brunswick, 2012). For example, the sand, water, and ions leached from bitumen and chemicals used to extract oil from oil sands are stored in 'tailing' ponds that can be acutely toxic (MacKinnon & Boerger, 1986). Contaminants are removed from crude oil and bitumen by washing with large amounts of water. The resulting waste water contains many chemicals, most notably benzenes. The crude oil then goes through catalytic reforming, which changes the crude oil long molecules into shorter lighter molecules. Catalytic reforming has been described as the largest source of airway pollution during refinement as it emits into the air sulphur dioxide, nitrous oxides, carbon monoxide, particulate matter, metals and ammonia (EPA, 2011b). In addition to these compounds, major emissions of interest in the oil sands regions include volatile organic compounds and ozone. Air pollution also occurs during hydraulic fracturing via the release of fugitive gasses through pipe or valve leaks, on-site spills and exhaust from equipment (Colborn, Kwiatkowski, Schultz, and Bachran, 2010). The EPA has suggested that 2.5% of all natural gas produced is leaked to the atmosphere, leading to methane, hydrogen sulfide, benzene, toluene, ethylbenzene, xylenes, hexanes and carbon monoxide

emissions (EPA, 2012). Aquatic contaminants related to the petrochemical industry frequently include polycyclic aromatic hydrocarbons, naphthenic acids, sulphate ions, ammonia and trace metals (Cruz-Martinez & Smits, 2012).

This diverse and incompletely characterized list of hazards from the oil and gas sector makes it difficult to compare different toxicological studies or amass enough high quality, epidemiologically realistic papers for meta-analysis or systematic review. Most investigators work on individual toxins to unambiguously link a toxin to an effect rather than address the complexity of exposures under realistic conditions. Accurate hazard characterization under normal conditions is difficult in part because of the lack of precise information on the composition of some products and in part because exposures can be highly variable for the population of concern and the type of pollutant, emission or products of interest.

Exposure

Animals can be exposed through dermal absorption, inhaling volatile compounds, ingesting oil, gas or products used in their extraction or refinement, or by ingesting contaminated soil, food or water. Some animals will be attracted to work camps or oil facilities because of increased ease of movement as a result of road construction, new or easily accessible food sources associated with wastes such as garbage, or access to salts in waste products (Tietje & Ruff, 1983; Weeden & Klein, 1971; Whittington et al., 2011,). The amount and duration of animal exposure will vary not just with the specific sector (i.e. oil sands vs. unconventional natural gas) but also with the life history of the animal (habitat, feeding behaviour), the animal's morphology and behaviour (i.e. fur vs. scales; flying vs. swimming), the medium of exposure (i.e. exposures by water will be different for fish eggs than for cattle drinking from the same pond) and climatic factors that affect evaporation rates, photolysis, microbial degradation and dilution of toxic substances in the environment. For example, since low temperature, darkness and ice cover slow the degradation of polyaromatic hydrocarbons (PAHs), arctic species could have longer duration of exposure from environmental contamination than animals in more southern locations (MacDonald et al., 2010).

Most literature deals with exposure under artificial or laboratory settings. Some research has attempted to use quasi-cohort studies by comparing animal health outcomes in areas in close association with oil and gas activities with those in distant locations. There are challenges in quasi-experiments because regions or landscapes cannot be 'replicated' and selecting true control sites is problematic at an environment/ecosystem level. The confounding of space, time, and/or other

environmental factors often allows studies to generate rather than confirm or disprove hypotheses (Hargrove & Pickering, 1992). While some jurisdictions require Before-After-Control-Impact studies (comparing pre- to post-construction conditions and reference to restoration sites) before new sites can be developed, this approach was not found in the literature related to animal risks. Threshold levels for concentrations of contaminants in soil and water have been developed to minimize the likelihood of significant unacceptable risks to livestock (American Petroleum Institute, 2004). Drinking water and soil quality guidelines (i.e. threshold values) for livestock protection have been developed by the Canadian Council of Ministers of the Environment and Alberta Environment (Canadian Council of Ministers of the Environment, 2008). These guidelines were developed, in part based on extrapolation from small mammal studies. Their suitability for other species is unknown.

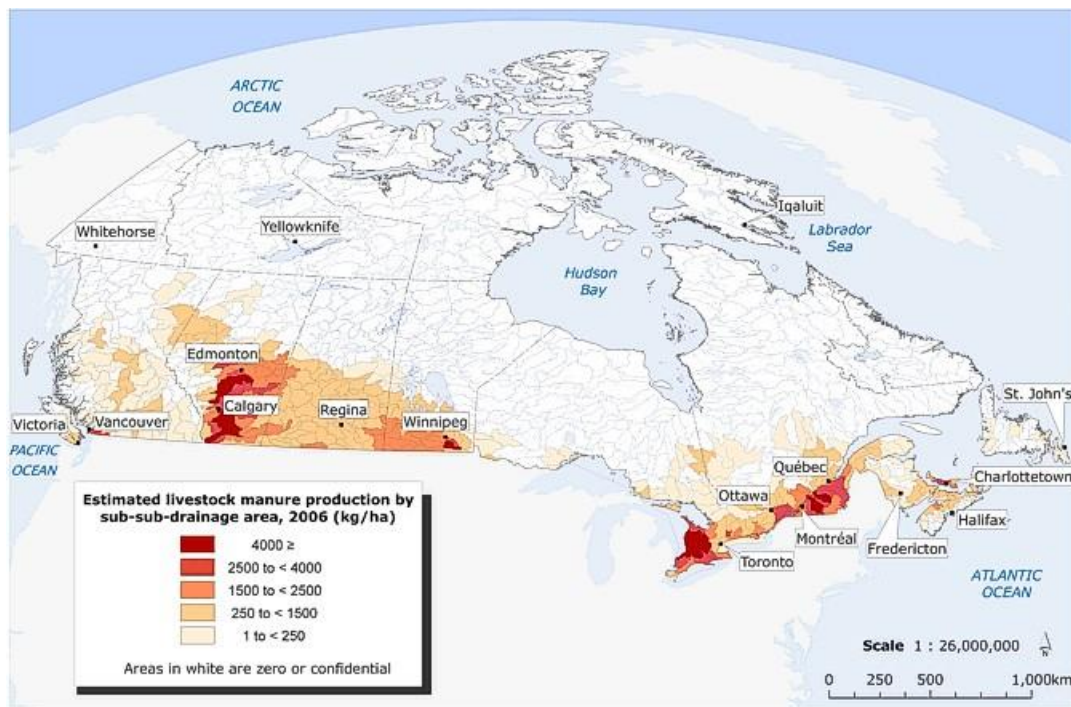
Both terrestrial and aquatic animals (domestic and wild) can potentially be exposed to hazards released into the air, water, food, or soil. Most Canadian research has been on livestock (predominately cattle) and a small selection of easily-studied wildlife. Experimental work on single celled organisms and bacteria are common but not directly relevant to this project. Little has been done on companion animals.

Livestock have the advantage of being largely contained or restricted in their movements throughout their life, making it easier to associate exposures to specific geographic locations. By mapping livestock manure production (a surrogate for animal biomass), it can be seen that the majority of livestock biomass is found in southern Canada (Figure 1). There is some spatial overlap (at a large scale) between livestock production and gas and conventional oil development, especially in southwestern Canada. More northern regions in Canada have been less disturbed by anthropogenic activities, including agriculture, suggesting that fish and wildlife may be more at risk to oil and gas activities than livestock in these regions. Wild species are especially relevant for marine and aquatic drilling which historically has occurred at significant distances from aquaculture operations.

Although wildlife are more likely to be found in remote areas and marine sites, there can be considerable challenges in tracking their movements and thus ascribing exposures to specific locations. Animals with limited ranges or those that have periods of their life with little mobility (ex. nestling birds) offer the advantage of spatial specificity in their movements. Detailed understanding of their life histories or dietary studies is needed to help estimate their various exposure routes, which differs from that of domestic animals whose food and water sources are controlled by their owners.

The most widely known and dramatic exposures of wildlife to oil has been accidental or unintentional exposures, especially marine oil spills or leaks of petroleum products into rivers. Other recently publicized encounters includes waterfowl landing on tailing ponds in Alberta and birds flying through flares at refineries in the New Brunswick. The Western Canada Study on Animal and Human Effects Associated with Exposure to Emissions from Oil and Natural Gas Field Facilities documented detailed airborne exposure information for cattle at a regional and individual level (Waldner, 2008b). Ongoing studies that strive to measure environmental levels of contaminants, contaminant levels in animals, and animal health outcomes, are described in Section 2.

Figure 1: A geographical profile of livestock manure production in Canada, 2006. From <http://www.statcan.gc.ca/pub/16-002-x/2008004/article/10751-eng.htm>.



From petroleum extraction to refinement, there are many possible intentional and unintentional exposures to raw, end-use and by- products as well as to non-petroleum chemicals; many of which are known to be toxic to animals (Coppock, Mostrom, Khan, & Semalulu, 1995). The dose, duration and route of exposure, the specific contaminant(s), individual and species-related factors (such as age, habitat preference, underlying immunosuppression, behaviour etc.), and environmental conditions that influence the weathering and decay of petroleum products can all affect the severity and nature of the

animal health impacts. These variations in exposure reduce the specificity of any particular animal health outcome as a generalizable indicator of oil or gas effects.

Ecotoxicological challenges that complicate exposure assessments under typical operational conditions include measuring low concentrations, long term (chronic) exposures, complex mixes of contaminants in the environment, lack of specificity of outcomes due to the presence of additional environmental stressors, and ecosystem complexity (MacDonald et al., 2010). Exposure assessment is further complicated by the unprecedented environmental changes that are occurring simultaneous to oil and gas development. In particular the effects of climate change on the partitioning and transport of chemical contaminants, particularly in more northern environments, complicates the extrapolation of exposure data from one setting or time to another (MacDonald et al., 2010).

Section 2: Animal health outcomes associated with oil and gas development

Effective animal sentinels show a detectable response to hazard exposure. This section provides an overview of the various taxa and species in which detectable responses have been described and summarises the types of responses that have been associated with exposure to oil, gas or their constituents. Readers are directed to more extensive reports elsewhere, which review laboratory and field-based experimental studies in more detail (ex. Cruz-Martinez & Smits 2012; Albers, 2003; Macdonald, Lockhart, & Gilman, 2010). The challenge in summarizing animal health impacts from oil and gas exposure relates to the complex and variable nature of the industry. Nevertheless, field and laboratory toxicological studies, along with opportunistic case studies from accidental exposures, have shown that animals are sensitive and have a variety of biological responses to oil and gas industrial chemicals or wastes.

Exposure to petroleum products and the associated harms that occur are influenced by the ecosystem, habitat preferences and behaviour of the species, route of exposure, and the nature of the toxin(s). For example, the toxic effects of oil are not uniform across oil types. ‘Light’ products, like gasoline and diesel, risk ignition on spill and have fumes that can be readily inhaled. Conversely, ‘heavy’ oil tends to be thick, and will coat animal’s fur or feathers, persist in the environment, and be associated with longer term health impacts (NOAA, 2014). Oil and gas “adversely affect organisms by physical

action (smothering, reduced light), habitat modification (altered pH, decreased dissolved oxygen, decreased food availability), and toxic action” (Albers, 2003, p. 349). Our understanding of the impacts of petroleum products is not uniform across the various sectors of this industry. In general, more research is available on oil than on natural gas, hydraulic fracturing or the various chemicals used to augment the industry’s oil and gas activities.

Much is known about the impacts of petroleum products on bacteria and invertebrate animals. Several studies have shown that these species can take up toxic components and have measurable effects (Macdonald et al., 2010). Invertebrate testing has been used to determine the toxicity of different products and there is a significant volume of literature on the effects of petroleum products on invertebrates and micro-organisms. Monitoring programs or special studies may benefit from understanding the responses of such species, but given that these species are not under routine observation or demonstrate impacts comparable to effects on people, they are not suited to act as sentinels.

Several authors have concluded that relatively little has been published on the population health impacts of chronic, low-level exposures to petroleum hydrocarbons from energy exploration and development activities (Medd & Bush, (unknown); Schwartz et al., 2004; Scott et al., 2003a; Marty et al., 1997). The few exceptions include sour-gas emission exposure studies in western Alberta’s cow-calf herds (Waldner et al., 2001 a,b; Waldner, 2008a; Waldner, 2009; Scott et al., 2003 a,b,c) and on-going ecological studies in Prince William Sound as a result of the *Exxon Valdez* oil-tanker spill in 1989 (Duffey, Bowyer, Testa, and Faro, 1994; Peterson et al., 2003; Rice et al., 2001), where the associations between exposure to pollutants and health outcomes have either been inconsistent (Scott et al., 2003c) or controversial (Rice et al., 2001). The effects of acute exposures, such as accidental ingestions or oil spills, form the bulk of our knowledge on the animal health impacts of petroleum products. In general, the work we found generally failed to take a cumulative effects approach. While some did consider oil or gas as a whole (i.e. as a product composed of several toxic compounds) or the interactions of oil or gas associated chemicals with other toxins or environmental conditions, none took a “total-pollutants” perspective (i.e. concurrently taking into account exposures to pollutants in addition to oil or gas associated contaminants).

Table 1 sub-divides the biological continuum of health impacts to reflect four general categories. Much of the literature on crude oil and petroleum began in response to large spills or point-source entry of oils into aquatic systems. Therefore, there are a substantial number of studies that deal with

immediate and post-accident impacts. The relatively few reports on acute and chronic impacts are largely laboratory-based and have not taken full advantage of modern analytic methods or more sensitive dose-response protocols (Macdonald et al., 2010). As a result, the quality of evidence to specifically link the health outcomes to oil and gas exposures decreases as we progress from per-acute to chronic exposures, and from laboratory to ‘real-world’ settings.

Table 1: General types of animal adverse health outcomes associated with the oil and gas industry described in the literature.

	Description	Examples
Immediate	Accidents and spills and immediate pathological effects	Irritate effects of contact with oils
Post-accident	Subsequent effects after a single point-source exposure event	Red blood cell anomalies in birds shortly after an oil spill
Acute toxicity	Effects occurring in a short time (relevant to the animals life cycle) after exposures	Hepatotoxicity Embryotoxicity
Chronic effects	Effects occurring in a longer time (relevant to the animals life cycle) after exposures	Reproductive effects Immunomodulation Ecologic change

Immediate to acute effects

Oil spills have immediate impacts on animals. While many small animals can be smothered by the oil, dermal exposure, ingestion and inhalation of the petroleum products can lead to pathological changes including but not limited to pulmonary emphysema, gastrointestinal inflammatory reactions and ulcers. Direct irritation of the skin, eyes and mucous membrane can cause disability and secondary infection, while the coating effects of heavy oils reduce buoyance and thermoregulatory abilities leading to hypothermia, smothering or drowning (Leighton, 2000). Birds are particularly vulnerable to the topical effects of oil, and even small amounts of oil on their plumage can have lethal thermoregulatory effects. The ingestion of toxic substances during preening is a well-known acute cause of morbidity and mortality in birds and sea mammals (Peterson et al., 2003), and mass mortality of these animals following large crude oil spills have been reported in the literature (Albers, 2003). The impacts of oil and gas on fish populations in large bodies of water are harder to quantify (Albers, 2003; Macdonald et al., 2010). When fish kills do occur they are often due to the rapid movement of large quantities of oil into shallow waters (Albers, 2003). Population impacts can be significant, and recovery depends largely on

the reproductive potential of the survivors and immigration to the spill site. The effects of spilled oil on wildlife can be expressed over much longer time frames than previously assumed. Following the Exxon Valdez spill, for example, the initial loss of 25% of the population of Harlequin ducks was compounded by decreased survival rates for 6-9 years after the spill (Iverson & Esler, 1989). Cumulative mortality associated with chronic exposure to residual oil may exceed acute mortality.

Adverse effects from post-spill clean-up activity can come from the physical disturbance of environments, mortality from the use of hot waters or chemicals used in cleaning or even the use of oil dispersants to deal with the spill. For example, a probabilistic hazard assessment of oil dispersants found that dispersants alone were generally less toxic than oil, but most dispersant:oil mixtures were more toxic than oil alone (Berninger, Williams, and Brooks, 2011).

Eggs, larvae, and early juvenile stages are more vulnerable to oil because they have limited or no ability to avoid it. The embryotoxic effects of oil has been well studied in a variety of animal species. Bivalve invertebrates such as mussels (*Mytilus edulis*), for example experienced reduced volume and density of female gonads, impaired gamete development and slower growth and developmental anomalies as larva when parents were exposed to oil (Baussant et al., 2011). PAHs from oil accumulate in fish embryos and may lead to adverse sequela appearing haphazardly over the lifespan of an exposed cohort, apparently as a result of damage to the neurological and cardiovascular systems during early embryogenesis (Short, Rice, Heintz, Carls, and Moles, 2003). Adult waterbirds that contact crude oil in their environments may transfer residues to their nests, eggs, and hatchlings. Considerable reduction in hatching with teratogenicity and stunted growth has been described in bird eggs exposed to petroleum products (Hoffman & Gay, 1981).

Acute toxicity from the voluntary ingestion of petroleum products have been described in detail for livestock (Coppock et al., 1995; Coppock, Mostrom, Stair, & Semalulu, 1996; Edwards, Coppock, & Zinn 1979). Clinical signs are varied and range from vomiting, diarrhea, coughing and dyspnea to ataxia, cardiac arrhythmias, seizures and sudden death (Coppock et al., 1995), with toxicopathological changes primarily targeting the lung, liver and kidneys (Coppock et al., 1996). Although the gastrointestinal absorption and uptake of radiolabeled hydrocarbons into kidney, liver, spleen, lung and brain has been established in animal studies (Ashkenazi, Bratton and Mann, 1961 cited in Dice, Ward, Kelley, Kilpatrick, and Washington, 1982), experimental evidence strongly suggests that pulmonary pathology occurs as a result of the aspiration of petroleum products following ingestion, and not via gastrointestinal absorption of those products (Dice et al., 1982; Wolfsdorf & Kundig, 1972). Unfortunately, it is not

always possible to identify a direct causal link between oil or gas exposure and pathological lesions. For example, the acute hemorrhagic gastroenteropathies and intestinal hemorrhages described from oil-exposed birds in the wild have not been replicated experimentally, leading some authors to suggest that these lesions are the result of the avian stress response and not direct toxicity from the oil (Jauniaux, Meire, Offringa, and Coignoul, 1998).

Chronic effects

A number of experimental and observational studies, often comparing exposed and non-exposed cohorts, have been conducted to better understand the impacts of chronic exposures to various oil and gas products. Because these experiments tended to have a narrow research design in terms of the species, route of exposure or chemical component under study, it is difficult to extrapolate these findings to other species or products. Observational studies under field conditions can be complicated by confounding factors that may obscure the ability to assign cause and effect relationships to any one specific chemical or factor (van den Heuvel, Power, Richards, Mackinnon, and Dixon, 2000). The following description of health outcomes is not an exhaustive inventory of all effects but, rather, examples to illustrate the diversity of species and health outcomes that have been found in association with oil or gas industries.

The absence of baseline data for fish in large bodies of water complicates our ability to identify their population health impacts (Albers, 2003). Under experimental conditions, reported sublethal effects in fish to exposures of less than 0.5 ppm total petroleum hydrocarbons have included gill structural damage and fin erosions, liver enlargement, reduced growth, corticosteroid stress response, immunosuppression, impaired reproduction, increased external and decreased internal parasite burdens and behaviour responses (Albers, 2003). Hicken et al., (2011) found that transient embryonic exposures of zebrafish to low concentrations of oil resulted in delayed and sublethal toxicity not counteracted by the protective effects of cytochrome P450. Changes in heart shape and significant reductions in swimming performance, indicative of reduced cardiac output, could be seen in the adult zebrafish nearly one year post-exposure. Controlled experimental exposures of juvenile coho salmon suggest that chronic exposure to oil can reduce growth rates, although the findings are contradictory. Pink salmon embryos incubated in gravel contaminated with artificially weathered Prudhoe Bay Crude oil had retarded development, increased mortality, ascites and induced cytochrome P4501A activity (Marty et al., 1997). However, Brannon et al. (2006) found no significant health impacts in pink salmon embryos exposed to naturally weathered Prudhoe Bay Crude oil, and significant increases in mortalities

only occurred with artificially weathered oils at extreme concentrations of 2,250 ppm total polycyclic aromatic hydrocarbons. Rice et al., (2001) suggest that the contrasting findings and conclusions from short and long term health impact studies of *Exxon Valdez* oil on pink salmon are primarily the result of different experimental designs. The effect of parasitism on the sensitivity of coho salmon fry to oil was determined by exposing fry with different levels of ectoparasitism to several concentrations of either the water-soluble fraction of Prudhoe Bay crude oil or the aromatic hydrocarbons toluene and naphthalene. Infested fry were more sensitive to each of the toxicants than uninfested fish (Moles, 1980)

Both goldfish (Nero et al., 2006) and yellow perch (van den Heuval et al., 2000) exposed to oil sands affected waters have been shown to develop degenerative gill changes. Other reported impacts in fish experimentally exposed to water affected by oil sands include alterations in growth, hormone and hematological anomalies, compromised survival and increased mortality (Cruz-Martinez & Smits 2012). Wood frog eggs placed into the tailings ponds had delayed time to metamorphosis or incomplete metamorphosis, and detectable physiological changes included increased 7-ethoxyresorufin-O-dealkylase (EROD) enzyme activity (a detoxification enzyme often used as a biomarker of contaminant exposure in wildlife) and thyroxine (T4) levels (Hersikorn & Smits, 2011). Mass mortalities of waterfowl landing on tailings ponds, and abnormal growth rates (smaller body size and mass) in waterfowl raised on wetlands contaminated by oil sands effluent have been reported (Cruz-Martinez & Smits, 2012). We did not find any published literature on the impacts of oil sands affected waters on mammals, a finding similar to that of Cruz-Martinez and Smits (2012).

Albers (2003, p. 354) writes that bird mortality from crude oil exposure is often linked to hypothermia and drowning, with the ingestion of oils more likely to cause “debilitating sublethal effects that promote death from other causes, including starvation, disease and predation”. Reported sub-lethal physiological and histological impacts in birds exposed to crude oils in natural and laboratory settings include: decreased body weight, acute haemorrhagic gastroenteropathy, cachexia, acute gastric ulcers, urate nephropathies (Jauniaux et al., 1998); hepatic hypertrophy and decreased liver:body weight ratios (Rattner, Capizzi, LeCaptain, and Melancon, 1995); decrease size of the bursa of fabricious (which has an immunological function) (Smits & Williams, 1999); reduced growth, increased adrenal gland weight, changes in liver and spleen weights, renal necrosis, haemolytic anemia (Macdonald et al., 2010); decreased cell-mediated immunity (Olsgard, Bortolotti, Trask, and Smits, 2008); gastrointestinal irritation, pneumonia, dehydration, impaired osmoregulation, immune system suppression, hormonal

imbalance, inhibited reproduction and abnormal behaviours (Albers, 2003). Some bird species may be more sensitive than others to the effects of oil and gas (Holmes, 1984 cited in Rattner et al., 1995). Although some exceptions have been described, overall many of the sublethal impacts such as changes in performance measures and local population sizes appear to dissipate with time once the exposure ceases (Macdonald et al., 2010; Albers, 2003). Perhaps, as suggested by Jauniaux et al. (1998), mild and long-term oil exposure acts as an additional stressor that, through cumulative effects, precipitates debilitation and declines in populations.

As with birds, many of the described health impacts in mammals are as likely to be a result of hypothermia, shock and stress as with direct toxicities, and it may be difficult to distinguish between the two types of causes (Albers, 2003). The described impacts of chronic exposures in mammals share many similarities to those in birds, and include increased gastrointestinal tract hemorrhage, renal failure, anemia, pulmonary emphysema, centrilobular hepatic necrosis, altered blood chemistries and reduced body weights (Albers, 2003). In mink experimentally fed petroleum-laced feeds, feed consumption, anemia, hypoproteinemia and hypoalbuminemia were described by Beckett, Aulerich, Duffy, Patterson and Bursian (2002), and Schwartz et al. (2004) observed an increase of circulating leukocytes, enlarged livers and enlarged adrenal glands. Decreased body weights have been described in river otters that ingested petroleum products (Duffy, Bowyer, Testa, and Faro, 1994). Sea otter and harbour seal population declines in the years following the *Exxon Valdez* oil spill have been documented, unfortunately, limited “pre-spill population information, movement of animals within the region, and natural fluctuations in survival and reproduction” make it difficult to identify the true consequences of the oil spill on the health of these animals (Albers, 2003, p. 356).

Efforts to link environmental pollutants to neoplasms or local population changes are complicated by uncertainties about the interactive effects of multiple pollutants and dose-response or temporal aspects of exposures (Albers, 2003). Evidence for carcinogenic effects of hydrocarbons is best for fish although some experimental evidence implicates them as carcinogens in laboratory mammals as well (Albers, 2003). There is a significant gap in our understanding of the effects of airborne contaminants on animals (Cruz-Martinez & Smits, 2012).

Oil and gas-related contaminants, such as heavy metals and fluorides at oil refineries and aerosolized particulates, hydrogen sulfide, sulfur dioxide and volatile organic compounds in sour-gas emissions have been described in the literature, with stronger evidence of health impacts from acute-exposure laboratory studies. Cotton rats trapped on oil refinery sites had increased evidence of dental

lesions from fluoride contamination (Paranjpe et al., 1994; Rafferty et al., 2000) and hamsters that had Kuwaiti gas-well fire particulates instilled into their lungs by bronchial alveolar lavage developed pulmonary inflammatory reactions (Brian, Long, Wolfthal, Dumyahn, and Dockery, 1998). Although respiratory lesions and heart muscle degenerative changes were described in beef calves exposed to sour gas emissions (Waldner 2008a), overall there are no clear associations between sour-gas exposure and such health criteria in cattle as twinning, abortion, stillbirths and neonatal mortality (Waldner et al., 2001 a,b; Waldner 2008a; Waldner 2009, Scott et al., 2003 a,b,c). Evidence of toxicities from exposure to the chemicals used in shale-gas exploration (e.g. fracking) (Bamberger & Oswald, 2012) are anecdotal in nature, and lack data on the toxicological and histopathologic findings from the affected animals.

It is now recognized that substantial long-term impacts on animal health and ecosystem function occur from indirect, delayed and cumulative effects of persistent petroleum products in the environment. Probable modes of action for chronic impacts include interactions between natural environmental stressors and compromised health of exposed animals, chronic toxic exposure from ingesting contaminated prey or foraging around pools of oil that persist in the environment, and the disruption of important social behaviours (Peterson et al., 2003).

Significant habitat alterations result from the oil and gas exploration, extraction and transport. To date, most reports of these activities have concentrated on individual or population level effects from a conservation perspective. For example, it has been estimated that the combination of seismic exploration, pipeline right-of-way clearing, well pad clearing and oil sands mining within the Western Canadian Sedimentary Basin results in the loss or disturbance of 11,840 to 60,380 migratory bird nests annually. This results in an estimated loss of 10,200 – 41,150 potential recruits into the migratory bird population in subsequent years (Van Wilgenburg, Hobson, Bayne, and Koper, 2013). Increased vehicle or boat traffic and habitat loss can disrupt daily or migratory movements, foraging or habitat use (Marine Mammal Commission, unknown). Long-term impacts can be indirect as well and have implications for ecosystem function. It has been shown, for example, that seabirds can shift their predation patterns to exploit different species of fish than their usual prey for several years after an oil spill (Moreno, Jover, Diez, Sarda-Palomera, and Sanpera, 2013). Socio-economic impacts associated with animals and oil spills have been best described for marine oil spills and their effects on commercial fisheries. They can be considerable. It has been estimated that on average, 22% of the annual U.S. commercial catch in the Gulf of Mexico was closed after the Deepwater Horizon spill representing a potential, minimum annual loss of \$247 million (McCrea-Strub & Pauly, 2011).

Summary of effects

Petroleum products, including individual fractions of these often complex chemical mixtures, have been associated with effects ranging from mild debilitation to death. Table 2 is adapted from Albers (2003). It summarizes reported effects associated with petroleum and individual PAH exposure in vertebrate animals. Table 3 summarizes some of the impacts, species and study types covered in our review. Experimental exposure trials strongly suggests that many different species of animals are sensitive to individual compounds typically found in crude oils, petroleum, and oil and gas by-products, and that these sensitivities result in measurable, interpretable and relevant health impacts on hematological, endocrine and hepatic systems. Impacts on other body systems are more variable, and appear to be affected by the species, duration or route of exposure, and the chemical composition of the substance under study. Comparatively fewer publications described chronic exposures in animals: They were largely experimental in design and resulted in variable health impacts that may be attributed to stress and other debilitating factors. Evidence for sensitivity from natural exposure to raw oil and gas is limited, and tends to focus on disasters such as oil spills. Such observational studies tend to occur in remote, usually marine, regions where exposed humans are most likely to be those involved with clean-up efforts. Studies involving small mammals conducted at oil refinery plants and following oil fires have shown measurable and negative health effects. However, long-term exposures of livestock to sour gas wells in rural and agricultural regions have not shown consistent health effects. Overall, chronic exposures have been described but are not uniform across the petroleum industry, products and by-products, species, and affected environment.

Table 2: Reported effects associated with petroleum and individual polyaromatic hydrocarbons (PAH) exposure in vertebrate animals (adapted from Albers, 2003).

Effect	Type of Organism			
	Fish	Reptile or Amphibian	Birds	Mammals
Death	x	x	X	x
Impaired reproduction	x	x	X	x
Reduced growth and development	x	x	X	
Altered DNA	x	x	X	x
Malformations	x		X	
Neoplasia	x	x		x
Immunomodulation	x		X	x

Effect	Type of Organism			
	Fish	Reptile or Amphibian	Birds	Mammals
Endocrine effects	x		X	
Altered behaviour	x	x	X	x
Hematological effects	x	x	X	x
Hepatic or renal effects	x		X	x
Hypothermia			X	x
Epithelial inflammation		x	X	x
Altered respiratory or cardiac rates	x	x		
Gill hyperplasia	x			
Fin erosions	x			
Local population changes	x		X	x

Table 3: Summary of species, clinical signs and diagnostic findings in animals exposed to oil, gas or their constituents.

Species	Industry	Route of Exposure	Described Clinical Signs	Specific Diagnostic Tests	Diagnoses Based on Diagnostic Tests	Citation
Experimental Study Design						
Acute Exposure						
Fish	Goldfish	Oil Sands	Immersion	N/D	Steroid Assay	Decreased testosterone and 17B-estradiol levels Lister, Nero, Farwell, Dixon, and Van Der Kraak (2008)
Mammals	Canine	Oil Products	Gastrostomy Tube	N/D	Radiograph; Histology	No pulmonary pathological changes Dice et al. (1982)
	Hamster	Crude Oil	Instillation	N/D	Broncheal alveolar lavage	Pulmonary Inflammation Brian et al. (1998)
	Vervet monkeys	Oil Products	Ingestion	N/D	Necropsy	Edematous lung; Pulmonary hemorrhage Wolfsdorf & Kundig (1972)
Chronic Exposure						
Bird	American Kestrel	Crude Oil	Inhalation	N/D	Serum ELIZA for antibody; Delayed-type hypersensitivity testing; Plasma Vitamin A Histology	Decreased cell-mediated immunity; No effect on B-cell mediated immunity Olsgard et al. (2008)
	Zebra finch	Oil Sands	Ingestion	N/D		Dose dependant decrease in size of bursa of fabricius Smits & Williams (1999)
	Northern Bobwhite quail	Oil Products	Ingestion	N/D	hematology	Increased CP450 (hepatic and renal) Brausch et al. (2010)

	Species	Industry	Route of Exposure	Described Clinical Signs	Specific Diagnostic Tests	Diagnoses Based on Diagnostic Tests	Citation
Fish	Atlantic Puffin Herring gulls	Crude oil	ingestion	Lethargic, pallor –brown mucous membranes,, pulmonary granulomas	Hematology histology	Anemia, hepatic necrosis, increased splenic red pulp, decreased bursal lymphocytes	Leighton (1986)
	Goldfish; Yellow Perch	Oil Sands	Immersion	N/D	Histology	Degenerative gill changes; Degenerative liver changes	Nero et al. (2006)
	Yellow Perch	Oil Sands	Immersion	White tumor-like growths on fins; Fin erosion	Histology	Gill chloride and epithelial cell proliferation; Gill aneurysms	van den Heuval et al. (2000)
	Pink Salmon eggs	Crude Oil	Immersion	Embryo mortality	N/D	N/D	Brannon et al. (2006)
	Pink Salmon larvae	Crude Oil	Immersion	Ascites; Mortality; Premature emergence	Histology; Cytochrome P4501A	CYP1A induction; Ascites; Hepatocellular glycogen; Apoptosis of gonadal cells	Marty et al. (1997)
	Pink Salmon eggs	Crude Oil	Immersion	Decreased embryo survival, Ascities, bulging eyes, Malformed heads, short opercular plates, external haemorrhaging, Oral deformations, Decreased survival, Slower growth rate	Histology CYTOCHROME P4501A	Increased CP450, hepatocellular necrosis, epidermal and gastric cell apoptosis, peritonitis	Carls, Heintz, Marty, Rice (2005)
	Pink Salmon eggs	Crude oil, Oil products	Immersion	Decreased embryo survival, Musculoskeletal deformities	PAH levels	Increased PAH levels	Heinz et al. (1999)

Species	Industry	Route of Exposure	Described Clinical Signs	Specific Diagnostic Tests	Diagnoses Based on Diagnostic Tests	Citation	
Herring eggs	Crude Oil	Immersion	Decreased incubation, increased mortality (egg and larval), Yolk sac edema. Musculoskeletal larval defects, Decreased swimming ability	None reported	None	Carls, Rice, Hose (1999)	
Tilapia	Oil products	Peritoneal injection	Reduced feed intake, lethargy, dermal hyperpigmentation, increased mortality	Hematology, Histology, Immunology	Leukocopenia	Hart et al. (1998)	
Multiple flat fish spp	Crude oil	Immersion	Decreased growth rate Caudal fin erosion / loss	Parasite levels, liver + gill histology	Gill hyperplasia, gill clubbing; increased parasite burden	Moles & Norcross (1998)	
Mammals	Mink	Crude Oil	Ingestion	Decreased feed consumption	Hematology; Histology	Anemia; Hypoproteinemia; Hypoalbuminemia	Beckett et al. (2002)
	Mink	Oil Products	Ingestion	No clinical differences	Hematology; Fecal cortisol; Cytochrome P450 activity; Necropsy	Increased circulating leukocytes; No change in fecal cortisol; enlarged liver and adrenal gland and decreased mesenteric Lymph Node weights (in experimental animals)	Schwartz et al. (2004)
	River Otter	Crude Oil	Ingestion	Decreased body mass	Hematology	Decreased Haptoglobin and IL-6	Duffy et al. (1994)

Species	Industry	Route of Exposure	Described Clinical Signs	Specific Diagnostic Tests	Diagnoses Based on Diagnostic Tests	Citation	
River Otter	Crude Oil	Ingestion	None described	Hematology	Decreased Haptoglobin and decreased hemoglobin	David, Duffy, Bowyer et al. (2001)	
River Otter	Crude Oil	Ingestion	Fewer dives for fish	Hematology	Decreased hemoglobin	David, Williams, Ormseth (2000)	
Amphibian or Reptile	Wood Frog	Oil Sands	Dermal contact; Immersion	Delayed time to metamorphosis; Incomplete metamorphosis	Thyroid hormone quantification; Liver microsome production; EROD activity	Increased EROD activity; No difference in T3; Increased T4	Hersikorn & Smits, (2011)
Wood Frog	Oil Sands	Dermal contact	Affected frogs had increased body weight	Thyroid hormone quantification; Liver microsome production; EROD activity	No detectable physiological changes; Chemical Residues in muscle	Smits, Hersikorn, Young, and Fedorak (2012)	

Surveillance and Laboratory Diagnostic Data

Acute Exposure

Bird	Guillemot	Crude Oil	Ingestion; Dermal contact	Found dead; Decreased body weight	Necropsy	Acute haemorrhagic gastroenteropathy; Cachexia; Oil contamination; Acute gastric ulcers; Urate nephropathies	Jauniaux et al. (1998)
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Chronic Exposure

Bird	Western Sandpiper	Crude Oil	Feed; Water	N/D	Necropsy; Tissue chemical analysis;	Hepatic hypertrophy; No change in Cytochrome P450	Rattner et al. (1995) 27
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Species	Industry	Route of Exposure	Described Clinical Signs	Specific Diagnostic Tests	Diagnoses Based on Diagnostic Tests	Citation	
					Cytochrome P450 activity	activity; Decreased liver:body weight ratio	
	Kittiwakes	Crude oil	Feed; water	decreased annual return	Hematology	Anemia	Walton, Turner, Austin, Burns, Monaghan (1997)
Fish	Fish spp.	Oil Refinery	Immersion	Increased parasitic infestations	Histology	Clear-cell foci in Liver (preneoplastic); Reactive/degenerative foci in Liver	Kuehn et al. (1995)
	Fish spp.	Crude oil		N/D	Cytochrome P450;	No change in CP450 activity	Aas & Klungsoyr (1998)
					Polyaromatic hydrocarbon metabolites	No increase in polyaromatic hydrocarbon metabolites	
	Sanddab	Crude Oil	Immersion	N/D	Histology	Very little evidence of conspicuous reproductive impairment	Love & Goldberg (2009)
Mammals	Cattle	Sour Gas	Inhalation	No associated reproductive effects	N/D	N/D	Waldner (2009)
	Cattle	Sour Gas	Inhalation	No associated reproductive effects	N/D	N/D	Waldner et al. (2001a)
	Cattle	Sour Gas	Inhalation	Some association with calf mortality	Necropsy	Respiratory lesions; Skeletal and heart muscle degeneration/necrosis	Waldner (2008a)

Species	Industry	Route of Exposure	Described Clinical Signs	Specific Diagnostic Tests	Diagnoses Based on Diagnostic Tests	Citation	
River Otter	Crude Oil	Ingestion	Decreased body mass	Hematology; fecal analysis	Increased liver enzymes, increased IL6, increased fecal Porphyrins	Bowyer et al. (2003)	
Amphibian or Reptile	Marine iguana	Oil Products	Dermal contact; Ingestion	Population declines	Steroid Assay	N/D	Wikelski et al. (2002)

Review and Opinion-piece Articles

Mixed Acute and Chronic Exposures

Mammals	Cattle; Human; Other	Shale Gas Drilling	Ingestion; Inhalation	Stillbirth & abortion; Neurological; Sudden Death; Congenital defects	Necropsy	Respiratory Failure; Circulatory collapse	Bamberger & Oswald, (2012)
	Cotton Rat	Oil products	Multiple	None described	Necropsy, histology	Decreased renal size / None	Kim et al. (2001)
Multiple	Fish spp.; Bird spp.; Mammal spp.	Crude Oil	Feed; Water	Mortality; Population-level impacts	N/D	N/D	Peterson et al. (2003)
	Multiple spp.	Oil Sands	Multiple	Multiple impacts described	N/D	N/D	Cruz-Martinez & Smits, (2012)
	Multiple spp.	Oil Products	Multiple	Multiple impacts described	N/D	N/D	Albers 2003
	Multiple spp.	Crude oil	Multiple	None	N/D	Immunocompromise	Barron (2012)

	Species	Industry	Route of Exposure	Described Clinical Signs	Specific Diagnostic Tests	Diagnoses Based on Diagnostic Tests	Citation
Fish	Pink Salmon	Crude oil	Immersion / ingestion	Decreased growth; increased embryo mortality	Hematology, CP450	Elevated CP450	Rice et al. (2001)

N/D = Not explicitly described by the author, or could not be inferred from the text of the article

Spp. = Refers to “species”, and is used when no further information is available to identify the animal to a species level

Section 3: Capacity to detect, assess and communicate animal health sentinel events

The bulk of the literature focused on answering mechanistic questions about, if or how specific chemicals associated with oil could create physiological or pathological changes in test animals. There was little reference to ongoing surveillance and monitoring using animal health outcomes. Health impact assessments or environmental impact assessments using animals as sentinels were not found using our search strategy. There was no description of an integrated system of linking animal health data with human health data, and few examples of projects attempting to integrate environmental data with animal ecology and animal health were found. Because the best known situations where animals have served as indicators of potential public health risks have resulted from “serendipitous observations of animals in the wild” (van der Schalie et al., 1999, p. 312), this section begins with a review of current means by which a sick or dead animal may present to a diagnostic facility.

We found no comprehensive reviews or descriptions of Canada’s animal health surveillance system. The vast majority of publications, meetings or policy statements about animal health surveillance have focused on emerging and endemic production-limiting infectious diseases, zoonotic diseases and diseases that affect globalization and competitiveness of export markets. The National Farmed Animal Health and Welfare Council (2011) concluded that “a number of the components of a successful surveillance system already exist as strengths (e.g. qualified and experienced individuals, advanced technology, access to a central data processing process, active relationship with the public health data processing system, syndromic surveillance in some provinces, and strong surveillance for reportable diseases). Unfortunately, these strengths are not organized and coordinated nationally and there is no national leadership” (p. 8). This same council further identified an “inability to detect trends or emerging diseases because of the fragmented and inconsistent state of the existing surveillance systems across the country; and a need for a common understanding of the value of surveillance to the farmed animal industry” (2011, p. 9)

As in public health, responsibility for animal health surveillance is divided between federal, provincial and territorial governments. As in public health, animal health surveillance faces challenges with cross-jurisdictional data sharing, privacy of information concerns and standardization of surveillance components. These challenges are amplified because of the numerous stakeholders (private sector, academic laboratories, NGO’s etc) that are involved. This structure fragments disease data and

creates additional challenges in accessing results. There is no consistent program and approach to monitoring and surveillance for all animals chosen as sentinels, in all jurisdictions.

Federal diagnostic laboratories have not been established to assist in the routine investigation of animal morbidity or mortality. Federal agencies have special service labs (ex. the National Centre for Foreign Animal Disease) or laboratories that can support research (ex. Wildlife Ecotoxicology group in Environment Canada's Pacific Wildlife Research Centre). Fisheries and Oceans Canada (DFO) has fish diagnostic laboratories but their involvement in natural fish kills or disease events is limited. Federal animal health surveillance has been developed in Canada largely to support declarations of disease-free animals required for international trade. It is best equipped to track infectious diseases of livestock. The Canadian Food Inspection Agency has responsibility for terrestrial animal health and nationally reportable diseases. DFO retains responsibility for animal health in oceans and some inland waters. Otherwise, animal health responsibilities resides with the provinces, except for internationally migrating wildlife which remain under federal jurisdiction.

All provinces have some capacity for government supported veterinary diagnostic laboratories. This ranges from jurisdictions such as British Columbia that have a provincial, diagnostic laboratory accredited by the American Association of Veterinary Laboratory Diagnosticians, to Alberta which dismantled its provincial diagnostic system several years ago, relying instead on private sector and special topic government surveys and investigations. In five provinces, veterinary colleges provide additional or specialized diagnostic support and contribute to the provincial diagnostic system. Provinces can have reportable diseases distinct from those tracked federally, but they vary between provinces and tend to focus on production limiting disease for livestock. It is reasonable to conclude that none of this diagnostic capacity has been developed to monitor and assess environmental contaminants, and that toxicology capacity is very limited for contaminants associated with oil and gas.

Domestic animal health is a private sector concern based on a user-pay system. Provincial and private diagnostic laboratory-based surveillance systems targeting domestic animals depend in large part on private veterinarians or animal owners to submit samples from cases to a laboratory. Provincial diagnostic systems typically subsidize diagnostic examinations for livestock, but costs for companion animals are borne exclusively by the owners.

The cost of laboratory testing is a known barrier in the agriculture sector and decreasing animal value and government support for laboratory testing has contributed to reduced submission rates over

time (Vrbova, 2013). Various selection biases affect the ability of provincial laboratory data to estimate population prevalence and detect emerging conditions. For example, Sawford, Vollman and Stephen's (2013) study of factors influencing Alberta veterinarians decisions to submit samples to laboratories found submissions were biased toward outbreaks of unknown cause, cases with unusual mortality rates, and issues with potential herd-level implications. There is also a strong species submissions bias wherein animals of lesser economic value are under-represented in domestic animals diagnostic databases (Vrbova, 2013). These and other biases limit the capacity for statistical trend analysis of the diagnostic data to find early warning signals in a timely and reliable fashion (Vrbova, 2013). However, it has regularly been the provincial or veterinary college diagnostic facilities that have detected and investigated new animal health problems in Canada through case detection and hazard discovery activities.

Private diagnostic laboratories serve companion animals and support clinical medicine rather than surveillance or environmental impact assessment. Access to their records is affected by client confidentiality issues except where reportable diseases are involved. Private companies can support industry efforts to measure contaminants in animals or animal tissues but generally do not provide diagnostic services. Their data would be held in confidence for their clients.

There is a variety of provincial and private initiatives in agriculture that strive to find a diversity of signals to detect changing or emerging animal health problems. For example, the Canadian Swine Health Intelligence Network is an industry driven attempt to address some of the deficits in surveillance identified by the National Farmed Animal Health and Welfare Council as described above. The Alberta Veterinary Surveillance Network is a provincially run systems that includes the Veterinary Practice Surveillance program that provides a secure web-based framework for veterinarians to report poultry and livestock disease and non-disease data via the Internet to a central organization. The Quebec Animal Health Surveillance Network (Réseau d'alerte et d'information zoonitaire -Le RAIZO) is a network of experts, laboratories and practitioners that strives to find early signs of changes of livestock health in the province. Several other similar examples exist – some are time limited, some are in development but most are biased towards infectious diseases of livestock and poultry. None to our knowledge have been systematically or fully evaluated.

Wildlife diagnostic services vary considerably across jurisdiction. There are some provincial or territorial wildlife veterinarians and wildlife health programs. Parks Canada has only one veterinarian involved in managing wildlife health. Other government wildlife health programs do not provide their

own comprehensive diagnostic services, relying instead on provincial, private or university diagnostic labs supplemented with selected in-house capacities. The Canadian Wildlife Health Cooperative (formerly the Canadian Cooperative Wildlife Health Centre) is a national organization with nodes in each of Canada's five veterinary colleges plus the British Columbia Animal Health Centre. It not only provides diagnostic services but also retains a national database of wildlife diagnostic data.

Figure 2 is five year retrospective summary of incidents where five or more wild animals were investigated by the CWHC in the four western provinces as well as the Northern West Territories and the Yukon. Of the 73 incidents in the database, diagnoses were obtained for 64, five of which were toxicoses including one that involved external oil contamination. This figure highlights two key factors: (1) the CWHC does receive samples from areas involved in oil and gas, but is biased more towards southern regions where people are more likely to encounter wildlife (see for example the cluster in southwestern BC) and (2) more samples come in from areas where the diagnostic group has profile within wildlife agencies and has history and capacity to receive samples and follow-up with investigation (i.e. Saskatchewan). The CWHC has recently undertaken field investigations associated with oil and gas, examples of which include: investigation of fish and bird deaths in Fort Chipewyan, Alberta; examination of birds from oil spills, including oil sand tailings ponds, an avian cholera outbreak among gulls detected on an off-shore oil rig, and scorched Blackpoll warblers who flew into gas flares on offshore and on-shore rigs/refineries. The CWHC has also been involved in providing diagnostic and investigative services for other initiatives seeking to track impacts from oil and gas. The Fish Health Program of an industry-led regional aquatic monitoring program encourages community members to send any caught fish that look abnormal to the CWHC for an independent assessment, in an effort to understand the possible cause of the observed abnormality or health condition (Regional Aquatics Monitoring program, 2014).

The CWHC and provincial wildlife programs largely rely on citizens and wildlife workers to submit samples. As a result, most samples are biased towards geographic locations in close proximity to major urban centres (with some exceptions, e.g. Fort Nelson). Remote locations tend to be severely underrepresented. An analysis of submissions to the British Columbia provincial wildlife veterinarian illustrates this peri-urban clustering (Table 4) and shows uneven coverage of submissions across the province (Figure 3). Because wildlife do not have an owner per se, diagnostic services are supported through public funds. Budgetary considerations have been a pervasive impediment to more extensive wildlife disease diagnostic services. This may, in part, reflect the relatively small number of submissions per region seen in Table 4.

Figure 2: Five year retrospective of reports of incidents of wildlife diseases involving 5 or more animal investigated by the Canadian wildlife health cooperative 2008-2014 (February).

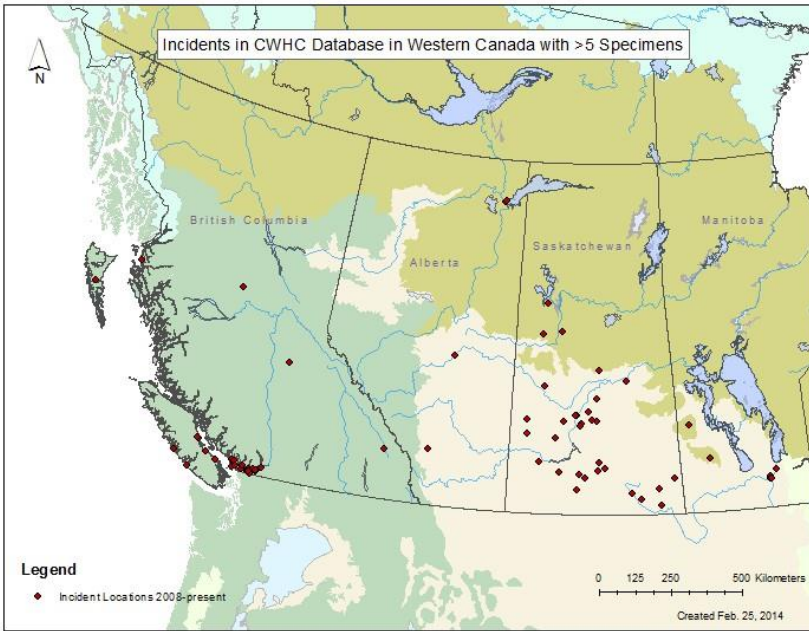


Figure 3: Proportional distribution of wildlife submissions (all species) to the British Columbia provincial, wildlife veterinarians 2002-2012 (data used with permission from Dr H Schwantje, BC Ministry of Forest, Lands and Natural Resource Operations).

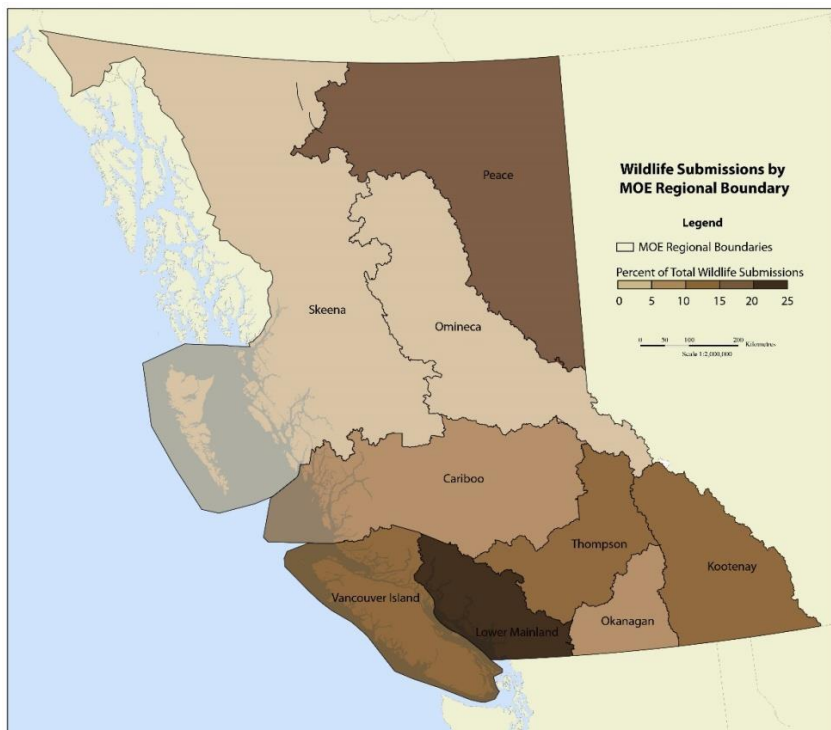
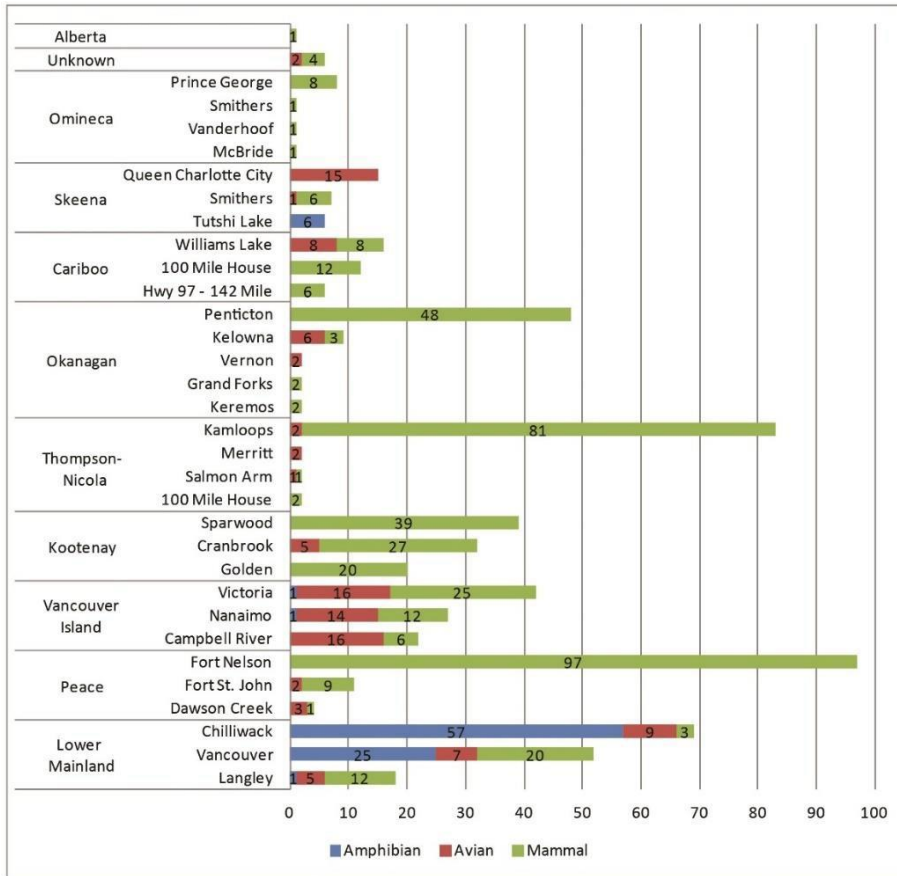


Table 4: Geographic sources of wildlife submissions to the British Columbia provincial wildlife veterinarians 2002-2012. (data used with permission from Dr H Schwantje. BC Ministry of Forest, Lands and Natural Resource Operations).



Animal health diagnostic laboratories are generally not set up for environmental hazard tracking, making the process of data extraction and analysis laborious. In addition, most attempts to integrate data from existing diagnostic laboratories have focused more on the detection of foreign animal diseases and other infectious diseases that are a threat to agriculture or public health. The Canadian Animal Health Surveillance Network (CAHSN), for example, is a network of animal health diagnostic laboratories intended to rapidly detect emerging animal health threats. CAHSN is a web-based information platform intended to link the network of animal health laboratories. Although it has shown success with some diseases (e.g. bovine spongiform encephalopathy), challenges remain in standardizing laboratories and case definitions across Canada, and it has yet to be used with non-infectious diseases.

Some governments do have capacity to investigate complaints associated with human and animal health. Alberta has a formal process for investigating complaints about impacts on animal health.

For example, the Alberta Energy Regulator, in 2013, launched investigations into complaints in the Peace River region about effects of odours and emissions coming from local oil sands development on human and animal health. Veterinarians from Manitoba Agriculture and Food have responded to complaints from local farmers regarding potential impacts of air quality issues arising from oil and gas activity on health of the livestock in the Tilston area. Results for both of these examples were not accessible within the timeline of this project.

Environmental Hazards Data

Government agencies have recently reorganized some of their contaminants programs, reducing efforts in some areas (ex. marine contaminants programs were cut at the Department of Fisheries and Oceans) and increasing interest in others (especially the oil sands). Industry also has some collaborations or requirements to monitor animals for evidence of contamination. However, most of the programs that sample animals for the presence of contaminants typically do not regularly subject those animals to diagnostic evaluation. Given the limitations described in the previous section, this creates a situation wherein agencies seeking animal health diagnoses typically do not or cannot test for contaminants and programs tracking contaminants generally do not seek diagnoses.

Environmental impact and effects monitoring has historically required lethal sampling of animals to determine tissue residues of contaminants. This limited the types of impacts that could be studied or detected. New non-lethal methods using minimally invasive biomarkers are being developed to reveal exposure to toxic substances and to indicate the magnitude of the effect. Biomarkers associated with contaminant exposure are often well preserved across vertebrate species, making them useful for cross species comparisons. Markers are being used to detect DNA damage, immunological changes, and hormonal status. An example of the use of this approach includes an academic-industry collaboration where experimental tailing ponds were used as test sites and tree swallows as sentinel animals to assess how to remediate contaminated sites. That study found “no differences among reclaimed wetland sites for tree swallow reproductive success, nestling growth rate, and immune response that could be attributed to tailings or tailings pond water additions” (Smits, Wayland, Miller, Liber, and Trudeau, 2000, p. 2951).

The Joint Canada-Alberta Implementation Plan for Oil Sands Monitoring includes a Wildlife Contaminants and Toxicology Monitoring program that focuses on assessing the levels and potential impacts on wildlife species of contaminants that may be released as a result of oil sands activities. Their

work includes sampling amphibians, colonial and insectivorous birds, using sentinel bird nest boxes and testing hunter animals, trapped animals or animals involved in interactions with tailing ponds. The program also seeks to monitor terrestrial biodiversity to attribute mechanisms for population change for key species. Data are not yet available on the program's website except for a report on mercury in birds (Government of Canada, 2013). That report noted increasing mercury levels in eggs of some but not all species nesting downstream of oil sands in northern Alberta, and implicated local sources of mercury (Hebert et al., 2013). While trends varied between species and only once exceeded toxic levels, the authors recommended continued monitoring and research to further evaluate trends and to conclusively identify sources.

Environment Canada's Integrated Oil Sands Environment Monitoring Program is linked to the program described above (Environment Canada, 2011). It includes terrestrial and aquatic components and attempts to link environmental monitoring with the monitoring of effects on wild species. Morphometrics and tissue contaminants are measured in fish from water bodies being monitored for contaminants. Amphibian development and reproduction is also tracked. Breeding water bird production and other non-lethal measures track bird health while tissue contaminants are measured in animals that are found dead or are hunted / trapped. Program descriptions emphasize inclusion of species that: (i) use habitat in oil sands regions for reproduction; (ii) are suffering population declines or are dependent on specific habitats; (iii) have cultural, traditional, nutritional, economic and/or aesthetic value; and (iv) are part of a suite of species known to show responses to a gradient of stressors. Details on sample sizes, frequency of monitoring and allocation of testing resources were not found online.

DFO set up the Centre for Offshore Oil, Gas and Energy Research (COOGER) in 2002 to support decision-making related to aquatic environmental issues associated with oil and gas development and transport. However, in 2012 DFO phased out the portion that focused on biological effects of oil and gas. In 2012, DFO also closed the nation's marine contaminants program. That program had provided world leading science on the distribution and effects of a suite of marine contaminants.

The Northern Contaminants Program is concerned with human exposure to elevated levels of contaminants in wildlife species that are important to the traditional diets of northern Aboriginal peoples. The program is chiefly interested in contaminants that reach the Arctic via long-range transport from source areas around the globe, primarily persistent organic pollutants and heavy metals such as mercury, however it does recognize the possible role of the oil and gas sector in producing some of these contaminants. Most work on animals involved tissue residue testing and thus is akin to a food

safety program, which, in domestic animals, is the responsibility of the Canadian Food Inspection Agency (CFIA). The CFIA does engage in some wildlife testing with selected ungulate hunts in northern Canada. The National Contaminants Monitoring Program routinely tests a sample of domestic animals at slaughter to establish if violative levels are below a threshold prevalence. It is focused on drugs and chemicals that could enter the food chain through agricultural practices than in testing for oil and gas related contaminants.

Some community and academic organizations undertake mortality surveys in and around oil and gas industry sights. Our review suggests that these are a patchy mosaic of ad hoc, often one-off mortality surveys, and rarely are samples sent to diagnostic facilities that either would allow association of mortality with exposures or allow such data to get into the public realm. Some exceptions exist. For example, “beached bird surveys” have been used to trace the presence of oil in marine environments and as a vague index of oil pollution of water bodies in the general area (Wiese & Ryan, 2003, p. 1090).

Regulations requiring industry to monitor animal health outcomes were not found through internet searches. We did explore in detail the BC Oil and Gas Commission website for requirements for fish and wildlife health monitoring (BC Oil & Gas Commission, 2014). No relevant articles or documents were found using the search words “health monitoring”, “animal health”, “health” and “monitoring” in the search function of this website. Of the media, annual reports and guidelines available on this website, none contained information relevant to health and toxicity monitoring in fish and wildlife. Two documents, the *Environmental Protection and Management Guideline* and the *Oil and Gas Handbook Drilling Waste Management Chapter*, did contain some information pertaining to mitigating adverse effects in fish and wildlife and their environments, and hydrocarbon monitoring (BC Oil & Gas Commission, 2013; BC Oil & Gas Commission, Unknown). Although the Environmental Protection and Management Guideline does not mention health and toxicity monitoring in animals, it does outline the need for oil and gas applicants to provide detailed mitigation strategies to prevent or reduce adverse effects on the: quality and quantity of water; diversity, productivity and sustainability of wildlife habitat and vegetation; and critical life stages of high priority wildlife. High priority wildlife were defined as those species identified under section 29 of the Oil and Gas Activities Act: Environmental Protection and Management Regulation as species at risk or species of concern under the federal Species at Risk Act, red or blue listed species by the Province of British Columbia, or otherwise have been identified as high priority wildlife (Province of British Columbia, 2010). The regulations specifically related to protecting

the environment and appropriately planning the timing and location of activities to minimize impacts. It does not provide guidance on animal health monitoring and toxicity surveillance in animals.

Section 4 of the Management Guideline and the Oil and Gas Handbook Drilling Waste Management Chapter describes the use of bioassay-based toxicity assessments to screen drilling wastes for the presence of components toxic to life forms, in particular if those components cannot be detected by routine chemical analysis. If toxins are found, the facility operator is responsible for identifying the source and managing the toxins within their overall waste disposal plan. Standards are in place for assessing petroleum hydrocarbon contamination in soils (e.g. Canada-Wide Standard for Petroleum Hydrocarbons in Soil), and Contaminated Sites Regulation (CSR) dictates that operators are responsible for performing hydrocarbon analysis for the full range of potential hydrocarbons likely to be present in the waste material, and for ensuring that the CSR standards are not exceeded (Canadian Council of Ministers of Environment, 2008).

Risk assessment

The Council of Canadian Academies (CCA, 2011) convened an expert panel on approaches to animal health risk assessment in 2011. The Panel was tasked with answering the question; What is the state and comprehensiveness of risk assessment techniques in animal health science, specifically pertaining to risks which may impact human health? The Panel concluded that animal health risk assessment in Canada seems to be meeting importation and international trade obligations. While animal health risk assessments have considered a range of consequences, the major focus is on the economic and trade consequences of infectious animal disease into Canada. A more integrated, coordinated, multidimensional approach was recommended to better support the risk-based decision-making process. The Panel concluded that integrating human health and environmental consequences into animal health risk assessments would improve their applicability and utility in risk-based decision-making (CCA, 2011).

Section 4: Conclusions

There is ample evidence of harm to animals from hazards associated with the oil and gas industries. A wide variety of species is susceptible and demonstrates measurable responses to exposures under normal production conditions nearby areas where people reside or work. These are useful attributes for sentinels (Table 5). Animals have been used to establish the toxicity of petroleum products in laboratory studies, and observational studies and quasi-experiments have associated exposures to oil and gas with pathological or physiological responses. However, there remains controversy as to the frequency or magnitude of effects of exposures outside of the laboratory or experimental setting and, thus, there are questions about the specificity and reliability of animal data for human health risk assessment.

Table 5: Summary assessment of the possible value of animals as sentinels for public health risks attributed to the oil and gas industries in Canada.

Criteria	Comments
Sensitivity to hazard	Experimental exposure trials have shown that many different species of animals are sensitive to individual compounds typically found in crude oils, petroleum, and oil and gas by-products. Evidence for sensitivity from typical exposures to raw oil and gas is more limited, with a focus in the literature on the acute health impacts from disasters such as oil spills. Long term exposure studies from oil spills and natural gas emissions show variable sensitivities.
Measurable, interpretable and relevant health impact(s)	Experimental field and laboratory exposure studies, including observational studies from oil spills, show measurable, interpretable and relevant health impacts on hematological, endocrine and hepatic systems across species. Impacts on other systems are more variable, and tend to be affected by animal species studied, duration or route of exposure, and the chemical composition of the substance under study.
Health impacts occur in animals before humans	We found no studies concurrently tracking animal and human health outcomes. This could be attributed to the lack of systematic and ongoing surveillance in either animal or public health, the lack of regular integration of human and animal health surveillance and research and/or challenges in assigning temporality to cause-effect relationships due to confounding, interacting and/or cumulative effects.
Relevant levels of exposure	Although most exposure data on animals has been controlled experimental exposures, ongoing research and monitoring are revealing measured effects under natural exposure conditions. Animals will most likely receive different doses than people due to differences in morphology, habit and diet, but they share the same exposure routes with people and are subject to the same types of general environmental contamination.
Geographic and temporal overlap between hazards, animals and people	While no single species occupies all possible media or exposure routes, there is a diversity of species able to show measurable responses to exposures that can be found in oil and gas development areas. Fish and wildlife are more abundant in northern and marine settings and thus more likely to be in exposure pathways whereas in southern locations, domestic animals offer the advantage of being contained and often in closer proximity to

Criteria	Comments
	people. Migratory wildlife presents problems as sentinels as they may move into and out of exposure areas, complicating attempts to identify specific geographic sources of contaminants.
Evidence is suitable for decision-makers	There is no consensus or standards with which one can incorporate animal health data into public health risk assessment or policy making. Opinions on the strength and utility of the evidence are diverse. Animal evidence can be very provocative for the public and has special significance for many Aboriginal communities and decision makers.

Animals may not be ideal sentinels for the oil and gas sectors for a number of reasons. First, most effort has focused on conventional oil spills and, more recently, oil sands. Little is written about animal responses to natural gas products (the large western Canadian study of the effects of sour gas on cattle is an important exception). Other hazardous situations – including the effects of ‘fracking fluids’, industrial wastes and chemicals associated with extraction and refinement, and habitat disturbance – have received comparatively little attention. This lack of research to date in these situations precludes evidence-based conclusions on the selection of specific animal health outcomes, limiting animal sentinels as general indicators of possible exposures or effects. The interaction of different chemical compounds with environmental and ecological variables results in a highly variable system that could result in a diversity of impacts in a variety of species. Therefore, there is no single “right” sentinel species or sentinel lesion to track. The available science is not yet able to identify specific animal outcomes, prevalence or intensity that could be actionable measures of human risk (except as a signal for further investigation). Additional research would be required to determine their utility across the oil and gas industries.

Second, we found no studies that concurrently examined outcomes and exposures in people and animals, making it hard to conclude that animals experience health impacts before people. Ongoing systematic animal health surveillance for detection and assessment of oil and gas industrial effects does not exist. Generally, animals are used as biological indicators of exposures or effects in restricted circumstances and rarely are they linked to human health outcomes (with some exceptions). Third, the strength of associations between animal effects and exposures are better for specific chemicals under controlled situations for subclinical, biochemical or physiological changes than for morbidity or mortality outcomes under normal industrial exposure settings (except for oil spills). Certainty in causal associations is, therefore, weaker for the animal health outcomes that most typically come to the attention of public health (i.e. bird die-offs, outbreaks of dermal lesions on fish; occurrence of tumours on large mammals). Fourth, exposure assessments were under-represented in the literature. The bulk of

work has either involved controlled exposures in experimental settings, has assumed exposure due to proximity of animals to an exposure source, or has been unable to fully characterize exposure due to the multitude of chemicals that are associated with oil and gas. The majority of work we found failed to take a cumulative effects perspective. While some did look at oil or gas as a whole (i.e. as a product composed of several toxic compounds) and a few looked at interactions of an oil or gas associated chemicals with other toxins or environmental conditions, none took a 'total-pollutants' perspective. Finally, we found no clear guidelines as to how animal data should be used in public health risk assessments, particularly at a local level.

Despite the limitations of animals as sentinels, animal health information should remain central to addressing concerns over the environmental and human health impacts of the oil and gas sectors. Significant investment has been and continues to be directed towards collecting and assessing animal health data in conjunction with measures of environmental contamination in order to detect, describe and assess environmental impacts. The majority of this work currently deals with the oil sands, leaving other sectors under-represented. Such studies are expensive, require prolonged time periods and are restricted to specific sites, hazards and outcomes. However, they are proving valuable for both generating and testing specific hypotheses about the distribution of contaminants and mechanisms of harm.

There are private, public and university laboratories that routinely receive diagnostic samples from wildlife and domestic animals that inhabit oil or gas production, transportation or refinement areas. Although economic barriers result in insufficient numbers to estimate prevalence or do statistical trend analysis as well as limit capacity for toxicology testing, these laboratories do provide capacity to assess animal health outcomes considered to be of greatest concern to the public. General diagnostic pathology plus field investigation capacity have been deployed to assess die-offs, outbreaks and unusual pathology or productivity in animals exposed to oil or gas production. Historically, general diagnostic and field investigation services have been central to identifying new and emerging health impacts from environmental pollution. Equally important, they provide rigour and response that can rule-out public concern by determining when the specific cause of death is due to something other than oil and gas associated hazards.

A number of initiatives focus on sampling animals for the presence of chemical contaminants. An infrastructure for testing has been developed through the National Chemical Residue Monitoring Program, the Northern Contaminants Program and other programs, but none emphasise oil and gas

associated chemicals. New programs, such as the joint Canada-Alberta plan for oil sands monitoring, do collect samples from hunted and fished wildlife and test for a selection of contaminants. Provincial wildlife health programs, sometimes along with Aboriginal communities or governments, have or are developing capacity to expand food safety testing of hunted and fished species. Industry too has been involved in sampling to identify tissue residues in some edible species.

Despite these and other activities, we found no ongoing, systematic approach to integrating animal health information related to the oil and gas sector and assessing it from a public health perspective. While the concept of One Health (which aims to link human and animal health information) has gained much attention in recent years, it has almost exclusively focused on infectious diseases. New relationships and governance models have been developed in Canada because of One Health thinking, but they have not been adequately extended to include contaminants.

Section 5: Recommendations

Animal Health Observatory for Oil and Gas

Health observatories are typically composed of small groups of highly qualified people who can network to provide health intelligence. They synthesise existing data and target specific areas for data collection to highlight health issues in order to inform policies and actions. Canada currently lacks an independent program that can synthesize and assess the current information on animals and animal health, and share that with public health to inform risk assessment, action or policy.

It is likely that an animal health observatory will need to reside within a 'neutral' party that lacks legislative or regulatory authority and is able to forge links across programs, industry and government agencies. Because the species, settings and hazard will differ with production type and location (e.g. offshore oil vs. hydraulic fracturing for natural gas), more than one observatory in more than one location may be required.

The observatory could have the dual responsibility of knowledge synthesis and mobilization. Synthesis would focus on trying to link various data and assemble it in a manner most useful for the intended audience (i.e. public health, public assurance, conservation). Knowledge mobilization would focus on ensuring parties responsible for interpreting animal health from a human health impact perspective have the most up-to-date information on the significance of animal health outcomes as

indicators of risk or impact. It could also support standardization of data generation and collection to facilitate synthesis of research and monitoring outputs.

Framework for use of animal data for public health purposes

Multiple independent studies and initiatives related to oil and gas impacts have been undertaken in recent years in academia, government and industry. However, there is currently no single commonly accepted approach to the assessment and application of animal health information for human health impact assessment or management. Extending the One Health philosophy to environmental contaminants would provide a foundation for further dialogue on how to collect, integrate and interpret animal, environmental and human health data together. A shared framework for using animal health information for public health purposes could guide future monitoring and assessment and could make environmental and health impact monitoring more efficient and consistent.

Enhanced response and investigative capacity

The current capacity to respond to public animal health concerns is limited by economic barriers that reduce the number of samples that can be examined, the proportion that can be toxicologically tested and the frequency of follow-up field investigations. Canada has highly trained personnel and facilities to support diagnostics, but most of this capacity is remote from oil and gas sites.

In the past, agribusiness supported a fund to the Western College of Veterinary Medicine that allowed investigators to undertake outbreak investigations. This was an annual fund that was used at the discretion of faculty to investigate diseases that could have public health or agribusiness significance. A similar model to funding an academic organization, the Canadian Wildlife Health Centre, or other similar program could be a significant step towards removing some of the limitations to following up on public concern or questions from public health. A parallel funding strategy would replace some of the lost federal and provincial capacity for toxicology testing.

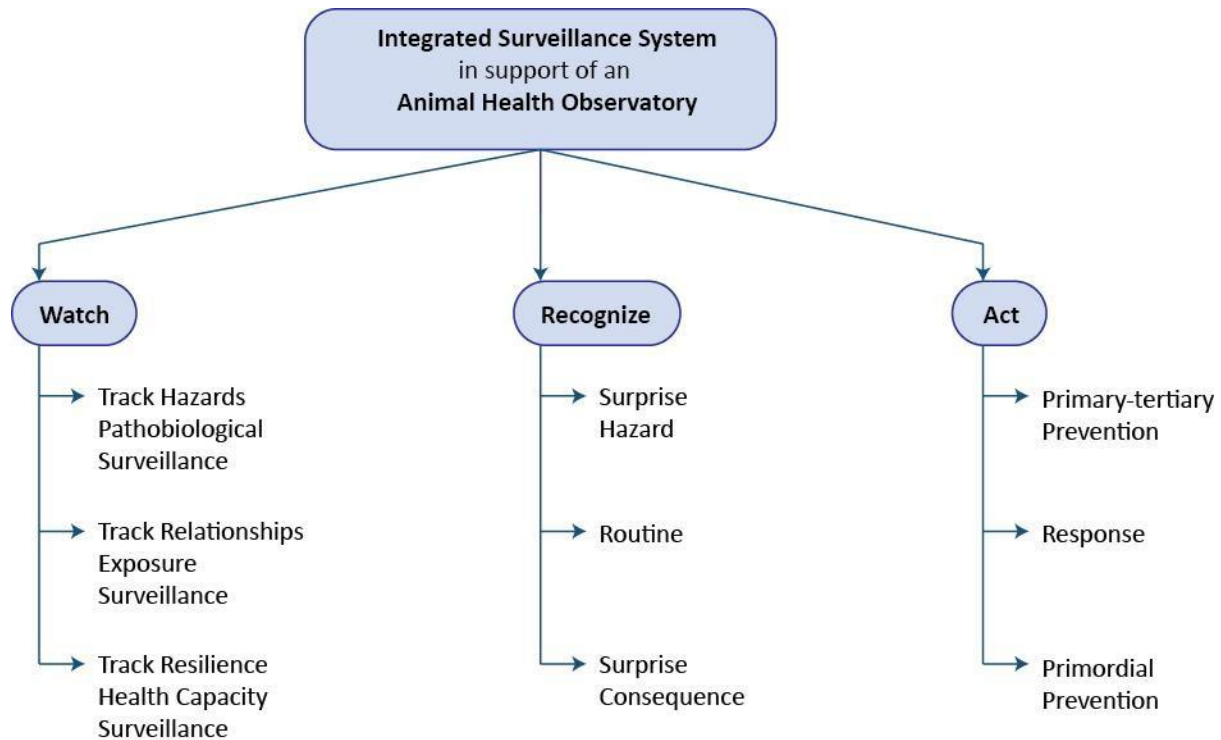
It is highly likely that most of the investigations will be of ‘false positives’ – animal health events presumed to be due to oil or gas industries but actually due to other factors such as infectious disease, environmental stressors, predation etc. The ability to assure the public that animals are not affected by pollution and that their food remains safe is an important product of enhanced response and investigative capacity.

Surveillance Science

It may seem intuitively appealing to recommend mandatory animal health surveillance in and around all oil and gas facilities. However, this review has highlighted significant impediments to the selection and interpretation of sentinel species to be monitored. Ongoing research is required to help design reliable and meaningful surveillance and monitoring. Not only is additional research needed to clarify cause-effect relationships but also new approaches to surveillance are needed to deal with cumulative effects monitoring. Figure 4 is a conceptual model of a monitoring program that may allow for the acquisition of the diversity of information needed to understand the significance of signals derived from animal health surveillance. This figure links to the concept of the animal health observatory.

Funding for research should address the imbalance in research occurring in different oil and gas sectors. Although the oil sands out pace all other sectors in terms of production, attention must also be placed on the burgeoning natural gas sector as well as offshore sources of oil. Funding for projects that aim to integrate human, animal and environmental information are notoriously difficult to fund in Canada as Tri-Council and other academic funding sources tend to separate human, animal and environmental health; making interdisciplinary work challenging to fund. Public-private consortia do exist for some projects and should be encouraged to address some of the research and development recommendations outlined in this report.

Figure 4: A conceptual model of an integrated surveillance system aimed to support an animal health observatory. Elements of this model also identify areas for surveillance science research.



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Appendix 1: Literature Search Terms

Database and Search Date	Key word	Total Results	Relevant Results
Google Scholar			
13/1/14	"animal health" and outcome*	49,000	-
13/1/14	"animal health outcomes"	42	-
13/1/14	"animal sentinel"	126	-
13/1/14	"animal sentinel" and "health outcomes"	13 (5)	5
13/1/14	"animal health" and environment and (toxin or chemical or oil or gas or petroleum)	2,120	-
13/1/14	"animal health outcomes" and environment and (toxin or chemical or oil or gas or petroleum)	0	-
13/1/14	"animal health" and "environment pollution" and (toxic or chemical or oil or gas or petroleum)	34	-
17/1/14	"animal health" and (oil or gas or petroleum)	3,810	-
Google			
13/1/14	oil and gas development and animal health surveillance	17,200,000	-
14/1/14	animal environment health pollution OR chemical OR toxin OR oil OR gas OR petroleum "oil and gas" filetype:pdf	1,040,000	-
14/1/14	"animal health" "oil and gas"	231,000	-
Canary database (canarydatabase.org)			
15/1/14	gas or petroleum or hydrocarbon or oil	144	-
15/1/14	(gas or petroleum or hydrocarbon or oil) NOT ("heavy metal" or warfare or "nerve gas" or "mill" or mine)	109 (22)	22
JSTOR			
19/1/14	((("animal health") AND (petroleum)) AND (cty:(journal) AND ty:(fla)) AND (year:[1990 TO 2014]) AND disc:(aquaticsciences-discipline OR environmentalscience-discipline OR health-discipline OR healthsciences-discipline OR publichealth-discipline OR zoology-discipline))	42 (0)	0
Web of Science			
19/1/14	TOPIC: ((oil or gas or petroleum) and development) AND TOPIC: ("animal health") Timespan=1990-2014. Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH.		CPCI-S, CPCI-SSH.
19/1/14	TOPIC: ((oil or gas or petroleum) and toxic*) AND TOPIC: ("animal health") Timespan=1990-2014. Indexes=SCI-EXPANDED, SSCI, A&HCI,	19/1/14	TOPIC: ((oil or

gas or petroleum) and toxic*) AND **TOPIC:** ("health outcomes") AND
TOPIC: (animal or mammal or bird or avian or reptile or amphibian or
fish)

27 (0) 0

38 (0) 0

6 (0) 0

Database and Search Date	Key word	Total Results	Relevant Results
	<i>Timespan=1990-2014. Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH.</i>		
06/02/14	Forward Citation Search on relevant Authors/Papers	269 (14)	14
BioOne			
23/1/14	"oil and gas" or petroleum or toxicology and Criteria:Abstract	135 (1)	1
23/1/14	Toxic* and ("oil and gas" or petroleum)	0	
23/1/14	toxic* and "animal health" and ("oil and gas" or petroleum) and Criteria:Full Text	13 (0)	0
23/1/14	(animal and health and disease and toxic* and Criteria:Abstract) and ("oil and gas" or petroleum and Criteria:Full Text)	0	-
23/1/14	(animal and (health or disease or pathology or toxic*) and Criteria:Abstract) and (("oil and gas" or petroleum and Criteria:Full Text)	9 (0)	0
PubMed			
23/1/14	((health or disease or pathology or toxic*)) AND ("oil and gas" or petroleum or "tar sands" or fracking) AND (animal or mammal or bird or avian or reptile or amphibian or fish)	4984	-
23/1/14	((health or disease or pathology or toxic*[Title/Abstract])) AND ("oil and gas" or petroleum or "tar sands" or fracking[Title/Abstract])) AND (animal or mammal or bird or avian or reptile or amphibian or fish[Title/Abstract])	3996	-
23/1/14	((animal) AND (health or disease or pathology or toxic*)) AND ("oil and gas" or petroleum)	2486	-
23/1/14	((animal[Title/Abstract]) AND (health or disease or pathology or toxic*[Title/Abstract])) AND ("oil and gas" or petroleum[Title/Abstract])	84 (6)	6

Appendix 2: Additional background on the oil and gas industry in Canada

Prepared by Jessica Romanow. Faculty of Veterinary Medicine. University of Calgary as part of a senior rotation at the Centre for Coastal Health, January 2014.

The oil and gas industry is comprised of multiple diverse and complex processes that are used to extract oil and natural gas from the environment. The industry is categorized into the following systems: exploration, upstream and downstream (Devold, 2013). The exploration process includes surveying and geological mapping to identify oil and gas deposits (Devold, 2013). The upstream sector is responsible for oil production through various methods, such as conventional and offshore drilling, tar sands and hydraulic fracturing. Downstream sectors are responsible for refining, distributing and marketing oil and gas products. The complex methods and chemicals that are required to produce and refine oil and gas may have potential risk of environmental contamination. Understanding the processes behind extraction and refinement can help better understand the potential exposure pathways and hazards associated with the oil and gas industry.

Natural gas

Natural gas is a combustible fossil fuel that is composed hydrocarbons, primarily methane (Government of Alberta, 2013). It is found underground in pressurized reservoirs trapped between layers of rock (Government of Alberta, 2013), and can be extracted from those reservoirs through conventional and unconventional methods.

Conventional methods focus on extracting free gas in porous zones of carbonate, sandstone, and siltstone formations (CAPP, 2014). Once a suitable gas formation has been identified, the area must be cleared for installation of a well head. The change of landscape may lead to habitat destruction, loss of soil productivity and erosion. Vertical or directional drilling is used to reach the reservoir, to an average depth of 1524 meters. Steel casings placed in the well are encased in the borehole by cement (NRC, 2013), and steel production tubing's connected to valves and pipelines at the surface are fed down the casings. The casing at that level of the gas reservoir is then perforated, which allows for the highly pressurized natural gas to rise to the surface where it can be collected. The extraction process can lead to contamination of ground water and surrounding soil if benzenes and formaldehyde are spilled on the surface or leak through cracks in the cement or casings in the well bore. The raw gas is dehydrated using glycol dehydration or flash tank condensers to remove most of its water before it is transported through a network of pipelines to a gas processing plant for refinement (NRC, 2013). There is potential

for air pollution through accidental leaks in the valves and pipes. The EPA has suggested that 2.5% of all natural gas produced is leaked to the atmosphere, leading to possible methane, hydrogen sulfide, benzene, toluene, ethylbenzene, xylenes and hexanes and carbon monoxide emissions (EPA, 2012; Earthworks, unknown)

Unconventional gas does not flow freely through the rock like conventional gas, and is found in low permeability rock formations such as tight sands, tight shale and coal beds (EPA, 2014).

Conventional drilling methods are unable to extract the gas so the process of hydraulic fracturing (“fracking”) is used to allow access to the gas. Fracking operations have recently increased in popularity due to their ability to increase the longevity of current wells, as well as their ability to extract large quantities of oil and gas at a minimal cost (EPA, 2014).

The process begins with the building of access roads and the clearing of a 3-5 acre site that will house the wellheads and materials required for fracking. In preparation for fracking, a vertical pathway ranging in depth from 1524-3657.6 meters is drilled (Rahm, 2011). The drilling process requires the addition of drilling fluid that can be comprised of compressed air, water, barite, clay, and chemical additives, and these assist in the cutting of the hole and lubrication of the drill. Upon completion of drilling the fluid must be collected and disposed of correctly. Steel casings are then inserted into the borehole. These casings are built to withstand extreme temperatures and pressure in order to separate the environment from the fracking process. The casings are placed central in the borehole and cement is then poured around it. The cement provides mechanical support to the hole and acts as a barrier to prevent back flow of fluids up the well. However, it has been documented that over time even properly constructed wells can fail due to corrosion and effects of down hole stresses (Bellabarba et al., 2008). The hole is then drilled to extend into a horizontal plane, averaging 600 meters (Rahm, 2011).

Large volumes, 7.6 to 19 million liters per well, of ground or surface water are collected for use in the fracking process, which may lead to water quality or quantity problems for the area (EPA, 2014). Chemical additives, proppants and water are mixed to create hydraulic fracturing fluid. The composition of the fluid is dependent on the company but often contains corrosion inhibitors, friction reducers, clay controls, crosslinkers, scale inhibitors, breakers, iron controls, gellants, biocides, and acids. A compiled list of 632 chemicals has been associated with fracking fluid, with many of them linked to potential health effects (Colborne et al., 2010). The fluid is pressurized and injected down the encased borehole. The pressure of the injected fluid causes the rock bed along the horizontal plane to crack and release natural gas that can be collected at the ground surface. The proppant is sand or ceramic particles that

are added to the fluid to keep the cracks in the rock bed open during the extraction process. There is concern that fluids may leak into surrounding water tables via well failure or fractures in the rock during the injection process; the mobilization of naturally occurring substances such as metal or radioactive materials in the rock may also result in contamination of the water table or surrounding soils (Olmstead, Muehlenbachs, Shih, Chu, and Krupnick, 2013; EPA, 2014).

When the pressure on the well is released the hydraulic fluid, natural gas, and formation water flows back up the well to the ground surface to be collected. The fluid collected may only reflect 15-85% of all fluid used during the fracking process (Rahm, 2011) The resurfaced hydraulic fluid is collected and stored on site in tanks or in pits before it is transported for water treatment, disposed of in surface water bodies or injected underground (Soeder & Kappel, 2009). The management of flow-back fluids may lead to contaminants entering the water table or nearby soils through drilling site discharge, spills during storage and transport, and inadequate disposal and treatment of waste water (Rozell & Reavan, 2012). A probability-bound analysis of potential water contamination completed by Rozell and Reavan (2012) showed that it is highly probable that up to 200 m² of contaminated fluid is leaked into the environment per each individual well.

Fracking may also cause air pollution via the release of fugitive gasses through pipe or valve leaks, on-site spills and exhaust release from equipment (Colborn et al., 2010). The mixture of volatile compounds, methane, and Benzene, Toluene, ethylbenzene, and Xylene (BTEX), and other hydrocarbons may be leaked from the site and mix with equipment nitrogen oxides in the air, which can potentially result in the formation of ground level ozone. Ground level ozone is highly reactive and can cause potential health issues as well as damage to flora surrounding the site (Colborn et al., 2010).

Natural gas from both conventional and unconventional methods is primarily transported through a network of pipelines that carry the raw gas from the well head to the gas processing plant (Energy Information Administration [EIA], 2006). The raw gas is then treated to remove impurities such as hydrogen sulfide, butane, propane, helium, carbon dioxide, mercury, and water (Abdel-Aal, unknown). Any liquid impurities that have economic value, such as butane, ethane, pentanes and propane, are separated through absorption or cryogenic expansion processes to be resold (Abdel-Aal, unknown). Removal of sulfur compounds and carbon dioxide from the natural gas is critical to reduce potential adverse health effects and is completed through the process of 'sweetening' with an amine solution (Abdel-Aal, unknown). The waste is then treated with the Claus process, a thermal and catalytic reaction to extract 97% sulfur from the waste gas (EIA, 2006). An additional 1% of sulfur can be

recovered through incineration of the gas through a process called flaring. Flaring is the combustion of waste gasses prior to their release into the atmosphere.

Refined natural gas is then pressurized moved large distances through transmission pipelines. The TransCanada Mainline extends from Alberta to Montreal and is one of the world's largest gas pipelines (Government of Alberta, 2013). Once the gas reaches its final destination an odorant is added to the gas and it flows through a low pressure distribution pipeline system where it is pumped through regulators at its point of use (Government of Alberta 2013; NRC, 2013). During transportation, leaks in the pipelines and valves can lead to methane and other hydrocarbons being released into the atmosphere. When not in the pipeline system, natural gas is stored pressurized underground or in a liquid form above ground in insulated cylindrical storage tanks.

Petroleum

Crude oil is a hydrocarbon based liquid that is formed by the compression and heating of organic matter over long periods of time (Kraus, 2011). Oil is located in underground reservoirs, and is found with seismology and gravity meters (Kraus, 2011). Once an appropriate drill site is identified it is surveyed for the following conditions: it must be a suitable for clearing and leveling; it must be accessible by road; a nearby water source is critical; there needs to be space for a plastic-lined reserve pit to collect the rock cuttings and drilling mud waste created during the drilling process.

Then a rig is set up to drill the well. It is powered by large diesel engines. Vertical drilling commences and drilling mud, a mixture of water, clay, weighting materials and chemicals, is pushed down the hole to lift the rock cuttings from the drill bit to the surface (Kraus, 2011). There is potential for the chemicals used in the drilling mud to leach into the soil or surrounding water table. The wellbore is lined with steel casing and cemented to seal the hole so that, in theory, all materials only rise via the steel casing hole. A perforating gun is lowered into the well to create perforations in the casing at the depth of the oil to allow for flow into the casings. Tubing is lowered down the pipe to facilitate passage of the crude oil to the surface where its flow is regulated by a valve at the ground surface. Acid or a blended fluid containing proppants is pumped down the and into the perforation holes to create pressure and flow of oil up towards the surface; this fluid is collected at the surface and either placed in the lined pit or transported for disposal. Once the oil is flowing a pump that creates suction is attached to the well head to draw the oil up. If the oil is too viscous to flow a second hole is drilled and steam is injected into the reservoir. The oil is then collected and transported for refinement. During the drilling

and collection process there is potential for casing leakage or accidental spills of crude oil that may leech into the soil or water table. Increased air emissions during the exploration and drilling process are seen with conventional drilling.

Oil reserves are also located on ocean and lake floors. These reserves are extracted through off-shore conventional drilling. Seismic waves used to detect oil deposits during exploration may cause harm and disorientation to aquatic animals (NRDC, 2009). The seismic survey may last up to several weeks and sound waves reach 250 dB; sound waves are reflected off of the sea floor. The disturbance caused from the seismic waves can alter the ability of marine animals to forage, escape predation, migrate, and reproduce (NRDC, 2009). The extraction process is similar to conventional drilling with the exception that a floating platform fixed to the ocean floor is constructed to contain the drilling rig and pump. The platform may also include worker accommodations. The supplies to create the platform are hauled to the site using helicopters and boats; this increases the noise, fuel emissions, and human activity in the area. There is increased onshore activity and infrastructure close to the off-shore well (NRDC, 2009). Vertical and directional drilling techniques are used to reach the oil deposits. Drilling mud containing, water, clay, barite, and chemicals is sent down the drill bit to lubricate the drill and help the rock fragments leave the well hole. A blowout prevention system is installed on the ocean floor in case pressurized oil is hit prior to the installation of well casings, and when activated in the case of oil back flow closes a valve that redirects all fluid into containment systems on the ocean floor to prevent the oil from flowing freely into the ocean. Once steel casings are cemented down the well, a smaller drill bores its way into the oil deposit and the bottom of the shaft is cased to close off the oil reservoir. A perforating gun is then used to blast holes into the casing at different depths to allow for the oil to surface under low pressure. As the pressure declines a pump is required to bring the oil to the surface. During this process there is potential for drilling mud and oil to leak into and contaminate the water. In 2010 a Deepwater horizon offshore platform experienced an explosion and released 4.9 million barrels of oil into the surrounding water (Spier, Stringfellow, Hazen, and Conrad, 2012). During the leak water samples analyzed concluded over 150 chemicals were introduced into the ocean (Spier et al., 2012). The act of drilling may also disturb natural stores of lead, mercury, and arsenic and release it into the surrounding water.

Bitumen is a form of semi-solid petroleum that along with sandstone, sand, clay, and water make up what is known as the oil sands. The oils sands are classified as unconventional petroleum deposits because the viscous nature of the bitumen makes it impossible to extract using conventional

methods. The percentage of oil that is recovered from the oil sands is variable based on the method of extraction, with mining yielding the highest rate of recovery. However, only 20% of the oil sands can be recovered through mining, the rest is recovered through in-situ methods such as conventional oil, conventional oil enhanced methods, bitumen cyclic steam stimulation, and steam assisted gravity drainage (Energy Alberta, 2013).

Bitumen deposits are frequently found under muskeg, and deposits within 75 m of the surface are extracted through mining. Once the muskeg has been removed, hydraulic shovels excavate the oil sand. For every one barrel of oil produced, approximately two tons of sand are mined (Oil Shale & Tar Sands Programmatic EIS, 2012, Energy Alberta, 2013). The oil sands are loaded into trucks that transport the oil sand to a cleaning plant where the bitumen is separated from the sand with the assistance of hot water, caustic soda and diluents including naphthenic and parafanic acids (Siwik et al., 2000). The bitumen is transported via pipelines to refineries where it is processed. The sand, water, ions leached from bitumen and chemical mixture is considered a waste product and is collected and stored in outdoor surface 'tailing' ponds. The tailing ponds are acutely toxic due to the naphthenic acids and have high salinity (MacKinnon & Boerger, 1986). There is potential for tailings to leech into nearby soil and water tables (MacKinnon & Boerger, 1986). Mining of the oil sands also leads to considerably high greenhouse gas (GHG) emissions, contributing approximately 22.9% of all GHG emissions (Energy Alberta, 2013). In comparison conventional oil extraction only contribute 6.9% of GHG emissions (Energy Alberta, 2013).

Bitumen that is buried 350-600 m is too deep to be mined and requires in situ recovery. In situ methods are similar to conventional oil but they require steam, solvents or thermal energy to reduce the viscosity of bitumen to allow it to flow up a well head. The most common in situ method is steam assisted gravity drainage (SAGD) operations (Energy Alberta, 2013). Once a suitable area has been identified, the land is cleared and two horizontal wells are dug. The bore holes are lined with cemented casings with perforations in the distal casings. Above ground, water is transformed into steam and piped down the well site where it heats the bitumen to room temperature. Two barrels of surface water is required for every barrel of oil produced. Once heated the bitumen flows by gravity downwards where it is collected by the second horizontal well where it condenses with the steam and flows to the surface. The oil and condensed steam is collected and piped from the well to the cleaning plant where the bitumen is separated from the water. Approximately 90% of the water is recovered and is recycled for

further use in SAGD operations (Energy Alberta, 2013). The other 10% either remains in the well or is lost through evaporation.

Regardless of the extraction methods used, crude oil is transported via pipeline, truck or rail to an oil refinery. The refinery then processes crude oil into its useable form as petroleum products, such as fuels (e.g. gasoline, diesel), non-fuel products (e.g. greases, asphalt) and raw materials for the chemical industry (Environment Canada, 2013). Refining crude oil involves many chemical processes. The crude oil is first desalted to remove contaminants from the oil that may lead to equipment corrosion. Desalting requires the oil to be washed with large amounts of water. The waste water is collected and contains many chemicals, most notably benzenes. The crude oil then goes through catalytic reforming and cracking, which changes the crude oils long molecules into shorter lighter molecules. This has been described as the largest source of airway pollution during the refinement process as it emits SO₂, NO_x, CO, PM, metals and ammonia into the air (EPA, 2011a). The last stages of refinement include sulfur recovery, thermal processing, and delayed coking, which lead to the final products of gas oil and petroleum coke. These processes also emit waste gasses.

All waste gasses are collected and go through a flaring or scrubbing process before being released back into the atmosphere. Scrubbers built into smoke stacks remove organic contaminants from the waste gas by changing them into a liquid form that then falls back down the smoke stack and is collected as waste water (EPA, 2011a). Flares are combustion controlled devices that burn off flammable gases as they enter the atmosphere (EPA, 2011a). There is risk that air emissions may still contain contaminants, which can have negative effects on the surrounding environment. Oil refineries have also been linked to environmental disturbances due to vibrations and noise that are emitted during the refinement process.

The oil and gas industry employs many methods for extraction and refinement. Although the processes may be different, overall the patterns of exploration, extraction, and processing are similar. A number of hazards and risks to the neighboring environment as a result of these processes have been described. By examining the processes of oil and gas extraction and refinement, we can better understand the multiple potential pathways where these hazards may come in contact with the environment.