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Accessing and Mobilizing "New" Data to Evaluate Emerging Environmental Impacts on Semi-Aquatic Mammals

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Abstract: This paper describes how knowledge mobilization evolved during a study that assessed a proposed increase in industrial water withdrawals from the Athabasca River in northern Alberta, Canada, and potential impacts on a suite of freshwater semi-aquatic mammals in the broader ecosystem. The oil sands region in northeastern Alberta faces various pressures that require rapid knowledge mobilization and decision making, while still acknowledging ecological sensitivities immediately downstream in the Peace-Athabasca Delta (PAD) in the Wood Buffalo National Park. Data were acquired using a multi-faceted approach, including literature reviews, acquisition and synthesis of raw data, and interviews with local knowledge holders. The final outcome of the study was then contextualized relative to elements of knowledge mobilization: (1) research, (2) dissemination, (3) uptake, (4) implementation, and (5) impact. Knowledge mobilization was easiest to quantify for the first two elements, yet was still present in varying forms in the latter stages. The cultural importance of beavers, muskrats, river otters, and mink for communities associated with the Athabasca River and the PAD allowed for increased engagement during all stages of the research process, which then facilitated the co-production of potential solutions among different organization and perspectives.

Keywords: data sources; Indigenous knowledge; industrial development; semi-aquatic mammals

1. Introduction

Understanding the potential impacts of temporal and spatial availability of fresh water is critical for the wise allocation and management of surface water at various scales. Many allocation schemes have a distinct focus on human needs [1], while over time there has been growing awareness of the obligation to meet ecological requirements as well [1,2]. The difficulty comes in balancing the two perspectives; it seems easier to quantify the average number of cubic meters of water required to run a household or an industry than to calculate required water depths, flow rates, and temperatures in the context of seasonal variability and ecological processes. Quantification of water storage, use, and renewal is difficult enough on just one major river system, especially when incorporating ecological considerations, but applying hydrological modeling and ecological predictions to areas where multiple major rivers and associated water bodies converge presents even greater challenges [3,4]. Various studies on the impacts that water allocation schemes have on fish highlight these challenges [5,6], while studies of other vertebrates (e.g., semi-aquatic mammals) are rare or non-existent for some species, and require multidisciplinary approaches for others, as seen with muskrats in northern Canada [7,8]. Despite the ability to access water-flow data from government agencies and peer-reviewed flow models and methods from the literature, synthesizing and translating those data into an ecological and land-based context requires more nuanced sources of original data and experiential knowledge. Hydrological modeling is just one tool in an overall assessment of how freshwater-dependent species might respond to environmental change; therefore, an integration of multiple data sources is needed to fully understand the ecological, cultural, and socio-economic implications of anthropogenic impacts on freshwater systems.

Globally, human demand for fresh water increased dramatically from 1900 to 2000 [9], which reflects concurrent population increases and associated water withdrawals for urbanization, industrialization and, in particular, irrigation [10]. According to the Government of Canada (www.canada.ca), Canada has 20% of the world's total freshwater resources, of which only 7% are considered renewable (i.e., returned back into the hydrological cycle in a usable form). In 2017, total withdrawals of fresh water were 35.6 billion m^3/year, with 78.9% used for industrial activities (2015 values; http://www.fao.org). As such, Canada is the 10th highest consumer of fresh water per capita in the world, despite having less than 0.5% of the world's population. The United States, at 444.3 billion m^3/year (47.2% of which is for industrial uses), is second only to China (598.1 billion m^3/year) in per capita water use (https://data.oecd.org). Rivers represent some of the most physiographically complex sources of fresh water because of their natural fluctuations in seasonal water flows and spatial extent. This complexity extends to freshwater habitats and the species they support.

As rivers flow through the landscape, they influence physical, chemical, and biological processes, thus creating a "shifting habitat mosaic" [11] that creates diverse riparian (river bank and shoreline) habitats well adapted to annual flood pulses and seasonal and cyclic changes in river flows [12,13]. In particular, aquatic connectivity and the interplay between the water body and adjacent riparian habitat is directly influenced by spatial and temporal variations in flow [11,13,14], which in turn can result in short-term availability of habitat for freshwater-dependent wildlife and plants [14–17]. Changes in availability can have immediate impacts on local communities that are dependent on these resources. Understanding the complexity of these systems requires a multi-disciplinary approach that can then be translated and mobilized in a meaningful way to all stakeholders throughout the watershed. This is no small challenge, given that most of the world's large river-floodplain ecosystems have been dramatically influenced by humans [13], and an increasingly warming climate [14,18]. The lower Athabasca River and its associated Peace-Athabasca Delta (PAD), present an excellent example of the complexity of data acquisition, its interpretation, and associated knowledge mobilization among the many residents and organizations living and operating within and adjacent to the area.

The Athabasca River flows from its glacial origins in the Canadian Rockies, then north across the province of Alberta, to the PAD in the Wood Buffalo National Park (WBNP), with the PAD being the largest inland freshwater delta in North America. Despite being the longest river (1231 km) in Alberta, there has been a disproportionate amount of research focused on the lower, more northerly, reaches of the river as it relates to Canada's bitumen extraction from the oil sands region [19]. In their systematic review of 386 publications focusing on the entirety of the Athabasca River over a 50-year period [19], Ana Lima and Frederick Wrona determined that the majority of studies concentrated primarily on a single stressor (68.4%), especially factors pertaining to pulp and paper manufacturing and oil sands projects. Much of the research investigated chemical pollutants, although water withdrawals were another stressor that received some attention. Water withdrawals from the lower Athabasca River from oil sands activities in 2017 were 37.9 million m^3 (0.56% to 2.5%) of the measured flow rate during winter, and from 0.17% to 1.15% of the measured flow rate during ice-free periods (www.environment.alberta.ca/apps/OSEM0). However, as with overall cumulative effects on the river, the total impact of oil sands mining on water availability is difficult to quantify. Associated removal of peatlands adjacent to the Athabasca River certainly impacts horizontal water flow from these wetlands into the river, but the volume of water lost to the river is unknown. Additionally, cumulative effects related to climate change and large hydro-electric projects (e.g., W.A.C. Bennett Dam in British Columbia on the Peace River) also play a major role in complex ecological relationships in the lower Athabasca River and its delta [14,18,20]. As Kevin Timoney and his colleagues note [4], the hydrological dynamics of the PAD are often oversimplified, given that the PAD is not a single delta, but rater three semi-independent sectors: the central main lakes, the delta of the Athabasca River, and the delta of the more northerly Peace River that flows northeast from British Columbia.

Adding to this complexity are the data gaps when assessing how current and future industrial water withdrawals might impact ecological needs within the lower Athabasca River and the PAD, especially as they relate to culturally and ecologically important species such as the American beaver (*Castor canadensis*), American mink (*Neovison vison*), muskrat (*Ondatra zibethicus*), and North American river otter (*Lontra canadensis*), all of which are semi-aquatic mammals. Applying computer simulations developed for one system and one industry (e.g., hydro-power production) [21], might not be appropriate for the assessment of the ecological balance of another system where species interactions are strongly influenced by climate, historical events, and unique habitats. These four species of semi-aquatic mammals perform important roles, ecologically, economically, and culturally in many of the communities along the lower Athabasca River and in the PAD within and adjacent to the Wood Buffalo National Park. Muskrats, in particular, have played a central role in many of the Indigenous communities within the PAD and along the lower Athabasca River for millennia [7,8,15,17,22]. Similarly, despite being a commonly trapped furbearer, beavers are highly valued for their ability to positively influence surface and groundwater storage [23–25] and enhance the habitat for other species [26]. In particular, river otters are strongly associated with beaver habitat [27–29], both because of enhanced fish habitat and aquatic connectivity provided by beaver impoundments, and the ability for beaver lodges, bank dens, and downed woody debris to serve as resting and rearing sites for otters [30]. In turn, river otters are an apex predator in freshwater systems, thereby aiding the ecological balance of the system. Similarly, mink are a key predator for muskrats, while also using muskrat huts and dens, and sometimes beaver lodges, as temporary resting cover instead of building their own structures [31,32]. The interdependence of these four species is well documented and highlights the multi-faceted nature of freshwater systems [33].

For all four species, seasonal water levels play a critical role in population dynamics. Areas of open water that are at least 1 m to 2 m deep are generally beneficial. Overly high water levels could present difficulties for muskrats where key forage species are inundated and unable to grow. In winter, if water withdrawals create low water levels under the ice (e.g., 1 m deep), beavers and muskrats can be "frozen out" and are unable to access food during the winter [23,34], and mink and otters would have difficulty accessing open water for travel and foraging [30]. Conversely, if water is discharged in winter, lodges, huts, and dens could be swamped, thereby resulting in the drowning of beavers and muskrats due to an inability to access air pockets under the ice. River otters also require air spaces to swim under the ice in winter to reduce energy loss on land [30]. As such, regulated rivers pose difficult challenges to semi-aquatic mammals in northern climates, whether it be from temporal changes in water flow produced by hydro-electric development, or reduction in water availability from industrial water extraction throughout the year. Predicting and accurately reporting the impacts of these changes provides similar challenges [35].

This paper presents a 2009 study (conducted by the author) that investigated how a proposed 15% increase in industrial water withdrawals from the lower Athabasca River for oil sands activities might influence beaver, muskrat, mink, and river otter populations in the downstream reaches of the river and the PAD within the WBNP. The study was done in the context of cumulative environmental effects and examined whether any models exist to quantify these effects [35]. Additionally, this paper details how various data sources, including original data records, traditional knowledge (TK), and published and grey literature were accessed and synthesized from multiple sources, and how knowledge derived from the research was mobilized to aid decision-makers and key constituents in the government, industry, local communities, other associated organizations in the study area specifically, and the broader community as a whole.

2. Materials and Methods

2.1. Study Area

At the request of the Instream Flow Needs Technical Task Group (IFNTTG) of the Cumulative Environmental Management Association (CEMA), the 2009 study focused on the portion of the lower Athabasca River from the city of Fort McMurray, Alberta downstream to, and including, the Peace-Athabasca Delta in the WBNP (Figure 1). CEMA is a multi-stakeholder group comprised of industry, government, non-governmental organizations, and Indigenous peoples, and was established to address and reduce long-term impacts of industrial development on the environment of the lower Athabasca River Watershed. The area is entirely within the Boreal Forest Natural Region (BFNR), which contains three Natural Subregions: the Central Mixedwood Natural Subregion, the Athabasca Plain Natural Subregion, and the Peace-Athabasca Delta Natural Subregion [36]. The Central Mixedwood Natural Subregion in the southern part of the study area is dominated by trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) forests, interspersed with Jack pine (*Pinus banksiana*). Peatlands (bogs and fens) are found throughout the area. Progressing northward to the Athabasca Plain Natural Subregion, just south of Lake Athabasca, the force of the river becomes more apparent with the representation of hummocky and rolling sandy and gravel-dominated uplands. These are rapidly draining soils, with sedge meadows, treed fens, and black spruce (*Picea mariana*) bogs in the lowlands, and Jackpine forest in the uplands. The Richardson, Old Fort, Harrison, Marguerite, and Firebag Rivers flow through this area into the Athabasca River. The Peace-Athabasca Delta Natural Subregion includes the area immediately south and to the west of Lake Athabasca. It is dominated by fluvial habitats, large open lakes, and perched basins [36]. The Athabasca River flows into the PAD in the southeast quadrant of the WBNP near Fort Chipewyan. The largest lakes include Lake Claire, and Mamawi, Baril, and Richardson lakes. Along with a number of perched basins, which fill during flood events, dominant wetlands are open water ponds, fens, and marshes. The PAD, much of which is protected within the WBNP, is a Ramsar site (designated by the Ramsar Convention as a wetland of international significance). The park itself was designated as a UNESCO World Heritage Site in 1983. Throughout the BFNR, the climate consists of long cold winters (average temperature −19 °C), and temperate summers (average July temperature 17 °C), although average temperatures have been recently increasing above the 30-year average [35].

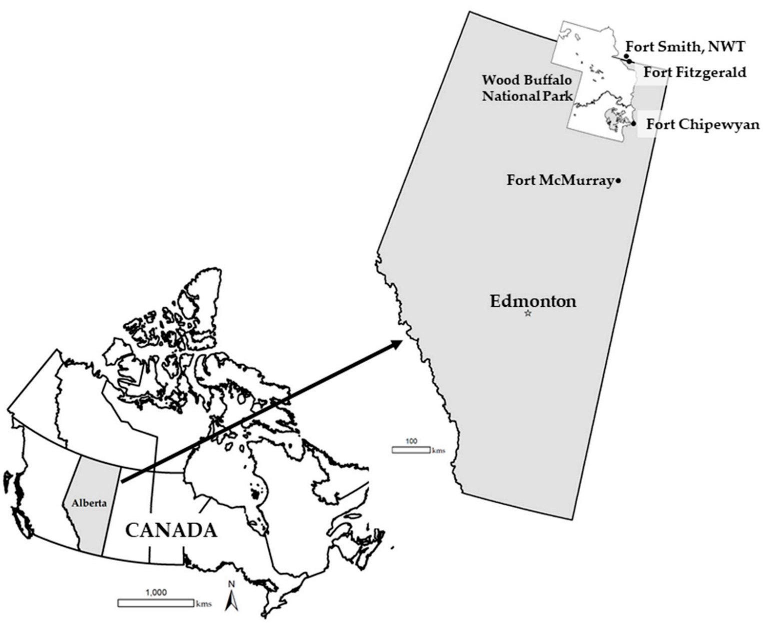

Figure 1. Study area including key communities involved in the project, and the Wood Buffalo National Park, Canada.

The region has supported Indigenous peoples for several thousand years, with the communities of Fort Chipewyan, Fort McKay, and Fort McMurray being important centers that formed during the colonial fur trade, peaking in the 18th to 19th centuries in what is now Alberta. Beaver, Cree, Chipewyan (Dene), Métis, and non-Indigenous trappers still live and work along the waterways throughout the area, although trapping as a primary profession is rare. Active trappers are most common in the PAD within the WBNP. Outside of trapping, the oil sands and associated service industries provide extensive employment in the region, while inside the WBNP, Parks Canada is the main employer.

2.2. Data Acquisition

This section provides an overview of how data were gathered during the 2009 study. Data within that context are defined as original numerical tallies, aerial imagery, interview responses, and modeling pertaining to how anthropogenic fluctuations in water levels in riverine, lacustrine, and wetland environments might influence population-level responses of semi-aquatic mammals. CEMA set an eight month timeline for the study, beginning from the start of the study in May 2009 to report delivery and presentation in December 2009. In part, the accelerated search and acquisition of these data was facilitated by an existing relationship of the principal investigator (G.A. Hood) with various organizations and community members, following a 19-year career with Parks Canada's Warden Service (including a posting in the WBNP).

2.2.1. Trapping Records

There were two main sources of trapping records: (1) photocopies of original fur tallies from the Hudson Bay Company (HBC) Archives, which were stored in the Parks Canada library in Fort Chipewyan, AB and, (2) original Parks Canada fur returns and notes on trapping activities within the WBNP, stored in the filing cabinets in the basement of the WBNP Parks Canada office in Fort Smith, NT. As identified in the *Wood Buffalo National Park Game Regulations*, trapping is legal within the park for designated trappers (named on a certificate of registration under the Regulations) from surrounding communities. In 1946, the Canadian federal government initiated the establishment of set trapping areas in the WBNP, which were formally established in 1947. This change meant that trappers who were once allowed to trap throughout the Peace-Athabasca Delta were no longer able to trap outside their assigned trapping areas. Those trappers were represented by the WBNP data, while trappers prior to the establishment of the park were represented by the HBC.

Once all records were located, I entered all trapping data into a Microsoft Excel spreadsheet and then tallied all fur returns by species to assess trends over time. For the WBNP fur returns, the number of trappers was included. Fur returns were used as a proxy for population dynamics of the four species of semi-aquatic mammals over time, while the number of trappers by year represented trapping effort.

2.2.2. Aerial Photograph Database

To catalog existing imagery for future hydrological modeling, my research team and I documented the availability of aerial photographs by searching the Alberta Sustainable Resource Development Air Photo Record System (APRS). Photographic coverage included all photographs beginning from the earliest available aerial photographs (1949) up to and including those available at the time of the study (2009). The search area included all images that included the Athabasca River from Fort McMurray to Fort Chipewyan and the PAD. We also documented all images one township width (~1.6 km) away from the main river course and the main lakes of the PAD to ensure side tributaries and perched basins were represented. Data entered into the Excel spreadsheet for each aerial photograph were categorized by: government project number, government project name, year, month, day, roll number, flight line, photo number, elevation (asl), scale, map sheet, township, range, meridian, origin, company flying the survey, the organization requesting the survey, color, calibration report, camera, lens, focal length, film, filter, duplicates, coverage (partial/complete), and comments. Due to time constraints, we did not construct a similar database for satellite imagery but instead provided references for obtaining these data.

2.3. Trapper, Community Member, and Biologist Interviews

Prior to beginning interviews, the Education, Extension, Augustana, and Campus Saint Jean (EEASJ) Research Ethics Board at the University of Alberta reviewed all questions (Appendix A) and methodologies. This review ensured that the project met all ethical guidelines prior to approval (project number Pro00007196). Using a semi-structured interview format, interviews focused mainly on active trappers, long-standing community members, and a biologist with extensive experience in the study area. I developed an initial list of participants using professional relationships developed while working in the WBNP, which was then augmented through snowball sampling. Questions focused around three central themes: (1) trapping experience and recent activity, (2) observed changes in the hydrology of the Athabasca River and the PAD, and (3) knowledge of the relationship between semi-aquatic mammals and water levels. Following the interviews, responses for each question were typed and organized by question to ensure anonymity. Then, I analyzed responses by categorizing them by central theme and identifying common trends in the content of responses [37]. To qualify species-specific responses to changes in water levels, I further summarized responses specific to whether they described beaver, muskrat, river otter, or mink.

2.4. Literature Review

Literature, in the context of this study, included all printed material (excluding ledgers of fur returns as noted in Section 2.2.1 above). My research team and I used the University of Alberta's library databases, along with Web of Science and Google Scholar, to locate all peer-reviewed literature pertaining to the study area, hydrological modeling, and species-specific ecology relative to changing water levels. We accessed much of the unpublished "grey" literature in the Parks Canada libraries and filing cabinets at the park offices in Fort Smith, NT, and Fort Chipewyan, AB after obtaining access permissions from the WBNP. Additional documents, in particular, environmental impact assessments and consultant's reports for numerous oil sands projects, were housed at the public library in Fort McMurray, AB. CEMA also provided various hydrological modeling studies it had commissioned over the years. We then summarized key points from each document in a common annotated bibliography. I then synthesized results from the literature review with the fur return data, aerial photograph database, and interview transcripts to provide a comprehensive report that assessed the potential effects of water withdrawals on semi-aquatic mammals, and identified any existing models applicable to the study area.

2.5. Knowledge Translation and Mobilization

The elements of knowledge mobilization proposed by David Phipps and his colleagues [38,39] set the framework to assess the extent of knowledge translation and mobilization of this study. Following the research phase, these elements include: (1) **dissemination** of research beyond traditional academic venues; (2) **uptake**, community access, and engagement of the research beyond academia; (3) **implementation** to inform organizational decisions; and (4) **impact** through the utilization of the research to effect meaningful change within the community [39]. Through an assessment of the research process, final report, and associated presentations, I assessed project conceptualization, design, implementation, dissemination, uptake, and impact through within the context of this framework.

3. Results

The original research question for the 2009 study remained true to the original request by CEMA: How might an increase in industrial water withdrawals from the lower Athabasca River impact semi-aquatic mammals, and do models exist that could quantify any impacts? My research team and I determined that there were no existing models that could be applied to the impact of increased water withdrawals on the semi-aquatic mammals in the lower Athabasca River and the PAD. Some research was available for the effects of water levels on muskrats in the PAD, but much of it was relative to population declines associated with the W.A.C. Bennett Dam on the Peace River, which feeds into the PAD from northern tributaries [15]. Despite some research on muskrats, any existing studies were more retrospective in nature. Nothing similar existed for beavers, river otters, or mink. The synthesis of the data and literature that we found, combined with in-person interviews (some at trapper cabins on the PAD), presented a single reference source to aid future model development if desired. The original 2009 report [35] provides detailed summaries, transcripts, and databases; however, a more detailed account of the data itself and the breadth of materials allows for an assessment of how information was mobilized within and beyond the research process.

3.1. Data Acquisition

My research team and I were able to acquire an extensive amount of data and information in all the categories specified in the original study design (i.e., original trapping records, aerial imagery, in-person interviews, and a review of the published and unpublished literature).

3.1.1. Trapping Records

Hudson Bay Company fur returns were available from 1821 to 1883. Although the records found in the Fort Chipewyan library were incomplete between the dates of 1821 to 1857, within the returns that were available in the library for this time period (1821 to 1883), there were 228,703 fur returns for muskrats, 31,728 for beavers, 1658 for mink, and 3127 for river otters recorded for the Athabasca District and Fort Chipewyan. It is important to note, however, that some of the beaver returns included coats, bonnets, cuttings, etc., thus making whole animal contributions difficult to quantify. There were more accurate tallies for two distinct periods ranging from 1858 to 1870, and 1871 to 1883 (Table 1). It is of note that, given the central role of Fort Chipewyan trading posts in the northwestern fur trade, furs could have come from other locations and then brought to the forts to trade, thereby inflating the fur returns associated with the lower Athabasca River and the PAD.

Table 1. Fur returns for muskrat, beaver, mink, and river otter in the Athabasca District, Canada from 1858 to 1883. Source: Hudson's Bay Archives.

Years	Muskrat	Beaver	Mink	River Otter
1858 to 1870	54,078	173,627	5364	2511
1871 to 1883	60,009	258,932	19,023	4159

The WBNP trapping records extended from 1934 to 1988. Muskrats represented the largest number of fur returns during that time, with a peak of 145,713 furs reported in the 1965/1966 trapping season and a minimum in the 1982/1983 trapping season (Figure 2a). Beaver fur returns reached their peak in 1940 (2520 furs), and a low of zero in the 1950/1951 trapping season (Figure 2a), when beavers were thought to be extirpated from the park [40]. Mink fur returns were lowest in the 1966/1967 trapping season and highest at 3169 in 1944/1945 (Figure 2a). Otters were consistently found in lower numbers, with the largest number of otter fur returns (65 pelts) in 1940, and only one otter fur registered in both 1955/1956, and 1974/1975 (Figure 2b). The number of trappers listed on the fur returns was 324 in 1951/1952, with the lowest number of trappers (n = 64) in 1971/1972 (Figure 2c), immediately after the filling of the Williston Lake reservoir associated with the W.A.C. Bennett Dam on the Peace River in 1971.

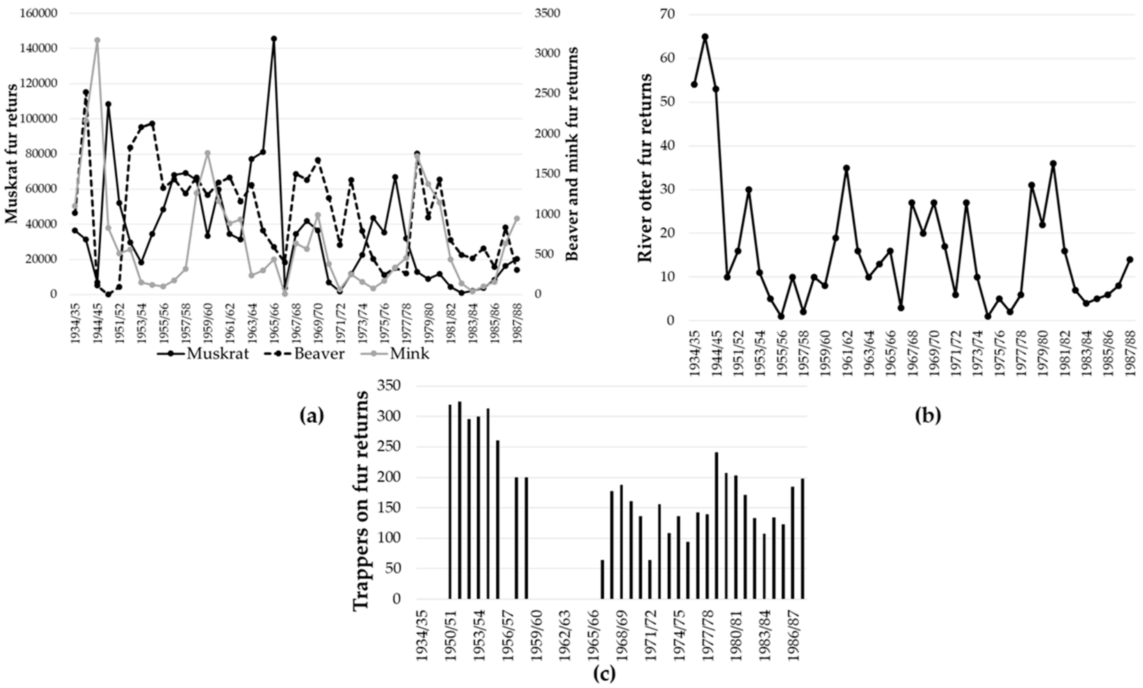

Figure 2. Fur returns muskrat, beaver, mink (**a**), and river otter (**b**), and number of trappers (**c**) for the Wood Buffalo National Park from 1934 to 1988. Source: Wood Buffalo National Park trapping records.

3.1.2. Aerial Photograph Database

We documented 1484 aerial photographs dating from 1949 to 2008; including 384 duplicates, (without duplicates = 1100 images). Images ranged from black and white to panchromatic, true color, false color, and infrared (Table 2; see Appendix B for a link to the full database). Despite the source agency, when evaluating the identified purpose of the images, the majority (35.8%) of the photographs were taken for forestry interests. The second highest identified application for the aerial photographs was for transportation planning (27.2%). Energy projects accounted for just under 10% of the images, although the use of the images in all categories likely would be interconnected. This data set represents the first tally for all images within a township width along the lower Athabasca River and the PAD over a 50-year period and allowed for a clear assessment of changes in surface water extent over time.

Table 2. Aerial photographs by source from 1949 to 2008 for the lower Athabasca River from Fort McMurray, AB to Fort Chipewyan, AB, including the Peace-Athabasca Delta (n = 1100 images).

Source	Number of Images	Percent of Total
Air Photo Coverage Map	22	2.0%
Air Photo Index	14	1.3%
Alberta Energy and Natural Resources	615	56.3%
Alberta Environment	59	5.4%
Alberta Environmental Protection	25	2.3%
Alberta Forestry, Lands and Wildlife	187	17.0%
Alberta Lands and Forests	78	7.1%
Alberta Sustainable Resource Development	96	8.7%

3.2. Trapper, Community Member, and Biologist Interviews

Of the people interviewed, 11 were trappers, 2 were long-term community members with close ties to local trapping history and its role in their community, and 1 was a wildlife biologist with over 20 years of experience in the region. Of the trappers, nine identified themselves as active trappers, despite having to work to supplement their income, which was not the case in earlier years. Within this group, four to five trappers lived on their traplines for >4 months of the year, with two trappers working their traplines for up to 9 months per year. Ages of the trappers ranged from their early 40s to their early 90 s, with a median age of 70 years old (*IQR* = 24). All trappers were from families who had trapped, sometimes over multiple generations, with six trappers living in Fort Chipewyan, two in Fort Smith, one in Fort Fitzgerald, and two in Fort McMurray (one of whom had formerly trapped along the Peace River and into the Peace-Athabasca Delta, and the other trapped near the mouth of the Athabasca River near Richardson Lake). Two trappers in the WBNP had formerly trapped along the Peace River (Trapping Area 1201) and had previously trapped in the PAD prior to the establishment of set trapping areas in 1947.

A notable decline in trapping over the past 30 to 40 years, either as a lifestyle or recreational pursuit, was a common theme in all of the interviews. During the interviews, there was some link to the impact of the residential school system on Indigenous trappers, but declining fur prices, declines in muskrat numbers after the opening of the W.A.C. Bennett Dam, and increased gas prices were consistently associated with the decline in trapping over time. With the decline in trapping as a whole, several trappers mentioned the lack of interest from younger generations (<30 years of age) to go out on the land. Trappers from Fort Chipewyan estimated that there were only five full-time trappers in the community at the time of the interviews (2009). Some community members still trapped recreationally. Trapping in Fort Smith (population ~2500) was even lower, with one trapper noting that only two trappers from that community were actively trapping for the past few years. Conversely, there were five to six active trappers (Indigenous and non-Indigenous) trapping full-time along the Athabasca River, with several others trapping as a "hobby".

Of the trappers in the WBNP, all but three trapped beavers, muskrats (when available) almost exclusively, and fine furs (e.g., lynx, wolf, marten, fox, and fisher) when available. One trapper from Fort McMurray noted that river otters were commonly trapped, but when population imbalances were noted by trappers (e.g., only catching adults), the trapping community would stop trapping them altogether until population structures were restored. The older trappers (>60 years old) noted that their best years of trapping were in the 1960s, prior to the construction of the W.A.C. Bennett Dam on the Peace River near Hudson's Hope, BC. In the 1960s, trapping returns for a single trapper in the PAD could range from 3000 to 4000 muskrats per year. Now muskrats are too difficult to find to warrant any concentrated trapping. A full account of trapper comments is in Appendix A of Hood, Bromley, and Tiitmamer Kur's 2009 report [35]. All comments are anonymous to meet ethics requirements.

3.3. Literature Review

Over the course of the study, we obtained and synthesized over 206 publications, of which 101 were formally cited in the final 2009 report [35]. Of the full suite of articles/reports (n = 206), 35% (n = 72) were peer-reviewed articles pertaining to species biology, hydrological modelling, and ecological processes in the study area, 56.3% (n = 116) were "grey literature" (unpublished reports and similar documents), 5.3% (n = 11) were books (mainly book chapters), and 3.4% were graduate theses (n = 7). Of the peer-reviewed articles, approximately half (51%, n = 37) addressed species ecology, while a third (33.3%, n = 24) addressed various aspects of riverine hydrology (e.g., flooding, ice jams, modeling water management). Within the grey literature, we obtained and synthesized 105 unpublished/technical reports, of which 35 documents (30.2%) were cited in the 2009 report, with an additional 13 documents not directly cited in the report (11.2%), but still providing raw data for the tabulation of fur returns for the WBNP. As a whole, all of the documents provided important context for wildlife ecology (n = 67, 57.8%), and hydrology (n = 46, 40%), including water quantity and quality.

Two reports within the grey literature tabulated and referenced data from several inaccessible consultant reports that contained species-specific survey data and inventories from 1970 to 2007 in the oil sands region [41,42] All but one [43] of the 53 consultant reports cited were specific to environmental impact assessments/reviews (ER) for oil sands projects. Of the ERs, 73.6% (n = 39) were written by environmental consultants who had conducted the wildlife surveys for various oil companies (n = 21 companies), while 24.5% (n = 13 reports) were ERs submitted to the government by industry as part of the formal project approval process. Wildlife surveys included in the ERs submitted by industry, however, were conducted by environmental consultants as supporting data for the final ER. Suncor Energy (n = 12 reports, 23.5%) and Syncrude Canada Ltd. (n = 11 reports, 21.6%) hired the majority of consultants who then wrote the reports for individual wildlife surveys. Most reports documented more than one species of semi-aquatic mammal. In Appendix B in the 2009 study [35], I further categorized these surveys into species-specific tables, along with their original source references.

From 1970 to 2006, there were 30 beaver surveys, all but one [35] conducted as part of proposals for oil sands projects. The one survey not associated with oil sands projects was a provincial analysis of fur production records from 1970 to 1975 [43], which included all four semi-aquatic furbearer species. From 1970 to 2006, there were 27 muskrat surveys, all but one connected to major oil sands projects, and the other being the previously mentioned trapline survey [35]. River otter surveys were quantified in 35 studies and, as with beavers and muskrats, all but one was associated with oil sands projects. Lastly, 35 studies quantified mink surveys in the study area, with all but one [35] associated with oil sands development.

The documents pertaining to beaver, muskrat, river otter, and mink that were specific to the lower Athabasca River, the PAD, or the WBNP (with park-wide data that included the PAD) comprised 17.4% (n = 36) of the documents surveyed for the study. Of these, only one was peer-reviewed (a river otter study) [30], while the rest were from the grey literature found in the two Parks Canada libraries. Of the grey literature, 42.9% (n = 15) of the reports were about muskrats (13 of which focused exclusively on the PAD). Six reports (17.1%) focused exclusively on beavers (with two of those reports specific to the PAD and four specific to the WBNP as a whole), and only two reports were specific to mink, one for the lower Athabasca River and one for the PAD. There was no grey literature pertaining exclusively to river otters, although there were 12 reports (34.3%) that included all four species together (one specific to the lower Athabasca River, five for the PAD, and six for the WBNP as a whole).

3.4. Knowledge Translation and Mobilization

3.4.1. Dissemination of Research beyond Traditional Academic Venues

The formal requirements from the funding agency (CEMA) for the 2009 research were a comprehensive technical report [35] and presentation of the final results to their board, to whom I submitted three printed copies and an electronic version of the final 91-page report on December 13, 2009. The oral presentation of the research was on December 4, 2009. As late as 2014, the report remained in CEMA's print library, but was later on CEMA's online library, although it was originally only accessible through a public login process. By 2018, it was openly available without login requirements (http://library.cemaonline.ca/ckan/dataset/2009-0017). I also provided two printed reports, one for the Fort Smith and one for the Fort Chipewyan Parks Canada libraries, and a digital copy to the park ecologist in the Wood Buffalo National Park (an ex-officio member of CEMA). At the time, the aerial photograph database (Appendix B) was provided on a computer disk, as well as through email. Rather than receiving individual copies, people interviewed during the project preferred that the report go directly to their affiliated community councils/organizations. As such, I also mailed printed reports to the Mikisew Cree First Nation, Athabasca Chipewyan First Nation, Smith's Landing First Nation, and the Metis Nation of Alberta Local #125, all of whom represented individual Indigenous trappers who had participated in the study. Sending these reports was not in the research contract agreement, but we considered it to be one of the more important aspects of initial research dissemination. Between 2010 and 2013, several environmental consultants requested digital copies of the report to use as a reference for their research and monitoring work in the lower Athabasca River and the PAD.

From 2008 to 2014, I presented the research beyond academia at eight different venues that ranged from public talks and multi-stakeholder forums to traditional academic conferences (Table 3).

The Unwrap the Research Conference in Fort McMurray, AB in 2010 was purposefully designed by Dr. Brenda Parlee of the University of Alberta to share research conducted in lower Athabasca and the PAD directly with affected parties in or nearby their home communities. The one talk that brought the research directly to the community that was most engaged in my 2009 research (Fort Chipewyan, Alberta) was the Peace Athabasca Delta Environmental Monitoring Program Forum in 2014. This talk served as the keynote address to open the Forum, in which community members, research scientists, Parks Canada staff, federal and provincial employees, and the general public, shared research and then worked collaboratively in break-out groups to address key issues of concern for the PAD and the lower Athabasca River. The results of the Forum were later provided to all participants by the WBNP in a summary report [44]. The report, combined with these presentations, helped increase public awareness of the ecological, economic, and cultural context of the area, past and present.

Table 3. Presentation of research beyond academia (2010 to 2012).

Date	Venue	Title	Audience
4 December 2009	Cumulative Environmental Management Association from Camrose, AB via web link	A review of existing models and potential effects of water withdrawals on semi-aquatic mammals in the lower Athabasca river	members of CEMA and ecologists from the WBNP
10 October 2010	Nordicity in Thought and Practice Conference, Camrose, AB	Bridging the gap: Indigenous knowledge of a northern ecology	visiting researchers from Norway, academics, and the public
23 October 2010	Unwrap the Research Conference, Fort McMurray, AB	Water, wildlife and change: How local knowledge helps answer big questions	local community members within the oil sands and the PAD region
29 November 2010	Augustana Faculty Colloquium Series, Camrose, AB	Potential effects of industrial water withdrawals on semi-aquatic mammals of the lower Athabasca River	alumni, academics, general public
12 March 2011	Alberta Chapter of the Wildlife Society, Camrose, AB	Potential effects of water withdrawals on semi-aquatic mammals in the lower Athabasca River	government biologists, environmental consultants, academics, university students, non-governmental organizations, wildlife professionals
24 January 2012	University of Alberta Calgary Centre, Alumni Education Series, Calgary, AB	Managing the oil sands environmental footprint	University of Alberta alumni and associates
24 September 2012	Augustana Faculty Colloquium Series, Camrose, AB	South Sudan and Canada: Water, culture and a marriage of ideas. [1]	Augustana alumni, academics, general public
18 February 2014	Peace Athabasca Delta Environmental Monitoring Program Forum. Fort Chipewyan, AB.	What can aquatic mammals tell us about healthy ecosystems? [2]	Indigenous groups, local citizens, trappers, Parks Canada staff, research scientists, government employees

[1] Co-presented with N. Tiitmamer Kur, co-author of 2009 report [35]. [2] Keynote address.

3.4.2. Uptake, Community Access, and Engagement of the Research beyond Academia

Relative to the uptake of the 2009 research by local communities and non-academic parties living and working within the study area, there were several reports generated by government staff and consultants that drew on data sets and information within our final 2009 report [35], which then helped inform future policy and practice. For example, in 2016, Parks Canada conducted an operational review of its ecological integrity monitoring program within the WBNP [45]. In particular, the synthesis of muskrat data, and water level predictions helped inform future research directions within the PAD, which is [7,8] a topic that remains of great concern for the community of Fort Chipewyan. One of the two academic studies within the WBNP [8] requested the use of the muskrat database that my team and I created for the 2009 research.

Our 2009 research was also noted in the 2011 *Athabasca Watershed Council State of the Watershed Report: Phase 1* [46]. Additional information for the report was presented on an associated CD. Our CEMA research helped inform contracted research on the potential impacts of beavers on the success of oil sands reclamation for CEMA in 2013 [47]. In this case, given my past experience with the 2009 research and additional studies specifically on beavers, the authors also asked that I peer-review their report prior to its final submission to CEMA, thus aiding the contextualization of the research relative to new research questions [38].

3.4.3. Implementation to Inform Organizational Decisions

As per Section 12 (2) of the Canada National Parks Act [48], "At least every two years, the Minister shall cause to be tabled in each House of Parliament a report on the state of the parks and on progress made towards the establishment of new parks". As noted in the previous sections, Parks Canada incorporated the 2009 research into its 2016 operational review of ecological integrity monitoring for the WBNP, and further highlighted the semi-aquatic mammal research at their 2014 Peace Athabasca Delta Environmental Monitoring Program Forum in Fort Chipewyan, AB. The opening remarks and presentations at the Forum set the stage for its key objectives: (1) identify the efficacy of current monitoring activities relative to ecological vulnerabilities in the PAD, (2) identify additional monitoring required to address these vulnerabilities, and (3) identify possible (and improved) collaborations, communication approaches, and ways to share and incorporate Traditional Knowledge [44]. During the rotating break-out group sessions during the two-day forum, participants focused on three specific themes: (1) contaminants, (2) water quantity and hydrology, and (3) "bringing Western Science and Traditional Knowledge together" [44], (p. 6). The results of this forum then helped inform policies within the WBNP, provided a venue to expand perspectives and provided a training opportunity to new park staff, and potentially leveraged new program funding, each of which is a metric defined in the co-produced pathway to impact framework outlined by David Phipps and his colleagues [38].

3.4.4. Impact Through Utilization of the Research to Effect Meaningful Change within the Community

The long-term impact of the research was more difficult to identify, although the final 2009 report was noted in the Mikisew Cree First Nation's submission of their petition to the World Heritage Committee (WHC) to request that the WBNP be placed on the *List of World Heritage in Danger* [49]. Rather than just address the decline of muskrats, as is often done to highlight declining water levels in the park, their petition noted our findings for all four species of semi-aquatic mammals that would be impacted by ongoing declines in water levels. The WHC did not include the WNBP on this list when the petition was submitted in 2017; however, ongoing consideration of its inclusion continues to be highlighted in the Canadian media.

4. Discussion

Rapid industrial change creates challenges in accurately assessing associated environmental and cultural impacts in an equally timely manner, particularly relative to the energy sector, where almost 140,000 million ha of boreal forest have been impacted through the mining of bitumen in northern Alberta, Canada over the past few decades [50,51]. The interaction of resource development projects with diverse and dynamic river systems creates added complexity, especially in areas where even basic ecological studies are rare or completely lacking. Such is the case with the lower Athabasca River and the PAD in northeastern Alberta, where semi-aquatic mammals have played important ecological and cultural roles for millennia, yet have faced population declines due to overharvesting and habitat alteration. Yet published literature for key species of semi-aquatic mammals in this area was almost non-existent [30], although two additional peer-reviewed studies on muskrat and based in the PAD have been published since 2018 [7,8]. Much of the research and monitoring of semi-aquatic mammals remains in the grey literature, with most of these documents housed in the Parks Canada libraries and filing cabinets in Fort Smith and Fort Chipewyan, which are generally inaccessible to the public. Of these unpublished documents, the majority were specific to muskrat populations in the PAD, especially following the establishment of the W.A.C. Bennett Dam and subsequent changes in flood pulses and water levels in the Peace River. Of note is that finding these documents within the WBNP libraries required my research team and I to physically examine the relevance of every single document on the shelves and tables in the two libraries because of a lack of up-to-date paper-based or electronic library database. A similar process occurred with documents housed in filing cabinets in storage areas.

In Parks Canada, and many other provincial and federal departments and agencies, it is very unusual to have a dedicated librarian and, although each park has a library, its organization and maintenance is either done as an additional secondary duty by an administrative assistant or becomes a side project for someone with an interest in library resources. Very seldom is there distinct library funding, often due to budget and staffing constraints. However, the documents in these libraries provided major contributions to the final 2009 report for CEMA [35] and allowed once forgotten data to resurface. Although we found no existing models directly applicable to the impact of increased water withdrawals on semi-aquatic mammals in the oil sands region, the variables required to develop a model were compiled in our final report, in no small part due to research, monitoring, and raw data contained within the grey literature and other unpublished documents (e.g., fur records, aerial photograph databases).

Although some scholars suggest that a solution to the increased use of the grey literature would be "to integrate access to grey literature within the databases that scholars regularly consult" [52] (p. 4), much of the grey literature we found that was applicable to the question of potential impacts of water withdrawals on semi-aquatic mammals in the lower Athabasca River and the PAD was not readily available to academic scholars. Indeed, without the author's previous knowledge and experience as a former Parks Canada employee, the lack of awareness of these libraries and associated archived files would have been an immediate barrier to knowledge mobilization in its initial stages ("Research") as defined by David Phipps and his colleagues [38]. The reduction and elimination of various government libraries and many of their holdings between 2014 and 2015 by Canada's federal government further limited the mobilization of invaluable knowledge stored within these libraries [53,54]. With many of the older reports used in our study that were produced with typewriters rather than computers, the loss of the historical ecology of the area would be permanent. Handwritten documents, including fur tallies, also would face the same fate. Projects, such as the creation of the *Antarctic Bibliography* in 1963, where data and publications (primarily grey literature) were copied to microfiche for preservation, provide a powerful example of foresight relative to knowledge mobilization for current and future scientists [55]. Now that microfiche is difficult to access and read, the National Science Foundation has created the *Polar Digitization* project to make the full-text grey literature materials from the *Antarctic Bibliography* (including rare government reports) openly available electronically [55]. Knowledge is impossible to mobilize if key reports and the historical context they document are not accessible; open electronic access ensures broad availability within and external to academia.

Much like the grey literature, peer-reviewed literature and academic books provided critical ecological information about the four species of interest: beaver, muskrat, river otter, and mink. However, as with hydrological models, the peer-reviewed literature, in particular, was often specific to a particular study area that was very different from boreal rivers and deltas of northern Alberta. Information with the greatest applicability to the lower Athabasca and the PAD, not surprisingly, came from the local trappers, residents, parks staff, and biologists. Fikret Berkes [56] notes that the complexity of socio-ecological systems, similar to those found in the lower Athabasca River and the PAD, results in knowledge that is dispersed among a varied hierarchy of groups and individuals, which then allows for management decisions to be assessed and mobilized at different temporal and spatial scales. In the WBNP and the surrounding communities, the Peace Athabasca Delta Environmental Monitoring Program (PADEMP) brings together traditional knowledge holders, scientists, and government personnel (including participants from Indigenous governments) to collaboratively achieve long-term monitoring and reporting on the ecological health of the PAD in particular, and the park more generally. Along with integrating Western Science and Traditional Knowledge, the PADEMP aims to provide open communication within and beyond the core group of participants. Its members include six First Nations, four Métis Associations, Parks Canada (WBNP), three additional federal departments, the governments of the Northwest Territories and Alberta, and two non-governmental organizations. Within this group, there is a broad age range, which helps expand the mobilization of knowledge across generations. As noted previously, the average age of the trappers interviewed in our study was 70 years old, and a common theme was the lack of youth engagement in land-based activities, trapping in particular. The opportunity to share perspectives within the PADEMP forum provides a means to foster a culture of co-management among groups, as well as intergenerational connections within groups.

When examining the movement of knowledge over a broad sociological landscape, decision-making is less impacted by scientific studies than expected [57]. Vivian Nguyen and her colleagues also note that it can take long periods of time before one really knows the true impact of knowledge on policy development or similar societal changes [57]. The length of time from the initiation of a scientific study to peer-review and publication can take years, which tends to provide important knowledge and possible solutions long after immediate needs for that research have passed (e.g., annual water allocation decisions without a current understanding of hydrological changes and impacts of past decisions). In the case of the 2009 study described in this paper [35], there was an eight-month turn around to assess how increasing industrial water withdrawals from the Athabasca River by an additional 15% would impact a suite of semi-aquatic mammals, all of which have different ecological requirements and niches. It required a multi-faceted approach to provide diverse pieces of the puzzle that might one day evolve into a workable model. Although an empirical model was not readily available in either the academic or grey literature, traditional knowledge, historical data, and varied literature sources provided a strong indication that further declines in water levels, especially timed outside of ecological norms, would add to the myriad of cumulative effects already experienced by these species and the people who depend on them. Over time, the impact of the study has slowly revealed itself within the local communities, consultancies, and academia. One example occurred after a presentation at the PADEMP Forum in Fort Chipewyan when people from the community, many of whom had participated or assisted with the interviews, expressed distinct appreciation that their lived experiences were included in the presentation in a manner that brought the cumulative body of knowledge back to the communities where solutions must be co-produced among different organization and perspectives for real change to take place.

Knowledge mobilization can only happen when those creating or translating it are able to speak. Academics possess the ability to retain intellectual property rights, and academic freedoms that provide a safe and open forum to present research findings through broad avenues. In the case of the semi-aquatic mammal study, these privileges allowed me to distribute the final CEMA report when it was not otherwise available. However, the manner in which knowledge is shared must be accessible beyond academic norms in presentation style and discourse. It must translate to the audience. Dissemination of the findings was the most robust aspect of knowledge mobilization in the case of this study. Uptake, implementation, and impact were much harder to quantify, yet are arguably more important for change. Therein lies the challenge for effective knowledge mobilization, how to assess and measure the true impact of research over different temporal and spatial scales, especially when rapid solutions are required for complex problems.

5. Conclusions

Rapid land-use changes challenge our ability to collect, synthesize, and report data in a timely and succinct manner. In the complex and dynamic riverine system of the lower Athabasca River and the Peace-Athabasca Delta in northern Alberta, Canada, the delicate balance between oil extraction and ecological integrity (particularly as required by law in the Wood Buffalo National Park) necessitates rapid knowledge mobilization and uptake. Unfortunately, access to data, documents, and relevant models can be difficult due to proprietary, political, and logistic realities. The study described in this paper presents a detailed assessment of the many sources of knowledge and the need to integrate these resources in a more open and accessible manner. Beyond these resources is the necessity of key actors within various organizations to be able to speak freely to the public without political interference. One cannot mobilize knowledge easily in the context of an anti-science agenda. For successful knowledge mobilization within policy development and its broader impact, multi-stakeholder involvement provides diverse venues through which knowledge can flow.

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Appendix A

Interview questions used in the study following approval by the Education, Extension, Augustana, and Campus Saint Jean (EEASJ) Research Ethics Board at the University of Alberta (project number Pro00007196).

1. Are you still an active hunter/trapper? Why not anymore? How often do you trap/hunt? Do you make a living trapping?
2. What area do you trap/hunt in?
3. How much trapping and hunting is still being done in your area?
4. Where are the hot spots for trapping beavers, muskrat, mink, and river otters?
5. How are beavers and muskrats important in your community?
6. What changes have you noticed in the number of muskrats and beavers? What are the reasons for the change?
7. What kind of short term or long term changes have noticed in the habitats of muskrats and beavers?
8. How do beavers react to changes in water levels in the river?
9. How do muskrats react to changes in water levels in the river?
10. What do they eat during droughts/floods/during different seasons?
11. Where are they normally found during droughts/floods/during different seasons?
12. Do beavers living in rivers act differently than beavers in the ponds and snyes? (Note: a snye is a backwater or side-channel of a main river or stream.)
13. Do muskrats living in rivers act differently than muskrats in the ponds and snyes?
14. How do mink react to changes in water levels? (high or low water levels)
15. How do river otters react to changes in water levels? (high or low water levels)
16. If you could study just one thing about lowering of water levels in the Athabasca River and these animals, what would it be?
17. Is the water level now what it used to be like in the river/Delta (does it flood like it used to)?
18. Have there been many times that the water level changed before or since the Bennett Dam was constructed?
19. Do you recall your parent's experiences with changes in the water level and these animals?
20. Are there other areas that fill with water that might replace the dry areas? Do they stay filled?
21. Do you know of someone else we should talk with?

Appendix B

Aerial photograph inventory from 1949 to 2008 for the lower Athabasca River from Fort McMurray AB up to and including the Peace Athabasca Delta, and Fort Chipewyan, AB. Coverage extends to within one township (~1.6 km) adjacent to the river and the delta. The database is available at: http://library.cemaonline.ca/ckan/dataset/2009-0017/resource/3299160c-24e6-40be-9702-0454689c7122.

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