Effect of pulp-mill effluents on White Sturgeon (*Acipenser transmontanus*) recruitment in Kamloops Lake and the Thompson River watershed

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Natural Resource Policy Analysis (BIOL4500)

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Case Study Introduction

Natural Resource Policy Analysis (BIOL4500) is a capstone course that is unlike other undergraduate courses in that it explores how science, culture, and management interact. BIOL4500 culminates with the production of a semester-long Case Study report which attempts to investigate some of the intricacies and nuances of each of the themes above. The Case Study serves as a lens in which a real-world ecological issue in Canadian Ecology and natural resource management can be explored. Similar to other courses, this Case Study requires students to search published primary scholarly and technical literature and synthesize complex concepts. However, unlike other undergraduate courses, which often present problems enclosed within a neat or tidy framework that is divorced from the complexities and intricacies of reality, BIOL4500 and the resulting Case Study report helps students gain a deeper understanding of the challenges of real-world problems by tasking them with finding and interacting with people who are intimately involved with actual ecological issues.

This Case Study serves as a single coherent professional document that provides useful insights into how scientific knowledge is acquired and implemented to manage natural resources in unpredictable real-world settings. The target "Reader" of this Case Study can include (but is not limited to) people in indigenous and local communities, resource managers, political decision-makers, and general scholars. Importantly, the Reader is not expected to be knowledgeable on the topics and themes explored in this Case Study or have any academic education beyond Canadian secondary school. Moreover, the Reader is expected to be open-minded and intelligent, and should be able to fully understand complex issues if they are clearly explained with plain communication and without unnecessary scientific jargon. In order to guide the Reader through this Case Study, attention will be regularly drawn back to the overarching Goal and underlying set of Objectives structuring this document.

The *Goal* of this Case Study is to explore the role of knowledge and knowledge systems in Canadian ecology and natural resource management and decision-making. Each section of this Case Study has specific Objectives which are each essential for achieving the Goal above. Each section of this Case Study and their associated Objectives are as follows:

- *Context and key ecological uncertainty (KEU)*: provide the contextual information necessary for understanding the KEU of a specific population of Canadian species.
- *Acts, policies and guidelines (APGs)*: Situate the KEU within the relevant legal, administrative and management context.
- *Knowledge systems (KSs)*: provide the Reader with a working understanding of what human knowledge systems are and why they are critical factors in natural resource management, and to provide relevant information on the knowledge systems specific to the KEU.
- *Bayesian Belief Networks (BBNs)*: provide the Reader with a working understanding of what BBNs are and how these models can help transform knowledge about States of Nature from different knowledge systems into a single form that can be used to consider cause-effect mechanisms.
- *Management strategy evaluation (MSE)*: to provide the reader with a working understanding of what an MSE is and how these models can help resource managers make decisions in an uncertain world.

Context and Key Ecological Uncertainty

Section introduction

In order to adequately explore the role of knowledge in Canadian natural resource management and ecology, a base of knowledge is required to orient the Reader. However, it is important to note that the scientific literature and broader body of knowledge relating to the topics explored in this KEU, and Case Study more generally, is incomplete. Whenever convenient, gaps in knowledge will be noted and relevant information from other populations will be drawn upon to fill in areas lacking data. The Objective of this section is to provide the contextual information necessary for understanding a key ecological uncertainty (KEU) for a specific population of Canadian species. The structure of this section will be outlined and key terminology will be defined.

This section will first identify and summarize a news article to show where the interest for this Case Study originated. Second, in order to help familiarized the Reader with the population of interest, contextual information on the species' life history characteristics, distribution, and abundance will be presented. Third, the specific KEU explored by this Case Study will be explicitly and succinctly stated.

Spawning: This term describes the upstream movement of individuals into fast-moving water in the spring where they broadcast eggs into the water column which then settle to bottom substrates (Migdalski, 1962; Scott & Crossman, 1973).

Barbels: Four of these important protruding sensory organs are located near the mouth and help individuals navigate and find prey in murky and turbid waters (Blood, 1997).

Origin of interest: The mysterious case of the Kamloops Lake monster, CBC, May 13th, 2019.

In 2019, Jeff Putnam, the City of Kamloops' Director of Parks and Recreation sparked public debate after he tweeted a picture of what appears to be a large animal swimming along the surface of Kamloops Lake, British Columbia. A Canadian Broadcast Corporation (CBC) news article was subsequently published which fueled public discussions. There was much speculation among residents regarding what the creature might be. Some claimed it was Ogopogo, a lake monster analogous to Loch Ness, while others argued it was simply a misidentified swimmer. Some local people, like Skeetchest'n Chief Ronald Ignace and fisherman Regan Birch, believe the creature to be a white sturgeon (*Acipenser transmontanus*). Notably, in the years leading up to Putnam's sighting, several unconfirmed cases were brought forward by fisherman; Many of whom, like Regan Birch, believe that white sturgeon (WS) can be found in Kamloops Lake. If this is true than it would have meaningful ecological, cultural, societal, and economic implications for British Columbians and Canadians as a whole. The WS thought to be in Kamloops Lake and the connected Thompson River watershed is the focus of this Case Study.

The particulars of this article have aroused intrigue and prompted many questions: Could some remnant of individual WS be trapped in Kamloops Lake; long-lived relicts of their historic range? Is there a self-sustaining and viable population of WS occurring in the Kamloops Lake-Thompson River watershed; unnoticed and disconnected from other populations? Could WS be moving up and down the Thompson River; somehow circumventing the impasse of Hell Gate without detection? With so many interesting questions, which ultimately led to the conception of this Case Study, one must ask: What *is* known about WS in Kamloops Lake and Thompson River watershed (KLTRW)?

Characterization of species life history

WS have many interesting and unique life history traits. However, due to the nature of this situation and the obvious lack of data on the target population, the following information from other populations should serve strictly as points of reference: WS are thought to be the largest freshwater fish in Canada: growing to be over six meters long and weighing as much as 635 kilograms (Scott & Crossman, 1973; Blood, 1997). They are capable of living for more than 100 years (Rieman & Beamesderfer, 1990) and grow (or mature) slowly. Adults reach sexual maturity between the ages of 15 and 32 years, with males maturing earlier (Cochnauer, 1983; Blood, 1997). WS may have evolved to compensate for their slow growth strategy by being very fecund: Once mature females produce between 700,000 and 4 million eggs (Migdalski, 1962; Scott & Crossman, 1973). Sexually mature WS are greater than 100 centimeters long (COSEWIC, 2012), and spawn infrequently at intervals of around 2 to 11 years for females and more frequently for males (Stockley, 1981; Cochnauer, 1983; Blood, 1997). Mortality rates in other nearby populations have been estimated at 0.9-9% (COSEWIC, 2012). Additionally, mortality is very high during the first year of life but declines precipitously thereafter (COSEWIC, 2012).

WS have a unique body plan with several evolutionary adaptations that have allowed them to be successful in their respective environments. For instance, specialised barbels and a protrusive mouth on the underside of their head are crucial anatomical features that facilitate demersal behaviour and a varied omnivorous diet (Scott and Crossman, 1973; Blood, 1997). This diet changes over the course of the life cycle from juveniles, which consume mollusks, invertebrates and insects, to adults who consume larger prey like fish (Scott & Crossman, 1973).

Characterization of likely population distribution and abundance

As alluded to in previous subsections, information on the abundance and distribution of WS is limited (Blood, 1997) with only a few abundance studies (e.g., Nelson et al., 2013) which often lack statistical power (e.g., McKenzie, 2000). Unfortunately, little information on the population of interest exists, however, for the purposes of this Case Study, information from other populations will be used to speculate on the abundance and distribution of WS in KLTRW.

Globally, WS are endemic to the west coast of North-America from California to Alaska (Perrin et al., 2003) with significant populations existing in four freshwater river systems (Figure 1; Hildebrand, 2016). In the Fraser River system, there are at least four distinct populations (Smith et al., 2002). Genetic evidence suggests that a major barrier (Hell's Gate), located 211 km from the mouth of the Fraser River, separates Lower and Middle Fraser Groups (Drauch Schreier et al., 2012). However, both downstream and upstream movements through Hell's Gate have been confirmed (Challenger et al., 2021). Although movements from one section of river to another is likely rare (e.g., Nelson, 2013; Robichaud et al., 2017), the Middle Fraser Group may represent a weak source of migrating individuals entering the KLTRW system at the Thompson River confluence (located upstream of Hell's Gate; Figure 2; COSEWIC, 2012).

The abundance of WS in KLTRW is likely low because (1) there are only four confirmed cases (COSEWIC, 2012; Aaron Gillespie, 2022, pers. comm.) and (2) WS abundances generally decrease in the upstream direction while oceanic inputs diminish (McKenzie, 2000). For example, the Lower Fraser Group was estimated at 44,713 (Nelson et al., 2013), while the upstream Nechako and Lower Stuart Group was estimated at less than 600 fish (McKenzie, 2000). Thus, we can assume that the abundance of WS in KLTRW is likely very low.

Key Ecological Uncertainty and Hypothesis

The combination of low abundances and slow life histories described in the previous subsections make the KLTRW population of WS particularly susceptible and sensitive to anthropogenic disturbances. One of the latter worth considering relates to effluents originating from pulp-mills. Several compounds produced during the process of producing bleached pulp (used for producing paper products) have been shown to have negative effects on the long-term survival of freshwater fish species: Lipophilic contaminants, like dioxins and furans, are by-products of bleached pulp production (Parsons et al., 1991) and have been shown to reduce incubation success and increase mortality during embryological development of rainbow trout (*Oncorhynchus mykiss*; Walker et al., 1992) and lake trout (*Salvelinus namaycush*; Spitsbergen et al., 1991; Walker et al., 1991; Macdonald et al., 1997). With the Weyerhaeuser Pulp Mill releasing an average of 182,000m^3 of effluent each day into the Thompson River upstream of Kamloops Lake (World Lake Database, 2022), it is worth considering how these effluents and their constituents may be impacting WS in KLTRW. The specific KEU explored in this Case Study is: Are toxins present in pulp-mill effluents limiting recruitment in WS in KLTRW, and potentially leading to extirpation? If the physiochemical and toxicological mechanisms previously identified in the literature are also occurring in WS in the KLTRW, then recruitment could be reduced and may not allow for population growth. This issue is important for Canadians for several reasons: WS represent an important economic resource; WS have an important role in ecosystem functioning and services; and WS have an inherent natural heritage value as large endemic Canadian freshwater fauna.

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Figures

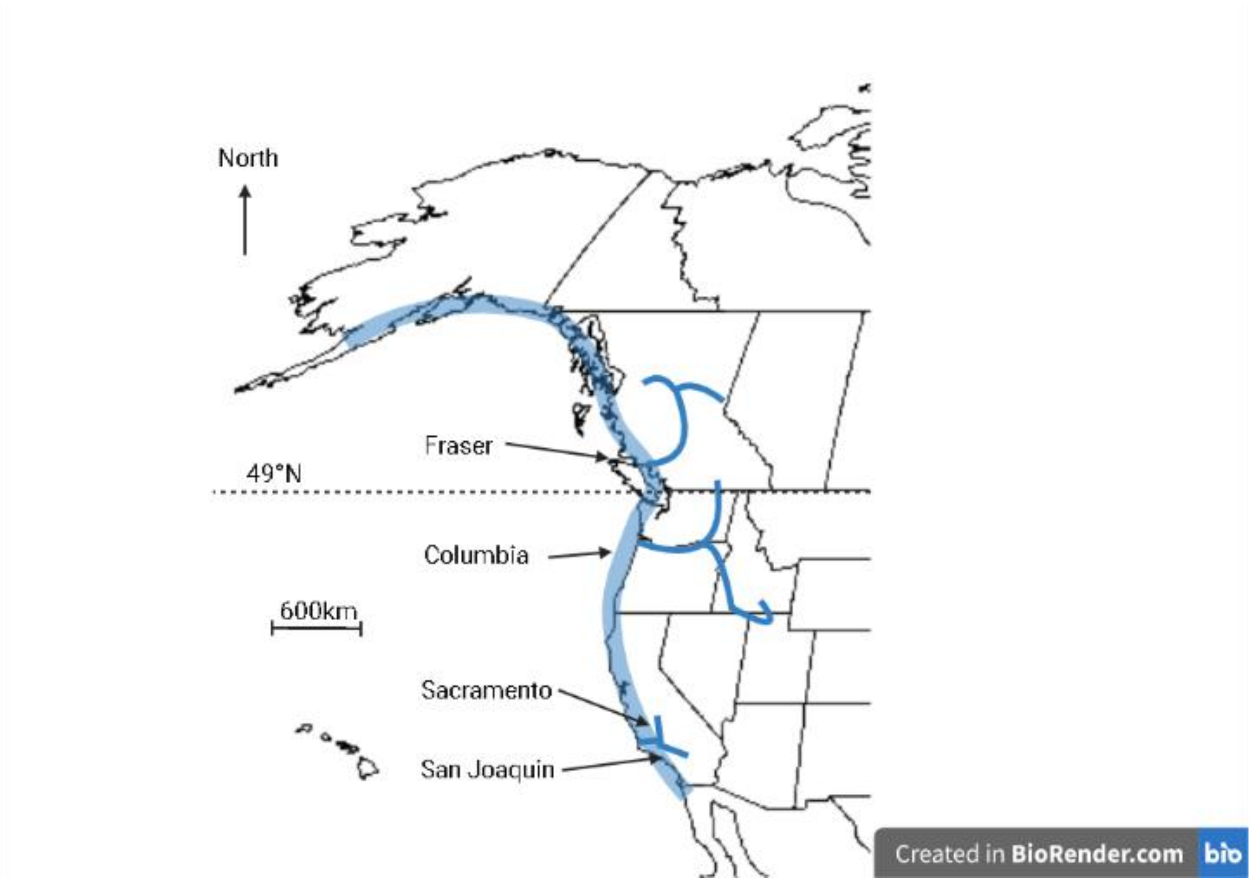

*Figure 1. Global historical distribution of white sturgeon (*Acipenser transmontanus*). The species is endemic to North American and is currently found in four major rivers in significant numbers. After Hildbrand et al., 2016. .*

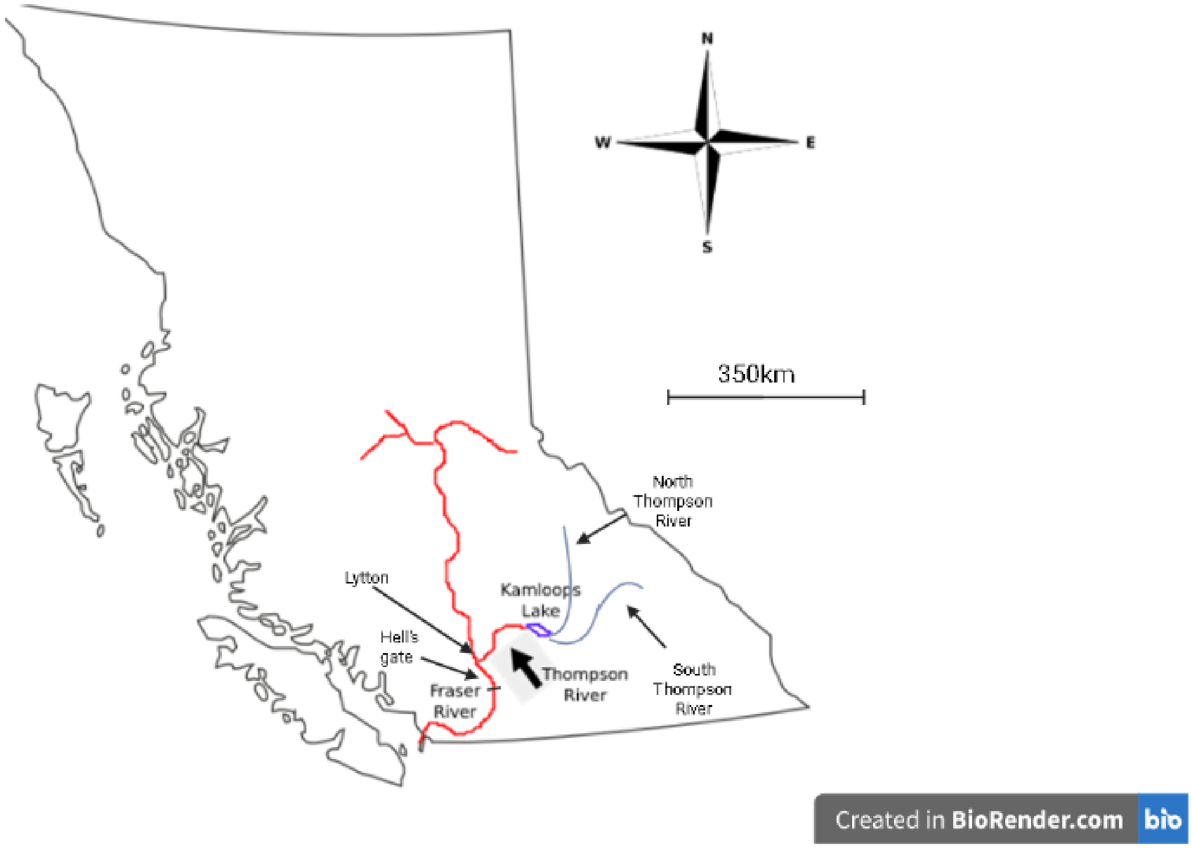

*Figure 2 Distribution of white sturgeon (*Acipenser transmontanus*) in Kamloops Lake and the Thompson River watershed in British Columbia, Canada. Kamloops lake lies at the confluence of the North and South Thompson Rivers. The Thompson River outlet flows into the Fraser River at the village of Lytton which in turn empties into the ocean*

Acts, policies, and guidelines

Section introduction

In order for this document to achieve its Goal, the KEU must be situated within the relevant legal, administrative and management context because implementing management actions of any kind ultimately depend on pre-existing Acts, policies, and guidelines (APGs). In this section, natural resource managers will be identified because they are best positioned to identify knowledge gaps that may prevent effective management decision-making (Barrett & Rodriguez, 2021). Subsequently, relevant APGs will be summarized and the author's opinion will be given with respect to how well these documents generally relate to this Case Study.

It is crucial that the terminology used in this section be well defined. For the purposes of this Case Study, the term "acts" refers specifically to laws or pieces of legislation at the provincial or federal level. The term "policies" refers to a course of action (or view) of a political party to govern present and future decisions (Wies, 1994). The term "guideline" refers to management and action plans that are produced and carried out by an arm of the government. Furthermore, a "management plan" considers trade-offs in decision-making and overarching management goals for a given system, and often generates a number of action plans (Levin et al., 2018). "Action plans" are documents that establish the activities needed to meet the objectives outlined in a recovery strategy (Fisheries and Oceans Canada, 2014). The latter are often the foundation on which management plans are built and will refer specifically to documents based on the best available scientific information that outline goals and objectives for arresting or reversing the decline of an at-risk species to improve the likelihood of the species' persistence (Fisheries and Oceans Canada, 2014).

Search for managers

In this subsection, important resource managers with responsibilities related to the KEU will be described. Since all Canadian WS are found in British Columbia (BC), the official webpage of BC was used to springboard the search. Exploring this portal, as well as the tangential pathways it generated, several important individuals were identified (see Appendix A). The Ministry of Environment and Climate Change (MECC) is an important managing body at one of the highest levels of organization because it is responsible for the effective protection, management and conservation of BC's water, land, air and living resources (British Columbia, 2022). Two important managers for Canadian WS were identified: The Minister Honourable George Heyman and the Deputy Minister Kevin Jardine. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC), which is arms-length to the advisory board of MECC, was searched and revealed Dr. Eric Taylor and Don McPhail as managers representing authoritative figures in the creation and implementation of APGs at the broadest level.

Managers at lower levels of organization may lack power (in one sense of the word) compared to the individuals noted above; however, because they are more directly involved with the population of interest and/or KEU, they are likely more knowledgeable with the actual issues. Interestingly, individuals at this level were not found through a government portal but during the author's personal search for post-graduate studies (see Appendix A). Aaron Gillespie (Operations Manager Shuswap Nation), Pat Matthew (Lead Communicator), Michelle Walsh (Biologist), and Andrew Klassen (Senior Fish Biologist) all have important responsibilities in terms of managing and learning about the KLTRW population of WS. Now that important managers have been identified, the most pertinent APGs for the KEU will be described.

Acts

This subsection will highlight three pertinent Acts important to consider in the context of the KEU and WS in KLTRW. First, the *Species at Risk Act* (SARA) has the purpose of preventing the extirpation and providing the means to recovery of wildlife species (*Species at Risk Act*, 2002, Section 6). In Subsection 37 (1) of SARA, it states that "a recovery strategy must be prepared once a species is listed as extirpated, endangered, or threatened". Therefore, if WS in KLTRW could be listed under SARA, they are likely to receive federal support. Unfortunately, there is currently insufficient data on WS in KLTRW to be listed. Therefore, information gathering projects, like those conducted by Aaron Gillespie and Michelle Walsh, are crucial in generating the antecedent information required for new legislation and management interventions. Moreover, a recent piece of legislation called the *Environmental Assessment Act* (2019) substantiates the involvement efforts of Aaron and the Shuswap Nation since it aims at ensuring greater participation from the public and Indigenous peoples at every stage of the assessment process for major resource projects (MECC, 2020). While this Act could expedite a listing under SARA in the near future by accelerating the collection of basic population-level demographic data, the *Fisheries Act* grants immediate protection for WS in KLTRW.

The *Fisheries Act* is a relevant document for two reasons: First, this Act prohibits the deposition of deleterious substances in water used by fish (*Fisheries Act*, 1985, 36(3)), which is highly relevant for the specific KEU selected for this Case Study. Second, this Act provides the Minister of Fisheries and Oceans with powers to protect and conserve fish and fish habitat (*Fisheries Act*, 1985, 35 (1)). In effect, this allows for the enforcement and implementation of action plans into the physical world.

Policies

This subsection serves as a snapshot of views held by Canada's two predominant political parties. The Liberal and Conservative parties have many overlapping and some differing visions for the future relating to environmental policies. The positions strategically held by a ruling party directly and indirectly impact conservation efforts carried out in Canada; as a result, these views are relevant for the current and future status of WS in KLTRW.

The Conservative Party believes in "protecting and enhancing all [fish] stocks" (National Policy Committee, 2021, p. 53), and in the importance of "responsible exploration, development, conservation and renewal of [the] environment (National Policy Committee, 2021, p. 24)". This perspective places emphasis on the value nature can provide to humans while simultaneously balancing ecological values. The Liberal perspective regarding environmental outlook is more ecocentric and emphasizes *action* in conservation; they believe that "we have a responsibility to act, to protect […] nature for today and for the next generations of Canadians" (Liberal Party of Canada, 2021, p. 47). Compared to the Conservative view, Liberal views focus on the intrinsic natural heritage value of nature while the Conservative might focus on providing broad-sale economic value to society. Each has advantages and disadvantages: For instance, the conservative view could lead to the influx of capitol for aquaculture and recreational sectors which would consequently fuel conservation efforts for WS in British-Columbia. In this sense, WS in KLTRW might benefit from economic incentives. On the other hand, the Liberal's eagerness to take action could accelerate conservation efforts. This approach may lead to the swift completion of information gathering projects, like the one previously mentioned, which are necessary for ensuring lasting protection under SARA.

Guidelines

Two important documents relating to Guidelines (recall these refer to management and action plans related to WS conservation and recovery) were found by non-systematically exploring the official webpage of BC (Appendix A). Two documents highlight the importance of information gathering projects like those conducted by Michelle Walsh and Aaron Gillespie: First, a five-year plan from the Government of BC states that “effective conservation actions depend on up-to-date information” (2013). Second, an agreement between the province of BC and Canada similarly states that “planning and actions (…) will be informed on the best available science” (Canada-British Columbia, 2005). The emphasis here is on *knowledge acquisition* since this is a prerequisite for the conception of a management and recovery plans.

Although the population of interest is currently not listed under SARA, we can speculate as to what Objectives and management actions may be determined once enough data is gathered for an official listing. If we consider the Action Plan developed for the Middle Fraser River population as a model for the future management of KLTRW WS, an Objective of reaching or exceeding distribution over the natural range could be expected (Fisheries and Oceans Canada, 2014, 2020). Moreover, specific management actions may include limiting pollutant discharges and protecting and enhancing water quality (Fisheries and Oceans Canada, 2014, Table B-1). If information gathering projects can lead to an official governmental recognition that a population of WS occurs in KLTRW, then WS can receive the protection of the aforementioned Acts and benefit from subsequential Guidelines. The latter may include improving water quality, which directly addresses the potentially detrimental effects of pulp-mill effluents; thereby aiding in WS conservation and increasing the likelihood of persistence.

Recommended improvements to APGs

The existing APGs presented in this section could, in theory, effectively address the KEU identified in this Case Study and help conserve WS in KLTRW. However, as it currently stands, the population of interest does not receive enough protection largely because it is not formally listed under SARA. The bureaucratic process of designation appears to be delayed by a lack of data on the population of interest. Ironically, many species at risk tend to exist in small numbers and yet classifications of “data deficient” are not rare. Unfortunately, absent or limited information are known hurdles to designation in species-at-risk decision-making (Lukey et al., 2010). This represents a difficult problem in conservation planning because species categorized as “data deficient” may experience unsuccessful conservation efforts and increased probability of extinction (Garnett et al., 2003; Stokstad, 2005), while overly generous designations may divert funding from species that need it (Hoffmann et al., 2008). Given that WS have been a species of concern in BC since the early 1990s (Lane, 1991), I would invoke the precautionary principle to argue that the KLTRW population of WS immediately receive some level of designation under SARA.

Systemic flaws in conservation decision-making have resulted in reduced top-down efforts for designating populations that lack information. Importantly, this highlights the work being done at the local level (e.g., work by Gillespie and Walsh) in generating valuable data. In brief, I believe the APGs presented in the previous subsections (Table 1) are robust, thorough, and relate to both the population of interest and the specific KEU identified in this Case Study; however, challenges in knowledge acquisition and dissemination in species-at-risk decision-making systems mean that the future of WS in KLTRW remains ambiguous.

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*Table 1 Summary of relevant Acts, Policies, and Guidelines for the selected Key Ecological Uncertainty and the Kamloops-Lake-Thompson River Watershed population of White Sturgeon (Acipenser transmontanus). *The Middle Fraser white sturgeon population was declined for SARA listing in 2006 but is included in the* Recovery Strategy for the White Sturgeon (*Acipenser transmontanus*) in Canada (Fisheries and Oceans Canada, 2014, Appendix B)*. ** At least one action plan for the four SARA-listed populations of White Sturgeon was due for posting on the Species at Risk Public Registry in March 2019 (Fisheries and Oceans Canada, 2020). The DFO is currently drafting a progress report on the implementation of the recovery strategy (Fisheries and Oceans Canada, 2020).*

Document type	Level	Name of document	Year	Important sections
Act	Federal	Fisheries Act (**S.C., 1985, c. F-14)**	1985	Section 35
Act	Federal	*Species at Risk Act **(S.C. 2002, c. 29)**	2002	Subsections 37(1) and 47
Act	Provincial	Environmental Assessment Act **(S.B.C., 2019, c. 83).**	2019	Whole document
Policy	Federal	Forward. For Everyone	2021	Page 47
Policy	Federal	Conservative Party of Canada Policy Declaration	2021	Sections 59 and 139-142
Policy	Provincial	Protecting Vulnerable Species: A Five-Year Plan for Species at Risk in British Columbia	2013	Whole document
Guideline – recovery strategy	Federal - DFO	Recovery Strategy for the White Sturgeon (Acipenser transmontanus) in Canada	2014	Whole document
Guideline	Federal	Canada-British Columbia agreement on species at risk	2005	Whole document
Guideline – action plan	Federal-provincial-municipal	Action Plan for SARA-Listed Populations of White Sturgeon (Upper Fraser River, Upper Columbia River, Upper Kootenay River, and Nechako River) **In draft form	**Late→ due for posting on the Species at Risk Public Registry in March 2019.	N/A

Knowledge Systems

<u>Section introduction</u>

In order to gain an understanding of the role of knowledge in Canadian resource management and decision-making, the various ways knowledge is acquired, disseminated, and utilized must be described. The Objective of this section is twofold: First, this section will provide the Reader with a working understanding of what human knowledge systems are and why they are critical factors in natural resource management. Second, this section will provide the Reader with relevant information on the knowledge systems specific to the KEU identified in this Case Study. For this section of the Case Study, attempts were made to contact expert knowledge holders with varying degrees of success, according to a methodology described in Appendix A. The structure of this section will be as follows: First, relevant indigenous, local, and scientific communities associated with the KEU population of interest will be identified. Second, relevant indigenous, local, and scientific knowledge systems will be characterized and experts imbedded in these systems of knowledge will be identified. Third, recommended improvements for improving the engagement of the three knowledge systems will be provided.

For the purposes of this Case Study, “networks” will refer to abstract representations of a system of nodes and the relationships or links between them (Kéfi, 2020). “Science” will include both the body of knowledge about the world in which we live, and the systematic and accumulative processes of inquiry in pursuit of that knowledge (Cornell et al. 2013). “Knowledge” will refer to the classical definition of justifiable true beliefs (Ayyub, 2010), and “knowledge systems” are made up of agents, practices, and institutions that organize the production, transfer and use of knowledge (Cornell et al. 2013).

Characterization of relevant indigenous, local, and scientific communities

The KLTRW region, like much of Canada, is rich with diverse communities of different people, often times with different language and culture. It's important to note that many subcommunities exist within each of these broad categories of people and that there is often overlap, in space or time, between communities (i.e., someone can be part of more than one community geographically or at different points in time). For instance, Aaron Gillespie, one of the expert knowledge holders contacted, is embedded to some degree in all three communities and exists at the interface of all three systems of knowledge.

Indigenous communities

It can be difficult to identify which groups of indigenous communities are associated with the TRKLW due to changing geographical boundaries of territories through time and the sometimes-nomadic way of life exhibited by indigenous peoples. Nonetheless, there is good information available on the historic and current territories of indigenous peoples in BC. Several indigenous communities' border or have territorial overlap with KLTRW; however, the Secwépemc (or Shuswap) and the Nlaka'pamux (or Thompson River People) appear to be most geographically associated with the KLTRW region. Other indigenous groups with territories in the surrounding areas are the St'at'imc (or Lillooet), Ktunaxa amakis (or the Ktunaxa Nation), and Syilx People of the Okanagan Nation. As alluded to above, there is great diversity or heterogeneity of subcommunities that exist nested within each of the larger classifications of indigenous peoples (Figure 3). For instance, there are at least nine Secwépemc communities in the southern interior of BC (Shuswap Nation Tribal Council, 2022). While it would be outside the scope of this document to describe the rich interrelated histories of indigenous communities on this landscape, it is interesting to note that the seasonally nomadic Secwépemc people have been interacting with WS from the Thompson River for hundreds of years (Matthew, 1986), likely giving them particular insight into how to manage this resource. Today there are around 6,755 Secwépemc and just over 3,000 Nlaka'pamux (Statistics Canada, 2016) compared to the relatively large number of people of European descent.

Local communities

Local communities in the TRKLW area can be divided into urban centers and a rural periphery. The City of Kamloops, located on the southern shore of Kamloops Lake, has the highest density of inhabitants in KLTRW with an estimated population of 117,000. The next largest city in the watershed is Salmon Arm with a population of approximately 19,000.

Scientific communities

There are several groups conducting scientific research in TRKLW. The Thompson River University and the Department of Fisheries and Oceans do work out of the Cultus Lake Salmon Research Laboratory. Here, work is being done on protecting the endemic Cultus sculpin (*Cottus aleuticus*) and on controlling invasive smallmouth bass (*Micropterus dolomieu*; Carlisle, 2014; Margetts, 2020). Moreover, The University of Northern British Columbia is conducting the Fishtrap Creek Watershed Project which investigates changes to channel morphology, hydrology, and sediment transport dynamics in the aftermath of forest fires (Eaton et al., 2010). Additionally, the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) based out the City of Kamloops runs the Forest Sciences program which conducts research on the effects of forest operations on a range of resources for the development of sustainable forest management policies and practices (MFLNRO, 2022).

Recommended Improvements for Knowledge System Engagement

It is the opinion of the author that the involvement of each KS in management efforts for WS in KLTRW is occurring to varying degrees of intensity. Based on my conversations with Dr. Heise of Thompson River University, I would argue that the involvement from the scientific community is lagging compared to local and indigenous communities. It appears as though small-scale initiatives can be mobilized much faster than the scientific enterprise which tends to be more egocentric. This attitude, present in many scientifically minded people, should be questioned given how well indigenous people can manage biodiversity on the landscape (Shuster et al., 2019) and the inseparability of cultural, social, economic, and ecological objectives (Godden & Cowell, 2016). Perhaps the discovery of WS in KLTRW is so recent that scientists have not been able to organize a concerted effort; however, one would expect more engagement between the scientific community and local/indigenous knowledge systems.

It would be beneficial if a consortium of individuals representing each KS could enter in productive and reciprocal dialogue to determine the best way to move forward under a common Goal, as opposed to each KS operating independently. In order to do, the scientific community should get on board with the other communities' current work on WS that are quite literally in their backyard. Moreover, they should vocalize an appreciation different knowledge system and the intra-cultural heterogeneity (Mazzocchi, 2008) present in indigenous cultures and respect this diversity when seeking productive engagement (Moller et al., 2009). The Eurocentric way of thinking inherent in scientific KS should give way to an integrated approach which can improve the mobilization of existing knowledge and enhance mechanisms for learning and decision making (Tengo et al., 2014).

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Figures

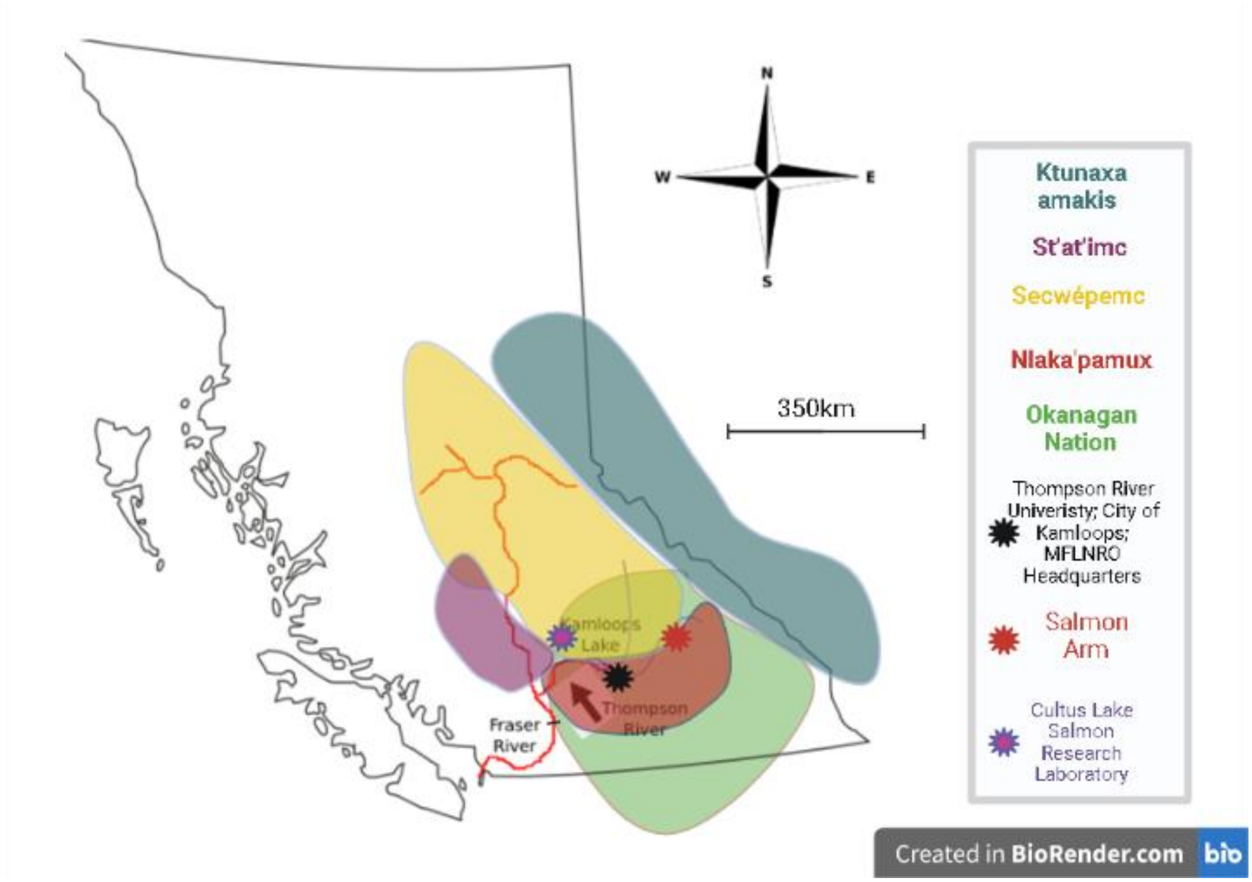

Figure 3 Map of important communities in the Kamloops Lake and Thompson River watershed in British Columbia, Canada. Information on indigenous groups and territories was sourced from the Canadian Geographic Indigenous Peoples Atlas of Canada published by The Royal Canadian Geographical Society *(2018).*

Bayesian Belief Networks (BBNs)

Section introduction

In exploring the role of knowledge in Canadian resource management and ecology, it is essential to investigate the different ways in which knowledge can be acquired and used in an uncertain world. The Objective of this section is to provide the Reader with a working understanding of what BBNs are and how these models can help incorporate knowledge from different KSs to consider cause-effect mechanisms which can be used to inform management decisions.

The structure of this section will be as follows: First each individual element comprising a BBN will be defined and explored independently. Then, a hypothetical BBN will be illustrated to show how they are structured. Second, the general BBN model shown will be adapted to include the specific KEU explored in this Case Study. Third, professional opinions regarding both benefits and challenges associated with using BBNs will be presented in the context of natural resource management planning and decision-making. However, it is important to define key terminology to help the Reader understand this potentially conceptually challenging topic.

For the purposes of this Case Study, “States of Nature” will refer to variables about the world (e.g., temperature or feature of an object, the occurrence of an event). “Belief” will refer to an estimate of the variables that matter and the relationship between them (Brienesse, 2015). “Bayesian” refers to a branch of statistics where prior beliefs influence how new evidence is used. This is in contrast to frequentist statistics that rely solely on data in relation to populations (Brienesse, 2015)

Characterization of Bayesian belief networks

A Bayesian Belief Network (BBN) is a representation of the world where prior knowledge is encoded in the form of a network to allow for reasoning under uncertainty (Pearl & Russell, n.d.). BBNs represent one possible way of integrating knowledge and uncertainty found among and within knowledge systems. Unlike traditional frequentist inference, these models depend on Bayesian inference to infer causality. The frequentist perspective

BBNs are structured such that nodes represent different States of Nature and links between them represent causal dependencies. Figure 4 shows two parent nodes (conditions) influencing a single child node (causation); note that the relationship (or link) is unidirectional and expresses either a positive or negative influence on the child node. The influence (insignificant, significant, or none) of a parent node on a child node is assigned a probability by different expert knowledge holder belonging to different Knowledge Systems. These probabilities are based on prior assumptions (or beliefs) held by expert knowledge holders and can vary between 0 and 1 (whereby both 0 and 1 represent certainties). For instance, “Ps” is the probability assigned by an expert knowledge holder from a science knowledge system. In this way, BBNs allow for the probability of a given cause-effect relationship to be updated by expert knowledge holders in the light of new evidence.

Figure 4 shows the structure of a BBN with two States of Nature (parent nodes) and a single child node. This basic structure can be expanded to include any number of nodes and links (e.g., Figure 5).

Characterization of Bayesian Belief Networks in the context of the KEU

Now that the structure of BBNs is understood, the general BBN model shown (Figure 4) will be adapted to include the specific KEU explored in this Case Study. In Figure 6 we can see a parent node “restrictions on furans in pulp mill effluents” has a positive influence on WS recruitment and “bank erosion” has a negative influence on WS recruitment.

In the broader context of natural resource management, BBNs could help solve some of the systemic flaws in species-at-risk-decision-making processes described in previous sections because they are able to incorporate and model uncertainty in decision-making (Akçakaya et al., 2000; Regan et al., 2005).

Evaluation of pragmatic benefits and challenges associated with BBNs and the KEU

The benefits associated with using BBNs in the context of the KEU explored in this Case Study are numerous. Perhaps the most relevant benefit stems from the complex toxicology and physiology at paly in the KEU. Pulp mill effluents contain a wide range of chemicals; each with different effects and interactions. Using a BBN to specifically understand the mechanisms in which different chemical compounds affect embryological development and recruitment of WS would be extremely useful. For example, BBNs could allow us to understand which compounds are particularly harmful for developing WS and inform management actions to either restrict their use in effluent manufacturing or produce some technology to remove them from effluents.

While BBN shown for this KEU (Figure 6) may appear to be simple, it would be quite challenging to assemble in reality. This is because expert knowledge holders’ opinions are likely to differ and its highly probable that several experts would need to provide opinions for the effects of effluents on WS development. Moreover, it’s unlikely local or indigenous people would be able to provide much useful insight into the complexities of toxicology and chemistry. Therefore, while BBNs may be well suited as interfaced between indigenous, local and scientific expert knowledge holders in many issues of natural resource management, it may not be worthwhile to have a local knowledge holder comment on cause-effect mechanisms related to toxicology.

Developing a rigorous BBN requires a number of expert knowledge holders to come together and assign probabilities to a large number of cause-effect relationships and would likely require someone familiar in computer sciences or mathematics. Moreover, a worthwhile BBN model runs thousands of iterations (or simulations) and would be computationally exhaustive; thus, appropriate computer technology and infrastructure would be required. Nonetheless. BBNs should be considered as a potentially highly useful tool for WS management in the context the KEU explored in this Case Study.

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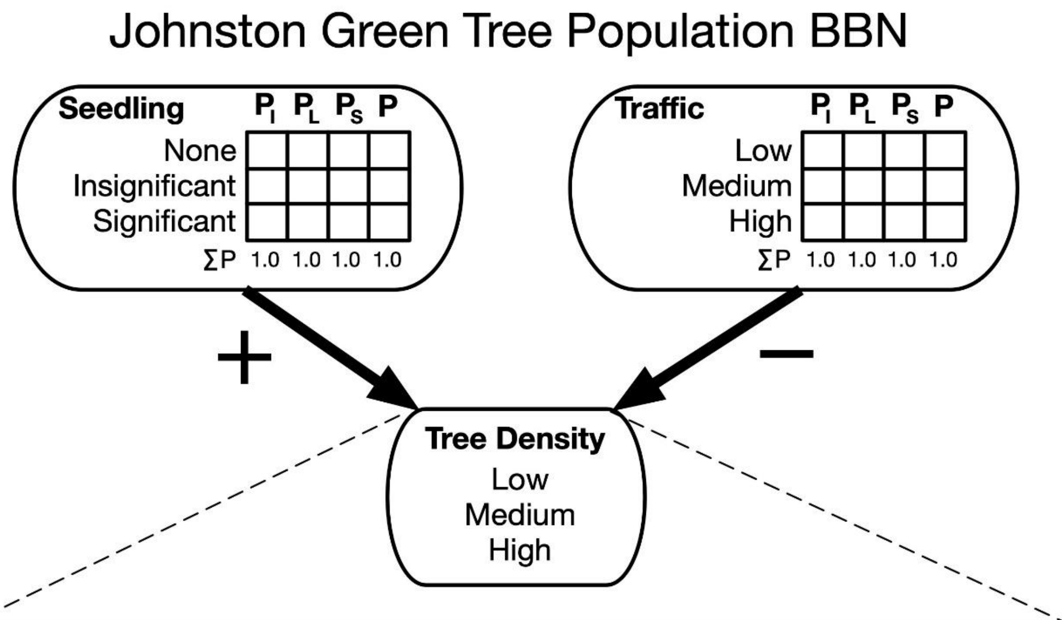
Figures



Contingency Probability Table of Tree Density

S	T	Low	Medium	High	∑P
N	L	P(D=L|S=N, T=L)	P(D=M|S=N, T=L)	P(D=H|S=N, T=L)	1.0
N	M	P(D=L|S=N, T=M)	•••	•••	1.0
N	H	P(D=L|S=N, T=H)	•••	•••	1.0
I	L	P(D=L|S=I, T=L)	•••	•••	1.0
I	M	P(D=L|S=I, T=M)	•••	•••	1.0
I	H	P(D=L|S=I, T=H)	•••	•••	1.0
S	L	P(D=L|S=S, T=L)	•••	•••	1.0
S	M	P(S=L|S=S, T=M)	•••	•••	1.0
S	H	P(S=L|S=S, T=H)	•••	•••	1.0

Figure 4 Generalized Bayesian Belief network of two parent nodes (causality) and one child node (condition). There are three levels of probability assigned to each cause-effect relationship; however, it is completely reasonable to have additional intermediate levels of probability. Moreover, within each parent node there is a matrix showing the probability assigned by knowledge holders of each knowledge system (e.g., P_S=Probability assigned by science expert knowledge holder). The contingency table below the parents-child node network illustrates each possible outcome for each combination of cause-effect relationships.

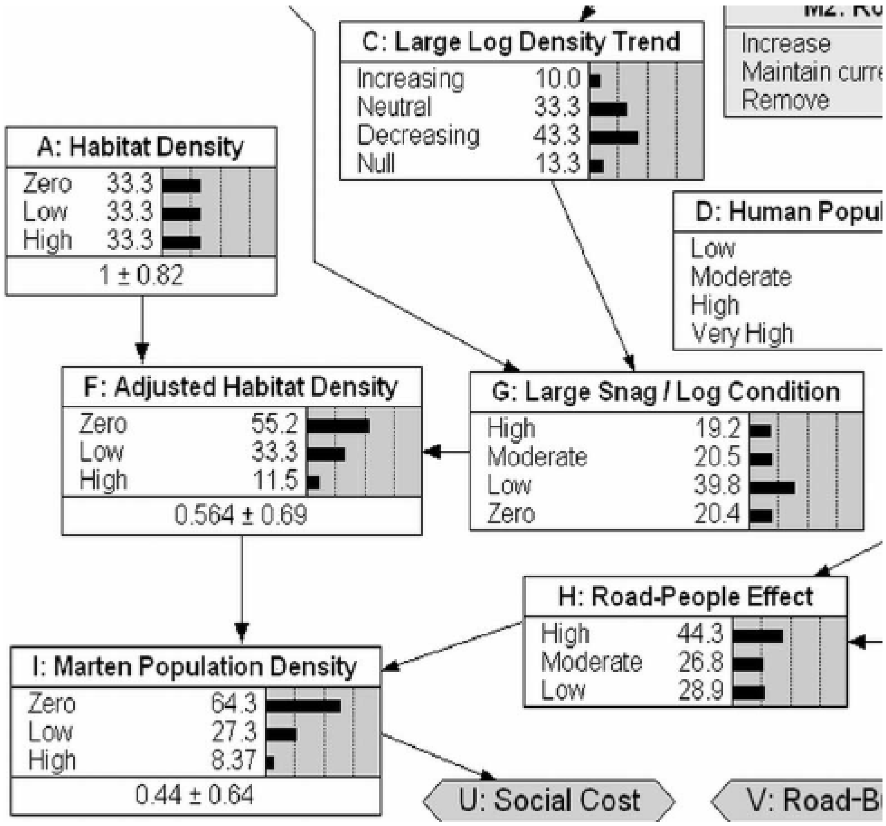


Figure 5 One part of a Bayesian Belief Network taken from McCann et al., 2006.

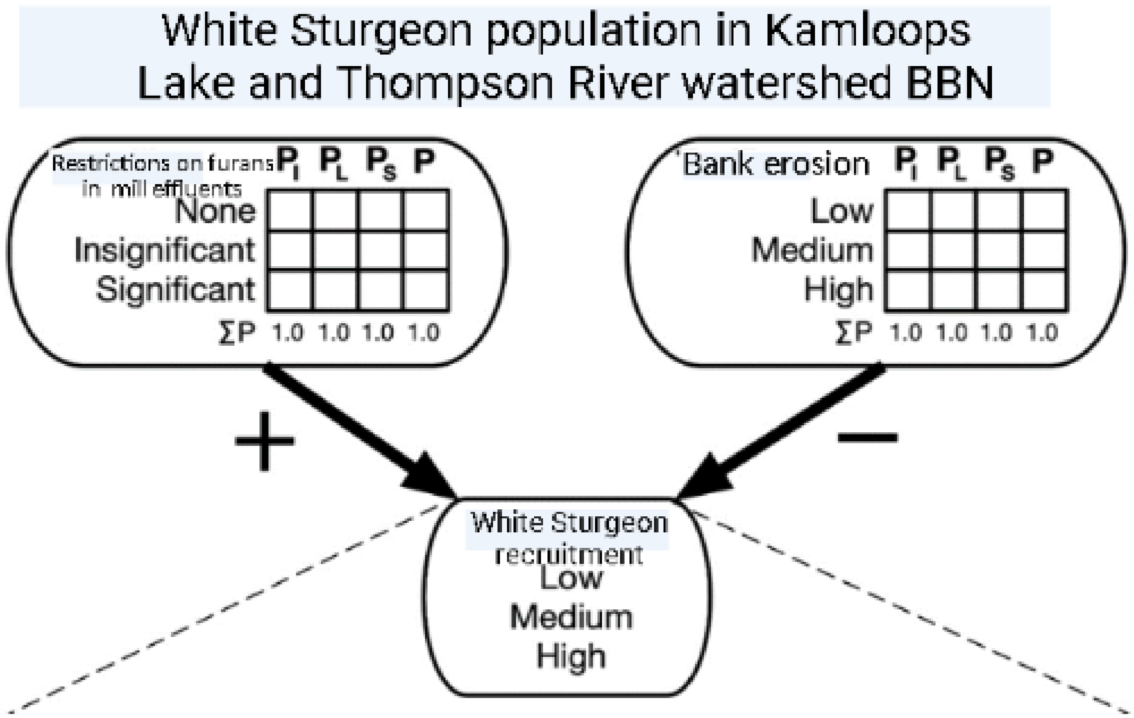


Figure 6 Hypothetical Bayesian Belief Network for White Sturgeon in Kamloops Lake and Thompson River watershed.

Management Strategy Evaluation

Section Introduction

In exploring the role of knowledge in natural resource management, it is important to evaluate how well a given management strategy is able to achieve its respective Goal. The purpose of this section is to provide the reader with a working understanding of what a management strategy evaluation (MSE) is and how these models can help resource managers make decisions in an uncertain world. Subsequently, the MSE framework will be characterized in the context of the KEU identified in this Case Study. Lastly in this subsection, the pragmatic benefits and challenges of using MSEs for the KEU will be evaluated.

In order to understand this section, essential concepts relating to MSE must be explained. The term “management” may seem to be centered on decision-making pertaining directly to resources. However, this idea does not accurately capture the role and responsibilities of managers. The term “management” here does not refer to controlling resources per se but rather to controlling the *people* who *use* the resources. The term “strategy”, sometimes referred to as “procedure” (Butterworth, 2007), has a single Goal and operates at higher levels of organization to guide local actions. Strategies differ from management actions in so far that management actions operate at local scales that support an overarching strategy. Lastly, the term “evaluation” simply asks: how well does a given strategy accomplish its Goal? Altogether, MSEs employ computer modelling and simulation to consider how well a variety of candidate strategies predict the outcome of a management action (Sainsbury, 2000) while being aware that some uncertainties will not be taken into account during the development of a management strategy (Punt et al., 2014).

General characterization of MSE

In this subsection, the fundamental concepts and processes associated with the general structure and function of MSEs in the context of natural resource management will be described. The elements of MSEs will be discussed further and a detailed description of a general MSE framework will be provided to help the reader understand its utility in natural resource management.

The process of evaluating a management strategy begins by identifying the Goal of the management strategy. A management strategy has one explicit and specific Goal by nature. A management strategy Goal has some achievable target of the “cause” variable that is associated with some desirable consequence of the “effect” variable. A “good” management Goal differs depending on the ecological issue; however, there are a couple generalizations that can be made. From the perspective of wildlife, a good management Goal is one that supports the natural reproduction of wild populations such that they are self-sustaining. The anthropocentric perspective of natural resource utilization might regard a “good” management strategy as one that ensures natural resources can be harvested sustainably (maintaining yields) and indefinitely. The Goal of any management strategy can take into account a variety of economic, political or cultural factors by including a multitude of variables. However, for the purposes of this Case Study and for the sake of simplicity, only ecological factors pertaining to population-level demographic parameters will be considered as management strategy Goals. Moreover, a population viability analysis (PVA) can be conducted to determine how population level demographic parameters might change through time which can subsequently be used to narrow in on a desirable “effect” variable could be for a management strategy Goal.

After the Goal has been established, the MSE framework is an iterative and stepwise process that follows a simple and logical general schematic (shown in Figure 7). First, the MSE framework employs computer modelling and simulation to predict how a variety of candidate management actions might lead to differential levels of success in achieving the overall management strategy goal (Sainsbury, 2000). Different management actions can accomplish the Goal of the overall strategy by either reducing negative effects on the population or increasing positive effects on the population. In addition to considering distinct management actions, the MSE framework considers how varying the level or intensity of a given management action (low, medium, high) might affect the overall outcome of the intervention. The predicted outcomes are generated using computationally intensive modelling which attempts to account for the complexity of ecosystem dynamics by assigning levels of uncertainty to management actions (Sainsbury, 2000). Importantly, in the MSE framework, the outcomes predicted by population modelling are ranked according to their efficacy in accomplishing the Goal of the management strategy. Importantly, the MSE loop must be closed by continuously adapting the management framework to integrate newly acquired knowledge. In this way, as new knowledge is acquired, the model can be updated to better inform management decision-making.

Characterization of MSE with respect to the KEU

There are several possible management actions that can be taken to enhance water quality in the Thompson River System to increase desirable population-level demographic parameters such as recruitment or birth-rate. Each potential management action has an associated degree of uncertainty in its likelihood of achieving the management Goal of reaching a self-sustaining population of White Sturgeon. In this subsection, the use of the MSE framework in fisheries management and its potential use for the specific KEU identified in this Case Study will be described.

The MSE framework has been used extensively in the management of fisheries across the globe and has been subsequently employed for conservation in terrestrial systems (Bunnefeld et al., 2011). Earliest uses of the MSE framework were in South Africa where they were used to understand the effects of different management strategies on stocks of anchovy (*Engraulis encrasicolus*; Butterworth and Bergh, 1993), sardine (*Sardinops sagax*; Geromont et al., 1999), and Cape hake (*Merluccius spp*.; Punt, 1992). Therefore, there is strong precedent for the use of MSE frameworks for populations of WS in KLTRW. If the existing models can be adapted to account for the specific nature of riverine dynamics and large long-lived fish, then good management actions could be generated to increase the chances of persistence of this population.

The national recovery Goal for WS according to the official SARA Recovery Strategy for White Sturgeon (*Acipenser transmontanus*) in Canada is to “ensure that each of the populations are sustainable throughout their natural range, are self-sustaining through natural reproduction, and to increase or restore opportunities for beneficial use, if and when feasible (Fisheries and Oceans Canada, 2014). To achieve this Goal, a series of population and distribution objectives and general activities have been identified, including specific recovery measures (Fisheries and Oceans Canada, 2014). The SARA recovery strategy for White Sturgeon in Canada outlines several management actions such as limiting and managing pollutant discharges and protecting, maintaining and enhancing water quality (Fisheries and Oceans Canada, 2014).

Let us consider three different potential management actions and insert them into a hypothetical MSE to exemplify how this framework functions (Figure 8). One potential action that could be taken is the reduction of pulp mill effluents, since they are known to negatively impact embryological development of eggs (Walker et al., 1991; Macdonald et al., 1997). This action reduces negative effects and therefore increases positive or desirable population level parameters like recruitment. Two other management actions can be found in Figure 8. These three different actions can be implemented at different levels of intensity; three levels of intensity are used here but any number can be included. Next, these actions are inputted into a computer simulation that accounts for uncertainty at various levels of the management process and the natural system (Bunnefeld et al., 2011). The predicted effects on population abundance (N) given each management action implemented at each level of intensity is generated by the computer model. To close the MSE loop, each predicted outcome is ranked based on how well it accomplishes the overall management strategy Goal. Crucially, a key feature of the iterative MSE process is the adaptive integration of new information to enhance the performance of the MSE and ultimately help manage natural resources in the face of many uncertainties.

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Figures

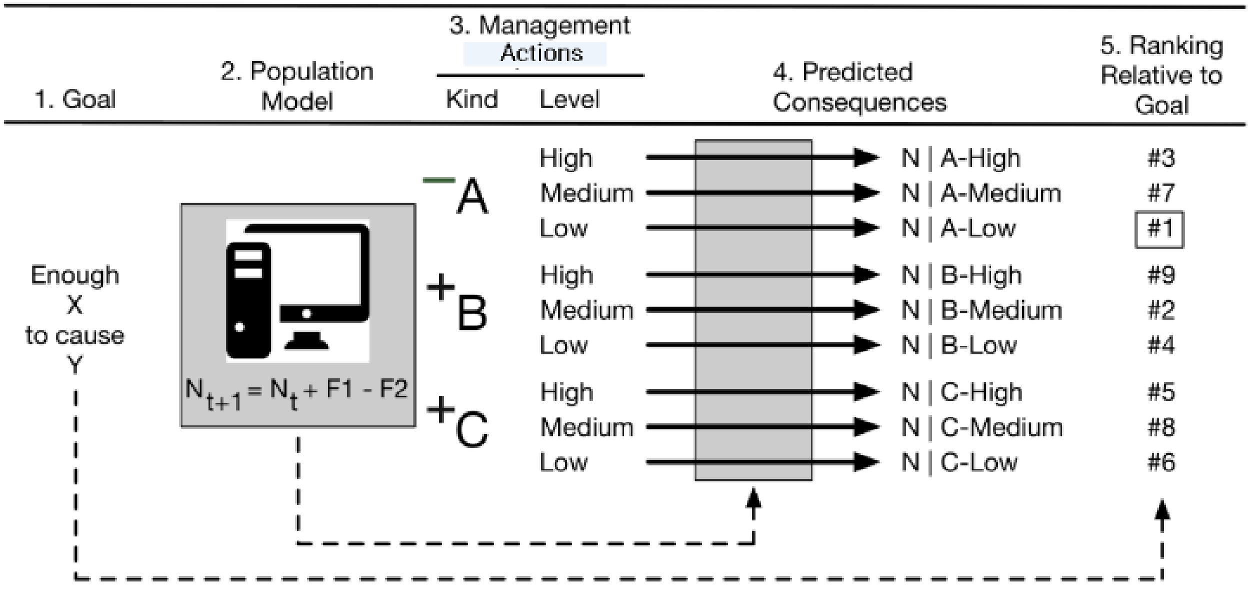

Figure 7 The Management Strategy evaluation framework is a stepwise process whereby specific management actions are ranked based on their predicted effects relative to the strategy goal. Management actions can be carried outat different levels of intensity and can increase a positive population level demographic or reduce a negative population level demogrpahic parameter.

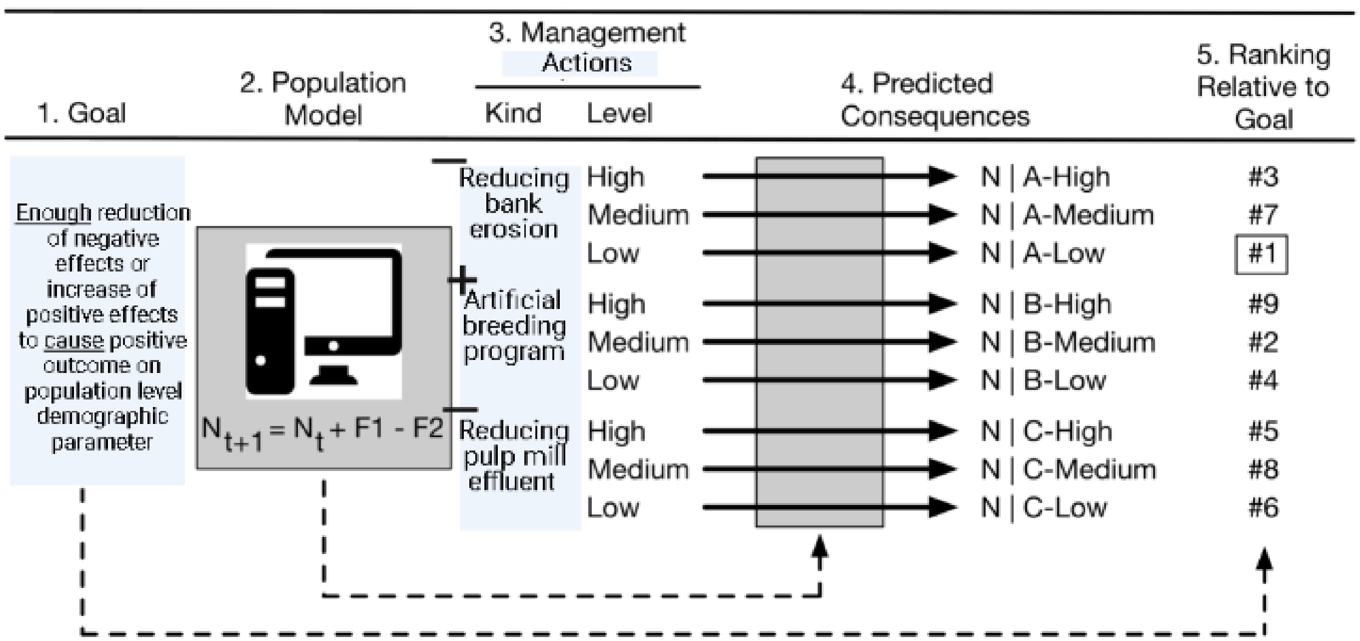

Figure 8 Hypothetical MSE framework specific to the KEU identified in this Case Study.

Case Study Discussion

Summary

In nearing completion of this undergraduate degree capstone course, it is important to take a step back and think about what I’ve learn and which skills I have acquired throughout this semester. This section of the Case Study will include the Goal, Objectives, and course deliverables; a reflection on the role of knowledge in the context of natural resource management; as well as a reflection on the important skills I’ve acquired and refined while completing this Case Study.

The Goal of this Case Study is to explore the role of knowledge and knowledge systems in Canadian resource management and decision-making and ecology. In order to achieve this Goal, five section-specific Objectives were accomplished.

This Case Study was produced in a stepwise fashion via the submission of deliverables and subsequent review and reworking of individual Case Study components. The five individual Case Study sections (KEU, APG, KS, BBN, MSE) were submitted at regular intervals throughout the academic semester with a peer-review period of three days after each section submission. To achieve the Goal of the Case Study, all five sections were consolidated in a final Case Study submission and included the following additional sections: Table of Contents, Case Study Introduction, Executive Summary, and Case Study Discussion.

Role of Knowledge and Knowledge Systems in Canadian Natural Resource Management

"Knowledge is power. Power to do evil...or power to do good." - Veronica Roth

The idea of knowledge equating power rings true in all domains. However, I would argue that the *way* in which it is used can dramatically increase or dampen its potential in generating meaningful change. Simply knowing things is not enough to proficiently and properly manage resources. In order to accomplish something in society one must continuously interact with other people. Thus, for management of any kind, the contents of the character and the manner in which one conducts oneself is at least equal to the value of raw knowledge in any field such as biology or ecology. Approaching a problem with arrogance will not lead to solutions even when if one "knows" each avenue and facet of the problem. I think this is what Theodore Roosevelt alluded to when he said that "people don't care how much you know until they know how much you care". Broaching complex ecological, cultural, and economic problems with curiosity, respect and genuine compassion is the only route towards lasting and meaningful change. I believe, in some ways, BIOL4500 has been an exploration of this idea.

Even the selfish mind would want to integrate diverse systems of knowledge in order to maximize positive outcomes and minimize pitfalls associated with any one way of thinking. A reoccurring theme in this course relates to the importance of cooperation and interacting with different people. Specifically, the impact of knowledge increases when a greater number of relationships exist between diverse groups of people. Importantly, participants must protect differences, seek similarities, and be willing to move towards a common Goal. The role of knowledge in Canadian resource management and ecology can only be appreciated in full when all parties have a seat at the table.

Reflections on Most Important Skills Learned

It is difficult to distill all I have gained from BIOL4500 into a single page of text. This course has improved my writing and widened my bandwidth for absorbing different types of information. It has improved my ability to assemble, organize, and synthesize an array of sources into a digestible format. Moreover, some sections of this course provided conceptual challenges that were enjoyable to wrestle with. Specifically, this course has changed the way I think about formal scientific inquiry, knowledge, and causality. It's made me think about thought and wonder how it is we can "know" something.

Since I tend to approach natural resource issues from an ecology-oriented mindset, it has been very useful for me to consider the intricacies of the external political, social and economic factors at play. I've learned and thought critically about the structure of management plans and how science is used in decision-making systems. To add, through this course I've gained a deeper appreciation for the values of empathy and openness. I was reminded that in a real-world application, listening and remaining open to the ideas, opinions, and experiences of others is equally as important as possessing a bounty of knowledge. I've gained a greater understanding of how to mediate interactions between diverse communities. While I'm not an expert in any one area, the skills and insights I have gained have brought me closer to becoming a well-rounded interdisciplinary-minded person who could some day play the role of knowledge broker in a real-world setting. "That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics" – Aldo Leopold

"Doing difficult work now makes the impossible work later possible." – Dr. Crawford