Ecological, social, and economic factors influencing the suitability of a waterbody for walleye stocking with a focus on Alberta, Canada

by

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A Thesis Submitted to the Faculty of Social and Applied Sciences
in Partial Fulfilment of the Requirements for the Degree of

MASTER OF SCIENCE IN ENVIRONMENT AND MANAGEMENT

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MARCH, 2022

COMMITTEE APPROVAL

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Abstract

This research provides a framework to evaluate waterbodies in Alberta to determine if walleye stocking will be ecologically appropriate and socially and economically beneficial. Data on ecological requirements and limitations for walleye, economic costs and benefits of walleye stocking and fisheries, and potential ecological and social costs and benefits were researched. This research was applied to Sylvan Lake, Alberta as an example. I discuss future research to improve analyses including detailed cost analyses and how stocking changes fishing pressure. This work may act as scientific advice for decision makers. Incorporation of ecological, social, and economic costs and benefits into stocking decisions provides a more holistic assessment. This may result in stocking waterbodies that will have direct net-economic benefits, accepting direct net-economic costs that may be offset by non-economic benefits, deciding to offset costs with special stocked waterbody licenses, or choosing to not stock walleye.

Keywords: Walleye stocking, Alberta, Cost-benefit analysis

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Acknowledgements

First and foremost, I would like to thank Dr. Gillian Kerr and Dr. Michael Sullivan for their support and advice throughout the planning and execution of this thesis. Your diverse knowledge and experiences were instrumental in bringing together the science and social science aspects.

I would like to acknowledge my cohort, friends, and coworkers for their advice and support throughout this thesis. I owe specific thanks to Melina Sorenson and Scott Seward who provided advice and support from day one. I also owe thanks to my parents, Sandi and Tim Robinson, and my husband, Kalvin Lebedynski, who encouraged and supported me throughout this journey.

This project would not have been possible without the funding and support from Alberta Conservation Association. Specifically, I would like to thank Todd Zimmerling, Peter Aku, and Paul Hvenegaard for their support in my initiation and completion of a MSc. program while maintaining full-time employment.

Evaluating ecological and economic considerations of walleye stocking in Alberta

Background

Many Albertan anglers, including myself, have grown up with the traditions of angling for and harvesting walleye (*Sander vitreus*). From the time I was a child living on Lesser Slave Lake taking pictures with my family and a string of walleye, to now when I rarely harvest fish, Alberta’s fisheries landscape and my understanding of conservation and sustainability have changed significantly. While current perceived walleye harvest opportunities are increasing compared to the 1980s and 1990s (M. Sullivan personal communication), they are decreasing relative to the perceived high harvest opportunities of the late 1990s and early 2000s when numerous waterbodies had regulations of 3 walleye over 43 cm or 50 cm total length depending on waterbody (Berry, 1996). High bag limits coupled with Alberta’s centralized population distribution and high proportion of anglers per lake compared to other provinces resulted in many collapsed walleye and northern pike (*Esox Lucius*) fisheries (Post et al., 2002).

The 2021 Alberta Fishing Regulations list 162 lentic waterbodies with specific walleye regulations of catch and release (60), minimum size limits (59), slot size limits (25), special harvest licenses (17), and one any size (1) (Government of Alberta, 2021a). Additionally, several lentic waterbodies may be covered under one regulation if they are highly connected, or may fall under the general regulations for their fisheries management zone (Government of Alberta, 2021a).

Fisheries are complex socio-ecological systems (SES) comprised of the fish resource and their ecosystem, resource users (i.e., subsistence, recreational, and commercial), and the governance or management regime (McLachlan & Defeo, 2018). A largely accepted theory in sustainability science is the "three pillars of sustainability" including economic, social and environmental aspects (Purvis et al., 2019). Sustainability, where use of a resource meets the needs of the present without compromising its use by future generations, requires a balance of these three aspects as they interact within the system (Purvis et al., 2019). The sustainability of Alberta's walleye fisheries has become strained due to a combination of stressors including fishing pressure, human population growth, increased anglers, land conversion, eutrophication, and climate change (Government of Alberta, 2018). As a result, many fisheries cannot sustain walleye harvest limits of one walleye greater than 43 cm or 50 cm total length (dependant on water body) per angler per day that were the norm in recent decades (Government of Alberta, 2018).

Walleye stocking has taken place within Alberta at various levels from 1926 to the present (Government of Alberta, 2021b; Sullivan, 2008). The peak of walleye stocking in Alberta occurred during the Walleye Enhancement Program that ran from 1982 to 1993 (Sullivan, 2008). From the early 2000's to the present, stocking of walleye in Alberta has occurred on a much smaller scale and used in specific cases for restoration (Alberta Environment and Parks, n.d.). Currently, Alberta has begun another age of stocking with the intention to increase walleye harvest opportunity with 10 waterbodies stocked in 2021 (Table 1) (Alberta Environment and Parks, n.d.; Government of Alberta, 2021b).

Table 1

Summary of reported walleye stocking in Alberta, 2021.

Waterbody Name	Fry Stocked	Fingerling Stocked
Burnstick Lake	34,680	0

Chin Lake	381,120	0
Forty Mile Coulee Reservoir	81,000	0
Lac Bellevue	55,320	1,161
Little Bow Lake Reservoir	97,560	6,394
McGregor Lake	634,440	3,219
Milk River Ridge Reservoir	183,840	22,175
Stafford Reservoir	46,440	0
Sylvan Lake	513,600	14,253
Travers Reservoir	276,840	3,277

Note. Adapted from "Fish stocking report 2021," by Government of Alberta, 2021, p. 1-28. Copyright 2021 by Government of Alberta.

In my personal life as an outdoorswoman and recreational angler, and professional career as a biologist with Alberta Conservation Association (ACA), I have noticed Alberta anglers and stakeholder groups, including Alberta Fish and Game Association (AFGA) and ACA, have become increasingly vocal that they would like to see increases in perceived walleye harvest opportunities. From personal experience, proponents of walleye stocking look to historical stocking programs in Alberta and current stocking programs in other regions of North America as a potential solution to increase walleye harvest opportunities.

Walleye stocking in Alberta has occurred in the past with the intentions to develop walleye populations in lakes that previously did not have walleye fisheries and as a tool in recovering walleye fisheries in Lac La Biche and Wabamun Lake (Alberta Environment and Parks, n.d.). Walleye are typically stocked at the fry or fingerling stage (Kerr, 2008). Once stocked, survival of fry and fingerling walleye depend on ecological aspects including major aspects of water quality, food availability for all life stages, pre-existing species assemblages of waterbodies, and waterbody morphology (Kerr, 2008; Raabe et al., 2020). Across North America, ecological considerations were frequently listed by jurisdictions while economic and social considerations were much less common (Table 2)(Kerr, 2008). Given the variation in ecological stocking criteria for walleye across North America and the lack of social and economic considerations, it is valuable to assess the specific ecological, social, and economic suitability of Alberta's waterbodies prior to considering stocking.

Table 2

Criteria used by North American resource managers to determine if a waterbody was suitable for walleye stocking.

Criteria	Number of responses
Availability of suitable forage	16
Suitable water quality and habitat conditions	14
Presence of potential predators/competitors	8
Previous stocking history (success/failure)	7
Public access	6
Potential for natural reproduction	6
Potential impact on resident biota	6
Size of waterbody (larger (e.g., > 1-200 ha) preferred)	6
Angler demand	4
Potential for emigration/escapement	4

Proximity to urban centers	3
Status of resident walleye population	3
Consistency with approved lake management plan	2
Historical presence of walleye in waterbody	2
Commercial fishing on waterbody	1
Night fishing allowed	1

Note. Reprinted from "A survey of walleye stocking activities in North America," by S.J. Kerr, 2008, Ontario Ministry of Natural Resources, p. 5. Copyright 2008 by Government of Ontario.

Research Question, Objectives, and Significance

To achieve sustainable walleye stocking in Alberta that meets the needs of today while not compromising the needs of the future, I believe decision makers should consider the three pillars of sustainability; ecology, economy, and society (Purvis et al., 2019). A review on walleye stocking activities in North America outlined the wide variety of considerations for walleye stocking that exist in different jurisdictions (Table 2) (Kerr, 2008). The majority of criteria were ecologically based, and the largest number of responses were basic criteria necessary for survival and growth (e.g. water quality, and food availability) (Kerr, 2008). Other ecological considerations included effects on the existing community assemblage, escapement potential, and the success or failure of previous stocking events (Kerr, 2008). Of the jurisdictions with social and economic considerations, they were limited to angler demand, geographic location, availability of public access, and presence of commercial fishing (Kerr, 2008). While jurisdictions clearly see these criteria as having value, I believe the criteria can be expanded to better include all three pillars of sustainability. No jurisdictions stated the inclusion of economic cost-benefit analyses or influence of potential gains or loses of ecosystem services. I believe additional economic and social considerations should be made prior to walleye stocking to balance the three pillars of sustainability. I believe a better understanding of the economics of walleye stocking are possible including accounting of stocking associated with harvesting gametes, hatching fry, rearing fingerlings, stocking of fry or fingerlings as well as the direct economic benefits through fishing license sales, tourism, and purchases of fishing equipment. Within the economic realm I recognize there will be some externalities that are more difficult to include, such as mortality of stocked fish and economic implications of pre-existing fisheries or neighboring fisheries.

Beyond ecological and economic benefits and costs, social benefits have not been previously included in considerations. Social benefits are difficult to place a direct value on but should not be disregarded. These may include connection to nature, time spent with family and friends, recreation, and general well-being (Brownscombe et al., 2019; Fenichel et al., 2013; Whitburn et al., 2020).

While stakeholders pushing for walleye stocking may have a desired result in mind, fisheries managers who are responsible for sustainable management may want to consider all aspects as they relate to the realities of the situation. Before fisheries managers stock walleye into a waterbody, it may be helpful to fully understand the ecological limitations, economic and social costs and benefits, and externalities associated with stocking walleye into a waterbody.

For my thesis, I will answer the research question of: *Within the context of Alberta, how can we evaluate waterbodies to determine if walleye stocking will be ecologically suitable and socially and economically beneficial?*

My passion for this proposed research question extends from wanting to see thriving walleye fisheries and happy anglers while doing so in an ecologically, socially, and economically responsible way. For completability of this thesis project I believe the scope needs to be limited, at this time, to evaluation of waterbodies for walleye stocking. This research can provide benefits for government led public consultations and a basis for answering further questions including if anglers are willing to pay to offset stocking costs. This research can provide insight into how to evaluate waterbodies for stocking of other aquatic species in Alberta or other jurisdictions.

Three research objectives will be combined into a fourth final objective of a framework intended to answer the research question (Table 3). This framework will include an example assessment of an Albertan waterbody using publicly available data to serve as a guideline for future suitability analyses. The following methodology section provides details on how each objective will be completed and combined into a framework.

Table 3

Individual objectives required to formulate a framework on evaluation of waterbody ecological and economic suitability for walleye stocking.

Objective	Name	Overview
1	Ecological requirements	Understanding of minimum ecological requirements for walleye growth and survival.
2	Costs	Determination of economic costs associated with reaching harvestable stocked walleye.

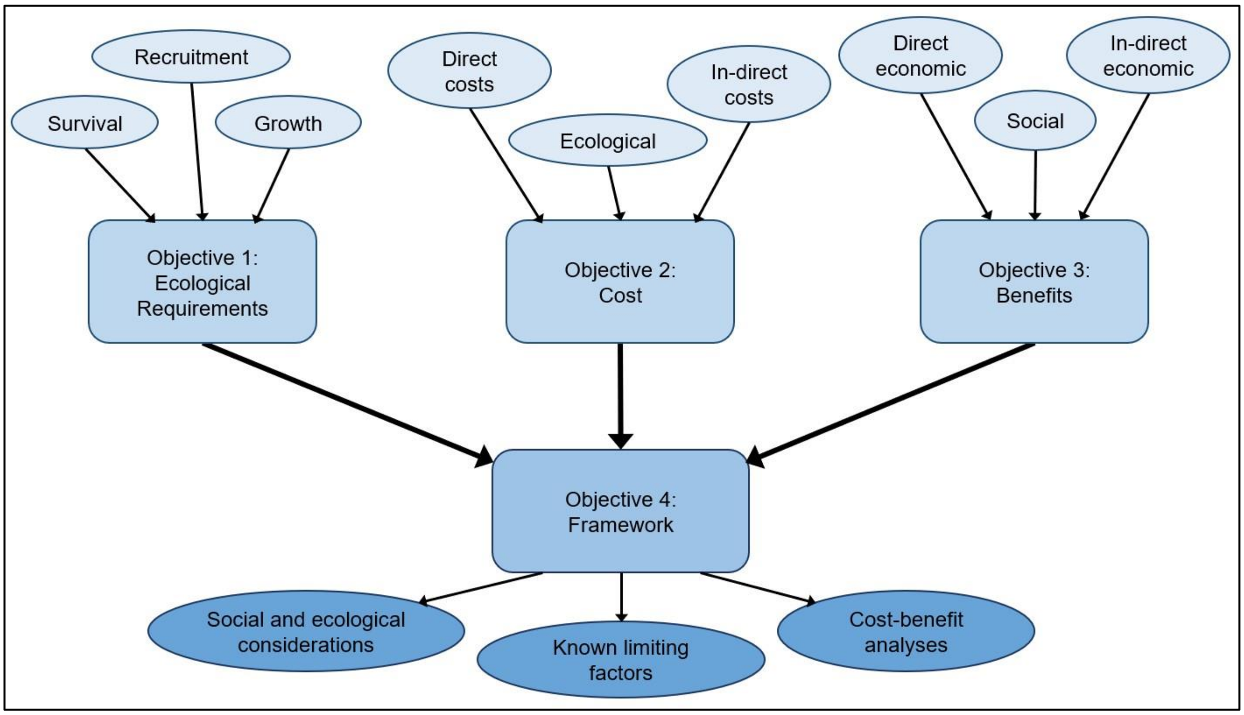
3	Benefits	Determination of economic and social benefits and calculation of economic benefits.
4	Framework	Combination of objectives 1-3 to outline a general approach and simple benefit-cost analysis.

Methodology

To answer the research question and to address each objective, I performed front-end evaluative research which intends to inform decision making for actions that have not yet occurred (O’Leary, 2017). This multidisciplinary research involves social, economic and ecological aspects consisted of both qualitative and quantitative methods to achieve each objective (O’Leary, 2017). Multidisciplinary research is an attainable form of integrated research that, while less integrative than inter- or transdisciplinary research, suits the scope of this project (Stock & Burton, 2011). Multidisciplinary research features different academic disciplines contributing to one thematic investigation where studies co-exist and co-inform (Stock & Burton, 2011). For my thesis, science and social science both contribute to the evaluation of walleye stocking. The combination of ecological, social, and economic theories and data co-informed to create a more holistic view of walleye stocking. When combined, objectives 1 to 3 fed into objective 4 on how to evaluate any given waterbody to determine if future walleye stocking activities have the potential to be ecologically appropriate and socially and economically beneficial (Figure 1). Each objective required specific methods as outlined in the following sections.

Figure 1

Multidisciplinary approach of ecological, economic, and social components to inform a more holistic view of walleye stocking activities.



Objective 1: Ecological requirements

To achieve the objective of understanding the minimum ecological requirements for walleye survival, growth, and recruitment, I explored previous research through a systematized literature review of walleye habitat and ecological requirements in North America (Grant & Booth, 2009). A systematized literature review was selected for its roots in the systematic review process while being less strict and requiring less resources than a full systematic review (Grant & Booth, 2009). Walleye and their habitats have been intensively studied in North America and therefore primary research was not required to fulfill this objective (Raabe et al., 2020). This research provided data on ranges, limitations, and considerations for physical habitat and ecological requirements relevant to walleye stocking.

To address general ecological limitations within Alberta, basic characteristics of waterbodies including their location, area, depth, and existing species presence data were obtained from the Fish and Wildlife Management Information System (FWMIS) (Fish and Wildlife Management Information System [FWMIS], 2021). Alberta's Fish and Wildlife Management Information System (FWMIS) catalogs a wide variety of raw survey data (Government of Alberta, n.d.). This data is accessible using the Fish and Wildlife Internet Mapping Tool (FWIMT) or through a data request as per the FWMIS Data Sharing Agreement (Government of Alberta, n.d.). Comprehensive water quality data for named and unnamed lakes in Alberta was not included in my general analysis as current and comprehensive water quality data is not available. I categorized lakes with available data into waterbodies with existing walleye populations, waterbodies with existing populations of northern pike but no walleye, and waterbodies without existing sportfish populations.

Objective 2: Costs

Costs of walleye stocking were broken up into the direct economic costs and more general and indirect societal or ecological costs. Identified non-economic costs were incorporated for decision makers to consider in addition to economic costs.

Economic Costs

To reveal the economic costs of stocking walleye, I determined the per fish cost, the appropriate stocking rate for walleye, and the probability of survival. This method was the most suitable given publicly available data and pre-existing literature from within Canada and North

America. Given the greater scope of this thesis beyond costs alone, time and financial restraints prohibit completion a primary analysis of detailed walleye stocking costs in Alberta.

Per Fish Cost. Within Canada, walleye stocking is typically completed by provincial governments (Kerr, 2008). Alberta, Saskatchewan, Manitoba, and Ontario currently have some degree of walleye stocking program (Alberta Environment and Parks, n.d.; Government of Manitoba, n.d.; Government of Ontario, 2021; Government of Saskatchewan, n.d.). To obtain direct economic cost data from public facilities, I emailed the Fisheries Departments of all provinces within Canada that currently stock walleye. In my email, I provided a brief description of this thesis project and requested estimates for the cost per stocked walleye fry and/or fingerling in that jurisdiction.

Stocking Rate. Per-fish costs of fry and fingerling must be multiplied by area-based stocking rates (expressed as fish/hectare), and then by the area of the waterbody to be stocked. Stocking rates for walleye were readily available in academic literature and from provincial government fisheries department reports. This includes methods for determining lake specific optimal stocking rates or historical stocking rates for Canadian jurisdictions (Fayram et al., 2005; Kerr, 2008; Ontario Ministry of Natural Resources [OMNR], 2002).

Survival and Success. Prior to addressing survival and success, it is helpful to understand the intention of walleye stocking efforts. Stocked walleye fishery success can be broken down into self-sustaining, irregular recruitment, and potential put-and-take fisheries (Sullivan, 2008). The number of stocked fish required to produce harvestable fish and a fishery is impacted by the survival rate of stocked fish (Mogensen et al., 2014). Accuracy and precision of this value will be limited by the variation of stocked fish survival from year to year within a waterbody resulting from environmental variables at the time of stocking and throughout the first year (Mitzner, 2002). Probability of survival and success of walleye stocking events have previously been researched. This includes international data and local estimates from Alberta completed through analysis of long-term recruitment trends and walleye densities in historically stocked waterbodies (Ellison & Franzin, 1992; Sullivan, 2008).

Cost Evaluation. To determine the economic cost of walleye stocking these components must be combined. In the simplest form:

$$\text{Cost} = \frac{(\text{Cost per fish} \times \text{Stocking Rate}) \times \text{Waterbody Size}}{\text{Probability of Success (as decimal)}}$$

Non-Economic Costs

To evaluate non-economic costs to walleye stocking, I accessed available literature through a systematized literature review and discussed with experts in the field (Grant & Booth, 2009). During initial exploration, I found that very little data exists on this topic which made research difficult. As such, these non-economic costs will be discussed generally to be considered as externalities.

Objective 3: Benefits

Benefits of walleye stocking were broken up into the direct economic benefits and more general at societal benefits. Identified societal benefits were incorporated for decision makers to consider if a waterbody is on the edge of being a net-benefit to Albertan society.

Economic Benefits

As identified in other economic valuations of inland fisheries, large time and financial requirements often limit researchers abilities to perform primary evaluations (Grantham & Rudd, 2015). Given these well known limitations, a benefits transfer method using suitable primary survey data from published economic valuation projects was the most suitable method for completing this objective (McComb et al., 2006). Early use of benefits transfer sparked debate on the validity of its use, however with increasing use and application in varying cases it has become widely accepted provided all caveats are presented (McComb et al., 2006).

Economic valuation data can be found through literature searches or online databases. Numerous economic valuation databases exist for use in performing benefits transfers including Environmental Valuation Reference Inventory (EVRI), Envalue, the Ecosystem Services Database (ESD), and the Review of Externality Database (RED) that are considered to be some of the best due to their usability and available data (McComb et al., 2006). I explored available primary economic surveys specifically looking for surveys in Alberta or Canada and recreational angling to determine the best available data for use in performing a benefits transfer and determination of economic value of recreational angling at stocked walleye waterbodies in Alberta.

In order to perform a benefits transfer I required an understanding of the level of angler use at Albertan waterbodies. To manage recreational fisheries resources, managers commonly utilize angler surveys to determine angling pressure on a fishery (Alberta Environment and Sustainable Resource Development [AESRD] & Alberta Conservation Association [ACA], 2015; Pollock et al., 1994). Multiple angler surveys are completed within the province in any given year at waterbodies ranging in location, size, and amenities (AESRD & ACA, 2015; Sullivan, 2021). This data is publicly available through online reports and can be summarized for application within a benefits transfer.

Non-Economic Benefits

To evaluate non-economic benefits to walleye stocking, I accessed available literature on social benefits and ecosystem services of recreational angling and fisheries through a systematized literature review (Grant & Booth, 2009). These benefits were considered through a lens of how they applied to stocked walleye fisheries. While some ecosystem services may be incorporated through economic valuations, these non-economic benefits will largely be considered generally through discussion.

Objective 4: Framework

To inform on the over-arching research question, in this objective I outlined the general process and theory that decision makers may wish to follow to analyze a specific waterbody prior to walleye stocking. Data and ideas from objectives 1 – 3 were combined to outline the process of combining overarching ecological considerations, calculation of estimated costs, calculation of estimated benefits, and how to use this data to perform a cost-benefit analysis according to the Treasury Board of Canada Cost-Benefit Analysis Guide (Treasury Board of Canada Secretariat, 2007). A cost-benefit analysis was used to quantitatively discuss economic aspects. Qualitatively I discussed considerations that are difficult to place a financial values on but may have positive or negative impacts either societally or ecologically.

To provide additional insight, I completed an example analysis of a waterbody. I chose a waterbody known to me based on the presence of existing publicly available data. To do this I assessed the known habitat attributes, estimated the cost to stock the waterbody, estimated direct economic benefits, completed a cost-benefit analysis, and considered non-economic costs and benefits.

Results

Objective 1: Ecological Requirements

General Requirements

Through my literature search, two documents provided the most comprehensive and current details on walleye ecological requirements for survival, growth, and reproduction. The book *Biology, Management, and Culture of Walleye and Sauger*, was published in 2011 by the American Fisheries Society and includes chapters on general habitat requirements, limiting factors, effect of climate on growth, and factors influencing stocking success (Barton, 2011). A more recent journal article, *Walleye inland lake habitat: Considerations for successful natural recruitment and stocking in North Central North America*, was published in 2020 and provides up-to-date summary information on walleye habitat requirements as they relate to stocking (Table 4) (Raabe et al., 2020). Within this article, the authors also provide a flow diagram for determining whether an inland lake is suitable for walleye stocking based on habitat and current species assemblages (Figure 2) (Raabe et al., 2020).

Table 4

Summary of influential water quality, physical structure, and biological factors for successful natural recruitment and self-sustaining walleye (Sander vitreus) populations.

Factor	Description
Water quality	
Water temperature: general	Coolwater, annual: <2400 degree days, base, = 5 C, <1750 degree days, base = 10 C, but varies by lake (e.g., surface area, other species)

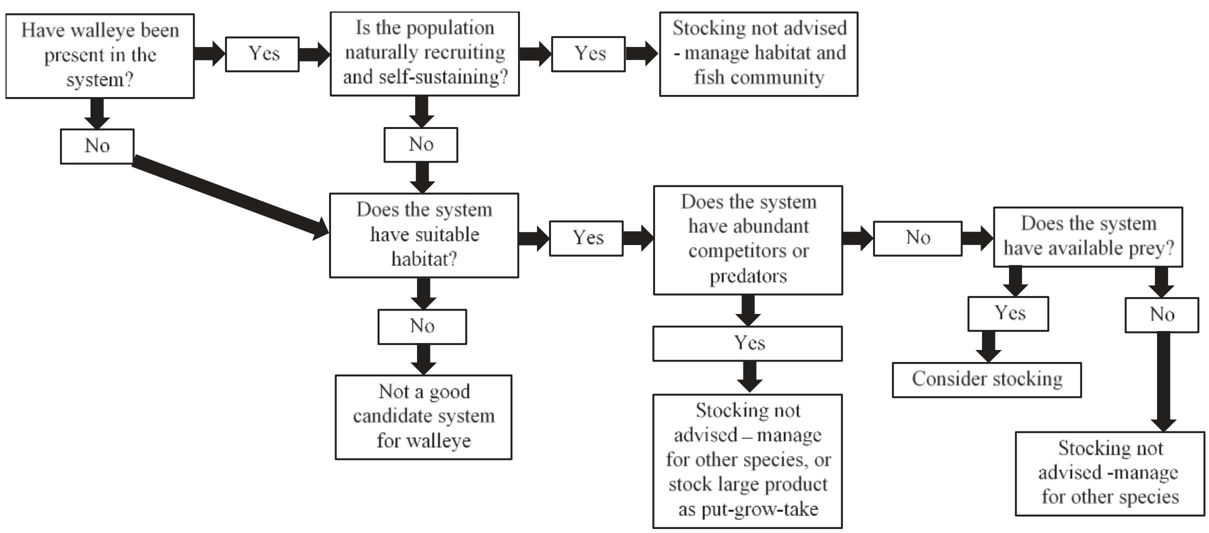
Water temperature: physiological	Overall: 18–24 C, gonadal development: <12 C, lethal: >27–31 C, fertilization: 6–12 C, incubation: 9–15 C, fry: 15–20 C
Water clarity	Lower: 1–3 m Secchi disk
Light	Lower: 8–68 lux
Productivity	Oligotrophic–eutrophic, but mesotrophic most common, typically intermediate for indirect metrics (e.g., alkalinity, conductivity, MEI)
Dissolved oxygen	Optimal: >5 mg/L; tolerable for periods: 1–3 mg/ L; lethal: <1 mg/L
pH	6–9
Physical structure	
Surface area	Positive relationship, typically intermediate to larger lakes: >100 ha
Water depth	Varies by lake (e.g., surface area, temperature, clarity), but typically shallow to intermediate depths, mean: 4 m, maximum <12 m
Morphometry	Extensive littoral and shoreline areas, intermediate shoreline development factor (SDF), mean = 2.6
Spawning habitat	Nearshore (≤3 m), shallow (≤0.3 m), gravel and cobble substrates, sand often present but very limited silt
Age-0 habitat	Initially pelagic, then demersal using macrophytes and sand areas
Juvenile and adult habitat	Varies by lake (e.g., clarity, temperature, available habitat), typically deeper, benthic areas or cover during day and shallows at night, cover includes boulders, macrophytes, and complex coarse woody habitat
Biological features	

Species interactions	Varies by lake (e.g., surface area, temperature), typically positive relationships with yellow perch and muskellunge, negative relationships with northern pike, largemouth bass, and smallmouth bass

Note. Adapted from “Walleye inland lake habitat: considerations for successful natural recruitment and stocking in North Central North America,” by J.K. Raabe, J.A. VanDeHey, D.L. Zentner, T.K. Cross, and G.G Sass, 2020, *Lake and Reservoir Management, 36*(4), p. 339. Copyright 2020 by Taylor and Francis Group.

Figure 2

Flow diagram for considerations of stocking walleye (Sander vitreus) into inland lakes in North Central North America



Note. Reprinted from “Walleye inland lake habitat: considerations for successful natural recruitment and stocking in North Central North America,” by J.K. Raabe, J.A. VanDeHey, D.L. Zentner, T.K. Cross, and G.G Sass, 2020, *Lake and Reservoir Management, 36*(4), p. 339. Copyright 2020 by Taylor and Francis Group.

As waterbodies are short-listed as potential candidates for walleye stocking, decision makers will need to analyze the water quality, physical characteristics, and biological assemblages to determine if a water is ecologically suitable. If a waterbody cannot meet the ecological requirements for walleye survival, growth, and recruitment it should not move forward into economic analysis and consideration for stocking. They must also consider the influence of existing community dynamics including how walleye will effect existing species assemblages or if current assemblages will limit the success of walleye stocking (Raabe et al., 2020).

Alberta's Lake Characteristics

FWMIS data shows there are 437 lentic waterbodies with location (UTM Nad83), surface area (ha), max and mean depth (m), and observed species data (FWMIS, 2021). This increases to 1013 lentic waterbodies when the search is expanded to not require mean depth. Of these 1013 waterbodies, 195 have had walleye present and sampled at some point in time (FWMIS, 2021). An additional 196 of these waterbodies have had northern pike, a competitor species shown to have a negative effect on walleye stocking success, present and sampled at some point in time (FWMIS, 2021; Raabe et al., 2020). Finally, 196 waterbodies have had fish species other than walleye or northern pike present and sampled. A total of 420 had no fish sampled (FWMIS, 2021). Summaries of the mean, median, and range of surface area and depths for each category are found in table 5. The FWMIS data for lakes with location, surface area, max depth and observed walleye (n=196) does not equal the number of waterbodies with walleye regulations in the 2021 Alberta Sportfish Regulations (n=162) (FWMIS, 2021; Government of Alberta, 2021). This does not mean that either data set is incorrect but highlights one potential data gap regarding current ecological data. For waterbodies in the angling regulations but not the FWMIS data set, they have known walleye populations but do not have depth data that has been entered into FWMIS. For waterbodies in the FWMIS data set but not the angling regulations, these waterbodies may exist in a listed complex of lakes in the regulations or at the very least, would fall under the general regulations.

Table 5

Surface area and depth data for lentic waterbodies in Alberta separated by type of available data and species assemblages.

Group	Statistic	Surface Area (ha)	Max Depth (m)	Mean Depth (m)
FWMIS lakes	Mean	2539.14	16.05	6.5
with walleye	Median	527.1	10.7	5.0
	Range	1.05 – 119267	1.4 – 122	0.2 – 49.9
	Sample size	n=196	n=196	n=143
FWIMIS lakes	Mean	618.1	11.0	4.71
with northern pike	Median	256.7	8.0	4.1
without walleye	Range	0.09 – 7902.21	1.1 – 61.0	0.5 – 19.1
	Sample size	n=196	n=196	n=124
FWMIS lakes	Mean	114.78	10.26	5.04
without northern	Median	12.29	6.1	3.9
pike or walleye	Range	0.07 – 3642.58	0.1 – 315.0	0.7 – 17.3
	Sample size	n=208	n=208	n=84
	Mean	163.26	3.94	2.96

FWMIS lakes	Median	39.29	2.45	2.2
with no fish	Range	0.2 – 11792.71	0 – 45	0 – 16.6
sampled to date	Sample size	n=425	n=425	n=92

Note. This table summarizes data raw, unpublished data obtained from Alberta's Fish and Wildlife Management Information System (FWMIS) database on June 22, 2021.

Objective 2: Costs of Stocking

Walleye Costs

Walleye may be stocked as fry, fingerling, and advanced fingerlings, each with different associated efforts to produce and costs. Within Canada, walleye stocking is completed by provincial governments in Alberta, Manitoba, Ontario, and Saskatchewan (Alberta Environment and Parks, n.d.; Government of Manitoba, n.d.; Government of Ontario, 2021; Government of Saskatchewan, n.d.). After submitting requests to all 5 provincial governments, I received responses from Alberta, Saskatchewan, and Ontario. Data on the size of fish, cost per fish, and jurisdiction are available in Table 6. There is a large disparity between the reported costs per fry between the three jurisdictions. Given that these numbers were sourced directly from the jurisdictions, and not determined through primary analysis for this cost analysis, this presents a likely source of error at this time. I hypothesize this is the product of each jurisdiction incorporating varying degrees of detail into their calculations. Since there is a large discrepancy, I believe there is merit in conducting a primary assessment of walleye stocking costs in the future.

Table 6

Available cost per fish data from Canadian provincial governments.

Walleye Size	Cost per fish	Jurisdiction	Source
Fry	$0.05	Alberta	C. Copeland, personal communication, September 8, 2021
Fingerling	$1.50	Alberta	C. Copeland, personal communication, September 8, 2021
Fry	$0.25	Saskatchewan	M. Duffy, personal communication, May 21, 2021
Fry	$1.75	Ontario	C. Wilson, personal communication, May 28, 2021

Stocking Rates

According to data from Kerr, stocking rates within North America ranged from 1,500 – 9,880 fry/ha, 11 – 865 fingerling/ha, and 10 – 124 advanced fingerling/ha (2008). Within Alberta, the average recorded historical stocking rate was 1313 fry/ha and 72 fingerling/ha (Sullivan, 2008). Alberta fish stocking data from 2021 shows walleye stocking rates of 90 – 240 fry/ha and 0.62 – 16.4 fingerling/ha (Government of Alberta, 2021b). A highly cited report from Ontario suggests that appropriate stocking rates are 2000 fry/ha, 100 – 125 fingerling/ha, and 25 – 50 advanced fingerling/ha (OMNR, 2002).

Stocking Success

The cost of creating a stocked walleye fishery must also include the probability of achieving a successful fishery from stocking efforts. The definition of success can include: Any success, self-sustaining fishery, irregular recruitment fishery, and potential put-and-take fishery (Sullivan, 2008). I will base my calculations on any success. However, fisheries managers may wish to determine their definition of success based on the management goal for a specific waterbody. Success of walleye stocking events in North America has been estimated at 32% for fry, 32% for fingerling, and 50% for advanced fingerling (Ellison & Franzin, 1992). Locally, success rates of walleye stocking in Alberta between 1982 and 2006 have been 27% for fry and 14% for fingerling (Sullivan, 2008).

To calculate the cost of one stocking event, we can use the formula:

$$\text{Cost} = (\text{Cost per Fish} \times \text{Stocking Rate}) \times \text{Waterbody Size}$$

Given the probability of success, estimated at 27% each stocking event, we need to account for multiple stocking events if we want to have a better likelihood of success. One way to do this is dividing the annual stocking cost by the probability of success in decimal form. In reality we cannot stock a waterbody 3.704 times to equal 100% and therefore should analyze costs based on completing stocking events for a whole number of times. Using 27% probability we would round 3.704 events up to 4. Because of this, the economic cost calculation should be:

$$\text{Cost} = ((\text{Cost per Fish} \times \text{Stocking Rate}) \times \text{Waterbody Size}) \times (\text{Events})$$

$$\text{Where: Events} = \frac{1}{\text{Probability of Success (as decimal)}} \text{ Rounded up to the nearest whole number}$$

Non-Economic Costs

Beyond direct economic costs, there may be environmental costs associated with stocking fish into a waterbody. New species added to an environment may cause shifts in the ecosystem equilibrium through changes to the community structure and introduce external pathogens (Brownscombe et al., 2019). When stocking additional fish of a species already existing in a waterbody there may be impacts to genetic diversity and increased within species resource competition while potentially not significantly increasing reproductive capacity (Brownscombe et al., 2019).

Objective 3: Benefits of Stocking

Economic Benefits

The best available data to understand the direct economic benefits of a fishery within Alberta comes from the *Survey of Recreational Fishing in Canada, 2015* (Fisheries and Oceans Canada, 2019). This primary survey data has been used by several organizations within Canada to assess and discuss the economic benefits of recreational fishing which confirms the value and applicability of this data set (Freshwater Fisheries Society of BC, 2013; The Conference Board of Canada, 2018). Other primary survey data was available but focused on other countries, was species specific, or focused on specific waterbodies. From the *Survey of Recreational Fishing in Canada, 2015,* 295,485 licensed anglers fished in Alberta comprised of resident and non-resident anglers and fished for 17 trip days/angler on average (Fisheries and Oceans Canada, 2019). Data on angler expenditures was separated into categories of direct expenditures, major purchases and investments wholly or partially attributable to recreational fishing, and major purchases and investments wholly attributable to recreational fishing (Table 7)(Fisheries and Oceans Canada, 2019). Direct expenditures were defined as “goods and services incurred during fishing trips or excursions” while major purchases and investments were defined as “durable goods in support of recreational fishing activities” (Fisheries and Oceans Canada, 2019). The durable, multi-trip nature of major investments does not make them suitable for application to benefit analysis of a waterbody based on angler usage calculated in trips. Based on total direct expenditures, total licensed anglers, and average days fished per angler, each angler spent approximately $45.98 per trip in 2015. Using the Bank of Canada's inflation tool, this equates to $52.02 in 2021 (Bank of Canada, n.d.). This value can be multiplied by the estimated angler trips to a waterbody to determine an annual economic benefit.

Table 7

Breakdown of direct expenditures, major purchases wholly or partially attributable to recreational fishing, and major purchases wholly attributable to recreational fishing.

Category and description of expense	Value spent by all anglers in 2015
Direct expenditures	
Package deals	$1,201,037
Food and lodging	$88,395,843
Transportation	$98,583,285
Fishing services	$12,732,890
Fishing supplies	$29,745,682
Other	$313,638
Total	$230,972,375
Major purchases and investments wholly attributable to recreational fishing	
Fishing equipment	$47,168,943
Camping equipment	$63,349,470
Boating equipment	$109,070,250
Special vehicles	$134,735,901

Land or building	$63,158,807
Other	$14,329,197
Total	$431,812,569
Major purchases and investments wholly or partly attributable to recreational fishing	
Fishing equipment	$47,168,943
Camping equipment	$145,948,238
Boating equipment	$134,184,576
Special vehicles	$303,126,326
Land or building	$495,701,403
Other	$15,337,853
Total	$1,141,467,339

Note. Adapted from “Survey of Recreational Fishing in Canada, 2015” by Fisheries and Oceans Canada, 2019. Copyright 2019 by Her Majesty the Queen in Right of Canada.

Angler Use Data

Regularly Alberta Environment and Parks (AEP) and ACA complete creel surveys on sport fisheries across Alberta to aid in fisheries management by estimating angler effort at any given waterbody (AESRD & ACA, 2015). These waterbodies vary in size, fishing regulations, location relative to urban centers, and amenities such as access sites, campgrounds, and cottage communities (AESRD & ACA, 2015). Summary data shows 197 angler survey records between 1985 to 2020 (Sullivan, 2021). Surveys exist on a scale of space and time as only a few waterbodies within the province can be surveyed each year. Multi-year data from individual lakes show changes in angler effort over time (Sullivan, 2021). These aspects limit the accuracy and precision of an average angler use per hectare value as they influence angler effort. To evaluate specific waterbodies, I suggest decision makers use angler survey data from waterbodies with similar features to the one being analyzed for walleye stocking. This may be done using existing angler survey data or an angler survey could be conducted for the most up-to-date data.

Non-Economic Benefits

Aside from obvious direct and indirect economic benefits, stocked walleye fisheries may provide additional ecosystem services benefits as well. Ecosystem services include provisioning services that provide a product, regulating services from ecosystem processes, cultural services that are non-material benefits, and supporting services necessary to produce all ecosystem services (Pope et al., 2016). Recreational fisheries have cultural benefits including recreation to promote personal well-being and education (Brownscombe et al., 2019; Fenichel et al., 2013). Recreational fishing may have long-term ecological benefits through connection to nature which has a positive connection to pro-environmental behaviour (Whitburn et al., 2020). Increased connection to nature may have influence on conservation activities with reach into larger environmental, social, and economic spheres (Whitburn et al., 2020). Enhanced walleye stocking may provide additional provisioning services to recreational and subsistence anglers through harvesting of fish (Pope et al., 2016). However, I feel it is important to note that many ecosystem services associated with recreational fisheries or their associated ecological systems exist without the addition of stocked fish and that non-stocking based conservation activities have potential to improve fish stocks and system-based ecosystem services (Pope et al., 2016).

Objective 4

Cost-Benefit Analysis

As discussed in objectives 2 and 3, estimating annual economic costs and benefits is relatively straightforward. However, we know that benefits are not only provided for one anglings season and statistically we must stock for multiple years to achieve success. Additionally, walleye stocked as fry or fingerling need time to grow to adult, harvestable size. Alberta Environment and Parks expects walleye stocked in 2021 to take approximately 4 to 5 years to reach harvestable size (Alberta Environment and Parks, n.d.). This is where a cost-benefit analysis is important.

The difference between the multi-year cost inputs and future benefits cannot be compared directly. To account for costs and benefits spread over several years we must apply a discount factor (Treasury Board of Canada Secretariat, 2007). This adjusts both costs and benefits that occur in the future to the present value (PV) (Treasury Board of Canada Secretariat, 2007). The current recommended discount rate for economic values is 8 percent while a 3 percent discount rate advised for social and ecosystem services (Treasury Board of Canada Secretariat, 2007). When calculating the present value of an expected future cost or benefit, you multiple the future value (FV) by a present value factor (Chartered Professional Accountants of Canada [CPAC], 2020). The formula for calculating present value is (CPAC, 2020):

$$PV = FV / (1 + i)n$$

i = discount rate as a decimal

n = number of years in the future

Every annual cost and benefit value needs to be multiplied by the equation with the appropriate discount rate and number of years in the future (CPAC, 2020). The present values for costs and benefits can be summed to obtain a net present cost/benefit (CPAC, 2020). If you subtract the net present cost by the net present benefit and obtain a positive value, you have a net benefit (CPAC, 2020). If you obtain a negative value, it is a net negative (CPAC, 2020). This may be completed for as short or long of a period as desired.

Detailed Example

Example Location Selection. AEP stocked 10 waterbodies with walleye in 2021; Burnstick Lake, Chin Lakes, Forty Mile Coulee Reservoir, Lac Bellevue, Little Bow Lake Reservoir, McGregor Reservoir, Milk River Ridge Reservoir, Stafford Reservoir, Sylvan Lake, and Travers Reservoir (Alberta Environment and Parks, n.d.; Government of Alberta, 2021b). As these waterbodies are currently relevant for discussion, I will provide an analysis for Sylvan Lake.

Sylvan Lake. Sylvan Lake (52°22’N, 114°11’W) is located in central Alberta approximately 20 km west-northwest of Red Deer. Sylvan Lake has a surface area of 4220 hectares, a max depth of 20.3 m and a mean depth of 9.9 m (AXYS Environmental Consulting Ltd., 2005; Government of Alberta, 2020). As one of the earliest waterbodies stocked in Alberta in 1926, it has been stocked on 13 occasions with the most recent stocking in 2021 (Government of Alberta, 2021b; Johnston & Paul, 2006). Sylvan Lake’s current walleye population is listed as having a high risk to sustainability (Government of Alberta, 2020).

Sylvan Lake Ecological Considerations. Fall index netting reporting shows that walleye present in Sylvan Lake are growing and surviving, indicating that ecological conditions are meeting minimum requirements (Government of Alberta, 2020). However, this same report identified issues with a lack of evidence for successful recruitment (Government of Alberta, 2020). As due diligence, ecological characteristics of Sylvan Lake and their suitability for walleye have been summarized (Table 8).

Table 8

Ecological conditions at Sylvan Lake as they relate to the suitability of the waterbody to walleye stocking.

Factor	Sylvan Lake Conditions	Suitability	Reference
Water quality			
Water temperature	Maximum measured temperature 19.4°C in August 2018	Suitable, does not exceed lethal limits.	(Alberta Lake Management Society, 2021)
Water clarity	Secchi depth 4.3 m average June – August	Suitable, water was clearer than suggested.	(Alberta Lake Management Society, 2021)
Light			
Productivity	Mesotrophic	Suitable, mesotrophic most common.	(Alberta Lake Management Society, 2021; AXYS Environmental Consulting Ltd., 2005)
Dissolved oxygen (DO)	DO greater than 6.5mg/L to 10 m depth June to August 2018. Survival of existing fish over winter suggests non-lethal lows.	Suitable during open water, unknown during winter but existing fish	(Alberta Lake Management Society, 2021)

		populations indicate suitable.	
pH	Mean pH 8.76	Suitable, within the range of 6-9.	(Alberta Lake Management Society, 2021)
Physical structure			
Surface area	4220 hectares	Suitable, greater than 100 hectares.	(Alberta Lake Management Society, 2021; AXYS Environmental Consulting Ltd., 2005; Government of Alberta, 2020)
Water depth	Mean 9.9 m, max 20.3 m	Suitable, mean and max depths both deeper than advised.	(AXYS Environmental Consulting Ltd., 2005)
Morphometry	18% of lake categorized as littoral zone (less than 3.5 m deep), 36.4 km of shoreline.	Difficult to gauge due to unequal metrics.	(AXYS Environmental Consulting Ltd., 2005)
Spawning habitat	Shoreline composed of sand or mixed rock and gravel.	Difficult to gauge due to lack of data.	(Alberta Lake Management Society, 2021)
Biological features			
Species interactions	Northern Pike are present in Sylvan Lake but currently listed	Northern pike listed as having a negative	(Government of Alberta, 2020)

	as very high risk to sustainability.	impact on walleye stocking, however they are present in low numbers and the two species currently co-exist.	

Note. Data for Sylvan Lake conditions were obtained from multiple sources referenced within the table. Suitability of each condition was compared to values in Table 4 of this document.

Aside from the basic ecological conditions, we can assess Sylvan Lake on the flow chart provided in Figure 2. There are walleye present in the system and they may be spawning but management reports indicate that recruitment is poor and the fishery is at high risk (Government of Alberta, 2020). As Figure 2 reveals, it does appear that the system has appropriate habitat, and this is confirmed by the survival and growth of the existing population. The lake does have a population of northern pike, a competitor, but at low numbers (Government of Alberta, 2020). Yellow perch and lake whitefish are both prey species that are listed in the angling regulations, plus the existing population signals prey availability (Government of Alberta, 2021a). While the presence of walleye and but lack of recruitment may signal issues with limiting factors for recruitment success, the system has appropriate conditions for survival and growth, making Sylvan Lake a suitable candidate waterbody for walleye stocking.

Estimated Economic Cost of Stocking Walleye in Sylvan Lake. To estimate the economic cost of one walleye stocking event into Sylvan Lake I will apply the known size, 4220 hectares, to the formula developed in objective 2. While actual stocking numbers are available for Sylvan Lake in 2021, walleye were stocked at a rate of 121.7 fry/ha and 3.4 fingerling/ha (Government of Alberta, 2021b). These values are well below the recommended stocking rates of 2000 fry/ha and 100 – 125 fingerling/ha, however it is important to note that recommendations were made for fry and fingerling separately and no values were presented for recommended combinations.

For these calculations I will use the recommended stocking rate of 2000 fry/hectare and a size of 4220 hectares. Given the wide span of cost per fry from the three available jurisdictions (Table 6), I will apply the formula using the lowest value of $0.05 per fry, the middle value of $0.25, the highest value of $1.25, and the average of all 3 values of $0.68 (Table 9).

Table 9

Calculations for cost per one walleye stocking event at a rate of 2000 fry/hectare at Sylvan Lake, Alberta using four different cost per fry values.

Cost Category	Calculation	Cost Estimate
Low	(0.05 × 2000) × 4220	$422,000
Middle	(0.25 × 2000) × 4220	$2,110,000
High	(1.25 × 2000) × 4220	$10,550,000
Average	(0.68 × 2000) × 4220	$5,739,200

Estimated Economic Benefit of Stocking Walleye in Sylvan Lake. To estimate the economic benefit that can be provided by stocking walleye at Sylvan Lake we will use the best available angler survey data and the average direct expenditures per angler per day from the *Survey of Recreational fishing in Canada, 2015* (Fisheries and Oceans Canada, 2019). The best available comparable angler survey information comes from Gull Lake in 2017 (Lebedynski, 2018). Similarities between Sylvan and Gull lakes include proximity to Red Deer (20 and 25 km respectively), presence of small towns each named after their respective lakes, multiple boat launches, multiple campgrounds, and cottage communities. One difference between the waterbodies is size, Gull Lake is 8110 hectares in size almost twice as large as Sylvan lake (Lebedynski, 2018). Other angler surveys from similarly sized waterbodies are available but have significantly different amenities and locations. Between May 15 and August 31, 2017 there were an estimated 17,436 angler trips at Gull Lake (Lebedynski, 2018). This works out to 2.15 angler trips/hectare. The annual economic benefit from anglers fishing at Sylvan Lake can be calculated using the following formula:

$$\text{Benefit} = \left(\frac{\text{Anglers}}{\text{Hectare}} \times \text{Area}\right) \text{Angler Expenditures}$$

$$\text{Benefit} = (2.15 \times 4220) \times \$52.02$$

$$\text{Present Value Benefit} = \$471{,}977.46$$

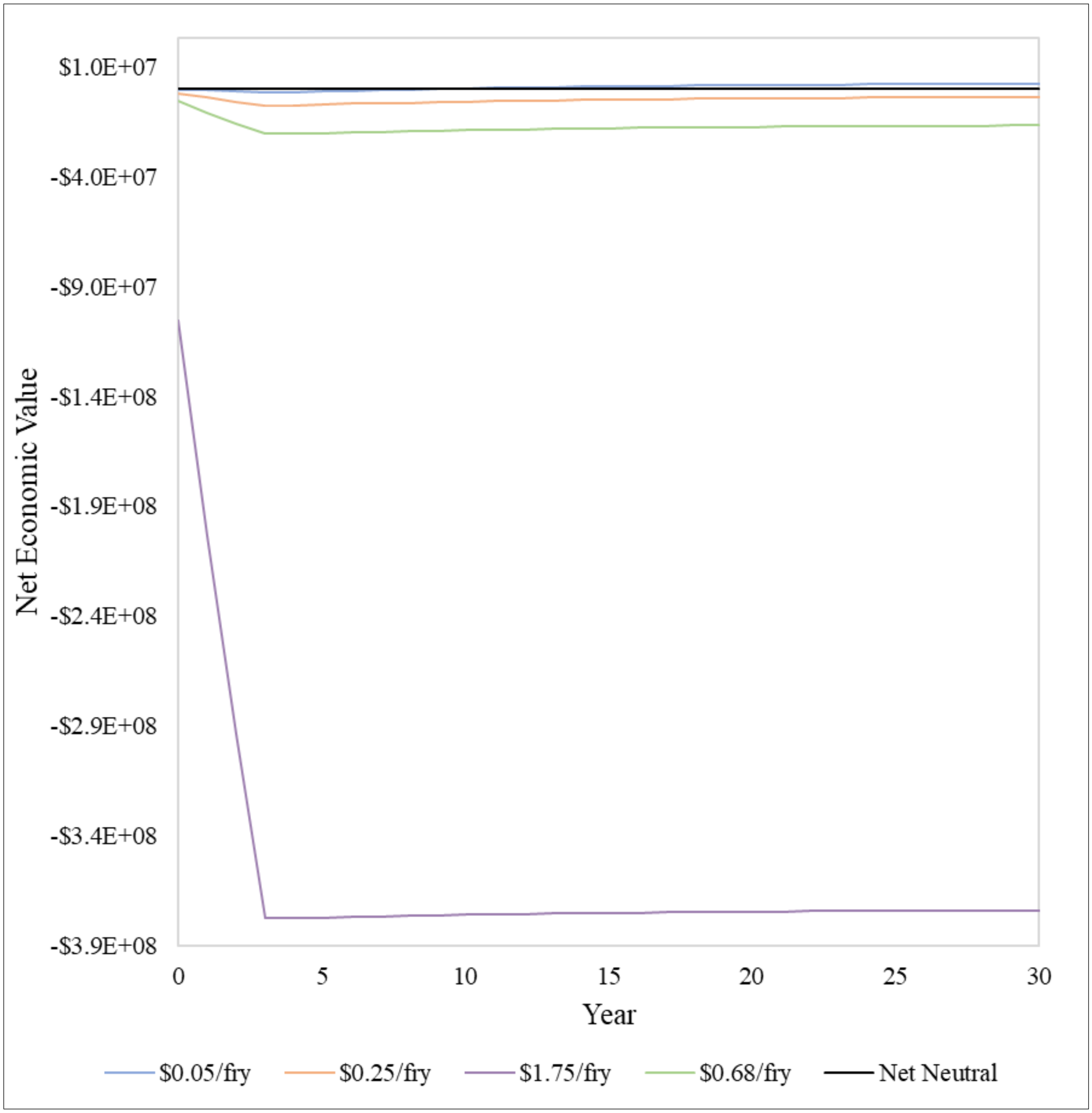
It is important to note that this value is imperfect as it uses data from an adjacent lake with similar features and does not account for any existing fishery at Sylvan Lake. To fully understand the economic benefit of walleye stocking, we would need baseline angler effort data from Sylvan Lake before and after stocking. When completing angler surveys for angler effort data, it may be worthwhile to include a question of whether anglers were fishing at the waterbody specifically because it was stocked with walleye.

Cost-Benefit Analysis for Sylvan Lake. Provided the cost of producing walleye fry does not change and walleye fry are stocked at the recommended rate, the cost of stocking walleye in Sylvan Lake will be at minimum $422,000 and at maximum $10,5500,000 annually for 4 years.

Using expenditure data and assumptions of estimated angler use, which is known to be imperfect data, there will be an annual $471,977.46 economic value after 4 to 5 years. I performed four cost-benefit analyses using all four cost input categories (Table 9) of walleye stocking costs from years 0 to 3 and a constant benefit output of $471,977.46 annually from year 5 to 30 (Appendices A to D). I used multiple cost input categories to provide a more robust analysis and highlight the importance of small changes in values creating large differences in time to net benefit. For this I used a discount rate of 8% for costs and an annuity rate of 8% for benefits (Treasury Board of Canada Secretariat, 2007). If ecosystem services with economic valuations were included in this calculation, I would apply a social discount rate of 3% to those benefit values (Treasury Board of Canada Secretariat, 2007). Under the assumption that there was no existing fishery and therefore no existing benefit, and that the benefit started 5 years after the first stocking event, a net economic benefit would occur in year 10 for the lowest cost fry and does not occur until some time after year 30 for the other 3 cost values applied (Figure 3a and 3b). Further, this assumes there is still an existing benefit from the walleye stocked in the first four years at year 10 and well beyond year 30 which is unlikely given natural and angling mortality. As we know, there is an existing walleye fishery at Sylvan Lake and therefore existing benefit which reduces the real economic benefit provided from walleye stocking, which would lengthen the time to reach a positive net economic benefit.

Figure 3a

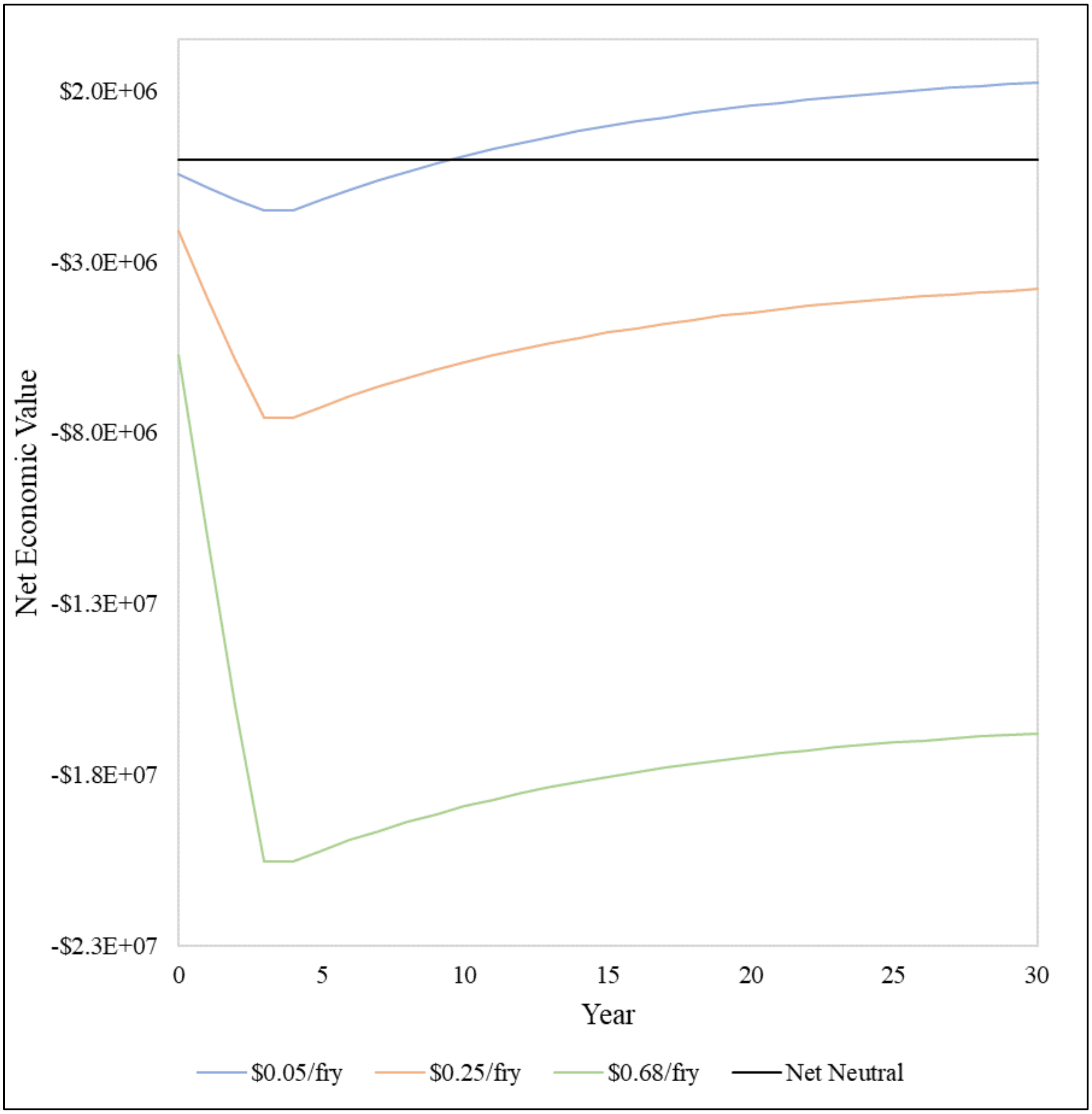
Net economic value per year for all four cost input categories.



Note. This figure shows the net economic value over time from the cost-benefit analysis of $0.05, $0.25, $1.75, and $0.68 per fry cost inputs over time at Sylvan Lake. The net economic value of the $0.05 fry cost evaluation reaches net benefit in year 11. The remaining costs do not reach net benefit within 30 years.

Figure 3b

Net economic value per year for the $0.05, $0.25, and $0.68 per fry cost input values.



Note. This figure shows a subsection of data presented in Figure 3 to improve the visualization of the net economic value over time of the $0.05, $0.25, and $0.68 per fry cost inputs over time.

The net economic value of the $0.05 fry cost evaluation reaches net benefit in year 11. The remaining costs do not reach net benefit within 30 years.

Discussion

While it is generally impossible to foresee all considerations for every possible scenario, this research should be used as a starting point to inform the process of assessing a waterbody for walleye stocking. Further, it is important for decision makers to remember that when performing front-end analysis, the outcomes are never guaranteed. Ecologically, conditions during transport or specific lake conditions at the time of stocking have a significant effect on initial survival of stocked fish and long-term stocking success (Mitzner, 2002; Sullivan, 2008). On the human side, the number of anglers within Alberta may increase or decrease over time but will never be infinite and these anglers will make choices of where and where not to fish (Fenichel et al., 2013). Individual choices may be driven by proximity to home, fishing regulations, fish species, catch rate, familiarity of the waterbody, amenities, presence or absence of other anglers, and personal preference (Fenichel et al., 2013; Patterson, 2011). These preferences are the results of individual angler choices to maximize the recreational experience while accounting for trade-offs of personal economic and time budgets (Fenichel et al., 2013).

My research started with a focus on waterbodies where stocking would create an entirely new fishery and therefore entirely new benefits however this ideal failed to take into system perspective. While waterbodies without walleye populations do exist, they are typically small and shallow making them unsuitable for walleye survival or have existing populations of other sport fish (Table 5). Additionally, walleye stocking has taken place in Alberta at various rates since 1926 placing walleye in many waterbodies across the province (Johnston & Paul, 2006; Sullivan, 2008).

Within North America, several jurisdictions, including Alberta, stock walleye fry and fingerling into existing fisheries (Kerr, 2008). When this occurs, the associate costs are not wholly responsible for creating the annual economic benefits of these fisheries. Stocking on top of fisheries may be appropriate when ecological conditions are suitable but recruitment is minimal, however waterbodies should still be assessed ecologically as stocking has been shown to be significantly less effective than protecting natural recruitment (Raabe et al., 2020). Additional assessment may be valuable on a case-by-case basis to compare costs of restoration for improved natural recruitment compared to stocking activities. When walleye are stocked into existing walleye or northern pike fisheries, the associate costs are not wholly responsible for creating the benefits of these fisheries.

Through the case study of this novel approach at Sylvan Lake, it became clear that many aspects required for a precise and accurate cost-benefit analysis are vague or completely unavailable. The disparity between cost estimates to stock fry into waterbodies between different jurisdictions is concerning and likely represents a large potential for error. Given the high variation in values, and the drastic effect they had on time to net economic benefit, future research on the cost inputs of stocking walleye would be valuable. Another place where error is created within the estimate is associated with the difference between existing benefit and new benefit due to walleye stocking. As previously discussed, there are a finite number of anglers who make choices regarding which waterbody to visit, no two waterbodies are the same, and many waterbodies have existing sport fisheries prior to walleye stocking. Long-term studies on waterbodies before and after stocking as well as human dimensions surveys are likely needed to fully understand these factors and likely have variation between waterbodies. Finally, reported stocking rates were much lower than the recommended stocking rates for walleye. This inherently will lower the cost of stocking. However, I am unsure of the impact low stocking rates have on lake walleye populations and therefore the potential benefit. In my research, I found very little formal literature on recommendations for walleye stocking rates, with one document largely cited but clearly not followed.

Aside from future research to address errors within this work, there are several applications of this approach. This could be applied in Alberta for stocking of several trout species that are stocked on an annual basis. This could be applied by fisheries managers in jurisdictions across North America. I believe this research to be applicable for non-aquatic stocking activities including game-bird release programs (Alberta Conservation Association, n.d.). Finally, I believe it may be applicable to evaluation and comparison of the costs and benefits of other fisheries management tools including habitat protection, restoration, or enhancement.

Conclusion

Resource managers are responsible for making decisions based on available scientific advice. This goal of my research has been to provide scientific advice to act as a primer for managers to think critically about whether or not to stock a waterbody with walleye. By performing a more holistic assessment of waterbodies prior to stocking walleye, decision makers will have more information when deciding how to allocation of fisheries management budgets towards stocking. This may occur by stocking waterbodies that will have a direct net-economic benefits, accepting direct net-economic costs that may be offset by social and ecological services, needing to offset costs with special stocked waterbody licenses, or simply choosing to not stock walleye.

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Appendix

Appendix A

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost	$4.22E+05	$4.22E+05	$4.22E+05	$4.22E+05	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Benefit	$0.00	$0.00	$0.00	$0.00	$0.00	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05
PV Cost 8%	$4.22E+05	$3.91E+05	$3.62E+05	$3.35E+05	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PV Benefit 8%	$0.00	$0.00	$0.00	$0.00	$0.00	$3.21E+05	$2.97E+05	$2.75E+05	$2.55E+05	$2.36E+05	$2.19E+05	$2.02E+05	$1.87E+05	$1.74E+05	$1.61E+05	$1.49E+05
PV factor 8%	1.0000	0.9259	0.8573	0.7938	0.7350	0.6806	0.6302	0.5835	0.5403	0.5002	0.4632	0.4289	0.3971	0.3677	0.3405	0.3152
To year cost	$4.22E+05	$8.13E+05	$1.17E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06
To year benefit	$0.00	$0.00	$0.00	$0.00	$0.00	$3.21E+05	$6.19E+05	$8.94E+05	$1.15E+06	$1.39E+06	$1.60E+06	$1.81E+06	$1.99E+06	$2.17E+06	$2.33E+06	$2.48E+06
To year net	-$4.22E+05	-$8.13E+05	-$1.17E+06	-$1.51E+06	-$1.51E+06	-$1.19E+06	-$8.91E+05	-$6.15E+05	-$3.60E+05	-$1.24E+05	$9.43E+04	$2.97E+05	$4.84E+05	$6.58E+05	$8.18E+05	$9.67E+05

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Benefit	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05
PV Cost 8%	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PV Benefit 8%	$1.38E+05	$1.28E+05	$1.18E+05	$1.09E+05	$1.01E+05	$9.38E+04	$8.68E+04	$8.04E+04	$7.44E+04	$6.89E+04	$6.38E+04	$5.91E+04	$5.47E+04	$5.06E+04	$4.69E+04
PV factor 8%	0.2919	0.2703	0.2502	0.2317	0.2145	0.1987	0.1839	0.1703	0.1577	0.1460	0.1352	0.1252	0.1159	0.1073	0.0994
To year cost	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06	$1.51E+06
To year benefit	$2.61E+06	$2.74E+06	$2.86E+06	$2.97E+06	$3.07E+06	$3.16E+06	$3.25E+06	$3.33E+06	$3.41E+06	$3.47E+06	$3.54E+06	$3.60E+06	$3.65E+06	$3.70E+06	$3.75E+06
To year net	$1.10E+06	$1.23E+06	$1.35E+06	$1.46E+06	$1.56E+06	$1.65E+06	$1.74E+06	$1.82E+06	$1.90E+06	$1.97E+06	$2.03E+06	$2.09E+06	$2.14E+06	$2.19E+06	$2.24E+06

Appendix A. Cost-benefit analysis spread sheet for Sylvan Lake, Alberta walleye stocking using the lowest cost estimate of $0.05 per fry.

Appendix B

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost	$2.11E+06	$2.11E+06	$2.11E+06	$2.11E+06	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Benefit	$0.00	$0.00	$0.00	$0.00	$0.00	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05
PV Cost 8%	$2.11E+06	$1.95E+06	$1.81E+06	$1.67E+06	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PV Benefit 8%	$0.00	$0.00	$0.00	$0.00	$0.00	$3.21E+05	$2.97E+05	$2.75E+05	$2.55E+05	$2.36E+05	$2.19E+05	$2.02E+05	$1.87E+05	$1.74E+05	$1.61E+05	$1.49E+05
PV factor 8%	1.0000	0.9259	0.8573	0.7938	0.7350	0.6806	0.6302	0.5835	0.5403	0.5002	0.4632	0.4289	0.3971	0.3677	0.3405	0.3152
To year cost	$2.11E+06	$4.06E+06	$5.87E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06
To year benefit	$0.00	$0.00	$0.00	$0.00	$0.00	$3.21E+05	$6.19E+05	$8.94E+05	$1.15E+06	$1.39E+06	$1.60E+06	$1.81E+06	$1.99E+06	$2.17E+06	$2.33E+06	$2.48E+06
To year net	-$2.11E+06	-$4.06E+06	-$5.87E+06	-$7.55E+06	-$7.55E+06	-$7.23E+06	-$6.93E+06	-$6.65E+06	-$6.40E+06	-$6.16E+06	-$5.94E+06	-$5.74E+06	-$5.55E+06	-$5.38E+06	-$5.22E+06	-$5.07E+06

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Benefit	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05
PV Cost 8%	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PV Benefit 8%	$1.38E+05	$1.28E+05	$1.18E+05	$1.09E+05	$1.01E+05	$9.38E+04	$8.68E+04	$8.04E+04	$7.44E+04	$6.89E+04	$6.38E+04	$5.91E+04	$5.47E+04	$5.06E+04	$4.69E+04
PV factor 8%	0.2919	0.2703	0.2502	0.2317	0.2145	0.1987	0.1839	0.1703	0.1577	0.1460	0.1352	0.1252	0.1159	0.1073	0.0994
To year cost	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06	$7.55E+06
To year benefit	$2.61E+06	$2.74E+06	$2.86E+06	$2.97E+06	$3.07E+06	$3.16E+06	$3.25E+06	$3.33E+06	$3.41E+06	$3.47E+06	$3.54E+06	$3.60E+06	$3.65E+06	$3.70E+06	$3.75E+06
To year net	-$4.93E+06	-$4.81E+06	-$4.69E+06	-$4.58E+06	-$4.48E+06	-$4.38E+06	-$4.30E+06	-$4.22E+06	-$4.14E+06	-$4.07E+06	-$4.01E+06	-$3.95E+06	-$3.89E+06	-$3.84E+06	-$3.80E+06

Appendix B. Cost-benefit analysis spread sheet for Sylvan Lake, Alberta walleye stocking using the middle cost estimate of $0.25 per fry.

Appendix C

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost	$1.06E+08	$1.06E+08	$1.06E+08	$1.06E+08	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Benefit	$0.00	$0.00	$0.00	$0.00	$0.00	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05
PV Cost 8%	$1.06E+08	$9.77E+07	$9.04E+07	$8.37E+07	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PV Benefit 8%	$0.00	$0.00	$0.00	$0.00	$0.00	$3.21E+05	$2.97E+05	$2.75E+05	$2.55E+05	$2.36E+05	$2.19E+05	$2.02E+05	$1.87E+05	$1.74E+05	$1.61E+05	$1.49E+05
PV factor 8%	1.0000	0.9259	0.8573	0.7938	0.7350	0.6806	0.6302	0.5835	0.5403	0.5002	0.4632	0.4289	0.3971	0.3677	0.3405	0.3152
To year cost	$1.06E+08	$2.03E+08	$2.94E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08
To year benefit	$0.00	$0.00	$0.00	$0.00	$0.00	$3.21E+05	$6.19E+05	$8.94E+05	$1.15E+06	$1.39E+06	$1.60E+06	$1.81E+06	$1.99E+06	$2.17E+06	$2.33E+06	$2.48E+06
To year net	-$1.06E+08	-$2.03E+08	-$2.94E+08	-$3.77E+08	-$3.77E+08	-$3.77E+08	-$3.77E+08	-$3.76E+08	-$3.76E+08	-$3.76E+08	-$3.76E+08	-$3.76E+08	-$3.75E+08	-$3.75E+08	-$3.75E+08	-$3.75E+08

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Benefit	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05
PV Cost 8%	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PV Benefit 8%	$1.38E+05	$1.28E+05	$1.18E+05	$1.09E+05	$1.01E+05	$9.38E+04	$8.68E+04	$8.04E+04	$7.44E+04	$6.89E+04	$6.38E+04	$5.91E+04	$5.47E+04	$5.06E+04	$4.69E+04
PV factor 8%	0.2919	0.2703	0.2502	0.2317	0.2145	0.1987	0.1839	0.1703	0.1577	0.1460	0.1352	0.1252	0.1159	0.1073	0.0994
To year cost	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08	$3.77E+08
To year benefit	$2.61E+06	$2.74E+06	$2.86E+06	$2.97E+06	$3.07E+06	$3.16E+06	$3.25E+06	$3.33E+06	$3.41E+06	$3.47E+06	$3.54E+06	$3.60E+06	$3.65E+06	$3.70E+06	$3.75E+06
To year net	-$3.75E+08	-$3.75E+08	-$3.75E+08	-$3.74E+08	-$3.74E+08	-$3.74E+08	-$3.74E+08	-$3.74E+08	-$3.74E+08	-$3.74E+08	-$3.74E+08	-$3.74E+08	-$3.74E+08	-$3.74E+08	-$3.74E+08

Appendix C. Cost-benefit analysis spread sheet for Sylvan Lake, Alberta walleye stocking using the highest cost estimate of $1.75 per fry.

Appendix D

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost	$5.74E+06	$5.74E+06	$5.74E+06	$5.74E+06	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Benefit	$0.00	$0.00	$0.00	$0.00	$0.00	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05
PV Cost 8%	$5.74E+06	$5.31E+06	$4.92E+06	$4.56E+06	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PV Benefit 8%	$0.00	$0.00	$0.00	$0.00	$0.00	$3.21E+05	$2.97E+05	$2.75E+05	$2.55E+05	$2.36E+05	$2.19E+05	$2.02E+05	$1.87E+05	$1.74E+05	$1.61E+05	$1.49E+05
PV factor 8%	1.0000	0.9259	0.8573	0.7938	0.7350	0.6806	0.6302	0.5835	0.5403	0.5002	0.4632	0.4289	0.3971	0.3677	0.3405	0.3152
To year cost	$5.74E+06	$1.11E+07	$1.60E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07
To year benefit	$0.00	$0.00	$0.00	$0.00	$0.00	$3.21E+05	$6.19E+05	$8.94E+05	$1.15E+06	$1.39E+06	$1.60E+06	$1.81E+06	$1.99E+06	$2.17E+06	$2.33E+06	$2.48E+06
To year net	-$5.74E+06	-$1.11E+07	-$1.60E+07	-$2.05E+07	-$2.05E+07	-$2.02E+07	-$1.99E+07	-$1.96E+07	-$1.94E+07	-$1.91E+07	-$1.89E+07	-$1.87E+07	-$1.85E+07	-$1.84E+07	-$1.82E+07	-$1.81E+07

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Benefit	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05	$4.72E+05
PV Cost 8%	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PV Benefit 8%	$1.38E+05	$1.28E+05	$1.18E+05	$1.09E+05	$1.01E+05	$9.38E+04	$8.68E+04	$8.04E+04	$7.44E+04	$6.89E+04	$6.38E+04	$5.91E+04	$5.47E+04	$5.06E+04	$4.69E+04
PV factor 8%	0.2919	0.2703	0.2502	0.2317	0.2145	0.1987	0.1839	0.1703	0.1577	0.1460	0.1352	0.1252	0.1159	0.1073	0.0994
To year cost	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07	$2.05E+07
To year benefit	$2.61E+06	$2.74E+06	$2.86E+06	$2.97E+06	$3.07E+06	$3.16E+06	$3.25E+06	$3.33E+06	$3.41E+06	$3.47E+06	$3.54E+06	$3.60E+06	$3.65E+06	$3.70E+06	$3.75E+06
To year net	-$1.79E+07	-$1.78E+07	-$1.77E+07	-$1.76E+07	-$1.75E+07	-$1.74E+07	-$1.73E+07	-$1.72E+07	-$1.71E+07	-$1.71E+07	-$1.70E+07	-$1.69E+07	-$1.69E+07	-$1.68E+07	-$1.68E+07

Appendix D. Cost-benefit analysis spread sheet for Sylvan Lake, Alberta walleye stocking using the average of all three cost estimates of $0.68 per fry.