Using a GIS-based Multi-Criteria Evaluation Model to Identify Suitable Spawning Habitat and Priority Restoration Sites for Lake Sturgeon (*Acipenser fulvescens*) in Eastern Georgian Bay

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List of Abbreviations

COSEWIC	Committee on the Status of Endangered Wildlife in Canada
EBG	Eastern Georgian Bay
GIS	Geographic Information System
HSI	Habitat Suitability Index
IPCA	Indigenous Protected and Conserved Area
MCE	Multi-Criteria Evaluation

1. Abstract

Anthropogenic impacts to the environment have caused many destructive effects, such as the decline and endangerment of several species, including lake sturgeon (*Acipenser fulvescens*). Sturgeon have historically been known to spawn within the Eastern Georgian Bay region, making it a key location to establish protected areas for population rehabilitation. In order to identify these sites, we have developed a habitat suitability index (HSI) using a multi-criteria evaluation model to identify the sites most suitable for sturgeon rehabilitation according to a variety of factors that contribute to successful spawning of lake sturgeon. The model weights factors such as water temperature, speed and depth, as well as contributing anthropogenic factors such as riparian land use and distance from dams and other physical obstructions. The resulting suitability map indicated that three out of six identified study areas; Harris Branch, Key River and Shawanaga River, provide the most suitable locations for habitat spawning. The three areas were taken through a secondary analysis to determine how protecting the riparian forest cover is beneficial to total river suitability. Suitability scores in Key River and Shawanaga River were found to quickly diminish even under the lowest riparian deforestation scenarios in comparison to the Harris Branch, suggesting they are less robust to change. Given the findings, this study suggests that aquatic systems are fairly sensitive to rapid changes in surrounding land cover and establishment of protected areas would be beneficial for long-term sturgeon spawning success. Additionally, the developed HSI can be used to identify areas of priority for future monitoring.

2. Introduction

2.1. Problem Context

2.1.1. Problem definition and Significance

The lake sturgeon (*Acipenser fulvescens*) is one of the largest benthic freshwater fish, prevailing in three North American drainages, the Mississippi in Central United States, the Great Lakes, and the Hudson Bay in Canada (Peterson, 2007). Human induced threats to sturgeon such as overfishing, habitat fragmentation, urban development, water manipulation, pollution and agricultural runoff have caused populations to become extirpated and threatened (Kerr et al., 2010). Due to these anthropological alterations, suitable spawning habitats are becoming increasingly difficult for lake sturgeon populations to find, especially since lake sturgeon do not adapt readily to changes in their environment (Government of Ontario, 2019). Lake sturgeon have a vital importance as a natural resource and has high cultural significance to Indigenous peoples. Indigenous people have been known to use lake sturgeon as a vital food source, in medicinal oils, as leather and use of the bones for various items (Bonnechere Algonquin First Nation, 2012). Across Canada, populations of lake sturgeon have identified either as special concern, threatened, or endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) including a decline in Eastern Georgian Bay (EGB) and its surrounding tributaries (Kerr et al., 2010).

It is important to preserve the future viability of this species by adequately protecting and managing sturgeon spawning habitats. This can be done with the use of Indigenous Protected and Conserved Areas (IPCAs). IPCAs have a primary role of conserving Canada's ecosystems through Indigenous laws and knowledge systems representing long-term commitments to conservation (ICE, 2018). This research project will attempt to identify suitable lake sturgeon spawning sites that can potentially be converted into IPCAs in EGB and its surrounding tributaries. This solution not only has the potential to stabilize sturgeon populations in the selected study area, but also provide the ability for local Indigenous populations to conserve both ecological and cultural contributing factors. The chosen study area encompasses the Shawanaga First Nation territory which has been implementing several projects related to the creation and management of conserved areas in partnership with Shared Value Solutions. These projects aim to monitor environmental changes in their territory and support the livelihoods of Indigenous communities.

2.1.2. Identified Research Gaps

There is currently a great deal of knowledge regarding lake sturgeon's biology, history, spawning and habitat requirements, and reasons why groups of lake sturgeon have been classified as special concern, endangered or threatened. Due to their classification under COSEWIC, there has been extensive research done on the species as per the committee's requirement to provide a comprehensive status report and assessment (COSEWIC, 2019). However, little is currently known about the degree of accessible sturgeon habitat, particularly spawning grounds, in tributaries of EGB, within the Parry Sound District (EGBSC, n.d.).

2.1.3. Importance of GIS Applications

Information regarding suitable spawning habitat in tributaries is inherently important in developing spatial-specific restoration strategies, such as IPCAs (Daugherty et al., 2009). Thus, the application of Geographic Information Systems (GIS) can provide a practical way to identify distinct areas of potentially suitable habitat and their degree of sensitivity to changing factors. The creation of Habitat Suitability Indexes (HSI) using Multi criteria Evaluation (MCE) has been previously used in other regions of the Great Lakes basin to inform population rehabilitation efforts for lake sturgeon (Daugherty et al., 2008; Daugherty et al., 2009). Thus, spatially explicit models that produce weighted predictive surface maps incorporating key variables to spawning success can assist the decision-making process for local stakeholders in future lake sturgeon management actions.

2.2 Purpose of Research

The purpose of this research is to develop a HSI using MCE to locate suitable spawning sites for lake sturgeon in EGB and surrounding areas. The identified sites serve to inform the establishment of IPCAs, which will monitor environmental conservation and support the livelihoods of Indigenous communities.

3. Research Objectives

1. Determining the factors and constraints associated with suitability for potential Indigenous protected and conserved spawning sites for sturgeon.

2. Developing a habitat suitability index (HSI) model using MCE.

3. Analyze how human disturbance via deforestation affects the results of the HSI and determine the best potential regions for IPCAs for spawning and restoration of lake sturgeon in the identified study area.

4. To evaluate the assets and limitations associated with the model and chosen study sites in order to identify potential future amendments.

4. Study Area

Shawanaga First Nation and their Partners, Shared Value Solutions and Georgian Bay Biosphere, have shown interest in implementing several projects related to the creation and management of IPCAs across their traditional territory, particularly in incorporating potential spawning areas for sturgeon populations (Georgian Bay Biosphere, 2021). The Shawanaga First Nation community borders EGB approximately 30 km northwest of Parry Sound, Ontario, and is part of the larger Anishnabek Nation that encompasses land across the northern shores of all the Great Lakes (Shawanaga First Nation, 2021). Our study sites spanned across 5 key tributaries flowing across their traditional territory within the EGB: Shawanaga River, Magnetawan River, Key River, Sucker's Creek, and Naiscoot River (Fig. 1). These tributaries were chosen to align with previous work related to the characterization of sturgeon habitat that has been conducted in the area by Eastern Georgian Bay Stewardship Council, as well as to establish potential opportunities for data sharing with Shawanaga First Nation and their Partners (Sargeant, 2018).

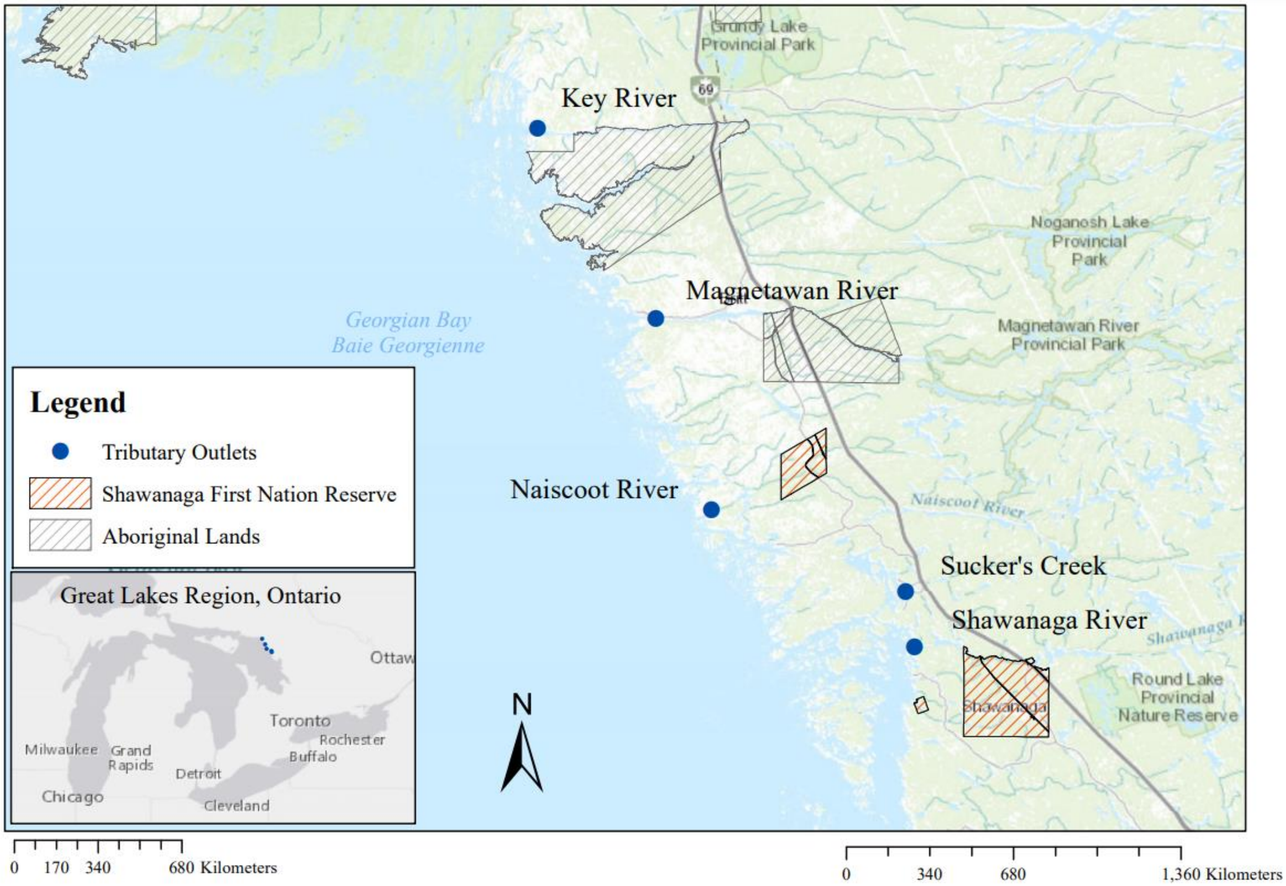

Figure 1. Isolated study sites focussing on five key tributaries flowing into Eastern Georgian Bay, Ontario, Canada. These tributaries have been identified as potential spawning sites for lake sturgeon (*Acipenser fulvescens*) in earlier research efforts conducted by the Eastern Georgian Bay Stewardship Council (Sargeant, 2018).

5. Methods / Research Approach

5.1. Objective One

5.1.1. Establishing Factors and Restraints

Lake sturgeon make use of numerous distinct habitats throughout the entirety of their lifespan, with different developmental stages requiring different habitat conditions (Auer, 1996). Successful initiation and recruitment of spawning activity largely depends on ambient environmental conditions, and therefore they must be accounted for in the proposed suitability model (Peterson et al., 2007). A literature review of the key ecological requirements related to lake sturgeon spawning success and site selection was conducted to establish the relevant factors and constraints to be used in our model. The chosen factors and constraints are outlined below.

Factors

Bathymetry: lake sturgeon have an optimal spawning site depth range (Baril, 2018). Depth varies according to seasonal changes in water discharge, which increases risk of egg stranding (EGBSC, 2018). Optimal depth for spawning is between 10-200 centimetres (Kerr et al., 2010).

Water temperature: Water temperature is one the main stimulus for spawning and has a critical influence on the speed and success of egg incubation (EGBSC, 2018). Lake sturgeon have optimal spawning and egg incubation windows that must be met to ensure recruitment success (Baril, 2018). Optimal temperature for reproduction ranges between 10-20˚C (Kerr et al., 2010).

Distance from Rapids: Higher water velocities and turbulence at rapids is an important factor for spawning site selection in Lake Sturgeon (Peterson et al., 2007). Spawning sturgeon tend to prefer sites with fast flowing waters and rapids contribute to better water chemistry conditions through facilitating higher dissolved oxygen concentrations (Kerr et al., 2010).

Riparian Land Use: Natural shorelines are vital in maintaining water quality (EGBSC, 2018). The presence of undeveloped riparian buffers mitigates harmful anthropogenic inputs into water systems, and as a result, promotes stability in community fish dynamics (Tong & Chen, 2002; EGBSC, 2018).

Distance from Dams: In addition to fragmenting available habitat by impeding upstream migration, dams can have lasting downstream effects on flow regimes, water chemistry and temperature (Kerr et al., 2010). In particular, variable flows at the base of dams can lead to adult sturgeon entrainment, as well as the as the stranding of eggs (Kerr et al., 2010; EGBSC, 2018).

Constraints

Dams and physical obstructions: One of the greatest factors repressing lake sturgeon populations is access blockage to migratory spawning routes and nursery habitat (Auer, 1994). Barrier dams are major obstacles in sturgeon spawning migration that disturb habitat connectivity (Auer, 1994).

5.1.2. Data Collection and Editing

Upon completion of the literature review and definition of key factors and constraints, appropriate spatial data was collected for the defined study region and transformed to a common 10 m resolution raster surface. The data utilized in this MCE analysis and the preprocessing is outlined in Table 1.

Table 1. Data collected for MCE analysis of suitable lake sturgeon (*Acipenser fulvescens*) spawning habitat in tributaries of EGB and the preprocessing conducted prior to use.

Factor/ Constraint	Data Layer Name	Source	Year	Scale	Description/Preprocessing
Bathymetry	Side Scan Sonar Data (.SL2 files)	Georgian Bay Biosphere	2016	Regional	Point side scan sonar data collected using a Lowrance unit along boat accessible segments of several EGB tributaries. ---- Underwent data type transformation and inverse weighted interpolation to form a continuous raster surface.
Water Temperature	Side Scan Sonar Data (.SL2 files)	Georgian Bay Biosphere	2016	Regional	Point side scan sonar data collected using a Lowrance unit along boat accessible segments of several EGB tributaries. ---- Underwent inverse weighted interpolation to from a continuous raster surface.
Distance to Rapids	Ontario Hydro Network (OHN) - Hydrographic	Ontario Ministry of Natural Resources	2010	Provincial	Line features showing the location of natural or manmade features that occur along water bodies, including falls, rapids, rocks, dams, etc. ---- Euclidian distance to rapids was calculated as a raster layer. A stream network distance calculation was not used due to the relative non-meandering nature of water bodies in the study.

Table 1. Data collected for MCE analysis of suitable lake sturgeon (*Acipenser fulvescens*) spawning habitat in tributaries of EGB (continued).

Factor/ Constraint	Data Layer Name	Source	Year	Scale	Description
Riparian Land Use	Provincial Landcover 2000 – 27 Classes	Ontario Ministry of Natural Resources	2002	Provincial	Raster layer classifying 27 broad land cover types consisting of categories of vegetation types and non-vegetated surfaces. ---- Zonal statistics calculating total percent (%) of land use that is natural vegetation in a 30m riparian buffer. Riparian buffers with a width of at least 30 m and are composed of native forest land are considered most effective at maintaining good water quality (NOAA, n.d.; Wenger and Fowler, 2000)
Distance to Dams	Dam and Barrier	Ontario Ministry of Natural Resources	2009	Provincial	Point features describing locations of obstacles impeding surface water flow, including both anthropogenic (i.e., dams) and natural (i.e., rapids, falls) features. ---- Euclidian distance to dams was calculated as a raster layer. A stream network distance calculation was not used due to the relative non-meandering nature of water bodies in the study.

5.1.3. Advanced Data Processing

Sonar data in the form of SL2 files was provided by the Georgian Bay Biosphere. This sonar data was of vital importance to the HSI as it contains accurate temperature and depth data. The SL2 file format was incompatible with project software/tools and required transformation prior to use. The SL2 files first had to be transformed into ESRI supported shapefiles through the use of an R script. Inverse distance weighted interpolation was used to create temperature and depth grids across all study sites. Figure 2 summarizes the entire GIS process applied specifically to this data.

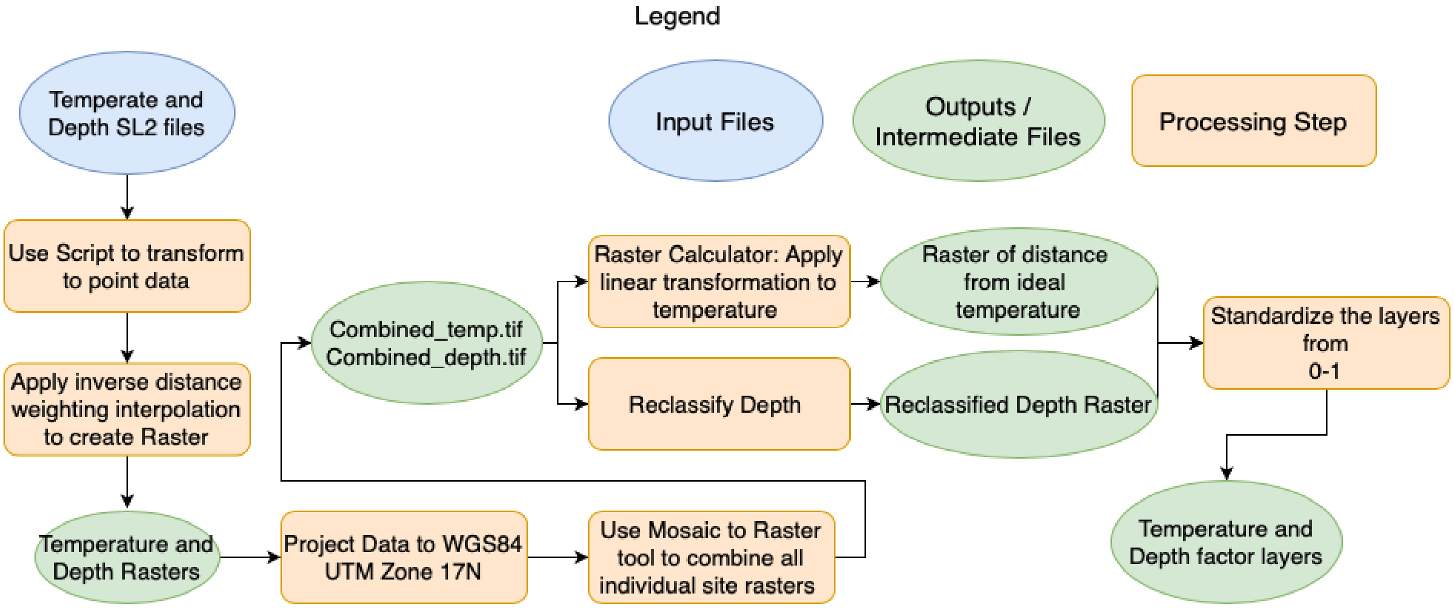

Figure 2. Workflow to produce temperature and depth factor layers.

Riparian land use was calculated from general land data. The GIS process used to create the factor layer can be seen in Figure 3.

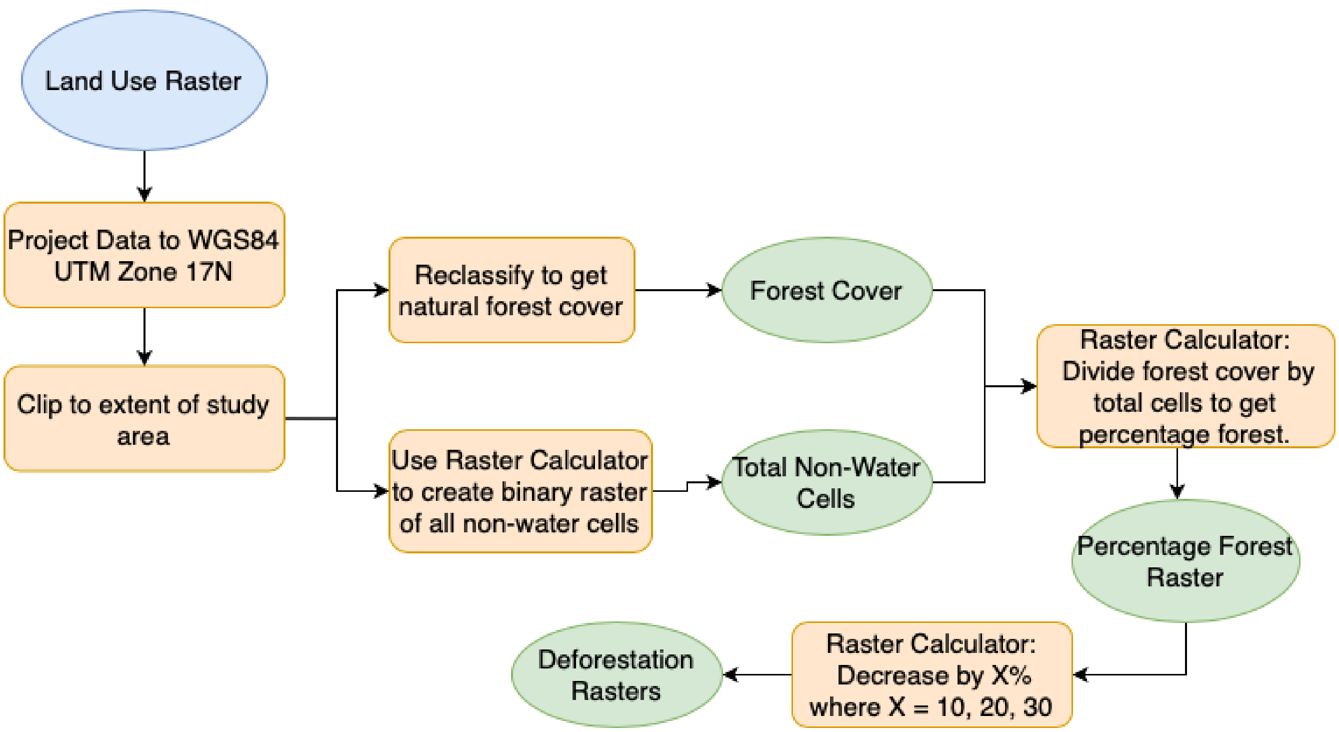

Figure 3. Workflow to produce riparian land use factor layers.

Locations of existing dams and rapids features missing within the 'Dam and Barrier' and 'Ontario Hydro Network (OHN) – Hydrographic' datasets were manually digitized and added to the existing data layers based on eyewitness accounts and Orthophotos (Data source information outlined in Appendix A) (EGBSC, 2018). The full GIS process applied to dam and rapids data can be seen in Figure 4.

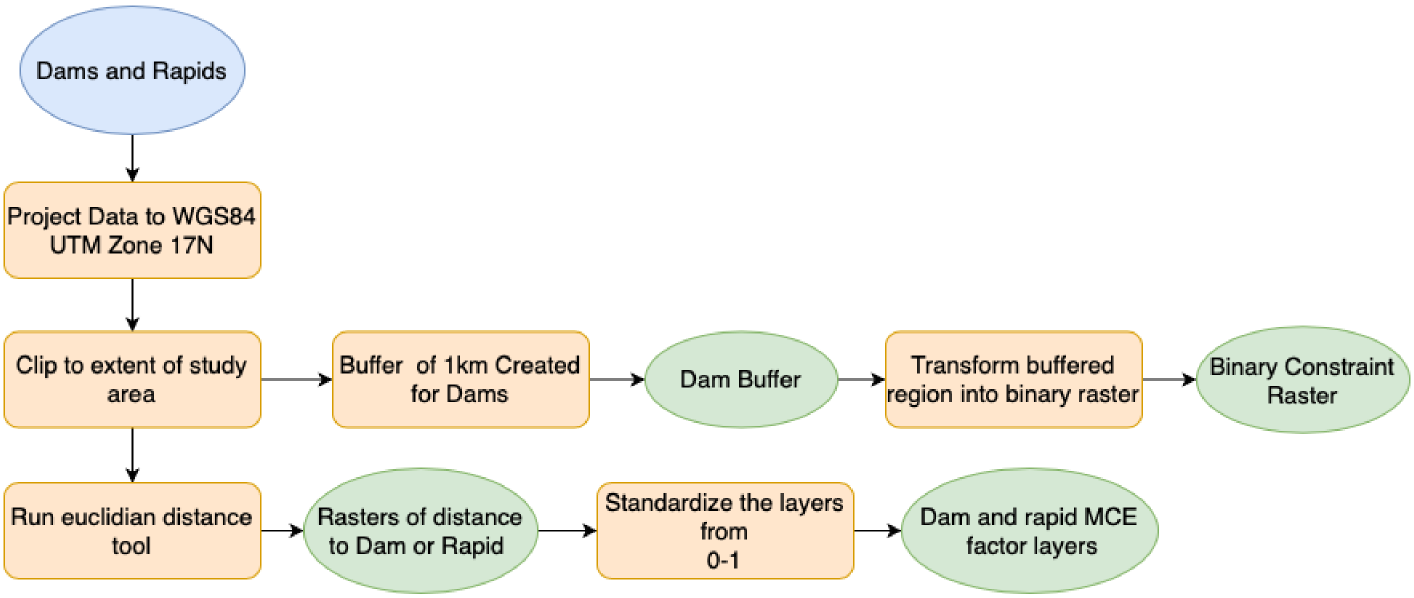

Figure 4. Workflow to produce dam and rapid raster factor and constraint layers.

5.2. Objective Two

5.2.1. Habitat Suitability Index (HSI) Modeling

To be comparably layered, transformed data surfaces were standardized to a common suitability scale of 0-1 by applying a linear stretch between on each criterion in the Raster Calculator. The linear rescaling to a consistent range (0-1) is as follows:

Eq. (1) – Beneficial Factors: $X' = \frac{X - X_{min}}{X_{max} - X_{min}}$

Eq. (2) – Cost Factors: $X' = 1 - \frac{X - X_{min}}{X_{max} - X_{min}}$

where *X'* is the resulting standardized value of the cell, *X* is the initial cell value, and X_{max} and X_{min} are the minimum and maximum dataset values, respectively.

Each factor was then multiplied by an assigned weight that reflects its relative importance to the spawning site selection and success of lake sturgeon. The factor weights were determined using the Analytical Hierarchy Process (AHP), developed by Saaty (Balubaid and Alamoudi, 2015). The AHP is a benefit measurement model that involves pairwise comparison between a given set of alternatives and rates priorities of each on a 9-point scale according to the judgment of the decision-maker (Table 2) (Wind and Saaty, 1980; Balubaid and Alamoudi, 2015). The pairwise comparisons and final weightings of the factors are shown in Table 3 and 4. Fractional values in in the bottom portion of Table 3 are inverse values of the upper portion of the table. Assigned weightings were reinforced with information from the literature, as well as a stakeholder survey provided to representatives from Shawanaga First Nation and Shared Solutions (See Appendix A).

Table 2. 9-point pairwise comparison scale used to establish AHP preferences (Song and Kang, 2016).

Numerical Rating	Verbal Judgements of Preferences
9	Extremely preferred
7	Very strongly preferred
5	Strongly preferred
3	Moderately preferred
1	Equally preferred
1/3	Moderately less preferred
1/5	Strongly less preferred
1/7	Very strongly less preferred
1/9	Extremely less preferred

Table 3. Pairwise comparison matrix of 5 factors influential on the site selection and success of spawning activities of lake sturgeon (*Acipenser fulvescens*). Relative importance was assigned from row to column based on a 9-point scale.

Criteria	Water Temperature	Depth	Riparian Land Use	Distance from Rapids	Distance from Dams
Water Temperature	1	3	5	5	9
Depth	1/3	1	3	5	7
Riparian Land Use	1/5	1/3	1	3	7
Distance from Rapids	1/5	1/5	1/3	1	3
Distance from Dams	1/9	1/7	1/7	1/3	1
Total	1.844	4.676	9.476	14.333	27

Table 4. Final weightings of lake sturgeon (*Acipenser fulvescens*) spawning factors based on pairwise comparisons of the relative importance.

Criteria	Water Temperature	Depth	Riparian Land Use	Distance from Rapids	Distance from Dams	**Weight (Average)**
Water Temperature	0.5423	0.6416	0.5267	0.3488	0.3333	**0.47854**
Depth	0.1808	0.2139	0.3166	0.3488	0.2593	**0.26388**
Riparian Land Use	0.1085	0.0713	0.1055	0.2093	0.2593	**0.15078**
Distance from Rapids	0.1085	0.0428	0.0352	0.0698	0.1111	**0.07348**
Distance from Dams	0.0603	0.0306	0.0151	0.0232	0.0370	**0.03324**
Total	1	1	1	1	1	1

The final weight for each criterion was calculated using Eq. (3), which divides the sum of its pairwise comparisons (c_{ik}) with the total number of criteria to be included (Feizizadeh & Blaschke, 2012).

Eq. (3): $w_i = \frac{\sum c_{ik}}{\#\ of\ crtieria}$

To produce the final HSI raster, a weighted linear combination algorithm was utilized, as shown in **Eq. (4)** (Eastman, 1999). In this method, each standardized criteria raster (X_i) was multiplied by their assigned weight (w_i), with results being summed (Eastman, 1999). The final criteria raster product was then multiplied by the product of all constraints (C_j).

Eq. (4): Suitability = $(f_1 w_1 + f_2 w_{2\ldots} f_n w_n) * \ (c_{1*} c_2 \ldots c_n)$

5.2.2. HSI GIS Workflow

All data was projected to WGS84 UTM Zone 17N as well as clipped to the extent of study area. Once specific processing for each data layer was complete, they were reclassified if necessary and normalized for use in the MCE model. Figure 5 gives an overview of the GIS processes used to create the HSI; for more specific information please refer to sections 5.1.2 and 5.1.3.

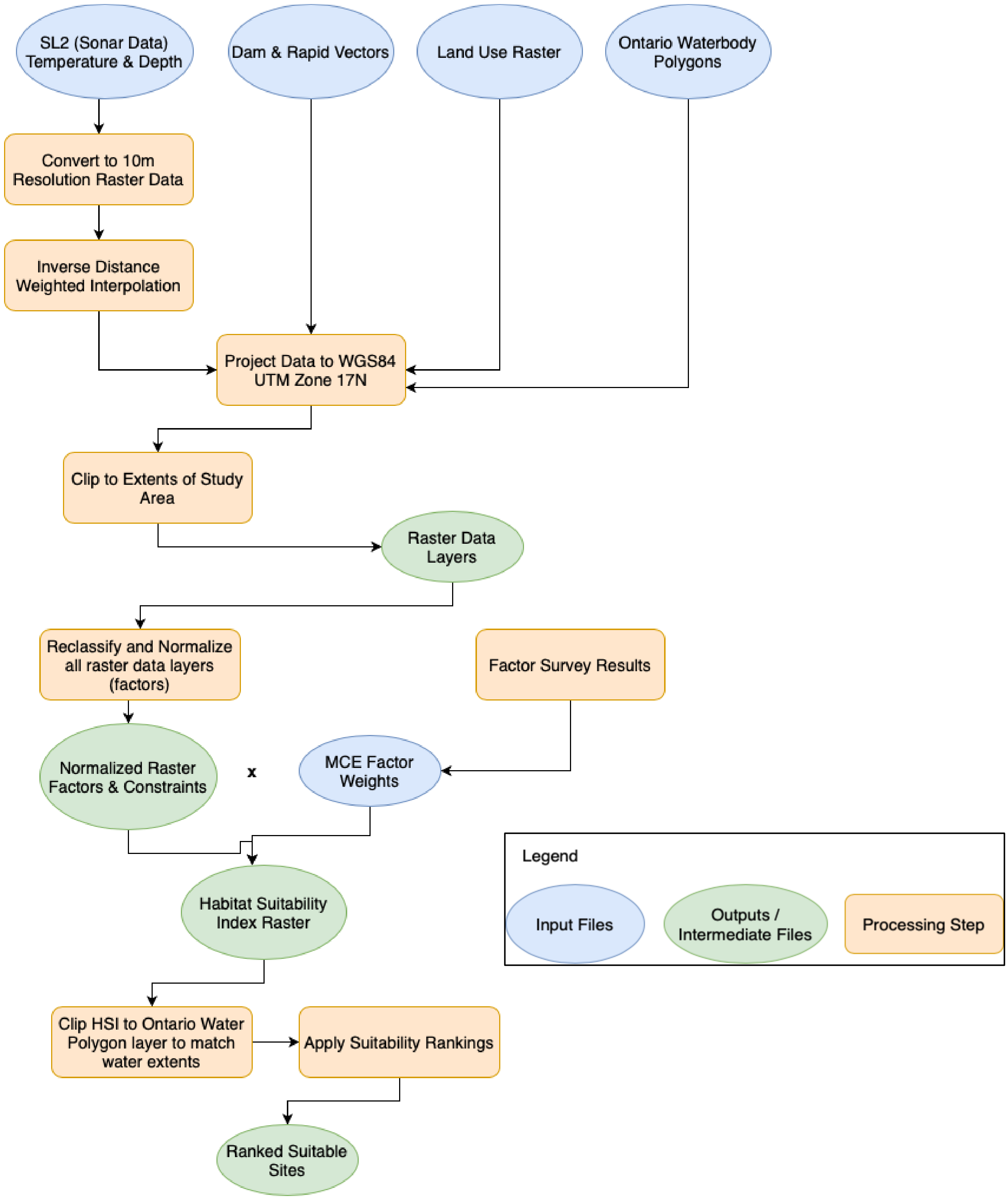

Figure 5. Flowchart describing relative workflow of data to create the habitat suitability index model. See Table 1 for more specific data transformation information.

5.3. Objective Three

The HSI is used to identify regions across the focused sites with the most suitable habitat rankings (Table 5). To achieve this, the HSI will be reclassified to the appropriate ranges. The most suitable sites will then be further analyzed to determine the impact that deforestation has on habitat suitability ranking. Deforestation rate scenarios of 10%, 20%, and 30% in the riparian region will be applied to each site of significance to assist in determining which locations may benefit most from IPCA protection.

Deforestation will be derived from the original riparian land use buffer, using raster calculations to reduce the percentage of current calculated tree cover as determined by zonal statistics. A comparison will then be completed of the most suitable sites previously identified.

Table 5. Ranking scale used in the Habitat Suitability Index (HSI) created for the mapping suitability of lake sturgeon (*Acipenser fulvescens*).

Ranking	HSI Value Range
Unsuitable	0 – 0.2
Very Poor	0.2 - 0.4
Poor	0.4 - 0.5
Moderate-Poor	0.5 - 0.6
Moderate	0.6 - 0.7
High	0.7 - 0.8
Very High	0.8 - 1.0

6. Research Findings

6.1. Habitat Suitability Index

Figures 6 and 7 give a general overview of the habitat suitability at each study site. Study sites of potential interest post HSI production were the Key River, Shawanaga River, and the Harris Branch (a portion of Naiscoot River). These were the only sites in which moderate or high-quality habitat were detected based on the developed suitability rankings (Table 5) and were selected for further analysis as potential spawning locations for sturgeon. The benefit provided by the higher water temperature of the further inland and smaller Harris Branch appeared to play a significant role in increasing its potential for sturgeon spawning.

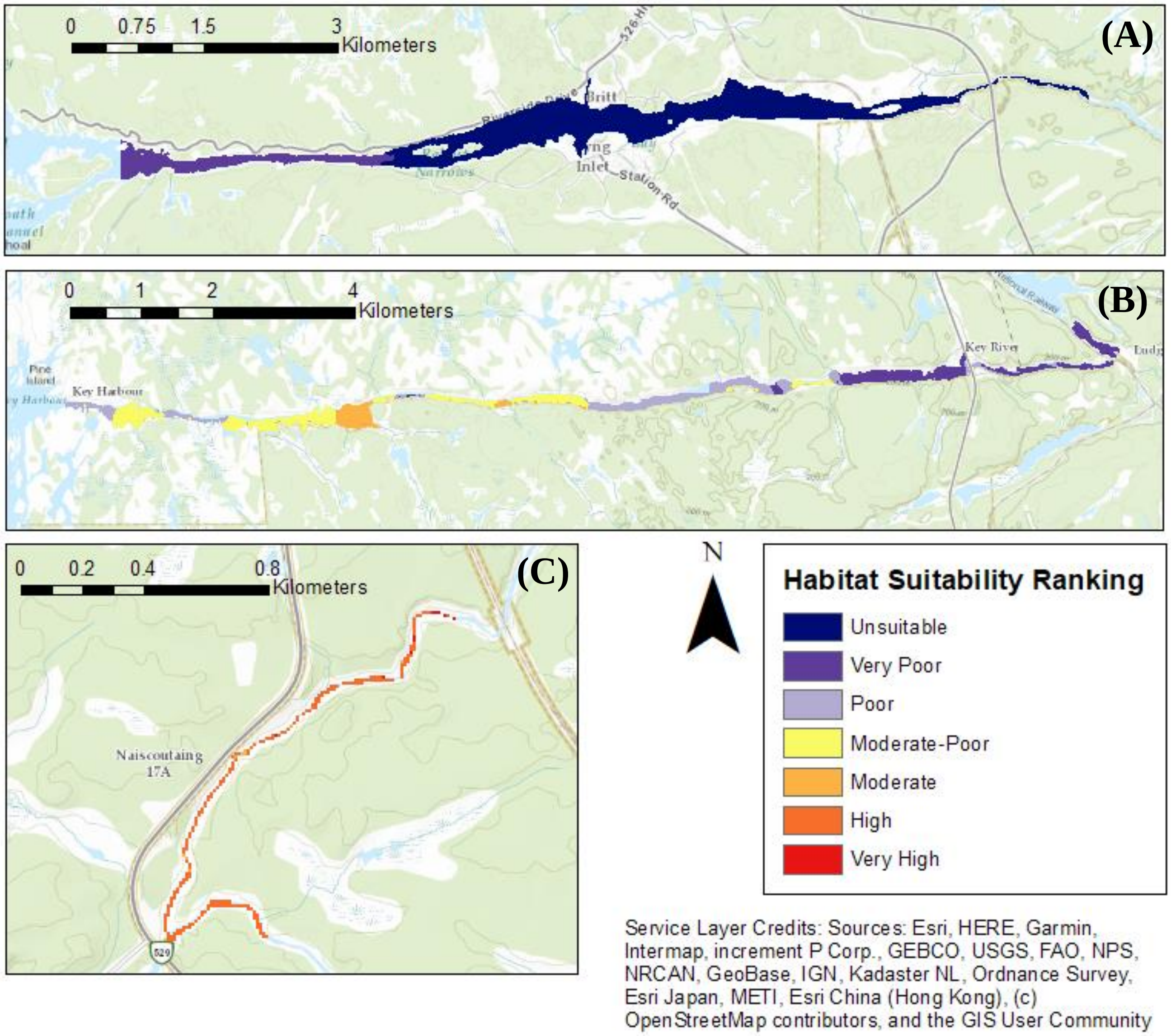

Figure 6. Habitat Suitability Ranking of: (A) Magnetawan River, (B) Key River, and (C) Naiscoot River: Harris Branch.

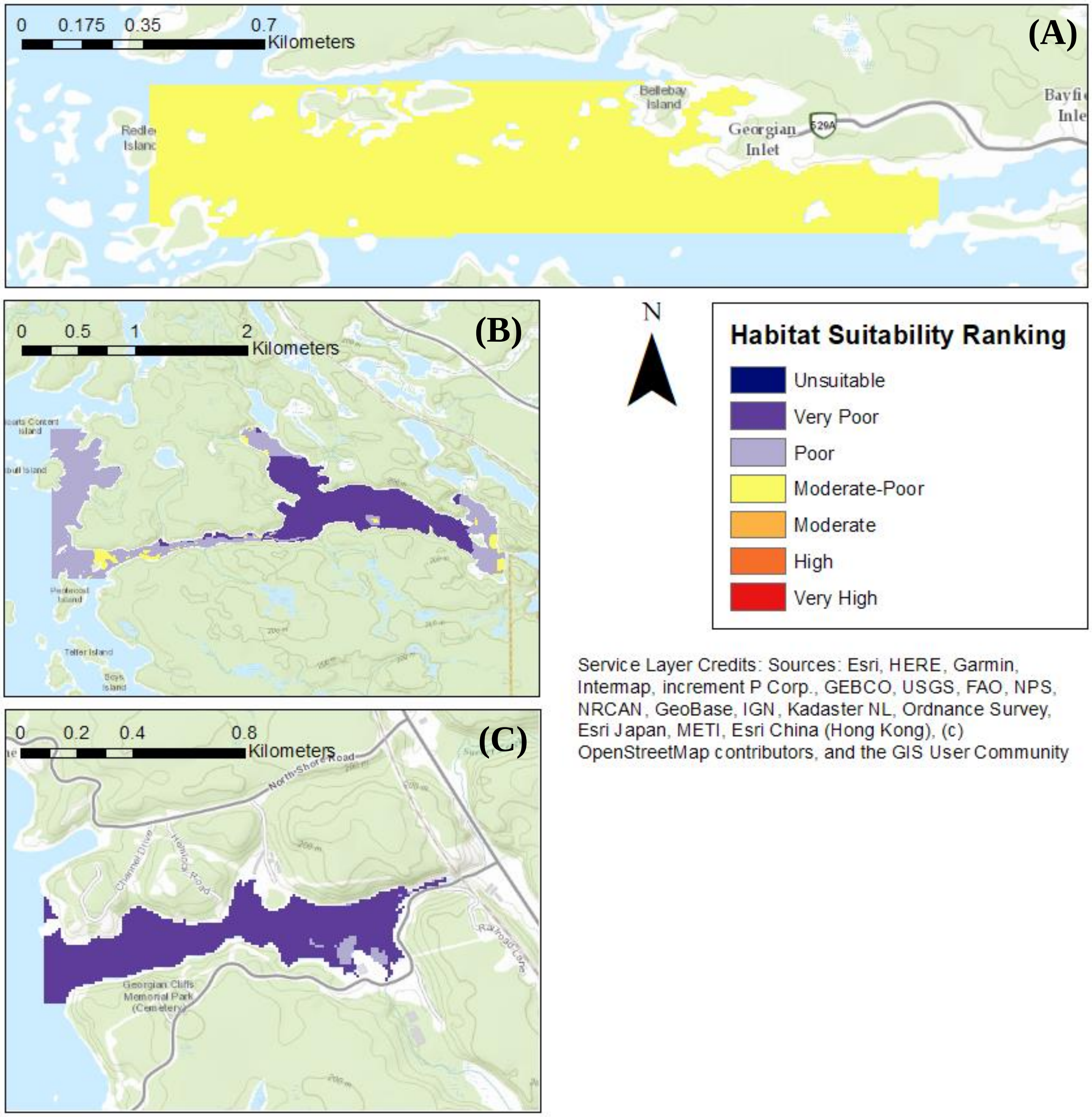

Figure 7. Habitat Suitability Ranking of the (A) Naiscoot River: Bayfield Inlet, (B) Shawanaga River, and (C) Sucker's Creek.

6.2. Deforestation Analysis (Future Human Impact on Suitability)

All sites of moderate habitat quality and above from the Key River, Harris Branch, and Shawanaga River were selected to undergo further zonal analysis to determine how vulnerable the sites were to human land development.

Figures 8 through 11 show the 3 selected study sites with varying reduction of forest cover percentage within the 30m riparian buffer (MCE factor weights remain consistent). The moderate habitat suitability areas in the Key River and Shawanaga River had significant decrease in habitat size and ranking with different deforestation values, beginning with values as low as 10%. The Harris Branch was far more resilient and maintained high quality habitat with up to 30% deforestation of the riparian region.

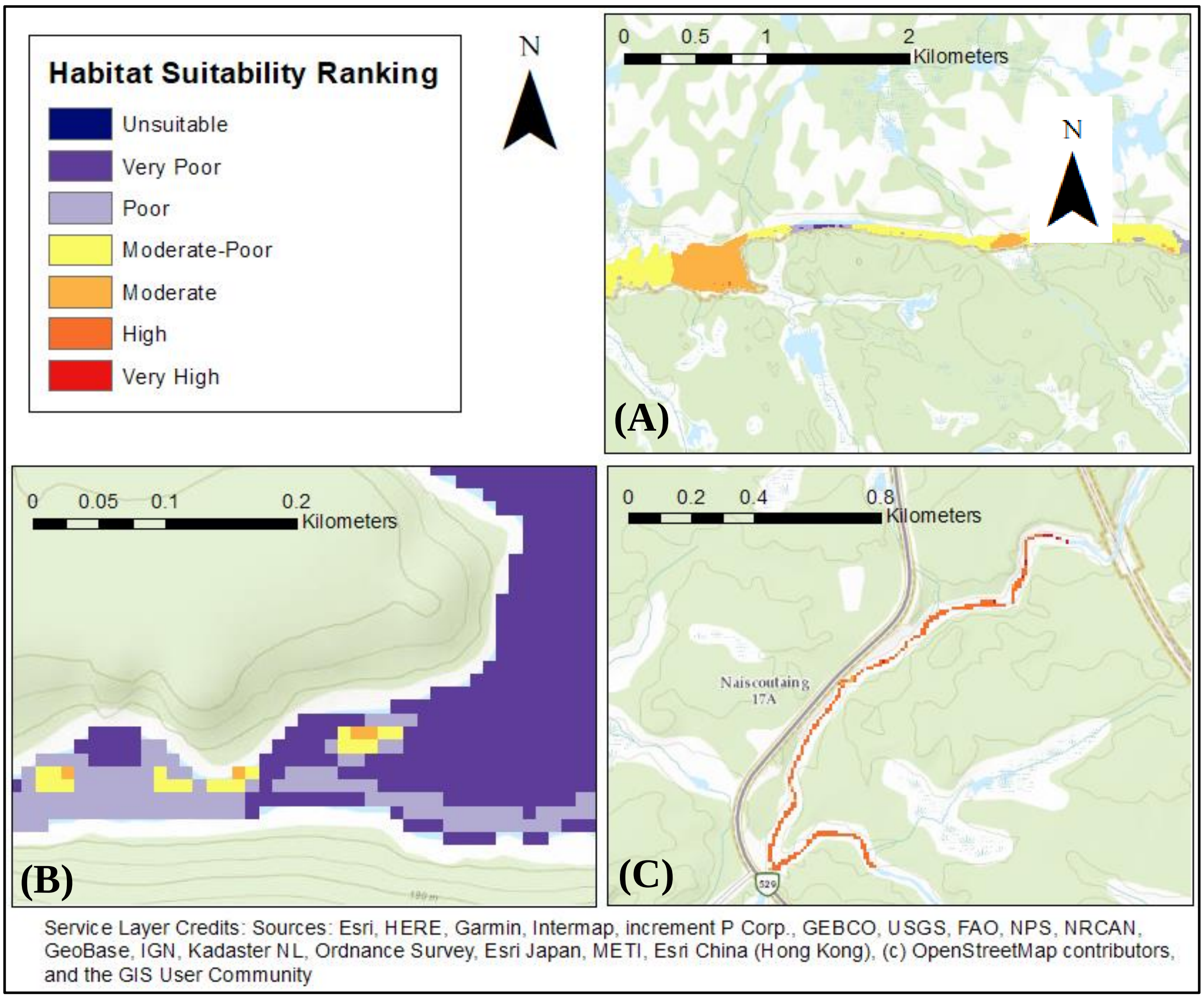

Figure 8. Sturgeon Spawning Suitability with no change in existing forest cover in the 30 m riparian buffers at: (A) Key River, (B) Shawanaga River, (C) Harris Branch.

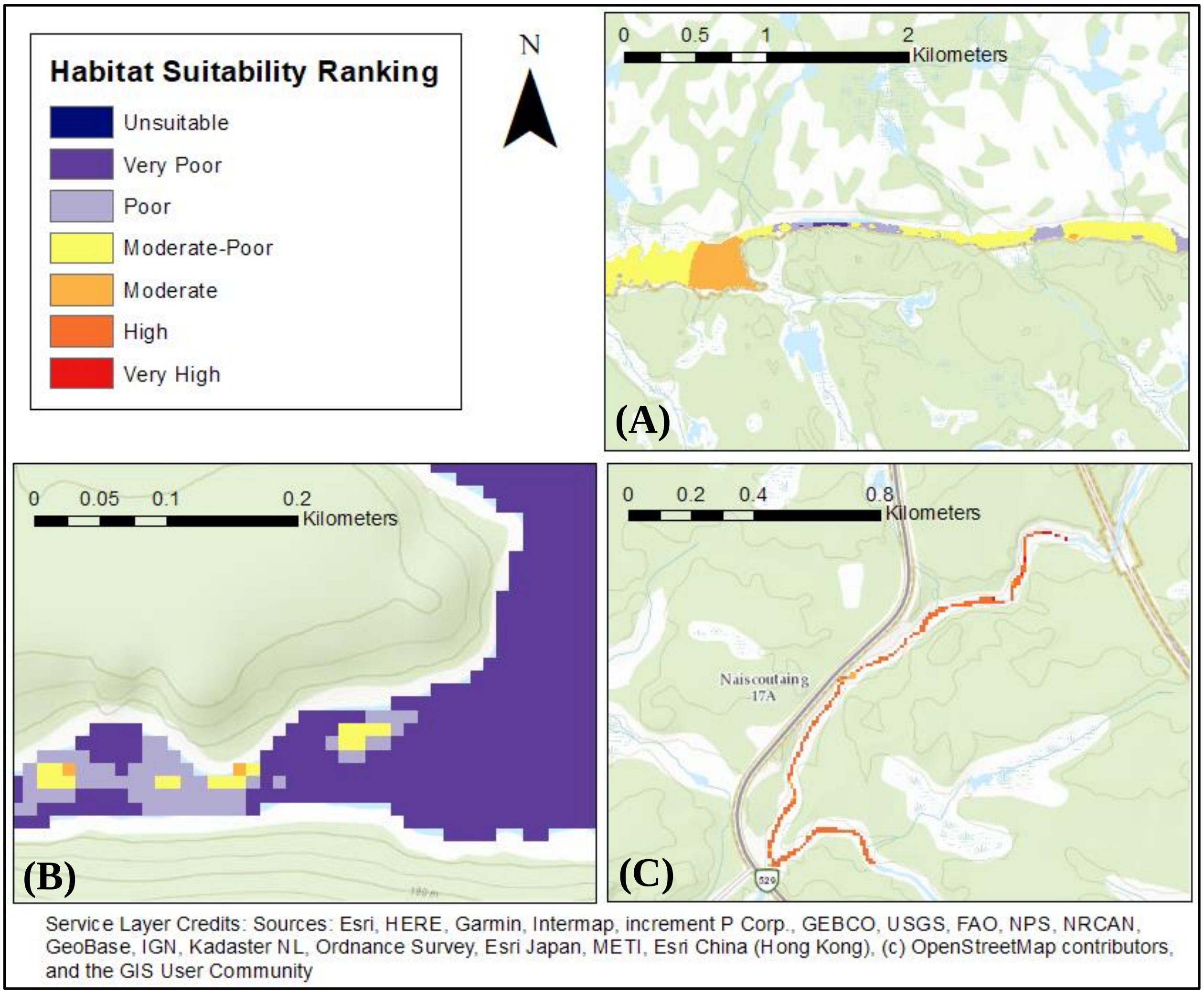

Figure 9. Sturgeon Spawning Suitability with 10% deforestation in existing forest cover in the 30 m riparian buffers at: (A) Key River, (B) Shawanaga River, (C) Harris Branch.

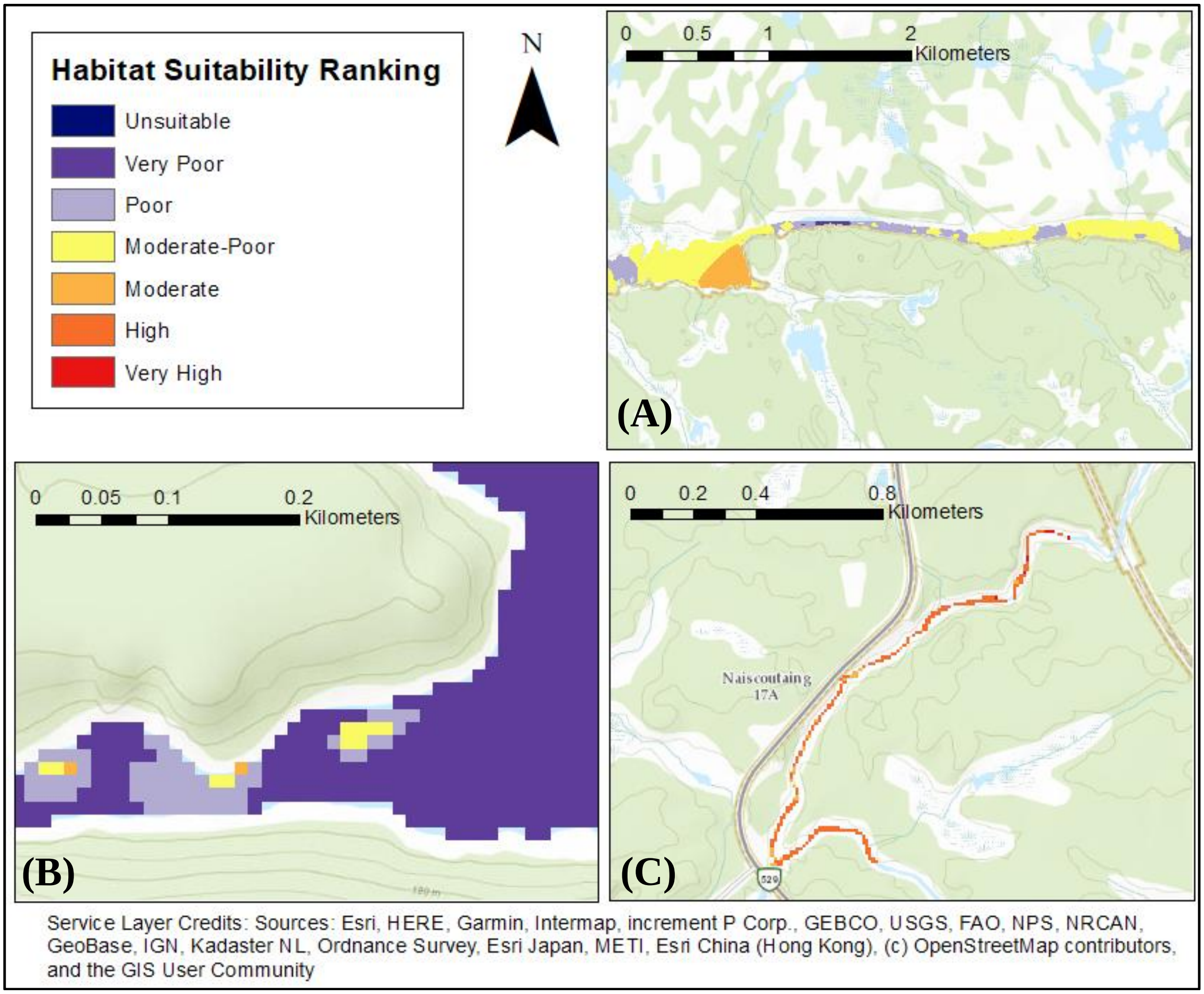

Figure 10. Sturgeon Spawning Suitability with a 20% deforestation in existing forest cover in the 30 m riparian buffers at: (A) Key River, (B) Shawanaga River, (C) Harris Branch.

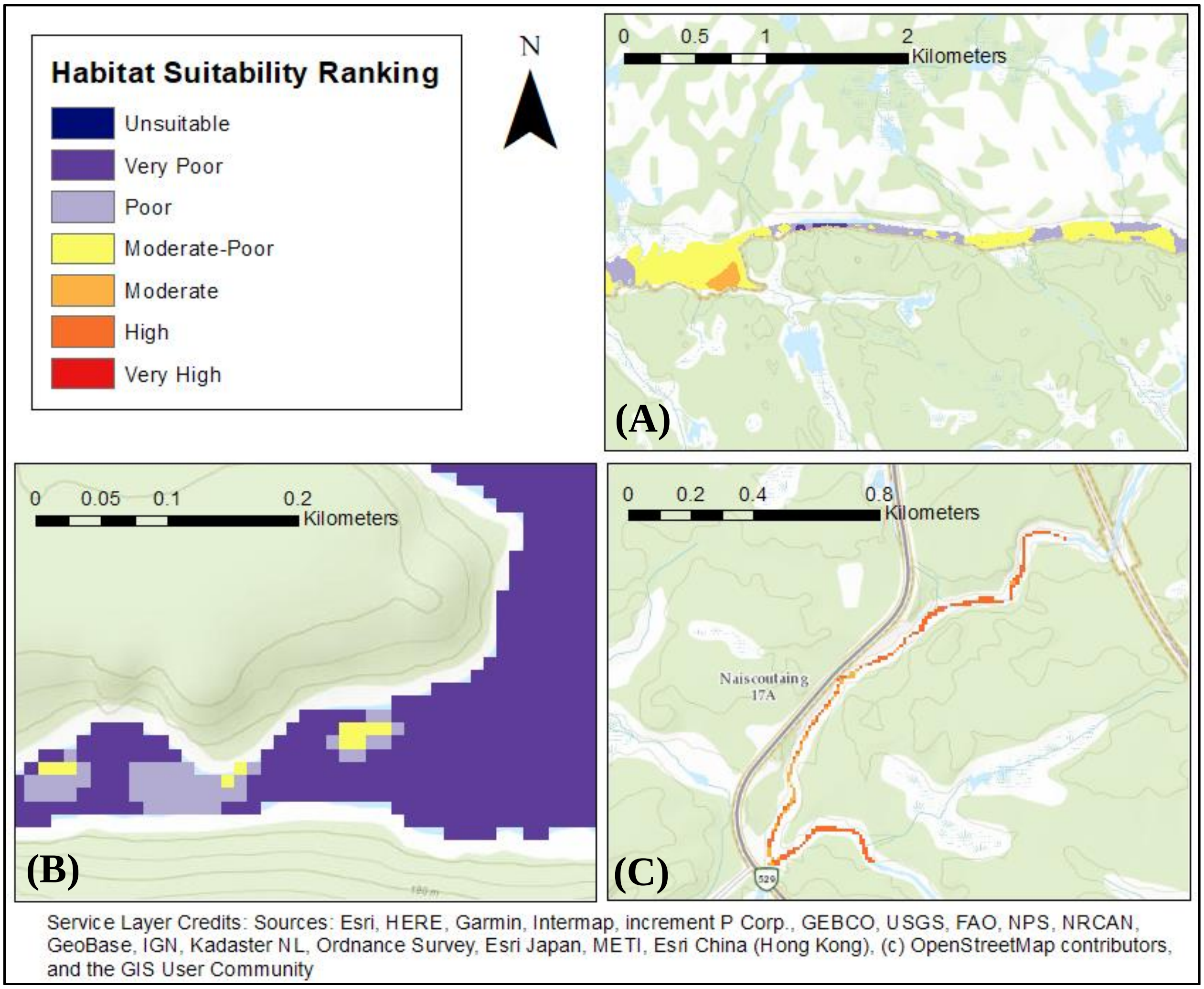

Figure 11. Sturgeon Spawning Suitability with a 30% deforestation scenario in existing forest cover in the 30 m riparian buffers at: (A) Key River, (B) Shawanaga River, (C) Harris Branch.

7. Discussion

The results of the HSI and deforestation analysis revealed that the most suitable site for sturgeon spawning was the Harris Branch by a substantial margin. Based on the incredibly strong results presented by the Harris Branch there is indication that data monitoring and surveying could be of large importance in rivers that are further inland from Georgian Bay. There were also small sites identified in the Shawanaga River and Key River that were of moderate – high habitat quality, however, we saw these sites quickly diminish in value as zonal statistics were calculated to account for future deforestation scenarios. These findings should not be seen as an indication that the Key River and Shawanaga River shouldn't be considered as sturgeon spawning territory, but rather that these areas are less robust and may benefit more from the land and environment protection of IPCA creation.

The shorelines and adjacent riparian areas of the study sites are predominately characterized by large stretches of exposed granite and shallow soils over bedrock (Leal et al. 2014). Vegetation along theses bedrock surfaces tend to be restricted to depressions and fractions in the rock surface (Leal et al. 2014). As a result, the re-establishment of lost vegetation along these shorelines is often a difficult and long-lasting process (Leal et al. 2014). Aquatic systems are particularly sensitive to rapid changes in the surrounding environment, and as shown in our results, even the lowest rates of forest cover decline in riparian buffers have significant effects on the overall potential suitability of sites for sturgeon spawning. The slow recovery potential of sites poses a significant threat to already declining sturgeon populations, making it pertinent that pre-emptive protection measures be implemented for suitable spawning habitat. We recommend that sites such as Key River and Shawanaga River, where both habitat suitability and sensitivity to deforestation are high, be considered more carefully for future IPCA development in the event where limited funding or efforts act as a constraint.

There are numerous biophysical characteristics embellished by this analysis, but when considering the establishment of IPCAs it is important to remember the additional socio-political context. This includes the consideration of local political affiliations and whether whoever currently oversees the identified areas are willing to give or sell the land for this purpose. In Ontario, often land use is used more for economic gain such as residential, industrial, transportation or agriculture, with conservation only taking approximately nine percent of Ontario (MECP, 2019). The federal government has begun funding more Indigenous communities with the aim to establish protected areas, including the Shawanaga First Nation in 2020 (Pickles, 2021). Further research could be conducted for identified areas through a cost-benefit analysis to test the economic feasibility of protecting lake sturgeon and establishing an IPCA in each area.

8. Conclusion

Considering the level of uncertainty regarding the degree of accessible sturgeon spawning habitat in the EGB, our study aimed to develop a HSI to identify suitable spawning sites within the region and inform potential establishment of IPCAs as a conservation strategy. Based on the results, there are several EGB tributary reaches that have the potential to support successful sturgeon spawning activities. However, we recommend that Key River and Shawanaga River be considered of higher priority for targeted protection under IPCAs due to their greater sensitivity to the suitability impacts of deforestation in riparian zones.

Despite finding variability in suitability scores, the predictive power of our MCE analysis was significantly hindered by the current level of available environmental data in the region. Not only do many key variables have no existing data (i.e., substrate type, water velocity, etc.), and therefore were excluded from the analysis, some variables that do have existing data were still collected out of season, making it less reliable in predicting site suitability within a specific temporal period. This was the case for water temperature, which was collected from July to September, while peak spawning activity typically occurs from April to June (Peterson et al., 2007). To account of these gaps in data, assumptions were made in leu of existing data in nearby regions, as well as through the use of proxy variables (i.e., presence of rapids, riparian land use). However, these decisions had the potential to introduce error that could propagate through the modelling process. It is clear that in the absence of reliable data, a HSI should only be considered a useful tool for identifying potential rather than exact locations of sturgeon spawning grounds. Due to this, we recommend our HSI be used to identify areas of priority for further monitoring. Identified areas with the high suitability likelihood, such as Key River, Shawanaga River, and the Harris Branch of Naiscoot River, should be targeted for intensified monitoring of environmental variables / data collection. GIS solutions are only as effective as the input data; therefore, future studies and management efforts should be directed towards increasing monitoring to better inform the planning and implementation of IPCAs in EGB.

9. Acknowledgments

We wish to acknowledge the guidance provided by Chris Burtch (Shawanaga First Nation), Steven Kell (Shawanaga First Nation), Rachel White (Shared Value Solutions), and Alison Gamble (Shared Value Solutions) in the development of project objectives and initial data inquires. We would also like to express our appreciation to Katrina Krievins and other employees of Georgian Bay Biosphere for organizing and sharing the side scan sonar data. Without the contributions of these individuals, this project would not have been possible.

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Appendices

Appendix A – Additional data source information

Table 1A. Data layer information used in data transformation and

Data Layer Name	Source	Year	Scale	Description
South Central Ontario Orthophotography Project (SCOOP) 2018	Land Information Ontario (LIO), Ontario Ministry of Natural Resources	2019	Southern Central Ontario	South Central Ontario Orthophotography Projects (SCOOP) imagery acquired in the spring (March-May) and fall of 2018/2019 in 1 km by 1 km coverage tiles.
Central Ontario Orthophotography Project (COOP) 2016 - 4 bands	Ontario Ministry of Natural Resources and Forestry	2016	Central Ontario	COOP orthoimagery is at a 20 cm resolution with colour images covering approximately 53 729 km^2. Images were taken in the spring (May-June) of 2016.

NOTE: using Orthophotographs, rapids were defined by the presence of white-water caps. Rapids are characterized by strong water turbulence leading to air entraining surface breaking waves, which appear as white-water caps (Brocchini and Peregrine, 2001).

Appendix B – Criteria Weighting Justification

The weighting can be reinforced with reports and literature conducted by scholarly, federal and provincial analyses. The Lake Sturgeon Recovery Strategy for Ontario noted that poor egg survival is attributed to unfavourable water temperatures, hence why temperatures are to be weighted highest in this analysis (Government of Ontario, 2019). Similarly, the official COSEWIC report stated that spawning and incubation periods are primarily influenced by water temperature (COSEWIC, 2019). According to the official COSEWIC report and the Ontario recovery strategy, the depth of water spawning is accessible at shallower depths, with observations of sturgeon spawning from anywhere between 1-12m in depth (COSEWIC, 2019). Riparian land use that contains higher agricultural or urban lands have been linked to higher levels of contaminants that negatively affect both the lifespan and survivability of ecosystems and species (EGBSC, 2018). The official COSEWIC inferred that since water velocity, or the distance from rapids is vital to the habitat utilization of sturgeon, it is also essential for the choice of location for spawning, especially since excessively rapid waters increase egg mortality (COSEWIC, 2019). Finally, dams are known to both increase temperatures of nearby water as well as altering water velocity, these obstructions negatively impact sturgeon potential spawning habitats due to their creation of artificial aquatic environments (FAO, 2002).

Table B1. Results of stakeholder survey shared with representatives from Shawanaga First Nations and Shared Solutions. For the exception of one, all questions were answered on a scale from 0 to 10, with 0 being not important and 10 being incredibly important. A single response was received within the timescale of the study.

Survey Question	Survey Response
How important is water temperature in spawning activities of lake sturgeon?	9
How important is water depth in defining suitable spawning habitat for lake sturgeon?	8
How important is distance from rapids/falls in the success of lake sturgeon spawning?	7
How important is water quality to the success of spawning activities of lake sturgeon?	8
What scale of land use is more influential on water quality of specific river and/or stream reach?	Land use within a 30-100 m buffer
What impact do low-level dams have on suitable spawning habitat characteristics?	6
How important is distance downstream from dams and/or barriers to water flow to success of spawning activities of lake sturgeon?	6

Appendix C – Criteria Reclassification Values

If the model were to be recreated the following reclassification value sets could be used for ranking criteria prior to normalization for the MCE model. Temperature data must be transformed to match the relative range of temperatures expected in the body of water for the months of April – June, which make up the prime spawning period for lake sturgeon (Peterson et al., 2007). The data used in this study was collected from July – September.

Temperature Ranking

Approximate average eater temperature at French River sensor during 2020 sturgeon spawning period: **13.25 degrees Celsius** (Government of Canada, 2021)

Approximate average water temperature at French River sensor during 2020, relative to data collection period (July – September): **19.54 degrees Celsius** (Government of Canada, 2021)

Adjustment factor = 19.54 - 13.25 = 6.29 degrees Celsius

This adjustment factor must be subtracted from the water temperature raster for the region to account for out of season data. The absolute value of the adjusted temperature raster less the average optimal temperature of 15 degrees Celsius was then taken from each cell. The factor was then calculated as a cost, with higher values meaning that the region was further away from the optimal temperature range.

For use in the MCE, depth ranges were categorized into 7 suitability ranges based on comparison of published findings regarding habitat requirements (Kerr et al., 2011).

Table C1. Reclassification categories of water depth based on suitability for lake sturgeon spawning (*Acipenser fulvescens*).

Original Value Range (metres)	Reclassified Value
0 - 1.0	0
1.0 - 3.0	5
3.0 - 6.0	4
6.0 - 9.0	3
9.0 - 12.0	2
12.0 - 15.0	1
15 +	0