A fine scale approach to riparian habitat classification and spatial analysis in the St. Mary's River, Nova Scotia, Canada

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AAFC	Agriculture and Agri-food Canada
ARA	Active River Area
ASCII	American Standard Code for Information Interchange
CLDFHD	Canada Landsat Derived Forest Harvest Disturbance
DFO	Fisheries and Oceans Canada
GIS	Geographic Information Systems
ID	Identifier
LCLU	Land cover and land use
LiDAR	Light detection and ranging system
NCC	Nature Conservancy of Canada
NRCan	Natural Resources Canada
NSFI	Nova Scotia Forest Inventory
NSTD	Nova Scotia Topographic Database
OBIA	Object-based Image Analysis
OGF	Nova Scotia Old Growth Forest Policy
SMR	St. Mary’s River
SVM	Support Vector Machine
US	United States

Abstract

Murray, C.A.E., Collison, B.R., Gromack, A.G., Lawler, M.M., Tuziak, S.M., and Butler, S.M.M. 2024. A fine scale approach to riparian habitat classification and spatial analysis in the St. Mary's River, Nova Scotia, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3610: viii + 61 p.

Human land-use activities that occur near and around watercourses and waterbodies play a critical role in the overall health, function and biodiversity of aquatic habitats. Changes to riparian zones, areas between a waterbody's high-water mark and the upland area, can cause cascading effects to aquatic environments. Many provinces throughout Canada have implemented fixed-width riparian buffer zones around watercourses to help mitigate impacts from land use change to aquatic ecosystems. There is a complex set of regulations and guidelines that apply to different land use activities in Nova Scotia's riparian zones due, in part, to overlapping jurisdictions. However, approaches to investigate riparian ecosystem health at the watershed scale have been underutilized in this region. The St. Mary's River, located along the Eastern Shore of Nova Scotia, is a relatively natural watershed with dynamic aquatic and riparian habitats. This study provides robust methods to classify land cover dynamics and land use activities using Sentinel-2A satellite imagery and four fixed-width riparian buffer zones (30 m, 100 m, 150 m, and 300 m) within the St. Mary's River watershed, Nova Scotia, Canada. Riparian zones were classified to identify fine-scale patterns in disturbance, identifying areas that may benefit from conservation or restoration across various land ownership types (i.e., Crown versus private land).

Résumé

Murray, C.A.E., Collison, B.R., Gromack, A.G., Lawler, M.M., Tuziak, S.M., and Butler, S.M.M. 2024. A fine scale approach to riparian habitat classification and spatial analysis in the St. Mary's River, Nova Scotia, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3610: viii + 61 p.

Les activités d’utilisation humaine des terres qui se déroulent à proximité et autour des cours d’eau et des plans d’eau jouent un rôle essentiel dans la santé, la fonction et la biodiversité globales des habitats aquatiques. Les modifications apportées aux zones riveraines, c’est-à-dire les zones situées entre la ligne des hautes eaux d’un plan d’eau et la zone sèche, peuvent avoir des effets en cascade sur les milieux aquatiques. De nombreuses provinces canadiennes ont mis en place des zones tampons riveraines de largeur fixe autour des cours d’eau pour aider à atténuer les répercussions des changements d’utilisation des terres sur les écosystèmes aquatiques. Il existe un ensemble complexe de règlements et de lignes directrices qui s’appliquent aux différentes activités d’utilisation des terres dans les zones riveraines de la Nouvelle-Écosse, en partie en raison de compétences qui se chevauchent. Toutefois, les approches visant à étudier la santé des écosystèmes riverains à l’échelle des bassins versants ont été sous-utilisées dans cette région. La rivière St. Marys, située le long de la côte est de la Nouvelle-Écosse, est un bassin versant relativement naturel où l’on trouve des habitats aquatiques et riverains dynamiques. La présente étude fournit des méthodes robustes pour classifier la dynamique de la couverture terrestre et les activités d’utilisation des terres en utilisant le système d’imagerie satellite Sentinel-2A et quatre zones tampons riveraines de largeur fixe (30 m, 100 m, 150 m et 300 m) dans le bassin versant de la rivière St. Marys, en Nouvelle-Écosse, au Canada. On a classé les zones riveraines afin de déterminer les schémas de perturbation à petite échelle et les zones qui pourraient bénéficier d’une conservation ou d’une restauration dans les différents types de propriétés (c’est-à-dire les terres de la Couronne et les terres privées).

1. Introduction

The riparian zone is defined as the area located between a waterbody's high-water mark and the upland area (DFO 2020a). Riparian habitats are unique and complex ecological systems that sustain considerable amounts of biodiversity and provide essential ecosystem services to both terrestrial and aquatic species and their habitats (Caskenette et al. 2020; Riis et al. 2020). Streams, floodplains, wetlands, and the adjacent surrounding land are dynamic and interlinked, representing a sensitive two-way connection that may transition across spatial and temporal hydrological shifts (e.g., river meandering; Tolkkinen et al. 2020). Migratory and resident fish depend on riparian ecosystems to maintain appropriate habitat attributes (e.g., temperature and water quality) for survival and reproduction. Healthy riparian zones function as a buffer to protect fish habitat from point-source threats, like sediment runoff, and chronic, longer-term threats, such as climate change (Albertson et al., 2018). When riparian zones are destroyed or degraded, negative cascading effects can often occur in aquatic environments (Figure 1). To mitigate land use impacts on aquatic ecosystems many provinces have implemented fixed-width riparian buffer zones around watercourses (Collison & Gromack 2022; Tiwari et al. 2016; Richardson et al. 2012; De Sosa et al. 2017).

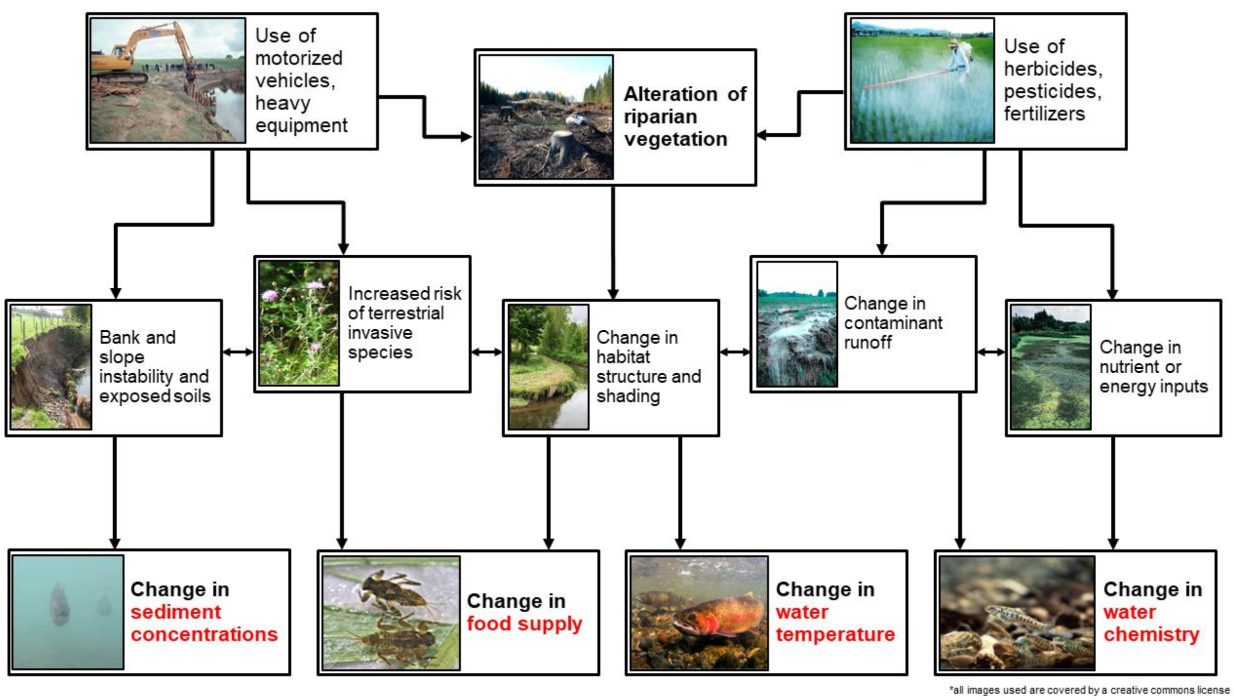

Figure 1. *Pathway of effects to fish habitat from riparian disturbances (Collison & Gromack, 2022).*

Advancements in the accessibility of satellite imagery have increased researchers' ability to remotely map and classify land cover and land use (LCLU) activities, including those within riparian ecosystems. Land cover refers to the physical morphology and biology of the landscape (such as forests, wetlands, impervious surfaces), while land use is how humans are modifying the land cover (Lambin et al. 2001; Collison & Gromack 2022). Several spatial monitoring techniques using geographic information systems (GIS) and satellite imagery have been applied globally to increase our understanding of land use activities, disturbance, and monitor changes to landscapes (Aresnault & O'Sullivan 2021; Daryaei et al. 2020; Eskandari & Pourghasemi 2022; Mary-Lauyé et al. 2022; Furuya et al. 2020; Piedelobo et al. 2019; Phiri et al. 2020; Rusnák et al. 2022). In Canada, the use of remotely sensed data (satellite imagery and light detection and ranging system (LiDAR)) has been used to characterize fish habitat to support management decisions for riparian conservation and restoration planning (Bachiller-Jareno et al. 2019; Budlong 2004; Coleshill & Watt 2017; Jones et al. 2006; Kupier et al. 2022; France & Pardy 2018; Tompinski et al. 2017; Roth et al. 2020). The use of satellite imagery to identify LCLU and disturbances are essential components in understanding what activities have altered riparian zones which have the potential to negatively impact aquatic ecosystems.

In Atlantic Canada, Nussey and Noseworthy (2020) adapted the United States (US) Nature Conservancy's Active River Area (ARA) model and applied it to the Northern Appalachian – Acadian Region. Land cover intactness was calculated within the ARA across different watersheds using a 30-metre resolution Landsat-derived product, which was classified as natural, clear cut, agriculture, or developed land (Nussey & Noseworthy 2020). In this context, "intactness" was defined as landcover types including forest, wetland, barren, and water (Nussey & Noseworthy 2020). While this product serves as a valuable resource at the regional level, there remains a need for higher resolution GIS and remote sensing analyses of the riparian zone at the watershed scale. This can be achieved by exploring the use of higher resolution satellite imagery, topographic datasets (i.e., LiDAR), and more detailed classifications of different land use activities. High resolution imagery (i.e., Sentinal-2A) can offer greater quantities of information to increase the accuracy of riparian zone classification compared to coarser resolution images such as those obtained by Landsat (Fauvel et al. 2012; Lacelle & Shi 2021; Kamenova & Dimitrov 2021; Parker & Lee 2016).

Fisheries and Oceans Canada (DFO) (2020) has indicated that "the goal of protecting riparian habitat is to ensure that there is sufficient area to provide the ecosystem services (i.e., processes) that the aquatic habitat requires; which also means maintaining a large enough riparian zone to allow for proper function and resilience of riparian features to natural variation and to extreme events". A literature review by Collison & Gromack (2022) evaluated recommended fixed-width riparian buffer sizes in Nova Scotia, Atlantic Canada, and the USA that are likely adequate for protecting fish and fish habitat. Several studies have examined the impact of different riparian buffer sizes on parameters important to fish and fish habitat, including protection against contamination, riparian corridor microclimate, stream temperature, invertebrate prey, leaf litter input, input of fine sediments, stream temperature, maintaining benthic communities, contamination, maintaining water quality, shading, and cumulative effects (Collison & Gromack 2022). Smaller buffer sizes (20-30 m) were adequate for parameters such as coarse woody debris recruitment and bank stability, while buffers of 15-20 m were adequate to maintain water quality. Consequently, increased buffer sizes, typically ≥ 30 m, are associated with greater ecological and environmental benefits including the protection of fish and fish habitat (Collison & Gromack 2022; Smokorowski & Pratt 2007; Stoffyn-Egli & Duinker

2013; Lahey 2018; Albertson et al. 2018; Cole et al. 2020; Lind et al. 2019). However, while wider riparian buffers would provide greater protection to fish and fish habitat, enforcing these buffers may be more difficult to implement in practice (Collison & Gromack 2022; Richardson et al. 2012; Tiwari et al. 2016).

DFO is now exploring the inclusion of riparian zones in *Species at Risk Act* (SARA) critical habitat (*Species at Risk Act*, s. 58(1)(b); Caskenette et al., 2021) and *Fisheries Act* Ecologically Significant Area (ESA; *Fisheries Act*, s. 35.2; Collison & Gromack 2022) designations and how it may be managed given the cross-jurisdictional responsibilities and potential challenges. A baseline understanding of riparian zone intactness is important to identify potential locations to apply conservation actions. Here, we highlight the application of fine-scale riparian zone spatial analysis to fish habitat, using the St. Mary's River (Mik'maw: Napu'saqnuk) watershed in Nova Scotia, Canada, with a diversity of LCLU dynamics.

1.1. Study area

1.1.1. Geographical scope

The St. Mary's River (Figure 2) is one of the longest rivers (250 km) in Nova Scotia, Canada, flowing through five counties (Guysborough, Antigonish, Colchester, Pictou and Halifax) and drains into the Atlantic Ocean at the Sonora estuary (Government of Canada 2021; St. Mary's River Association 2019). The watershed covers approximately 1,350 km^2 and is comprised of three main branches; East, West, and North, which combine to form the main branch that drains into the Atlantic Ocean (St. Mary's River Association 2019).

1.1.2. Biodiversity

The St. Mary's River contains a wide diversity of fish species, including Atlantic Salmon *(Salmo salar*; Nova Scotia Southern Upland designatable unit), Brook Trout (*Salvelinus fontinalis*), American Eel (*Anguilla rostrata*), White Sucker (*Catostomus commersonii*), Sea Lamprey (*Petromyzon marinus*), and Rainbow Smelt (*Osmerus mordax*) (St. Mary's River Association 2019). Both Atlantic Salmon (Southern Upland population) and American Eel have been assessed as by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and are under consideration for *Species at Risk Act* (SARA; Atlantic Salmon as Endangered and American Eel as Threatened) listing (COSEWIC 2010; COSEWIC 2012). Brook Floater (*Alasmidonta varicosa*), a freshwater mussel listed as Special Concern under the SARA, is also present in the East and North branches of the watershed (Government of Canada 2018; St. Mary's River Association 2019). The species is also listed as Threatened under Nova Scotia's *Endangered Species Act and* has 'core habitat' identified along the entire East and North branches of the watershed, including a 30 m riparian buffer extending out from the high-water mark in areas where the species is found (Nova Scotia Department of Natural Resources and Renewables 2022). According to the *Endangered Species Act,* core habitat refers to "specific areas of habitat essential for the long-term survival and recovery of endangered or threatened species and that are designated as core habitat pursuant to *s. 16* or identified in an order made pursuant to *s. 18*" (Nova Scotia Department of Natural Resources and Renewables 2022).

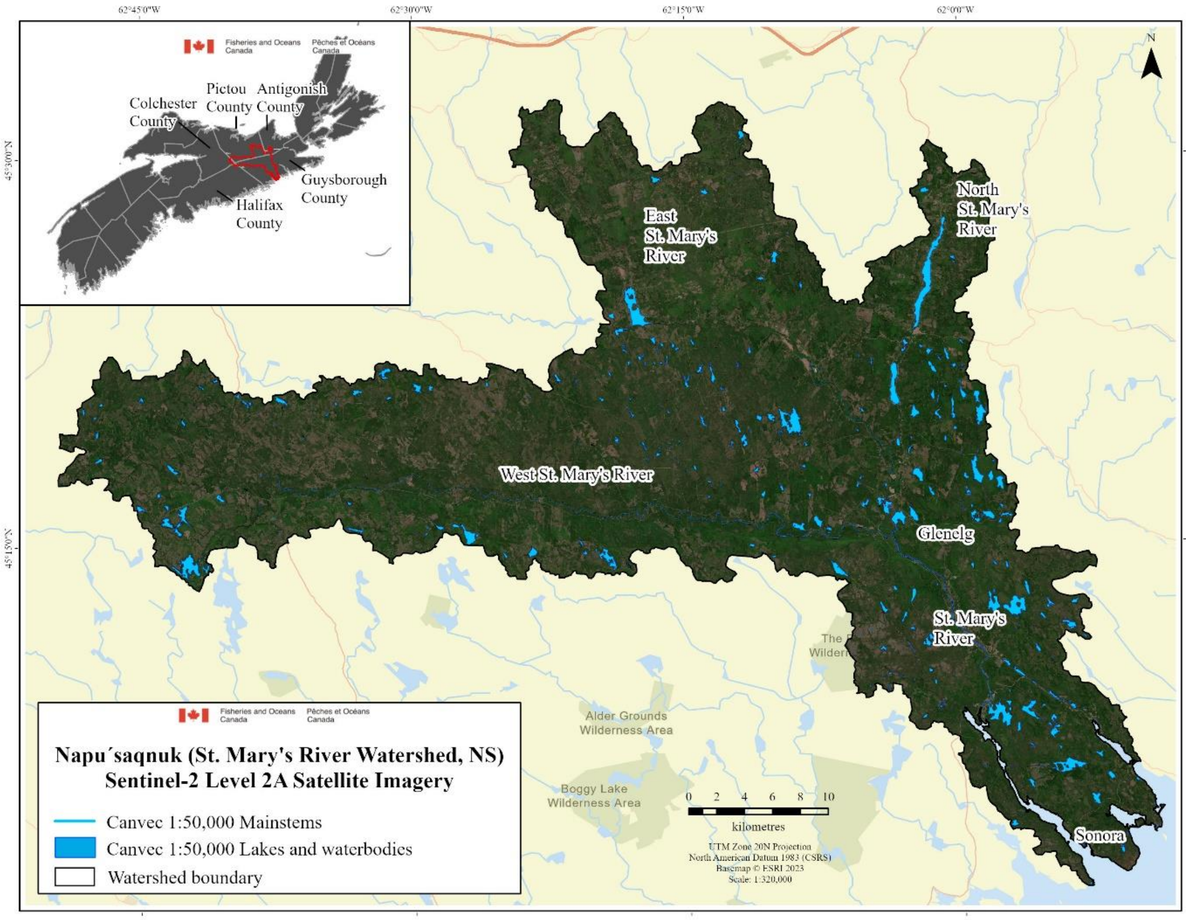

Figure 2. *The 12-band Sentinel 2A satellite imagery of the St. Mary's River watershed (June 10, 2019). The 12-band image is displayed in true colour composite (bands 4-R 3-G 2-B). Images were derived from tile identifier named 'TNR' and 'TNQ' footprints. Bands in each image were resampled to 10 m and mosaicked in ArcGIS Pro v.2.8 to obtain complete coverage of the watershed. The watershed boundary shapefile was obtained from Open Data Nova Scotia (1:10,000 Primary Watersheds layer).*

1.2. Research objectives

Objectives of this project were to:

1. Identify LCLU within the riparian zone of the St. Mary's River and all connecting surface waterbodies (including lakes, rivers, streams, wetlands, and estuaries);
2. Determine the proportion and types of land use activities occurring within fixed-width riparian buffers;
3. Identify how LCLU activities vary between Crown and private land; and
4. Rank sub-watersheds in terms of "intactness" to determine which areas of the watershed may benefit most from proactive riparian conservation and/or protection.

2. Methods

Terrestrial LCLU classes within the St. Mary's River watershed were characterized using a supervised support vector machine (SVM) classification of Sentinel-2 satellite imagery. Previous classified land cover maps as well as field-validated data sources were used to train the classification and to validate the LCLU classified image (Figure 3).

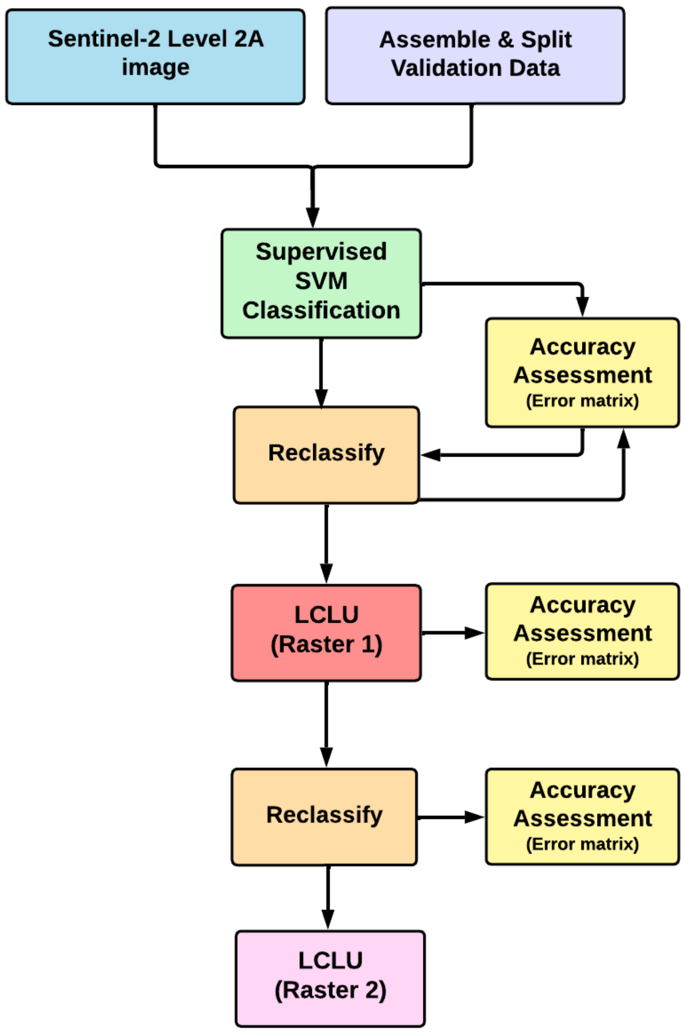

Figure 3. *Methodological workflow for generating the LCLU map for the St. Mary's River watershed.*

2.1. Acquisition and preparation of satellite imagery

Atmospherically corrected satellite images were downloaded from the Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/ #/home). Sentinel 2 Level 2A top of atmosphere imagery was acquired, as this satellite offered open-source data with a high temporal (5-day re-visit time) and spatial (10-60 m) resolution compared to Landsat (16-day revisit time and a 30 m resolution; (European Space Agency 2022a; 2022b). Images were filtered by the following criteria: (1) less than 5% cloud cover, and (2) whether appropriate to mosaic together for full watershed coverage. Two images from June 10, 2019 were used, demonstrating full coverage of the watershed. All 12 bands of the Sentinel-2A imagery were downloaded and resampled to 10 m in ArcGIS Pro v. 2.8 using the *Resample* tool and the 'nearest' sampling technique.

2.2. Validation and identification of land cover land use classes

Datasets considered for validating the LCLU classification map of the St. Mary's River watershed classification came from five sources: 1) Nova Scotia Forest Inventory (NSFI); 2) Nova Scotia Topographic Database (NSTD) – 'roads, trails and rails' line layer and the 'break line' layers (merged and dissolved together); 3) Canada Landsat Derived Forest Harvest Disturbance (CLDFHD); 4) Natural Resources Canada (NRCan) Classified Land Cover; and 5) Agriculture and Agri-food Canada (AAFC) Annual Crop Inventory (Table 1).

Table 1. *Description and data sources used in the validation of land cover and land use classification of the St. Mary's River watershed. Note: data source webpages are hyperlinked to the names in the 'Dataset name' column.*

Dataset name	Description	Organization	Data type, Coordinate System, Resolution	Year(s)
Nova Scotia Forest Inventory (NSFI)	This dataset includes 23 forested classes and 26 non-forested classes (e.g., agriculture, freshwater wetlands and coastal habitats). Forested stands include attributes for tree species, percentage, height and crown closure, plus calculated values such as volume. Inventory is maintained through aerial photo interpretation and is supplemented with field data at select locations.	Province of Nova Scotia	Polygon vector, NAD83 UTM (1:10,000)	2004-2018
Nova Scotia Topographic Database (NSTD) *– roads, trails, and rails*	This layer contains information on roads, trails and rails and was used to identify roads as urban areas.	Province of Nova Scotia	Line vector, WGS 1984 (1:10,000)	2002-present
Canada Landsat Derived Forest Harvest Disturbance (CLDFHD)	This raster contains 16 classes that reflect the year forest loss occurred. The raster does not contain information on the type of loss, only the year loss occurred. This includes any conversion of natural forests, be it plantations, selective logging or shifting cultivation practiced by local communities.	Canadian Forest Service	Raster, NAD83 UTM (30 m resolution)	1985-2020
Natural Resources Canada Classified Land Cover Map 2020 (NRCan)	This raster contains information on land cover with a total of 15 classes.	Natural Resources Canada	Raster, WGS 1984 (30 m resolution)	2020
Agriculture and Agri-food Canada Annual Crop Inventory Classified Land Cover Map (AAFC)	This raster contains 72 classes including information on forest cover, wetlands, agriculture, etc.	Agriculture and Agri-food Canada	Raster, WGS 1984 (30 m resolution)	2021

Forest composition and relative age can have a major influence on riparian zone service provisioning to the aquatic environment. Many old growth hardwood and Acadian forest stands have been lost due to timber harvesting throughout Nova Scotia, shifting the composition of tree species over time (Noseworthy & Beckley 2020). The long history of forest management in the St. Mary's River warranted an investigation into the general composition of forest stands to better understand potential interactions with freshwater fish habitat in the watershed. Therefore, the first classification separated forest into coniferous, deciduous, and mixedwood classes.

Validation points were grouped into nine general land cover classes: 1) coniferous, 2) deciduous, 3) mixedwood, 4) shrubland, 5) grassland, 6) wetland, 7) agriculture, 8) barren, and 9) urban based on what was observed to be consistent among all five datasets (Table 2). Only the first three datasets (NSTD, NRCan, and AAFC) were used to guide (i.e., train) the classification. The remaining two datasets (NSFI and CLDFHD) were then used for reclassification and validation of the reclassified raster.

Table 2. *LCLU class name and associated descriptions as defined in the assembled validation datasets. Only the first three validation datasets (NRCan, AAFC, and NSTD) were used for the first image classification.*

Class #	LCLU Class	Class description
1	Coniferous	Coniferous forested stand which has not been treated silviculturally and does not qualify as clear cut, partial cut, burn, old field, windthrow, alders, brush, or dead categories. Those identified as natural stand under NS forest inventory layer.
2	Deciduous	Deciduous forested stand which has not been treated silviculturally and does not qualify as clear cut, partial cut, burn, old field, windthrow, alders, brush, or dead categories. Those identified as natural stand under NS forest inventory layer.
3	Mixed wood	Mixed forest stand which has not been treated silviculturally and does not qualify as clear cut, partial cut, burn, old field, windthrow, alders, brush, or dead categories. Those identified as natural stand under NS forest inventory layer.
4	Shrubland	Predominantly woody vegetation of relatively low height (generally +/-2 metres). May include grass or wetlands with woody vegetation, regenerating forest. This is classified in the AAFC layer and NR Can land cover data as shrubland.
5	Grassland	This class includes native grasses and other herbaceous vegetation and may include some shrubland cover.
6	Wetland	Any wet area, not identified as a lake, river or stream, excluding open and treed bogs, and beaver flowage.
7	Urban	Any area used primarily as residential, industrial and related structures such as streets, sidewalks, parking lots, railway surfaces, industrial sites, mine structures, etc. This includes NSDNR roads and railways.
8	Agriculture	Periodically cultivated areas. These include tame grasses and other perennial crops such as alfalfa and clover grown alone or as a mixture for hay, pasture, or seed. It also includes any hay field, pasture, tilled crop, or orchard including annual and perennial crops which contain no merchantable tree species.
9	Barren	Land that is predominately non-vegetated and non-developed. Includes: glacier, rock, sediments, burned areas, rubble, mines, other naturally occurring non-vegetated surfaces. Excludes fallow agriculture.

To prepare validation points for classification, the NSTD vector layer was converted to raster and the NRCan and AAFC rasters were resampled to match the pixel resolution of the Sentinel 2A satellite imagery. Classes from each dataset were reclassified based on their class code (Appendix A). Water classes were removed from all validation datasets. The NRCan validation data used all classes except urban, as this class was better represented by the NSTD roads layer. The AAFC dataset was reduced to include only agriculture, grassland, urban, and barren classes while the NSTD layer only used for the urban class (roads). A 10 m x 10 m grid generated for the watershed was used to extract class values from all resampled rasters and cleaned to remove duplicates. The points were exported from ArcGIS Pro (v.2.8) and imported into R Studio (v.4.2.2) to derive a random sample of points and to split the validation data into training and testing data for classification and evaluating classification accuracy. A total of 15,644,309 validation points were extracted and reduced to train and validate the supervised classification of the LCLU map for the St. Mary's River watershed (Table 3).

Table 3. *Validation datasets used to classify the Sentinel 2A image.*

	Dataset			
Land Cover Land Use Class	**NRCan**	**AAFC**	**NSTD**	**Total Validation Points**
Coniferous	4,295,188	0	0	4,295,188
Deciduous	4,832,617	0	0	4,832,617
Mixed wood	4,191,192	0	0	4,191,192
Shrubland	1,184	0	0	1,184
Grassland	1,013,054	60,082	0	1,073,136
Wetland	23,931	0	0	23,931
Urban	280,117	175,792	374,066	829,975
Agriculture	135,829	130,609	0	266,438
Barren	661	129,987	0	130,648
Total	**14,773,773**	**496,470**	**374,066**	**15,644,309**

An initial point reduction was done in R Studio (*subset* function) through filtering each dataset (Table 1) individually for each corresponding LCLU class (e.g. filtering the NRCan dataset for the 'urban' class). A random sample of 1000 validation points per class was then obtained for each dataset using the *sample* function in R Studio. Validation points from all datasets were then merged into a single dataset, in which all duplicates were removed using the unique grid ID. This ensured only a single point (and validation class) fell within each 10 m pixel for validation. The sample size for the NRCan barren class was limited to 661 points, therefore all validation points were used.

The final validation dataset was split into testing (80%) and training (20%) validation datasets using the *caret* package in R. The final reduced and resampled validation dataset resulted in a total of 20,665 validation points (n = 16,533 training data and n = 4,132 testing data) to guide and validate the classification (Table 4, Table 5). All validation data was verified and reclassified on an as-needed basis against the Sentinel 2A satellite imagery before this data was used to train and validate the classification. Contrasting the previously assembled datasets (Table 2) against the satellite image was essential, as validation data did not represent field ground-truthing. Validation points obtained from NRCan and AAFC were comprised of classified data derived from classification outputs (i.e., NRCan accuracy of 86.9% and AAFC accuracy of 64.4%).

Table 4. *Training data used to classify the Sentinel 2A satellite image. A random sample of 1000 points per class was used to reduce the number of validation points.*

	Land Cover Land Use Class									
Dataset	**Conif.**	**Decid.**	**Mixed wood**	**Shrub land**	**Grass land**	**Wet land**	**Urban**	**Agri.**	**Barren**	**Total**
NRCan	2,438	1,730	2,247	163	268	506	2,182	1,483	817	11,834
AAFC	6	33	39	1,940	34	21	70	1	193	2,337
NSTD	256	442	284	60	1104	15	76	5	120	2,362
Total	**2,700**	**2,205**	**2,570**	**2,163**	**1,406**	**542**	**2,328**	**1,489**	**1,130**	**16,533**

Table 5. *Testing data used to classify the Sentinel 2A satellite image. A random sample of 1000 points per class was used to reduce the number of validation points.*

	Land Cover Land Use Class									
Dataset	**Conif.**	**Decid.**	**Mixed wood**	**Shrub land**	**Grass land**	**Wet land**	**Urban**	**Agri.**	**Barren**	**Total**
NRCan	565	478	579	19	62	128	571	368	185	2,955
AAFC	1	17	7	555	3	1	0	0	0	584
NSTD	44	85	72	16	343	2	19	0	12	593
Total	**610**	**580**	**658**	**590**	**408**	**131**	**590**	**368**	**197**	**4,132**

2.3. Supervised Classification

A supervised SVM classification was conducted using the 12-band original Sentinel-2A satellite image to classify LCLU activities within the St. Mary's River watershed. The SVM was conducted using the 80% training data in ArcGIS Pro using the *Train Support Vector Machine* tool (Spatial Analyst) with a maximum of 1000 samples per class, the 12 band Sentinel 2A image, and a nine class schema (as described in Table 2). Training areas were examined against the classified SVM raster using the *Inspect training samples* tool which assigned a score from 0 (inaccurate) to 1 (accurately classified) to help identify misclassified training areas. The reduced LCLU class validation points (Table 4; Table 5) were manually inspected to validate the class assigned to a given point against the raw satellite image. True classification errors were manually assigned to a new class, but areas misclassified by the SVM and identified by the *Inspect trailing samples* tool as incorrect were not re-assigned as they were technically correct, but the SVM predictor was not. Similar spectral signatures prevented the SVM from distinguishing between classes in some locations (e.g., abandoned roads, barren vs. urban), and factors such as misaligned image capture timing or sensor resolution may have contributed to initial classification errors. The classified raster was imported to R Studio to further investigate accuracy and generate error matrices. A script was developed to generate an error matrix and calculate an overall accuracy and kappa statistic. The results of this script were exported as an American Standard Code for Information Interchange (ASCII; .csv) file. Once the overall accuracy and kappa statistic of the classified raster was sufficient (kappa between 0.4-0.8), the classified raster was reclassified into nine broader classes using all five datasets (Table 3; Appendix B).

2.4. Reclassification

The loss of mature riparian forest through natural (e.g., wildfire) or anthropogenic (e.g., timber harvesting) disturbance can significantly influence freshwater ecosystems (Fuller et al. 2022; Cunningham et al. 2023). Further study into the relative age of the riparian forests can offer insights at the spatial and temporal scale that broad tree species composition cannot. The classified LCLU raster was reclassified to incorporate areas of forest loss and secondary growth and re-group forest classes such as coniferous, deciduous, and mixedwood into one category named natural stand (Appendix A). Forest loss and secondary growth classes were reclassified using the NSFI and CAFDHD datasets (Appendix A). The reclassified raster was comprised of nine broader classes: 1) natural stand, 2) secondary growth, 3) forest loss, 4) agriculture, 5) barren, 6) shrubland, 7) grassland, 8) wetland, and 9) urban (Table 6). Creation of the final reduced and resampled validation dataset followed the same approach described in Section 2.2. and 2.3., which resulted in 4,732 testing validation points to validate the reclassified raster (Table 6).

Table 6. *Re-grouped LCLU used in the reclassified land cover map. The reclassified map used all five validation datasets. For class codes see Appendix A.*

Class #	LCLU Class	Class description
1	Natural Stand	Any forested stand which has not been treated silviculturally and does not qualify under clear cut, partial cut, burn, old field, windthrow, alders, brush, or dead categories. Those identified as natural stand under NS forest inventory layer.
2	Secondary Growth	Forest or woodland area which has re-grown after a timber harvest or clear-cut for agriculture, wind-throw, or wildfire. Areas identified in NSDNR Forest inventory as of 2009 as burn, old field, windthrow, clear cut, partial depletion, partial cut are presumed to now be Secondary Growth (2019 satellite image).
3	Forest Loss	Canadian Landsat Forest Harvest Derived Forest Harvest Disturbance 1985-2021 dataset represents 36 years of harvest change over Canada’s forests. These data represent annual stand replacing forest changes by wildfire and harvest labelled by year of disturbance.
4	Shrubland	Predominantly woody vegetation of relatively low height (+/-2 meters). May include grass or wetlands with woody vegetation, regenerating forest. This is classified in the AAFC layer and NRCan land cover data as Shrubland.
5	Grassland	This class includes native grasses and other herbaceous vegetation and may include some Shrubland cover.
6	Wetland	Any wet area, not identified as a lake, river, or stream, excluding open and treed bogs, and beaver flowage.
7	Urban	Any area used primarily as residential, industrial, and related structures such as streets, sidewalks, parking lots, railway surfaces, industrial sites, mine structures. This includes NSDNR roads and railways.
8	Agriculture	Periodically cultivated areas. These include tame grasses and other perennial crops such as alfalfa and clover grown alone or as a mixture for hay, pasture, or seed. It also includes any hay field, pasture, tilled crop, or orchard consisting of annual and perennial crops (i.e., this does not contain merchantable tree species).
9	Barren	Land that is predominately non-vegetated and non-developed. These includes glacier, rock, sediments, burned areas, rubble, mines, other naturally occurring non-vegetated surfaces. Excludes fallow agriculture.

Table 7. *Testing data (20%) used to validate the reclassified raster.*

	Land Cover Land Use Class									
Dataset	**Nat. Stand**	**Second. Growth**	**Forest Loss**	**Agri.**	**Urb.**	**Barren**	**Grass land**	**Wet land**	**Shrub land**	**Total**
NRCan	1,305	0	0	14	57	120	343	366	144	2,349
AAFC	21	0	0	548	3	1	0	0	0	573
NSTD	166	0	0	13	298	2	9	0	9	497
NSFI	0	343	0	0	10	0	0	0	0	353
CLDFHD	2	0	351	0	0	0	0	0	0	353
Total	**1,494**	**343**	**351**	**575**	**368**	**123**	**352**	**366**	**153**	**4,125**

The CLDFHD raster was resampled from 25 m to 10 m to match the pixel resolution of the satellite imagery. The 2004-2018 NSFI polygon layer was converted to a raster with a resolution of 10 m. Both the CLDFHD and NSFI data were clipped to the St. Mary's River watershed and had water classes removed. For this study, the NSFI data layer is considered older validation data and therefore disturbances listed in NSFI layer were considered re-growth in the 2019 image. The CLDFHD layer was also used to compare areas of loss that may have demonstrated regrowth in the 2019 image. Similarly, other classes such as agriculture, barren, wetland, urban, etc., were not used from this layer as changes to the land may have occurred within the data gap years. Finally, the CLDFHD 2000-2021 data layer was used to obtain the Forest Loss class for years ≥ 2011 and ≤ 2019. The CLDFHD layer records what year loss occurred yet does not indicate the type of land-based activity or disturbance that caused Forest Loss as found in the NSFI layer. The *Reclassify* tool was used to reclassify raster values and the *Mosaic to new raster* tool was used to mosaic the reclassified pixels and non-reclassified areas back together. The final reclassified raster consisted of nine broader classes: natural stand, secondary forest, forest loss, agriculture, barren, shrubland, grassland, wetland, and urban.

2.5. Data Analysis: Riparian Zone Fixed-width Buffers

Baseline riparian buffers begin at the ordinary high-water mark or landward edge of a floodplain and extend outward into the upland habitat around all connecting watercourses and waterbodies including lakes, rivers, streams, and wetlands (Collison & Gromack 2022). In this study, four fixed-width riparian buffers (30 m, 100 m, 150 m, and 300 m) were generated within the St. Mary's River watershed. The 30 m riparian buffer was chosen as this size is consistent with current buffer regulations in Nova Scotia and is sufficient in capturing changes to LCLU (Collison & Gromack 2022). The three additional fixed-width buffers of 100 m, 150 m, and 300 m offered a larger sample size of classified LCLU types to assess and analyzed riparian LCLU at broader spatial scales.

Riparian fixed-width buffers (30 m, 100 m, 100 m estuarine coastline, and 300 m) were derived from the 1:50,000 CanVec hydrographic features of water courses and water bodies layers (Appendix C, estuarine Coastline). A 150 m riparian fixed-width buffer was generated using the NCC water line and water bodies layer. Buffers of varying widths were used to assess the potential differences in LCLU distribution ranging from near-shore riparian habitat and extending outward from the high-water mark. The NCC water layer was compared with the CanVec layer to examine differences in LCLU distribution (using a middle width buffer between our maximum and minimum) based on the predictive hydrological model base layer used to build the buffer zone.

LCLU classes within each of the four fixed-width buffers were examined using the reclassified raster clipped to each riparian buffer. The proportion (%) of LCLU was calculated for each buffer throughout the watershed. To examine how land classes were distributed among various land ownerships, the Nova Scotia Crown Land layer was clipped to each of the four riparian fixed-width buffer zones.

The *Nova Scotia Old Growth Forest Policy* (OGF) data was used to examine natural old growth areas that are currently protected (Natural Resources and Renewables 2022). The current provincial OGF Policy layer represents old growth areas protected from timber harvesting that occur inside and outside of protected areas. Using the OGF layer, old growth and old growth restoration opportunities that are located on crown land outside of protected areas (select method = 1) and OGF located inside protected areas (crown or private) (select method = 2) were examined (Natural Resources and Renewables 2022). Total areas that were intact (natural) and disturbed were summarized for each riparian fixed-width buffer size. The amount of natural and disturbed areas was calculated for crown land, private lands, and OGF areas. Tools were placed in ArcGIS ModelBuilder for each calculation and run separately to extract and summarize information for each LCLU class, by ownership layer, and OGF Policy, for each of the various riparian buffers (Figure 4). Batch clips and other relevant tools were placed in model builder were frequently used for all repetitive analyses. Private land in this analysis did not include privately owned conservation lands and protected areas.

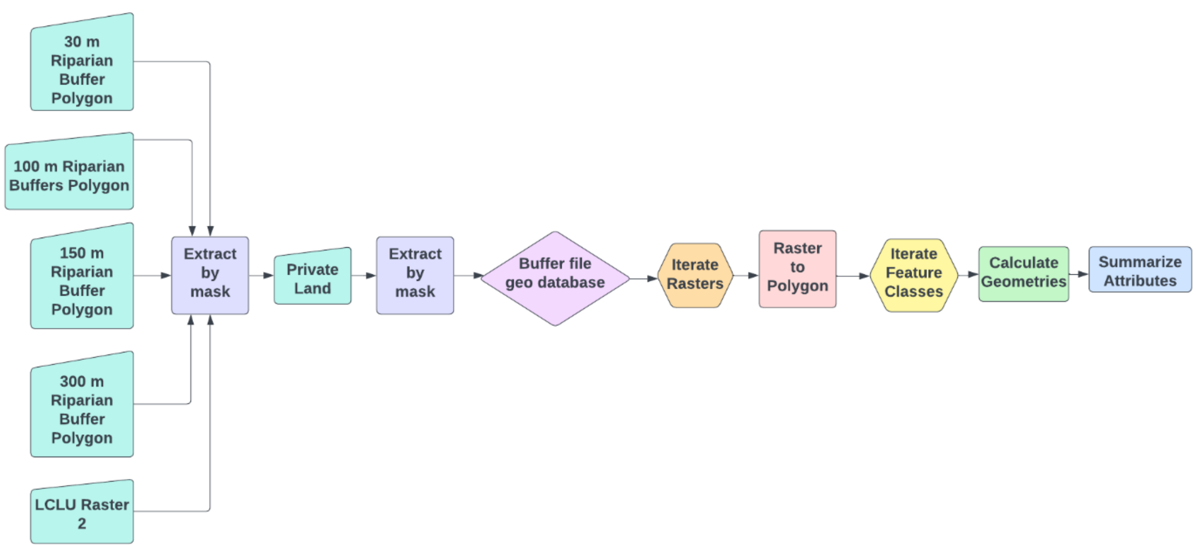

Figure 4. *An example of data summarized for private lands within each of the four fixed-width riparian buffers. The 100 m riparian buffer was done for the entire watershed as well as just the estuarine coastline. Tools and layers were placed in model builder to summarize and calculate proportions of LCLU within each buffer layer and this process was performed for all summary data. Outside of the model, each buffer and land ownership data were clipped using a batch clip.*

2.6. *Data Analysis: Weighting and Ranking*

To identify which sub watersheds would benefit from proactive riparian conservation /protection (i.e., riparian habitat is highly intact), using a 100 m buffer, land cover classes were ranked from 1 to 9 where 1 was most intact or highly natural (1 = natural stand) and 9 was least intact or less natural (9 = urban). Three versions of ranking were generated to examine results (Tables 7, 8 and 9; Figure 5).

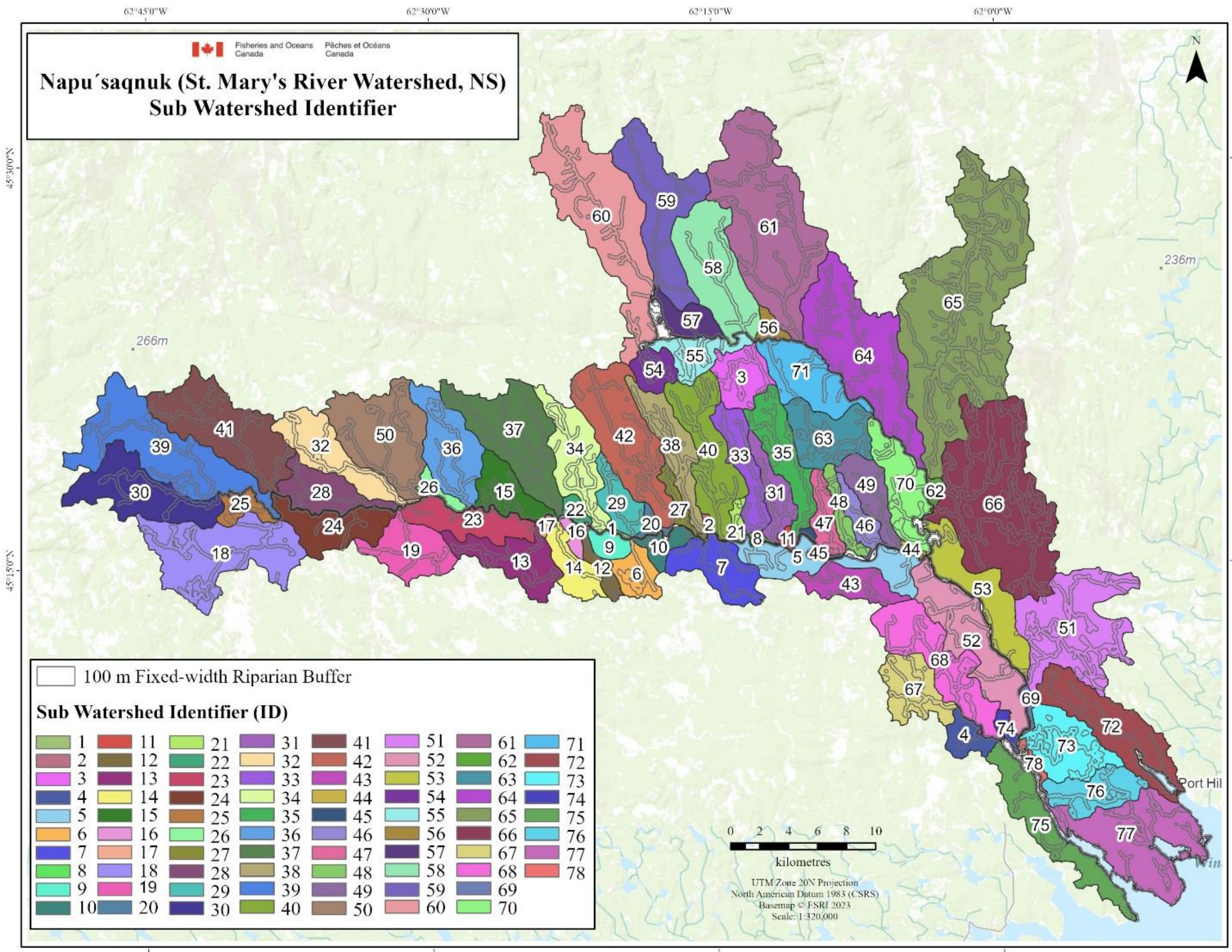

Figure 5. *Sub watershed identifiers (ID) within the St. Mary's River watershed derived from the Nova Scotia 1:10,000 tertiary and sub-tertiary watershed boundary data layers.*

In model builder, the reclassified land cover land use raster was clipped to the 100 m fixed-width riparian buffer. The resulting clipped 100 m riparian land cover land use buffer was then joined with the Nova Scotia sub watershed layers via the *Spatial join* tool. Each land cover class was extracted using the *Select* tool. Once all classes were extracted, each LCLU layer was re-joined using the *Add join* tool to determine the percent of each land class grouping per sub watershed.

For example, in version 1, the sum (area m^2) of the 'natural stand' class and wetland class within a given sub watershed identifier (ID) were added together as natural stand, which was divided by the total sum of all classes to obtain the percent of the 'natural stand' class (Appendix D.). In version 2, no classes were combined and therefore each layer represented the proportion of each LCLU class, and in version 3, select LCLU classes were grouped together into 'highly natural', 'regenerative', and 'regeneration unlikely' categories (Table 9).

Once the proportion of area of each LCLU class grouping per sub watershed was determined for all three versions, a single raster representing the proportion of a given LCLU grouping were generated (i.e., total of 9 raster's version 1, 8 raster's version 2, and 3 raster's version 3) (Tables 7,8 and 9). A weighting for each class was assigned according to the importance (rank) of each land cover class. The *Weighted Sum* tool was used to summarize the results of the three different ranking versions and was used to identify areas based on sub watershed that may benefit from proactive riparian conservation /protection using a 100 m buffer.

Table 8. *Ranking of each LCLU from 1-9. Ranking is assigned from most intact (natural) to least intact (less natural). Assigned weights sum to 100.*

Rank	Overall Category	Version 1 LCLU Class Grouping	Weight (%)	Weight (%) by Category
1	Highly Natural	Natural Stand	0.28	0.64
2		Wetland	0.16	
4		Shrubland	0.12	
6		Grassland	0.08	
3	Regenerative	Secondary Growth	0.14	0.24
5		Forest Loss	0.10	
7	Regeneration Unlikely	Agriculture	0.06	0.12
8		Barren	0.04	
9		Urban	0.02	

Table 9. *Ranking of each LCLU from 1-8 where natural stand and wetland are grouped as a single class. Ranking is assigned from most to least intact (natural). Weights sum to 100. Overall Category column represents a means to compare maps and versions of weighting.*

Rank	Overall Category	Version 2 LCLU Class Grouping	Weight (%)	Weight (%) by Category
1	Highly Natural	Natural Stand + Wetland	0.44	0.64
3		Shrubland	0.12	
5		Grassland	0.08	
2	Regenerative	Secondary Growth	0.14	0.24
4		Forest Loss	0.10	
6	Regeneration Unlikely	Agriculture	0.06	0.12
7		Barren	0.04	
8		Urban	0.02	

Table 10. *Ranking of each Land Cover Land Use (LCLU) from 1-3 where 1) highly natural is comprised of natural stand, wetland, shrubland, and grassland 2) regenerative forest is comprised of secondary growth and forest loss, and 3) regeneration unlikely which is comprised of urban, agriculture, and barren. Ranking is assigned from most to least intact (natural). Weights sum to 100.*

Rank	Overall Category	Version 3 LCLU Class Grouping	Weight (%)	Weight (%) by Category
1	Highly Natural	Natural Stand + Wetland + Shrubland + Grassland	- - - -	**0.64**
2	Regenerative	Secondary Growth + Forest Loss	-	**0.24**
3	Regeneration Unlikely	Agriculture + Barren + Urban	- - -	**0.44**

3. Results

3.1 Land Cover and Land Use Supervised SVM Classification

The supervised SVM LCLU classification classified approximately 1,487 km^2 of terrestrial habitat in the St. Mary's River watershed. The St. Mary's River watershed (SMRW) is comprised primarily of coniferous forest followed by deciduous and mixedwood forest, grassland, shrubland, urban, agriculture, wetland, and barren (Table 11). The classified map did not account for waterbodies, rivers or streams. The SVM LCLU classification achieved an overall accuracy of 84.4% and a kappa statistic of 0.82, which is considered substantial agreement (Sim & Wright 2005) (Figure 6; Table 12). The classification demonstrated the wetland (92.6%) class to have the greatest number of correctly identified pixels (producer's accuracy) followed by agriculture (91.3%), barren (89.1%), coniferous forest (88.7%,) urban and grassland (both at 86.8%), mixedwood forest (86.6%), deciduous forest (84.9%), and shrubland (44.8%) class (Table 12). Shrubland had the least amount of correctly identified pixels, and was most misclassified with agriculture and deciduous areas (Table 12).

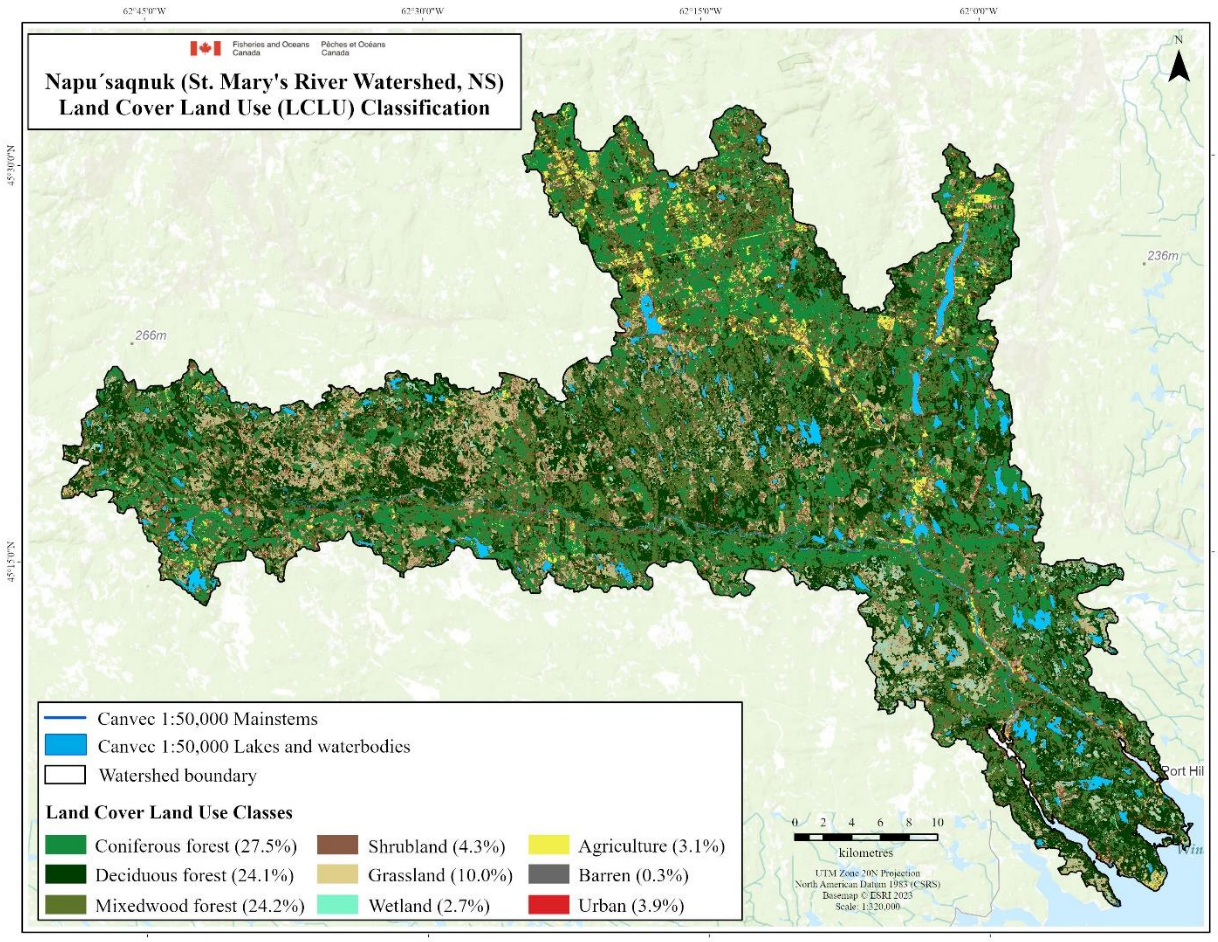

Figure 6. *Results of the classified raster (LCLU raster 1) supervised Support Vector Machine (SVM) land cover land use classification of the 12-band Sentinel-2A satellite imagery June 10, 2019.*

Table 11. *Distribution of LCLU classes within the St. Mary's River watershed from the Sentinel 2 Level 2A satellite image, June 10, 2019.*

LCLU class	Count of pixels	Area (km^2)	% Area
Coniferous	4,088,139	408.81	27.49
Deciduous	3,587,684	358.77	24.13
Mixedwood	3,591,716	359.17	24.16
Shrubland	634,760	63.48	4.27
Grassland	1,490,452	149.05	10.02
Wetland	398,218	39.82	2.68
Urban	573,783	57.38	3.86
Agriculture	466,142	46.61	3.13
Barren	38,176	3.82	0.26
Total	**14,869,070**	**1,486.91**	**100.00**

Table 12. *Accuracy assessment of Raster 1 supervised Support Vector Machine Land cover land use classification of the 12-band Sentinel-2A satellite imagery June 10, 2019 using 20% testing and 80% training data. LCLU class 1) coniferous, 2) deciduous, 3) mixedwood, 4) shrubland, 5) grassland, 6) wetland, 7) urban, 8) agriculture, and 9) barren. Descriptions can be found in Table 2.*

	LCLU Class Number											
Class Name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**	**User Acc**	**Omission Error**
Conif.	551	5	36	3	3	6	6	0	0	610	90.3	9.7
Decid.	1	501	25	16	16	0	8	13	0	580	86.4	13.6
Mixed	57	39	517	13	13	6	10	3	0	658	78.6	21.4
Shrub	2	9	5	154	7	1	5	14	0	197	78.2	21.8
Grass	0	5	0	83	474	11	8	8	1	590	80.3	19.7
Wetland	5	2	0	4	17	338	0	1	1	368	91.8	8.2
Urban	5	13	12	1	0	1	375	0	1	408	91.9	8.1
Agri.	0	16	1	66	15	2	7	473	10	590	80.2	19.8
Barren	0	0	1	4	1	0	13	6	106	131	80.9	19.1
Total	621	590	597	344	546	365	432	518	119	**4,132**		**Kappa: 0.82**
Prod. Accuracy	88.7	84.9	86.6	44.8	86.8	92.6	86.8	91.3	89.1	**Overall accuracy: 84.4%**		

The reclassified raster was comprised primarily of natural stand followed by secondary growth, grassland, forest loss, urban, shrubland, wetland, agriculture, and barren (Table 13; Figure 7). Approximately 916 km^2 (61%) of the watershed is natural stand (Table 13). The reclassified raster resulted in a higher overall accuracy of 90.0% and a kappa statistic of 0.89 demonstrating a substantial agreement (Table 14; Figure 7). Grouping all forested classes (coniferous, mixedwood, and deciduous forest) as natural stand and validating against the NSFI natural stand likely increased accuracy as error in differentiating between forest type was removed. For example, the classified raster (LCLU 1) demonstrated areas where mixedwood was misclassified with coniferous and deciduous forest and contributing to the second highest omission error (Table 12). In the reclassified raster no error was found between secondary growth and other classes as these areas were carefully masked (clipped and erased) and assessed to match the satellite imagery using the NSFI layer and the CLDFHD layers together. Secondary growth was the most accurately classified LCLU class as this class was comprised of areas that were previously classified as forest loss (NSFI and CLDFHD) and did not occur in areas classified as natural stand (Table 14). It is possible that some areas of secondary growth may be misclassified as natural stand and/or forest loss due to varying stages of secondary growth occurring throughout the watershed and this is apparent in natural stand being misclassified as forest loss (Table 14).

While the results of the error matrix for the reclassified raster (LCLU 2) (Table 13) demonstrate a high overall accuracy, there remains a need for careful attention in distinguishing natural stand (intact areas), secondary growth, and forest loss LCLU classes using the NSFI and CLDFHD layers and when considering automation processes. Natural stand remained the LCLU class that had the greatest mis-classified validation points (Table 14). The natural stand class was the most complex LCLU class due to the nature of assembling multiple forest types and based on the spectral signatures may easily be confused with shrubland or agricultural classes. Urban held the highest number of misclassified points within natural stand likely due to pixels placed too closely to the road, on the shoulder of the road, or in regenerating areas. Similar trends in LCLU raster 2 were found in LCLU raster 1 where shrubland class was misclassified with agriculture as the shrubland class often occurred near crops for berries or edges of crops and fallow fields. The reclassified LCLU raster 2 revealed the watershed has experienced ~6.08% forest loss between 2011 and 2019 (Table 14). In contrast, ~13.11% of the watershed has regenerated.

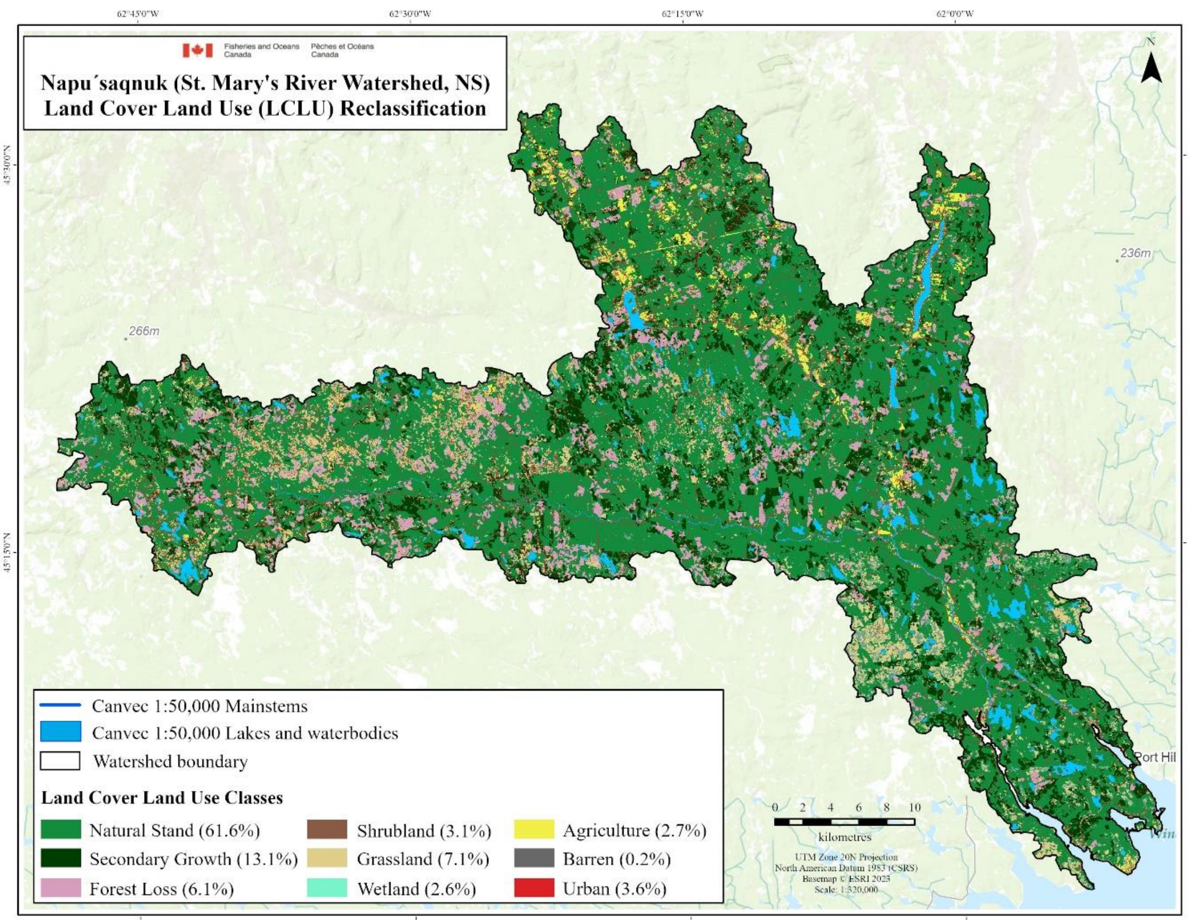

Figure 7. *Results of the reclassified raster (LCLU raster 2) using remaining validation datasets (NSFI and CLDFHD).*

Table 13. *Distribution of LCLU classes within the St. Mary's River watershed from the reclassified raster.*

LCLU class	**Count of pixels**	**Area (km²)**	**% Area**
Natural Stand	9,156,081	915.61	61.57
Secondary Growth	1,949,342	194.93	13.11
Forest Loss	903,829	90.38	6.08
Shrubland	454,329	45.43	3.06
Grassland	1,055,988	105.60	7.10
Wetland	394,531	39.45	2.65
Urban	532,005	53.20	3.58
Agriculture	390,891	39.09	2.63
Barren	33,515	3.35	0.23
Total	14,870,511	1,487.05	**100.00**

Table 14. *Accuracy assessment of the reclassified land cover land use map. LCLU class 1) natural stand, 2) secondary growth, 3) forest loss, 4) shrubland, 5) grassland, 6) wetland, 7) urban, 8) agriculture, and 9) barren. Descriptions can be found in Table 6.*

	LCLU Class Number											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**	**User Acc**	**Omission Error**
Natural Stand	1380	0	12	28	25	12	24	13	0	1494	92.4	7.6
Second. Growth	0	343	0	0	0	0	0	0	0	343	100.0	0.0
Forest Loss	1	0	345	1	3	0	1	0	0	351	98.3	1.7
Shrub-land	11	0	0	120	4	1	5	12	0	153	78.4	21.6
Grass-land	2	0	2	39	289	11	5	4	0	352	82.1	17.9
Wetland	5	0	0	4	17	338	0	1	1	366	92.3	7.7
Urban	29	0	0	1	1	2	333	1	1	368	90.5	9.5
Agriculture	16	0	0	62	12	2	7	466	10	575	81.0	19.0
Barren	1	0	1	4	1	0	13	6	97	123	78.9	21.1
Total	1445	343	360	259	352	366	388	503	109	4125		**Kappa: 0.89**
Prod. Accuracy	95.5	100	95.8	46.3	82.1	92.3	85.8	92.6	89.0	**Overall accuracy: 90.0%**		

This study reclassified all LCLU classes that occurred within the secondary growth and forest loss areas and therefore captured areas where changes have occurred throughout the watershed between 2011 and 2019. Conducting reclassification in the LCLU raster 2 demonstrated results that are useful in monitoring and measuring changes to landscapes (Table 15). For example, within the SMRW 47.90% of forest loss occurred in areas previously classified as grassland in LCLU raster 1. Other previously classified LCLU classes demonstrated forest loss between 2011-2019 for example shrubland (19.88%), followed by deciduous (12.31%), and agriculture (8.22%). Similarly, areas where forest loss occurred between 2011 to 2019 demonstrated varying signs of regeneration where secondary growth is regenerating as deciduous forest (87.18%), mixedwood forest (70.23%), and coniferous forest (37.21%). The comparison in the classified raster (LCLU 1) and reclassified raster (LCLU 2) demonstrate methods in which changes to landscape may be monitored and measured moving forward whether it is due to anthropogenic impacts or natural events.

Table 15. *Pixels reclassified using LCLU Raster 1 to generate LCLU Raster 2. Coniferous, deciduous, and mixedwood forests were reclassified based on the NSFI and CLDFHD layers for years 2011-2021.*

Reclassified Class	LCLU Raster 1 Class	Reclassified pixels (Count)	Reclassified area (km^2)	Reclassified area (%)
Secondary Growth	Coniferous	372100	37.21	19.09
	Deciduous	871800	87.18	44.72
	Mixed wood	702300	70.23	36.03
	Shrubland	390	0.039	0.02
	Grassland	920	0.092	0.05
	Wetland	46	0.0046	0.002
	Urban	680	0.068	0.03
	Agriculture	980	0.098	0.05
	Barren	49	0.0049	0.003
Total		**1,949,265**	**194.93**	**100.00**
Forest Loss	Coniferous	19900	1.99	2.21
	Deciduous	111000	11.1	12.31
	Mixed wood	36400	3.64	4.04
	Shrubland	179300	17.93	19.88
	Grassland	431900	43.19	47.90
	Wetland	3700	0.37	0.41
	Urban	40800	4.08	4.52
	Agriculture	74100	7.41	8.22
	Barren	4600	0.46	0.51
Total		**901,700**	**90.17**	**100.00**
Natural Stand	Coniferous	3695200	369.52	40.38
	Deciduous	2603900	260.39	28.45
	Mixed wood	2852200	285.22	31.17
Total		**9,151,300**	**915.13**	**100.00**

3.2 Riparian Fixed-width Buffer Summaries

Using the four fixed-width riparian buffers (30 m, 100 m, 150 m, 300 m) the proportion (%) of land cover that is in a natural state across the watershed was determined (Figure 8). Results indicate that the SMRW is fairly natural across all riparian buffer sizes. Across the various buffers, 76.2 to 85.5% of LCLU classes are in a ‘natural state’ (Table 16). Disturbance within all fixed-width buffers demonstrated secondary growth as the greatest contributor to disturbance, followed by urban, forest loss, and agriculture classes (Table 16). The estuary coastline revealed a higher proportion of urban as expected due to roads along the coastline.

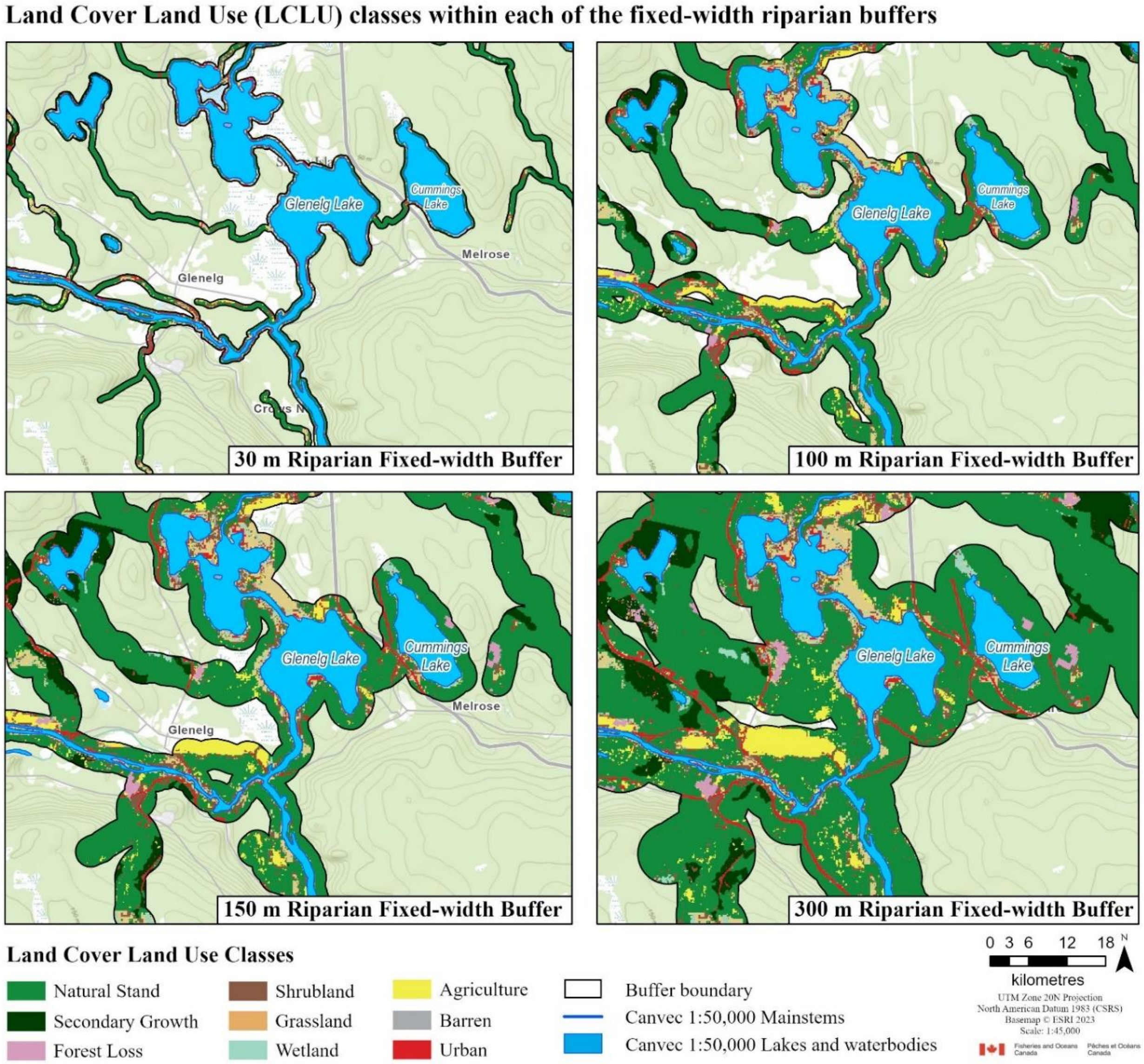

Figure 8. *LCLU reclassified raster clipped to each of the fixed-width riparian buffers and zoomed to Glenelg, St. Mary's River watershed, Nova Scotia. For the estuarine coastline fixed-width buffer see Appendix D.*

Table 16. *Proportion of LCLU that is natural and disturbed for each fixed-width riparian buffer.*

Type	LCLU Class Name	CanVec			NCC ARA	CanVec estuary coastline
		Buffer type and size (m)				
		30	**100**	**300**	**150**	**100**
Natural	Natural Stand	64.95	65.06	62.64	64.32	45.11
	Wetland	6.76	3.79	2.86	3.08	3.86
	Barren	0.76	0.54	0.34	0.36	9.15
	Shrubland	5.26	3.71	3.16	3.4	9.83
	Grassland	7.77	7.56	7.23	7.38	12.67
	Total (%)	**85.50**	**80.65**	**76.23**	**78.55**	**80.62**
Disturbed	Secondary Growth	5.73	8.82	11.92	10.29	4.48
	Forest Loss	1.9	3.51	5.2	4.32	0.23
	Urban	4.66	4.15	3.71	3.89	10.38
	Agriculture	2.21	2.87	2.93	2.95	4.28
	Total (%)	**14.50**	**19.35**	**23.77**	**21.45**	**19.38**

Land ownership is a key factor in developing policy recommendations and making informed decisions regarding habitat. Within 100 m of the SMR and connected waterbodies, 49.0% of terrestrial habitat occurs on private land and 51.0% on Crown land (Table 17). Private land within the watershed is concentrated along the main tributaries of the SMR.

Examining the distribution of LCLU classes across the various fixed-width buffers and among land ownership demonstrated ~ 75.5 – 88.9% of the watershed is intact and ~ 11.08 – 26.7% of it is disturbed within the four main riparian buffer zones (Table 18). However, the estuarine coastline appeared more natural with ~7.2% disturbed and ~ 92.8% intact, yet this is due to the presence of coastal barrens. Among all riparian buffers analyzed, secondary growth is the greatest contributor to disturbance followed by forest loss, urban, and agriculture classes (Table 17; Figure 8).

Table 17. *Distribution of land ownership within each of the three main branches of the St. Mary's Watershed (Figure 2).*

Sub watershed boundaries	Crown land (hectares)	Crown land (%)	Private land (hectares)	Private land (%)
West St. Mary's River	12,313	64.0	6,910	36.0
North St. Mary's River	4,397	38.0	7,242	62.0
East St. Mary's River	604	19.0	2,590	81.0
Mainstem and estuary	4,588	53.0	4,069	47.0
Total	**21,902**	**51.0**	**20,811**	**49.0**

Table 18. *Distribution of LCLU activities on crown lands ("C") compared to private lands ("P") within each fixed-width riparian buffers.*

		30		100		150		300	
	Ownership	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**
Natural	Natural Stand	70.43	65.23	69.31	63.18	68.00	62.17	65.61	60.47
	Wetland	6.86	4.45	4.22	2.61	3.50	2.06	3.39	2.02
	Barren	0.14	0.99	0.10	0.82	0.00	0.55	0.07	0.55
	Shrubland	2.77	5.61	2.07	4.71	2.00	4.35	2.07	4.10
	Grassland	8.71	6.79	8.43	6.77	8.4	6.40	8.25	6.13
	Total (%)	**88.9**	**83.1**	**84.1**	**78.1**	**81.9**	**75.5**	**79.4**	**73.3**
Disturbed	Secondary Growth	6.1	5.95	9.72	8.28	11.2	9.66	12.78	11.30
	Forest Loss	1.68	2.22	3.24	3.74	4	4.82	4.84	5.53
	Urban	2.66	4.89	2.35	4.51	2.3	4.3	2.4	4.02
	Agriculture	0.64	3.85	0.55	5.38	0.57	5.7	0.57	5.87
	Total (%)	**11.1**	**16.9**	**15.9**	**21.9**	**18.1**	**24.5**	**20.6**	**26.7**
Total (km^2)		**45.05**	**40.28**	**150.5**	**132.4**	**411.1**	**332.57**	**214.26**	**186.79**

OGF stands identified on Crown land under the *Nova Scotia Old Growth Forest Policy* (Natural Resources and Renewables 2022) are granted proactive protection from timber harvesting and other disturbances (Figure 9). In the St. Mary's River watershed, 1,089.86 hectares of protected OGF overlap with a 100 m riparian buffer on Crown land, and 239.37 hectares of OGF are located in 100 m buffers within protected areas (Table 19). These stands may include any forest types that meet the OGF minimum tree age requirements present in *s*. 3 of the policy (e.g., 140 years for Tolerant Hardwood stands) or forested areas that have "yet to develop into old-growth forest but are expected to do so with the passage of time" and are known as OGF restoration opportunity areas (Natural Resources and Renewables 2022).

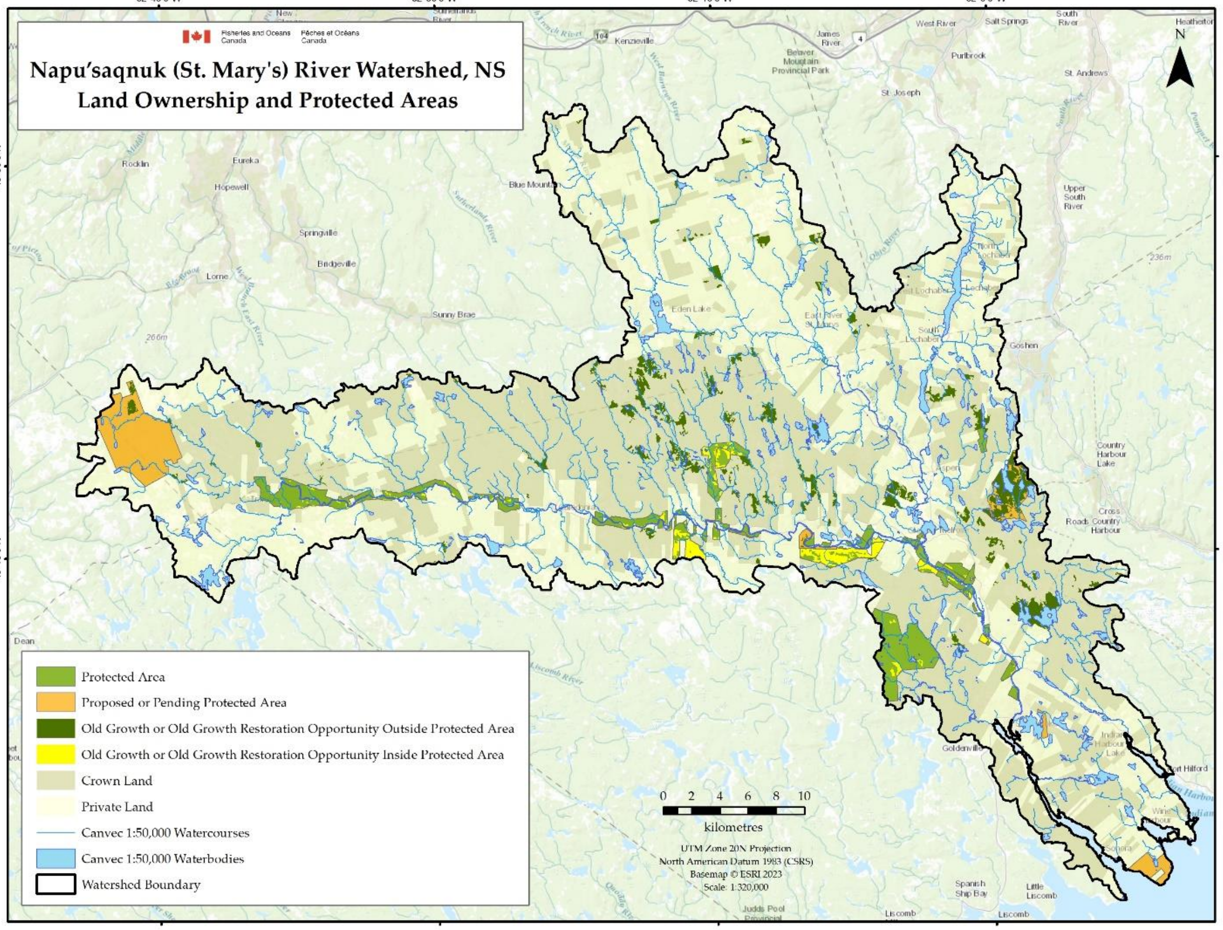

Figure 9. *Land ownership and protected areas within the St. Mary's River watershed, Nova Scotia. Protected areas depicted in the map reflect protected area status at time of analysis (April 2023).*

Table 19. *Total area (in hectares) of OGF in the St. Mary's River watershed that is protected under the Nova Scotia Old Growth Forest Policy, split by land ownership.*

Layer	Land Type	Total Area (hectares)	100m Riparian Fixed-width Buffer (hectares)
OGF restoration opportunities **outside** of protected areas	Crown	3,469.13	1,089.86
OGF restoration opportunities **inside** of protected areas	Crown	942.34	239.37
Total OGF in the St. Mary's River watershed		**4,411.17**	**1,329.23**

3.3 Weighting and Ranking

Three versions of ranking and weighting the LCLU classes, derived from the reclassified raster (Figure 2), for "intactness" resulted in similar patterns (Figures 10,11 and 12). The greatest amount of natural stand occurred in the north and western regions of the watershed where Crown land was present, and most disturbance occurring on private land, particularly in the southern and eastern regions of the watershed (Figures 10,11 and 12). Results of the weighting and ranking for all maps demonstrated trends where sub watershed IDs 16, 54, 55, 57, 59, 60 and 62 would benefit from proactive protection (Figures 10, 11, and 12). Meanwhile discrepancies in ranking and grouping of classes into 8 or 9 classes highlighted additional sub watershed IDs 67,68,72,75, and 77 as potential areas that may benefit from proactive protection. Sub watersheds identified as potential areas that may benefit from proactive protection occurred predominately on private land while areas that are highly natural across all weighted maps occurred on areas of Crown land.

Grouping wetland with natural stand and performing no grouping of LCLU classes resulted in an increase in less natural sub watersheds, whereas grouping LCLU classes into only three classes (highly natural, regeneration likely, regeneration unlikely), resulted in more natural sub watersheds identified. The discrepancy between grouping and weighting maps occurred for several reasons. First, maps were calculated using a 100 m riparian fixed-width buffer and as a result may only cover a significantly small portion of the actual sub watershed. Therefore, there may be instances where a sub watershed is indeed natural but appears less natural because it has a low proportion of land cover compared to other sub watersheds. For example, sub watershed ID 68 covers approximately 29.38 km^2. Using the 100 m buffer the LCLU class covers a total of 6.08 km^2 (Appendix D). In the resulting weighted maps sub watershed ID 68 appears less natural in both the weighted and ranked 1-8 classes (Figure 10) and the non-grouped 1-9 classes (Figure 11) compared to the 1-3 grouped classes (Figure 12) portrayed this sub watershed as 'Highly Natural'.

Second, the nature of the symbolized scale from 0-100 may demonstrate areas that are natural as less natural due to a lower proportion of LCLU class obtained from the buffer and size of the sub watershed. For example, in sub watershed ID 68 the weighted and ranked 1-9 version resulted in the greatest proportion of LCLU being natural stand (14.8%) followed by shrubland (3.6%), secondary growth (1.7%), wetland (1.6%), grassland (1.5), urban (0.2%), barren (0.8%), forest loss (0.7%), and agriculture (0.1%). However due to the low proportion of LCLU cover, the resulting map portrayed sub watershed ID 68 as less natural as the greatest LCLU class is 14.8%. Similarly, in sub watershed ID 68 of version 2 where classes are ranked from 1-8 natural stand & wetland obtained a greater proportion of highly natural category (27.8%), followed by shrubland (3.6%), secondary growth (1.7%), wetland (1.6%), grassland (1.5), urban (0.2%), barren (0.8%), forest loss (0.7%), and agriculture (0.1%). However, weighting LCLU classes into three groups highly natural (54.7%), regeneration likely (3.07%), and regeneration unlikely (0.2%) demonstrated a higher proportion of highly natural for sub watershed ID 68 compared to grouping LCLU classes into 8 classes or no grouping at all. Therefore, weighting results may be natural yet there may not be enough proportion of natural stand to be reflected on the 0-100 scale depending on the grouping being analyzed.

Finally, differences may occur between maps as the nature of the classes grouped and the weighting applied to each of the individual LCLU classes themselves slightly differ. For example, grouping wetlands and natural stands together (version 1, 8 classes) as one layer combined the sum of natural stand class area and the sum of the wetland class areas together (Table 8, see methods 3.3). In version 2 (no grouping of classes, 1-9) the natural stand and wetland classes were themselves separate layers that were each weighted individually compared to version 1 where natural stand and wetland were combined into one layer and weighted. In version 3, the classes grouped into three categories appeared more natural compared to version 1 as a greater number of LCLU classes (n=4) were combined in the highly natural class (Tables 7,8,9, methods section 2.6). For example, in version 3, highly natural combined the area sums for natural stand, wetland, shrubland, and grassland classes for a weighted sum of 0.64%. Version 1 combined only natural stand and wetland and weighted grassland and shrubland separately (3 layers and 3 weights to sum to 0.64%). Therefore, while the weights applied to each version of weighting and ranking for natural stand each sum to 0.64% the input layers being weighted themselves are slightly different (e.g. version 1 and 3: natural stand and wetland together as a single layer and grassland and shrubland as two separately weighted individual layers compared to version 2: where all layers were independent and weighted as such).

Summarizing natural and disturbed areas using a 100 m riparian fixed-width buffer and a weighted sum and ranking method for each sub watershed can appear misleading (less natural) across various grouping of LCLU classes. If the weighted maps are to be used in management decisions, the size of the sub watershed (area), the sum of the LCLU area, the proportion of each LCLU class, and the size of the riparian buffer should all be considered among and between sub watersheds (see Appendix D). Using the values outlined in Appendix D for each version of ranking and assigned weighting, each map can be validated.

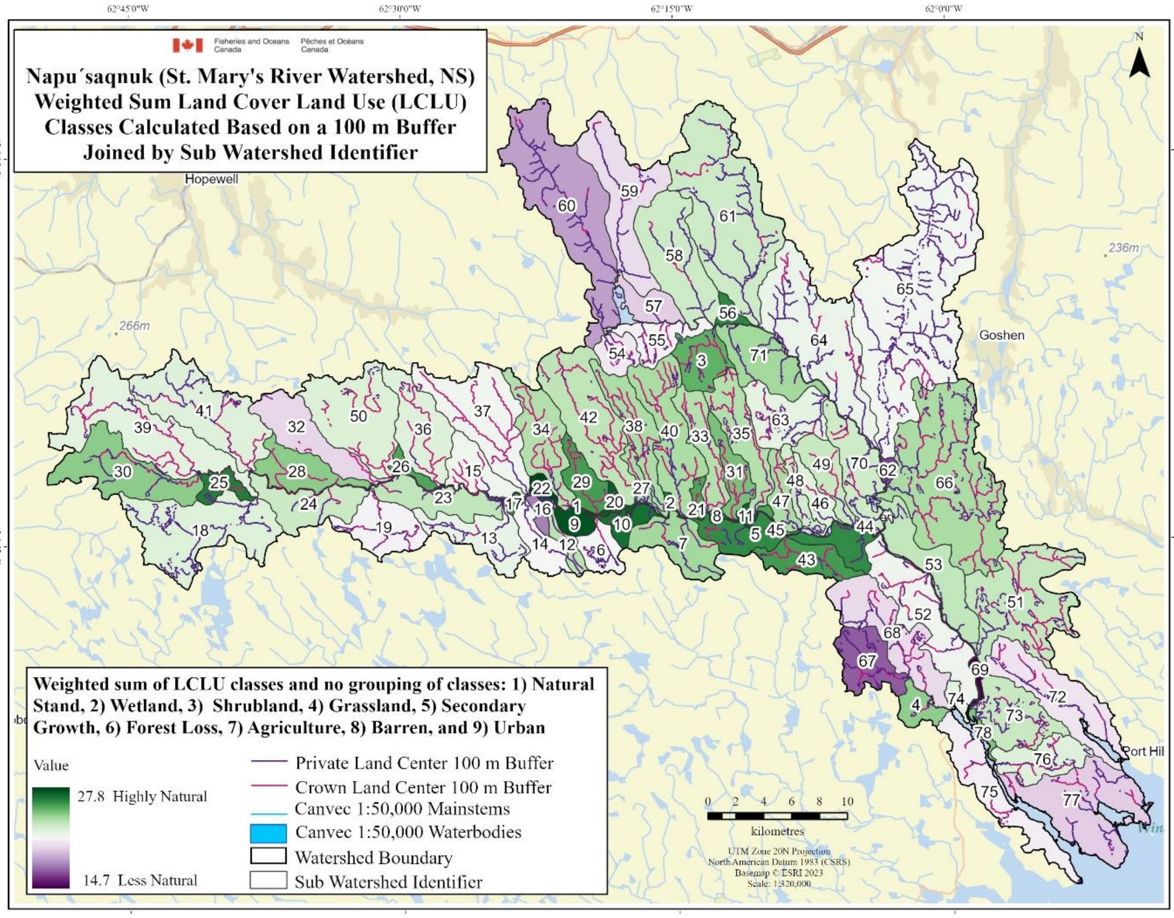

Figure 10. *Results of the weighted sum and ranking 1-9 using the classified land cover land use classified raster clipped to and calculated based on a 100 m riparian fixed-width buffer. Results determined the proportion of each land cover class within the fixed buffer and each sub watershed. Classes were ranked from 1-9 where 1 was the most natural and 9 was least natural. Results were based on a weighting of the ranking criteria from 0-100 (see methods section 2.6, Table 8). Numbers within the map represent the sub watershed ID.*

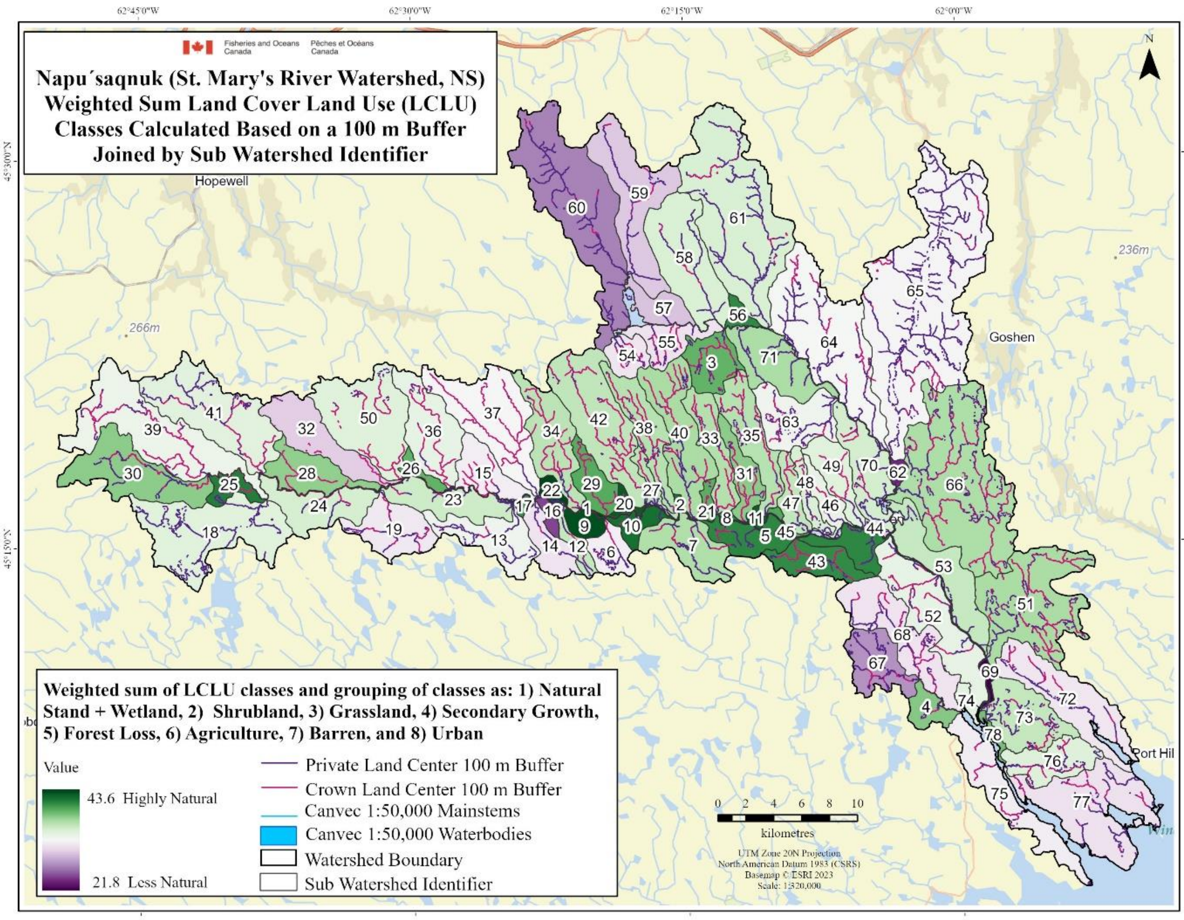

Figure 11. *Results of the weighted sum and ranking 1-8 using the classified land cover land use classified raster clipped to and calculated based on a 100 m riparian fixed-width buffer. Results determined the proportion of each land cover class within the fixed buffer and each sub watershed. Classes were ranked from 1-8: 1 was the most natural and 8 was least natural. Results were based on a weighting of the ranking criteria from 0-100 (see methods section 2.6, Table 9). Numbers within the map represent the sub watershed ID.*

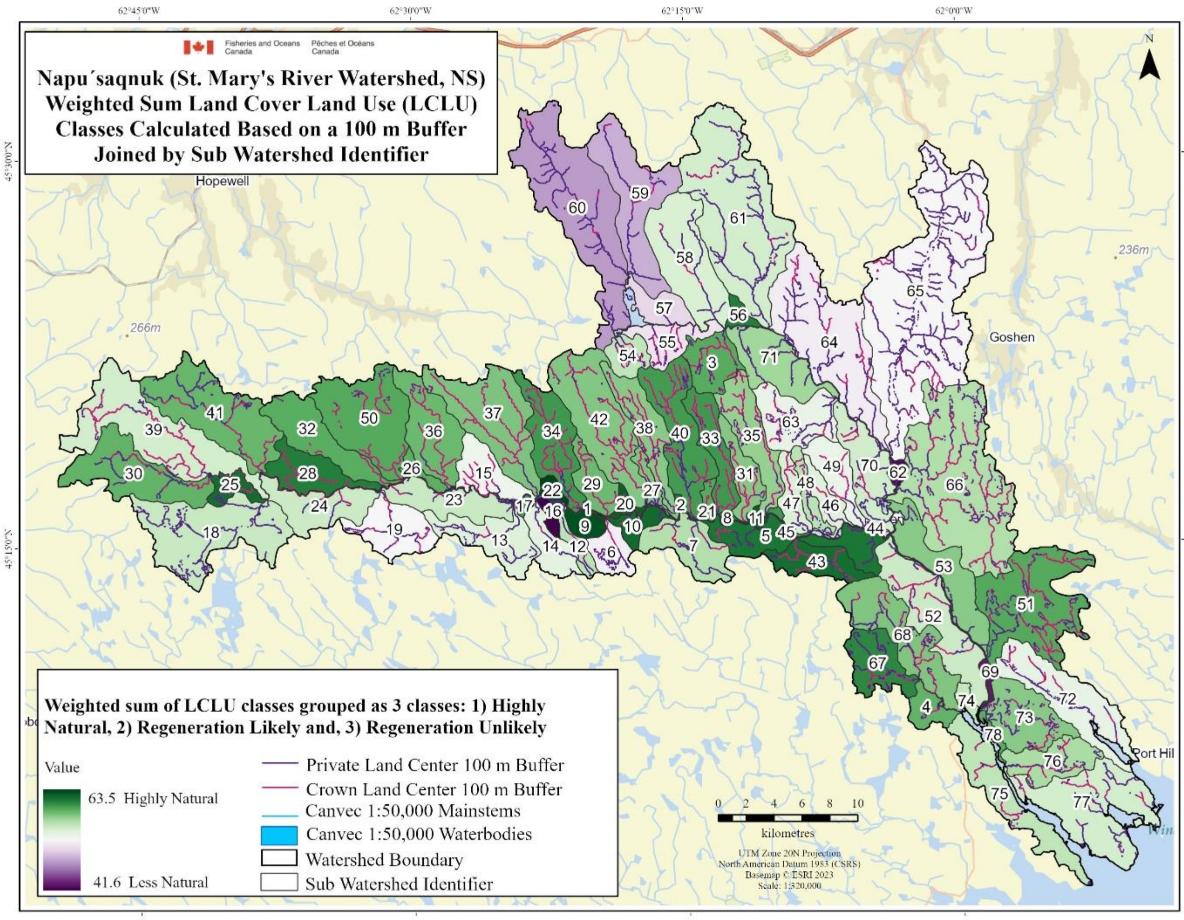

Figure 12. *Results of the weighted sum and ranking 1-3 using the classified land cover land use classified raster clipped to and calculated based on a 100 m riparian fixed-width buffer. Results determined the proportion of each land cover class within the fixed buffer and each sub watershed. Classes were ranked from 1-3: 1 was the most natural and 3 was least natural. Results were based on a weighting of the ranking criteria from 0-100 (see methods section 2.6, Table 10). Numbers within the map represent the sub watershed ID.*

Using a 100 m riparian buffer, the class with the greatest proportion of area (m^2) within a sub watershed among all classes identified in the LCLU map and using each ranking system was determined. Natural stand was the class with the greatest proportion of LCLU among all ranking systems using a 100 m riparian buffer for each sub watershed (Appendix D).

4. Discussion & Conclusion

Human land-use activities that occur near watercourses and waterbodies play a critical role in the overall health, function, and biodiversity of the aquatic environment (Albertson et al. 2018; Kanno & Beazley 2004; Stoffyn-Egli & Duinker 2013). Riparian zones serve as an interface between aquatic and terrestrial habitats and are sensitive to LCLU changes. LCLU activities that occur within the riparian zone may have negative cascading effects on aquatic habitats and the species that live within them. Understanding the types of LCLU that occur within an area provides a means to assess current riparian buffer regulations, identify potential risks to species and associated habitat, and identify areas that may benefit from proactive protection.

The results of this work demonstrate that the St. Mary’s River watershed is very natural. Very little disturbance was found throughout the watershed from urban and agricultural classes. Natural stand was found to be the dominant class occurring in the north and western regions where crown land was present. Some areas of secondary growth on private land occurred near agriculture and are likely regenerating crops. Within the St. Mary's River watershed, the majority of disturbance occurred from the forest loss LCLU class due to silvicultural practices, clear cuts, and partial clear cuts, as observed by the NSFI layer. Furthermore, agriculture classes occurred more on private land that was located along the main stem and tributaries within the watershed. Forest loss and secondary growth occurred more in areas of crown land compared to private land. We hypothesize that this may be a result of tree plantations or harvesting for forestry purposes as observed in the NSFI and CLDFHD layers.

Validation points used for LCLU raster 1 did not include the detailed LCLU information contained in the NS Forest Inventory, and instead were assembled from the results of other classified land cover maps produced using different satellites/sensors. A limitation of this approach was the different spatial resolution and image capture dates associated with the validation land cover products in comparison with the Sentinel-2A satellite image used in this study. Additional uncertainty should be considered when using and reviewing the results generated in the study as validation points used for training and testing required significant re-classification and verification against the RGB Sentinel-2A image before classification. Reclassification of validation points was time intensive given the considerable number of points used. Technicians may consider further reducing the number of validation points used (e.g., minimum of 10 - 30 times the number of bands depending on the classifier method) to decrease processing time and compare accuracies (Li et al. 2014).

The 2019 classified raster achieved a lower overall accuracy (84.4%) compared to both the AAFC in 2021 (87.94%) and NRCan classified Land Cover 2020 (86.9%) maps. However, the reclassified raster achieved a higher accuracy (90.0%) compared to the NRCan and AAFC classifications. It is possible that the initial classified raster (LCLU raster 1) obtained a slightly lower accuracy compared to the AAFC and NRCan due to the large number of validation points used for training and testing. While we try to examine and validate every point it is possible that not every single point was correctly classified as there were over 26,000 points. This was observed in the accuracy assessment where some areas identified as urban (secondary roads) yet the image demonstrated forest had started to regenerate and the secondary roads had become less easily identified causing decreases in accuracies. These errors were often misclassified as forested or shrubland LCLU classes. Consequently, some inaccuracies occurred due to too few numbers of validation points for some classes such as shrubland, barren, grassland, and wetland. Shrubland and grassland were often misclassified with agriculture while barren was often misclassified with roads. Barren and urban classes are likely to be misclassified as they are often flat and hard bare earth surfaces that are highly reflective. Similarly, pixel reflectance values of low vegetation associated with shrubland and grassland are very similar to those associated with agriculture. While the final reclassified raster included agriculture LCLU on crown land (0.57% of crown land LCLU within 300 m fixed width buffer), one can assume these are misclassified pixels as agricultural land use is likely limited to private land. Furthermore, errors were identified in select areas of the watershed classified as agriculture following discussions with the provincial Department of Agriculture (NSDA). Future iterations of LCLU classification using this methodology could be improved by accounting for land ownership type (i.e., crown versus private), and by incorporating more field validation data on these specific LCLU types.

Validation points used in the reclassified raster (LCLU 2) incorporated more detailed information on LCLU offered through the NS Forest Inventory dataset, which may have increased accuracy. However, the majority of the forest inventory data available in the St. Mary's River watershed is based on aerial photography collected between 2007 and 2008, compared with the more recent 2019 satellite image used for this study. Obtaining more recent field data to validate the analysis would provide more descriptive knowledge on forest loss and disturbance within a region. Currently the NSFI data is the only validation data that provides descriptive attributes on forest loss such as clear cut, partial clear cut, burn, wind throw, etc. Other available data layers such as the Hansen Global Forest Loss (Hansen et al. 2013) and the CLDFHD (used in this study) only provide information on the year that forest loss occurred. By identifying the reason for forest loss, one can obtain informative results on the types of LCLU activities and potential risks to riparian and aquatic habitats. This knowledge may identify or rank areas based on sensitivity to disturbance in addition to ranking LCLU class alone, and identify whether change to landscapes are a result of natural or anthropogenic impacts. In Nova Scotia, natural events such as Hurricane Dorian (2019) and post-tropical storm Fiona (2022) have left drastic changes in forested habitat and likely riparian habitat. These changes may only be observable by comparing satellite images and conducting change detection analysis. Obtaining recent validation data and comparing several satellite images over time together would contribute to accurate validation for classified LCLU maps, particularly for forest loss and secondary growth. While limited on the ground field validation data was available for this work, the LCLU maps generated by this study provide relatively high resolution (10 m) baseline information required to examine LCLU within riparian habitat to identify areas where disturbance and/or alterations to riparian habitat may exist.

To date, the greatest resolution of classified LCLU maps across Canada is 30 m and is generated on a yearly basis (i.e., AAFC dataset) or every 5 years (i.e., NRCan dataset). However, LCLU products available may not adequately capture small scale changes due to its coarse resolution. High resolution imagery offers a greater spatial detail with more bands and therefore greater quantities of information that can be used to increase the accuracy of classification compared to coarser resolution images such as those obtained by Landsat (Fauvel et al. 2012; Lacelle & Shi 2021; Kamenova & Dimitrov 2021; Parker & Lee 2016). This study contributed robust and simple methods to generate fine-scale (10 m) classified LCLU maps that may be applied to examine riparian analysis on a watershed-to-watershed scale and may be used to classify other watersheds in the Maritimes region. Using these methods, technicians and researchers may generate fine scale LCLU maps as they see fit (e.g., shorter temporal scales, between seasons, between months, or on specific dates). Methods outlined in this study are replicable and may be refined by researchers to examine LCLU changes to habitats. Geoprocessing tools used to classify this watershed are robust enough to be automated using Python scripts, with the exception of image download, cloud removal, and validating training and testing points before classification. Moreover, scripts generated in RStudio can aid to decrease, assemble, and combine multiple validation datasets together and automate error matrices to determine the accuracy of classifications. Overall, this study provided a comparative analysis on various fixed-width buffer sizes within the St. Mary's River watershed to complement literature reviews and examine LCLU classes against current regulations in Nova Scotia.

Riparian LCLU analysis can help fill knowledge gaps required to identify sensitive areas and determine the quality of aquatic habitat. Similar riparian spatial analysis and LCLU classified maps have been used to characterize fish habitat (Bachiller-Jareno et al. 2019; Jones et al. 2006; Kuiper et al. 2022; Tompalski et al. 2017), conduct threat assessments of riparian areas (Coleshill & Watt 2017), determine suitable locations for riparian buffers by sub watershed (Budlong 2004), conduct assessments for riparian buffer zone by stream order among basins and ecoregions (Mary-Lauyé et al. 2022), assess the health and vulnerability of watersheds (Roth et al., 2020) and examine exposure based assessments and vulnerability from land-use threats (France & Pardy 2018).

This study faced some limitations including obtaining complete coverage of the study area using the most recent satellite imagery data. To complete the analysis using the most up to date image data, we attempted to use open-source high resolution satellite images captured post-Hurricane Fiona (after September 23, 2022). However, the Sentinel 2 sensor did not consistently capture full coverage of the pre-planned tile footprint. As a result, we could not find usable images captured post-Hurricane Fiona that could be mosaicked together. The 2019 satellite image still provides a means to classify LCLU within the SMRW where this data together with forest disturbance and regeneration (secondary growth), has not previously been mapped. We recommend that our study is replicated using high resolution satellite imagery that has been captured since Hurricane Fiona and using images captured within the same season. Future work may consider purchasing high resolution imagery with a more frequent re-visit time such as World View 2, World View 3, or Pléiades. Researchers may also consider the use of other image collection applications such as UAVs, and aerial photography.

One limitation for this study exists within the validation data. Validation points used to guide classification in this study were not conducted using true on the ground field validation and therefore there is a need to build additional uncertainty into the interpretation of these analyses. While classification products are readily available from NRCan, AAFC, and NCC, validation data used by these organizations to generate these products are not readily accessible. In many cases validation sources used by organizations are created from scanning satellite imagery or in the case of the AAFC, field validation data is collected. Obtaining access to on the ground field validation would be useful to improve and validate classification accuracy as having access to only final classified products means that our accuracy is limited to the accuracy achieved by input data and therefore requires careful reclassification. This limitation restricted our ability in automating classification across other watersheds. This limitation, however, can be overcome by cleaning and reclassifying validation data. Results of this study are still valid as they provide an overall high accuracy compared to coarser Landsat derived products generated by the AAFC and NRCan. Although data may not be true on the ground field validation, validation points used in training and testing were assessed individually against the RGB satellite image prior to classification and therefore should accurately validate and reflect LCLU classes within the St. Mary's River watershed.

Another limitation of this study exists within the classifier method. Due to the nature of using a pixel-based supervised SVM classification approach, the resulting LCLU maps produced a noisy result where individual or small groups of pixels are scattered or appearing out of place. For example, several areas of the agriculture class may appear outside of a clearly defined crop outline. LCLU classification may be improved using an unsupervised or supervised Object Based Image Analysis (OBIA) method to classify data. Previous studies have found that applying an OBIA approach to original bands, without band indexes or ancillary data, yields greater (87-88%) overall accuracy using Sentinel-2 compared to Landsat 8 (Sánchez-Espinosa & Schröder 2019). Alternatively, researchers may need to develop and refine object and segmentation parameters to reflect threshold sizes of the classes they wish to identify. Using the OBIA method parameters may need to be refined at an individual watershed scale.

Future work may consider using remote sensing software such as PCI Geomatica, ENVI, or ECognition where lookup tables can be generated to drive pixel-based image classification. Generating lookup tables can help to automate classification and decrease processing time required to classify large areas and examine landscape changes within shorter time frames. Platforms such as Google Earth Engine handle multi-temporal mosaics, cloud cover, and footprint cover well, however, the St. Mary's River watershed was too large for this platform.

The classified LCLU map generated in this project may be used in species distribution and/or habitat suitability modelling by providing information on riparian cover that can help inform shading, bank stability, filtration and infiltration within the buffer zone. This work could be further developed through the incorporation of LiDAR-derived canopy height models to derive metrics of canopy shading in riparian areas (Kuiper et al. 2022; Tompalski et al. 2017). Furthermore, imagery paired with the Nova Scotia Forest Inventory layer can be used to further estimate and examine the percent of crown cover for broad leaf tree species in examining shading which is critical for maintaining natural variation in water temperature. Information on forest type and or height can also be used to calculate a riparian score and help fill data gaps that exist within regulatory monitoring such as the Canadian Aquatic Biomonitoring Network (CABIN) and may be embedded within a suitability and/or species distribution model.

There is no one-size fits all approach in designing riparian fixed-width buffers. Rideout et al. (2012) suggest considering what ecological functions or habitat components each parameter contributes to or is influenced by, and where within the riparian zone is the most sensitive to disturbance. Standardized methods to classify habitats at the watershed or regional scale would be useful for consistency and comparing accuracies, yet this outcome requires access to recent on the ground field validation, a standardized method to reclassify validation data, and/or a standard method to generate validation data across images. Furthermore, reviewing historical or longer-term changes across buffer sizes may help to better understand and compare the performance of different buffer width management measures and the impacts to aquatic ecosystems (Dey et al. 2021). This report provided an example of robust methods to classify satellite imagery and analyze results according to various fixed-width buffers, land ownership, and identify areas that may benefit from proactive protection. LCLU information can help direct restoration planning by identifying areas that are more degraded but where regeneration is possible. Information of LCLU activities should be coupled with biological information on critical areas for aquatic species to help assess risk and inform protection measures. The methodology and results outlined in this report can help to inform riparian management approaches to protect fish and fish habitat in the St. Mary’s River watershed, and beyond. With continued data collection and analyses, this work can also set the foundation to support long-term scientific and compliance monitoring.

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Appendix A – Validation and Class Codes

Table A1. *Reclassification of the validation points assembled and used to classify the St. Mary's River watershed Nova Scotia, Canada. Validation points were then reduced to 1000 points per class and split into training (80%) and testing (20%) datasets.*

Original dataset	Land Use Reclass	Class/ FOR-NON Code	Class Name	Description by	Validation Points Per Class
AAFC	Agriculture	194	Nursery	Nursery	27
	Agriculture	192	Sod	Sod	1,686
	Agriculture	182	Blueberry	Blueberry	33,807
	Agriculture	158	Soybeans	Soybeans	1,280
	Agriculture	147	Corn	Corn	10,521
	Agriculture	122	Pasture/forages	Periodically cultivated. Includes tame grasses and other perennial crops such as alfalfa and clover grown alone or as mixtures for hay, pasture or seed.	83,288
	Grassland	110	Grassland	Predominantly native grasses and other herbaceous vegetation, may include some shrubland cover.	60,082
	Urban	34	Urban/developed	Land that predominantly built-up or developed and vegetation associated with these land covers. This includes road surfaces, railway surfaces, buildings and paved surfaces, urban areas, industrial sites, mine structures, golf courses, etc.	175,792
	Barren	30	Exposed land/Barren	Land that is predominately non-vegetated and non-developed. Includes: glacier, rock, sediments, burned areas, rubble, mines, other naturally occurring non-vegetated surfaces. Excludes fallow agriculture.	129,987
NRCan	Grassland	10	Temperate or sub-polar Grassland	Temperate or sub-polar grassland	1,015,111
	Coniferous	1	Temperate or sub-polar needleleaf forest	Temperate or sub-polar needleleaf forest	4,320,910
	Mixedwood	6	Mixed forest	Mixed forest	4,197,120
	Urban	17	Urban and built-up	Urban and built-up	284,486
	Wetland	14	Wetland	Wetland	24,075

Table A1 (continued). *Reclassification of the validation points assembled and used to classify the St. Mary's River watershed Nova Scotia, Canada. Validation points were then reduced to 1000 points per class and split into training (80%) and testing (20%) datasets.*

Original dataset	**Land Use Reclass**	**Class/ FOR-NON Code**	**Class Name**	**Description by**	**Validation Points Per Class**
	Deciduous	5	Temperate or sub-polar broadleaf deciduous forest	Temperate or sub-polar broadleaf deciduous forest	4,835,441
	Shrubland	8	Temperate or sub-polar Shrubland	Temperate or sub-polar shrubland	1,178
	Barren	16	Barren Lands	Barren Lands	667
	Agriculture	15	Cropland	Cropland	136,606
NSTD	Urban	NA	Road	A vector file containing all the roads in Nova Scotia	374,066
NSFI	Natural Stand	0	Natural Stand	Any forested stand which has not been treated silviculturally and does not qualify under clear cut, partial cut, burn, old field, wind throw, alders, brush or dead categories.	6,287,490
	Secondary Growth	2	Burn	Any stand that has been destroyed by fire leaving less than 25% crown closure. In cases of partial burn, the remaining live stand is to be categorized and not classed as burn.	174
	Secondary Growth	5	Old field	Any field that has an indication of merchantable tree species growing in with less than 25% crown closure. All normal attributes are assigned to existing commercial tree material as the main story.	20,685
	Secondary Growth	6	Wind throw	Any stand where more than 25% of the trees have been pushed over to more than 45 degrees from the vertical by wind action. All normal attributes are assigned to live tree material as the main story.	14,345
	Secondary Growth	1	Treated	Treatment not classified, an area where silviculture activity has occurred, but the actual treatment is not identified in field data from other Department programs. This treatment excludes stands that are defined by other forest codes, such as plantations, Christmas trees, sugar bush, etc.	286,219

Table A1 (continued). *Reclassification of the validation points assembled and used to classify the St. Mary's River watershed Nova Scotia, Canada. Validation points were then reduced to 1000 points per class and split into training (80%) and testing (20%) datasets.*

Original dataset	**Land Use Reclass**	**Class/ FOR-NON Code**	**Class Name**	**Description by**	**Validation Points Per Class**
	Secondary Growth	12	Treated stand	Treatment classified-an area where silviculture activity has occurred, and the actual treatment has been identified primarily by field data from other Department programs. This treatment excludes stands that are defined by other forest codes, such as plantations, Christmas trees, sugar bush etc.	204,866
	Secondary Growth	60	Clear cut	Any stand that has been completely cut and any residuals make up less than 25% crown closure and with little or no indication of regeneration. Site values are retained. Residual live commercial material is described as the second story.	1,151,463
	Secondary Growth	61	Partial depletion verified	Any stand that has been cut and residuals make up 25% or more of the crown closure on the site. Site values are retained.	124,604
CLDFHD	Forest Loss	2011	2011	Forest harvest disturbance	78,995
	Forest Loss	2012	2012	Forest harvest disturbance	88,075
	Forest Loss	2013	2013	Forest harvest disturbance	106,317
	Forest Loss	2014	2014	Forest harvest disturbance	78,098
	Forest Loss	2015	2015	Forest harvest disturbance	97,213
	Forest Loss	2016	2016	Forest harvest disturbance	123,155
	Forest Loss	2017	2017	Forest harvest disturbance	134,182
	Forest Loss	2018	2018	Forest harvest disturbance	135,738
	Forest Loss	2019	2019	Forest harvest disturbance	95,379
Total					**24,713,128**

Appendix B – Data cleaning and pre-processing

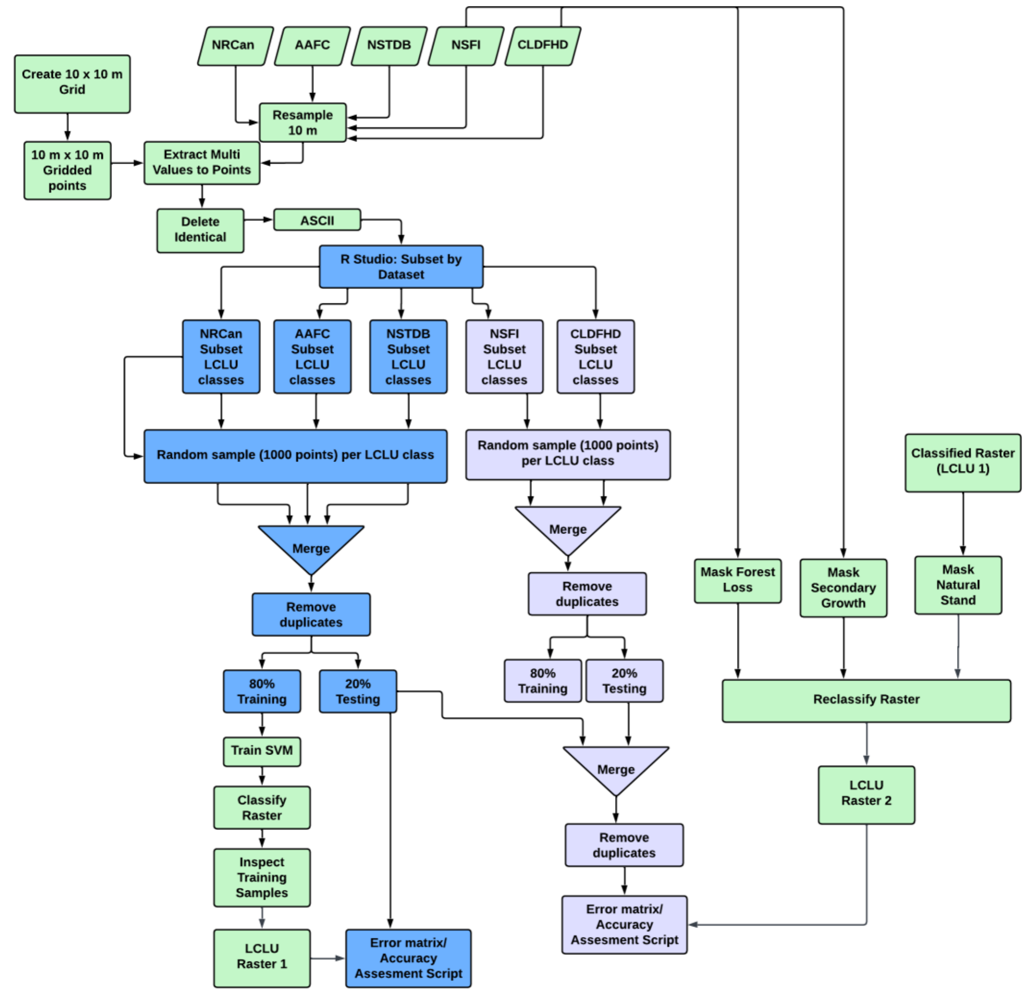

Figure B1. *Data cleaning and classification process for the supervised support vector LCLU classification for the St. Mary's River watershed. Boxes in green were performed in Arc GIS Pro (v. 2.8), boxes in blue and light blue were performed in RStudio (v. 4.2.2). Boxes in darker blue represent data and processes for the classified raster while boxes in light blue represent data and processes used in the reclassified raster. Note all validation data must be checked against the desired image.*

Appendix C – Fixed-width Riparian Buffers (estuary coastline)

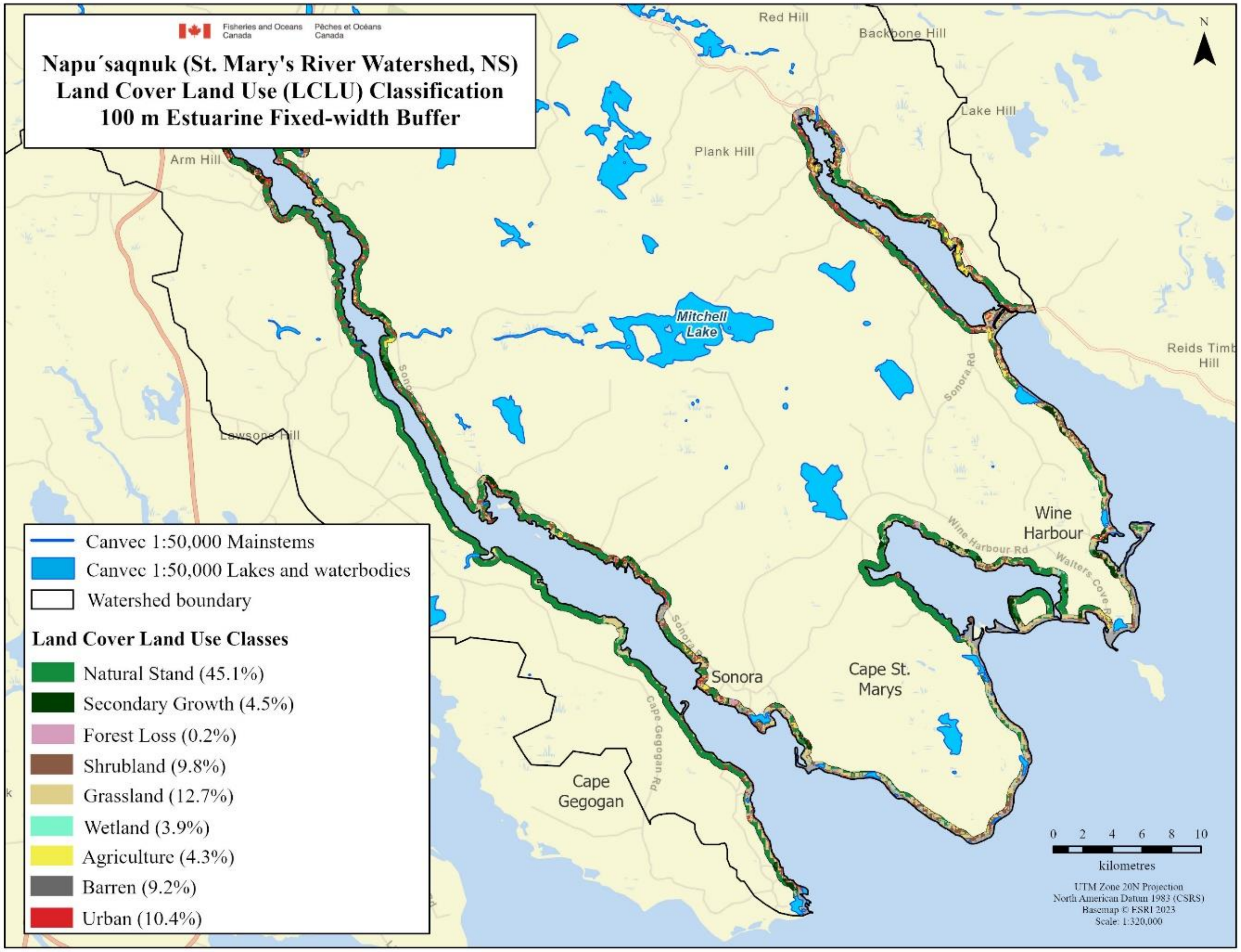

Figure C1. *Land cover land use classification of a zoomed in version of the 100 m Fixed width riparian buffer along the estuary coastline within the St. Mary's River watershed. Scale 1:28,000.*

Appendix D – Proportion of LCLU Class per sub watershed ID (100 m riparian buffer)

Table D1. *LCLU class distribution by sub watershed using the 100m riparian buffer zone & 9 classes.*

Sub watershed			Sub watershed Percent (%) Distribution								
Rank			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
ID	**Area (km^2)**	**LCLU Class Area (km^2)**	**Natural Stand**	**Wetland**	**Second. Growth**	**Shrubland**	**Forest Loss**	**Grassland**	**Agriculture**	**Barren**	**Urban**
1	0.58	3.68	98.81	0.03	0.94	0.01	0.00	0.09	0.00	0.00	0.12
2	0.80	0.73	94.10	0.09	0.00	0.65	0.00	0.31	0.01	0.00	4.84
3	13.12	3.69	82.33	2.78	7.99	1.23	0.00	2.65	0.53	0.08	2.41
4	6.88	1.84	77.04	4.78	8.73	1.66	0.95	4.46	0.18	0.04	2.17
5	20.52	6.89	88.12	2.30	3.70	1.42	0.24	2.23	0.75	0.01	1.24
6	8.53	1.77	62.45	2.95	13.52	2.55	6.85	4.61	0.91	0.52	5.65
7	17.99	5.01	76.01	1.84	7.43	1.20	9.37	2.40	0.19	0.00	1.54
8	0.86	0.95	90.91	0.29	2.50	1.77	0.00	0.53	1.15	0.03	2.82
9	4.51	0.99	97.13	0.59	0.00	0.13	0.00	0.15	0.09	0.00	1.92
10	5.61	3.78	93.12	0.42	1.68	0.98	0.00	0.97	0.75	0.01	2.07
11	1.33	2.22	95.50	0.13	0.00	0.66	0.13	0.57	0.95	0.00	2.07
12	4.71	1.94	74.80	1.65	3.33	1.37	11.56	3.30	0.56	0.07	3.36
13	18.67	3.85	65.77	3.07	6.77	3.42	10.86	5.34	1.04	0.20	3.53
14	10.41	1.58	61.94	1.58	10.53	3.72	8.57	9.19	0.96	0.04	3.48
15	13.20	3.15	63.90	0.91	15.99	3.57	2.84	6.60	0.85	0.08	5.26
16	2.74	0.21	41.70	1.27	26.35	3.47	14.04	1.26	2.07	0.05	9.80
17	1.19	1.39	89.76	0.41	1.77	0.97	0.00	0.55	0.37	0.25	5.92
18	43.38	7.58	69.78	2.82	5.28	3.35	6.47	4.90	1.00	0.63	5.77
19	18.11	3.11	61.09	3.19	11.86	2.19	8.98	6.66	0.74	0.19	5.10
20	2.35	4.50	95.69	0.04	1.91	0.34	0.92	0.22	0.20	0.01	0.68
21	2.54	1.18	83.84	1.25	9.53	1.12	0.10	2.46	0.50	0.01	1.19
22	2.66	4.09	98.45	0.11	0.63	0.30	0.00	0.14	0.16	0.00	0.21
23	16.66	4.11	73.99	1.01	8.10	3.21	3.40	2.66	1.95	0.47	5.21
24	18.27	2.58	72.84	1.39	7.40	3.94	4.19	2.58	0.50	0.35	6.80
25	5.71	5.73	91.61	0.41	0.52	1.63	0.98	1.57	0.75	0.24	2.31
26	3.28	1.03	84.10	0.60	9.21	1.71	0.00	1.99	0.52	0.00	1.88
27	4.13	2.59	76.73	0.59	6.95	1.67	2.09	7.41	1.07	0.04	3.46
28	15.40	3.78	80.96	1.30	0.05	2.21	3.56	9.02	0.55	0.03	2.32
29	9.96	5.44	84.56	0.62	10.38	0.26	1.97	1.18	0.47	0.00	0.55
30	28.93	5.07	78.58	3.32	4.73	2.37	4.08	3.93	0.92	0.02	2.04
31	10.29	3.97	80.36	1.14	5.42	1.02	7.92	2.57	0.29	0.02	1.27
32	21.03	4.06	58.15	3.43	1.46	6.10	4.46	21.66	0.83	0.06	3.85
33	14.45	4.78	73.80	3.96	6.79	1.83	1.05	11.00	0.59	0.00	0.97
34	22.21	5.96	74.47	2.23	6.59	3.72	0.97	10.08	0.39	0.02	1.53
35	19.29	6.44	72.15	4.68	10.75	1.85	3.16	5.56	0.47	0.04	1.33
36	23.46	4.17	68.74	2.03	6.49	2.85	3.27	13.88	0.31	0.04	2.39

Table D1 (continued). *LCLU class distribution by sub watershed using the 100m riparian buffer zone & 9 classes.*

Sub watershed			**Sub watershed Percent (%) Distribution**								
Rank			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
ID	**Area (km^2)**	**LCLU Class Area (km^2)**	**Natural Stand**	**Wetland**	**Second. Growth**	**Shrubland**	**Forest Loss**	**Grassland**	**Agriculture**	**Barren**	**Urban**
37	35.64	6.63	65.79	2.18	3.05	4.11	5.79	14.59	0.78	0.05	3.65
38	17.43	6.07	74.57	2.50	11.38	1.70	0.34	6.53	0.23	0.00	2.74
39	45.97	8.30	66.25	2.52	9.61	3.37	7.74	6.72	0.97	0.14	2.69
40	28.82	8.87	76.01	3.33	5.38	1.66	1.40	9.57	0.54	0.01	2.09
41	38.89	8.22	68.73	3.16	5.57	3.78	2.36	12.41	1.03	0.08	2.90
42	37.25	7.52	71.96	3.95	10.04	1.22	2.12	8.40	0.15	0.07	2.09
43	13.04	3.58	85.21	4.60	4.01	0.96	0.84	3.68	0.13	0.03	0.55
44	0.93	0.76	61.42	2.04	4.04	7.54	0.00	2.67	14.46	0.51	7.31
45	1.54	0.63	86.88	0.57	1.58	3.53	0.00	1.03	4.22	0.00	2.19
46	6.67	1.42	70.60	0.57	4.14	3.24	6.94	4.28	4.98	0.30	4.95
47	8.01	2.66	74.12	0.84	14.98	1.65	1.76	1.51	3.12	0.01	2.00
48	5.96	1.82	70.52	2.40	7.44	2.80	7.53	5.54	0.53	0.08	3.15
49	12.14	2.51	70.13	0.55	15.40	1.33	5.15	3.10	1.94	0.03	2.37
50	35.90	6.70	69.37	2.94	5.17	3.79	2.19	13.16	0.33	0.11	2.93
51	45.53	10.81	70.07	9.00	6.13	1.69	2.49	8.27	0.90	0.18	1.28
52	30.71	6.04	64.05	7.01	6.97	3.90	1.63	6.49	5.99	0.31	3.64
53	23.13	5.16	75.50	1.36	0.36	5.91	1.22	4.94	7.69	0.44	2.58
54	7.60	2.11	57.45	6.14	10.39	3.49	6.98	13.14	0.26	0.03	2.12
55	11.17	4.30	61.25	2.26	10.39	2.07	13.66	4.54	0.84	0.04	4.94
56	3.10	1.50	90.36	0.46	1.45	1.48	0.06	1.68	2.58	0.02	1.91
57	8.78	2.21	59.62	1.41	3.60	7.82	2.24	3.98	12.04	0.81	8.49
58	33.06	4.93	72.56	0.73	9.00	3.22	1.93	3.23	4.62	0.09	4.63
59	35.47	4.41	58.75	1.07	13.24	2.80	5.78	3.61	9.28	0.19	5.28
60	59.38	8.62	51.13	0.93	10.03	6.36	5.29	6.93	10.55	0.94	7.85
61	71.28	11.87	72.14	1.33	9.24	3.36	2.54	3.21	2.94	0.10	5.15
62	2.00	1.01	44.99	1.10	1.47	9.39	0.44	2.31	33.99	0.73	5.58
63	20.14	5.34	66.10	2.36	11.41	2.33	7.13	4.90	2.35	0.14	3.27
64	53.67	12.48	66.71	1.16	11.30	3.66	1.68	2.37	7.68	0.99	4.45
65	114.08	26.38	66.11	1.75	8.42	4.93	1.95	2.81	6.23	0.77	7.03
66	77.67	18.13	74.52	3.63	10.50	1.98	3.08	2.28	0.90	0.21	2.90
67	16.25	4.25	36.00	17.50	5.11	2.11	2.29	36.41	0.06	0.01	0.52
68	29.38	6.95	53.11	10.13	12.08	2.98	0.75	19.37	0.24	0.21	1.14
69	1.84	0.51	38.93	3.01	0.00	10.10	0.00	7.48	9.16	19.09	12.24
70	19.71	5.26	73.14	1.89	5.13	3.81	1.54	2.64	6.37	0.40	5.10
71	21.23	6.45	78.72	1.18	3.45	2.51	2.33	2.92	5.54	0.32	3.05
72	30.83	5.47	60.12	5.59	8.60	5.50	0.11	7.03	2.81	2.18	8.06
73	21.44	4.28	70.98	4.88	8.85	2.25	0.30	7.78	0.74	2.21	2.01

Table D1 (continued). *LCLU class distribution by sub watershed using the 100m riparian buffer zone & 9 classes.*

Sub watershed			Sub watershed Percent (%) Distribution								
Rank			1	2	3	4	5	6	7	8	9
ID	Area (km^2)	LCLU Class Area (km^2)	Natural Stand	Wetland	Second. Growth	Shrubland	Forest Loss	Grassland	Agriculture	Barren	Urban
74	2.65	0.53	71.65	2.08	0.00	7.00	0.00	3.23	6.74	0.82	8.48
75	23.94	3.33	61.23	4.77	10.33	2.38	0.00	13.75	0.74	2.10	4.70
76	15.69	3.41	65.12	6.32	12.80	1.50	2.68	9.53	0.57	0.13	1.34
77	40.55	8.19	53.07	10.98	9.93	3.61	0.72	12.73	0.97	4.87	3.11
78	2.14	2.46	83.48	1.58	0.66	2.83	0.14	2.55	1.72	2.71	4.32

Table D2. *LCLU class distribution by sub watershed using the 100m riparian buffer zone and 8 classes.*

Sub watershed			Sub watershed Percent (%) Distribution							
Rank			1	2	3	4	5	6	7	8
ID	Area (km^2)	LCLU Class Area (km^2)	Natural Stand & Wetland	Second. Growth	Shrubland	Forest Loss	Grassland	Agriculture	Barren	Urban
1	0.58	3.68	98.84	0.94	0.01	0.00	0.09	0.00	0.00	0.12
2	0.80	0.73	94.19	0.00	0.65	0.00	0.31	0.01	0.00	4.84
3	13.12	3.69	85.11	7.99	1.23	0.00	2.65	0.53	0.08	2.41
4	6.88	1.84	81.82	8.73	1.66	0.95	4.46	0.18	0.04	2.17
5	20.52	6.89	90.42	3.70	1.42	0.24	2.23	0.75	0.01	1.24
6	8.53	1.77	65.40	13.52	2.55	6.85	4.61	0.91	0.52	5.65
7	17.99	5.01	77.85	7.43	1.20	9.37	2.40	0.19	0.00	1.54
8	0.86	0.95	91.20	2.50	1.77	0.00	0.53	1.15	0.03	2.82
9	4.51	0.99	97.72	0.00	0.13	0.00	0.15	0.09	0.00	1.92
10	5.61	3.78	93.54	1.68	0.98	0.00	0.97	0.75	0.01	2.07
11	1.33	2.22	95.63	0.00	0.66	0.13	0.57	0.95	0.00	2.07
12	4.71	1.94	76.45	3.33	1.37	11.56	3.30	0.56	0.07	3.36
13	18.67	3.85	68.84	6.77	3.42	10.86	5.34	1.04	0.20	3.53
14	10.41	1.58	63.52	10.53	3.72	8.57	9.19	0.96	0.04	3.48
15	13.20	3.15	64.80	15.99	3.57	2.84	6.60	0.85	0.08	5.26
16	2.74	0.21	42.97	26.35	3.47	14.04	1.26	2.07	0.05	9.80
17	1.19	1.39	90.17	1.77	0.97	0.00	0.55	0.37	0.25	5.92
18	43.38	7.58	72.61	5.28	3.35	6.47	4.90	1.00	0.63	5.77
19	18.11	3.11	64.28	11.86	2.19	8.98	6.66	0.74	0.19	5.10
20	2.35	4.50	95.73	1.91	0.34	0.92	0.22	0.20	0.01	0.68
21	2.54	1.18	85.09	9.53	1.12	0.10	2.46	0.50	0.01	1.19
22	2.66	4.09	98.56	0.63	0.30	0.00	0.14	0.16	0.00	0.21
23	16.66	4.11	75.00	8.10	3.21	3.40	2.66	1.95	0.47	5.21

Table D2 (continued). *LCLU class distribution by sub watershed using the 100m riparian buffer zone and 8 classes.*

Sub watershed			**Sub watershed Percent (%) Distribution**							
Rank			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
ID	**Area (km^2)**	**LCLU Class Area (km^2)**	**Natural Stand & Wetland**	**Second. Growth**	**Shrubland**	**Forest Loss**	**Grassland**	**Agriculture**	**Barren**	**Urban**
24	18.27	2.58	74.23	7.40	3.94	4.19	2.58	0.50	0.35	6.80
25	5.71	5.73	92.02	0.52	1.63	0.98	1.57	0.75	0.24	2.31
26	3.28	1.03	84.70	9.21	1.71	0.00	1.99	0.52	0.00	1.88
27	4.13	2.59	77.32	6.95	1.67	2.09	7.41	1.07	0.04	3.46
28	15.40	3.78	82.26	0.05	2.21	3.56	9.02	0.55	0.03	2.32
29	9.96	5.44	85.18	10.38	0.26	1.97	1.18	0.47	0.00	0.55
30	28.93	5.07	81.90	4.73	2.37	4.08	3.93	0.92	0.02	2.04
31	10.29	3.97	81.50	5.42	1.02	7.92	2.57	0.29	0.02	1.27
32	21.03	4.06	61.58	1.46	6.10	4.46	21.66	0.83	0.06	3.85
33	14.45	4.78	77.76	6.79	1.83	1.05	11.00	0.59	0.00	0.97
34	22.21	5.96	76.70	6.59	3.72	0.97	10.08	0.39	0.02	1.53
35	19.29	6.44	76.83	10.75	1.85	3.16	5.56	0.47	0.04	1.33
36	23.46	4.17	70.78	6.49	2.85	3.27	13.88	0.31	0.04	2.39
37	35.64	6.63	67.97	3.05	4.11	5.79	14.59	0.78	0.05	3.65
38	17.43	6.07	77.07	11.38	1.70	0.34	6.53	0.23	0.00	2.74
39	45.97	8.30	68.76	9.61	3.37	7.74	6.72	0.97	0.14	2.69
40	28.82	8.87	79.35	5.38	1.66	1.40	9.57	0.54	0.01	2.09
41	38.89	8.22	71.89	5.57	3.78	2.36	12.41	1.03	0.08	2.90
42	37.25	7.52	75.91	10.04	1.22	2.12	8.40	0.15	0.07	2.09
43	13.04	3.58	89.81	4.01	0.96	0.84	3.68	0.13	0.03	0.55
44	0.93	0.76	63.46	4.04	7.54	0.00	2.67	14.46	0.51	7.31
45	1.54	0.63	87.45	1.58	3.53	0.00	1.03	4.22	0.00	2.19
46	6.67	1.42	71.18	4.14	3.24	6.94	4.28	4.98	0.30	4.95
47	8.01	2.66	74.97	14.98	1.65	1.76	1.51	3.12	0.01	2.00
48	5.96	1.82	72.92	7.44	2.80	7.53	5.54	0.53	0.08	3.15
49	12.14	2.51	70.68	15.40	1.33	5.15	3.10	1.94	0.03	2.37
50	35.90	6.70	72.31	5.17	3.79	2.19	13.16	0.33	0.11	2.93
51	45.53	10.81	79.07	6.13	1.69	2.49	8.27	0.90	0.18	1.28
52	30.71	6.04	71.07	6.97	3.90	1.63	6.49	5.99	0.31	3.64
53	23.13	5.16	76.86	0.36	5.91	1.22	4.94	7.69	0.44	2.58
54	7.60	2.11	63.59	10.39	3.49	6.98	13.14	0.26	0.03	2.12
55	11.17	4.30	63.52	10.39	2.07	13.66	4.54	0.84	0.04	4.94
56	3.10	1.50	90.82	1.45	1.48	0.06	1.68	2.58	0.02	1.91
57	8.78	2.21	61.02	3.60	7.82	2.24	3.98	12.04	0.81	8.49
58	33.06	4.93	73.29	9.00	3.22	1.93	3.23	4.62	0.09	4.63
59	35.47	4.41	59.82	13.24	2.80	5.78	3.61	9.28	0.19	5.28

Table D2 (continued). *LCLU class distribution by sub watershed using the 100m riparian buffer zone and 8 classes.*

Sub watershed			**Sub watershed Percent (%) Distribution**							
Rank			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
ID	**Area (km^2)**	**LCLU Class Area (km^2)**	**Natural Stand & Wetland**	**Second. Growth**	**Shrubland**	**Forest Loss**	**Grassland**	**Agriculture**	**Barren**	**Urban**
60	59.38	8.62	52.05	10.03	6.36	5.29	6.93	10.55	0.94	7.85
61	71.28	11.87	73.47	9.24	3.36	2.54	3.21	2.94	0.10	5.15
62	2.00	1.01	46.09	1.47	9.39	0.44	2.31	33.99	0.73	5.58
63	20.14	5.34	68.46	11.41	2.33	7.13	4.90	2.35	0.14	3.27
64	53.67	12.48	67.87	11.30	3.66	1.68	2.37	7.68	0.99	4.45
65	114.08	26.38	67.86	8.42	4.93	1.95	2.81	6.23	0.77	7.03
66	77.67	18.13	78.15	10.50	1.98	3.08	2.28	0.90	0.21	2.90
67	16.25	4.25	53.49	5.11	2.11	2.29	36.41	0.06	0.01	0.52
68	29.38	6.95	63.24	12.08	2.98	0.75	19.37	0.24	0.21	1.14
69	1.84	0.51	41.94	0.00	10.10	0.00	7.48	9.16	19.09	12.24
70	19.71	5.26	75.03	5.13	3.81	1.54	2.64	6.37	0.40	5.10
71	21.23	6.45	79.90	3.45	2.51	2.33	2.92	5.54	0.32	3.05
72	30.83	5.47	65.72	8.60	5.50	0.11	7.03	2.81	2.18	8.06
73	21.44	4.28	75.86	8.85	2.25	0.30	7.78	0.74	2.21	2.01
74	2.65	0.53	73.72	0.00	7.00	0.00	3.23	6.74	0.82	8.48
75	23.94	3.33	65.99	10.33	2.38	0.00	13.75	0.74	2.10	4.70
76	15.69	3.41	71.44	12.80	1.50	2.68	9.53	0.57	0.13	1.34
77	40.55	8.19	64.06	9.93	3.61	0.72	12.73	0.97	4.87	3.11
78	2.14	2.46	85.07	0.66	2.83	0.14	2.55	1.72	2.71	4.32

Table D3. *LCLU class distribution by sub watershed using the 100m riparian buffer zone and three classes: Highly Natural, Regeneration Likely, and Regeneration Unlikely.*

Sub watershed			**Sub watershed Percent (%) Distribution**		
Rank			**1**	**2**	**3**
ID	**Area (km^2)**	**LCLU Class Area (km^2)**	**Highly Natural:** Natural Stand, Wetland, Grassland, Shrubland	**Regeneration Likely:** Second. Growth & Forest Loss	**Regeneration Unlikely:** Agriculture, Barren, Urban
1	0.58	0.21	98.94	0.94	0.12
2	0.80	0.16	95.15	0.00	4.85
3	13.12	3.00	88.99	7.99	3.02
4	6.88	0.88	87.94	9.67	2.39
5	20.52	4.09	94.07	3.94	1.99
6	8.53	1.72	72.55	20.38	7.07
7	17.99	3.54	81.46	16.81	1.73
8	0.86	0.25	93.50	2.50	4.01

Table D3 (continued). *LCLU class distribution by sub watershed using the 100m riparian buffer zone and three classes: Highly Natural, Regeneration Likely, and Regeneration Unlikely.*

Sub watershed			**Sub watershed Percent (%) Distribution**		
Rank			**1**	**2**	**3**
ID	**Area (km^2)**	**LCLU Class Area (km^2)**	**Highly Natural:** Natural Stand, Wetland, Grassland, Shrubland	**Regeneration Likely:** Second. Growth & Forest Loss	**Regeneration Unlikely:** Agriculture, Barren, Urban
9	4.51	0.30	97.99	0.00	2.01
10	5.61	0.91	95.49	1.68	2.83
11	1.33	0.25	96.85	0.13	3.02
12	4.71	1.58	81.12	14.89	3.99
13	18.67	3.30	77.60	17.63	4.77
14	10.41	1.39	76.42	19.10	4.48
15	13.20	2.93	74.97	18.84	6.19
16	2.74	0.20	47.69	40.39	11.92
17	1.19	0.33	91.69	1.77	6.54
18	43.38	7.25	80.85	11.75	7.40
19	18.11	3.06	73.13	20.84	6.03
20	2.35	0.79	96.29	2.83	0.88
21	2.54	0.70	88.66	9.63	1.70
22	2.66	0.37	98.99	0.63	0.37
23	16.66	2.71	80.87	11.50	7.63
24	18.27	2.55	80.76	11.59	7.65
25	5.71	1.52	95.21	1.50	3.30
26	3.28	0.43	88.39	9.21	2.39
27	4.13	1.69	86.40	9.03	4.57
28	15.40	2.86	93.48	3.61	2.90
29	9.96	1.96	86.62	12.35	1.02
30	28.93	3.62	88.20	8.81	2.98
31	10.29	2.56	85.08	13.33	1.58
32	21.03	3.78	89.34	5.93	4.73
33	14.45	4.10	90.59	7.84	1.57
34	22.21	5.36	90.50	7.57	1.94
35	19.29	5.10	84.24	13.91	1.84
36	23.46	3.92	87.51	9.76	2.73
37	35.64	6.29	86.67	8.84	4.49
38	17.43	5.09	85.30	11.73	2.97
39	45.97	7.17	78.85	17.36	3.79
40	28.82	7.05	90.59	6.79	2.63
41	38.89	6.44	88.07	7.93	4.00
42	37.25	6.95	85.53	12.16	2.31

Table D3 (continued). *LCLU class distribution by sub watershed using the 100m riparian buffer zone and three classes: Highly Natural, Regeneration Likely, and Regeneration Unlikely.*

Sub watershed			**Sub watershed Percent (%) Distribution**		
Rank			**1**	**2**	**3**
ID	**Area (km^2)**	**LCLU Class Area (km^2)**	**Highly Natural:** Natural Stand, Wetland, Grassland, Shrubland	**Regeneration Likely:** Second. Growth & Forest Loss	**Regeneration Unlikely:** Agriculture, Barren, Urban
43	13.04	2.73	94.44	4.85	0.71
44	0.93	0.63	73.67	4.04	22.29
45	1.54	0.53	92.02	1.58	6.41
46	6.67	1.15	78.69	11.07	10.23
47	8.01	2.00	78.13	16.74	5.13
48	5.96	1.67	81.27	14.98	3.76
49	12.14	2.29	75.11	20.55	4.35
50	35.90	5.97	89.26	7.37	3.37
51	45.53	10.35	89.04	8.61	2.35
52	30.71	5.88	81.46	8.60	9.94
53	23.13	2.78	87.71	1.58	10.71
54	7.60	1.99	80.22	17.38	2.40
55	11.17	3.26	70.13	24.05	5.82
56	3.10	0.34	93.98	1.51	4.52
57	8.78	1.31	72.83	5.83	21.34
58	33.06	4.24	79.74	10.92	9.34
59	35.47	4.31	66.23	19.02	14.75
60	59.38	8.39	65.35	15.31	19.34
61	71.28	11.08	80.04	11.78	8.19
62	2.00	0.82	57.79	1.92	40.30
63	20.14	4.71	75.69	18.55	5.76
64	53.67	11.34	73.89	12.98	13.12
65	114.08	24.52	75.60	10.37	14.04
66	77.67	17.65	82.41	13.58	4.01
67	16.25	3.77	92.01	7.40	0.59
68	29.38	6.08	85.59	12.83	1.58
69	1.84	0.43	59.51	0.00	40.49
70	19.71	5.05	81.48	6.66	11.86
71	21.23	3.89	85.32	5.77	8.91
72	30.83	5.31	78.25	8.71	13.05
73	21.44	4.21	85.89	9.16	4.96
74	2.65	0.51	83.96	0.00	16.04
75	23.94	3.36	82.12	10.33	7.54
76	15.69	2.96	82.47	15.48	2.04
77	40.55	7.57	80.40	10.64	8.96
78	2.14	0.62	90.45	0.80	8.75

Table D4. *LCLU grouping for each version for each sub watershed using the 100m riparian buffer zone. Version 1: no grouping of classes – nine LCLU classes (1) Natural Stand, 2) Wetland 3) Grassland, 4) Shrubland, 5) Secondary Growth, 6) Forest Loss, 7) Agriculture, 8) Barren, and 9) Urban). Version 2: grouping of natural stand and wetland – LCLU eight classes (1) Natural Stand and Wetland 2) Grassland, 3) Shrubland, 4) Secondary Growth, 5) Forest Loss, 6) Agriculture, 7) Barren, and 8) Urban . Version 3: grouping LCLU classes into three categories – 1) Highly Natural, (Natural Stand, Wetland, Grassland, Shrubland), 2) Regeneration Likely (Secondary Growth, Forest Loss), and 3) Regeneration Unlikely (Agriculture, Barren, and Urban).*

			Version 1		**Version 2**		**Version 3**	
Sub watershed ID	**Area (km^2)**	**Land Cover Class Area (km^2)**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**
1	0.58	0.21	98.84	Natural Stand & Wetland	98.81	Natural Stand	98.94	Highly Natural
2	0.80	0.16	94.19	Natural Stand & Wetland	94.10	Natural Stand	95.15	Highly Natural
3	13.12	3.00	85.11	Natural Stand & Wetland	82.33	Natural Stand	88.99	Highly Natural
4	6.88	0.88	81.82	Natural Stand & Wetland	77.04	Natural Stand	87.94	Highly Natural
5	20.52	4.09	90.42	Natural Stand & Wetland	88.12	Natural Stand	94.07	Highly Natural
6	8.53	1.72	65.40	Natural Stand & Wetland	62.45	Natural Stand	72.55	Highly Natural
7	17.99	3.54	77.85	Natural Stand & Wetland	76.01	Natural Stand	81.46	Highly Natural
8	0.86	0.25	91.20	Natural Stand & Wetland	90.91	Natural Stand	93.50	Highly Natural
9	4.51	0.30	97.72	Natural Stand & Wetland	97.13	Natural Stand	97.99	Highly Natural
10	5.61	0.91	93.54	Natural Stand & Wetland	93.12	Natural Stand	95.49	Highly Natural
11	1.33	0.25	95.63	Natural Stand & Wetland	95.50	Natural Stand	96.85	Highly Natural
12	4.71	1.58	76.45	Natural Stand & Wetland	74.80	Natural Stand	81.12	Highly Natural
13	18.67	3.30	68.84	Natural Stand & Wetland	65.77	Natural Stand	77.60	Highly Natural
14	10.41	1.39	63.52	Natural Stand & Wetland	61.94	Natural Stand	76.42	Highly Natural
15	13.20	2.93	64.80	Natural Stand & Wetland	63.90	Natural Stand	74.97	Highly Natural

Table D4 (continued). *LCLU grouping for each version for each sub watershed using the 100m riparian buffer zone. Version 1: no grouping of classes – nine LCLU classes (1) Natural Stand, 2) Wetland 3) Grassland, 4) Shrubland, 5) Secondary Growth, 6) Forest Loss, 7) Agriculture, 8) Barren, and 9) Urban). Version 2: grouping of natural stand and wetland – LCLU eight classes (1) Natural Stand and Wetland 2) Grassland, 3) Shrubland, 4) Secondary Growth, 5) Forest Loss, 6) Agriculture, 7) Barren, and 8) Urban . Version 3: grouping LCLU classes into three categories – 1) Highly Natural, (Natural Stand, Wetland, Grassland, Shrubland), 2) Regeneration Likely (Secondary Growth, Forest Loss), and 3) Regeneration Unlikely (Agriculture, Barren, and Urban).*

			Version 1		Version 2		Version 3	
Sub watershed ID	**Area (km^2)**	**Land Cover Class Area (km^2)**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**
16	2.74	0.20	42.97	Natural Stand & Wetland	41.70	Natural Stand	47.69	Highly Natural
17	1.19	0.33	90.17	Natural Stand & Wetland	89.76	Natural Stand	91.69	Highly Natural
18	43.38	7.25	72.61	Natural Stand & Wetland	69.78	Natural Stand	80.85	Highly Natural
19	18.11	3.06	64.28	Natural Stand & Wetland	61.09	Natural Stand	73.13	Highly Natural
20	2.35	0.79	95.73	Natural Stand & Wetland	95.69	Natural Stand	96.29	Highly Natural
21	2.54	0.70	85.09	Natural Stand & Wetland	83.84	Natural Stand	88.66	Highly Natural
22	2.66	0.37	98.56	Natural Stand & Wetland	98.45	Natural Stand	98.99	Highly Natural
23	16.66	2.71	75.00	Natural Stand & Wetland	73.99	Natural Stand	80.87	Highly Natural
24	18.27	2.55	74.23	Natural Stand & Wetland	72.84	Natural Stand	80.76	Highly Natural
25	5.71	1.52	92.02	Natural Stand & Wetland	91.61	Natural Stand	95.21	Highly Natural
26	3.28	0.43	84.70	Natural Stand & Wetland	84.10	Natural Stand	88.39	Highly Natural
27	4.13	1.69	77.32	Natural Stand & Wetland	76.73	Natural Stand	86.40	Highly Natural
28	15.40	2.86	82.26	Natural Stand & Wetland	80.96	Natural Stand	93.48	Highly Natural
29	9.96	1.96	85.18	Natural Stand & Wetland	84.56	Natural Stand	86.62	Highly Natural

Table D4 (continued). *LCLU grouping for each version for each sub watershed using the 100m riparian buffer zone. Version 1: no grouping of classes – nine LCLU classes (1) Natural Stand, 2) Wetland 3) Grassland, 4) Shrubland, 5) Secondary Growth, 6) Forest Loss, 7) Agriculture, 8) Barren, and 9) Urban). Version 2: grouping of natural stand and wetland – LCLU eight classes (1) Natural Stand and Wetland 2) Grassland, 3) Shrubland, 4) Secondary Growth, 5) Forest Loss, 6) Agriculture, 7) Barren, and 8) Urban . Version 3: grouping LCLU classes into three categories – 1) Highly Natural, (Natural Stand, Wetland, Grassland, Shrubland), 2) Regeneration Likely (Secondary Growth, Forest Loss), and 3) Regeneration Unlikely (Agriculture, Barren, and Urban).*

			Version 1		**Version 2**		**Version 3**	
Sub watershed ID	**Area (km^2)**	**Land Cover Class Area (km^2)**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**
30	28.93	3.62	81.90	Natural Stand & Wetland	78.58	Natural Stand	88.20	Highly Natural
31	10.29	2.56	81.50	Natural Stand & Wetland	80.36	Natural Stand	85.08	Highly Natural
32	21.03	3.78	61.58	Natural Stand & Wetland	58.15	Natural Stand	89.34	Highly Natural
33	14.45	4.10	77.76	Natural Stand & Wetland	73.80	Natural Stand	90.59	Highly Natural
34	22.21	5.36	76.70	Natural Stand & Wetland	74.47	Natural Stand	90.50	Highly Natural
35	19.29	5.10	76.83	Natural Stand & Wetland	72.15	Natural Stand	84.24	Highly Natural
36	23.46	3.92	70.78	Natural Stand & Wetland	68.74	Natural Stand	87.51	Highly Natural
37	35.64	6.29	67.97	Natural Stand & Wetland	65.79	Natural Stand	86.67	Highly Natural
38	17.43	5.09	77.07	Natural Stand & Wetland	74.57	Natural Stand	85.30	Highly Natural
39	45.97	7.17	68.76	Natural Stand & Wetland	66.25	Natural Stand	78.85	Highly Natural
40	28.82	7.05	79.35	Natural Stand & Wetland	76.01	Natural Stand	90.59	Highly Natural
41	38.89	6.44	71.89	Natural Stand & Wetland	68.73	Natural Stand	88.07	Highly Natural
42	37.25	6.95	75.91	Natural Stand & Wetland	71.96	Natural Stand	85.53	Highly Natural
43	13.04	2.73	89.81	Natural Stand & Wetland	85.21	Natural Stand	94.44	Highly Natural
44	0.93	0.63	63.46	Natural Stand & Wetland	61.42	Natural Stand	73.67	Highly Natural

Table D4 (continued). *LCLU grouping for each version for each sub watershed using the 100m riparian buffer zone. Version 1: no grouping of classes – nine LCLU classes (1) Natural Stand, 2) Wetland 3) Grassland, 4) Shrubland, 5) Secondary Growth, 6) Forest Loss, 7) Agriculture, 8) Barren, and 9) Urban). Version 2: grouping of natural stand and wetland – LCLU eight classes (1) Natural Stand and Wetland 2) Grassland, 3) Shrubland, 4) Secondary Growth, 5) Forest Loss, 6) Agriculture, 7) Barren, and 8) Urban . Version 3: grouping LCLU classes into three categories – 1) Highly Natural, (Natural Stand, Wetland, Grassland, Shrubland), 2) Regeneration Likely (Secondary Growth, Forest Loss), and 3) Regeneration Unlikely (Agriculture, Barren, and Urban).*

			Version 1		**Version 2**		**Version 3**	
Sub watershed ID	**Area (km^2)**	**Land Cover Class Area (km^2)**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**
45	1.54	0.53	87.45	Natural Stand & Wetland	86.88	Natural Stand	92.02	Highly Natural
46	6.67	1.15	71.18	Natural Stand & Wetland	70.60	Natural Stand	78.69	Highly Natural
47	8.01	2.00	74.97	Natural Stand & Wetland	74.12	Natural Stand	78.13	Highly Natural
48	5.96	1.67	72.92	Natural Stand & Wetland	70.52	Natural Stand	81.27	Highly Natural
49	12.14	2.29	70.68	Natural Stand & Wetland	70.13	Natural Stand	75.11	Highly Natural
50	35.90	5.97	72.31	Natural Stand & Wetland	69.37	Natural Stand	89.26	Highly Natural
51	45.53	10.35	79.07	Natural Stand & Wetland	70.07	Natural Stand	89.04	Highly Natural
52	30.71	5.88	71.07	Natural Stand & Wetland	64.05	Natural Stand	81.46	Highly Natural
53	23.13	2.78	76.86	Natural Stand & Wetland	75.50	Natural Stand	87.71	Highly Natural
54	7.60	1.99	63.59	Natural Stand & Wetland	57.45	Natural Stand	80.22	Highly Natural
55	11.17	3.26	63.52	Natural Stand & Wetland	61.25	Natural Stand	70.13	Highly Natural
56	3.10	0.34	90.82	Natural Stand & Wetland	90.36	Natural Stand	93.98	Highly Natural
57	8.78	1.31	61.02	Natural Stand & Wetland	59.62	Natural Stand	72.83	Highly Natural
58	33.06	4.24	73.29	Natural Stand & Wetland	72.56	Natural Stand	79.74	Highly Natural
59	35.47	4.31	59.82	Natural Stand & Wetland	58.75	Natural Stand	66.23	Highly Natural
60	59.38	8.39	52.05	Natural Stand & Wetland	51.13	Natural Stand	65.35	Highly Natural

Table D4 (continued). *LCLU grouping for each version for each sub watershed using the 100m riparian buffer zone. Version 1: no grouping of classes – nine LCLU classes (1) Natural Stand, 2) Wetland 3) Grassland, 4) Shrubland, 5) Secondary Growth, 6) Forest Loss, 7) Agriculture, 8) Barren, and 9) Urban). Version 2: grouping of natural stand and wetland – LCLU eight classes (1) Natural Stand and Wetland 2) Grassland, 3) Shrubland, 4) Secondary Growth, 5) Forest Loss, 6) Agriculture, 7) Barren, and 8) Urban . Version 3: grouping LCLU classes into three categories – 1) Highly Natural, (Natural Stand, Wetland, Grassland, Shrubland), 2) Regeneration Likely (Secondary Growth, Forest Loss), and 3) Regeneration Unlikely (Agriculture, Barren, and Urban).*

			Version 1		Version 2		Version 3	
Sub watershed ID	**Area (km^2)**	**Land Cover Class Area (km^2)**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**
61	71.28	11.08	73.47	Natural Stand & Wetland	72.14	Natural Stand	80.04	Highly Natural
62	2.00	0.82	46.09	Natural Stand & Wetland	44.99	Natural Stand	57.79	Highly Natural
63	20.14	4.71	68.46	Natural Stand & Wetland	66.10	Natural Stand	75.69	Highly Natural
64	53.67	11.34	67.87	Natural Stand & Wetland	66.71	Natural Stand	73.89	Highly Natural
65	114.08	24.52	67.86	Natural Stand & Wetland	66.11	Natural Stand	75.60	Highly Natural
66	77.67	17.65	78.15	Natural Stand & Wetland	74.52	Natural Stand	82.41	Highly Natural
67	16.25	3.77	53.49	Natural Stand & Wetland	36.41	Natural Stand	92.01	Highly Natural
68	29.38	6.08	63.24	Natural Stand & Wetland	53.11	Natural Stand	85.59	Highly Natural
69	1.84	0.43	41.94	Natural Stand & Wetland	38.93	Natural Stand	59.51	Highly Natural
70	19.71	5.05	75.03	Natural Stand & Wetland	73.14	Natural Stand	81.48	Highly Natural
71	21.23	3.89	79.90	Natural Stand & Wetland	78.72	Natural Stand	85.32	Highly Natural
72	30.83	5.31	65.72	Natural Stand & Wetland	60.12	Natural Stand	78.25	Highly Natural
73	21.44	4.21	75.86	Natural Stand & Wetland	70.98	Natural Stand	85.89	Highly Natural
74	2.65	0.51	73.72	Natural Stand & Wetland	71.65	Natural Stand	83.96	Highly Natural
75	23.94	3.36	65.99	Natural Stand & Wetland	61.23	Natural Stand	82.12	Highly Natural
76	15.69	2.96	71.44	Natural Stand & Wetland	65.12	Natural Stand	82.47	Highly Natural

Table D4 (continued). *LCLU grouping for each version for each sub watershed using the 100m riparian buffer zone. Version 1: no grouping of classes – nine LCLU classes (1) Natural Stand, 2) Wetland 3) Grassland, 4) Shrubland, 5) Secondary Growth, 6) Forest Loss, 7) Agriculture, 8) Barren, and 9) Urban). Version 2: grouping of natural stand and wetland – LCLU eight classes (1) Natural Stand and Wetland 2) Grassland, 3) Shrubland, 4) Secondary Growth, 5) Forest Loss, 6) Agriculture, 7) Barren, and 8) Urban . Version 3: grouping LCLU classes into three categories – 1) Highly Natural, (Natural Stand, Wetland, Grassland, Shrubland), 2) Regeneration Likely (Secondary Growth, Forest Loss), and 3) Regeneration Unlikely (Agriculture, Barren, and Urban).*

			Version 1		**Version 2**		**Version 3**	
Sub watershed ID	**Area (km^2)**	**Land Cover Class Area (km^2)**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**	**% Class Cover (100 m Buffer)**	**Dominant Class Name**
77	40.55	7.57	64.06	Natural Stand & Wetland	53.07	Natural Stand	80.40	Highly Natural
78	2.14	0.62	85.07	Natural Stand & Wetland	83.48	Natural Stand	90.45	Highly Natural