SOCIAL NETWORK ANALYSIS OF LAKE STURGEON IN THE NAMAKAN RIVER AND RESERVOIR, FORT FRANCES DISTRICT, ONTARIO

by

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An undergraduate thesis submitted in partial fulfillment of the requirements for the degree of Honours Bachelor of Environmental Management

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ABSTRACT

Keywords: lake sturgeon, Namakan River, Namakan Reservoir, social network analysis, social structures, telemetry

Social network analysis is the study of individuals or units and the relationship between them at a given time. It allows insight about evolution, maintenance of social relationships, and behavioural characteristics. These networks can help measure and describe the overall structure and stability or vulnerability of a group. Such measures of vulnerability are especially important for Lake Sturgeon (*Acipenser fulvesens*), due to their threatened status across Canada. This study had three objectives: (1) to find groups of Lake Sturgeon residing in the Namakan River, Fort Frances District, Ontario that might consistently migrate upstream at the same time, (2) to find groups of Lake Sturgeon that consistently arrive at the same spawning reaches each year, and (3) to determine if groups of Lake Sturgeon residing in the Namakan Reservoir consistently interact with one another. Telemetry data from the Namakan River and Reservoir were used to determine if social networks were forming over a period of five years. No social groups were found in the Namakan River during this time, but there was evidence of their formation in the Namakan Reservoir. This information can aid in developing management plans for Lake Sturgeon in the Namakan River and Reservoir.

TABLE OF CONTENTS

FIGURES AND TABLES

LIST OF FIGURES

LIST OF TABLES

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INTRODUCTION AND OBJECTIVES

Currently there are 25 species of sturgeons worldwide, most of which are labeled as threatened or endangered (Auer, 1996). Sturgeon are considered more critically endangered than any other group of species (International Union for Conservation of Nature, 2017). Lake Sturgeon (*Acipenser fulvesens*) have a long history involving overharvesting, which dates back in Ontario to at least 1850. They were perceived as nuisance fish due to the destruction of fishing gear (Ontario Species at Risk, 2014). Their economic value was later realized in the late 1800s, and Lake Sturgeon became prized for their meat, caviar, and isinglass, an ingredient in winemaking. The sudden value for Lake Sturgeon led to millions of pounds being caught annually in commercial fisheries. Unsustainable fishing practices paired with environmental factors such as pollution, habitat loss, and construction of dams along tributaries of the Laurentian Great Lakes led to the demise of Lake Sturgeon populations. The 20^{th} century sturgeon fishery collapse resulted in strict regulations and subsequent closure of viable fisheries (U.S Fish and Wildlife Service, 2016).

Lake Sturgeon have had difficulties recovering their population from being overharvested due to their extremely slow reproductive cycle. Currently, Lake Sturgeon, the only endemic sturgeon species to the Laurentian Great Lakes basin, is listed as threatened in Ontario (Ontario Species at Risk, 2014). Lake Sturgeon are protected in the Canadian waters of the Great Lakes, with closed seasons, size limits, creel limits and gear restrictions. Lake Sturgeon reproductive cycles have been studied heavily, but little is known about their seasonal habitat use.

Social network analysis (SNA) is a fairly new statistical approach, and includes the study of individuals or units and the relationship between them at a given time. SNA can be relevant to many taxa, giving insights about evolution and maintenance of social relationships. SNA allows us to understand the causes and consequences of sociality. Social networks can have consequences for the social life of animals, such as distribution of diseases and negative effects on communication and mating systems. SNA can describe the overall structure and possible stability or vulnerability of a species, especially important to conservation efforts in providing information that will assist in developing appropriate management techniques. Exploration of SNA in Lake Sturgeon may be crucial if it can assist their recovery in North America.

Here, I examined seasonal habitat use of Lake Sturgeon in the Namakan River in Fort Frances District, Ontario, Canada. The Namakan River is an unregulated stream until it reaches the Namakan Reservoir upstream of several dams, where it becomes the Namakan Reservoir, shared waters between Ontario and Minnesota, USA. This study on the Namakan system has three main objectives. The first objective determines if there are groups of Lake Sturgeon residing in the Namakan River that consistently migrate upstream at the same time or if the departure time is random. The second objective tests if there are groups of Lake Sturgeon that consistently arrive at the same spawning reaches each year or if migration entails random distances upstream. The third objective determines if there are groups of Lake Sturgeon residing in the Namakan Reservoir that consistently interact with one another. The null hypothesis would be random assortment of Lake Sturgeon in the Namakan River and the Namakan Reservoir.

LITERATURE REVIEW

HISTORY

The oldest sturgeon fossil dates back to the upper Cretaceous (Peterson et al., 2007). The genus *Acipenser* evolved 100 million years ago and Lake Sturgeon *(Acipenser fulvescens*) appeared at this same time (Pollock et al., 2015). Lake Sturgeon were once abundant in all primary watersheds in Ontario (Chiasson et al., 1997). Lake Sturgeon also provided important roles in native culture and commercial fisheries (Pollock et al., 2015). All sturgeons have experienced declines in abundance caused by overharvesting, barriers to migration, disturbance and pollution (Auer, 1996). A recent survey showed that Lake Sturgeon are now absent or rare throughout most of Ontario (Chiasson et al., 1997). Over the past 100 years, Lake Sturgeon populations have been in decline or had slow recoveries across North America (Pollock et al., 2015). The Committee on the Status of Endangered Species in Canada (COSEWIC) has proposed eight “designatable units” for Lake Sturgeon in Canada under the Species at Risk Act (Ontario Ministry of Natural Resources and Forestry, 2009). Ontario has two such units listed as “endangered,” two as “special concern” (including the Namakan River system), and one listed as “threatened.”

Lake Sturgeon can be considered the largest and most unique freshwater fish in North America (Pollock et al., 2015). The unique characteristics of Lake Sturgeon that have been adapted over the past 100 million years are also a disadvantage in that they make the fish vulnerable to anthropogenic impacts. Life history factors such as slow growing, late maturing, and intermittent spawning make recovery complicated and protection difficult (Auer, 1996). Pollock et al. (2015) used the example of delayed sexual maturation, which allows fast growth to large size and decreases predation risk. This adaptation was a useful advantage for Lake Sturgeon 100 million years ago, but makes it difficult for populations to recover from recent disturbances. Auer (1996) stated in one study that the greatest factors keeping sturgeon populations repressed are loss of spawning and nursey habitat and blockage of migratory spawning routes.

Each river has a unique or different human induced stress and physical characteristic, and thus Lake Sturgeon abundance varies across rivers in Ontario, particularly due to the construction of hydroelectric generation stations (Haxton et al., 2014). For example, Lake Sturgeon historically spawned in 22 tributaries in Lake Superior, but now 8 of these populations are extirpated due to exploitation, habitat loss, pollution and migration barriers (Pratt et al., 2014). Lake Sturgeon populations are greatly depressed from their historic abundance today, and few populations meet recovery goals. Lake Sturgeon are vulnerable due to very specific habitat requirements, which include optimal temperatures, flow velocities and substrates. Recent collapse in sturgeon fisheries and the worldwide demand for sturgeon caviar and meat has resulted in increased pressure on remaining Lake Sturgeon (Ontario Ministry of Natural Resources and Forestry, 2009).

BIOLOGY

Lake Sturgeon are similar to most other *Acipenser* species. They are endemic to larger mesotrophic and oligotrophic systems located in central United States, Laurentian

Great Lakes and Hudson Bay drainages (Peterson et al., 2007). Lake Sturgeon have many features that make them unique among freshwater fishes, such as a long life span, maturity at late ages, and protracted spawning periodicity. Other primitive morphological features that make Lake Sturgeon unique are absence of scales, five lateral rows of bony plates called scutes, a spindle-shaped body, heavily armoured skull, and barbels that are situated closer to the tip of the snout than to the mouth. Primitive features also include a cellular swim bladder that retains some lung-like characteristics, as well as spiral valve intestine, which has been adapted to a diet of benthic crustaceans and molluscs. Lake Sturgeon colouration variates between stocks. The usual colouration is dark brown or dark gray dorsally, with similar lighter colours on lateral surface.

HABITAT

Habitat selection by Lake Sturgeon varies with life stage (Peterson et al., 2007). Juveniles prefer habitat with deep pools (>2 m) within their natal streams. They use this habitat primarily for feeding and overwintering. Adults prefer deep waters (<9 m) in large lakes during cooler months. In a shallow lake with depths <7 m, like Lake Winnebago, Wisconsin Lake Sturgeon occur at all depths, while in a deeper lake, like Black Lake, Michigan adults were found mostly at depths of 6-12 m. Likely, seasonal habitat selection depends on water temperature and abundance of prey.

Long-term, seasonal movement by Lake Sturgeon is poorly understood (Rusak and Mosindy 1997). Data from the Lake of the Woods and Rainy River, Ontario and Minnesota suggested two discrete populations can exist within the same system, differentiated by seasonal habitat use, movement patterns and timing of spawning. Lake Sturgeon in continuous lakes and river systems are thought to use lakes most of the year and rivers primarily for spawning and summer feeding. Lake populations and river populations were compared by Rusak and Mosindy (1997), who showed that lake populations prefer lentic winter habitats and move later in spring and summer, while river populations also inhabit the river during the winter months. Overwintering areas of Rainy River occurred where benthic communities have shown the greatest recovery from past pollution. In general, movement rates were greater in spring and summer and decreased with decreasing water temperature, and areas with faster water movement were preferred both in winter and summer, often located around peninsulas and channels. Lake Sturgeon habitat selection also varies with foraging behaviour. Population differentiation may be prevalent for this species, given diversity in habitat and spawning cues.

DIET

Lake Sturgeon are benthic feeders, and feeding relies on a combination of olfactory, chemosensory, tactile and electrosensory receptors (Chiasson et al., 1997). They feed primarily on benthic macroinvertebrates, but diet varies depending on availability of food. Where density and diversity of benthic fauna are low in substrates dominated by sand and clay, Lake Sturgeon forage exclusively on benthos, especially on Ephemeroptera, Diptera and Tricoptera. They are more active at night, due to better foraging conditions at night. Lake Sturgeon can also obtain large portions of their diet from organic material derived directly or indirectly from fish, and stable isotope analysis provides evidence for seasonal or temporal shifts in diet (Smith et al., 2016). These results are important, because they establish a baseline to understand what may occur with future changes in food web structure due to anthropogenic stressors

MANAGEMENT AND CONSERVATION

Recruitment factors and early life history are poorly understood for Lake Sturgeon. Research has focused on identifying and assessing the size structure of remnant stocks, spawning habitat, and factors affecting reproductive success (Peterson et al., 2007). Additional studies are needed to improve hatchery techniques and better understand recruitment mechanisms.

The Ontario Ministry of Natural Resources and Forestry (2009) implemented a zero-harvest for recreational fishing in 2008 and a zero-harvest for commercial fisheries in 2009. Michigan's Department of Natural Resources has the goal to conserve and rehabilitate self-sustaining populations of Lake Sturgeon to a level that will permit delisting as a threatened species, to a population that can maintain itself indefinitely without supplemental stocking (Hay-Chielewski and Whelan, 1997). Within self-sustaining populations, there must be sufficient individuals to prevent inbreeding, sufficient spawning, habitat for all age structures and low human induced mortality. To achieve this goal of a self-sustaining population, the Michigan strategy lists three objectives. The first is conserving self-sustaining populations, the second is re-establishing extirpated populations, and the third is establishing populations in waters within suspected historic ranges. The lake sturgeon rehabilitation strategy for Michigan also states three obstacles to rehabilitating sturgeon populations worldwide: physical obstacles for migrating fish, physical effects on spawning and nursery areas, and effects of overfishing. Each of the Laurentian Great Lakes is considered to have a discrete Lake Sturgeon stock consisting of many populations. Management plans for Lake Sturgeon should thus consider individual populations as a genetically distinct management unit. Most of Lake Superior may be inhospitable habitat for Lake Sturgeon, with the exception of nearshore areas in Goulais Bay (Pratt et al., 2014). Established populations could help repopulate the southeastern part of Lake Superior, which also contains suitable habitat.

Impacts on Lake Sturgeon may be site- or river-specific, and conservation strategies may not be transferable from one to another population (Haxton et al., 2014). Each river has a unique or different human induced stress and physical characteristic, and because of this lake sturgeon abundance varies across rivers in Ontario. Likely, hydroelectric generation stations have the strongest effect on Lake Sturgeon abundance across Ontario, and recovery strategies should aim to revise management plans involving hydroelectric dams. Fishways often appear in a management plan for Lake Sturgeon. Fishways are designed to provide safe passage for jumping fish (Peake et al., 1997). Only recently have non-jumping species, such as Lake Sturgeon, been considered in the design of fishways. Lake Sturgeon swimming performance relative to body length is inferior to salmonids, which can easily pass fishways. Fishway designs for Lake Sturgeon passage thus need to consider their swimming ability, space requirements, and behaviour.

Management plans need to be based on information gathered from free-reigning populations, but at the same time, information from individual populations may not give a true picture of Lake Sturgeon life history. Efforts to conserve the species must include knowledge of minimum viable population size and range needs (Auer, 1996). Range needs must be considered when developing management plans, because habitat selection varies throughout life cycles of Lake Sturgeon. A barrier-free 250-km combined river and lake range should be a minimum distance to support a self-sustaining population. Fishery managers should take greater consideration in removing barriers and fish passages, rather than focussing efforts on habitat enhancement for populations that are isolated with restricted ranges.

SOCIAL NETWORK ANALYSIS

Social animals live and interact together forming complex relationships and social structure, often important for the species fitness (Wey et al., 2007). Prior to SNA, commonly used measures of social complexity included group sizes and mating systems that could only provide indirect reflections of the social relationships between individuals. In contrast, SNA aims to provide deeper understanding of social complexity by measuring social relationships directly. The SNA approach addresses the structure of relationships and the correlation between individuals and a group. Wey et al. (2007) suggested many different measurements and terminology that encompass individual measures, intermediate measures, and group measures (Table 1).

Table 1. Terminology to describe social network structures in three categories: individual measures, intermediate measures and group measures (Wey et al., 2007).

Individual measures	**Definition**
Betweeness centrality	Centrality based on the number of shortest paths between every pair of other group members on which the focal individual lies
Centrality	A measure of an individual's structural importance in a group based on its network position
Closeness centrality	Centrality based on the shortest path length between a focal individual and all other members of the social group
Degree centrality	Centrality based on the number of direct ties an individual has
Node degree	The number of ties a focal animal has' the number of other animals with which the focal individual interacts
Intermediate measures	**Definition**
Clustering coefficient	The number of ties between neighbours is dived by the maximal possible number of ties between them
Cliquishness	How much the network is divided into cohesive subgroups; a clique is a set of nodes where each node is directly tied to each other
Group Measures	**Definition**
Average path length	The average of all path lengths between all pairs of nodes in the network
Density	The number of realized ties divided by the number of possible ties in the network

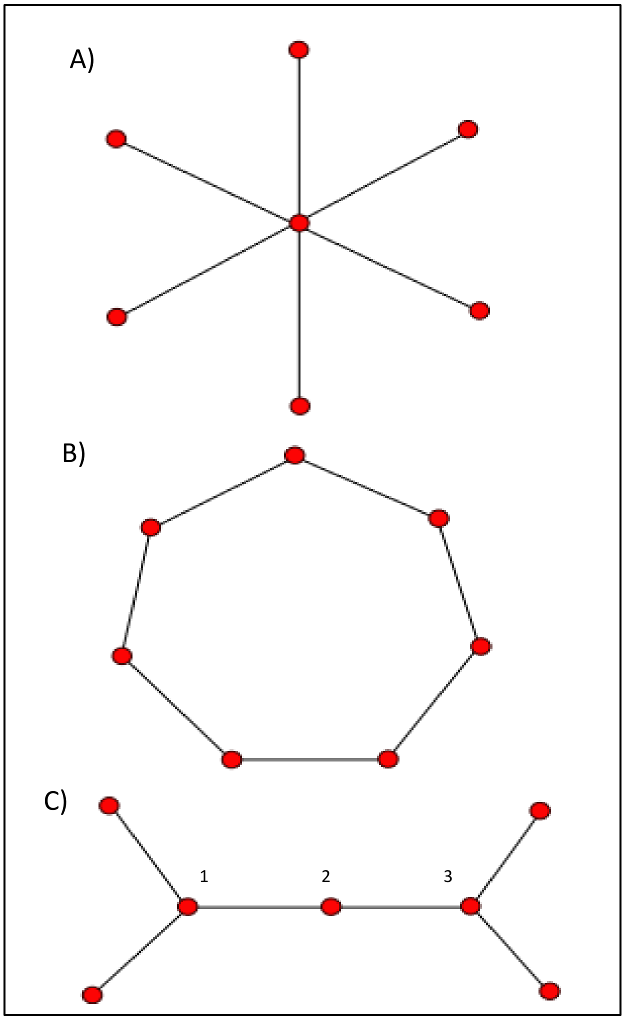

Figure 1. Three different social network structures (Wey et al., 2007).

Wey et al. (2007) discussed SNA in terms of nodes and ties. Nodes are defined as social entities pertaining to either individuals or units (represented by red dots; Figure 1). Ties are the social relationships between two nodes at any given time (represented by the black lines between the nodes; Figure 1). Type A is a star network and the individual in the middle has the most closeness and between centrality, making it the most important in the group. Type B is a closed or circular network where all individuals have equal closeness and betweeness, while centralization does not occur. Type C is a network where individuals 1 and 3 have the highest ties to other individuals, but individual 2 has the highest closeness and betweeness. Individuals 1 and 3 are indirectly tied to each other through 2. Wey et al. (2007) discuss these scenarios with the example of social networking in the Guppy (*Poecilia reticulate*). The Guppy typically has a social network structure and predicted patterns of cooperation. Guppies were compared to Three-spine Stickleback (*Gasterosteus aculeatus*) where social cliquishness is more typical. The mechanisms proposed to explain the cliquishness are the fact that individuals are similar sized, have similar shoaling tendencies, and repeated interactions between individuals.

Wey at al. (2007) also indicated that not all social structures have beneficial effects. White-striped Free-tail bats (*Tadarida australis*) have a single habitat tree that is the hub of the social network, surrounded by different roosting trees. The topology of this social network could have consequences on the social life of the bats, such as distribution of diseases and negative effects on communication and mating, due to the bats being spread over a large area.

MATERIALS AND METHODS

STUDY SITE

The Namakan River is located 80 km southeast of Fort Frances, Ontario, downstream of Lac La Croix and upstream of Namakan Reservoir (Figure 2; Welsh and Mcleod, 2010). The Namakan River follows along the Quetico Provincial Park border for 12 km and drains a watershed close to 8860 km^2 in area. The Namakan Reservoir, beyond the mouth of the Namakan River, consists of many smaller basins, including the Namakan, Kabetogama, Crane, Sand Point, and Little Vermilion lakes (Cohen and Radomski, 1993). This series of lakes is a part of the headwaters of the Hudson Bay drainage basin (Cohen and Radomski 1993). The mean depth of the Namakan Reservoir is 13.6 m, 45.7 m at its maximum, with a surface area of is 25,973 ha. The Namakan

Reservoir borders the U.S and Canada, with the U.S. portion within Voyageurs National Park.

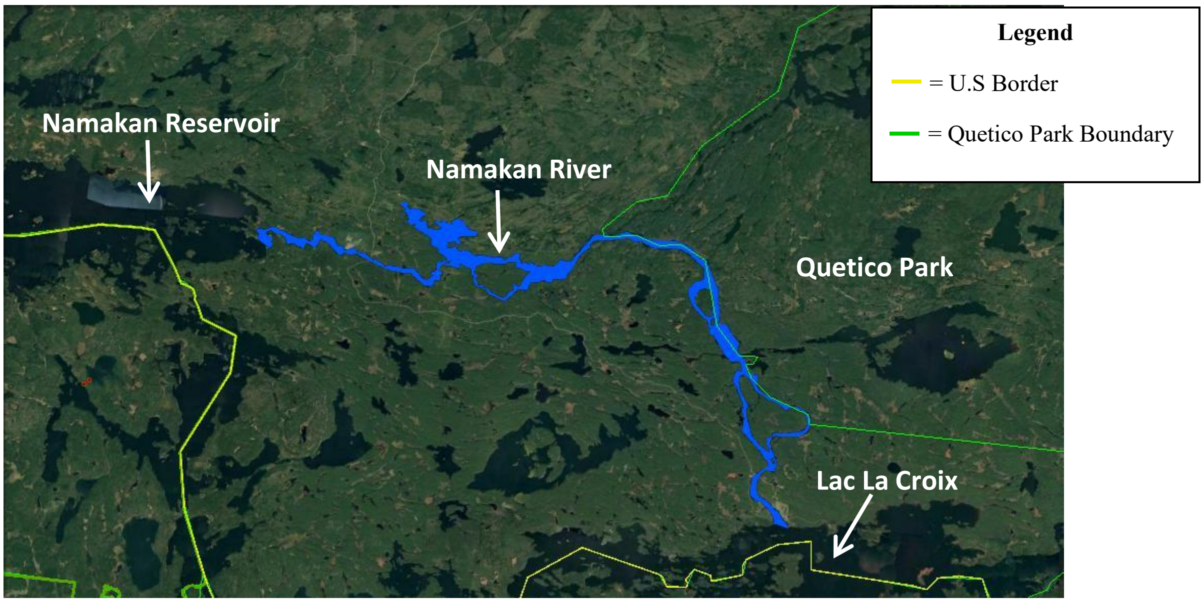

Figure 2. Location of Namakan River with Lac La Croix, Namakan Reservoir and Quetico Park.

ACOUSTIC DATA COLLECTION

A series of acoustic receivers (Vemco, Inc.) were installed along the Namakan River and Reservoir from 2007-2011, 18 stations (active during 2007-2009) for the river, and 22 stations (active during 2009-2011; Figure 3) for the reservoir (Table 2). Stations in the river were typically installed at narrows, requiring Lake Sturgeon with transmitters to swim near them. Whenever two or more fish pass by a receiver at the same time, the time of passage and location are recorded on a datalogger at the station.

Table 2. Station names throughout the Namakan River and Namakan Reservoir.

Namakan River Stations	Namakan Reservoir Stations
Above Hay Rapids	56 Rapids – Loon River
Above Ivy Falls	Bearpelt Creek
Above Quetico Rapids	Below Kettle Falls- Rainy Lake
Above Snake Falls	Below Squirrel Falls – Rainy Lake
Above Squaw Rapids	Blackstone Is. (Namakan Lake) – Ontario
Back Channel	East End Namakan
Bearpelt Creek	Grassy Bay (Sand Point Lake)
Below Hay Rapids	Kabetogama Narrows (Kabetogama Lake)
Below High Falls	King Williams Narrow
Below Kettle Falls – Rainy Lake	Little Vermillion Narrows
Below Lady Rapids	Moose River (Namakan Lake)
Below Myrtle Falls	Namakan Narrows (Namakan Lake)
Below Snake Falls	RB01
Below Squirrel Falls- Rainy Lake	RB02
Bill Lake	RB03
East End Namakan	RB04
Quetico River	RB05
Three Mile Lake	RB06
	Redhorse River – Ontario
	Smugglers Point (Namakan Lake)
	Squaw Narrows (Namakan Lake)
	Vermillion Gorge - powerline

Multiple software packages were used to convert data from the receivers. VEMCO, a trademark program designed for underwater telemetry and tracking systems, read the data from the receivers. The data were filtered by years and stream reaches. For the Namakan River, the data were separated into periods during and after spawning. The time period for the spawning was from May 20th until June 1st for every year. These dates were based on spawning observations.

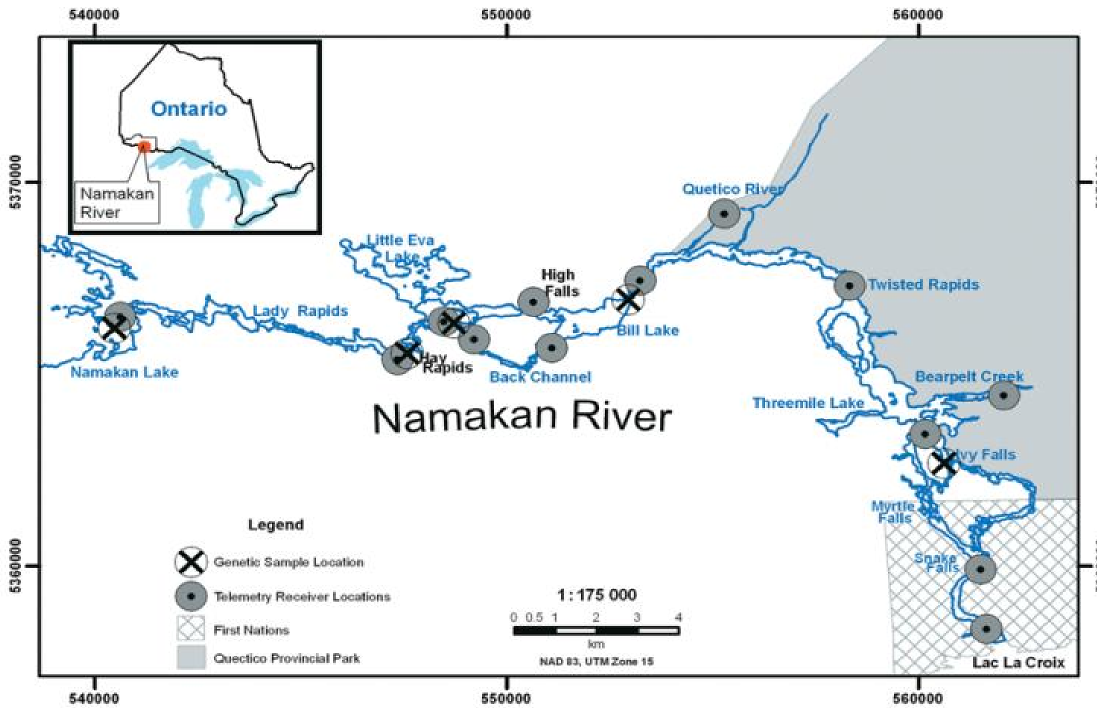

Figure 3. Locations of receiver stations along the Namakan River.

The post-spawning period was from June 2nd until October 15th for each year. For the Namakan Reservoir, data were divided into summer (June 1st until October 15th) and winter (November 1st until February 28th) periods. The filtered data was then converted into comma separated value (CSV) files, to be saved in a table structured format.

DATA ANALYSIS

The program VIM was used as a text editor with a series of commands to format the data so that it could be read by other programs. The set of commands consisted of:

- :%s/VR2W-\(\d\d\d\d\d\d\),A69-1303-\(\d\{3,6}\).*/\1,\2/g
- :set nobomb
- : wq

The third program used was PostgreSQL, a general purpose, open source, relational database management system that allowed the filtered files to be manipulated and reformatted. In VIM, the following command was used to remove all the commas within the data:

- :%s/"//g

Gephi, which is a network visualization and analysis program, was the last program to receive the data, used to illustrate patterns and trends by creating graphs. The layout used was ForceAtlas 2, which helps spread out the data without overlapping. Gephi output created a different node to represent each individual Lake Sturgeon with a transmitter. The scaling of the nodes and edges were changed to make the output more visually appealing. Modularity and average degree were calculated for each output. Modularity represents the different groups or communities, which in Gephi are assigned classes with different colours. Average degree, the number of other individual with which each focal individual interacts, was represented in Gephi by different size nodes and edges. The larger nodes and edges represented Lake Sturgeon individuals with a higher average degree. Labels were then added to every node, which allowed each individual to be identified. For every data set, the number of nodes and edges were recorded, as well as the modularity and average degree.

All Gephi output together was then used to determine if groups of individuals were consistently staying together throughout the years by visual inspection. A series of tables separated all the groups and compared the node numbers. The tables were then examined and either represented distinct group movements or not. A distinct group was classified if groups of fish stayed together over 50% of the time.

RESULTS

The Namakan River dataset in its entirety showed no significant group formation. The Namakan Reservoir dataset showed possible social network structures in each lake basin. There appeared to be fewer individuals present, or likely less movement among individuals in the Namakan River during the spawning period compared to the post-spawning period. Social networks during the spawning period had an average of 20.4 nodes from 2007-2011, and during the post spawning period had an average of 38.6 nodes. The maximum number of nodes for the spawning period was 30 during 2009, and for the post spawning population was 47 during 2011 (Figure 4).

Node and edge numbers tended to correspond with each other. For both spawning and post spawning periods, the highest node and edge numbers co-occurred, and the difference in edge numbers was much greater than the difference in node numbers. The highest edge number for the spawning period was 91 and in the post spawning period was 226 (Figure 5). The edge numbers were also much more variable compared to the node numbers. The average number of edges was also much lower during the spawning period (54.0) than during the post spawning period (181.2). The highest modularity number occurred in 2008 for both periods (Table 3). The highest modularity number for the spawning period was 0.516, and for the post spawning period was 0.447. The average modularity numbers for both periods were similar, 0.374 for the spawning period and 0.386 for the post spawning period.

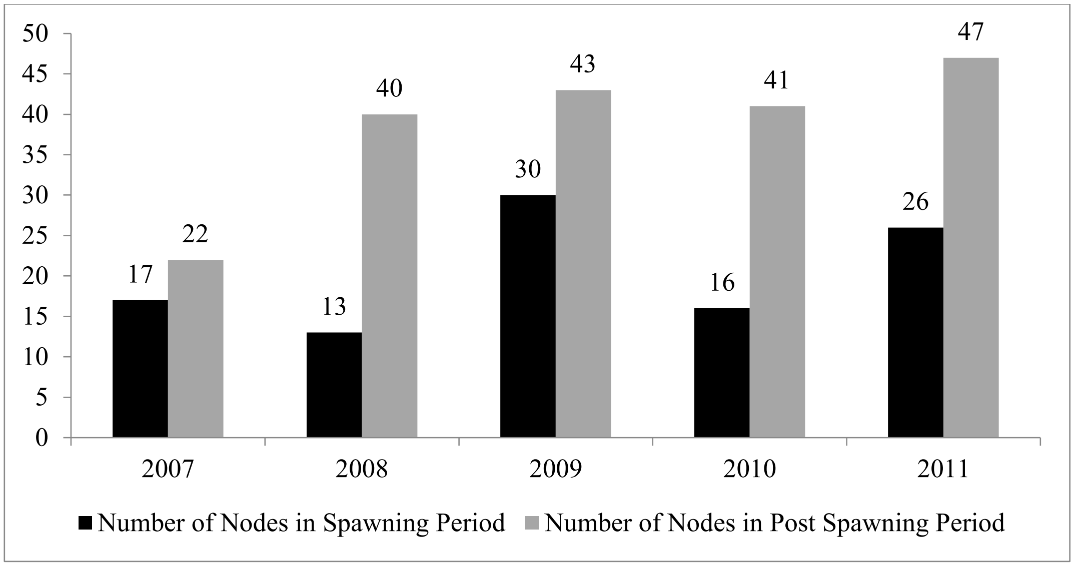

Figure 4. Number of nodes in the spawning and post spawning populations in the Namakan River.

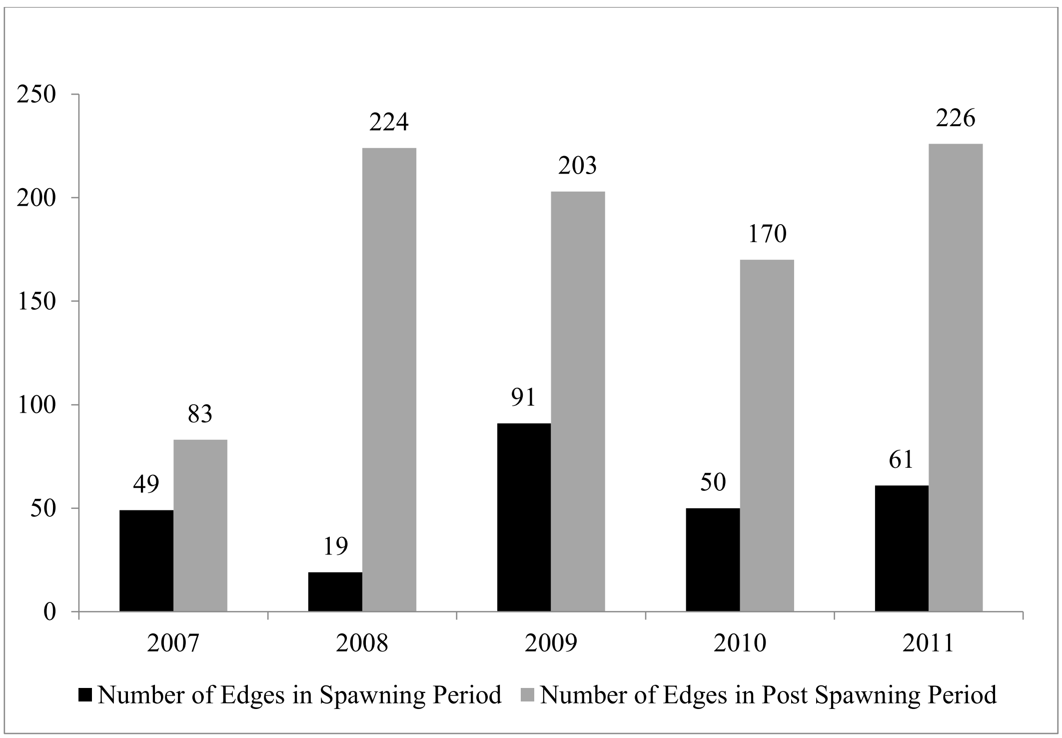

Figure 5. Number of edges in the spawning and post spawning populations in the Namakan River.

Table 3. Comparison between the modularity and average degree for spawning and post spawning periods.

	Spawning		**Post Spawning**	
Year	Modularity	Average Degree	Modularity	Average Degree
2007	0.280	5.765	0.365	7.544
2008	0.516	2.923	0.447	11.20
2009	0.419	6.067	0.388	9.442
2010	0.178	6.260	0.357	8.293
2011	0.475	4.692	0.371	9.617

Snake Falls appears to be the furthest reach of the Namakan River in which an individual Lake Sturgeon, 4640, migrated (Table 4). A majority of individuals travelled to Myrtle Falls or High Falls. The average distance travelled upstream was 16.27 km. The furthest distance travelled (Snake Falls) is 28.8 km upstream.

Table 4. Upstream reach of Namakan River May 2008 - October 2009

ID	Furthest Upstream detection	Distance Upstream (km)
49638	Mouth of Namakan River	0
49650	Mouth of Namakan River	0
8495	High Falls	11.7
49641	High Falls	11.7
49642	High Falls	11.7
49647	High Falls	11.7
49643	Quetico River	17.5
49633	Three Mile Lake	24.7
49630	Myrtle Falls	25.5
49634	Myrtle Falls	25.5
49635	Myrtle Falls	25.5
49637	Myrtle Falls	25.5
49653	Myrtle Falls	25.5
49640	Snake Falls	28.8

NAMAKAN RIVER

In the Namakan River, there appeared to be no significant groups forming over the course of five years. In the spawning period, there were sixteen opportunities for the groups to be formed. Out of the sixteen possible opportunities, no groups remained together over the five years (Table 5). In the post spawning period, out of sixteen possible opportunities, there appeared only four instances of groups forming. Although there were no full groups formed, there were three individuals that remained in the same group through all five years in the post spawning period: 4602, 4594, and 4591 (Figure 6), the only instance of complete group adherence over the five-year period.

Table 5. Post spawning in the Namakan River 2007-2011**.**

	After Spawning Period		
Year	Modularity	Consistent Groups Present	Group Adherence
2007	Purple	Yes	15/28
2007	Orange	Yes	19/32
2007	Green	Yes	12/24
2008	Purple	No	-
2008	Green	No	-
2008	Orange	No	-
2008	Blue	Yes	10/16
2009	Purple	No	-
2009	Orange	No	-
2009	Green	No	-
2010	Purple	No	-
2010	Orange	No	-
2010	Green	No	-
2011	Purple	No	-
2011	Orange	No	-
2011	Green	No	-
Total Groups Formed			4/16

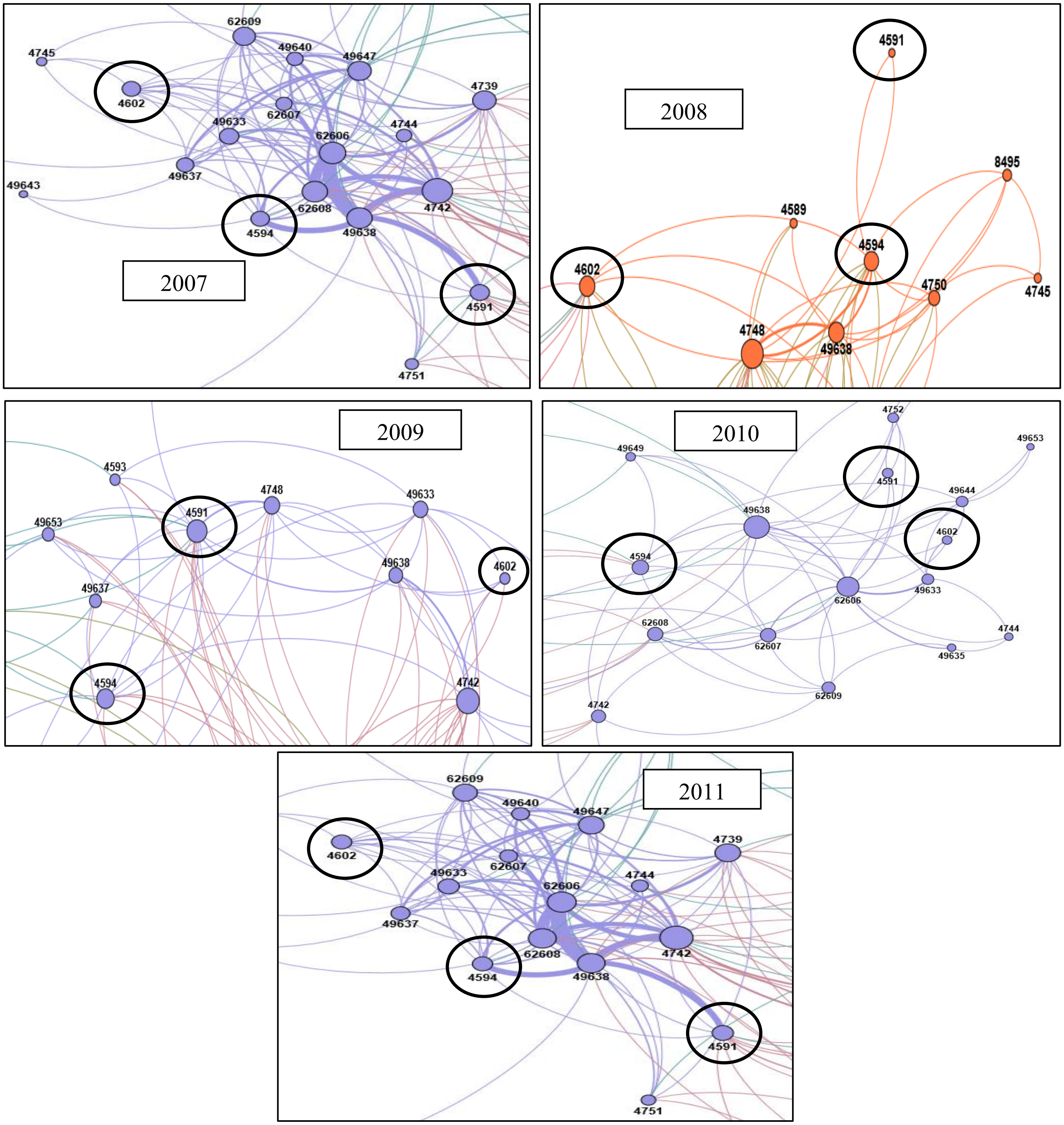

Figure 6. Coincident locations of individuals 4591, 4602 and 4594 in the 2007-2011 post spawning period in the Namakan River.

NAMAKAN RESERVOIR

In the Namakan Reservoir, on the other hand, Lake Sturgeon may form social network structures, often star networks, while in the confines of the Reservoir lakes (Figures 7, 8). Another network formed in the data analysis was similar to Type C (Figures 1, 9). Although social network structures appear each year, the dataset was inconclusive in determining if these networks travel together over time.

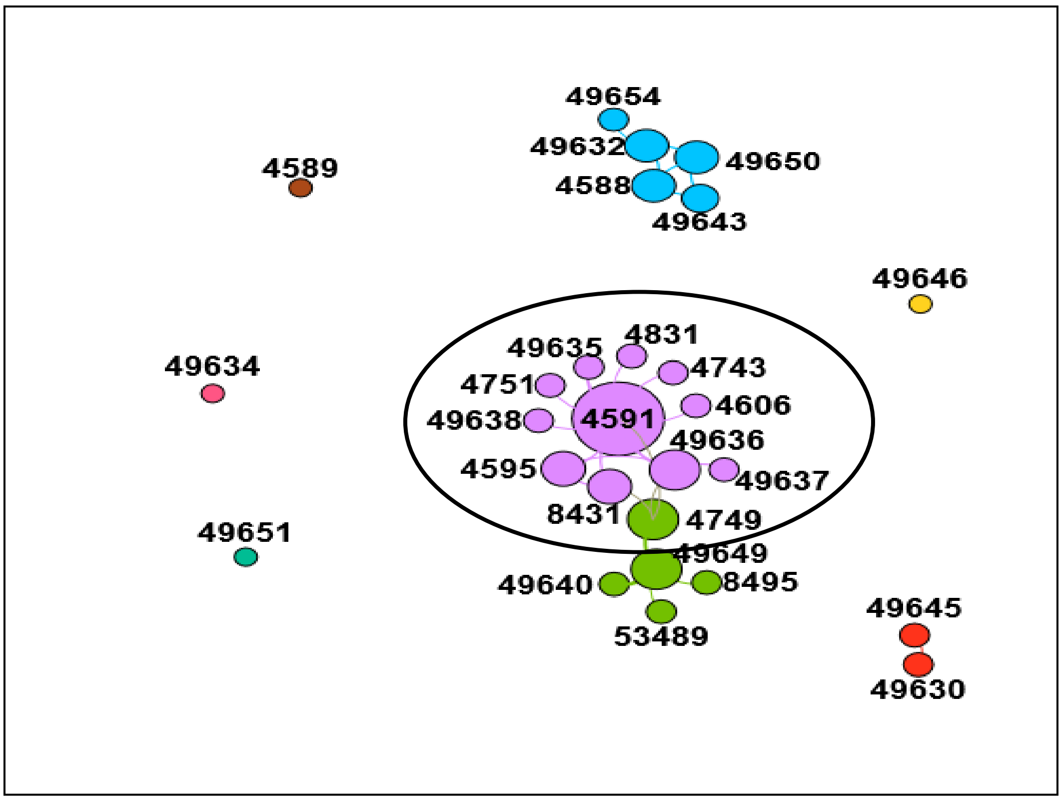

Figure 7. Type A network structure in the Namakan Reservoir (2009).

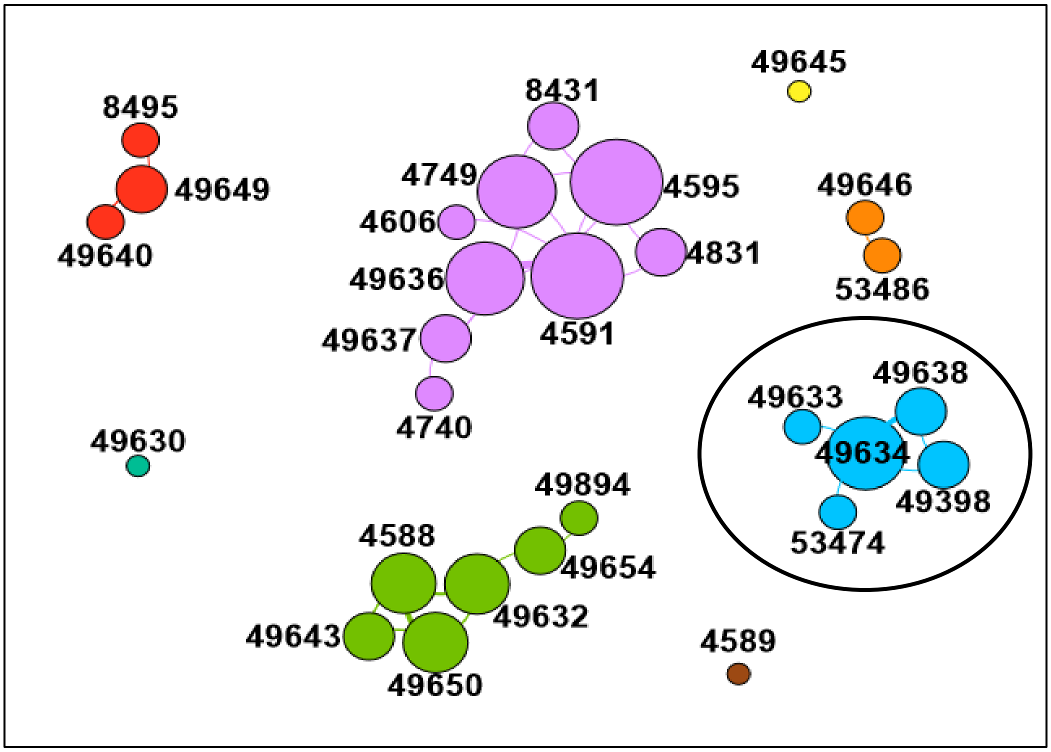

Figure 8. Type A network structure in the Namakan Reservoir (2010).

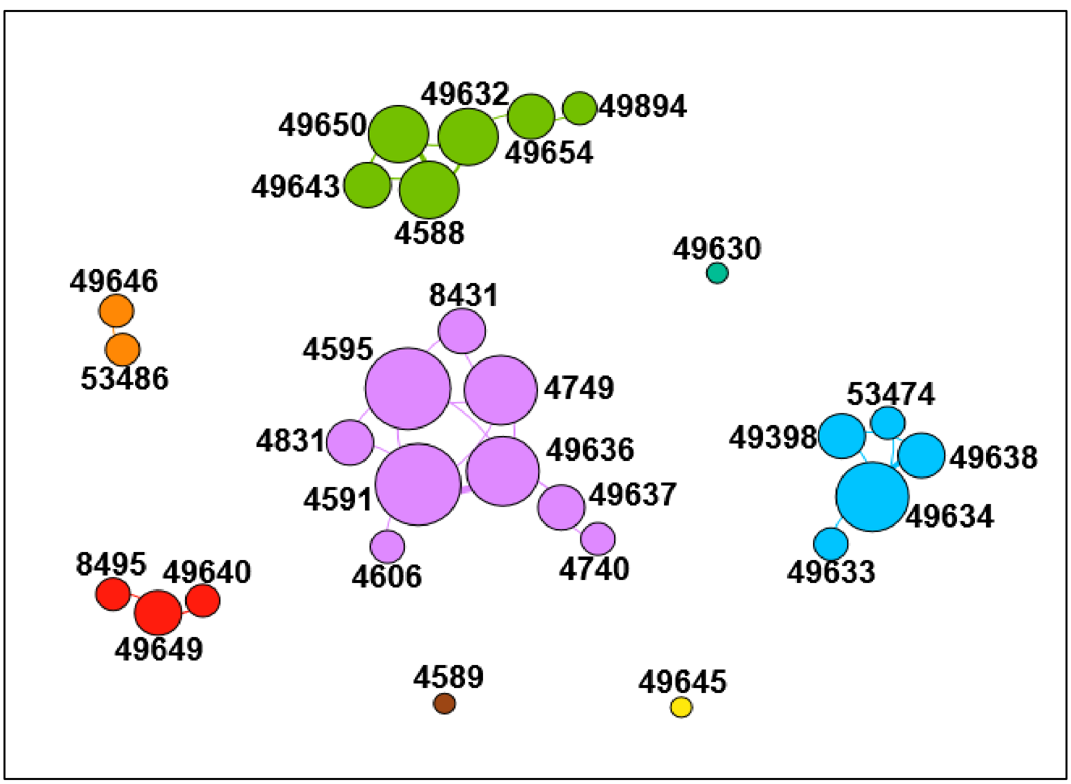

Figure 9. Type C network structure in the Namakan Reservoir (2011).

DISCUSSION

Very little research has explored SNA in fish populations (Wey et al., 2007). Since social behaviours are likely part of the life history of Lake Sturgeon, it becomes important to understand the social networking of this species. Information gained through SNA of Lake Sturgeon can aid in understanding this threatened species (Auer, 1996; Pratt et al., 2014). Identifying whether Lake Sturgeon form social networks can help determine whether developments, such as hydropower, would disrupt the social networks, which in turn could be a factor in reducing reproduction. As mentioned earlier, there are three main types of social network structures; Type A, Type B, and Type C (Figure 1). The results of this study indicate that Lake Sturgeon do not form social networking structures within the Namakan River, and management plans can be applied with this information. Likewise, knowledge that Lake Sturgeon do form social networking structures in the Namakan Reservoir can assist in developing individual-lake management plans that accommodate these behaviours.

It can be speculated that Lake Sturgeon do not form social networking structures in the Namakan River, due to various factors, such as differing spawning maturities, interrupted spawning cycles, and differing habitat and food sources (Peterson et al., 2007); for these reason, entrance into the river seems to be sporadic and random. In contrast, in the Namakan Reservoir, it is postulated that a separate social network structure is formed in each smaller lake basin. Since the dataset suggested no social network structures remained in the Namakan River, it can be assumed that the groups formed in the Namakan Reservoir do not travel together into the Namakan River.

Before this study was conducted, it was hypothesized that sex may play a role in social networking structures. According to Wey et al. (2007), an individual at the center of a Type A network has the most closeness and between centrality, making it the most important in the group. It was thought, for example, that male Lake Sturgeon might be at the center of Type A networks. However, there were many examples with females were at the center of Type A networks, like individual 49649 (Figures 7-9). This female was at the center of the Type A network in one of the lakes, and had a high average degree. According to Kempinger (1988), female Lake Sturgeon are surrounded by males during spawning. As a result, the females would have a higher average degree. My results indicate that both male and females can be at the center of social structures. A high average degree illustrates that an individual exhibited many interaction with other Lake Sturgeon (Table 1). One male individual, 4591, appeared to have a very high average degree and was positioned at the center of Type A networks that formed each year in the Namakan Reservoir (Figures 7-9). This male also appeared with high average degree in the Namakan River, even though social network structures were not formed there.

Many studies indicate that Lake Sturgeon travel upstream into shallower and faster waters for spawning (Smith 2003; Holtgren and Auer 2004). Lake Sturgeon have been known to migrate 200k m upstream. The results of my study indicated that the furthest reach travelled to is Snake Falls, approximately 28.8 km upstream from the Namakan Reservoir. Since only one individual, 49640, migrated to Snake Falls, it is not representative of the population. The average distance migrated was 16.27 km. Since most of the Lake Sturgeon migrated to High Falls and Myrtle Falls, it can be assumed these spawning areas are the preferred. With this in mind, these high density spawning sites should be protected within management strategies.

LIMITATIONS

There are various limitations of my study that may have affected the results. First, only five years of data for the Namakan River and three years of data for the Namakan Reservoir were accessible. This limitation, combined with an offset range of data, proved not sufficient to draw strong conclusions. Since only 14 individuals were analyzed in regard to distance reached upstream, the findings are not representative and would need a larger sample size to draw conclusions about common use of spawning sites. Second, the data received for the reservoir was inconsistent. The Namakan Reservoir dataset was filtered by summer and winter months. There were only data for the winter in 2009 and 2010, while there were only data for the summer months in 2010 and 2011, making it difficult to compare results over time. The analysis was also very much based on the researcher's personal discretion and observations, which may have led to errors and bias, since there is no standardized method for SNA. Personal discretion may be a cause of the experimenter expectancy effect, in which results are forced.

RECOMMENDATIONS FOR FUTURE RESEARCH

This study had limited information on each Lake Sturgeon individual. It is recommended that future research obtain more information, such as sex, size, lake location, and age of each tagged individual to better allow conclusions to be made. It is also recommended that further research be done with data from a longer and more consistent period of time. Since most of the conclusions were drawn through observation of graphs, it is recommended that further research be done to develop a software program with standardized methods to find social networking structures, eliminating experimenter expectancy effects. The last recommendation is to use this method for various fish species, such as commercially important fish, where information gained through SNA could be crucial to the industry.

CONCLUSION

In this study, SNA was used to analyze Lake Sturgeon locations in the Namakan River and Reservoir, Ontario, a watershed without manmade barriers. This information can aid in developing management plans of Lake Sturgeon in the Namakan River and Reservoir.

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