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Occupancy, movement, and behaviour of namew (lake sturgeon *Acipenser fulvescens*) in an intact river in Canada

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ABSTRACT: Most sturgeon populations are imperilled and living in fragmented rivers. Here, we studied namew (lake sturgeon *Acipenser fulvescens*), fish important to Iliwak (Moose Cree Peoples), in the North French River: a free-flowing, intact river in Kit Aski Nahnuun (the Moose Cree Homeland) in northern Ontario, Canada. This study was co-created alongside members of Moose Cree First Nation and used acoustic telemetry to passively track 20 tagged namew over 6 yr (2016–2022). Namew occupied the entire monitored river reach: about 45 km. Namew used 2 overwintering areas and occupied more overall river sections during spring and summer (out of 6 total seasons often used by Iliwak). We did not detect namew moving upstream or downstream during freeze-up and winter. Generally, namew showed the greatest acceleration and travelled the longest distances during spring and summer, and they occupied shallower water during summer at lower water levels and deepest waters during freeze-up. We found an interaction between season and diurnal period, where namew occupied shallower depths and had higher acceleration at dawn and night relative to morning and afternoon in most seasons; dusk behaviour was variable among seasons. However, this pattern was absent in spring, when namew showed no diurnal pattern in acceleration and were in shallower water during morning and afternoon. Diurnal patterns were less pronounced, but detectable, during ice-affected seasons. This river provides year-round habitat for namew, and our data reveal distinct patterns of namew occupancy, movement, and behaviour in a free-flowing, intact river. Our work is an example of successfully co-creating research that addresses both scientific and community priorities.

KEY WORDS: Research co-creation · Indigenous · First Nations · Lake sturgeon · Acipenseridae · Intact rivers · Acoustic telemetry · Fish movement · Fish behaviour

1. INTRODUCTION

There is increasing recognition that Indigenous leadership is essential for achieving equitable and effective conservation outcomes (Garnett et al. 2018, Schuster et al. 2019, Dawson et al. 2021). There are also increasing efforts to co-create knowledge and research more equitably with Indigenous communities (e.g. Hessami et al. 2021, Reid et al. 2021). Here, we present a scientific study that was co-created with Moose Cree First Nation, a First Nation that governs the Kit Aski Nahnuun (the Moose Cree Homeland), in

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what is now called northeastern Ontario, Canada (Fig. 1). This study has the goal of addressing Moose Cree First Nation priorities for water and species monitoring and stewardship in Kit Aski Nahnuun while providing information that is of interest and value to the scientific community.

This study arose from Moose Cree First Nation identifying priorities of knowledge gathering and monitoring of namew (pronounced nam-ay-o; lake sturgeon *Acipenser fulvescens*) within an intact river in Kit Aski Nahnuun. We focused on namew because they are important culturally to Iliiliwak (Moose Cree

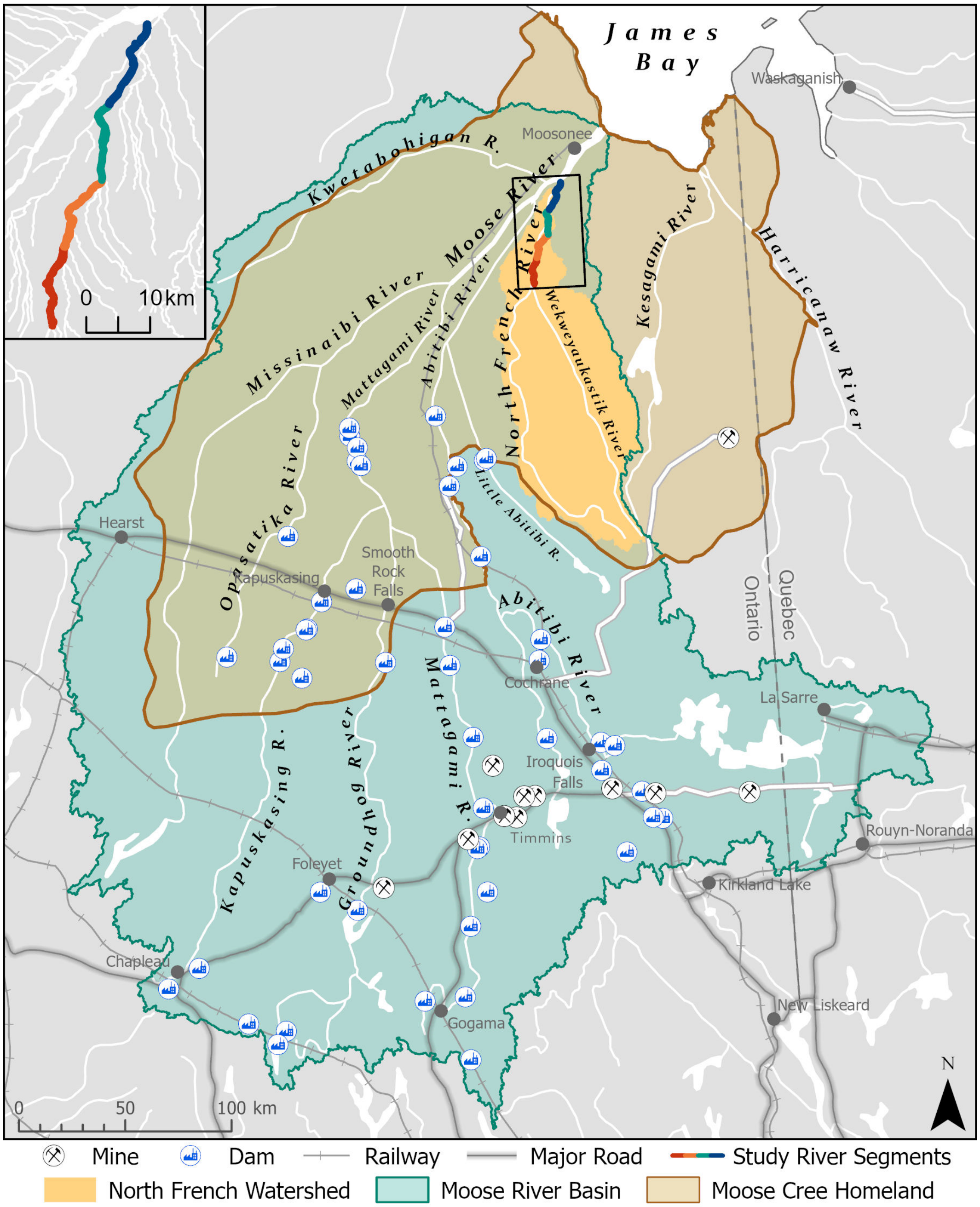

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Fig. 1. North French River watershed located within the larger Moose River Basin and Kit Aski Nahnuun (Moose Cree Homeland), Ontario, Canada. The sections of the study area are indicated in red (farthest upstream); orange (above the winter road); green (below the winter road); and blue (farthest downstream). Current mines, dams, roads, and railways, and the relative absence of these development features in the intact, undisturbed North French River watershed, are shown

Peoples) and are a species of conservation concern (IUCN 2010, COSEWIC 2017). Ililiwak are currently a population of about 3000, whose ancestors have lived and fished the lands and water systems of Kit Aski Nahnuun for millennia, including fishing namew (Louttit 2009). Namew are therefore an important part of Ililiwak culture and history, as many Ililiwak and Ililiwak Elders see this interrelationship between food and Peoples as having strong historical and spiritual significance (Louttit 2009). Animals and Ililiwak have an important relationship, where, since time immemorial, animals like namew are respected as teachers and share a close bond with Ililiwak (Simard et al. 2021). Ililiwak believe it is their cultural duty, obligation, and commitment to look after namew in the best possible way. Namew have helped Ililiwak survive and can also act as a cultural keystone species where prioritization of conservation and stewardship actions for these cultural keystone species can maintain or improve both social and ecological outcomes of freshwater ecosystems (Noble et al. 2016). By using science alongside (i.e. not ‘incorporating’, see McGregor 2021) Indigenous Knowledge Systems, Ililiwak can monitor and safeguard namew as a shared value and resource.

From the scientific perspective, studying namew in an intact river is of interest because of the globally imperilled status of Acipenseriformes (sturgeon and paddlefishes). As a brief note on terminology, namew is the name for lake sturgeon in Ililîmowin (the dialect of Cree spoken by Ililiwak), and so we chose to use namew when we are referring to lake sturgeon within Kit Aski Nahnuun. However, we use lake sturgeon when we are speaking of wider geographic areas, since other Indigenous Peoples have different names for lake sturgeon in their own Homelands. We use sturgeon when we are speaking of Acipenseriformes more generally. Sturgeon are ancient fishes that have existed in the fossil record for at least 175 million years (Hilton & Grande 2006). However, these ancient and historically resilient fishes continue to be threatened and are globally one of the most imperilled groups, with 85% of sturgeon species now at risk of extinction (IUCN 2010) due to overharvesting, habitat degradation, and river fragmentation (Auer 2004). Sturgeon are large-bodied and long-lived, attaining sizes of up to 8 m, living 100 yr or longer, and in some populations not reaching maturity until 20 yr or later (Bemis & Kynard 1997, Billard & Lecointre 2000). Late age of maturity and temporal gaps in spawning cycle life history makes sturgeon populations vulnerable (Bemis & Kynard 1997). Most sturgeon also migrate long distances, sometimes hundreds of kilometres, to reach critical habitats such as freshwater spawning sites where river depth, substrate, and flows are suitable for reproduction (Bemis & Kynard 1997, Billard & Lecointre 2000). Extensive global river developments, including industrial development, deforestation, and the construction and operation of hydroelectric dams and other water-regulation infrastructure (Jackson & Marmulla 2001), have fragmented rivers and reduced water quality; these impacts can degrade sturgeon habitat and make natural sturgeon migration routes impassable (Rochard et al. 1990, Birstein 1993, Lenhardt et al. 2006). Cumulative impacts of river development negatively impact sturgeon populations (Rochard et al. 1990, Birstein 1993, Lenhardt et al. 2006, Reinartz & Slavcheva 2016) and contribute to their endangered status (Cooke et al. 2012).

Despite many threats facing sturgeon, some populations have persisted (Reinartz & Slavcheva 2016). In northern Canada, the southern Hudson and James Bay watersheds encompass Kit Aski Nahnuun, as well as Homelands of other First Nations. This area supports lake sturgeon that are currently designated regionally as special concern, which indicates being particularly sensitive to human activities or natural events but not endangered or threatened (COSEWIC 2017). Many of the lake sturgeon in northern rivers still live in long intact rivers that are not affected by fragmentation, water flow alteration, and industrialization (Haxton et al. 2018). Lake sturgeon in the southern Hudson and James Bay watersheds are globally significant both for their conservation status and habitat rarity. Lake sturgeon here represent some of the only remaining sturgeon globally that are not critically endangered and which also live in intact, free-flowing rivers (Haxton & Cano 2016). Learning about lake sturgeon that are part of the southern Hudson Bay and James Bay designated unit and living in intact rivers therefore represents an opportunity to gather reference data to inform sturgeon conservation at multiple spatial scales and can guide and focus conservation efforts (e.g. restoration, protection) (Haxton & Cano 2016). Information gathered from intact rivers can also serve as reference or benchmark values (McNellie et al. 2020), as a comparison point to guide conservation project targets, and provide the basis for assessing recovery outcomes for endangered species like lake sturgeon (Haxton & Bruch 2022).

We focused our 6 yr (2016–2022) study on the river known as the Kah-pana-yow-sîpiy (river that widens) or the Mehkipwâmeštik-sîpiy (red willow river) in Ililîmowin, or the North French River in English, which lies within Kit Aski Nahnuun (Fig. 1). Because the river is known as both Kah-pana-yow-sîpiy and Mehkipwâmeštik-sîpiy in Ililîmowin, and because the English name is commonly used locally by Moose Cree Peoples, for the remainder of this paper we will only refer to this river as the North French River, though we acknowledge this is only one of its names. At about 150 km long, the North French River is considered a medium length river (Grill et al. 2019). The North French River is an intact tributary of the Môso-sîpiy (Moose River). There is extensive development and industrial activity (hydropower, forestry, roads, mines, and urbanization) on and surrounding the more southern tributaries of the Môso-sîpiy (WWF Canada 2020, Simard et al. 2021; Fig. 1). We focused on the North French River because of its intactness and its cultural importance to Ililiwak.

The goals of our co-created research efforts include addressing both the scientific priority of collecting reference information and the priorities and environmental questions related to namew stewardship identified by members of Moose Cree First Nation. This study, as part of Ki Kiskinohamâkonânawan Namewak (Learning from Lake Sturgeon; see https://learningfromlakesturgeon.ca/ for more information) relies on advice from an Elders Advisory Group and from Ililiwak Knowledge Holders to guide the work, starting from the initial exploration of the research interests to the focused purpose, methodology, and assessment of results. The information we gathered was primarily quantitative data, but guided by Ililiwak Knowledge Systems, and moved forward with Ililiwak participation and leadership in the study design, data collection, data analyses, and interpretation.

2. MATERIALS AND METHODS

2.1. Study area in Kit Aski Nahnuun

The North French River (51.07° N, 80.77° W; Fig. 1) is located within Kit Aski Nahnuun and the Môso-sîpiy basin, which drains into James Bay. The North French River watershed covers an area of about 6650 km^2, with headwaters starting in the forests of the Boreal Shield in northeastern Ontario. Small waterbodies (i.e. lakes, wetlands, marshes) and north-flowing streams merge, and eventually become the North French River (Fig. 1). The entire watershed of the North French River remains free from flow alteration, industry, or development (WWF Canada 2020). This waterway then flows through the wetlands and peatlands of the Hudson Bay Lowlands and into the Môso-sîpiy, about 30 km south of where the Môso-sîpiy drains into the western shores of James Bay.

The more southern tributaries of the Môso-sîpiy have been impacted by river regulation, urbanization, and industrial development, including the forest product industry. The closest dams to the confluence of where the North French River flows into the main Môso-sîpiy are the Otter Rapids Generating Station on the Apihtipîštik (Abitibi River; about 120 km south) and the Kipling Generating Station on the Mattagami River (about 160 km south). The closest settlements are Moose Factory and Moosonee (about 15 km north). While other tributaries of the Môso-sîpiy have experienced various anthropogenic impacts, there is no flow alteration (i.e. no dams or diversions) nor industrial development (i.e. no mining, forestry, transmission lines, permanent roads, or settlements) within the watershed area of the North French River (Fig. 1). The only transportation feature in the North French River watershed is a seasonal winter ice road, which crosses the study river about 25 km south of the confluence with Môso-sîpiy (Fig. 1).

The natural and unregulated water level and discharge of the North French River varies considerably throughout the year. The mean discharge during the 6 yr study period (2016–2022) was 105 m^3 s^{-1}, but the maximum discharge during the spring freshet was typically above 500 m^3 s^{-1}, and occasionally above 1000 m^3 s^{-1} (ECCC 2020; Fig. 2). Discharge was considerably reduced during the summer, with a 40 m^3 s^{-1} rate on average (ECCC 2020; Fig. 2). The North French River is approximately 500 m across at its widest extent, with some pools that retain a depth of 4 m or more year-round. There is an abundance of shallow areas (<1 m) and rocky rapids. We retrieved data from temperature loggers in the North French River only between June 2018 and October 2020 which were deployed approximately 2 m below the water surface, and at this depth, overall annual mean water temperature was 7°C. Water temperatures were, on average, <4°C for 54% of each year, and >20°C for 14% of each year. Several groundwater seeps feed into the North French River, which keep water temperatures cool in the local area of the seeps throughout the year (A. Litvinov pers. comm.). During the winter, there is complete ice coverage of the river surface, followed by intense ice movement during the ice break-up period. On average, there was ice coverage for 48% of each year during the 6 yr study period (ECCC 2020).

On the advice of the Moose Cree Elders Advisory Group, and Ililiwak Knowledge Holders, we focused on the farthest downstream section of the watershed because of its cultural significance (Fig. 1). This sec-

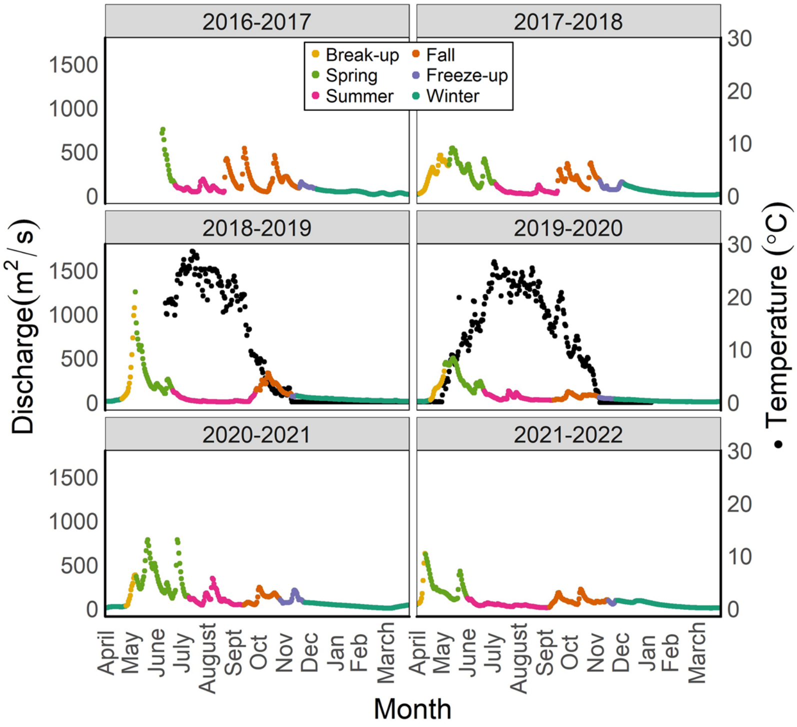


Fig. 2. North French River flow discharge (m^3 s^{-1}) at Station 04MF001 (ECCC 2020), which was used to classify seasons in this study, and water temperature approximately 2 m below the water surface for the period when temperature loggers were retrieved. Colours indicate the delineations of the 6 seasons over the 6 yr study (June 2016 to May 2022) and correspond to the left axis (discharge); black indicates water temperature and corresponds to the right axis (temperature)

tion is about 55 km in length, bounded at the southern upstream extent by a waterfall that may be a barrier to namew movement. At the northern, downstream, extent, there are no barriers between the North French River and the Môso-sîpiy.

2.2. Acoustic telemetry

Acoustic telemetry was used to passively track namew within a ~45 km study area of the lower North French River for 6 yr between June 2016 and May 2022. In practice, acoustic telemetry uses a series of transmitters (on or in fish) to emit sound signals ('transmissions'), and receivers (anchored in the water) to detect and log these transmissions. The transmitters are small electronic tags that emit coded information about the fish at a pre-programmed interval (GLATOS 2023). Receivers are data-logging computers that detect the transmissions and store the information from these detections until the receivers are retrieved and the information is downloaded to a laptop computer or tablet (Thorstad et al. 2013).

2.2.1. Receiver array

We used Vemco VR2W receivers (Innovasea Systems) to track namew in the study river. We did not have enough receivers for full receiver coverage of the approximate 55 km lower reach of the North French River, so we placed up to 8 receivers in selected locations, approximately 5 km apart (see Table S1 in the Supplement at www.int-res.com/articles/suppl/n054p059_supp.pdf) along most (about 45 km) of the river reach (Fig. 1). We based selected locations on discussions with Iliiliwak Knowledge Holders, who requested we present these data publicly at the level of general river sections. Therefore, we divided the river into 4 sections of similar length, and we present our data aggregated to these sections. As described above, the only industrial or transportation feature on the North French River is a seasonal winter road, also known as an ice road, which crosses the river about 30 km south of the confluence with the Môso-sîpiy (Fig. 1). The river is shallow at the winter road crossing, and it is possible that the river ice reaches to the river bottom and becomes impassable for fish during the winter. We therefore divided the river based on the position of the winter road, with 2 sections downstream from the winter road, and 2 sections upstream (south) of the winter road. Each section is about 14 km in length (mean = 14.40 km; range = 13.33–15.96 km; Fig. 1).

We anchored all receivers approximately 1 m off the substrate using 12-strand high modulus polyethylene fibre rope tied through eyebolts affixed to granite blocks that were approximately 40 kg each. Floats held the receivers upright and were at least 2 m below the water surface to avoid being encapsulated in surface ice. Most anchors were tethered loosely to trees on shore using a 100–200 m length of steel cable, to aid with finding and retrieving the receivers. However, a few anchors were instead double-anchored to a secondary, smaller (approximately 20 kg) granite block using a steel cable, and we retrieved them by grappling between the anchors for the cable. We had greater success with retrieving shore-tethered receivers compared to double-anchored receivers, and this may have been because receivers in this river became buried. We had 2 cases where we could locate the receivers using a VR100 manual receiver deck (Innovasea Systems), but despite multiple attempts could not retrieve the receivers.

Moose Cree First Nation community members and scientists worked together for all receiver deployment and maintenance. This relationship included community land users and Knowledge Holders, Indigenous business owners, and Indigenous youth. Members of the field team received pay for time, effort, and knowledge which helped the project, and Elders received honoraria for their participation in the project. The only exception was in the field season of 2020, when COVID-19 pandemic restrictions prevented non-community members from travelling to the study site; thus, only Moose Cree First Nation community members undertook the fieldwork. Uncertainty about the duration of COVID-19 restrictions meant that we decided to remove most receivers in October 2020, and then deployed all receivers again in May 2021 (see Table S1 for full description of receiver number and coverage). Receivers were also occasionally lost to the ice over the winter. Because of unpredictable receiver loss, the length of receiver coverage and number of receivers throughout the study period was variable. River receiver coverage spanned 38–51 km, and we retrieved data from between 5 and 8 receivers for most of the study duration (except between October 2020 and May 2021, mentioned above, where we only had data from 1 receiver; Table S1).

2.2.2. Range testing and detection efficiency

We performed a preliminary and coarse manual range testing in June 2016 using an anchored V16 transmitter tag on high transmission power (158 dB) and a VR100 manual receiver deck. We tested whether the VR100 manual receiver was able to detect the expected number of transmissions at increasing distances between 250 and 1250 m. To determine how detection efficiency varies across the year, we deployed an additional VR2Tx receiver (Innovasea Systems) approximately 400 m from one of our VR2W receivers between June 2018 and May 2019, and approximately 600 m from one of the VR2W receivers between May 2021 and May 2022. We programmed this VR2Tx receiver to transmit a signal every 10 min on lower power (148 dB) at 400 m in 2018–2019, and on high power (154 dB) at 600 m in 2021–2022. We attempted 2 other distances, but unfortunately lost the corresponding VR2W receivers. However, with the data we retrieved, we calculated the daily detection efficiency (i.e. the percentage of expected detections received on the nearby VR2W receiver each day) to understand how detection efficiency at these distances and power levels changed through the year. For range and detection efficiency findings, see Section 3.

2.2.3. Calculating detection efficiency

We calculated the daily detection efficiency for each VR2Tx and VR2W receiver pair by dividing the number of transmissions per day on the VR2W receiver by the expected number of transmissions from the VR2Tx and multiplying by 100% to get a percentage detection efficiency. From this daily detection efficiency, we understand how detection efficiency at a given distance and power level changed through the year. Typically, the distance at which a receiver under ‘worst-case scenario’ detects 50% of expected transmissions is considered the reliable range of a transmitter and receiver pair (Innovasea Systems 2020).

2.2.4. Acoustic tags

We used 3 types of Vemco transmitters (Innovasea Systems): V16, V13AP, and V13P transmitter tags (see Table 1). The V16 tags (68 mm long, 24 g in air) transmit a unique identifying signal that is associated with a fish ID, on an 80–160 s random interval, on high power (158 dB), and have a battery life of 2435 d. The V13AP tags (50 mm long, 13 g in air) transmit fish ID, and values of pressure (i.e. a measure of depth) and acceleration (i.e. a measure of general activity, reported as a root mean square value of measured acceleration on 3 axes), on lower power (147 dB), and have a battery life of 364–460 d. The V13P tags (39 mm long, 11 g in air) transmit fish ID and pressure on lower power (147 dB), and have a battery life of 778 d. Both V13AP and V13P tags transmit on a 50–130 s random interval. See Table 1 for full details.

2.3. Namew capture, tagging, and sampling

We caught 20 namew at 5 sites within our study area on the following dates: 10–13 June 2016; 9–11 June 2018; and 8–10 October 2018 (Table 1). Sites were selected based on conversations with and the guidance of Iliiliwak Knowledge Holders during the sampling process on the river. Most namew were captured using bottom set 178 mm mesh gillnets, although a small number of namew during June 2016 were caught using baited trot lines with 7/0 Octopus hooks. We typically deployed net sets overnight (approximately 12 h); however, in a few instances, they were set during the day, and those were checked approximately every 3 h. Because gillnet mesh size was large, we had very few instances of bycatch, and had no mortalities of namew. All namew were released displaying no reflex impairment (McLean et al. 2016). After checking nets or lines, we transported captured namew to shore sampling sites in 190 l bins filled with fresh river water. Namew were held before tagging in a 2300 l pool filled with fresh river water and covered with tarps to minimize stress. Water was refreshed regularly with river water to regulate temperature and oxygen levels.

Moose Cree First Nation community members, including Knowledge Holders, traditional land users, and youth, worked alongside our team for all namew tagging and sampling, including the methodology and procedures described herein, with the exception of the surgical tag implantation, which was performed only by trained members of our research team. For sampling and tagging, we removed namew by hand from the pool, and placed them on their dorsal side on a rubber mesh fish sling submerged in a 190 l bin filled with fresh river water, ensuring water was continuously circulating over their gills. In 2016, we used river water containing the lowest possible dose of anaesthetic solution (Aqualife tricaine methane-sulfonate buffered with sodium bicarbonate; Syndel Laboratories) required to achieve stage-2 anaesthesia (loss of gross motor movements but retention of opercular movements). The dose ranged between 12.5 and a maximum of 50 mg l^{-1} only if necessary to sedate namew for tagging. Because these namew are part of a subsistence fishery, we put up notices in public areas in Moose Factory, on Facebook, and spoke to individuals known to participate in the subsistence fishery, to inform them that we were conducting the study, and fish should not be consumed within 30 d of using this anaesthetic solution. We switched to electric fish handling gloves (Smith-Root) to immobilize namew for tagging in 2018 and onwards, because it eliminated the use of chemicals and any potential impacts with subsistence fisheries and community harvesters. As has been previously reported (Ward et al. 2017, Ackerman et al. 2020), electroanaesthesia achieved effective immobilization and reduced the recovery period for the namew.

We disinfected all surgical equipment, as well as transmitter tags, in a solution of 10% poviodine-iodine prior to the surgical procedure. We implanted transmitter tags by making a small incision (<2 cm) with a scalpel on the midline slightly posterior to the pelvic girdle, inserted the disinfected tag into the intracoelomic cavity, and then closed the incision with 3 interrupted sutures using absorbable polydioxanone monofilament (3-0 PDS II with 24 mm FS-1 reverse cutting needle; Ethicon). After the surgical implantation, we collected blood samples (approximately 2 ml) for a different study using a 21-gauge, 38 mm length Vacutainer-style needle with a 4 ml lithium-heparinized Vacutainer (BD) in the ventral side of the caudal peduncle, anterior to the anal fin, perforating the skin between the scutes. We inserted a passive integrated transponder (PIT) tag into the dorsal muscle along the left side of the dorsal fin and collected a small caudal fin clip for a different study. Finally, we weighed the namew using a spring scale, measured body size, and took photos of the fish on a measuring board for another study. On average, the namew that were tagged measured 105 cm in total length (range = 79−147 cm) and weighed 8.3 kg (range = 3.0−17.5 kg; Table 1). The entire tagging and sampling operation for each namew took approximately 10 min total. In 2016, we placed namew back in the 2300 l pool to recover prior to release, since it sometimes took a few minutes for them to regain equilibrium and display unimpaired reflexes after the use of the chemical anaesthetic solution. In 2018, namew were released immediately if the sampling site was near the capture site or transported back to capture sites in 190 l bins for release. Because recovery was immediate with the use of electroanaesthesia, we could reduce overall holding time by eliminating the recovery pool. Namew were released by holding them upright in the river and letting them swim away on their own.

We had conversations with the Moose Cree Elders Advisory Group before we initiated any work on the study and confirmed through discussions that they understood and agreed to all sampling and fish handling approaches to be used. We captured fish under Ontario Ministry of Natural Resources and Forestry (MNRF) Licences to Collect Fish for Scientific Purpose (Licence Nos. 1083368, 1088952, and 1091198, in June 2016, June 2018, and October 2018, respectively). Our fish handling followed the conditions of these licences, and we adhered to the Lakehead University Animal Care Committee practices (AUP 06-2016).

2.4. Data processing and statistical analyses

We performed all data processing and analyses in R versions 3.5.3 and 4.1.2 (R Core Team 2020, 2021) and R Studio versions 1.1.463 and 1.3.959 (RStudio Team 2020). Packages used (and described in more detail below) were 'glatos' 0.3.0 (Binder et al. 2018, GLATOS 2019), 'tidyverse' (Wickham 2019), 'lubridate' (Spinu et al. 2020), 'nlme' (Pinheiro et al. 2023), and 'emmeans' (Lenth 2022).

2.4.1. Telemetry data filtering

In total, the receivers logged over 3 million (n = 3 471 642) raw detections between June 2016 and May 2022. First, we filtered the data using the 'glatos' package. False detections can occur when 2 tags within range of a receiver produce a signal at the same time, and the 2 signals collide, to produce a combined, incorrect transmitter ID code (Simpfendorfer et al. 2015). First, the 'glatos' false detection filter removes detections if they have an incorrect transmitter ID code or if they are either too close together (<30 s) or too far apart (>3600 s) to credibly represent true detections (Binder et al. 2018). We removed 3.03% of all raw detections (n = 105 380). Next, to mitigate any effects of handling (e.g. short-term changes in behaviour caused by the capture and tagging experience), we removed detections that occurred within the 7 d after tagging for each fish (n = 7582). We also separated all transmissions originating from the VR2Tx receivers (n = 103 267), which were used to calculate detection efficiencies (see below).

We paired VR2Tx receivers close to VR2W receivers for detection efficiency purposes, but VR2Tx receivers log fish detections in addition to the acoustic transmissions from VR2W receivers. However, we did not want to artificially increase our calculations of the distance travelled by fish by assuming that fish were moving back and forth between the 2 receivers, when they were probably stationary within the detection range of both receivers. Therefore, we first compared the transmissions detected each day at each VR2Tx receiver and at the paired VR2W receiver. There were only 2 cases where the VR2Tx receiver detected a transmission from a tagged namew on a day where the paired VR2W receiver did not; in both cases, this occurred on 2 sequential days. We retained the rare cases (n = 628 total detections for the 2 namew, each over 2 d) where the tagged namew were detected solely at the VR2Tx receiver. We removed all other namew detections that were logged in duplicate by the VR2Tx receivers (n = 154 828). Finally, the remaining namew detections logged by VR2W receivers or solely logged by VR2Tx receivers (final total filtered detections n = 3 100 585) were retained and used for further analyses.

2.4.2. Assigning seasons

We assessed seasonal differences in occupancy, movement, and behaviour (acceleration and depth use) of namew in the North French River. Following conversations with the Moose Cree Elders Advisory Group and community members involved in the project, we divided the year into 6 seasons: break-up, spring, summer, fall, freeze-up, and winter to match a common Iliiliwak view of seasonality. Since Iliiliwak seasons are based on natural events, and not by a specific time length, we defined the start and end of each season for our study based on some of the natural events that could be quantified, like river discharge and ice conditions. We also confirmed with community members that our delineations matched their understanding. The seasonal delineations therefore represent a combination of environmental metrics considered important for lake sturgeon (COSEWIC 2017, Moore et al. 2021) and a culturally relevant understanding of seasonality.

For our study, we primarily defined the beginning and end of each season by analyzing the flow discharge and water levels in the river throughout the year, using existing data (Government of Canada monitoring station #04MF001) that is in North French River near the confluence with the Môso-sîpiy (ECCC 2020). Discharge and water level fluctuate throughout the year depending on ice coverage, air temperature, and other physical factors, and these ice and water changes helped us define each of the 6 seasons (Fig. 2). We visualized and summarized the discharge data for the entire study period, and considered discharge values below the median (130 m^3 s^{-1}) to be lower discharge (i.e. lower water flow) and discharge values above the median to be higher discharge (i.e. higher water flow). We also examined the percent change in discharge day-to-day and considered a percent change of <3% to be stable. Finally, we considered B-flags in the hydrological data from Environment Canada. This hydrologic measure indicates the presence of ice near the river monitoring station as a hydrological metric influenced by ice (Rokaya et al. 2018). We then delineated the seasons based on discharge (i.e. higher or lower flows), change in discharge (i.e. stable or variable), and ice conditions (i.e. presence or absence of B-flags).

Overall, we used season-defining methods like methodologies described by Beltaos (1997), de Rham et al. (2008), and Lesack et al. (2013). We based the beginning of break-up on an increase in discharge by 3% d^{-1} or more from the sustained low and stable levels that defined the winter season. This higher and variable discharge continued through spring, but we considered the end of B-flags to indicate the ending of break-up and the start of spring. The ending of spring, and the start of summer, was based on when the water levels dropped to stable, lower discharge that was sustained through the warmer months (i.e. when the discharge stopped changing by 3% and dropped below the median). The ending of summer, and the start of fall, was marked by an increase in discharge of 3% and higher discharge levels (i.e. increased above the median). The start of B-flags marked the beginning of freeze-up. We based the ending of freeze-up, and the beginning of winter, on when the water levels dropped to stable, lower discharge levels that were sustained through the colder months (i.e. when the discharge stopped changing by 3% and dropped below the median). We verified the dates of season beginnings and endings produced from the flow and water level data through discussions with Moose Cree First Nation community members. We considered individual observations of the ice and timing of key seasonal events, such as the opening and closing of the winter road and the start and end of seasonal helicopter service, to help confirm winter, break-up, and freeze-up seasons annually.

2.4.3. Assigning diurnal periods

As another way of exploring variation in namew behaviour, we assessed potential diurnal effects on acceleration and depth use. We obtained sunrise and sunset times for 2016–2022 for the North French River at the centre point of our study area from the National Research Council Canada (NRCC 2020). For each day, we then assigned any detection occurring between an hour before the start of civil twilight and an hour after sunrise as 'dawn'; between an hour after sunrise and solar noon as 'morning'; between solar noon and an hour before sunset as 'afternoon'; between an hour before sunset and an hour after the end of civil twilight as 'dusk'; and any detection occurring more than an hour before the start of civil twilight or more than an hour after the end of civil twilight as 'night.'

2.4.4. Estimating namew occupancy

We determined namew use of each river section by calculating a 'seasonal occupancy percentage' which is the percentage of namew with active tags that we detected in each section on each day across the season. The seasonal occupancy percentage therefore lies between 0% (no tagged namew detected in a river section during that season) and 100% (all possible tagged namew detected in that section on all possible days). In theory, adding the sections together could give a value of more than 100% if namew moved between multiple sections each day; however, we found that only 6 namew moved between multiple sections within in a day across the entire study period. In calculating occupancy, we made no extrapolations or inferences for namew location when we did not detect a namew on a given day. If a namew was not detected on a day, its location was considered unknown for that day.

2.4.5. Estimating seasonal movement rates

To estimate namew movement in the study river, we calculated 'seasonal movement rate' as a proxy for longer-distance river movements of each fish in each season. We considered the midline river distance between each receiver to be an estimate of the distance travelled (m) by namew between receivers and then calculated the total distance travelled in a season (m) for each fish by summing the distance travelled between subsequent detections within each season. We controlled for different seasons having different lengths (in number of days) by dividing the total distance travelled by a namew in a season (m) by the total number of days in that season. This gives the final metric of seasonal movement rate (m d^{-1}) as a proxy of longer-distance namew movement.

Note that this is an underestimate of actual movement or distance travelled; this is because we are considering linear movements (along the river midline) between receivers, and animal movement is rarely linear (Turchin 1998). Furthermore, movement in and out of range of a single receiver would not contribute to the estimated movement rate, because subsequent detections would indicate the same receiver. Similarly, we could not detect or measure any movement outside of the range of the telemetry array. Thus, we consider these movement patterns a conservative estimate.

2.4.6. Processing namew acceleration and depth data

We converted raw data from V13AP and V13P tags to correct units using conversion equations provided by the manufacturer. Due to the relatively small number of namew with V13AP and V13P tags (n = 11; Table 1) and very large number of observations per namew per day (often approximately 1000 observations per fish per day), we reduced the bias caused by the non-independence of the observations by thinning the acceleration and depth data. To do so, we randomly selected 1 observation per fish per day using the random subset function within the 'tidyverse' package (Wickham 2019). We chose to use a randomly selected observation rather than using a summary metric (e.g. mean daily value, or similar) because doing so retained the time of day of the observation, which allowed us to examine variation in both season and diurnal period. We further reduced the bias by accounting for non-independence of data within the models (see below).

2.4.7. Statistical analyses

We had 2 seasons where we consistently did not observe any longer-distance namew movements between receivers during the period 2016–2022 and therefore could not perform statistical analyses for these seasons. We fit a generalized linear mixed model using the 'nlme' package (Pinheiro et al. 2023) to examine differences in longer-distance movements between the remaining 4 seasons. For acceleration and depth use, we fit separate generalized linear mixed models using the 'nlme' package (Pinheiro et al. 2023) using the randomly thinned data (see above). In these models for acceleration and depth, our predictor variables were season (break-up, spring, summer, fall, freeze-up, or winter) and time of day (dawn, morning, afternoon, dusk, and night). We also included an interaction effect between season and time of day in both the acceleration and depth model. For all models, individual fish ID was included as a random effect to account for repeated measures (Zuur et al. 2009), and we included a covariance structure term to reduce the bias caused by the temporal autocorrelation of measurements, because we collected our data over a range of space and time (Brownscombe et al. 2019). For longer-distance movements, we tested for post hoc differences between seasons, and for acceleration and depth, we tested post hoc pairwise differences between diurnal periods within season (i.e. the interaction effect) using least squared means with the 'emmeans' package (Lenth 2022). We verified the model fit by examining plots of residuals versus predicted values.

3. RESULTS

3.1. Detection efficiency of acoustic transmitters and receivers

Our tests were able to determine the reliable range distances under varying conditions. During our basic preliminary manual range testing in June 2016, we found that we were reliably able to detect 100% of expected transmissions from a high power (158 dB) tag at 250, 500, and 750 m with the VR100 receiver. This dropped considerably to approximately 50% of transmissions at 1000 m range, and we were unable to pick up transmissions by 1250 m.

Based on this preliminary and coarse test of range, we did a test of detection efficiency on high power (154 dB) at approximately 600 m in 2021–2022. We found that, except for on 11 days (27–28 May, 5 June, 17–19 and 21–22 November 2021; and 26–28 April 2022), at least 50% of all expected detections were logged each day by the receiver placed approximately 600 m away. The mean daily detection efficiency was 98% during the winter and 86% during the period with open water or partial ice coverage. Overall, we considered that our range was at least 600 m with the high power (V16) tags based on the preliminary range test and overall high detection efficiency at 600 m.

During our test of the detection efficiency at lower power (148 dB; which corresponds closely to the V13AP and V13P tags at 147 dB) at approximately 400 m, we found that our detection efficiency was considerably lower. We found the mean daily detection efficiency was 27% during the winter and 44% during the period with open water or partial ice coverage. Given the overall lower detection efficiency, we concluded that our range was <400 m for the V13AP and V13P tags, but we could not be certain how much lower. The detection efficiency at the ranges we tested indicates that our reliable range also varied considerably throughout the year, which is typical of acoustic telemetry arrays, which are affected by the changes in ambient noise caused by water levels and ice conditions (see review by Kessel et al. 2014). We attempted to do another range test at a closer distance in 2019–2020, but unfortunately lost the receiver to ice. Because we could not determine the reliable range where we could detect 50% of transmissions under a worst-case scenario for the lower-power tags, we chose to be conservative in our assumptions about namew detection, and we did not attempt to extrapolate namew location between detections, in case of missed detections. Despite our conservative estimate, our detection radius (i.e. <400 m) is slightly larger than that of a similar field study for lake sturgeon in which the detection radius was estimated at 350 m (Barth et al. 2011) and presents generally acceptable efficiencies (Kessel et al. 2014).

The North French River is approximately 500 m at its widest extent and narrower at all receiver locations. Because of the width of the study river and our calculated range and detection efficiency, we are confident that we could detect namew tagged with high-power tags (V16 tags) across the width of the river with our telemetry array if they swam past. However, we recognize that under noisy conditions, we may not have detected all namew with lower-power tags (V13AP tags) moving past receivers. Therefore, if we did not detect a namew, we considered it as having an unknown location rather than extrapolating based on the last known detection. Future studies could consider solely using high power (e.g. V16) tags, or if not possible, then increasing receiver coverage in studies where lower-power (e.g. V13AP) tags are used, to enable more fine-scale analyses of namew or fish movement.

3.2. Namew tagging and detection

All tagged namew in the North French River in 2016 and 2018 (n = 20; Table 1) were regularly detected for at least 7 mo (Fish 17) after tagging and several namew were regularly detected for considerably longer. Of these 20 namew, 11 remained (Fish 01–06, Fish 08–11, and Fish 15) in the study area and were recorded by the receiver array for the full duration of the study period or until the tags expired (Table 1). We observed all these namew within 10 d of either the most recent receiver download or the estimated end of battery life of their tag. For 7 namew (Fish 13, Fish 14, and Fish 16–20), we had no observations within 30 d of the estimated end of battery life of their tags. However, all of these namew had tags with a battery life that ended between May 2019 and May 2021, when we had significantly reduced receiver coverage due to receiver loss and logistic constraints on fieldwork due to COVID-19 (Table S1). Therefore, we speculate that these namew likely survived to the end of the battery life of their transmitters, and the lack of detection was due to the reduced receiver array. A Moose Cree subsistence fisher retained 1 of the tagged namew (Fish 07; Table 1) in May 2018 and returned the tag to our team. Fish 12 was detected

Table 1. Summary information for tagged namew (n = 20) passively tracked over the 6 yr study (June 2016 to May 2022) in the North French River, Ontario, Canada. ID: serial number of tag; A: acceleration; P: pressure (used to calculate depth). Dates are given as yr-mo-d

Fish ID	Tagging date	Type of tag	Information transmitted by tag	Expected tag battery life (d)	Date of last detection	Total length (cm)	Fork length (cm)	Mass (kg)
Fish 01	2016-06-10	V16	ID	2435	2022-05-10	141	128	16
Fish 02	2016-06-10	V13AP	ID, A, P	364	2017-06-10	117	106	11
Fish 03	2016-06-10	V13AP	ID, A, P	364	2017-06-14	83	73	4.5
Fish 04	2016-06-10	V13AP	ID, A, P	364	2017-06-06	79	71	4.5
Fish 05	2016-06-11	V16	ID	2435	2022-05-02	89	87	6.5
Fish 06	2016-06-11	V13AP	ID, A, P	364	2017-06-15	147	136	17.5
Fish 07	2016-06-11	V16	ID	2435	2018-05-12	108	97.5	8.5
Fish 08	2016-06-11	V16	ID	2435	2022-05-09	109.5	96.5	7.7
Fish 09	2016-06-11	V16	ID	2435	2022-04-30	114.8	103.4	9.6
Fish 10	2016-06-12	V16	ID	2435	2022-05-01	98.2	88.4	7.1
Fish 11	2016-06-12	V16	ID	2435	2022-05-02	90.9	81.4	5.8
Fish 12	2016-06-12	V16	ID	2435	2020-10-16	117.2	110.5	11.6
Fish 13	2018-06-10	V13AP	ID, A, P	460	2019-05-14	130	–	15.5
Fish 14	2018-06-10	V13P	ID, P	778	2019-04-30	100	92.5	7.5
Fish 15	2018-06-10	V16	ID	2435	2022-04-30	121	114	12
Fish 16	2018-06-11	V13AP	ID, A, P	460	2019-08-14	91	81	5
Fish 17	2018-10-08	V13AP	ID, A, P	460	2019-05-09	87.5	77	3
Fish 18	2018-10-08	V13AP	ID, A, P	460	2019-07-21	98.5	93	5.4
Fish 19	2018-10-09	V13AP	ID, A, P	460	2019-10-19	81	71	3
Fish 20	2018-10-10	V13P	ID, P	778	2020-08-25	88	76.5	3.9
Minimum						79.0	71.0	3.0
Maximum						147.0	136.0	17.5
Mean						104.6	93.9	8.3

regularly for >4 yr after tagging: similar to Fish 01 and Fish 08–11. However, unlike these other namew, Fish 12 was undetected after October 2020, when it is possible that it was captured or left the study area (observed in the most upstream section).

3.3. Namew occupancy

Namew occupied all sections of the North French River throughout the study period (Fig. 3). By far, namew most frequently occupied the section directly upstream (south) of the winter road across all seasons (Fig. 3). Although there were typically more receivers in the section upstream of the winter road compared to other sections (Table S1), namew disproportionately occupied the section upstream of the winter road, even after taking differences in receiver numbers into account. For example, if detections were randomly distributed among receivers, we would expect approximately 40% of detections to occur within this section upstream of the winter road, 30% of detections in the section farthest upstream (south), and 14% of detections in each section downstream of the winter road. However, 94% of total detections occred in the section upstream of the winter road (compared to 40% expected if detections were random), demonstrating that receiver distribution alone does not explain the differences in namew detections observed among sections. Namew occupied all 4 sections of the river during the ice-free periods of the year (i.e. spring, summer, and fall; Fig. 3). However, namew were only detected in the section above (upstream/south of) the winter road, and in the most downstream (northernmost) section, during the seasons affected by the presence of ice (i.e. freeze-up, winter, and break-up; Fig. 3).

3.4. Seasonal effects on namew movement, acceleration, and depth use

We documented no movement between receivers in freeze-up and winter (i.e. all seasonal movement rates = 0.0 m d^{-1} for those 2 seasons). Therefore, we could not run models including these seasons. When we ran statistical analyses on the remaining 4 seasons, we found that seasonal movement was higher in the spring and summer relative to fall and break-up (ANOVA, df =3, $F = 10.9$, $p < 0.001$; Fig. 4; Tables S2 & S3).

We found significant main effects of both season (ANOVA, df = 5, $F = 71.97$, $p < 0.001$ for acceleration and $F = 34.18$, $p < 0.001$ for depth) and diurnal periods (ANOVA, df = 4, $F = 33.15$, $p < 0.001$ for acceleration and $F = 46.74$, $p < 0.001$ for depth) on both namew acceleration and depth use, respectively (Table 2). We also found a significant interaction effect between season and diurnal period (ANOVA, df = 20, $F = 1.93$, $p < 0.01$ for acceleration and $F = 5.19$, $p < 0.001$ for depth) on both namew acceleration and depth use (Table 2). We therefore assessed differences among diurnal periods within seasons using post hoc pairwise comparisons (Tables S4 & S5) and found that namew acceleration (which is a measure of acceleration in 3 dimensions and indicates overall fish activity) was generally highest in the spring and summer and lowest in the ice-affected seasons (break-up, freeze-up, and winter). During most seasons, namew acceleration was lowest during morning and afternoon. However, this pattern was absent in the spring, where there were no diurnal acceleration patterns. Namew acceleration was highest at night during the ice-affected seasons, highest at dawn in the summer, and highest and dawn and night in the fall (Fig. 5; Fig. S1, Table S4).

Namew generally occupied the shallowest depths in the summer and the deepest during freeze-up. The impact of diurnal periods on namew depth use was less modest, but still detectable. During most seasons, namew were recorded in shallower water at dawn and night relative to the morning, afternoon, and dusk, and this pattern was more pronounced during break-up and fall. However, in the spring, namew were at shallower depths in the morning and afternoon and deeper at dawn. Namew also showed the most variation in depth use in the spring (Fig. 5; Fig. S1, Table S5).

4. DISCUSSION

Our co-created study used acoustic telemetry to understand namew movement and behaviour in the North French River, an intact river that is culturally important to Moose Cree First Nation, over a period of 6 yr (2016–2022). Namew showed distinct preferences for one section of the study river, upstream (or south) of the winter road, particularly during winter. Additionally, we found that namew tended to be less active in the ice-affected seasons, with the greatest acceleration and highest longer-distance seasonal movement rates in the spring and summer. Namew were generally at the shallowest depths in the summer and deepest during freeze-up. There was an interaction effect between season and diurnal period for both namew acceleration and depth use, where namew occupied deeper water and had lower acceleration during the morning and afternoon and occu-

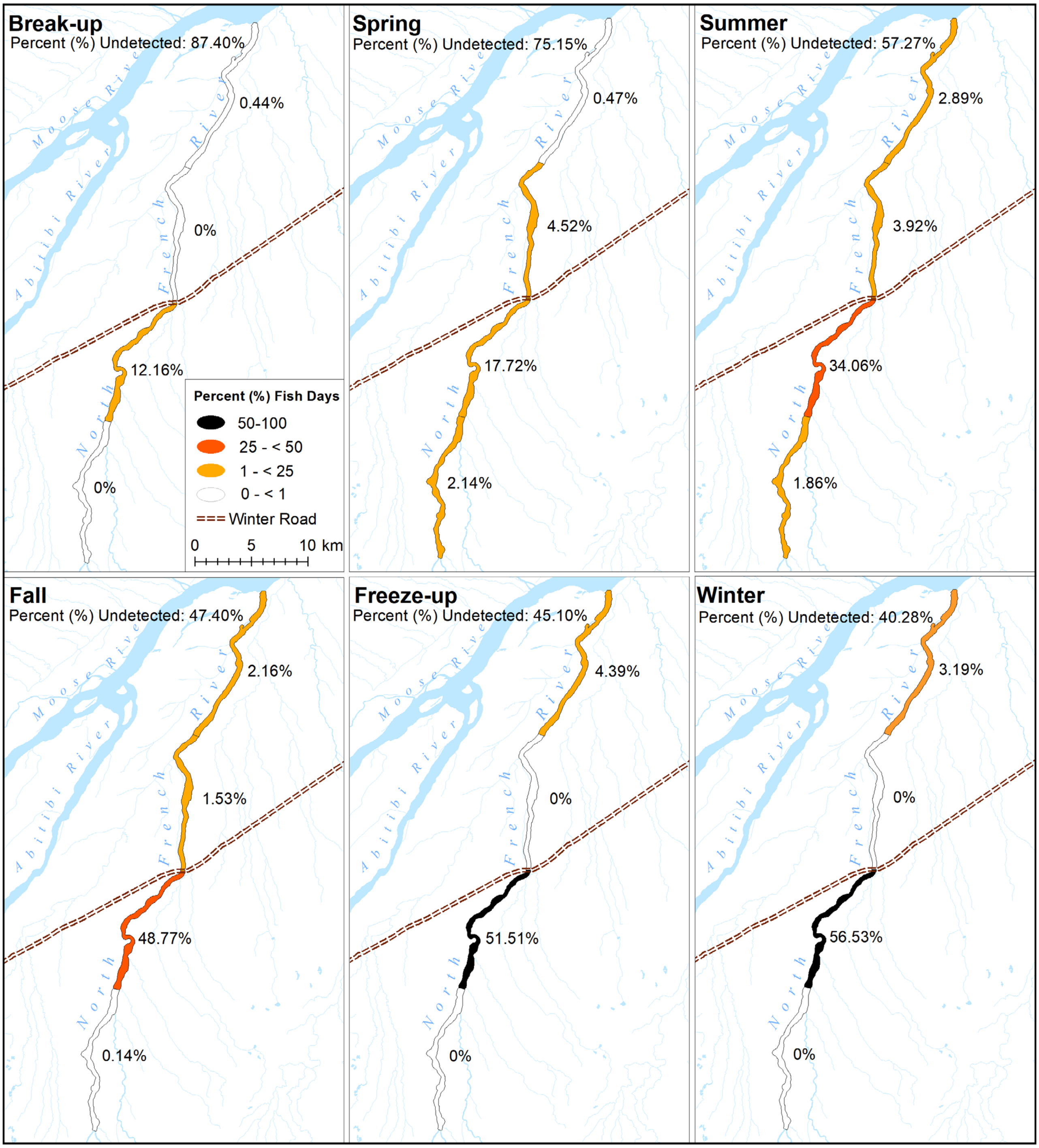


Fig. 3. Namew (n = 20) occupancy in 4 river sections in the North French River during 6 seasons (break-up, spring, summer, fall, freeze-up, winter). The percentages shown are the mean seasonal values over the 6 yr study (June 2016 to May 2022) for seasonal occupancy percentage of namew with active tags that were detected in each section on each day across the season. Seasonal occupancy percentages therefore lie between 0% (no tagged fish detected in a river section during that season) to 100% (all possible tagged fish detected in that section on all possible days)

pied shallower water and had higher acceleration at night and dawn in most seasons. However, the pattern of depth use was reversed in the spring, with namew occupying shallower water during morning and afternoon and showing no diurnal patterns of acceleration in the spring. Diurnal patterns of depth use were less

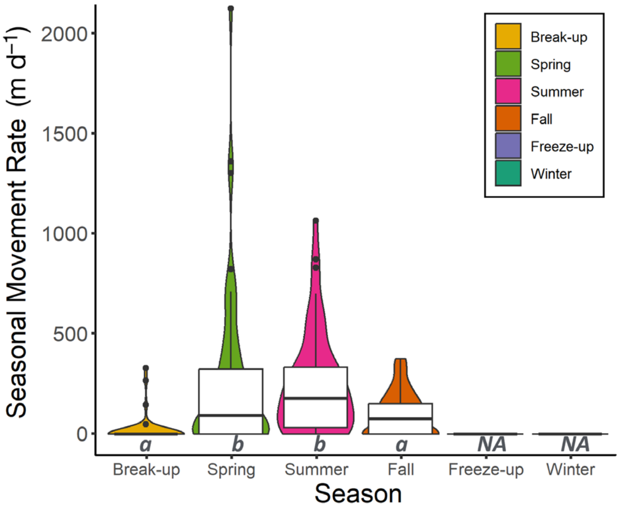


Fig. 4. Seasonal movement rate of tagged namew (n = 20) in the North French River during 6 seasons (break-up, spring, summer, fall, freeze-up, winter) during the 6 yr study (June 2016 to May 2022). This metric only captures longer-distance movements between receivers. Width of the violin plot represents the number of observations at that value. Dots represent outliers. The box plots within the violin plots represent the quartiles and 95% confidence intervals. Lowercase letters underneath represent significant differences in seasonal movement rate between seasons based on post hoc pairwise comparisons of the 4-season model, with 'NA' denoting where freeze-up and winter were not included in the statistical analyses, because there were no movements between receivers in those seasons (see Section 3.4)

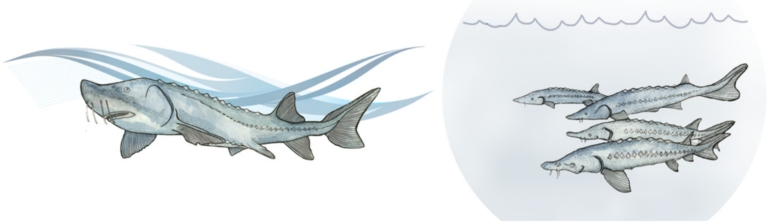
pronounced but still present during winter. These patterns give us a clearer understanding of how namew use this river, their behaviour, and the seasonal and diurnal influences on these important fish. Results are important for informing Moose Cree First Nation monitoring and decision-making processes and provide a helpful reference for conservation of sturgeon in other, more impacted areas.

4.1. The importance of a co-created approach to research

Indigenous Peoples play a globally important role in conservation, with lands managed by Indigenous Peoples contributing disproportionately to global biodiversity and representing many of the remaining intact ecosystems (Garnett et al. 2018, Schuster et al. 2019). Further, there is clear evidence that when Indigenous Peoples play a central role in decision-making, there are more positive conservation and social outcomes (Dawson et al. 2021). There are increasing efforts to develop frameworks and guidance to co-create knowledge and research more equitably with Indigenous communities (e.g. Hessami et al. 2021, Reid et al. 2021), and we have tried in our work to follow these frameworks when possible and to develop and continually adapt our own approaches through our ongoing relationship.

In this work, we used a co-created approach with Moose Cree First Nation to design, implement, and interpret a scientific study to address community priorities for knowledge gathering. Historically, most environmental studies have not been designed to address the needs of Indigenous communities, results have often not been communicated back to Indigenous communities, and Indigenous Peoples have not benefited from the research that has taken place on their Homelands. In this case, however, the study was designed from the start with Moose Cree First Nation, intended to generate information to guide Moose Cree First Nation decision-making and to contribute to a larger Moose Cree First Nation environmental monitoring program. We designed and communicated the work with guidance from the Elders Advisory Group, and we had the involvement of Knowledge Holders in the entire research process. Collectively, these efforts have meant that the information generated is relevant and accessible for Moose Cree First Nation decision-making, and the information supports Moose Cree First Nation's efforts to look after the land. We believe that our work can serve as one example

Table 2. *F*- and p-values for models investigating the effect of season (break-up, spring, summer, fall, freeze-up, winter), diurnal period (dawn, morning, afternoon, dusk, night), and the interaction effect on namew acceleration and depth. We included fish ID as a random effect, and included a covariance structure term to account for temporal autocorrelation. Artwork by Shannon Kitley



	Acceleration (m s^{-2})		Depth (m)	
	F	p	*F*	p
Season	71.97	< 0.001	34.18	< 0.001
Diurnal period	33.15	< 0.001	46.74	< 0.001
Interaction	1.93	0.008	5.19	< 0.001

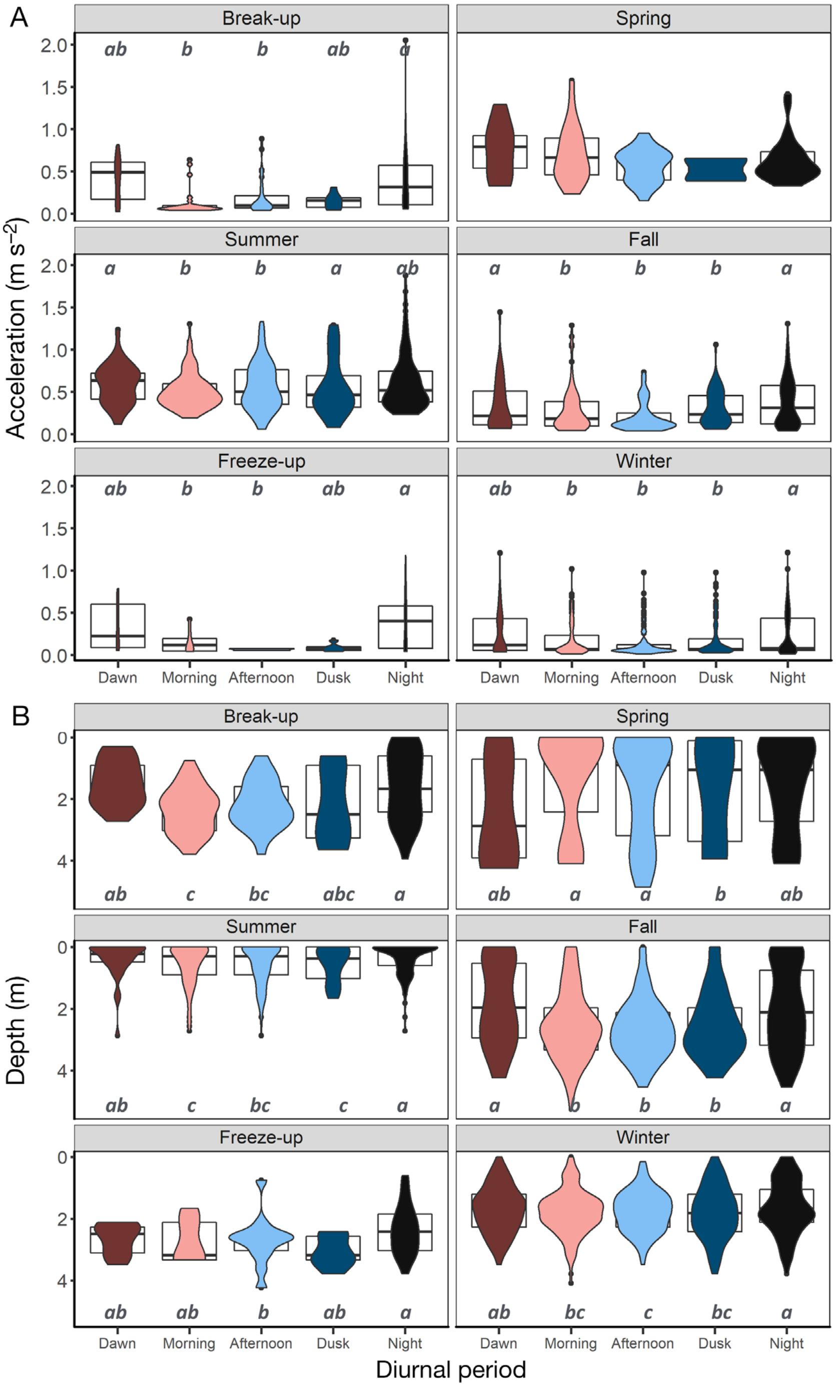


Fig. 5. (A) Acceleration and (B) depth of tagged namew in the North French River between June 2016 and June 2017 (n = 4 for both acceleration and depth), as well as between June 2018 and June 2019 (n = 5 for acceleration; n = 7 for depth). Acceleration and depth data are shown for 5 diurnal periods (dawn, morning, afternoon, dusk, night) within 6 seasons (break-up, spring, summer, fall, freeze-up, winter). Width of the violin plot represents the number of observations at that value. Dots represent outliers. The box plots within the violin plots represent the quartiles and 95% confidence intervals. Lower case letters above (A) and underneath (B) each graph represent significant differences among each diurnal period within each season based on post hoc pairwise comparisons of the interaction effect, which was found to be significant in overall models for both acceleration and depth

of a co-created approach to research that makes environmental research more useful, more likely to have positive outcomes for conservation, and where local communities are more likely to benefit from the process and results of the research.

4.2. Namew show high core habitat use with occasional long-distance movements

4.2.1. Namew show high core habitat use, particularly in winter

During the study period, all tagged namew (n = 20) were detected within the river section directly upstream (south) of the winter road; some (n = 7) were never detected outside of this river section, indicating clear preference for a ‘core’ area. This result is consistent with other studies documenting that lake sturgeon use core areas (Fortin et al. 1993, Knights et al. 2002, Haxton 2003, Barth et al. 2011), as do other sturgeon species such as the Gulf sturgeon *Acipenser oxyrinchus desotoi* (Sulak et al. 2009) and green sturgeon *A. medirostris* (Erickson et al. 2002). This has also been demonstrated in past research on the Môso-sîpiy, between the Apihtipîŝtik and Kwetabohigan River, Ontario, Canada, the latter of which is about 6 km upstream of the confluence with the North French River (Threader & Broussaeu 1986). In that study, all namew were captured within 5 km of their original tagging site after 1 yr (Threader & Broussaeu 1986). However, our results add to those of Threader & Broussaeu (1986), in that we tracked namew for 6 yr and still found similar behaviour.

In general, we did not observe namew moving between receivers often, indicating that fish were relatively resident (i.e. moving <5 km, which was a typical distance between receivers in our study river) in most seasons. This resident behaviour was most obvious during freeze-up and winter. The North French

River completely ices over during winter, beginning during freeze-up and ending during break-up, which can cause shallow areas to completely ice through from surface to substrate and which may create seasonal physical barriers to river movement. Because of this, reduced travel throughout the study river during winter is predictable and is what we observed in the North French River (0 m d^{-1}), and this has been documented previously in other populations of sturgeon (Harkness & Dymond 1961, Scott & Crossman 1973, Rusak & Mosindy 1997, Knights et al. 2002). Winter lake sturgeon movement rates in lentic environments, like Lake of the Woods, Canada and USA, are higher (about 1100 m d^{-1}; Rusak & Mosindy 1997), and greater distances travelled during ice-affected seasons may be more possible for lake sturgeon in deeper water (such as Lake of the Woods; Rusak & Mosindy 1997). In the North French River, namew were most commonly found in the river section upstream of the winter road and occasionally found in the river section farthest downstream. This indicates 2 identified suitable overwintering areas. Identifying these overwintering areas is important for lake sturgeon conservation efforts, as they have the potential to act as a 'temporal bottleneck' for populations, where a concentrated area and reduced movement makes lake sturgeon vulnerable to any existing or potential impacts (Thayer et al. 2017).

Based on both Iliiwak knowledge of namew locations and on the intense use of a core area by namew documented here, namew use the river section upstream (south) of the winter road throughout the year. Furthermore, it is likely that this section provides suitable habitat for multiple biological functions for namew (i.e. overwintering and feeding). Barth et al. (2011) concluded similarly that year-round habitat requirements could be met for lake sturgeon within short river sections relative to the length of the whole river in some cases. However, we also captured all namew in the current study in the same section upstream of the winter road identified as a core use area. Future research could attempt to capture namew outside of that section to understand if this observed core area is related to habitat quality or site fidelity and to identify if there are other high-quality areas in the North French River that we did not identify in our study.

4.2.2. Namew make occasional long-distance migrations, and use the whole river reach

Despite the general pattern of core-use areas described above, we did observe namew making some long-distance migrations during the 6 yr (2016–2022) study period in the North French River. Lake sturgeon are known to travel long distances, of up to 198 km (over a period of about 6 mo, at 1100 m d^{-1}; Knights et al. 2002) and 456 km (>31 d, at 14 700 m d^{-1}; Auer 1999) in other freshwater systems. Conversely, some populations of lake sturgeon travel lesser distances; for example, a mean total linear distance of 15.5 km in 83 d (180 m d^{-1}) was reported in the Sturgeon River, Michigan, USA, which is a more developed, less intact river (Holtgren & Auer 2004). We did observe occasional long migrations by namew, particularly in spring and summer, and these migrations in our study took place over only a few days. Here, in the North French River, the longest single journey that we recorded was 47.3 km in 2 d (Fish 09, June 2018). Other namew also made considerable journeys in short periods, including Fish 15 travelling 22.3 km in 2 d in June 2019. These longer movements in short periods are comparable to movements reported by Eccelstone et al. (2020), who found lake sturgeon travelling about 100 km in 10 d in the Pic River, Ontario, Canada, a tributary of Lake Superior. However, as noted above, longer-distance movements were infrequent, and mean annual distance travelled by namew in our study area was only 24.3 km yr^{-1} (60 m d^{-1}).

In general, the seasonal movement rates of namew in the North French River (median = 0 m d^{-1}; mean = 110 m d^{-1}; range = 0–2125 m d^{-1}) fall within the documented movement rates for lake sturgeon. Trembath (2013), Rusak & Mosindy (1997), and Holtgren & Auer (2004) found a similar range of juvenile lake sturgeon movement rate at 40–1030, 110–840, and 300–1600 m d^{-1}, respectively. Namew movement rates in the North French River were higher, on average, than tagged lake sturgeon in the Rainy River, Minnesota (USA)/Ontario (Canada) watershed where maximum movement rates only reached 800 m d^{-1} during June and May (Adams et al. 2006). Namew in the North French River also had higher movement rates than those of namew in the Mattagami River, Ontario, which has several large hydroelectric facilities, and where daily maximum distance travelled only reached 500 m d^{-1} (McKinley et al. 1998). However, we also note that we only had receiver coverage for about 45 km of the North French River for most of the study period, and fish may have moved in and out of the study area. Further, our metric of seasonal movement rate is an underestimate, given the distances between our receivers, and we could not measure any movement that was not detected by the next receiver. Therefore, namew almost certainly travelled farther than we have documented here.

Overall, while namew in our study did primarily use a core area, they were detected in all river sections of the North French River (Fig. 3), demonstrating that most of these fish do make use of the entire river reach where we had receivers. This is similar to a comparable genetic study of an intact river, which showed a related lake sturgeon population using the entirety of an approximately 100 km intact reach of the Attawapiskat River in northern Ontario (Haxton et al. 2018) and is consistent with a pattern of high core use between long-distance migrations (see review by Cleator et al. 2010). Our findings demonstrate that despite long periods of resident behaviour in core areas of the river, namew do intermittently make long migrations and use large areas of intact rivers. Studies and conservation efforts for sturgeon species should consider this, particularly if data are only collected over a short period of time or are from few individuals, since there is risk that the amount of habitat used could be underrepresented.

4.3. Namew show distinct seasonal patterns in movement and behaviour

4.3.1. Namew exhibit 2-step migration

We observed a general seasonal pattern of intense core use in the winter and longer migrations and more wide-ranging occupancy in the warmer months in namew in the North French River. This pattern has been called 2-step sturgeon migration, where sturgeon species migrate to overwintering areas in the fall and migrate back to spawning ground areas in the spring (Bemis & Kynard 1997, Peterson et al. 2007). Determination of the exact spawning site was outside the scope of this study. However, knowing that most namew were regularly detected within the monitored river sections, including during the spawning period, we can assume that the North French River also provides spawning grounds for namew. Seasonal use of river sections or habitat areas by lake sturgeon has been demonstrated in other systems (Rusak & Mosindy 1997, Adams et al. 2006) as well as in other sturgeon species, including Atlantic sturgeon *A. oxyrinchus oxyrinchus* (Ingram & Peterson 2016, Vine et al. 2019) Gulf sturgeon (Peterson et al. 2016), and lake sturgeon (Rusak & Mossindy 1997, Adams et al. 2006). Other studies have similarly found that some individual lake sturgeon will remain in overwintering areas, while others show seasonal movement patterns in and out of overwintering areas in spring and fall, e.g. in the Winnipeg River, Manitoba, Canada (Barth et al. 2011). Our findings are also similar to a recent long-term study which demonstrated that lake sturgeon used the entire Blanche River, Ontario, (about 54 km) and used different river sections only during the spring and summer season (McDonald & Haxton 2023).

4.3.2. Namew make more long-distance movements and have higher acceleration in the spring and summer relative to ice-affected seasons

As well as documenting more longer-distance movements during warmer months, our acceleration data, as a measurement of general activity, demonstrates that namew acceleration was higher in spring and summer in the North French River, likely in response to hydrological and temperature shifts. Borkholder et al. (2002) found that lake sturgeon movements were related to changes in river discharge, while McKinley et al. (1998) and Struthers et al. (2017) observed that lake sturgeon movements coincided with changes in season and temperature. Others have found that lake sturgeon acceleration or locomotor activity varied with seasonality and water temperature (McKinley & Power 1992, Thuemler 1997, Knights et al. 2002, Adams et al. 2006, Struthers et al. 2017). A review of lake sturgeon telemetry studies found most studies reported higher movement rates and acceleration during the spring season (Moore et al. 2021), similar to our observations of namew.

The seasonality of namew longer-distance movement rates was dissimilar to Haxton (2003), who found no significant differences among average distance travelled by lake sturgeon in different seasons in an intact section of the Ottawa River, Ontario. However, this difference may be because we used the 6 Iliiwak seasons, as compared to 4 seasons (Haxton 2003), and our sample size (n = 20) was slightly larger (n = 4; Haxton 2003). Our findings are also strikingly dissimilar to namew of similar size in the Mattagami River, a dammed, fragmented river geographically close and hydrologically linked to the North French River, where movement rates (i.e. distance travelled per day) of namew were lower during warmer summer months and were attributed to high water temperatures (McKinley et al. 1998). Similarly, Knights et al. (2002) observed significantly higher movement rates in spring, but not summer, when compared to fall and winter. Contrasting these results, we observed the second-highest acceleration and significantly higher seasonal movement rates during summer and spring relative to fall and break-up. The North French River has cold-water seeps (A. Litvinov pers. comm.), and namew may have been taking advantage of more cold-water refugia within the study river to avoid temperatures that are physiologically challenging (lake sturgeon have been known to avoid water above 23°C; Bugg et al. 2020). In any case, we did not document the same decline in activity with increasing temperature (McKinley & Power 1992) in our study, although this is an important consideration for monitoring in the future, especially with the potential impact of climate change on northern rivers and streams.

4.3.3. Namew show seasonality in their diurnal patterns of acceleration and depth use

Our observations of diurnal patterns in namew acceleration and depth use generally align with known life history patterns of lake sturgeon in the literature. Previous studies have found that lake sturgeon come to more shallow areas at night to feed (Chiasson et al. 1997) and return to deeper water during the day (Holtgren & Auer 2004). Lake sturgeon have also been documented as having greater activity during dawn and dusk (Forsythe et al. 2012) or have nocturnal behaviour (Kough et al. 2018). Here, we found a similar diurnal pattern of namew acceleration and depth use: where namew were generally less active during the day. Namew occupied deeper water and had lower acceleration during morning and afternoon and occupied shallower water and had higher acceleration at night in most seasons. These patterns were most pronounced in the fall and were less pronounced (although still present) during ice-affected seasons. The only season where this pattern shifted was spring, where namew showed no diurnal patterns of acceleration, were more active overall, and occupied shallower water during morning and afternoon and have the highest variation of depth use. We hypothesize that the lack of diurnal patterns in namew acceleration in spring could be attributable to the fact that not all sturgeon spawn every year, and thus some namew may have been spawning while others were not (Magnin 1966, COSEWIC 2017). This variation in behaviour could be masking diurnal patterns in spring, because we likely had subsets of fish spawning each year and individuals intermittently spawning over the 6 yr study period.

Previous studies have found that lake sturgeon generally spawn and feed in shallower water during the spring and summer and overwinter in deeper pools (Bajkov & Neave 1930, Knights et al. 2002). Lake sturgeon typically occupy deep pools and have lower movement rates during the winter (Rusak & Mosindy 1997), when they do not have the same temperature (Kough et al. 2018, Moore et al. 2021) and light (Forsythe et al. 2012) cues as during the ice-free seasons. However, most fish telemetry studies that occur in areas where rivers freeze over annually do not include any data from winter, often because of logistical and capacity challenges (Marsden et al. 2021). Therefore, our findings that namew do retain some diurnal patterns in acceleration and depth use, even under the ice, is useful and advances our understanding of lake sturgeon overwintering behaviour. It would be interesting for future studies to continue to use winter data from tagged lake sturgeon to confirm this observed pattern of behavior. Lastly, though our study did examine seasonal and diurnal effects on namew behaviour, we did not examine specific environmental cues. For example, Gulf sturgeon have been known to respond to barometric pressure changes as cues for activity patterns (Grammer et al. 2015). It would be interesting to determine if namew also respond similarly, and to monitor if climate change (Brooks 2013) in northern landscapes may impact behaviour of this important fish over time.

4.4. Limitations of comparisons with other sturgeon telemetry studies

In comparing of our findings to those in literature, it is important to note that not all methodologies were consistent between these studies, with varying numbers of receivers and different tracking techniques (i.e. passive vs. active), although Trembath (2013) and Adams et al. (2006) used similar methodology to our own. Other studies used radio telemetry to calculate sturgeon movement and movement rates (e.g. Rusak & Mosindy 1997, Knights et al. 2002, Adams et al. 2006). Comparisons using radio telemetry to our calculated movement rates should be interpreted with caution. For example, our observed maximum and second-highest seasonal movement rates (2125 and 1363 m d^{-1}, respectively) were comparatively lower than those of Knights et al. (2002), who reported 17 500 m d^{-1} in the Mississippi River (Minnesota, Wisconsin, and Iowa, USA). However, one explanation for the higher movement rates of lake sturgeon observed by Knights et al. (2002) could be that the radio telemetry methodology involves actively searching for tagged fish and provides a more robust way to determine exact locations of lake sturgeon compared to our stationary acoustic receivers.

Furthermore, larger (e.g. Blanche River, Ontario; McDonald & Haxton 2023), and hydroelectrically dammed rivers (e.g. Mississippi River, USA; Knights et al. 2002) can have drastically different flow regimes and temperature profiles compared to the intact, relatively shorter North French River, and river discharge can affect seasonal lake sturgeon movements (Borkholder et al. 2002, McDonald & Haxton 2023). Including considerations of the differences in methodologies and flow regimes when comparing results among studies is important for drawing contextualized conclusions and for comparing fish movement and behaviour between impacted and intact river systems.

5. CONCLUSION AND CONSERVATION IMPLICATIONS

Sturgeons are vulnerable to continued fragmentation of watersheds and development activities globally. Overall, our findings provide information on the variation in namew movement and behaviour in a river that is free from industrial development (i.e. there are no dams, flow alterations, forestry, mines, all-season roads, or permanent settlements) and in a place where Iliwak have been, are, and will continue to be, the stewards of the lands and waters. Iliwak Knowledge Holders know that the North French River provides spawning, overwintering, and feeding grounds for namew. Our study corroborates that namew stay in the North French River over all 6 Iliwak seasons, with core use of the area upstream of the winter road and seasonal use of the entire river where we had receiver coverage, and that individual namew will occasionally make longer journeys (i.e. 10s of km) within short time periods (i.e. days) in this river. Our findings also provide information on how seasonal and diurnal cycles influence namew activity and depth use in an unregulated river and intact watershed. These results provide a better understanding of namew in a culturally important area for Iliwak while providing a useful ecological reference for sturgeon globally (Haxton & Cano 2016).

The value of intact river systems like the North French River and other rivers in Kit Aski Nahnuun have been quantified in billions of Euros (Riepe et al. 2019), but it is important to frame these rivers as being both of conservation significance for globally imperilled sturgeon species (Haxton & Cano 2016) and of deep cultural value beyond quantification (Louttit 2009). Species like namew, which have deep cultural connection to the Indigenous communities whose Homelands they share, can serve as cultural keystone species for both sociological and ecological protection (Noble et al. 2016). To protect intact rivers and the endangered species like namew that live in these rivers, conservation actions for sturgeon species globally should include research from intact systems and partner with Indigenous Peoples who have been and continue to steward these species. Information from these intact rivers can help advance conservation of intact rivers and help advance recovery and protection of sturgeon in more impacted environments globally (Haxton & Cano 2016). Conventional ideas of protected and conserved areas also often do not include freshwater or river connectivity in their consideration (Nel et al. 2009, Southee et al. 2021), despite evidence that including freshwater considerations improves conservation outcomes (Juffe-Bignoli et al. 2016). As exemplified in this study, intact rivers can provide year-round habitat for imperilled species like lake sturgeon. Therefore, the protection of intact freshwater systems should be particularly emphasized and advocated for by both researchers and stewards in the context of endangered species like sturgeon globally.

Finally, our work, co-developed with scientists and Moose Cree Knowledge Holders, exemplifies how we can collaboratively pursue research that addresses knowledge gaps from multiple perspectives to address priorities at multiple scales. We anticipate these results will be useful to address Iliwak environmental questions and priorities while also serving as a contemporary reference for sturgeon conservation and management. Overall, we hope this study provides information on namew occupancy, movement, and behaviour in an intact river in Canada that is important to Iliwak and which can answer questions that are valuable to Moose Cree First Nation and wider audiences interested in sturgeon for the purpose of decision-making and conservation at local and broader scales. We offer this example to the growing number of studies (see Moola & Roth 2019, Reid et al. 2021) that testify collaborative approaches being a valuable way to increase understanding and promote better outcomes for wildlife and people.

POSITIONALITY STATEMENT

This statement represents the background, expertise, and identity of the authors to help readers better understand the context of our work and study. We are a group of people with experience as community leaders, fish and boreal scientists, technicians, analysts, academics, and writers who currently work, or have previously worked, as part of the Learning from Lake Sturgeon team. Learning from Lake Sturgeon (Ki Kiskinohamâkonânawan Namewak) is a co-created effort between the Moose Cree First Nation Resource Protection and Wildlife Conservation Society Canada (WCS Canada) to learn more about the river ecosystems of Kit Aski Nahnuun (the Moose Cree Homeland) through scientific research and First Nations perspectives. We work with an Elders Advisory Group, and we include youth programming as an integral part of our work. We are committed to returning all learnings that arise from the Learning from Lake Sturgeon program to Moose Cree First Nation leadership and the community and working with Indigenous and non-Indigenous decision-makers so that results can support efforts to advocate for namew and the lands, waters, and Peoples who are connected to them. Our authorship is made up of both Iliiwak (Moose Cree) Indigenous authors, on whose Homeland this study has taken place, as well as non-Indigenous authors who reside on various Indigenous lands in what is now called Canada. Two of our authors (J.S. and S.L.) are Iliiwak leaders who drove the creation of the project and one of whom continues to co-lead the Learning from Lake Sturgeon program (J.S.). The other 6 authors who form the remainder of the authorship include the other program co-lead (C.M.O.) and other contributors to the program during and after their employment with WCS Canada (C.E.F., F.M.S., L.C.-F., D.P.S., and J.L.S.). Overall, our 8 authors include those who self-identify as (but are not limited to): Moose Cree, Indigenous, non-Indigenous, settlers, women, men, scientists, supportive scientists, mothers, writers, musicians, and geospatial experts. This study represents only the views and understandings of the individual co-authors and does not represent Moose Cree First Nation as a whole. It should not be referenced as a Moose Cree First Nation position nor does it represent Iliiwak Knowledge Systems. Rather, our study serves as an example of a research partnership that acknowledges both Indigenous and Western worldviews and perspectives in the design and implementation of the research. Any Indigenous Knowledge shared with authors by community members and Iliiwak Elders communicated through this paper have only been shared with consent and within the context of Learning from Lake Sturgeon to honour and uphold looking after namew and the lands and waters in Kit Aski Nahnuun.

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