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Factors influencing the spatial ecology of Lake Sturgeon and Walleye within an impounded reach of the Winnipeg River

Daniel P. Struthers · Lee F.G. Gutowsky · Eva C. Enders · Karen E. Smokorowski · Douglas A. Watkinson · Ana T. Silva · Maja Cvetkovic · Eric Bibeau · Steven J. Cooke

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Abstract Impoundments of free-flowing rivers for hydropower generation often confine fish to relatively small reaches that can restrict movement, limit habitat availability, and alter life history strategies. Here, acoustic telemetry was used to describe the seasonal habitat use, locomotory activity, and depth use for Lake Sturgeon (*Acipenser fulvescens*) and Walleye (*Sander vitreus*) within an impounded reach on the Winnipeg River, Manitoba, Canada. Lake Sturgeon foraged and overwintered in the riverine-lacustrine transitionary habitat as well as immediately below the tailrace of the upstream run-of-river facility. Walleye demonstrated high site fidelity to the upstream habitat situated near the tailrace of a hydropower facility. Contrary to Lake Sturgeon, that used multiple habitat types, Walleye used the tailrace for spawning, foraging, and overwintering, given their high residency rates throughout all months at this location. Activity for both species increased with water temperature and when residing in habitat types located farther upstream, but were minimally active during the winter season throughout the impounded reach. On average, Lake Sturgeon utilized 73% of the available depth while Walleye utilized 62% of the available depth across habitat types and months. Overall, the habitat located within the tailrace and below run-of-river facilities should be a conservation priority for both Lake Sturgeon and Walleye populations. There was persistent presence of Lake Sturgeon and Walleye throughout the spawning, foraging, and overwintering periods in the SSGS tailrace and within the first rkm downstream of the tailrace. The habitat proximal to run-of-river facilities generally encompasses small areas of the total potential habitat within impoundments, yet is important to both species studied here. The results provide information

D. P. Struthers (✉) · S. J. Cooke
Fish Ecology and Conservation Physiology Laboratory, Department of Biology, Carleton University, Ottawa, ON K1S 5B6, Canada
e-mail: danstruthers88@gmail.com

L. F. Gutowsky
Aquatic Resource and Monitoring Section, Ontario Ministry of Natural Resources and Forestry, Peterborough, ON K9L 1Z83, Canada

E. C. Enders · D. A. Watkinson
Fisheries and Oceans Canada, Freshwater Institute, 501 University Crescent, Winnipeg, MB R3T 2N6, Canada

K. E. Smokorowski
Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences, 1219 Queen Street E, Sault Ste. Marie, ON P6A 2E5, Canada

A. T. Silva
Norwegian Institute for Nature Research, P.O Box 5685 Sluppen, 7485 Trondheim, Norway

M. Cvetkovic
Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences, 867 Lakeshore Road, Burlington, ON L7R 4A6, Canada

E. Bibeau
Department of Mechanical Engineering, University of Manitoba, Winnipeg, MB R3T 0C4, Canada

on the seasonal habitat use and biological responses to environmental cues for Lake Sturgeon and Walleye that will enhance management and ecological understanding for populations that are confined to impounded reaches.

Keywords Lake Sturgeon · Walleye · Run-of-river Impoundments · Acoustic telemetry · Spatial ecology

Introduction

Large rivers have been altered for hydroelectric developments (Cada 1998; Bednarek 2001). There is considerable diversity in hydropower infrastructure and operations, but in general a dam is built to store water to create hydraulic head before water is released through turbines that generate electricity (Baxter 1977; Bednarek 2001). Storage reservoirs and run-of-the-river systems are common and lead to the creation of impoundments (Geen 1974; Baxter 1977) that can affect the natural flow regime of river systems (Poff et al. 1997). Lake Sturgeon (*Acipenser fulvescens*) and Walleye (*Sander vitreus*) are two fish species that can be found in larger storage reservoirs and typically smaller run-of-river reservoirs (McDougall et al. 2014; Haxton 2011, 2015). Both species can move large distances between spawning, foraging, and overwintering locations (Caswell et al. 2004; Haxton et al. 2015). Fragmented river systems may threaten Lake Sturgeon and Walleye populations by reducing habitat availability, altering natural behaviours, and causing genetic structuring (Gyllensten 1985). Habitat fragmentation can diminish resiliency to environmental stochasticity (e.g., drought, extreme flooding events) or human-induced stressors such as abrupt discharge reductions, habitat alterations or recreational angling pressure (Saunders et al. 1991; Rosenberg et al. 1997; Haxton et al. 2015). In Canada, populations of Lake Sturgeon have been assessed as a species of special concern, threatened, or endangered across their native range (COSEWIC 2006) and they are being considered by Fisheries and Oceans Canada for federal protection under the *Species at Risk Act* (SARA; DFO 2010). While Walleye have not been designated as at risk, this species is an important commercial, subsistence, and recreational fisheries resource in central and eastern North America (Sullivan 2003; Bozek et al. 2011).

Building an understanding of the behaviour and spatial ecology at the population level is important for achieving conservation goals (Caro 1998; Cott et al. 2015). Spatial ecology, movement, and behaviour of fish have been related to biological and environmental cues such as ontogeny, water temperature, ambient light, and discharge (Lucas et al. 2001). For Lake Sturgeon, environmental variables such as water temperature and discharge are thought to initiate spawning behaviour in the early spring (Forsythe et al. 2012; Dempsey and Auer 2013; McDougall et al. 2014). Walleye are a photophobic species that are generally more active during the crepuscular and nocturnal periods (Swenson and Smith 1973; Kelso 1978; Einfalt et al. 2012), and their spawn timing and foraging are correlated to water temperature, photoperiod, and discharge (Ellis and Giles 1965; Ryder 1977). Furthermore, seasonal habitat selection of Lake Sturgeon and Walleye can be predicted based on ontogeny, water temperature, and discharge (Auer 1996; Knights et al. 2002; Peterson et al. 2007). However, habitat use, movements, and biological responses to environmental cues are not well documented for Lake Sturgeon or Walleye in run-of-river impoundments.

Biotelemetry technology has enabled researchers to investigate animal space-use and movement with minimal human interference (Cooke et al. 2004a, b; Hussey et al. 2015). Transmitters can be equipped with environmental and biological sensors (e.g., temperature, depth, and acceleration) that provide detailed animal-borne information to make inferences about behaviour and physiology relative to abiotic variables (Cooke et al. 2004a, 2004b; Wilson et al. 2015). Relatedly, acoustic telemetry has been used to track the migrations of acipenserids (McDougall et al. 2014; Raischi et al. 2016). Here, we used an acoustic telemetry array to investigate the habitat use, locomotory activity, and depth use for Lake Sturgeon and Walleye in a run-of-river impoundment situated on a large boreal shield river system. Specifically, we explored two questions: 1) what type of habitat do Lake Sturgeon and Walleye utilize seasonally in impounded systems, and 2) how can the relationships between fish behaviour and abiotic variables be used to increase our understanding of ecology of these fishes in impounded large rivers? This information will build upon the known ecology of these two fishes to aid the management for Lake Sturgeon and Walleye populations that reside within impoundments.

Methods

Study location

This study was completed in an impounded reach located on the Winnipeg River. The Winnipeg River extends 260 km downstream from Lake of the Woods, Ontario, to Lake Winnipeg, Manitoba, and has eight run-of-river hydropower facilities located along the length of the river system. The study reach is bound on the upstream end by the Seven Sisters Generating Station (SSGS; 50°7′14″N, 96°1′04″W) and the downstream end by McArthur Falls Generating Station (MFGS; 50°23′52″N, 95°59′50″W; Fig. 1). The telemetry array extends across 50 km typical of run-of-the-river systems where the upper region (~12 rkm) is characterized by mostly riverine habitat while the remaining portion of the reach (30 rkm) is mainly lacustrine that is associated with the backwater area of the downstream generating station (Fig. 1).

Fish capture and tagging

Based on recent assessments with egg counts and gillnet sampling within the upstream region of this impoundment, there were Lake Sturgeon of all age classes present and recruitment appeared to be occurring (Hrenchuk et al. 2009; Manitoba Fisheries Branch 2012). Fish capture and tagging procedures were conducted between May 20 and June 2, 2014. Multi-panel multifilament gillnets with large mesh size (200 mm to 300 mm) and boat electrofishing were used to capture Lake Sturgeon. Gillnet panels were placed in deep pools situated downstream of the SSGS tailrace. Spring upstream spawning migrations commonly occur for Lake Sturgeon (Auer 1996) and Walleye (Crowe 1962), consequently, the individuals captured below the SSGS tailrace (1–1.8 rkm from SSGS powerhouse) were expected to be a mixture of spawning and non-spawning fish. Gillnets were set at dusk (~17:00–21:00 CDT) and pulled at dawn (soak time of 10–12 h). Walleye were captured with a combination of fine- (100–200 mm) and large- (200–300 mm) meshed multi-panel gillnets, and with boat electrofishing during the crepuscular and nocturnal periods.

Upon capture, Lake Sturgeon and Walleye were placed in holding tanks filled with ambient river water prior to surgical procedures. Total length (TL, measured to the nearest mm) and weight (kg) were recorded for each fish during the tagging procedure. During the capture period, no Lake Sturgeon or Walleye were recaptured during netting or electrofishing procedures. We used conventional transmitters (V13; n = 40; lifespan: 818 days; Vemco, Halifax, Nova Scotia, Canada), as well as transmitters with integrated biological sensors (V13AP; n = 40; lifespan: 649 days; Vemco). The sensor transmitters provided an equal ratio of depth (i.e., hydrostatic pressure; max. Depth = 50 m; accuracy = ± 2 m; resolution = 0.5 m) and locomotory activity using integrated sensor accelerometers. Acceleration provides a general locomotory activity measured across three axes (x, y, and z) that is averaged from 5 samples/s with a 10 s accelerometer sample time. These sampled values are then root-mean-squared and summed using the formula, $\sqrt{x2 + y2 + z2}$, which provides locomotory activity in SI units ($m \cdot s^{-2}$). The transmitters were divided equally between Lake Sturgeon (n = 40) and Walleye (n = 40) for both transmitter models (20 V13 and 20 V13AP per species). Transmitters propagate a unique coded ID at 69 kHz frequency to distinguish each tagged fish. Acoustic transmitters were manufactured with a random delay range of 50–130 s (nominal average delay = 90 s) to help reduce code collisions from multiple fish (Heupel et al. 2006).

Lake Sturgeon were immobilized in a fine-mesh cradle that was submerged in ambient river water and oriented into a supine position to induce catatonic immobility and to access the ventral side for the tagging procedure. No anaesthetic was used to immobilize Lake Sturgeon during tagging procedures as per previous tagging operations (Thiem et al. 2013). The head and gills remained submerged in a trough filled with fresh river water to maintain normal respiration during the tagging procedures. All surgical tools, gloves, and acoustic transmitters were disinfected using a 10% povidone-iodine solution (Betadine®, Stamford, Connecticut, USA). An incision (~2 cm) was made with a scalpel on the midline positioned slightly posterior to the pectoral girdle and an acoustic transmitter was inserted posteriorly into the coelom cavity. This was followed by three simple interrupted sutures (3–0 polydioxanone-II violet monofilament; Ethicon, Cincinnati, Ohio, USA) to close the wound. Each tagging procedure took less than 5 min to complete. The tagged Lake Sturgeon were held in a tank filled with fresh river water to monitor for post-tagging effects for 10–15 min, then released at a location downstream from the capture site.

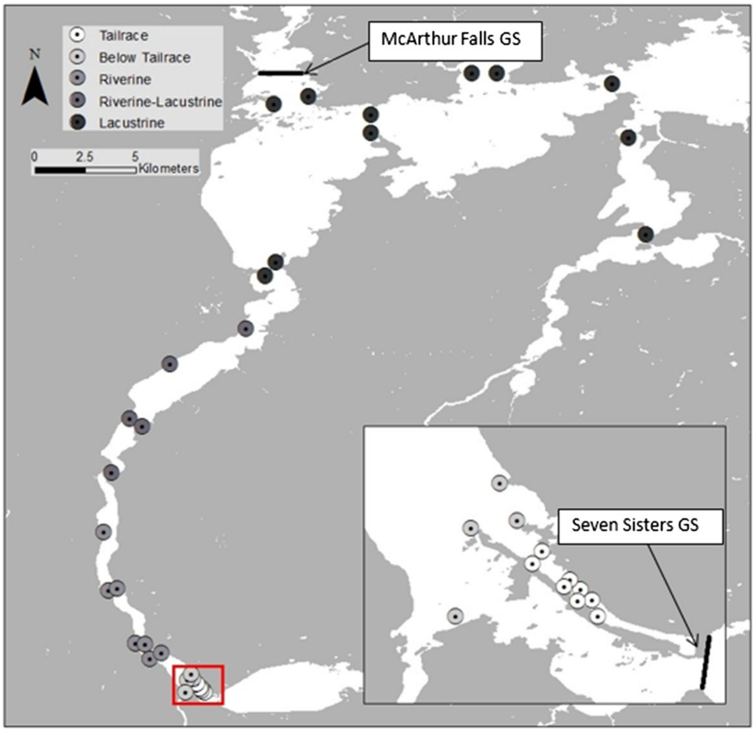

Fig. 1 An overview of the VR2W acoustic receiver (Vemco) array within the impounded reach situated between the Seven Sisters GS and McArthur Falls GS on the Winnipeg River. The receivers are shaded by their habitat types. The map inset shows the acoustic receivers that are in the tailrace (*white*) and below the Seven Sisters GS (*grey*)

Similarly, the captured Walleye were implanted with either a V13 or V13AP acoustic transmitter. Certain methods (i.e., tool disinfection, gloves worn, incision location, and number of sutures used to close wound) were identical to those that were used for Lake Sturgeon. However, Walleye were immobilized using stage-4 electro anaesthesia (Summerfelt and Smith 1990) using a Portable Electro Sedation Unit (PES; Smith-Root, Vancouver, Washington, USA; Vandergroot et al. 2011) prior to tag implantation. The PES was set to 100 Hz, 25% duty cycle, and 40 Volts. Pulsed direct current is an appropriate anaesthetic for adult Walleye, providing a surgery window of 250–350 s, short recovery time, and has minimal impact on vertebral integrity (Vandergroot et al. 2011). Upon stage-4 anaesthesia, Walleye were placed supine in a padded v-shaped trough. Ambient river water was continuously pumped into the mouth and over the gills using a recirculating pump system to maintain normal respiration during the tagging procedure (< 5 min).

No mortality was observed in Lake Sturgeon or Walleye during or immediately after the tagging procedures. All tagged fish were below the 2% transmitter-to-fish weight ratio that is recommended to minimize the chance of altering their natural behaviour due to transmitter presence (Rogers and White 2007). Fish handling and surgical procedures were approved and followed the Canadian Council on Animal Care animal use protocol (AUP #101065). This research project was also approved by Manitoba Water Stewardship, Fisheries Branch under Scientific Collection Permit No. 14–14.

Receiver array

An array of 32 acoustic telemetry receivers (VR2W; Vemco, Halifax, NS) were used to passively-track tagged Lake Sturgeon and Walleye throughout the impounded reach during the study period. The receivers were set as singular or paired gates (i.e., a receiver anchored on each river bank) depending on river width and flow characteristics. Prior to receiver placement, we performed stationary range testing, using a V13 transmitter that was identical to fish tags, to assess detection range of the VR2Ws in relation to the general flow characteristics (i.e., high, moderate, minimum flow) that were visually identified in the field when setting up the acoustic receiver array. Upon completing in-situ range testing, the detection range was considerably lower (~75 m) within the SSGS tailrace due to ambient noise in comparison to riverine (~200 m) and lacustrine

(~500 m) habitat types. Due to the limited detection range in the tailrace, the acoustic receivers were spaced closely together to maximize detection coverage in the tailrace area. The SSGS tailrace extends approximately 1200 m downstream from the powerhouse, with a width of 40–70 m. The upper region of the tailrace (0–400 m) was unsuitable for placing VR2Ws due to swift currents and the lack of suitable anchoring locations. There were no receivers placed near the SSGS spillway because this area was dangerous to navigate by boat. Receivers were spaced farther apart throughout the riverine and lacustrine habitat because of the greater detection range. The VR2Ws were affixed to 3/8″ braided line and situated between a granite anchor (27–36 kg) and a sub-surface buoy. The receivers that were placed in swift-water conditions were tethered to shore using 1/4″ galvanized steel cable, and positioned 50–200 m away from the shoreline in 2–6 m of water. Receivers located in still-water conditions were set in 5–11 m depth with an additional trailing anchor attached to the granite anchor with 10–20 m of line. Receivers were retrieved to offload data by catching the line between the anchors with a grappling hook. The anchor systems were not affected by the hydraulic conditions in the river and remained in place for the duration of the study. Receiver deployment commenced from June 2 to August 9, 2014, inclusively. Data collection commenced when all receivers were anchored and continued up to the date of the final data offload. Overall, the passive study period commenced on August 10, 2014 through to July 6, 2015, for a duration of 330 days.

Database management

The internal clocks of the VR2Ws drift over time, therefore, time of arrival for detections were corrected using a linear regression algorithm in the Vemco User Environment (VUE; Vemco) prior to filtering data. In addition, false-positive transmissions needed to be identified and removed from the dataset prior to performing analyses. False-positive detections can occur when multiple tags transmit simultaneously within the detection range of a receiver. This collision of transmissions may produce erroneous tag identification (Skalski et al. 2002; Pincock 2011). False-positives were first assessed in the VUE as single detections from unidentified coded transmitters. The database was further filtered by assessing spatiotemporal order of detections. Distance and time between consecutive detections was calculated for each fish. If a fish was detected at an unrealistic speed between two consecutive detections (i.e., movement velocity > 5 $m \cdot s^{-1}$) then the subsequent detection was removed from the data set (Skalski et al. 2002; Pincock 2011). Because of the proximity of some receivers, a transmission from a fish could be detected multiple times if a fish is within range of multiple receivers. As such, duplicate transmissions were filtered from the database by identifying consecutive detections from each fish that was recorded less than the minimal tag delay (i.e., < 50 s). If a fish was detected at the same receiver continuously for 6 months (i.e., no change in lateral or vertically position or with swimming acceleration), then the fish was assumed dead and the post-mortality data removed. Data filtration was completed using the R Statistical Environment (R Core Development Team 2016), MS Access, and VUE software (Vemco).

Data were grouped per calendar month, and across five general habitat types characterized by water velocity, which included: (1) *Tailrace*, (2) *Below Tailrace* (3) *Riverine*, (4) *Riverine-Lacustrine*, and (5) *Lacustrine* (Fig. 1). Daily discharge data ($m^3 \cdot s^{-1}$) from the SSGS powerhouse and spillway, as well as tailrace height (m), was acquired from Manitoba Hydro (Fig. 2). Daily water temperature readings were acquired from the township of Powerview-Pine Falls (Fig. 2). Local solar information was retrieved online (acquired from www.ptaff.ca) and used to summarize the detection data into diel periods (i.e., day: ≥ sunrise and < sunset; night: ≥ sunset and < sunrise).

Residency

To investigate residency, we calculated the proportion of tagged fish that were present monthly in each habitat type. Sometimes, a tagged fish went undetected on a given day due to the limited spatial coverage of the acoustic receiver array, particularly in the riverine-lacustrine and lacustrine habitats. When this occurred, the previous position was estimated using the last-observation-carry-forward approach (Shao and Zhong 2003; McDougall et al. 2014). When a fish went undetected, it was assumed to be near the last known position, which was used to infer its position for the undetected day(s). When implementing this approach, the inferred position was always generated in the same habitat type as the previous and subsequent positions. This indicates that the fish did not move considerable

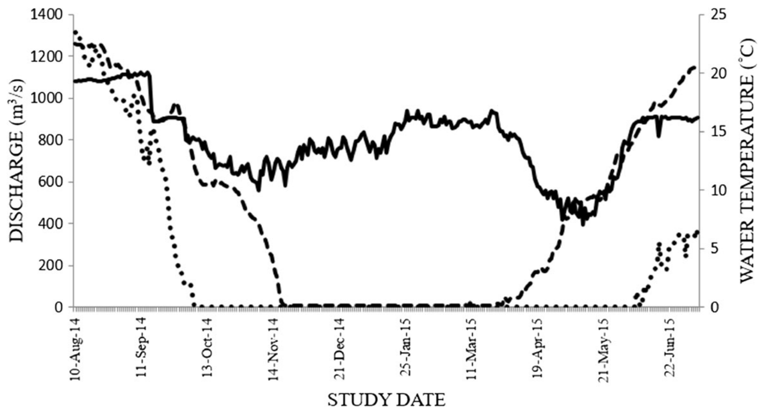

Fig. 2 An overview of the daily water temperature (°C; *dashed line*) acquired from the township of Powerview-Pine Falls, as well as discharge ($m^3 \cdot s^{-1}$) from the Seven Sisters GS spillway (*dotted line*) and powerhouse (*solid line*) provided by Manitoba Hydro through the study period (August 10, 2014 to July 6, 2015)

distances between detection events and that this approach is accurate for coarse-scale positioning (i.e., positioning within broader habitat classes) of the tagged fish when going undetected on a given day. For a fish to be present in a habitat type on any given study day, it was required to be detected at least two times daily on the receivers associated within that specific habitat type. For each study day, the number of fish were summed for each habitat type and divided by the total number of fish remaining in the system for the entire study period to calculate a residency index. Daily values were then grouped according to the calendar month of the study period. This provided a proportional outcome for fish presences that ranged between 0.0–1.0, where 0 would be no fish and 1 would be all fish being present.

Depth use

Depth use (hydrostatic pressure sensors; m) was investigated to understand habitat selection of Lake Sturgeon and Walleye in habitat types found in impounded reaches. Daily depth averages for detected fish were calculated when a minimum of 10 detections were recorded on any given day of the study period (Gutowsky et al. 2013). For depth use, we generated a depth electivity index (DE_I) by determining depth position relative to the maximum depth available near a receiver. The receiver depths in the SSGS tailrace were corrected using the daily change in the tailrace water surface elevation. Digital bathymetry maps of the study area were used to measure maximum depth within the estimated detection range of the acoustic receivers (i.e., 50 m radius within and below the SSGS tailrace, and a 500 m radius within all other habitat types). The average daily depth values were divided by the maximum depth for the receiver that recorded the detections to generate a DE_I value for each sampled fish. Daily DE_I values for each sampled fish were averaged by the calendar months and habitat types. The DE_I response has a proportional data structure that ranges between 0 and 1, where values of 0 would be surface water and values near 1 would be at the maximum depth available. DE_I values for each sampled fish were also analysed in relation to the mean water temperature, powerhouse discharge, and spillway discharge.

Locomotory activity

Locomotory activity (tri-axial acceleration from V13AP tags; $m \cdot s^{-2}$) was investigated to understand Lake Sturgeon and Walleye movement behaviour when residing in various habitat types found within run-of-river impoundments. Acceleration averages ($\bar{x}$) for detected fish were calculated when a minimum of 10 detections were recorded on any given day of the study period (Gutowsky et al. 2013). Average sensor values of less than 0.1 were removed from analyses since they were considered erroneous or unrealistic with being near the threshold of no activity. Since daily values were expected to be similar between days, the daily values were averaged for each week of the study period and further summarized by diel period and calendar months. Locomotory activity for each sampled fish were also analysed in relation to the mean water temperature, powerhouse discharge, and spillway discharge.

Data analyses

AIC model selection was applied to determine appropriate models for residency, depth use, and locomotory activity (Zuur et al. 2009). The dependent variables were fitted with models that could include water temperature, powerhouse discharge, spillway discharge, diel period, calendar month, or habitat type, as well as selected two-way interactions. Separate candidate model sets were generated for each species to discriminate species-specific trends for residency, depth use, and locomotory activity. Generalized linear models (GLM) were fitted to the residency data, which assumed a binomial outcome due to the proportional structure of the data. GLMs were specified using the built-in *GLM* function in the R statistical environment (R core team 2016). Linear mixed-effects modelling (LME) were fitted using 'lme' function from the 'nlme' package (Bates et al. 2015; Pinheiro et al. 2015) in R to model depth use and locomotory activity. Because the sensor data (i.e., depth use and locomotory activity) were summarized for each individual fish, the variance was expected to be dependent on the sampled individuals. As such, the ID for the tagged fish was included as a random effect in all LME models. All data were visually examined for outliers, correlation, and heterogeneity using boxplots, pair-plots, and Cleveland dot-plots, respectively. Fitted models were checked for residual homogeneity, independence, and normality following techniques described by Zuur et al. (2009). When modelling locomotory activity, we tested whether residual homogeneity was improved depending on fixed terms by testing the inclusion of residual covariates for model terms that demonstrated heteroscedasticity when plotting model residuals (Pinheiro et al. 2015).

Results

During the study period, the acoustic array retrieved 2,888,832 valid detections. Tagged Lake Sturgeon provided 1,280,860 (43.7%) and Walleye 1,649,823 (56.3%) of all detections over the monitoring period and habitat types. Of the total detections, 657,177 were depth records and 658,215 were acceleration records. The remaining 1,615,292 were positional detections. Nine Walleye were reported as harvested by recreational anglers, and eight additional Walleye either died or moved to areas within the study reach where they were no longer detected. All tagged Lake Sturgeon survived or did not dispel internal tags throughout the study period based on the retrieved data.

Seasonal residency

The top model fitted to the residency data included the interaction between habitat type and water temperature (Table 1). However, the models that included interactions between spillway and powerhouse discharge with habitat type were ranked 2nd and 3rd amongst the fitted models (Table 1). When total discharge (i.e., Powerhouse + Spillway) was below 1000 $m^3 \cdot s^{-1}$, individuals were dispersed throughout the impoundment. However, more fish were present in the lacustrine habitat and at a lesser extent in the riverine-lacustrine habitat as discharge increased towards 2000 $m^3 \cdot s^{-1}$. Overall, Lake Sturgeon were only detected in the SSGS tailrace habitat between weeks 11 to 27 (i.e., March 9 to July 5, 2015). These residency rates were measured between the dates of May 10-20, 2015. There were moderate proportions of Lake Sturgeon residing below the SSGS tailrace throughout the study period, but more so in winter months (Fig. 3). The greatest proportions of Lake Sturgeon (i.e., 16–38% of tagged individuals) were present at the SSGS tailrace when water temperatures measured between 9.1–9.8 °C (Fig. 4), while SSGS powerhouse discharge measured 429.9–502.4 $m^3 \cdot s^{-1}$ (Fig. 2). The lacustrine habitat was found to have the highest residency rates of Lake Sturgeon during the months of June (0.54), July (0.49), and August (0.40). Through June and July of 2015 there were increasing numbers of Lake Sturgeon residing in the riverine and lacustrine habitats, while decreasing numbers of fish residing below the SSGS tailrace and the riverine-lacustrine habitat (Fig. 3). This trend appears to be driven by water temperature since the top candidate model included only the interaction between habitat type and water temperature (Table 1). There was a trend for the tagged Lake Sturgeon to move to downstream habitats as water temperature increased, whether they were residing below the SSGS tailrace or in the riverine-lacustrine habitat (Fig. 4). Lake Sturgeon were found to overwinter below the SSGS tailrace, the riverine-lacustrine habitat, and lacustrine habitat.

The top model for Walleye residency included the interaction between habitat type and water temperature (Table 1). Walleye had an preferred the habitat within and below the SSGS tailrace (Fig. 3). In general, the residency rate was higher during the autumn (0.55), winter (0.70), and spring (0.57) in the habitat located below the SSGS tailrace. Walleye moved upstream into the SSGS tailrace and downstream into the riverine

Table 1 Model selection statistics from the linear mixed-models (LMM) for residency (SR_I) and locomotory activity, as well as the selected generalized Linear mixed-models (Binomial GLMM) to explain depth use (DE_I) for Lake Sturgeon and Walleye on the Winnipeg River, Manitoba, Canada. K is the number of parameters; AICc is the bias-corrected Akaike Information Criterion; ΔAICc is the difference in bias-corrected AIC between a given model and the top ranked model; wAICc is the relative weight of the bias-corrected AIC; Cumul.Wt is the cumulative Akaike weights and; L-Lik is the log-likelihood of the model

Species	Response	Model No.	Model Terms	K	AICc	ΔAICc	wAICc	Cumul.Wt	*L*-Lik
Lake Sturgeon	*Residency*	**mod 10**	**Habitat*Temperature**	**10**	**820**	**0**	**1**	**1**	**−400**
		mod 12	Habitat*Powerhouse	10	828	8	0	1	−404
		mod 11	Habitat*Spillway	10	833	13	0	1	−406
		mod 7	Month + Habitat	16	844	23	0	1	−406
		mod 6	Month + Habitat + Temperature	17	846	25	0	1	−406
		mod 1	Month + Spillway + Powerhouse + Habitat*Temperature	23	846	26	0	1	−400
		mod 5	Month + Habitat + Spillway + Powerhouse	18	848	27	0	1	−406
		mod 8	Month	12	848	28	0	1	−412
		mod 4	Month + Habitat + Spillway + Powerhouse + Temperature	19	850	29	0	1	−406
		mod 3	Month + Spillway + Temperature + Habitat*Powerhouse	23	855	35	0	1	−404
		mod 2	Month + Powerhouse + Temperature + Habitat*Spillway	23	859	38	0	1	−406
		mod 9	Habitat*Month	52	883	62	0	1	−387
	Depth Use	**mod 7**	**Powerhouse + Temperature*Habitat**	**13**	**−696**	**0**	**1**	**1**	**361**
		mod 8	Spillway + Temperature*Habitat	13	−694	3	0	1	360
		mod 6	Temperature*Habitat	12	−685	11	0	1	355
		mod 5	Diel + Temperature*Habitat	13	−684	13	0	1	355
		mod 4	Month + Temperature*Habitat	22	−651	45	0	1	348
		mod 3	Month + Diel + Temperature*Habitat	23	−649	47	0	1	349
		mod 2	Month + Diel + Powerhouse*Habitat	23	−619	77	0	1	333
		mod 1	Month + Diel + Spillway + Powerhouse + Temperature	17	−415	281	0	1	225
	Locomotory Activity	**mod 10**	**Month + Habitat*Temperature**	**28**	**−594**	**0**	**1**	**1**	**326**
		mod 2	**Diel + Month + Habitat*Temperature**	**29**	**−592**	**2**	**0**	**1**	**326**
		mod 1	Habitat + Diel + Month + Temperature + Powerhouse + Spillway	27	−569	25	0	1	312
		mod 3	Diel + Month + Habitat*Powerhouse	29	−539	55	0	1	299
		mod 4	Habitat + Month	23	−536	58	0	1	292
		mod 8	Habitat*Temperature	17	−516	77	0	1	275
		mod 9	Habitat*Powerhouse	17	−359	234	0	1	197
		mod 5	Temperature	9	−337	256	0	1	178
		mod 6	Spillway	9	−248	346	0	1	133
		mod 7	Powerhouse	9	−240	354	0	1	129

Table 1 (continued)

Species	Response	Model No.	Model Terms	K	AICc	ΔAICc	wAICc	Cumul.Wt	*L*-Lik
Walleye	*Residency*	**mod 10**	**Habitat*Temperature**	**10**	**712**	**0**	**1**	**1**	**−346**
		mod 1	Month + Spillway + Powerhouse + Habitat*Temperature	23	735	23	0	1	−344
		mod 12	Habitat*Powerhouse	10	758	46	0	1	−369
		mod 7	Month + Habitat	16	761	49	0	1	−364
		mod 6	Month + Habitat + Temperature	17	761	49	0	1	−363
		mod 4	Month + Habitat + Spillway + Powerhouse + Temperature	19	762	50	0	1	−362
		mod 11	Habitat*Spillway	10	763	51	0	1	−371
		mod 5	Month + Habitat + Spillway + Powerhouse	18	763	51	0	1	−363
		mod 9	Habitat + Month + Habitat*Month	55	764	52	0	1	−325
		mod 3	Month + Spillway + Temperature + Habitat*Powerhouse	23	765	53	0	1	−359
		mod 2	Month + Powerhouse + Temperature + Habitat*Spillway	23	769	57	0	1	−361
		mod 8	Month	12	1331	619	0	1	−653
	Depth Use	**mod 2**	**Month + Diel + Powerhouse*Habitat**	**24**	**−302**	**0**	**1**	**1**	**176**
		mod 7	Spillway + Temperature*Habitat	13	−293	9	0	1	160
		mod 3	Month + Diel + Temperature*Habitat	24	−287	15	0	1	168
		mod 5	Diel + Temperature*Habitat	13	−286	16	0	1	156
		mod 4	Month + Temperature*Habitat	23	−285	17	0	1	166
		mod 6	Temperature*Habitat	12	−285	17	0	1	154
		mod 8	Powerhouse + Temperature*Habitat	13	−283	18	0	1	155
		mod 1	Month + Diel + Spillway + Powerhouse + Temperature	18	−220	82	0	1	128
	Locomotory Activity	**mod 12**	**Month + Habitat*Temperature**	**28**	**−355**	**0**	**1**	**1**	**207**
		mod 10	**Habitat*Temperature**	**13**	**67**	**43**	**0**	**1**	**−19**
		mod 1	Month + Spillway + Powerhouse + Habitat*Temperature	13	26	42	0	1	1
		mod 12	Habitat*Powerhouse	13	−14	40	0	1	21
		mod 7	Month + Habitat	12	−55	39	0	1	41
		mod 6	Month + Habitat + Temperature	12	−96	38	0	1	61
		mod 4	Month + Habitat + Spillway + Powerhouse + Temperature	12	−136	37	0	1	81
		mod 11	Habitat*Spillway	12	−177	36	0	1	101
		mod 5	Month + Habitat + Spillway + Powerhouse	11	−218	34	0	1	121
		mod 9	Habitat + Month + Habitat*Month	11	−258	33	0	1	141
		mod 3	Month + Spillway + Temperature + Habitat*Powerhouse	11	−299	32	0	1	161
		mod 2	Month + Powerhouse + Temperature + Habitat*Spillway	11	−340	31	0	1	181

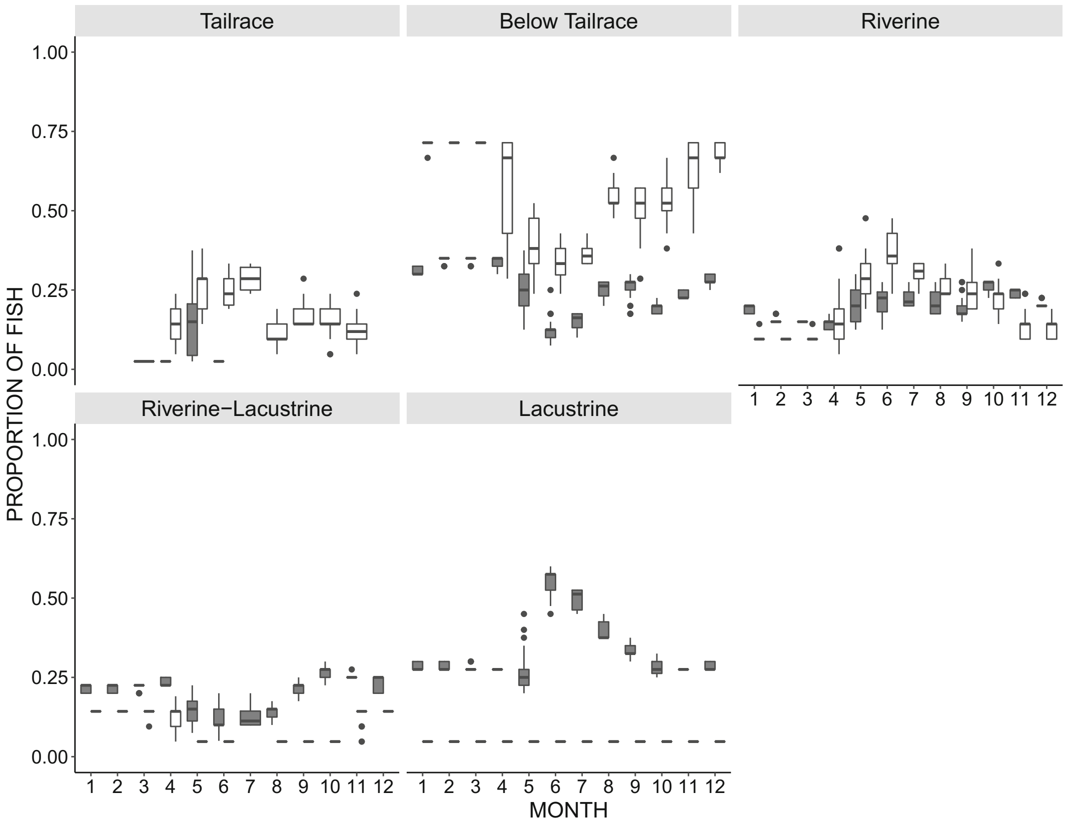

Fig. 3 The proportion of tagged fish for Lake Sturgeon (*shaded plots*) and Walleye (*open plots*) residing in five habitat types across the study months (x-axis) located between the Seven Sisters GS and McArthur Fall GS on the Winnipeg River

habitat during the months of May to July. A small proportion (13.2–14.3%) of the tagged Walleye used the riverine-lacustrine habitat to overwinter between the months of November 2014 to April 2015. Only one fish was found to reside in the lacustrine habitat across the study months. Some of the Walleye moved out of the area below the SSGS tailrace as water temperature approached 15 °C. Walleye residency within the SSGS tailrace and riverine habitat increased between 15 and 20 °C. Walleye residency diminished in the riverine-lacustrine habitat when water temperature increased above 5 °C and remained low in the lacustrine habitat across the water temperature range (Fig. 4).

Depth use

The top candidate model for explaining depth use for Lake Sturgeon included the interaction between habitat type and water temperature, as well as powerhouse discharge (Table 1). The random effect of individual fish was found to improve the full model for Lake Sturgeon (ΔAIC = −495.9). On average, Lake Sturgeon utilized depths closer to the maximum depth recorded in the tailrace of the SSGS (DE_I = 0.97 ± 0.05 SD) and riverine habitat (DE_I = 0.90 ± 0.16 SD). Depth utilization was similar for Lake Sturgeon that were residing below the SSGS (DE_I = 0.63 ± 0.21), riverine-lacustrine (DE_I = 0.72 ± 0.20), and lacustrine (DE_I = 0.68 ± 0.15) habitats (Fig. 5). Lake Sturgeon utilized greater depths below the SSGS tailrace and riverine habitat when water temperature and powerhouse discharge increased (Fig. 6).

The top fitted model for explaining the depth use of the tagged Walleye included month, diel period, and the interaction between powerhouse discharge and habitat type (Table 1). The random effect of individual fish was found to improve the fitted models (ΔAIC = −1752.4). On average, Walleye utilized habitat at 0.62 (± 0.16) across all habitat types and through the full study period. Walleye were found to utilize shallower depths when detected in the lacustrine habitat (DE_I = 0.51 ± 0.30) and greater depths when located in the riverine habitat (DE_I = 0.74 ± 0.19; Fig. 7).

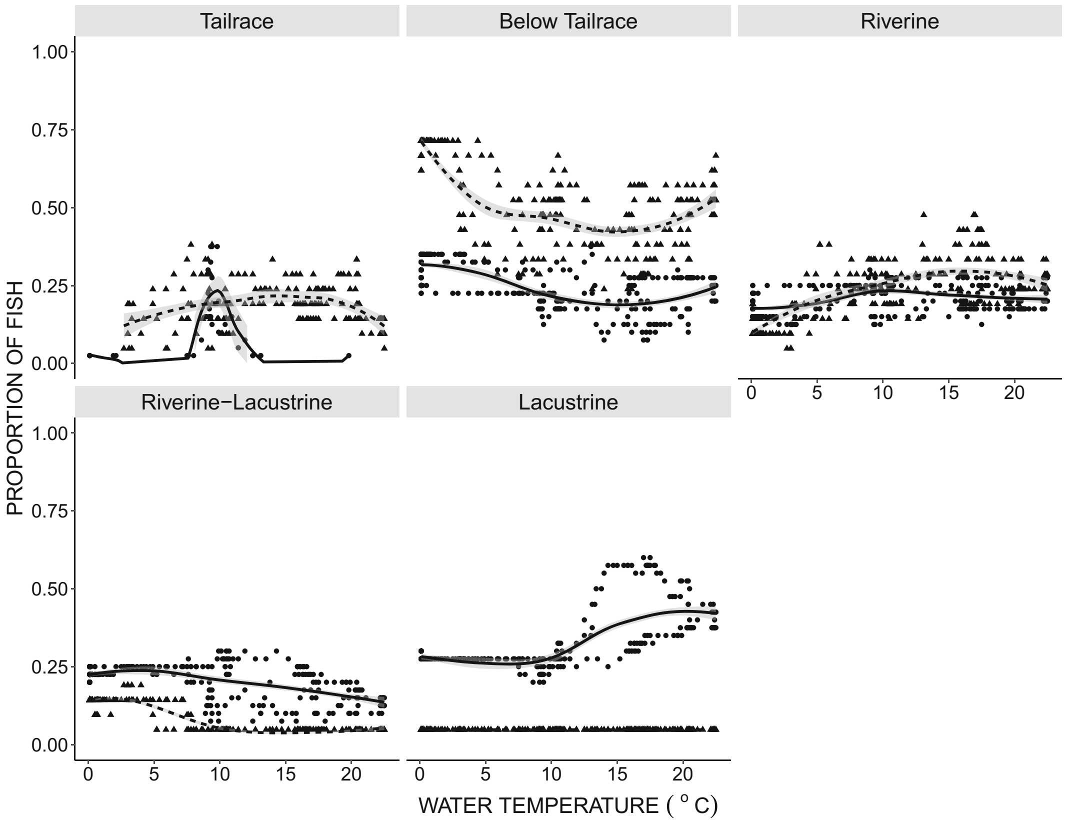

Fig. 4 The proportion of fish present in each habitat type (y-axis) across the water temperature range (x-axis) for Lake Sturgeon (*circles*; *solid line*) and Walleye (*triangles*; *dotted line*) that reside within the impounded reach situated between Seven Sisters GS and McArthur Falls GS on the Winnipeg River

Walleye depth use was similar when located within the tailrace (DE_I = 0.60 ± 0.27), below the tailrace (DE_I = 0.67 ± 0.19), and within the riverine-lacustrine habitat (DE_I = 0.63 ± 0.24; Fig. 7). On average, Walleye resided in less than 0.60 of the available habitat during the months of July (DE_I = 0.55), August (DE_I = 0.48), and September (DE_I = 0.58), while all other month were situated in depths greater than 0.60 of the available habitats (Fig. 5). When powerhouse discharge increased, Walleye moved into shallower habitat when located in the tailrace environment. Walleye remained at similar depths in all habitat types as the powerhouse discharge rate changed.

Locomotory activity

The best model that best explained locomotory activity for Lake Sturgeon included the term for month, as well as the interaction between habitat and water temperature (Table 1). The inclusion of individual fish as a random effect improved the model (ΔAIC = −695.4). Allowing the residual variance to depend on month and water temperature improved residual homogeneity in the candidate models. Lake Sturgeon locomotory activity varied through the study period with a range between 0.1 and 1.48 $m{\cdot}s^{-2}$ (Fig. 7). In general, Lake Sturgeon became more active with rising water temperature, and remained similarly active when water temperatures ranged between 10 to 25 °C (Fig. 8). Lake Sturgeon were most active in the riverine habitat ($\overline{x}$ = 0.85 $m{\cdot}s^{-2}$ ± 0.25 SD) while moderately active in the SSGS tailrace ($\overline{x}$ = 0.69 $m{\cdot}s^{-2}$ ± 0.18 SD) and in the habitat located below the tailrace ($\overline{x}$ = 0.70 $m{\cdot}s^{-2}$ ± 0.33 SD). Lake Sturgeon were relatively less active when residing in the riverine-lacustrine ($\overline{x}$ = 0.48 $m{\cdot}s^{-2}$ ± 0.19 SD) and lacustrine ($\overline{x}$ = 0.47 $m{\cdot}s^{-2}$ ± 0.20 SD) habitat types. On average, locomotory activity rates for Lake Sturgeon were elevated between May through to October, while lowest from December through to March (Fig. 7). Locomotory activity was only recorded in

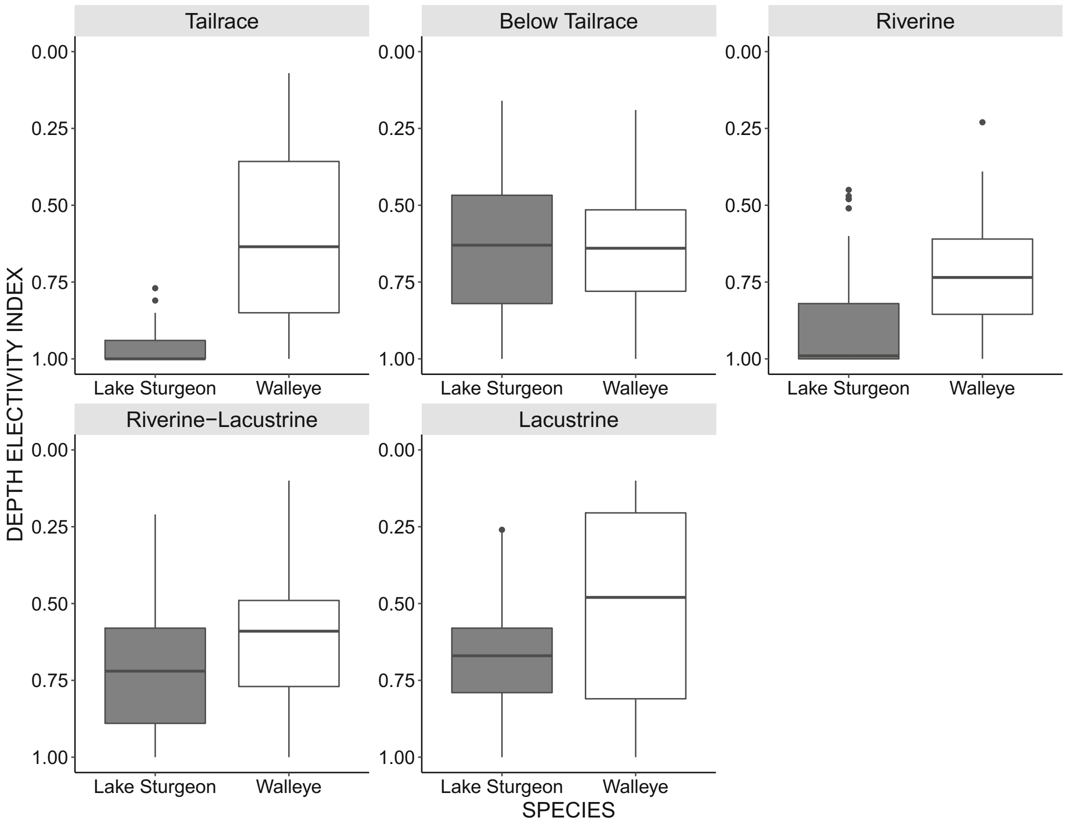

Fig. 5 Comparing the indexed depth use (DE_I) for Lake Sturgeon (*shaded plots*) and Walleye (*open plots*) across habitat types within the impounded reach situated between Seven Sisters GS and McArthur Falls GS on the Winnipeg River

the SSGS tailrace during the month of May for Lake Sturgeon, with an average activity value of 0.69 $m \cdot s^{-2}$ (range: 0.61–0.81 $m \cdot s^{-2}$). Locomotory activity from Lake Sturgeon within in the SSGS tailrace was recorded when powerhouse discharge measured between 467 and 616 $m^3 \cdot s^{-1}$ and water temperature were between 8.8–12.3 °C.

The top model for Walleye locomotory activity included month, as well as the interaction between habitat type and water temperature (Table 1). The inclusion of individual fish as a random effect improved the model ($\Delta AIC = -91.4$) and the inclusion of a variance covariate for month improved the residual homogeneity. Walleye activity rates ranged between 0.06–2.65 $m \cdot s^{-2}$ across habitat types during the study period, being more active through June ($\bar{x} = 0.78$ $m \cdot s^{-2}$), July ($\bar{x} = 0.77$ $m \cdot s^{-2}$) and August ($\bar{x} = 0.82$ $m \cdot s^{-2}$) and less active between December through to March (range: 0.21–0.29 $m \cdot s^{-2}$; Fig. 7). Walleye became more active as water temperatures approached 20 °C, which was dependent on the habitat type they were residing (Fig. 8). Walleye were most active when situated in the SSGS tailrace ($\bar{x} =$ 0.85 $m \cdot s^{-2}$ ± 0.33 SD; range: 0.60–1.01 $m \cdot s^{-2}$) and riverine habitat ($\bar{x} = 0.62$ $m \cdot s^{-2}$ ± 0.21 SD), whereas less active when residing in the other three habitat types (range: 036–0.39 $m \cdot s^{-2}$).

Discussion

This telemetry study was implemented to evaluate and compare the spatial ecology of Lake Sturgeon and Walleye within run-of-river impoundments using biotelemetry. The technology that was applied generated a large dataset, which was used to assess habitat use, depth use, and locomotory activity for these species in a Boreal Shield river impoundment. Habitat use and ecological information of Lake Sturgeon have been limited for riverine/impounded populations (McKinley et al. 1998; McDougall et al. 2013a, 2013b, 2014). Furthermore, the movement behaviour for Walleye within run-of-river impoundments has only recently begun to be documented in the primary literature (Haxton et al. 2015). The habitat below the upstream run-of-river

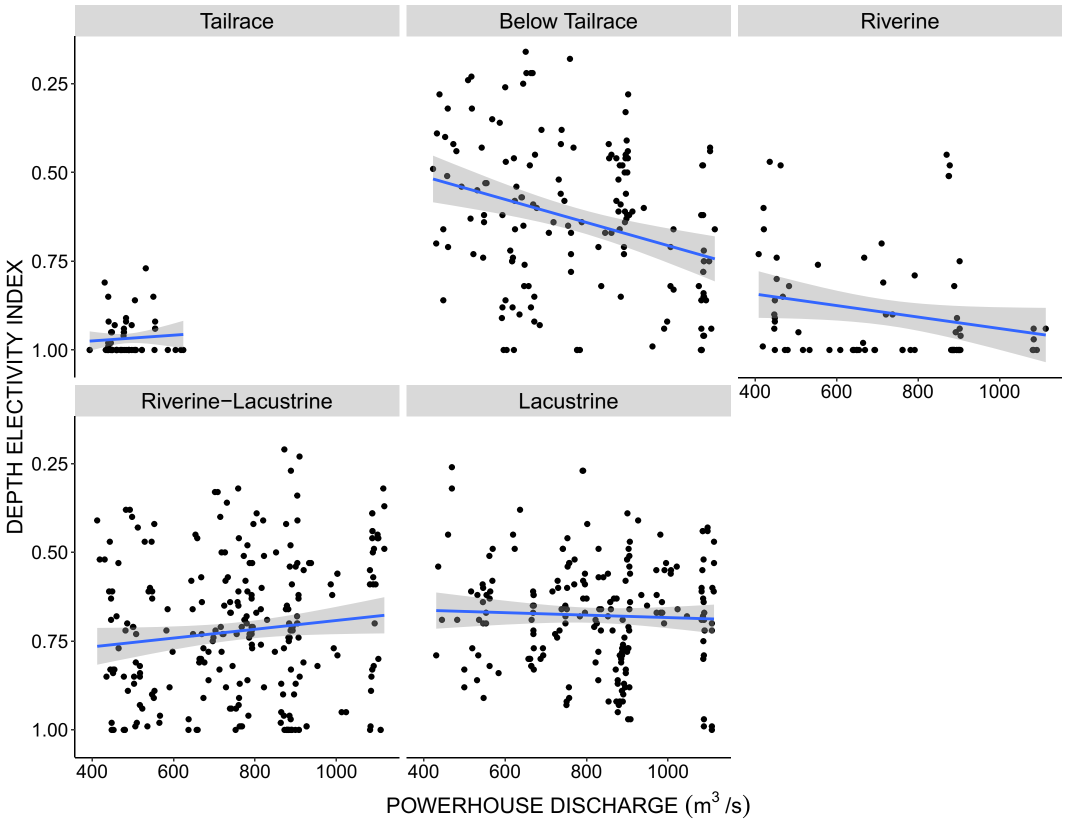

Fig. 6 Indexed depth use (DE_I) for Lake Sturgeon within the habitat types of the impounded reach plotted across the Seven Sisters GS powerhouse discharge range

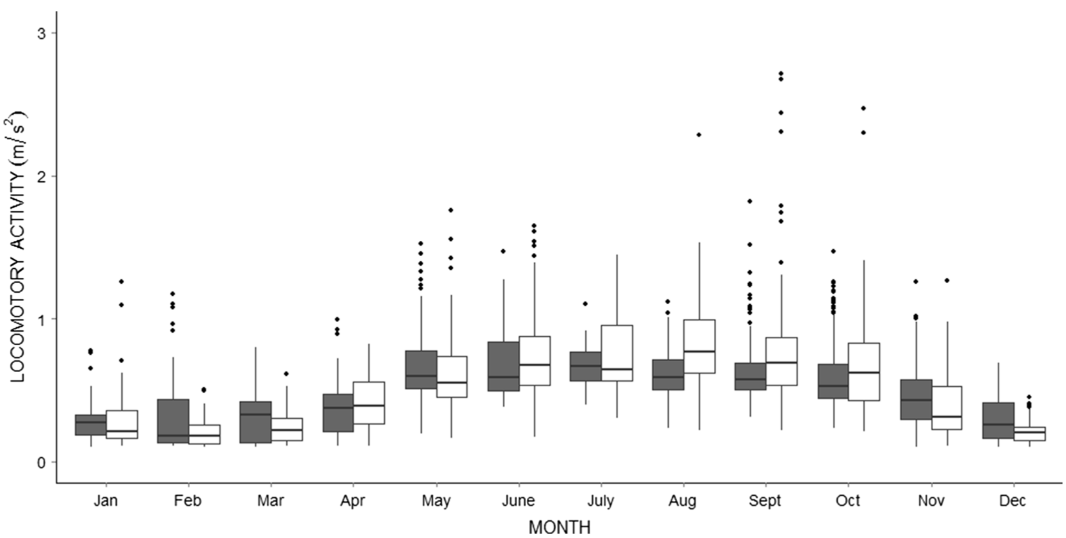

Fig. 7 Locomotory activity rates ($m \cdot s^{-2}$) across the study month for Lake Sturgeon (*shaded plots*) and Walleye (*open plots*) relative to habitat type in the impounded reach situated between Seven Sisters GS and McArthur Falls GS on the Winnipeg River

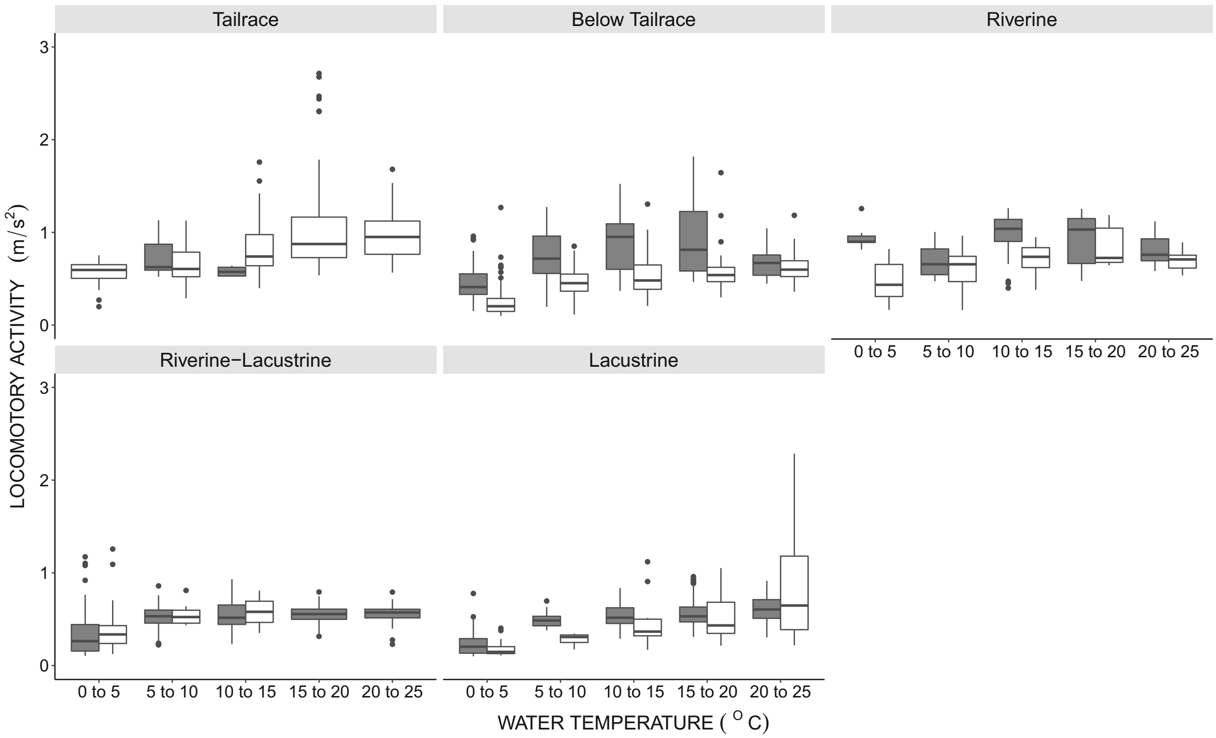

Fig. 8 Locomotory activity rates (m·s^{-2}) across water temperatures for Lake Sturgeon (*shaded plots*) and Walleye (*open plots*) relative to habitat type in the impounded reach situated between Seven Sisters GS and McArthur Falls GS on the Winnipeg River

hydropower facility (SSGS) was particularly important for both Lake Sturgeon and Walleye. Water temperature was an important driver of habitat use for Lake Sturgeon and Walleye. As water temperature rose, Lake Sturgeon generally moved to habitat located further downstream, while Walleye moved upstream (i.e., tailrace habitat) and downstream (i.e., riverine habitat) from the area below the SSGS tailrace. Both species became increasingly active as water temperatures approached 15–20 °C throughout the impoundment, and less active through the winter period as water temperatures approached 5 °C. Depth use for Lake Sturgeon and Walleye was found to be related to habitat type and water temperature. On average, Lake Sturgeon utilized greater depths than Walleye within the SSGS tailrace and lacustrine habitat, while utilizing similar available depths in the other habitat types.

Outcomes for Lake sturgeon

In open systems, Lake Sturgeon are known to migrate upstream from lake environments after winter to spawn at the base of natural barriers such as steep falls or river narrows (Mosindy and Rusak 1991; Peterson et al. 2007). Similar results were found within this impounded reach as Lake Sturgeon mainly utilized the upstream habitat of the SSGS tailrace during the spring season. The residency data, indicated that when water temperature was 9.1–9.8 °C and discharge was 429.9–502.4 m^3·s^{-1} the greatest numbers of tagged Lake Sturgeon were located in the SSGS tailrace. These water temperatures were within the optimal temperature range reported for Lake Sturgeon spawning (8–19 °C, Roussow 1957; LaHaye et al. 1992; Bruch and Binkowski 2002). On a large peaking impoundment on the Mattagami River, Ontario, Canada similar observations of Lake Sturgeon at spawning locations occurred when water temperatures ranged between 8 and 10 °C (McKinley et al. 1998). Previous work has also documented greater abundances of fish and lower residency durations in habitat near a hydropower facility during run-of-river flow versus hydropeaking operations at the same facility (Auer 1996). This may occur because more consistent powerhouse discharge rates occur at run-of-river facilities, allowing Lake Sturgeon to spawn when desired water temperature corresponds with optimal discharge levels. We posit that tagged Sturgeon in the current study were either utilizing tailrace habitat to spawn or, based on their return to the area in proximity of the SSGS facility where they were tagged the previous spring, were migrating with spawning conspecifics. There was no Lake Sturgeon detected in the SSGS tailrace after week 27, suggesting that Lake Sturgeon spawning was completed within this ten-day period. Food and habitat for Lake Sturgeon is generally restricted in spawning locations due to the swift conditions near hydropower facilities, so fish do not spend a considerable amount of time in this habitat prior to or after spawning (Auer 1996).

Based on the residency data, Lake Sturgeon were dispersed across the entire impoundment across all months. Lake Sturgeon generally migrate between spawning, foraging, and overwintering habitats or move to avoid conditions that are unfavourable (Auer 1996; Peterson et al. 2007). Here, Lake Sturgeon utilized habitat closer to the SSGS (i.e., in and below the SSGS tailrace) more so during the spawning season, yet, some individuals remained just downstream of the SSGS tailrace to forage and overwinter. In an impoundment located farther upstream (Point De Bois GS – Slave Falls GS), Lake Sturgeon of all age classes were also found residing below the upstream facility in all seasons (McDougall et al. 2014). Indeed, Lake Sturgeon residency was highest during the overwintering period in the habitat below the SSGS tailrace. Lake Sturgeon appear to generally prefer habitat with a transition zone between riverine and lacustrine conditions to overwinter and forage (Rusak and Mosindy 1997; Knights et al. 2002). Refugia from flow are important for fish to tolerate elevated flow events (Murchie and Smokorowski 2004). Given that Lake Sturgeon are rheotaxic (McDougall et al. 2013b), individuals may reside immediately below the tailrace during the period of increased flow because of the available complex habitat structures (i.e., rock peninsula, several small islands, confluence with a small tributary; Fig. 1) that create flow boundaries and make this area less energetically taxing for Lake Sturgeon to reside here. Also, there were observations of fine silt/sand located below the SSGS tailrace when recovering receivers, which is typical substrate used by Lake Sturgeon for foraging (Chiasson et al. 1997; Peterson et al. 2007) and overwintering (McKinley et al. 1998). The lacustrine habitat appears to be a preferred foraging habitat for Lake Sturgeon during June, July, and August. During these months, approximately 50% of the tagged fish utilized this habitat. Lake Sturgeon have been found to prefer substrate that consist of fine organic materials such as silt and clay (Chiasson et al. 1997), which is characteristic of the lacustrine habitat in this impoundment. Water temperature and discharge were key determinants of habitat use for Lake Sturgeon in this impounded reach. The Lake Sturgeon demonstrated movement into the lacustrine habitat as water temperatures exceeded 10 °C. Other research has also found that Lake Sturgeon habitat use can be influenced by water temperature, as well as having preference for specific habitat locations (McDougall et al. 2014).

Locomotory activity was explained by the interaction between habitat type and water temperature for Lake Sturgeon. The results here demonstrated that locomotory activity rates increased as water temperature ranged between 10 and 15 °C, then decreased marginally as temperatures approached 20 °C. Past work has found that locomotory activity decreases as water temperatures approach 19 °C (Power and McKinley 1997) and Lake Sturgeon avoid areas where water temperatures exceed 23 °C (Ono et al. 1983), which correspond to our results. The tagged Lake Sturgeon were noticeably less active during the overwintering period with lower water temperatures (i.e., December – March). Lake Sturgeon are known to forage throughout the year, but feeding may slow in northern populations during the winter (Priegel and Wirth 1974). Interestingly, discharge from the SSGS powerhouse and spillway, and their interaction with habitat type, were not identified as important predictors of locomotory activity for Lake Sturgeon within the impounded reach.

The results indicate that the interaction between habitat type and water temperature was important in the best model for explaining depth use of Lake Sturgeon. Lake Sturgeon utilized greater depths below the SSGS and within the riverine habitat as water temperature increased, while vice versa in other habitat types. However, Lake Sturgeon generally utilized 52% (i.e., DE_I of 0.52) of the available depths amongst habitats and months. Lake Sturgeon is a demersal species, having fidelity with the substrate to overwinter and forage (Scott and Crossman 1973; Dempsey and Auer 2013). Lake Sturgeon are thought to reside in deeper waters during the summer months based on water temperature (McKinley et al. 1998). Based on the DE_I results, the tagged Lake Sturgeon were generally found in less than 50% of available depth through the spring, summer, and autumn months. As a fish with affinity to the substrate, it is likely that the tagged sturgeon are residing in shallower areas rather than residing midway in the water column. Lake Sturgeon may select depths that contain a rich source of benthic macroinvertebrates when foraging (Harkness and Dymond 1961). Lake Sturgeon generally selected depths that were approximately 60–80% of the available depth during the foraging and overwintering months. Depth data were only generated in the SSGS tailrace between late-May to early-June when tagged fish were present. Lake Sturgeon used greater depths when located in the SSGS tailrace relative to the other four habitat types located further downstream. Although measurements were not taken, the water velocity is typically lowest adjacent to the substrate (Allan 1995), therefore, the tagged individuals may reside at greater depths to minimize energy expenditure through the spawning season.

Outcomes for walleye

Walleye habitat use was relatively restricted to the first ~9 rkm of the impounded reach. On the Ottawa River, Ontario, Canada, Walleye were found to move to a lesser extent in an impounded reach compared to an open river system, with downstream movement being limited (Haxton et al. 2015). Walleye particularly preferred the riverine and tailrace habitat during the summer months, while residing below the SSGS tailrace through all months of the year. Past research documented that Walleye utilize small habitat areas located near spawning habitat during non-reproductive periods (DePhilip et al. 2005). In open systems, Walleye generally do not move between connected systems (Weeks and Hansen 2009) and demonstrate fidelity to a specific habitat area (Palmer et al. 2005). The area proximal to the SSGS (i.e., SSGS tailrace and below the tailrace) have riffle sections with coarse substrate, which is typically important for spawning Walleye (Priegel 1970; Hartley and Kelso 1991). There was a pronounced increase in Walleye residency in the tailrace and riverine habitats during the summer period, which is a productive foraging and growing period for Walleye when water temperatures are optimal (Bozek et al. 2011). The SSGS may provide a unique foraging habitat as it is a barrier to fish moving upstream and a location where entrained fish would likely be available as a food source.

Homing in Walleye is an adult-learned behaviour that is strengthened through repeated annual homing movements across several years (Olson et al. 1978). With Walleye being relatively rare in the lacustrine and riverine-lacustrine habitats throughout the study period, it appears that habitat in the upstream area of the impoundment is important for the tagged Walleye. As a schooling species, older individuals may show younger conspecifics where optimal foraging and spawning habitats exist (Palmer et al. 2005; Bozek et al. 2011). Additionally, Walleye subpopulations may exist based on habitat preferences. There are three unique life history strategies that Walleye employ: 1) river resident – river spawning, 2) lake residency – river spawning, and 3) lake residency – lake spawning (Bozek et al. 2011). Distinct populations of Walleye are known to coexist in connected riverine – lacustrine systems (Palmer et al. 2005). The tagged individuals are more likely to be 'river resident – river spawning' individuals since the fish were captured/tagged from the upstream portion of the impoundment. The two receivers located farthest downstream from the SSGS did not detect any tagged Walleye, which further indicates fidelity to the areas adjacent to SSGS while showing little association with the backwater area near the MFGS.

Locomotory activity for Walleye was best explained with a model that included habitat type, diel period, water temperature, and SSGS discharge. Tagged Walleye were more active with rising water temperatures, with those in the tailrace, lacustrine, and riverine habitats becoming more active as water temperatures approached 20 °C. Optimal temperature for growth and foraging activity occurs within the 18–24 °C range (Wismer and Christie 1987; Christie and Regier 1988). Peak spawning activity for Walleye occurs when water temperature ranges between 4 and 14 °C (Bozek et al. 2011). Given the locomotory activity and residency in the tailrace at these temperatures during spring, Walleye utilized the area near the SSGS during the spawning period as this area contains coarse-grain substrate material and cold, well oxygenated water (DePhilip et al. 2005). Similarly, tailrace environments characterized by rocky, turbulent conditions provide important habitat for other important recreational fisheries species, such as Smallmouth Bass (*Micropterus dolomieu*) (Janssen 1992; Weathers and Bain 1992). Indeed, the tailwaters of the Wilson and Wheeler Dams on the Tennessee River, Alabama, USA, have been popular and productive recreational fisheries for Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass, Catfish (*Ictalurus* spp.), and Freshwater Drum (*Aplodinotus grunniens*) (Janssen and Bain 1994).

Depth use for Walleye was best explained by month, diel period, and the interaction between powerhouse discharge and habitat type. Walleye selected deeper water when residing in the riverine-lacustrine habitat compared to other habitats. Walleye were found to reside in the riverine-lacustrine habitats during the winter period, when they are less active and likely selecting deeper refugia habitat to conserve energy resources. Alternatively, Walleye were found in less of the available depth ($DE_I = 0.59$) when residing within the tailrace of the SSGS, particularly during high powerhouse discharge. The area near the shoreline provides flow refugia and shallower depths (~ 0–3 m), whereas waters located 2–5 m away from the shoreline provides greater available depths (~ 8–15 m). Walleye are likely selecting favourable habitat based on flow conditions rather than depth preferences when located in tailrace in effort to avoid the consistently high flow velocity regions found below run-of-river powerhouses. Other literature sources have indicated that Walleye prefer depths between 3 and 12 m, with larger individuals associating with greater depths (Bozek et al. 2011). Although diel period was important for explaining the variance in the fitted data, there was not discernable difference in depth use between day and night periods for Walleye.

Management considerations

Overall, the habitat located within the tailrace and below run-of-river facilities should be a conservation priority for both Lake Sturgeon and Walleye populations. There was persistent presence of Lake Sturgeon and Walleye throughout the spawning, foraging, and overwintering periods in the SSGS tailrace and within the rkm located immediately downstream. The habitat proximal to run-of-river facilities generally encompasses small areas of the total potential habitat within impoundments. As such, anthropogenic developments and potential threats (e.g., fishing pressure) to impounded populations should be managed rigorously in these areas in comparison to other habitat types found within run-of-river impoundments. Palmer et al. (2005) noted that river populations of Walleye are at risk year-round by angling pressure since they have fidelity to a small area and are under heavy fishing pressure in rivers in comparison to lake systems. Indeed, 47.5% of the 40 tagged Walleye disappeared or provided erroneous sensor data over the course of the study (August 10, 2014 to July 6, 2015). Of the tagged fish, 23% (n = 9) of the Walleye were confirmed to be harvested by recreational anglers. The tags that disappeared were not returned by anglers, but could possibly have been harvested by anglers.

The depth use and locomotory activity findings presented here provide further insight into the ecology of Lake Sturgeon and Walleye residing in impoundments. The findings for these ecological responses elucidate how the abiotic environment can influence depth selection and movement of these fishes. When working to conserve populations within run-of-river impoundments, conservation initiatives and stock assessment methods should consider habitat types water temperature, and discharge as influential variables for the ecological responses of Lake Sturgeon and Walleye.

The goal in this study was to provide fisheries managers, regulators, and hydropower proponents with pertinent information that can be applied to aid in the conservation of Lake Sturgeon and Walleye. The generated information provides an in-depth description of what motivates these species to utilize different habitats found in restricted river systems on a multi-seasonal basis. The information garnered from this study will also aid managers in conducting population assessments in impounded reaches by providing a general census on the expected seasonal trends in residency and depth use across various habitat types found in impoundments. The documented information will help to prioritize habitat augmentation initiatives, and managing endangered Lake Sturgeon and recreationally important Walleye fisheries where they are impounded by hydropower facilities.

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