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Space use of juvenile and subadult yellow perch (*Perca flavescens*) in the Detroit River using acoustic telemetry: incorporating variable detection ranges in vegetated areas

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Abstract

Understanding the space use of fishes in early life stages provides information that can contribute to effective fisheries management; however, it can be difficult to track fish in shallow, densely vegetated areas. Using acoustic telemetry, 60 subadult yellow perch (*Perca flavescens*) were tagged and monitored in a vegetated area of the Detroit River (May-Nov 2018). Variable detection range from submerged aquatic vegetation (SAV) was incorporated in estimates by applying a spatio-temporal correction to aid with interpretation of seasonal changes in activity space. Although subadult yellow perch were commonly detected in the array, demonstrating the importance of SAV habitat (mean detection residency index: 0.85), 60% of individuals were not detected following August, the period with highest activity space estimates, likely due to seasonal movements and predation. Individuals were more commonly detected during the daylight hours compared to night, but activity peaked at crepuscular periods. This study provided spatial information about the often-overlooked early life history of yellow perch, increasing the ecological information available for a species of management and conservation interest in the Great Lakes.

Keywords: yellow perch, detection range, submerged aquatic vegetation, Laurentian Great Lakes, space use, biotelemetry

34 Introduction

35 Examining the movement and distribution of fishes can provide insight into their
36 fundamental ecology including habitat use and other interactions within their environment
37 (Brownscombe et al. 2019; Selby et al. 2019). Despite the abundance of research examining
38 how adult fishes use available resources, the habitat of small-sized juveniles/subadults may
39 differ from adult stages (e.g., Tolimieri et al. 2020) and, therefore, should also be considered
40 for species of interest. Several fish species exhibit ontogenetic shifts in movement and habitat
41 use that alter their functional roles in an ecosystem (Byström et al. 2003; Snover 2008).
42 Juvenile and subadult fishes are a substantial source of energy subsidies to food webs and can
43 influence the movement and distribution of predators (Vander Zanden and Vadeboncoeur
44 2002; Hansen et al. 2019). Consequently, it is important to understand the basic ecology of
45 wild animals across multiple life history stages to inform conservation and management
46 efforts (Cooke et al. 2012).

47 Yellow perch (*Perca flavescens*) are one of the most common fish species in
48 temperate regions of North America and play an important ecological and economic role in
49 freshwater ecosystems. In addition to directly sustaining valuable recreational and
50 commercial fisheries as adults, yellow perch juveniles and subadults indirectly support major
51 fisheries as an abundant prey species, particularly in Lake Erie (Knight et al. 1984; Belore et
52 al. 2006) and historically in Lake Michigan (Francis 1995; Francis et al. 1996). Yellow perch
53 are known to occupy a wide breadth of ecological niches in freshwater systems occupying
54 both nearshore and offshore habitats and being consumed by a variety of predators during
55 early life stages, including walleye (*Sander vitreus*), smallmouth bass (*Micropterus*
56 *dolomieu*), largemouth bass (*Micropterus salmoides*), and larger conspecifics (Forney 1977;
57 Liao et al. 2004; Dembkowski et al. 2015; Fetzer et al. 2015). Predation of yellow perch
58 primarily occurs on fish aged 0 to 2 years (Forney 1977; Nielson 1980; Fetzer et al. 2015);

however, subadult yellow perch up to 200 mm (~3 years) are also consumed by fish predators (Weinz et al. 2020). Yellow perch have been described occupying a wide variety of ecological niches in temperate freshwater rivers and lakes, but general habitat use patterns of yellow perch have been described (reviewed by Semeniuk et al. 2015). In brief, after a short period of pelagic development, young-of-the-year yellow perch typically return to vegetated nearshore areas where they forage on zooplankton and macroinvertebrates. There is an ontogenetic niche shift from planktonic to benthic prey (e.g., macroinvertebrates) during the first year of life and a subsequent shift towards piscivory during the second year of life in many populations (Knight et al. 1984; Scott and Crossman 1998; Pothoven et al. 2000). However, juvenile and subadult yellow perch also show plasticity in habitat use and diet patterns (Semeniuk et al. 2015), which has been attributed to a combination of food availability and predation pressure in the ecologically similar Eurasian perch (*Perca fluviatilis*; Mustamaki et al. 2014). Like many small fishes (<150 mm), the space use patterns of subadult yellow perch within these shallow vegetated areas remains largely unknown beyond presence-absence measures in nearshore vs. offshore habitats. Uncovering the extent of yellow perch residency and space use in nearshore areas can improve our understanding of fine-scale space use and individual variation in behaviour.

Acoustic telemetry has become a widely used method to monitor fish movements and space use to further our understanding of fish ecology across marine and freshwater ecosystems (e.g., Cooke et al. 2013; Donaldson et al. 2014). Technological advances, such as the miniaturization of tags, have permitted the acoustic tracking of smaller fishes, such as subadult yellow perch (e.g., Weinz et al. 2020); however, logistical and technical challenges still exist. For example, detection range – the distance that acoustic receivers can detect tagged animal transmissions – is influenced by environmental conditions (e.g., water temperature, wind), noise, and physical obstructions such as vegetation and topography

(Payne et al. 2010; Gjelland and Hedger 2013; Kessel et al. 2014). Failure to account for spatial or temporal variability due to biotic and abiotic factors can lead to erroneous interpretation of fish behaviour (e.g., changes in activity space due to seasonally variable detection ranges; Topping and Szedlmayer 2011).

Given the expanding use of acoustic telemetry to track space-use of species with economic and conservation value, there is need for accurate assessment of habitat-use, reproductive areas, and migratory corridors, among others (Binder et al. 2016; Cooke et al. 2016). In nearshore habitats, submerged aquatic vegetation (SAV) is often seasonally variable and has a strong influence on detection efficiency - the distance between a transmitter and receiver at which a specified proportion of detections are estimated to occur - resulting in lower detection range where and when SAV is abundant. For example, Swadling et al. (2020) found that detection range decreased by more than 50% when stationary tags were placed in the seagrass canopy of a temperate Australian bay. In the Detroit River, Weinz et al. (2021) observed a substantial reduction in mean detection range from 186 to 6 m correlated with seasonal changes in the biovolume of SAV. Therefore, it is important to take into consideration these changes and their effect on detectability of tagged fish in acoustic telemetry research. Fine-scale positioning techniques that use triangulation of simultaneous detections on multiple hydrophones (e.g., Espinoza et al. 2011) are not typically feasible in areas with high vegetation due to costs and logistical constraints of deploying enough receivers that are close enough to achieve simultaneous detections. Other studies have aimed to develop methods to account for variable detection efficiency within a study area by weighting seasonal activity space estimates (Brooks et al. 2019), correcting the relative number of site-specific detections (Payne et al. 2010; Brownscombe et al. 2020) or by improving the accuracy of position estimates (e.g., Charles et al. 2016; Winton et al. 2018). In areas where detection efficiency is primarily driven by SAV, there is the potential to

combine range testing and monitoring of SAV biovolume to improve spatial position estimates of fishes.

The goal of this study was to evaluate the residency and space use patterns of yellow perch in an area of the Detroit River that features a secondary navigation channel flanked by shallow flats with seasonally variable SAV. To account for the influence of SAV on detection efficiency and range in the study area (Weinz et al. 2021), we applied a SAV-weighted positioning and scaling approach to estimate relative changes in seasonal activity space. Specifically, the objectives were to (1) describe the activity space of small-sized yellow perch (< 200 mm total length); and (2) determine the biological and environmental factors influencing residency and activity space of yellow perch in the Detroit River. We expected that, similar to sunfish (*Lepomis* spp.) monitored in the same area of the Detroit River (Klinard et al. 2018), juvenile and subadult yellow perch would maintain relatively stable summer home ranges and would be unlikely to show frequent movements in-and-out of the focal study area. Furthermore, we predicted that yellow perch activity would be concentrated in the shallow, densely vegetated margins of the river over the open-water navigation channel. Finally, crepuscular periods were hypothesized to be associated with increased foraging activity in yellow perch (Reynolds and Casterlin 1979, Jansen and Mackay 1992); therefore, we predicted increased tag detections during the dawn and dusk hours compared to other times of day.

Materials and methods

Study area and receiver array

This study was focused on the Detroit River, a connecting channel between Lake St. Clair and Lake Erie of the Laurentian Great Lakes, which contains both channelized areas as deep as 16 m for shipping and navigation and shallow nearshore habitats as deep as 6 m. The

study area was near the midpoint of the Detroit River between the shores of LaSalle and Fighting Island (Fig. 1). An acoustic receiver array consisting of 24 VR2W-180 kHz receivers (InnovaSea Systems Inc., Nova Scotia, Canada) was deployed in the nearshore areas surrounding the navigation channel ranging in depth from 2-6 m. Fourteen receivers were located on the eastern side of the channel and 10 on the western side (Fig. 1). Due to the soft sediment of the study site and shallow bathymetry (~2 m at nearshore stations), low-profile moorings were designed to sit directly on the bottom without surface floats or lines to secondary anchors. Each mooring consisted of a cinder block with a PVC pipe concreted into each opening on the block to position acoustic receivers upright and provide protection, with only the hydrophone exposed. Stations located along the edge of the navigation channel were also equipped with a yellow float buoy positioned approximately 0.5 m above the receiver to aid with visual identification during retrievals. Eight reference tags (V9 180 kHz, 1750-1850s min-max delay; InnovaSea Systems Inc., Nova Scotia, Canada) were attached to receiver moorings (~20 cm above the receiver) via a line with a small buoy throughout the study area including locations designated as channel and shore (Fig. 1).

Perch tagging

A total of 60 yellow perch (mean $\pm$ SE: 144 ± 3 mm total length; range: 108-190 mm total length) were implanted with acoustic transmitters, hereafter “tags”, during May ($n = 40$) and July ($n = 20$) 2018 following capture by electrofishing. The tags used (V5D-180 kHz, 300 s nominal day, 173-day battery life; InnovaSea Systems Inc., Nova Scotia, Canada) detected predation events allowing for increased accuracy regarding acoustic data filtering and identifying the fate of tagged individuals (Halfyard et al. 2017; Weinz et al. 2020). A relatively restricted size range of yellow perch was selected to balance tag burden as a function of fish size and the goal of monitoring space use of juvenile and subadult perch. Maturation in male and female yellow perch is variable, but is generally reached between

ages 3 and 4, or approximately 196 mm and 216 mm, respectively (Scott and Crossman 1998). Therefore, most tagged individuals were likely juveniles or subadults. The first six perch tagged were anesthetized in a buffered solution of tricaine methanesulfonate (MS-222; 100 mg/L) whereas the remaining 54 perch were electrosedated with a PES unit (4 sec pulsed DC, 100 V, 30 Hz, and 25% duty cycle; Smith-Root Inc, Washington). Following anesthetization, their total length and wet weight were measured to the nearest 1 mm and 1 g, respectively. A mid-ventral incision of approximately 10 mm was made adjacent to the *linea alba* (midline), a tag was inserted, and the incision was closed using two interrupted sutures (3-2-2 knot and 5-0 needle; Ethicon coated VICRYL Plus Antibacterial). Fish were held in recovery for approximately 15 min in an aerated tank of fresh water from the Detroit River until normal activity resumed. Fish were then released in the approximate location of original collection. Additional details of fish capture and tagging procedures are described by Weinz et al. (2020) which used the same fish described in this study.

Submerged aquatic vegetation mapping

Submerged aquatic vegetation mapping was performed 22 times (May 22-Nov 14, 2018) to measure SAV biovolume (% volume of vegetation in the water column) throughout the study area using hydroacoustics. A research vessel mounted with a Lowrance Elite-4 Chirp sonar unit paired with a single-beam Lowrance 83/200 kHz transducer set to 200 kHz was used to collect sonar imagery. The vessel completed multiple passes parallel to the shore spaced approximately 25 m apart at speeds ≤ 5 km/h on each side of the navigation channel (where receivers were placed). For each second, one GPS point was recorded, and 5-30 acoustic signals were produced for each GPS point. Sonar logs were uploaded to BioBase (<https://www.biobasemaps.com/>), an online cloud-based automated data processing tool for aquatic spatial data (Navico, Minnesota, USA). The vegetation height and depth data were used to calculate the mean proportion of plant height to water depth (biovolume) for each

GPS point and produce a heat map of predicted SAV biovolume (e.g., Helminen et al. 2019).

The grid data for each mapping event was exported from BioBase for use in data analysis.

Average SAV biovolume was calculated around each receiver (20m radius) for each day the study area was surveyed. A linear interpolation was used to estimate daily SAV biovolume between sampling dates at each receiver location in order to incorporate SAV-corrected spatial estimates (see *Data analysis*).

Data preparation

Only detection data between the first and last dates when SAV mapping was conducted (May 22 - Nov 14, 2018) were used to be able to incorporate SAV-related impacts in the study area. If applicable, data compiled after a transmitter had switched from a non-predated to a predated designation (i.e., it was no longer representative of yellow perch but a predator) were also removed, as well as 24 hrs prior to the last pre-predation signal to ensure the data did not reflect a consumed yellow perch prior to signal switch (Halfyard et al. 2017). The first 24 hrs of detection data were removed for analyses to help avoid irregular behaviours associated with tagging, e.g., post-surgical recovery period or fish returning to a home range following displacement from capture. The final 24 hrs of detection data for fish not signaled as predated was also removed in case a predation event had occurred, but the tag was carried out of the detection range of the array prior to the tag changing signal.

Data analysis

Residency

Residency of each yellow perch within the study area was described using a residency index (detection RI) calculated as the proportion of days with detections relative to the detection period (i.e., days between first and last detection) for each individual. For those fish not detected as predated by the tags, we also calculated a total RI, in which the number of

days with detections was divided by the total number of days that a tag could have been detected between the day of release and end of the study in November.

Random forest models explored the importance of factors influencing yellow perch residency within the detection period (i.e., between first and last detection; detection RI) of each individual. Individuals were considered present in the array (or within the detection range) if they were detected at least twice during 4-hr periods. Only individuals detected ≥ 10 unique days were included in this analysis (48/60 individuals) to avoid including data from yellow perch with sparse information relating to presence in the array. Explanatory variables included: mean 4-hr water temperature (measured with Hobo pendant loggers, Onset Computer Corp, Onset MA, USA; $n = 10$; Fig. 1), mean daily SAV biovolume (based on a 20 m radius around each receiver), total length of yellow perch, the side of the channel where yellow perch were released (east or west), the release group of tagged fish (May or July), month, hour category (e.g., 0:00, 4:00, 8:00, 12:00, 16:00, 20:00), and fish ID (as a proxy for individual variation). These models work by fitting a series of recursively partitioned data trees each subsetted with random predictor variables with the goal of optimizing prediction of the response variable (Breiman 2001; Strobl et al. 2009). The *randomForest* R package (Liaw and Wiener 2002) was used to fit models based on 23,102 observations and using 1,000 trees without replacement (to avoid predictor scaling bias; Strobl et al. 2007). The relative performance of the models was evaluated with out-of-bag prediction error (OOB error) based on the proportion of non-training data incorrectly predicted (Cutler et al. 2007). Variable importance was quantified using the mean decrease in accuracy (MDA), where variables with larger decreases equate to greater loss of model accuracy if that variable is removed (i.e., therefore it is more important).

231 *Position estimates*

232 Prior to estimating the activity spaces of tagged fish we applied a correction to
233 detection locations that incorporated the relationship between SAV biovolume and detection
234 range. Instead of using the receiver location as the position of a detection, each detection was
235 repositioned around the receiver in a random direction based on probability-distance
236 functions derived from range tests in the area (see Weinz et al. 2021). These probability-
237 distance functions were applied relative to the average SAV biovolume around that receiver
238 (20 m radius) during the day of the detection (Fig. 2). Based on the SAV biovolume, the
239 functions were derived from a probability table using the predicted detection efficiency (0-1)
240 across a range of distances from a receiver (see Fig. 4b in Weinz et al. 2021). For each
241 detection, a distance between 0 and 200 m from the receiver, weighted by the probability-
242 distance function, and an angle around the receiver, were randomly selected and applied to
243 the existing receiver location. Also, the total area that detections could be repositioned in
244 decreased as SAV biovolume increased due to the concurrent reduction in detection range
245 (Fig. 2; Weinz et al. 2021). This method enabled us to estimate space use of yellow perch in
246 an acoustic environment that considered the impact of SAV biovolume on detection range of
247 receivers.

248 *Activity space*

249 Kernel density estimates (95% utilization distributions, UD_s) of yellow perch were
250 calculated weekly to quantify activity space based on SAV-weighted positions using the
251 *adehabitatHR* package (Calenge 2006) in R (version 3.5.1; R Core Team 2019). A low
252 smoothing factor ($h = 10$) was used for kernel estimates because positioning error had already
253 been incorporated when using the probability-distance functions. To help reduce any
254 influence of small sample size on UD_s, each individual had to be detected on at least 10
255 unique days and only weeks with ≥ 25 detections were included.

There was potential bias using UD_s to directly compare yellow perch activity space over time because periods of low SAV biovolume typically resulted in larger UD_s compared to periods of high SAV biovolume. Therefore, yellow perch UD_s were standardized each week relative to observed detection patterns of stationary reference tags. Specifically, weekly UD_s were also calculated for each reference tag within the array using SAV-weighted positions (as described above). To account for potential yellow perch mortality (e.g., due to tagging effects, predation without signal switch) or expelled tags leading to erroneous transmissions (Klinard and Matley 2020), weekly periods when yellow perch UD_s were smaller than the minimum UD estimate of reference tags in the corresponding habitat (channel or shore) were marked as ‘suspect’. As a conservative approach to avoid including ‘suspect’ detections, these weeks were removed from further analyses unless UD_s increased above the minimum reference tag UD following the week in question (i.e., indicating the individual eventually moved enough to be considered alive). This approach may have also eliminated weekly periods when individuals permanently migrated outside of the system (if <25 detections that week). The mean UD size among reference tags in each habitat was then used to calculate an activity space (AS) coefficient relative to yellow perch UD_s during the same week. This weekly (i) AS coefficient was calculated for each individual as follows:

$$AS_i = \frac{\text{Yellow Perch } UD_i}{\text{Reference Tag } UD_i \text{ (mean)}}$$

where AS coefficients larger than 1 represented UD_s larger than stationary reference tags – the larger the AS coefficient, the greater relative space being used during that week. By contrast, AS coefficients smaller than 1 indicated limited movement relative to detection range.

Random forest models were also used to quantify the relative importance of environmental and biological variables influencing weekly AS coefficients. Explanatory variables included: month, mean weekly water temperature in the study area, number of

weekly detections (to incorporate influence of sample size), mean weekly SAV biovolume at receivers with detections during that week, total fish length, release side of the channel, the release group of tagged fish (May or July), the habitat where most detections occurred during that week (shore vs channel), and fish ID (to account for individual variation). The relative performance of the models was assessed as described above, and variable importance was quantified using the percent increase in mean square error (%IncMSE), which is equivalent to MDA for continuous response variables. For the variables that influenced residency and AS coefficients the most in random forests, separate exploratory plots illustrating the relationship were completed (see Results).

Results

Five of the initial 60 yellow perch tagged were not detected after release; therefore, detection data from 55 yellow perch (~350,000 detections) were available for analysis (Table 1; Table S1). Partial data from 17 individuals were filtered because tag sensors indicated a predation event had occurred at the end of their detection period (Table S1). Seven out of the 55 yellow perch had <10 unique days of detections and were not included in residency and activity space analyses. Submerged aquatic vegetation biovolume around receivers was variable throughout the study period ranging between 1% and 99% (mean daily vegetation of all receivers ranged between 3% and 55%; Fig. 3). Shore receivers commonly experienced SAV biovolume values >80% particularly between June and October (Fig. 3).

Residency

Yellow perch were detected within the array for an average of 61 days (range: 2-173 days) and were resident with a mean detection RI (i.e., the number of days detected relative to the first and last detection - not including detections that were identified as predated) of 0.85 (range: 0.25-1; Table 1). However, it is important to note that 12/60 (20%) yellow perch

tagged were detected <10 days, and based on possible detection days throughout the duration of the study, the mean total RI (i.e., the number of days detected relative to the first detection and end of study period in November - not including individuals that were identified as predated) was 0.46 (range: 0.02-1; Table 1).

Residency patterns during the detection period of individuals were classified with a high degree of confidence (variance explained 84.58%; OOB error 15.42%) in random forest models. The hour category was the main variable contributing to yellow perch detection RI (Fig. 4a) with greater 4-hr presence (or detectability - see Discussion) during the day compared to the night, with peaks at crepuscular periods (Fig. 4b). Mean vegetation was the next most important variable with higher SAV biovolume corresponding to fewer detections across 4-hr periods and lower RIs in the study area (Fig. 4c). Yellow perch that were not signalled as predated typically left the array a few months after release, although at least 15 individuals were detected after the end of the study period in November when vegetation mapping ended (11 of which were detected throughout the ~173-day battery life of tags; Fig. 5).

Activity space

Of the 530 weeks of UD estimates from the 48 individuals analyzed, 12 weeks of data were removed at the end of detection periods of five individuals because activity space estimates were smaller than stationary reference tags (Table S1), suggesting that a migration or mortality event occurred. For the remaining detections, the mean ($\pm$ SE) 95% UDs and AS coefficients of yellow perch throughout the study period ($n = 518$ weekly UDs) were 26328 ± 1601 m² and 2.03 ± 0.03 , respectively (Table 1; Table S1; Fig. S1). In total, 429 UDs were identified in shore habitat and 79 in the channel habitat.

The random forest models were moderately successful at classifying AS coefficients relative to the covariates included with 50% variance explained (OOB error ~50%). Based on

the percent increase in mean square error (%IncMSE), month and UD habitat were the most important variables contributing to space-use changes relative to all the variables considered here (Fig. 6). Specifically, in August, AS coefficients were largest indicating yellow perch used proportionally larger areas compared to other months (Fig. 6). AS coefficients were also larger in nearshore habitat compared to the river channel (Fig. 6). The location of release, fish length, and release batch were the least contributory covariates to the model (Fig. 6).

Discussion

This study revealed residency and space-use patterns of subadult yellow perch in a highly vegetated area of the Detroit River. Subadult yellow perch were more readily detected during the day and crepuscular periods and residency decreased with increasing SAV biovolume in the study area. A detection positioning method helped account for spatio-temporal variation associated with SAV among detections at each receiver. This enabled weekly activity space estimates of yellow perch to be compared against baseline UD of stationary reference tags during the same period to provide a standardized space use indicator (i.e., AS coefficient). As a result, it was evident that yellow perch used larger areas in August compared to other months. These findings identify influences of SAV on yellow perch behaviour during a poorly understood life history period, to inform management and conservation efforts in the Great Lakes. This study also highlights potential biases associated with detectability in nearshore vegetated areas and demonstrated one approach to position estimates that incorporated vegetation density over time.

There were three different types of residency patterns displayed by yellow perch in the study area. First, detection residency was high (mean detection RI: 85%) for most individuals indicating that nearshore vegetated areas provided suitable habitat for several months in the summer or longer. Second, the intermediate-level total RIs showed that

detection periods were shorter than the tag battery life, consistent with yellow perch leaving the study area and not returning during the observation period. Finally, based on zero or limited detection counts, 20% of individuals were deemed not resident for the analysis, either departing the detection area or being predated in the first days after tagging. For example, Weinz et al. (2020) found that 5/19 predation events that occurred in this group of fish were within three days after release, raising potential questions about predation risk following tagging. Other mortality events, such as fishing mortality were also possible but were likely negligible as this size range is below those typically targeted by recreational fishers in the area.

The high detection residency of yellow perch in the study area indicates the importance of densely vegetated nearshore habitat. This region of the Detroit River, particularly the Fighting Island study area used here, includes the largest wetland habitat remaining in the river and supports one of the most diverse and abundant fish assemblages (Lapointe et al. 2010). Previous river surveys identified juvenile and subadult yellow perch as one of the most abundant fish species in the Detroit River (Lapointe et al. 2010). Like many fishes, especially juveniles (Shoup et al. 2003; Lapointe et al. 2007), the yellow perch tagged here probably benefit from some combination of the protection and foraging opportunities provided by nearshore SAV and wetland habitats (Valley et al. 2004). For example, Weber and Brown (2012) identified submerged vegetation in a glacial lake as important juvenile habitat for yellow perch after finding that catch rates were highest there compared to other habitats during summer.

Based on the diel presence patterns in this study and others (e.g., Bauer et al. 2009) SAV in nearshore areas appeared to be used for resting at night (i.e., fewer detections because fish were less likely to be moving and pass within range of a receiver) and actively foraging during the day. The highest presence of yellow perch during crepuscular periods is also

hypothesized to be associated with increased foraging because yellow perch are most active during dawn and dusk periods (Reynolds and Casterlin 1979) with stomach fullness peaking at dusk (Jansen and Mackay 1992). Diel patterns relating to detectivity (e.g., due to environment noise) were not contributory to these differences (Weinz et al. 2021). It is also possible that diel residency patterns were not a result of reduced detectability due to limited movements, but a consequence of individuals moving to different habitats at night. For example, a radio telemetry study of closely related Eurasian perch larger than those studied here (~250 mm total length) reported that fish residing in vegetated nearshore areas of a lake switched between littoral and limnetic zones in response to increased foraging opportunities during the day (Zamora and Moreno-Amich 2002). Hypoxic conditions in vegetated areas have also driven diel changes in habitat use, in which juvenile yellow perch avoided cattail beds at night (high dissolved oxygen) but returned during the day (low dissolved oxygen) to forage (Suthers and Gee 1986). Furthermore, even shallow lakes that do not undergo summer stratification can experience significant diel changes in oxygen levels at different depths (Andersen et al. 2017). Ultimately, more research is needed to effectively identify whether habitat switching or poor detectability was responsible for diel activity patterns observed.

In addition to SAV biovolume, variability among individuals was a factor explaining residency and activity space differences. Interindividual differences in behaviour have been documented across a wide range of taxa (e.g., Sih et al. 2004, Reale et al. 2007), including juvenile fishes (Xu et al. 2021) and perch (Semeniuk et al. 2015). While considered to be beyond the scope of the current study, at least some degree of the movement patterns observed here could be related to individual variation expected in populations and not due to specific external cues (e.g., water temperature). Considering that the fish tagged here were not sexually mature, variation among individuals may be driven more by strategies related to growth and survival rather than reproduction. Overwinter survival of temperate fishes,

particularly in the first years of life, has been linked to growth and accumulation of lipid stores for the relatively resource-poor winter months (Hurst and Conover 2003). While speculative, individual variation may reflect trade-offs between foraging for growth and predation risk (e.g., Biro et al. 2004, 2005). Indeed, thirty-two percent of tagged yellow perch (19/60) were identified as predated based on acoustic-tag signals between May 2018 and January 2019, with 9 of these predation events occurring during the month of August (also see Weinz et al. 2020). The increased space-use during August could be consistent with a preparatory response to increase energy reserves for the upcoming winter (e.g., Cargnelli and Gross 1997) and may have resulted in increased predation risk during this time period. However, departures from the study area and variation among individuals may also be independent of predation.

Rationale for yellow perch leaving the study area during summer and before the end of the tag battery life best relates to ontogenetic or seasonal shifts in space-use. Ontogenetic changes in distribution have been identified in larval and juvenile (<30 mm) yellow perch in which nearshore areas become increasingly important with size (Post and McQueen 1988). As adults, yellow perch typically inhabit deep open-water offshore habitats compared to juveniles or subadults, which are abundant nearshore (Scott and Crossman 1979; Lapointe 2010). Consistent with these size-based distributions, our nearshore study site had very few large adults during electrofishing sampling (Weinz pers. comm.) but larger yellow perch were collected in deeper areas of the Detroit River in previous sampling efforts (e.g., Lapointe et al. 2010). Departures from the array could have been related to some subadults shifting to offshore or deeper habitat in other areas of the Detroit River in the months following tagging, but we did not observe size-related residency patterns during the study period.

In addition to ontogenetic shifts in distribution, seasonal changes have been observed in yellow perch. For example, spawning adults selected deeper areas during autumn

431 compared to summer months in a glacial lake, likely due to specific habitat characteristics
432 (Radabaugh et al. 2010). In a broad Detroit River sampling effort, yellow perch across
433 multiple sampling sites were twice as abundant during spring compared to summer and
434 autumn (Lapointe et al. 2010). The latter finding supports size-independent movements
435 outside the study area or behavioural changes leading to reduced capture. Temperature and
436 dissolved oxygen associated with summer stratification were identified as primary drivers of
437 depth distribution in yellow perch in a northern US lake (Hubert and Sandheinrich 1983).
438 Even though the area sampled in this study is relatively shallow and summer stratification
439 nearshore is unlikely, the seasonal variation in temperature and dissolved oxygen levels could
440 result in periods where even small-sized yellow perch leave the study array (Weber and
441 Brown 2012). Greater absence during warm summer months with high vegetation support
442 this rationalization; however, concomitant decreases in detection range limit interpretation.

443 The ability to incorporate potential error in space use estimates due to variable
444 detection patterns (e.g., SAV or other environmental variables) helps interpret animal
445 movements from acoustic tracking (Winton et al. 2018; Brownscombe et al. 2020). Seasonal
446 and inter-annual changes in the aquatic environment often create highly variable acoustic
447 areas (Jossart et al. 2017, Klinard et al. 2019) that can alter the ability of receivers to detect
448 animals uniformly. Discrepancies in detection efficiency throughout a study can therefore
449 result in inherently biased interpretation of space-use (Payne et al. 2010). In an area with
450 variable detection ranges, such as the Detroit River, the ability to compare activity spaces
451 over different time periods elucidated relevant activity space size with greater confidence.
452 Without the application of SAV corrections, the interpretation of yellow perch space-use may
453 have differed considerably. If not addressed, the decrease in detection range during the
454 summer/autumn due to SAV growth likely would have been interpreted solely as the use of
455 smaller areas compared to prior and subsequent periods. Similar to our approach, Brooks et

al. (2019) weighted UD estimates of walleye (*Sander vitreus*) in Lake Ontario due to seasonal variability by multiplying activity space estimates by seasonal detection efficiencies. However, the use of the AS coefficient that incorporated SAV-weighted distance-probability functions scaled relative to stationary reference tags on-site provided a ground-truthed adjustment method. The main limitation with our approach is that the AS coefficient was scaled linearly relative to reference tags, which may not be consistent when estimates are derived from an increasing number of receivers with detections (i.e., activity spaces may increase at a scale greater than 1:1 as animals are detected by additional receivers). Nevertheless, this method still provides a relative indication of space use under changing conditions and could be developed for most types of studies when site- or array-specific variation affects detection efficiency (e.g., habitat, topography and noise).

Conclusions

Broadening our understanding of activity patterns and habitat use of small fishes, such as yellow perch, in nearshore vegetated areas helps discern the spatial ecology occurring in these important habitats. Acoustic tracking of subadult yellow perch showed diel changes in habitat use that appeared to be influenced by individual variability as well as a summer period of increased activity space. Seasonal changes in SAV biovolume further supported observed changes in yellow perch space use and behaviour potentially related to foraging and predation risk. In nearshore habitats, SAV is important for small fishes, however, seasonal variation in vegetation density increases the complexity in how fish respond behaviourally and adds challenges with regards to monitoring movements and space use. The use of novel analytical techniques, such as those demonstrated here, revealed previously unknown information about the spatial ecology of juvenile and subadult yellow perch and provides a foundation for future studies on this and other species in densely vegetated habitats.

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Draft

Table 1. Summary of tagging, detection, and space-use information for yellow perch studied between May and November 2018. Mean values $\pm$ SE are shown with the numbers in brackets representing the range of values. The detection residency index (RI) represents the number of days detected relative to the first and last detection during the study period (May-Nov 2018) and the total RI represents the number of days detected relative to the first detection and end of study period in November.

Variable	Value
No. yellow perch tagged	60: 40 – May; 20 - July
No. individuals with <24 hrs of detections	5 (8%)
No. individuals with <10 days of detections	7 (12%)
No. individuals used in analyses	48 (80%)
No. individuals predated based on predation tags	17
Mean No. detections	7054 $\pm$ 852 (140-24324)
Mean No. days detected	70 $\pm$ 7 (2-173)
Mean Total length (mm)	144 $\pm$ 3 (108-190)
Mean Detection RI	0.85 $\pm$ 0.03 (0.25-1.00)
Mean Total RI	0.46 $\pm$ 0.05 (0.02-1.00)
No. weeks removed due to low AS coefficient	12/530 (from 5 individuals)
No. individuals filtered out due to low AS coefficient	0
Mean AS coefficient	2.03 $\pm$ 0.16 (0.51-5.25)
Mean Activity space (95% UD; m ²)	26328 $\pm$ 1601 (7746-58841)

Figure Captions

Figure 1. Location of study area within the Laurentian Great Lakes (a) and Huron-Erie Corridor (b) denoted by an orange circle. The study area in the Detroit River (c) features channel (n = 9) and shore receivers (n = 16) represented by black triangles and circles, respectively. Reference tags (n = 8) are designated by orange rectangles and HOBO temperature loggers (n = 10) by purple rectangles. Although variable, the main areas where submerged aquatic vegetation was abundant (i.e., shore) are delineated. Depth also varied, but vegetated shore areas were shallower (~1.5-3 m) than the less vegetated boating channel (~3-9 m). Map was created in ArcMap 10.6 using Great Lakes Aquatic Habitat Framework base maps (GLAHF 2016).

Figure 2. Conceptual diagram highlighting the positioning of detections (n=100; black points) around a receiver (red point) weighted based on submerged aquatic vegetation (SAV) biovolume distance-probability functions derived from range tests in Weinz et al. (2021). The SAV biovolume used for positioning was calculated within 20m of each receiver and each day. A maximum distance of 200m was selected in computations.

Figure 3. Daily submerged aquatic vegetation biovolume (% as category) during study period based on 22 independent days of vegetation mapping between May 22 and November 14. For days that were not mapped, biovolume values were interpolated linearly between sampling days. Study site map denotes receiver station locations represented by station number.

Figure 4. Model output from random forests demonstrating the most important variables contributing to yellow perch presence in the array (a; based on 4-hr periods). Variable

importance was quantified using the mean decrease in accuracy (MDA), which is the relative decrease in model prediction accuracy in non-training data when a variable is removed from the model. Presence in the array explained 85% of total variance in the model. The main covariates contributing to random forests (hour and mean vegetation) are included to depict patterns relative to presence in the array: b) Presence via mean percent of detections relative to hour of day (shaded grey area represents $\pm$ SE); c) presence in the array relative to mean submerged aquatic vegetation measured as the proportion of the water column containing vegetation, referred to as vegetation biovolume (plotted as a binomial general linear model).

Figure 5. Summary of the final month that each individual was detected in the array for perch that were identified as predated (red) and those that either left the array or suffered an undetectable mortality event (blue). Receiver detections up to January 2019 were included in order to incorporate the full detection period of tags. Only those detected >24 hrs after tagging are included. Individuals that were detected in the array for the full life of the transmitter battery are indicated.

Figure 6. Model output from random forests demonstrating the most important variables contributing to weekly yellow perch activity space (AS) coefficients. Variable importance was quantified using the percent increase in mean square error (%IncMSE; a). The AS coefficient explained 50% of total variance in the model. The main covariates (plotted as boxplots) contributing to random forests, month (b) and UD habitat (c) are included to depict patterns relative to AS coefficients.

Figure 1.

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Figure 3.

Figure 4.

Figure 5.

Figure 6.