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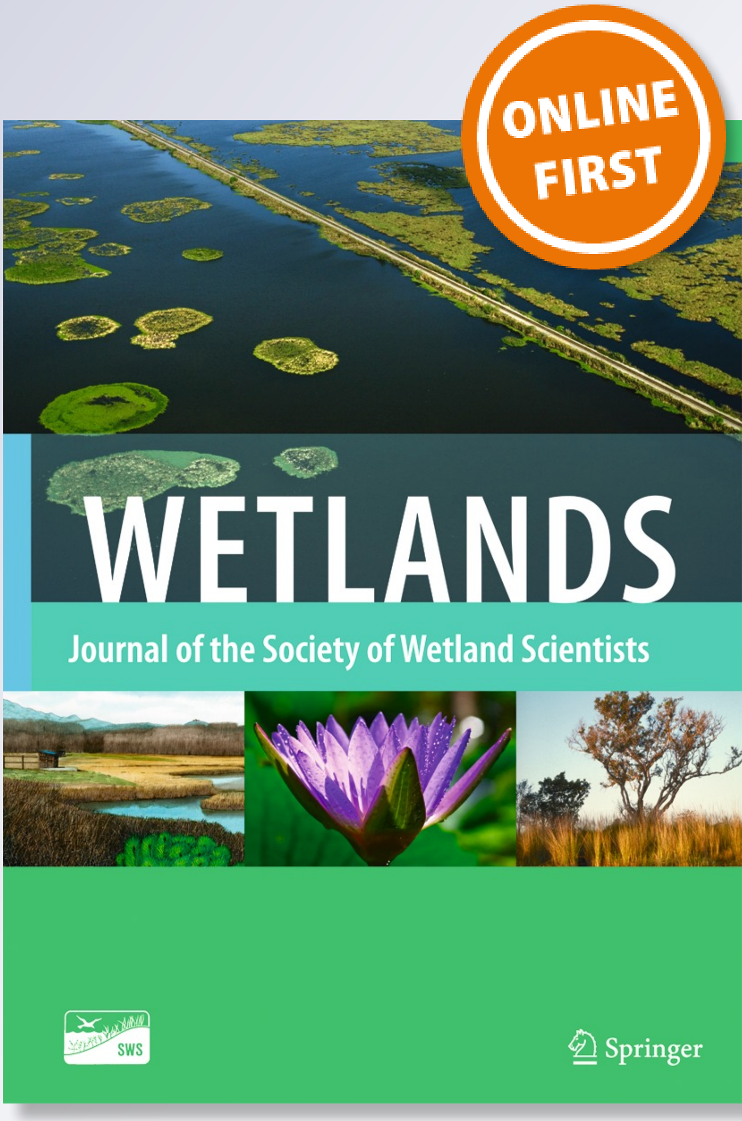


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ORIGINAL RESEARCH

# Connecting Coastal Marshes Using Movements of Resident and Migratory Fishes

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**Abstract** In the Laurentian Great Lakes, diurnal migration of fishes into and out of coastal wetlands is well documented, but movement among wetlands is more poorly understood despite important conservation implications. We assessed movements of typically resident species using mark-recapture. For seven species, only 9 (6.2 %) individuals were recaptured in a wetland different from where they were tagged. Conversely, based on radio-tracking, typically migratory Northern Pike (*Esox lucius*) moved among wetlands that were 1.4 km apart, although some moved as far as 3.9 km. Results suggest that while the majority of fishes remain in a single wetland throughout the year, a large top predator requires multiple wetlands over comparatively larger areas. Currently, coastal wetlands in Ontario are evaluated for protection if greater than 2 ha, but smaller proximate marshes (within 750 m) can be grouped into complexes. Our results demonstrate that while this distance likely protects fish habitat for most resident fishes, it fails to cover the observed movement patterns of Northern Pike. A modification to this grouping rule for coastal wetlands would delineate more ecologically appropriate complexes by incorporating movement among wetlands by top predators. Delineating larger wetland complexes would protect critical fish habitat and populations in the Great Lakes.

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**Keywords** Wetland management, OWES · Coastal Wetlands, Great Lakes, Wetland Complex, Northern Pike · Pumpkinseed

## Introduction

Habitat is inherently defined at a species-specific scale (Franklin et al. 2002), yet conservation measures are typically implemented at regional scales for protection of multiple species and ecosystems. Therefore, conservation efforts must incorporate the diverse spatial requirements of all species in order to protect and maintain biodiversity (Noss 1992; Sale 1998). While the spatial requirements of organisms that move diurnally and seasonally require greater effort to quantify, such information is critical for species, such as fish, that form metacommunities (Sale 1998; Gotelli and Taylor 1999; Mouillot 2007). It is widely accepted that many fish exhibit diurnal movements between the nearshore and offshore in freshwater ecosystems; however, few studies exist that document movements among discrete environments within a region (notable exceptions of Jepsen et al. 2001 and Murphy et al. 2012), even though such dispersal among metapopulations helps to maintain genetic diversity at both a population and community level (Jackson et al. 2001) and can contribute to nutrient cycling among spatially heterogeneous habitats (Cederholm et al. 1999).

Thousands of coastal marshes occur along the shore of eastern Georgian Bay (Ontario, Canada). These are highly productive transitional zones between terrestrial and aquatic ecosystems that are dominated by hydrophytic vegetation and provide spawning and foraging habitat for the majority of fish species (Jude and Pappas 1992; Randall et al. 1996; Wei et al. 2004; Cvetkovic et al. 2010). The littoral portion of these wetlands (referred to as *low marsh*) is the only portion that can be used by the fish community. Although these wetlands



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are currently in relatively pristine condition (Chow-Fraser 2006; Cvetkovic and Chow-Fraser 2011), the negative impact of recreational and urban development has risen in recent decades and is expected to increase. A more insidious threat is the loss of critical habitat due to more than a decade of sustained low water levels that has been associated with a decline in fish species richness (Midwood and Chow-Fraser 2012). Climate change models forecast even lower water levels that would likely diminish overall fish habitat quality and quantity, and thus continue to negatively affect the coastal fish community (Mortsch and Quinn 1996; Sellinger et al. 2008; Angel and Kunkel 2010; Fracz and Chow-Fraser 2013). Protection of these pristine wetlands is therefore important to prevent human disturbance from compounding the observed impact of declining water levels.

Because Georgian Bay falls entirely within the province of Ontario, protection of its coastal marshes falls under the jurisdiction of the Ontario Ministry of Natural Resources (OMNR). Wetlands must therefore undergo an evaluation based on the Ontario Wetland Evaluation System (OWES; OMNR 2013) in order to be designated as provincially significant, and thereby provided some measure of provincial protection. To qualify for evaluations, wetlands must be at least two hectares in size. Alternatively, OWES allows small wetlands, such as the ones in eastern Georgian Bay, to be grouped into complexes if they are within 750 m of each other (straight line distance) and there is a biological rationale for grouping them (OMNR 2013). A recent inventory of eastern Georgian Bay wetlands found that 89 % of the 3,771 aquatic marshes are less than two hectares in size (mean=1.4 ha; Midwood et al. 2012). This excludes the majority of Georgian Bay wetlands from protection unless they are within 750 m of each other or there is documented evidence of fish movement amongst them. To date, no studies have been conducted to quantify the distances moved by fishes in and among coastal wetlands of Georgian Bay.

Fish movements among coastal wetlands have been studied from the perspective of metapopulations. For example, Murphy et al. (2012) documented Pumpkinseed (*Lepomis gibbosus*), Largemouth Bass (*Micropterus salmoides*) and Yellow Perch (*Perca flavescens*) movements among proximate embayments in Toronto Harbour, Lake Ontario. The results of this work suggested that proximate wetlands support metapopulations; however, specific distances among wetland units were not determined. In addition, Jude and Pappas (1992) categorized Great Lakes fish species according to life-history characteristics that reflected the degree to which each species may use multiple habitats. The division resulted in two groups of wetland fishes: residents and migratory species. Resident fishes are typically small-bodied fishes that are wetland obligates, completing their entire life history in wetlands. Migratory fishes fall into three groups: "spawning non-resident" visit wetlands only during their spawning season, "nursery" species remain in wetlands only until they reach maturity, and "wanderers" occasionally pass through wetlands, but are uncommon.

To fully evaluate fish movements among wetlands, it is our belief that both migratory and resident fish species should be studied. Three very common and abundant resident taxa in Georgian Bay wetlands include the Pumpkinseed, Yellow Perch, and Largemouth Bass (Cvetkovic et al. 2010). Fish and Savitz (1983) calculated home ranges for these species and found a home range of 0.23–1.12 ha for Pumpkinseeds, 0.54–2.20 ha for Yellow Perch, and 0.18–2.07 ha for Largemouth Bass. Assuming these home ranges can be applied to Georgian Bay, it is conceivable that at least some individuals may use multiple wetlands throughout their lives, while others may not move at all. By comparison, Northern Pike (*Esox lucius*), which is a much larger piscivorous species and often the top predator in littoral systems (Scott and Crossman 1998), has been identified as a migratory species that uses wetlands for both spawning and nursery habitat and can move daily up to 8 km (Diana and Mackay 1977; Cook and Bergersen 1988; Jude and Pappas 1992; Koed et al. 2006; Kobler et al. 2008). Sub-populations of Northern Pike, which can be broadly categorized as sedentary or highly mobile, are also thought to exist (Jepsen et al. 2001). It is therefore likely that Northern Pike in Georgian Bay would move freely among several adjacent wetlands.

Our overall goal in this paper is to quantify the movement of common fish species (both resident and migratory fishes) in and among wetlands in order to evaluate the appropriateness of the current OWES complexing distance of 750 m. To determine average distances moved by resident fishes, we used a mark-recapture program in two minimally disturbed embayments. In one of these embayments, we then carried out a radio-tracking study to track the distance moved by a migratory fish, the Northern Pike, among adjacent coastal wetlands. By knowing how far each species travels away from the wetland where they are tagged, we can contribute to appropriate guidelines that combine wetlands into wetland-complexes that reflect meaningful ecological relationships.

## Study Sites

Coastal wetlands in eastern Georgian Bay typically form in protected embayments. The underlying substrate is granitic rock, and consequently the water is characteristically dystrophic with low nutrient levels (DeCatanzaro and Chow-Fraser 2011). We used the McMaster Coastal Wetland Inventory (MCWI; Midwood et al. 2012) to identify several clusters of small wetlands that included at least 3 wetlands within 750 m of each other and 1 wetland slightly beyond this distance to serve as an out-group. Site selection was further refined to: 1) minimize the potentially confounding impacts of human disturbance on fish behaviour and 2) ensure easy access to the study sites. Based on these search criteria, we identified two wetland clusters in eastern Georgian Bay that are accessible and minimally degraded: Moon Island and Tadenac Bay (Chow-Fraser 2006; Cvetkovic and Chow-Fraser 2011; Fig. 1). Dominant vegetation and substrate texture differed between these two complexes, but both were nearly devoid of human impact.

The Moon Island cluster was located in Massasauga Provincial Park. Five coastal wetlands (MA, MB, MC, MD, and ME) ranging in size from 0.43 to 1.71 ha (mean=1.20 ha) were sampled in Moon Island (Fig. 1; Table 1). The distance between wetland centroids ranged from 268 to 1,679 m. Initially, only four of the five wetlands were sampled due to limited availability of sampling gear; however, wetland ME was dropped mid-sampling after it became hydrologically disconnected because of the development of a beaver dam. In its place wetland MC was added.

The second wetland cluster was located in Tadenac Bay, a privately owned fishing camp. Recreational fishing is the main activity in this Bay and catch-and-release angling is typically practiced. Four coastal wetlands were sampled in Tadenac Bay (TA, TC, TD, and TE; Fig. 1; Table 1). These wetlands ranged in size from 1.45 to 2.36 ha (mean=1.54 ha; Table 1), and distance between them from 268 to 1,563 m.

## Methods

### Mark-recapture

#### *Fish Sampling*

In 2010, fyke nets were set over eight weeks from May to September (four weeks in Moon Island and four weeks in Tadenac Bay) such that each cluster was sampled on a monthly basis. In order to limit biases associated with selection of sampling location, we divided up the shoreline of each wetland into 15 m-wide segments, and a random number table was used to select the segments where the nets were to be set. Each week, 3 sets of paired fyke nets (2 large nets, 4.25 m long, 1 m×1.25 m front opening with 13 and 4 mm bar mesh and 1 small net, 2.1 m long, 0.5 m×1.0 m front opening with 4 mm bar mesh; see Seilheimer and Chow-Fraser 2007) were set twice in each wetland on alternating days. Fyke nets were left in each wetland for ~20 h in order to capture the diurnal movement of fishes. In Moon Island, wetland ME was sampled during weeks 1 and 2 and wetland MC was sampled during weeks 3 and 4.

To assess the potential for over-winter movement, in the summer of 2011 we resampled the wetlands in Tadenac Bay over a two week period following the same protocol. Each wetland was sampled four times, twice in late May and twice

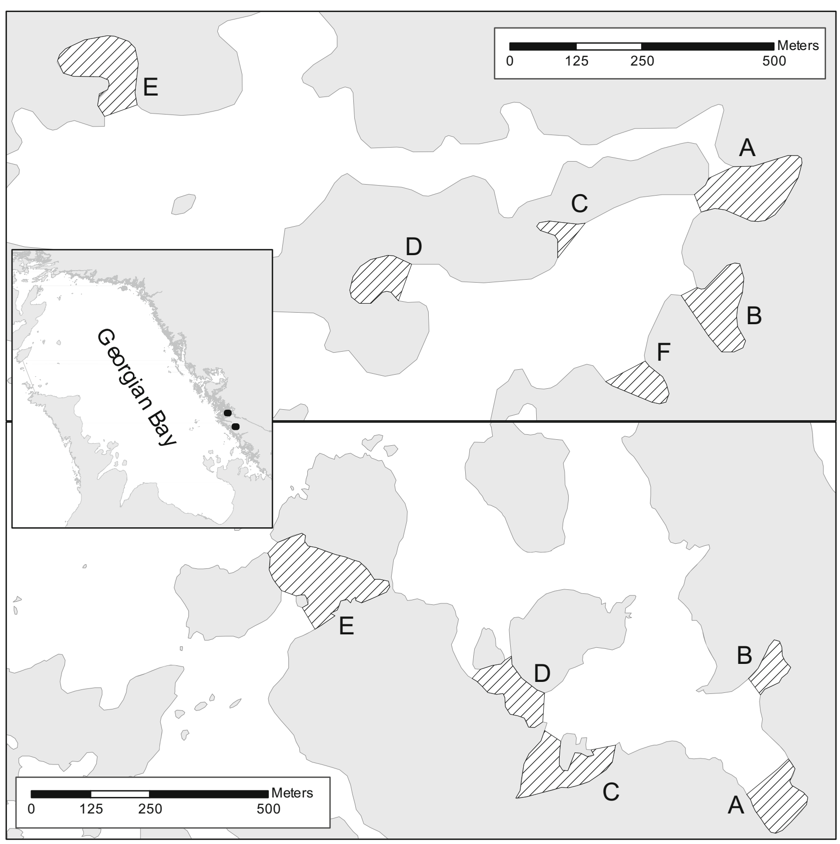


**Fig. 1** Location of study sites in Moon Island (*top map*) and Tadenac Bay (*bottom map*) used in the tagging study

**Table 1** Sampling year and size of each wetland along with the number of fish tagged and recaptured in each wetland. Finally, the number of fish that were recaptured, but were tagged in a different wetland are shown as the number of movers

| Year | Wetland code | Area (ha) | Number captured fish | Number tagged fish | Number fish recaptured | Number of movers |
|---|---|---|---|---|---|---|
| 2010 | MA | 1.71 | 508 | 442 | 5 | 1 |
| 2010 | MB | 1.23 | 619 | 580 | 17 | — |
| 2010 | MC | 0.43 | 382 | 354 | 12 | 2 |
| 2010 | MD | 1.29 | 908 | 861 | 37 | 2 |
| 2010 | ME | 1.33 | 204 | 204 | — | — |
| 2010 | TA | 1.45 | 702 | 681 | 15 | — |
| 2010 | TC | 1.96 | 1,087 | 1,045 | 30 | 2 |
| 2010 | TD | 1.95 | 778 | 749 | 19 | 2 |
| 2010 | TE | 2.38 | 638 | 621 | 11 | — |
| | | Total | 5,844 | 5,537 | 146 | 9 |
| 2011 | TA | 1.45 | 1,344 | 1,310* | 6 | 1 |
| 2011 | TC | 1.96 | 404 | 395* | 9 | — |
| 2011 | TD | 1.95 | 381 | 376* | 6 | — |
| 2011 | TE | 2.38 | 1,290 | 1,278* | 4 | 1† |
| | | Total | 3,419 | 3,359* | 25 | 2 |

* These values do not represent the number of fish tagged in 2011 since no tagging was conducted during these surveys. Instead, these numbers represent the number of captured fish that might have been tagged in 2010 (i.e. excludes brown bullheads and fish smaller than 50 mm)

† This fish was not tagged as part of this study, instead, in a companion study we captured fish in an additional wetland using seining and tagged them with a unique colour. This individual was observed to have travelled 1,660 m over the winter. Please see note in the discussion for more information

in July. Each fish was inspected for tags (see below) from the previous summer; no new fish were tagged.

### *VIE Tagging*

Fish tagging only occurred during the summer of 2010. Visible Implant Elastomer (VIE) tags (Northwest Marine Technology Inc., Shaw Is., Washington, USA) were selected for this project because they are easily applied, have a negligible impact on the fishes, are low cost, and are viable for the duration of the study (Malone et al. 1999; McCairns and Fox 2004; Hoey and McCormick 2006; Jacobus and Webb 2006). Each wetland was assigned a unique colour and all fish captured, with the exception of those less than 50 mm in length, were identified to species, measured, and tagged in one of four body-locations depending on the week they were captured. Due to handling difficulties, no Brown Bullheads (*Ameiurus nebulosus*) were tagged. Prior to tagging, fish were anaesthetized in a solution of 0.4 % clove oil until they could no longer right themselves (typically 3–5 min). In weeks one and two, fish were tagged on the right and left cheek, respectively. For weeks three and four, fish were tagged on the right and left side of the body, respectively, anterior to the caudal fin. Adjusting the tag location allowed us to determine the week a fish had been tagged if they were recaptured. Since large fish (>250 mm) were only caught infrequently, we did not vary their tagging location. Instead, these fish was tagged multiple times on the caudal fin. We also found that fish in the family Cyprinidae could not be tagged in any of the four body-locations; instead these fishes were tagged on the right (weeks 1 and 3) or left (weeks 2 and 4) side of the dorsal fin.

### Radio-tracking

Due to the large home range of Northern Pike, mark-recapture methods were not a viable option, and we opted to instead track Northern Pike across the >400 ha embayment of Tadenac Bay (Fig. 2). Tadenac Bay was selected over Moon Island for this portion of the study because it has only one access point to Georgian Bay, which would potentially allow us to determine if Northern Pike had left our study area. In addition, Tadenac Bay has 39 wetlands containing 63.8 ha of potential fish habitat.

### *Fish Sampling*

Northern Pike were captured with trap nets (2 m×3 m) that were set overnight, perpendicular from shore, and in a minimum water depth of 2 m. Nets were set between 3 May and 10 May 2011 in four locations spaced throughout Tadenac Bay (Fig. 2). Site 1 was situated in the same embayment as our mark-recapture study. Site 2 was in a location where Northern Pike had been found during the OMNR End-Of-Spring-Trap-Net surveys (E. McIntyre pers. comm.). The final two locations (Sites 3 & 4) were situated in areas where anglers of the

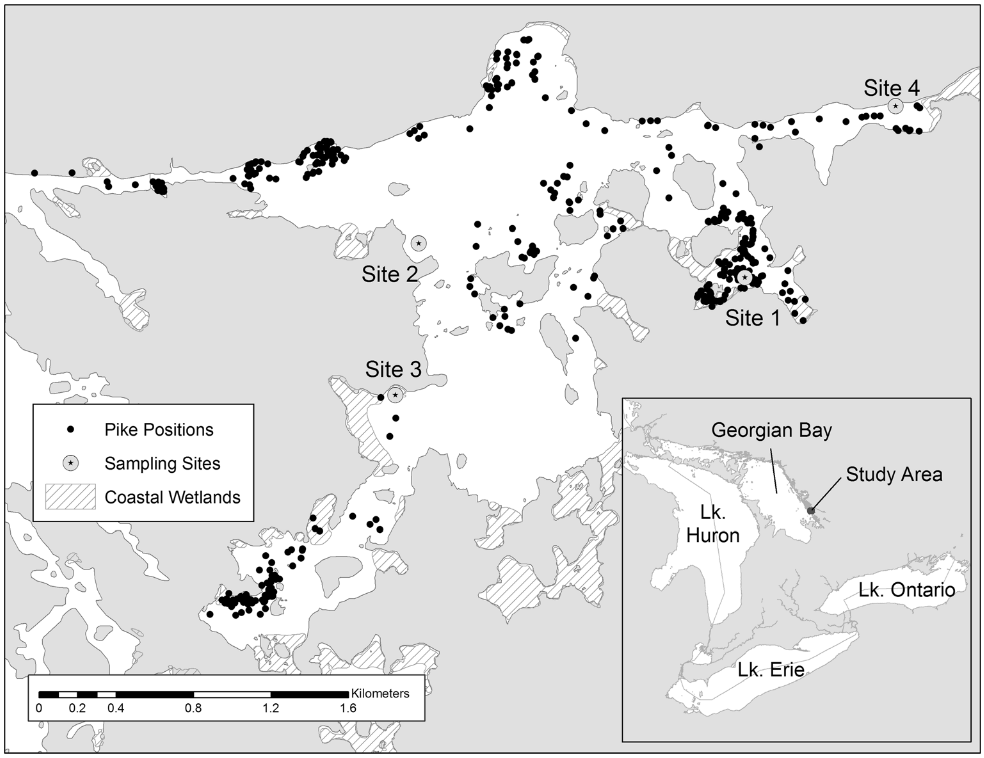


**Fig. 2** Location of Northern Pike throughout Tadenac Bay. Stars represent the four locations where Northern Pike were initially captured and tagged

Tadenac Club tend to catch Northern Pike (M. Trudeau pers. comm.).

*Fish Radio Tagging*

Following capture, the length and mass of each Northern Pike was recorded. Age based on length was estimated as outlined by Wainio (1966, in Scott and Crossman 1998). Northern Pike were then anaesthetized in a solution of 60 ppm clove oil and surgically implanted with a 16 g radio transmitter (MCFT2-3A, Lotek, Newmarket, ON, 16 mm diameter × 46 mm length). A detailed discussion of the tagging procedure, which is known to have minimal impact on the fish (Jepsen and Aarestrup 1999), can be found in Cooke et al. (2003) and Koed et al. (2006). Following surgery, fish were allowed to recover in water from their natural environment.

Northern Pike tracking began two weeks after surgery, which is the recommended time to ensure that they had recovered and returned to their natural movement patterns (Rogers and White 2007; Kobler et al. 2008). We conducted intensive morning, afternoon, and evening surveys once a month throughout the summer, for a total of four weeks, starting 24 May and ending on 24 August. Between these four weeks, four single-day surveys (at roughly weekly intervals) were conducted opportunistically for a grand total of 52 surveys. A survey consisted of driving a set route by boat through our study area. During this drive, Northern Pike were manually located with a radio receiver (Lotek SRX_400A/WX5G). During the afternoon survey, we located the Northern Pike using a standard triangulation method; for the morning and evening surveys, Northern Pike locations were not triangulated due to time constraints, and a single GPS point was transcribed onto a map to represent the Northern Pikes' location.

GIS Analysis & Statistics

Mark-recapture data were brought into a GIS (ArcMap 9.2 ESRI Inc., Redlands, California, U.S.A., 2006) and the minimum distance between the initial tagging and recapture locations were measured for all recaptured fishes (regardless of whether they had moved into a new wetland). Distances were measured as the shortest straight-line distance passing through the water between the initial tag location and the capture point. If the exact tagging location of an individual could not be determined (as was often the case for Pumpkinseeds), an average distance was calculated from all possible tagging locations to the recapture site. These movement distance measurements likely represent a conservative estimate of actual movement. Fishes that were recaptured in a wetland different from where they had been tagged are herein referred to as 'movers'.

For the Northern Pike, all sample locations (from both triangulation and mapping) were entered into a GIS for further analysis. By overlaying their positions on a file containing all wetlands, we were able to determine the number of wetlands with which each Northern Pike was associated. The MCWI (Midwood et al. 2012) was used as the base layer for wetlands since it was derived from high-resolution imagery (~1 m pixels) and therefore able to delineate both large and small wetlands (<2 ha). We considered a Northern Pike to be "associated" with a wetland if it was found within that wetland or it was within 35 m of the wetland. This distance was deemed to be a conservative estimate that would include the submerged aquatic vegetation adjacent to the wetland (J. Midwood pers. obs.). Once these wetlands were identified for each Northern Pike, the mean, minimum, and maximum distances among them were calculated.

## Results

### Mark-recapture

#### *Summary of Fish Caught*

In Moon Island, a total of 2,441 fish were tagged in the five wetlands (Table 1). Pumpkinseeds (*Lepomis gibbosus*) were by far the most commonly captured species, accounting for 71.7 % of the total catch (Table 2). Other common species included Largemouth Bass (*Micropterus salmoides*) and Yellow Perch (*Perca flavescens*) (12.4 % and 8.6 %, respectively). Of the remaining 13 species, only two accounted for more than 1 %: Rock Bass (*Ambloplites rupestris*) and Bluntnose Minnows (*Pimephales notatus*) at 2.3 % and 2.1 %, respectively.

In the four wetlands in Tadenac Bay, a total of 3,096 fish were tagged (Table 1). Pumpkinseeds (*Lepomis gibbosus*) were once again the most common species, accounting for 68.6 % of the total catch (Table 2). Other common species were Largemouth Bass (*Micropterus salmoides*), Bluntnose Minnow (*Pimephales notatus*), Longear (*Lepomis megalotis*), and Yellow Perch (*Perca flavescens*) at 9.6 %, 6.6 %, 5.6 %, and 4.1 %, respectively. Of the remaining 11 species, only two accounted for more than 1 %: Rock Bass (*Ambloplites rupestris*; 2.6 %) and Black Crappie (*Pomoxis nigromaculatus*; 1.2 %).

#### *Overall Movements*

In the summer of 2010, a total of 146 of 5,537 fish were recaptures, with the majority (93.8) being recaptured in the wetland where they were tagged. With the exception of Bowfin (*Amia calva*), the six most commonly tagged fishes were also the only species that were recaptured. Based on the estimated distance between tagging and recapture location, Bowfin and Largemouth Bass travelled the furthest

**Table 2** Summary by fish species of tagged (T) and recaptured (R) in both Tadenac Bay and Moon Island in the summer of 2010. Numbers in brackets in the recapture column show the number of fish that were recaptured in a different wetland. The proportion of the total catch represented by each species ($P_{Catch}$) and the percentage of tagged individuals that was recaptured ($P_{Recap}$) are also presented

| Species | Common name | Tadenac Bay | | | | Moon Island | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | T | $P_{Catch}$ | R | $P_{Recap}$ | T | $P_{Catch}$ | R | $P_{Recap}$ |
| *Fundulus diaphanus* | Banded Killifish | 2 | 0.07 | — | — | 1 | 0.04 | — | — |
| *Pomoxis nigromaculatus* | Black Crappie | 37 | 1.20 | — | — | 3 | 0.12 | — | — |
| *Notropis heterondon* | Blackchin Shiner | 12 | 0.39 | — | — | 5 | 0.20 | — | — |
| *Notropis heterolepis* | Blacknose Shiner | 4 | 0.13 | — | — | — | — | — | — |
| *Pimephales notatus* | Bluntnose Minnow | 205 | 6.62 | 3 | 1.5 | 50 | 2.05 | 1 | 2.0 |
| *Amia calva* | Bowfin | 3 | 0.10 | — | — | 24 | 0.98 | 3 (3) | 12.5 |
| *Umbra limi* | Central Mudminnow | 1 | 0.03 | — | — | 2 | 0.08 | — | — |
| *Semotilus atromaculatus* | Creek Chub | — | — | — | — | 1 | 0.04 | — | — |
| *Notemigonus crysoleucas* | Golden Shiner | 5 | 0.16 | — | — | 1 | 0.04 | — | — |
| *Micropterus salmoides* | Largemouth Bass | 296 | 9.56 | 7 | 2.4 | 302 | 12.4 | 5 (2) | 1.7 |
| *Lepomis megalotis* | Longear | 172 | 5.56 | 5 | 2.9 | — | — | — | — |
| *Lepisoteus osseus* | Longnose Gar | 12 | 0.39 | — | — | 2 | 0.08 | — | — |
| *Esox lucius* | Northern Pike | 13 | 0.42 | — | — | 14 | 0.57 | — | — |
| *Lepomis gibbosus* | Pumpkinseed | 2,125 | 68.64 | 58 (5) | 2.7 | 1,750 | 71.69 | 57 | 3.3 |
| *Ambloplites rupestris* | Rock Bass | 80 | 2.58 | 2 | 2.5 | 56 | 2.29 | 3 | 5.4 |
| *Micropterus dolomieu* | Smallmouth Bass | 1 | 0.03 | — | — | 19 | 0.78 | — | — |
| *Perca flavescens* | Yellow Perch | 128 | 4.13 | — | — | 211 | 8.64 | 2 | 1.0 |
| Total | | 3,096 | | 75 | | 2,441 | | 71 | |

(480 m ±206 m and 135 m ±214 m, respectively). Longear sunfish were next at 82 m ±35 m, but they were only found in Tadenac Bay. Pumpkinseeds were recaptured most frequently (115) and on average travelled 78 m ±51 m. Rock Bass and Bluntnose minnows were found to move the shortest distances of 40 m ±29 m and 27 m ±17 m, respectively. Due to the low number of recaptured Yellow Perch (2), which were only recaptured in Moon Island, mean distance travelled could not be calculated with standard deviation. Movement distance between 2010 tagging and recapture in 2011 were not estimated for individuals unless they were observed to have changed wetlands.

### *"Movers"*

Of the 146 fish recaptured in 2010, only 9 (6.2 %) were movers. Moon Island had five movers including three Bowfin and two Largemouth Bass that moved distances ranging from 345–714 m and 341–755 m, respectively; none of the 57 recaptured Pumpkinseeds moved beyond the wetland where they were initially tagged. In Tadenac Bay, all five movers were Pumpkinseeds that moved distances ranging from 206–459 m between wetlands.

### Radio-tracking

Twelve Northern Pike were tagged in early May 2011. For simplicity, we will refer to each Northern Pike in a coded fashion, where Pike 12 will be referred to as P12. Pike length ranged from 563 to 962 mm (mean =750 mm ±152 mm) and their mass ranged from 1.1 to 6.4 kg (mean =3.4 kg ±2.2 kg; Table 3). With the exception of P19, we were able to determine the sex for all Northern Pike; six were determined to be male and the remaining five were female. Age estimates suggested that half of the Northern Pike were relatively young (2–5 years) and the other half were between 3 and 8 years of age (Table 3).

Following the two-week recovery period, two Northern Pike (P17 and P22) were no longer found within the study area; these Northern Pike were subsequently found to be alive and living outside of Tadenac Bay. Four other Northern Pike did not spend sufficient time in our study area (P14, P16, P18 and P21; Table 3). The remaining six Northern Pike were associated with one to five wetlands (Table 4). For each Northern Pike, with the exception of P15, which was associated with just one wetland, we estimated the minimum, maximum, and mean distance between each wetland in which they were observed (Table 4). For all six Northern Pike, the mean distance traveled between adjacent wetlands was 1,440 m ±740 m. The maximum observed distance traveled between wetlands for one Northern Pike was 3,900 m (P11) (Fig. 3), although it must be acknowledged that P13 moved beyond our study area for several weeks and it is possible that she utilized wetlands that were a greater distance apart (Fig. 3).

## Discussion

There was a clear distinction between the movement distances of resident and migratory fishes. Not surprisingly, the majority

**Table 3** Length, mass, sex, and estimated age (from Scott & Crossman 1998) for the 12 Northern Pike radio tracked in this study. Location of the tagging sites can be found in Fig. 2. Tracking window refers to the time, in days, between the first and last observation

| ID | Site Tagged | Length (mm) | Mass (kg) | Sex | Estimated Age | Tracking Window (Days) | Total Observations |
|---|---|---|---|---|---|---|---|
| P11* | 1 | 632 | 1.5 | M | 2–5 | 93 | 52 |
| P12* | 1 | 583 | 1.2 | M | 2–5 | 60 | 39 |
| P13* | 1 | 962 | 6.0 | F | 6–8 | 93 | 47 |
| P14 | 1 | 773 | 3.2 | M | 3–8 | 38 | 29 |
| P15* | 3 | 563 | 1.2 | M | 2–5 | 93 | 52 |
| P16 | 1 | 912 | 6.4 | F | 5–8 | 6 | 7 |
| P17 | 2 | 817 | 4.1 | F | 4–8 | — | 2 |
| P18 | 4 | 913 | 5.2 | F | 4–8 | 44 | 20 |
| P19* | 1 | 574 | 1.1 | N/A | 2–5 | 87 | 48 |
| P20* | 1 | 620 | 1.5 | M | 2–5 | 90 | 39 |
| P21 | 1 | 916 | 6.4 | F | 4–8 | 18 | 10 |
| P22 | 2 | 729 | 2.6 | M | 2–7 | — | 2 |
| | Average | 750±152 | 3.4±2.2 | | | | |

* Indicates Northern Pike that remained within the study area long enough to estimate wetland association

**Table 4** Number of wetlands associated with each Northern Pike. Also included is a summary of the mean, minimum and maximum distances among wetlands where each Northern Pike was found. With the exception of P15 that used only one wetland, all Northern Pike used wetlands that were greater than 750 m apart

| ID | Number Wetlands | Mean Distance (km) | Minimum Distance (km) | Maximum Distance (km) |
|---|---|---|---|---|
| P11 | 5 | 2.37 | 0.14 | 3.90 |
| P12 | 3 | 0.75 | 0.23 | 1.03 |
| P13 | 5 | 2.12 | 0.33 | 3.77 |
| P15 | 1 | — | — | — |
| P19 | 4 | 1.05 | 0.41 | 1.90 |
| P20 | 4 | 0.93 | 0.19 | 1.20 |
| | Average | 1.44±0.74 | 0.26±0.11 | 2.36±1.39 |

of the recaptured resident fish did not stray beyond the wetland where they were tagged. In contrast, radio tracking of Northern Pike demonstrated that the majority of these migratory fish move among multiple wetlands that are on average 1.4 km apart. By studying the distances moved by these two groups of wetland obligate fishes we can begin to develop species-specific conservation strategies and also provide a scientific rationale for complexing coastal wetlands under the OWES.

**Resident Fishes: Movement Patterns**

During the summer of 2010, only a small percentage (6.2 %) of the recaptured resident fishes were observed to leave the wetland where they were initially tagged. Based on our observations during the summer and resulting return of most individuals to the same wetland following the winter, we can conclude that majority of fishes do not move among wetlands and therefore many species show seasonal site fidelity. This is

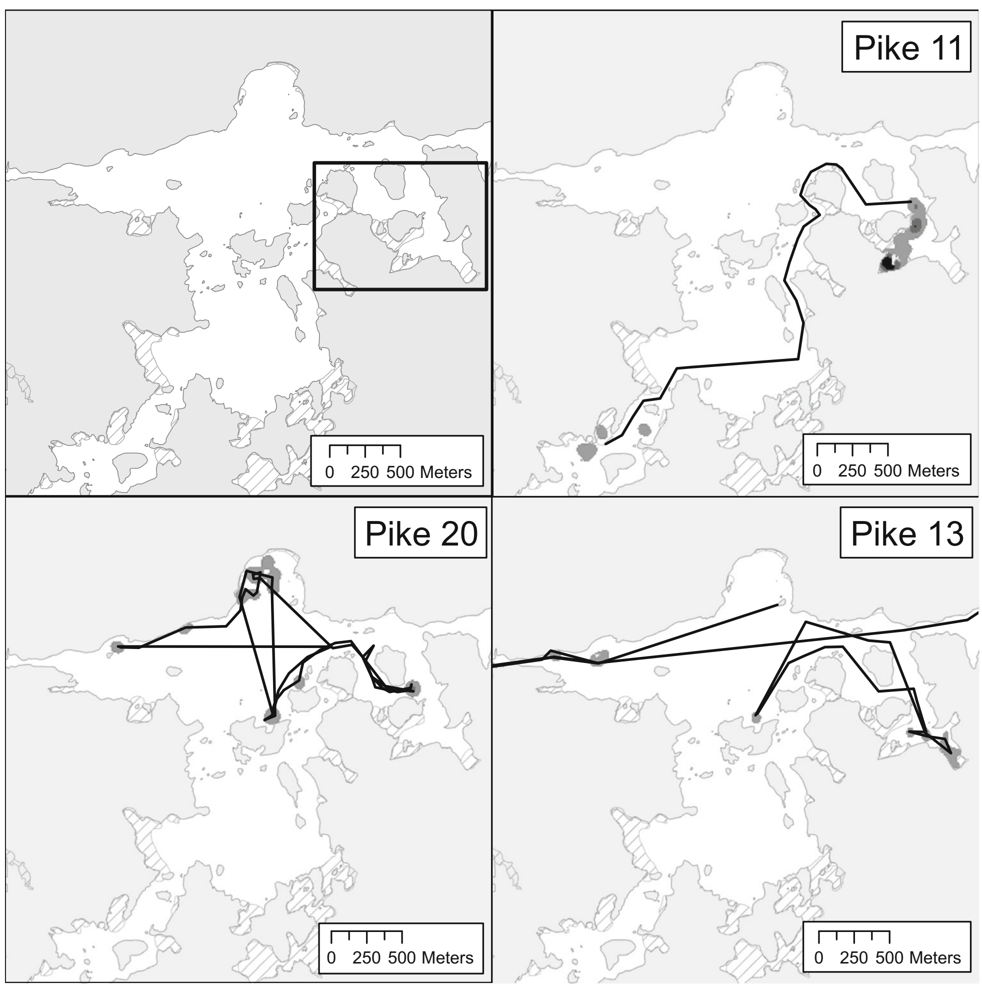


**Fig. 3** Example of observed movements of three Northern Pike from 24 May 2011 until 24 August 2011. The black bounding box in the first panel represents the location of the tagging study conducted in the summer of 2010. Movement patterns for P13 clearly show it exited Tadenac Bay on multiple occasions. The movements of this Northern Pike beyond the study area are unknown

consistent with previous studies where high site fidelity has been observed for Pumpkinseed, the most common resident species in Georgian Bay wetlands (98 %; McCairns and Fox 2004).

Although we observed minimal dispersal among wetlands by Pumpkinseeds, Largemouth Bass, and Bowfin, McCairn and Fox (2004) suggest that even low levels of dispersal among populations can provide important gene flow. Indeed, low percentages (~6.0 %) of Atlantic salmon (*Salmo salar*) straying from their natal rivers to spawn is sufficient to maintain gene flow among behaviorally isolated populations (Jonsson et al. 2003). Concurrent with our fish tagging in the summer of 2010, we used a 6 m seine net to sample an additional wetland in our Tadenac Bay study region, Tadenac B (TB; data not shown). We did not include the results of this sampling in this study due to unequal effort and different sampling gear, but all fish caught in wetland TB were tagged with a unique VIE tag colour. In the summer of 2011, we recaptured one Pumpkinseed (length =115 mm) that migrated over the winter from wetland TB to wetland TE, covering a distance of 1,660 m. While we are unable to estimate what proportion of the population would attempt such a migration, a single individual moving this far may suggest that, for Pumpkinseeds, gene flow may exist at a larger spatial scale than would be anticipated based on a single season's movement. Indeed, the findings of Murphy et al. (2012) support the concept that over-winter re-assortment by species such as Pumpkinseeds can maintain a metapopulation among proximate coastal embayments.

Despite some inter-wetland movements, most Pumpkinseeds stayed within the wetland where they were tagged throughout the summer and winter. Thus, wetland conservation that is focused on preserving Pumpkinseed habitat should focus at the scale of a single wetland or several closely situated sites (below the 750 m OWES complexing rule; OMNR 2013). However, if protection is focused at the scale of the Pumpkinseed metacommunity, our observation of movement among wetlands as far away as 1,660 m coupled with observed over-winter movements by Murphy et al. (2012) would suggest that regional protection of wetlands beyond the 750 m OWES complexing rule is critical for maintaining a metapopulation. Furthermore, identification of the types of habitat that are used as movement corridors and help maintain connectivity among wetlands is an important avenue for future research.

Results of this study reconfirm the fish species groupings outlined by Jude and Pappas (1992). For three of the six commonly occurring fishes categorized as resident wetland species (Bluntnose Minnow, Longear, and Rock Bass), we did not observe individuals to move beyond the wetland where they were initially tagged. Of the remaining species, the majority of recaptured Pumpkinseeds and Largemouth Bass did not move (96.6 % and 83.3 %, respectively), confirming that they are predominantly wetland residents.

In contrast, all three recaptured Bowfin moved to a new wetland. These observations may suggest that while they are wetland residents, within a season Bowfins may not exhibit the same degree of site fidelity as other species. For a large species such as the Bowfin, our findings demonstrate that habitat protection at the local site level is ineffective without regional habitat protections. The three recaptured Bowfins moved an average distance of 480 m suggesting that the current 750 m OWES complexing rule may be appropriate for these individuals. It should be noted, however, that we tagged a total of 24 Bowfin and only recaptured 3, and that the locations of the remaining Bowfin are unknown. It is therefore possible that up to 21 Bowfin dispersed beyond our study area. While not often a species of interest for recreational fisheries, Bowfin are top predators and their large scale dispersion could play an important role in energy transfer among insular wetlands. Wide scale tracking of Bowfin (using radio or acoustic telemetry) could provide a more accurate estimate of their home range and movement patterns.

An important caveat to the mark-recapture approach is that for all species, we would likely be unable to identify sub-populations of highly migratory individuals without an extensive expansion of sampling effort. In contrast, the radio telemetry approach used for Northern Pike is ideally suited for tracking highly mobile individuals, and indeed has been used to differentiate sub-populations of highly mobile and sedentary Northern Pike in a Danish reservoir (Jepsen et al. 2001). As such, the noted movements of what are primarily thought of as resident fishes likely represent a conservative estimate of their movement ranges in the summer. With the availability of increasingly smaller radio and acoustic transmitters, these species should be tracked in greater detail to fully document their range of movements over multiple seasons (see Cooke et al. 2013).

## Migratory Fish: Northern Pike Tracking

In accordance with Jude and Pappas (1992), based on their observed movement among wetlands, Northern Pike appear to be wetland migratory fish. While our study did not start until after the Northern Pike had spawned, most of the Northern Pike that remained in Tadenac Bay moved among multiple wetlands. Some of the smaller Northern Pike, whose ages were estimated to be between 2–5 years (Wainio 1966 in Scott and Crossman 1998), were found predominantly within wetlands (e.g., P11, P12, P15, P20), while larger Northern Pike (e.g., P13) tended to be in deeper waters adjacent to a wetland. Age of sexual maturity for Northern Pike has been estimated at between 3 and 4 years for females and between 2 and 3 years for males (Scott and Crossman 1998). Therefore, smaller Northern Pike are assumed to use wetlands primarily as nursery habitat. If this is the case, it is possible that P19 was a transitional individual, because it eventually moved out of Tadenac Bay into Georgian Bay in a similar fashion as the older Northern Pike.

Kobler et al. (2008) suggested that the size of the activity centre for lake-dwelling Northern Pike is related to the size of the lake itself. This highlights the need for site-specific studies, especially in large systems like the Great Lakes. Based on our observations of six Northern Pike within our study area, it appears that the majority of Northern Pike are dependent on more than one wetland to fulfill their life history requirements and that wetlands nurture a source population for Northern Pike. Thus, the 750 m complexing rule will not adequately protect wetland habitat for large, mobile predators such as Northern Pike. In order to protect younger Northern Pike (2–5 years), wetlands should instead be grouped at a minimum of 1,500 m apart. Based on the precautionary principle and our observation of a maximum movement of 3,900 m, a superior complexing distance would be closer to 4,000 m. Such a change would move legislation toward protecting a range of habitats necessary for the dispersion of large predatory fishes, which exert top-down control on multiple wetlands throughout their life history.

## Summary and Conclusions

Currently, there is an opportunity in Georgian Bay to be proactive towards wetland conservation and fish habitat protection. Wetlands in the Bay are still relatively pristine, making restoration or remediation unnecessary. Instead, protecting the wetlands from human development could help ensure and maintain a healthy ecosystem and fishery. Currently, OWES provides the best method for identifying and protecting ecologically important wetlands in Ontario. In order to more accurately delineate coastal wetland complexes, we recommend that the current wetland complexing distance of 750 m (OMNR 2013, Wetland Complexes Section Rule 2, pg 19) be increased up to 4,000 m for coastal wetlands that are directly connected to the Great Lakes.

Due to the observed global decline in fisheries production, Suski and Cooke (2007) have suggested that current approaches to fisheries management are deficient and a more regional approach to fisheries management and protection can help to maintain important source populations (Hedges et al. 2010). The research presented here has demonstrated the importance of regional species-specific research. Two wetland groups, migratory and resident, show different habitat utilization and movement patterns. Despite these differences, wetland protection tailored towards a migratory top-predator like the Northern Pike would simultaneously provide protection for resident species like Pumpkinseeds and Rock Bass, as the new delineation would cover their maximum dispersal distances. This is not to suggest that conservation practitioners should dismiss individual small wetlands; small insular wetlands also represent an important component of a heterogeneous aquatic landscape, and many resident species rely on them for essential habitat. This study is one of the first to concurrently document movement patterns for both resident and migratory wetland fish species. Results of this study can be applied to update wetland complexing criteria in OWES and can also help to inform conservation strategies in regions with similar fish communities.

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