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A snapshot of the distribution and demographics of freshwater turtles along Toronto's Lake Ontario coastal wetlands

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ABSTRACT

The aim of this study was to provide a baseline assessment of the turtle community in the coastal wetlands of the Greater Toronto Area. We documented turtle species diversity, abundance, reproductive classes, sex-ratios, and evidence of inter-wetland movement. Our study consisted of a series of mark-recapture surveys across eleven Lake Ontario coastal wetland complexes of the Greater Toronto Area performed between 2016 and 2019. We captured and marked 532 individual turtles of four native species (298 midland painted, *Chrysemys picta marginata;* 180 snapping, *Chelydra serpentina*; 7 Blanding's, *Emydoidea blandingii,* and 5 map, *Graptemys geographica*) and three non-native species (40 red-eared slider, *Trachemys scripta elegans*; 1 false map, *Graptemys pseudogeographica*, and 1 Chinese softshell, *Pelodiscus sinensis*). Of note was the capture of an exceptionally large male snapping turtle, one of the largest recorded in Canada for both length and mass. The age classes of both snapping and midland painted species presented large proportions of breeding-sized adults, yet midland painted turtles showed a potential low recruitment with an underrepresentation of non-reproductive females. The sex ratios of both midland painted and snapping turtles across the whole waterfront did not differ from the expected 1:1 ratio. We also recaptured 198 turtles (135 midland painted, 53 snapping, 6 Blanding's and 12 red-eared Sliders). The recaptured turtles revealed inter-wetland movements of 12 km over a two-year span for a midland painted turtle and an 8 km journey for a snapping turtle, potentially demonstrating some connectivity between geographically separate wetland complexes.

Introduction

Historically southern Ontario was rich in wetland habitat, both on the Lake Ontario waterfront and in the mid and upper reaches of the watershed. Wetlands became impaired and were lost as the area was settled by Europeans (Eyles et al., 2013; Weninger and McAndrews, 1989), first due to land clearing and agriculture, and then due to development as urbanization occurred. It is estimated that the Lake Ontario northern shoreline area has lost approximately 85% of its original wetlands (Whillans, 1982). Furthermore, shoreline armoring against erosion and stabilizing barrier beach erosion dynamics, typically for property and public infrastructure protection, resulted in further wetland deterioration, sedimentation and vegetation infill in the remaining wetlands contributing to lower water quality (Croft-White et al., 2017; Howell et al., 2012) and flow acceleration (Trudeau and Richardson, 2015).

Throughout their ranges, modern day abundances of freshwater turtles likely represent a small fraction of historical abundances (Congdon et al., 1986; Iverson, 1982). Turtles are the amongst the most threatened groups of vertebrates and are struggling to survive in modern times with 61% of the 356 turtle species under threat or already extinct (Lovich et al., 2018). Major threats to turtles range from habitat loss, subsidized predators, road mortality, and collection for the pet trade (Rhodin et al., 2017). Additionally, the development of turtles is negatively influenced by exposure to persistent contaminants that reduce hatching success and increasing hatchling deformities (de Solla et al., 2008; Bishop et al., 1998).

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Evidence from several studies point to the large biomass of turtles before the Anthropocene and the importance of turtles to the ecosystem (Froyd et al., 2014; Jackson et al., 2007; Iverson, 1982). Lovich et al. (2014) described two factors that cause society to overlook the decline of turtles as the "*perception of persistence*" and "*shifting baseline syndrome*". Both these factors can dull society's collective ecological memory and can doom long-lived and slow to reproduce animal populations such as turtles. The "*perception of persistence*", adapted from an article on teaching critical concepts of conservation (Mortimer, 1995), describes a scenario where there is no recruitment into a long-lived, apparently healthy, breeding class of turtles. This scenario is not unlikely even in protected areas (Keevil et al., 2018; Congdon et al., 1994) where the probability of survival from egg to maturity has been estimated at 0.000692 for snapping turtles (Brooks et al., 1991). In urban areas, predator density is higher due to subsidization of food resources (Rodewald et al., 2011; Prange and Gehrt, 2004). Higher densities of generalist predators such as raccoon (*Procyon lotor)* and Virginia opossum (*Didelphis virginiana*) take a toll on turtle nests (Geller, 2012; Eskew et al., 2010). In some urbanized areas 99 to 100% of turtle nests are depredated annually (Bowles et al., 2007; Browne, 2003; Gillingwater, 2001). Urban subsidized predators such as raccoon can also kill gravid females (Karson et al., 2018; Roosenburg et al., 2014) as well as preferentially killing smaller (and younger) adult females (Tucker et al., 1999) thereby reducing recruitment (Congdon et al., 2003) to effectively zero.

The second factor is "*shifting baseline syndrome*" caused by "*generational amnesia*", i.e. where there is no longer the collective memory of past biological richness, e.g. periods when turtles were orders of magnitude more abundant and when they were often the dominant species in an ecosystem by virtue of their large biomass. The current and unaware generation accepts this new reality reduced biological richness as "normal", and they thus are blind to the historic change (Steen and Jachowski, 2013; Papworth et al., 2009). This may be especially true in urbanized areas where wetlands have been severely degraded. A factor that may reinforce generational amnesia is the change to the visual landscape caused by invasive species, including new algae, fishes, invertebrates and plants. It is estimated that the Great Lakes basin has hundreds of non-native aquatic species introduced by commercial shipping (Lodge et al., 2006), including 181 non-native species that warrant a specific management plan (Sturtevant et al., 2016).

Ontario has eight extant native species of turtles, and seven have been documented in the Ontario portion of Lake Ontario or its tributaries at some time in the past: midland painted (hereafter painted; *Chrysemys picta marginata*), common snapping (hereafter snapping; *Chelydra serpentina serpentina*), northern map (hereafter map, *Graptemys geographica*), eastern spiny softshell (*Apalone spinifera spinifera*), eastern musk (*Sternotherus odoratus*), spotted (*Clemmys guttata*), and Blanding's (*Emydoidea blandingii*). The eastern spiny softshell is now considered locally extirpated in Lake Ontario (Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2016). The wood turtle (*Glyptemys insculpta*) has been documented in the tributaries on the southern shore of Lake Ontario, in New York State, and it is likely that it may have been present on the Ontario side at some point in the past. Ontario has one extirpated species, the eastern box tortoise, *Terrapene carolina*. The red-eared slider (*Trachemys scripta elegans*) is the most common non-native turtle found in Ontario and it along with other *Trachemys*, *Pseudemys*, *Deirochelys*, and *Apalone* species have been introduced through pet releases.

We do not know much about the past densities of turtles of the Toronto (Canada) region from historical records, although we can glean some insight as to species presence. In the first faunal survey of the Greater Toronto region, Faull (1913) mentions two species of turtles (snapping and painted) as being common, especially at the Toronto Islands. The next survey of the turtle population of Toronto was by Johnson (1983) in a series of visual surveys where he found four species (painted, snapping, Blanding's and map) at multiple sites. Johnson (1999) reported and mapped the number of sites where these turtles could be found throughout the Greater Toronto Area: painted (179 sites), snapping (106 sites), Blanding's (26 sites) and map (16 sites). More recent studies along the Lake Ontario's shore regularly found up to four native turtle species present: the painted, the snapping, the Blanding's and the map (DeCatanzaro and Chow-Fraser, 2010; Oldham and Weller, 2000). Eastern musk turtle sightings had not been reported in the Greater Toronto Area since 2003 (Ontario Amphibian and Reptile Atlas) until one specimen was discovered at Heart Lake in Brampton (Dupuis-Desormeaux et al., 2019).

Based on previous work described above, we expected to find four native turtle species in Lake Ontario (painted, snapping, Blanding's and map). These turtles are long-lived and slow to mature. The maturity for female turtles varies from 14 years for painted (COSEWIC, 2018), 15–20 years for snapping (COSEWIC, 2008), to 14–26 years for Blanding's (COSEWIC, 2016) and 12 years for the map turtle (COSEWIC, 2012). These species are also temperature sex determined. Based on reported ratios at many sites (Ernst and Lovich, 2009) and in the Toronto area (Dupuis-Desormeaux et al., 2018, 2019) we expected that sex ratios would be near 1:1. However, the sex ratios of captured turtles can vary depending upon capture method (Ream and Ream, 1966; Tesche and Hodges, 2015) and environmental factors. Recent studies have noted that turtle populations in North America are trending to a male-skewed population sex ratio and this skew has been attributed to greater road mortality of females due to their propensity to nest by the roadsides or cross roads in search of nesting sites (Marchand and Litvaitis, 2004; Gibbs and Steen, 2005; Steen et al., 2006; Dupuis-Desormeaux et al., 2017). However, reported road injuries in Ontario as a whole do not appear to be sex-skewed (Carstairs et al., 2019).

The goal of this capture-mark-recapture (CMR) study was to set a baseline assessment of the turtle population and demographics across the major Toronto coastal marshes. These data allowed us to explicitly describe species assemblages, examine recruitment into the reproductive class, and test species sex-ratios against an expected 1:1 ratio. We also estimated the size of the turtle population in the individual wetlands. By performing this first Toronto-wide CMR study, we now have a snapshot of the turtle community at this time that we can compare with any future CMR data, gleaning longevity and growth information, population dynamics and assessing potential movement between distinct wetlands.

Methods

Study sites

Eleven coastal wetland complexes were surveyed, most with multiple wetlands (48 total individual wetlands and four tributaries) along the Toronto waterfront from 2016 to 2019 inclusively. Wetland sites along the Lake Ontario waterfront within the Toronto and Region Conservation Authority jurisdiction were selected based on habitat features favorable to turtles and prior sightings (Table 1, Fig. 1a and 1b). For workflow reasons, the waterfront was divided into three sections: the Western (Colonel Sam Smith Park, Mimico Creek and Humber Marsh, sampled in 2018), the Central (Toronto Islands sampled in 2018 and 2019 and Tommy Thompson Park sampled in 2016, 2017 and 2018 see Fig. 1a), and the Eastern (Highland Creek, Rouge Estuary, Frenchman's Bay, Hydro Marsh, Duffin's Marsh and Carruther's Marsh, sampled in 2019, see Fig. 1b). Smaller sites were sampled with fewer traps

Table 1
Brief description of the various Toronto area coastal wetlands, area estimate, year(s) of trapping survey, trapping effort and number of traps, and type of restoration work performed. Sites are listed by trapping year.

Site	Wetland area	Year trapped	Trapping effort Year-effort-in trap-days (td)	Type and last year of restoration
Tommy Thompson Park (Central)	70 ha	2016–2018	2016–496 td (13 traps × 38 days) 2017–514 td (17 traps × 30 days) 2018–120 td (30 traps × 4 days)	Carp gate-2016, Structural habitat-2014, Aquatic planting-2017, Constructed wetland-2016, Turtle nesting-2016, Water level management-2018
Toronto Islands (Central)	216 ha	2018–2019	2018–360 td (30 traps × 12 days) 2019–60 td (15 traps × 4 days)	Structural habitat – 2013, Aquatic planting – 2013, Constructed wetland – 2013, Turtle nesting – 2013
Colonel Sam Smith Park (West)	5 ha	2018	120 td (15 traps × 8 days)	Structural habitat – 1995, Constructed wetland – 1995, Turtle nesting – 1995
Mimico Creek (West)	30 ha	2018	120 td (15 traps × 8 days)	Carp gate – 2012, Structural habitat – 2017, Aquatic planting – 2017
Humber Marsh (West)	78 ha	2018	480 td (30 traps × 16 days)	Carp gate – 2014, Structural habitat – 2014, Water level management – 2014
Highland Creek (East)	45 ha	2019	45 td (15 traps × 3 days)	No restoration
Rouge Estuary (East)	98 ha	2019	400 td (50 traps × 8 days)	No restoration
Frenchman's bay (East)	112 ha	2019	360 td (45 traps × 8 days)	No restoration
Hydro Marsh (East)	33 ha	2019	160 td (20 traps × 8 days)	No restoration
Duffin's Marsh (East)	183 ha	2019	350 td (30 traps × 7 days)	Carp gate – 2011, Structural habitat – 2018, Turtle nesting – 2006, Water level management – 2007
Carruther's Marsh (East)	26 ha	2019	120 tdt td(30 traps × 4 days)	Structural habitat – 2016, Aquatic planting – 2016
Total			3705 trap days	

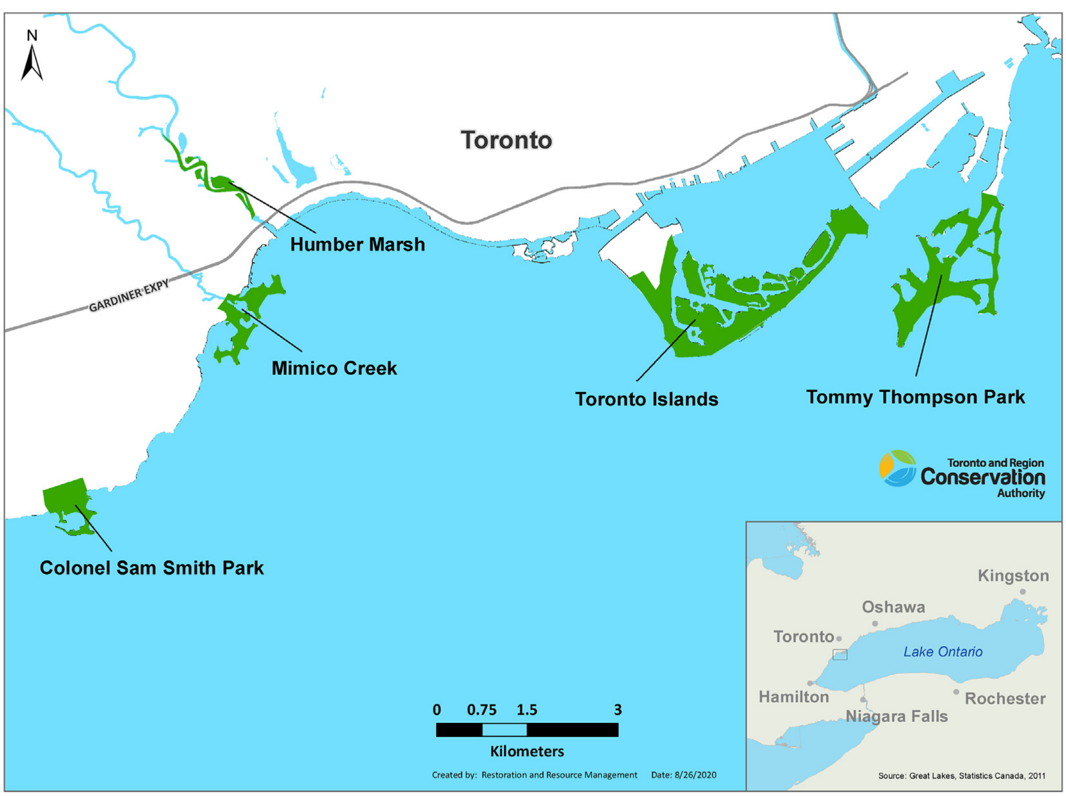

Fig. 1. Location of studied wetland complexes: a) West and Central study areas and b) East area.

and for a shorter duration, while larger sites required up to 50 traps and were sampled for up to three weeks at a time (details in Table 1), and this methodology will have affected detection probability. The Western and Eastern sites are set within a heavily urbanized landscape matrix that includes highways, housing developments, schools, industrial complexes and roads. For example, Hydro Marsh lies next to a nuclear generating station. The Central study section benefits from little motorized traffic and consists

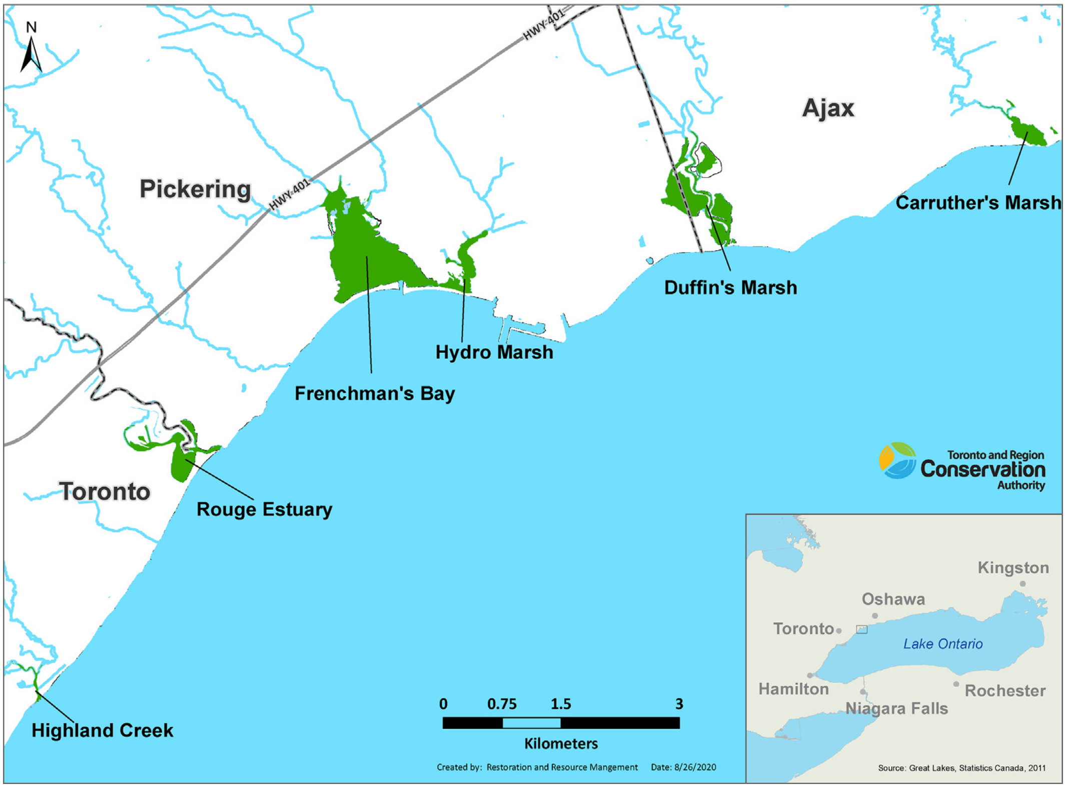

Fig. 1 (*continued*)

of Tommy Thompson Park, a mostly vehicle-free nature reserve built on an artificial peninsula constructed into Lake Ontario, and the Toronto Islands, a series of urbanized islands with very limited vehicle access, with permanent cottages, yacht clubs, an amusement park and public land, including an airport (accessible on foot or by ferry).

Survey methods

The turtle population survey was conducted using a capture-mark-recapture (CMR) methodology. Between 15 and 55 baited hoop traps were used per day, depending on the year and wetland. Trapping started in mid-May and ended in mid-August. Traps were set during the day and checked the next morning, at a minimum of once every 24 h. Traps were set and baited on Mondays and checked on Tuesdays through Fridays. On Fridays traps were removed and disinfected in a solution of bleach and water and dried over the weekend (if they were to be moved to a new wetland on Monday) or closed in place. The following Monday traps were reopened and refreshed with bait or moved to another location. Hoop traps were placed at the researchers' discretion and location was dependent on water depth, proximate vegetation (native versus invasive), suitable soil substrate to anchor and to reduce chances of human disturbance.

Traps were one-meter diameter, three-ring hoop nets (no.15 net with 6.25 cm mesh from Champlin Net Company, Jonesville, LA, USA). The mesh size precluded capturing very small turtles (hatchlings), therefore our demographic information was skewed toward larger juveniles and adults that could be captured in our nets. The hatchling turtles that we did capture were done so opportunistically by hand as we worked in the wetlands. Traps were baited with a variety of food, including frozen fish, canned cat food, and canned sardines depending on availability. Bait was placed in perforated bags hung near the back of the traps at such a height that the bait was in the water. The traps were three-quarters submerged in water in order to leave the top quarter exposed to the air to permit any trapped animals to breathe. Four floating basking traps of various sizes (ranging from 1.0 m × 1.0 m to 1.5 m × 2.0 m) were also used during the first year of the study but not in subsequent years due to low trapping success in 2016. A fyke net with 10 m wings was also used in 2016 but was not available in other years. Captured turtles were placed in rubber bins on shore in a shady area while awaiting processing. Data collected included species, weight, body morphology characteristics including plastron length (PL), straight carapace length (SCL), carapace width (CW), body depth, precloacal tail length, foreclaw length and sex (if possible). The sex of turtles was determined using secondary sexual characteristics using accepted methodology (Ernst and Lovich, 2009). The marginal scutes were notched to give each turtle a unique identifying number (Cagle, 1939). After processing, turtles were returned to the general area of the capture trap.

Data reported include population density and relative abundance of painted turtles to snapping turtles for comparison to other study sites. Relative abundance between species in a community can give clues as to how each species copes with environmental change over time.

The sex-ratios for the most abundant species are reported and tested using a Chi-Square test for significance. Capture Per Unit Effort (CPUE) was calculated and a nonparametric Kruskal-Wallis one-way analysis of variance test was used determine if there were significant differences between capture rates in different years and different wetlands. CPUE was calculated by dividing the number of individual turtles captured by the trapping effort, where the trapping effort was measured by the number of traps deployed per day multiplied by the number of days deployed in each location. CPUE is useful in tracking the general abundance of a species and the catchability in certain locations or in certain conditions (Harley et al., 2001). Comparing multiple years of CPUE will be useful in avoiding the *perception of persistence* syndrome.

The turtle population density for each wetland complex was calculated as the number of individually captured turtles per hectare. The area of the wetland complex was estimated using aerial photography and included all water and surrounding terrestrial habitat that was not urbanized.

Estimates of painted and snapping turtle population size were calculated using a Schnabel estimator (Krebs, 2009). This method assumes closed populations (no immigration, emigration, births or death during the sampling time frame), and equal and independent chances of capturing marked or unmarked individuals. Given that our sampling for most wetlands was done within a few weeks, the assumption of a closed population for each wetland was probably not violated. The assumption of equal and independent catchability is harder to ascertain and most likely violated (Tesche & Hodges, 2015) as it is for most surveys of this kind. The 95% confidence limits used a Poisson frequency distribution as our recapture rates were too low (below 100 individuals per wetland) to use a normal distribution (Krebs, 2009). Analysis was performed in Excel (v.16.44).

Permits. This study was conducted with the approval of York University's Animal Care Committee (YUACC#2016-16W, #2017-16W-R1, #2018-16W-R2, #2019-16W-R3) and under the Ontario Ministry of Natural Resources and Forestry (Wildlife Scientific Collector's Authorization numbers # 1083601, 1085922, 1089105, 1089108) and Endangered Species Act Permit for Species Protection or Recovery (AU-B-007-16, AU-B-006-17, AU-B-008-18, AU2018-0541).

Results

We captured 730 turtles, 532 unique individuals and 198 recaptures (703 in traps and 27 by hand). The 532 individual turtles were comprised of 298 painted, 180 Snapping, 7 Blanding's and 5 map turtles and three non-native species (40 red-eared slider, *Trachemys scripta elegans*; 1 false map, *Graptemys pseudogeographica*, and 1 Chinese softshell, *Pelodiscus sinensis*). Another softshell species (*Apalone spinifera sp.*) was sighted and photographed but not captured in each survey year at Tommy Thompson Park. Of the 27 hand-captured turtles, 15 were hatchlings near shore (12 painted, 3 snapping) and 12 were adults captured either on roads (1 painted, 2 snapping and 1 Blanding's), nesting (3 snapping) or opportunistically in the water near the traps (2 painted, 1 snapping, 1 Blanding's, 1 red-eared slider). The 198 recaptured turtles were comprised of 135 painted, 53 snapping, 6 Blanding's and 12 red-eared sliders (Electronic Supplementary Material (ESM) Table S1 which gives information on individual captured turtles). Our trapping effort was spread over a total of 3705 trap-days representing a varied annual catch per unit of effort (CPUE):

- 2016–0.254, 126 turtles over 496 trap-days;
- 2017–0.200, 103 turtles over 514 trap-days;
- 2018–0.259, 303 turtles over 1169 trap-days;
- 2019–0.122, 198 turtles over 1622 trap-days.

There was no significant differences between years (Kruskal-Wallis $X^2(2) = 0.3$, p = 0.861). Although CPUE rates varied between 0.22 and 0.31 between wetlands (Table 2), the variation was not significant (Kruskal-Wallis $X^2(10) = 10$, p = 0.440). Population estimates for painted and snapping turtles varied considerably in each wetland complex and are presented in Table 2 below. Tommy Thompson Park (TTP), an artificially constructed wetland complex that benefitted from three years of sampling, had the highest estimated painted turtle population at 153. New painted turtles were added to the population with each survey year (69, 36 and 12 respectively), clearly demonstrating the value of multiple sampling years. Duffin's marsh had the highest estimated snapping turtle population at 169.

Turtle densities (also reported in Table 2) varied between species and wetland complex, ranging from 0 turtles per ha to 1.8 turtles per ha for painted turtles and from 0 turtles per ha to 0.6 turtles per ha for snapping turtles. The highest density of painted turtles was found in Colonel Sam Smith Park, a small five-hectare wetland complex. The highest density of snapping turtles was found in the Humber marshes, a contaminated marsh and tributary system with high concentrations of microplastics (Ballent et al, 2016; Corcoran et al., 2015), fecal matter (Staley et al., 2016), phosphorus (Makarewicz et al., 2012), pesticides (Struger and Fletcher, 2007) and PCBs (Bhavsar et al., 2018).

Turtle assemblages varied considerably between wetlands, where the ratio of painted to snapping turtles ranged from 35:3 (11.7:1) to 10:28 (0.36:1) and for all wetland complexes combined was 298:180 or 1.65 (Table 2).

Species abundance

We captured 298 individual painted turtles, 141 males, 134 females, 18 unsexed juveniles and 5 hatchlings. Male to female sex ratios did not differ from the expected 1:1 ratio in aggregate, [Chi-Square (1, N = 275) = 0.422, p = 0.673] but did so in one wetland (Frenchman's Bay), where the ratio was 2.2:1 (24:11), [Chi-Square (1, N = 35) = 2.197, p = 0.028]. Our sample included 124 females of breeding size (PL > 125 mm, COSEWIC, 2018), representing 92.5% of the captured females (124 of 134 females). All individual wetlands contained at least one breeding-sized female except for Highland creek, where we did not capture any painted turtles.

We captured 180 snapping turtles, 78 males, 93 females, 6 juveniles and 3 hatchlings. The sex ratios did not differ from the expected 1:1 in aggregate [Chi-Square (1, N = 171) = 1.147, p = 0.251] or in any particular wetland. We found 60 breeding size females (SCL > 250 mm, Galbraith et al., 1989), representing 64.5% of captured females (60 of 93 females). Of note, we captured a male snapping turtle in the Humber marshes weighing 21.3 kg, with PL = 314 mm, and SCL = 429 mm, one of the largest (measured by SCL) and heaviest ever recorded in Canada (Galois et al., 2019 recorded a male snapping turtle measuring SCL = 432 mm and mass of 19.8 kg).

We captured seven adult female Blanding's as well as five adult female map turtles during our surveys, and visuals surveys identified another two adult female map turtles and six smaller unsexed juveniles or males. We did not capture any males of these two species. Non-native turtles were captured in almost every wetland and were mostly red-eared sliders (18 males, 22 females), one female Chinese softshell and one female false-map turtle.

Inter-wetland movement

We recaptured a female painted turtle in 2018 in the Humber marshes that had been captured and marked in 2016 at Tommy Thompson Park, a minimum straight-line distance through water of 12 km. We also recaptured a female snapping turtle that had originally been captured in the Humber marshes in 2003 (de Solla et al., 2008) and was recaptured in 2018 in the Toronto Islands, a minimum distance of 8 km. Although we expect that these inter-wetland migrations happened naturally, we can't rule out the possibility of human-mitigated transfers. However, this is unlikely in the case of the snapping turtle due to the aggressive response of this species to being handled (Munscher et al., 2017).

Table 2
Capture results showing total count of each species per wetland as well as mean CPUE for all captured turtles. Sexes are indicated as male, female or unsexed juveniles (m,f,j). Blanding's and Map turtle data not presented. Estimated populations based on a Schnabel estimator with confidence limits (lower limit (LL) and upper limit (UL)).

Wetland	CPUE	*Chrysemys picta marginata* Captured (m,f,j) Density (turtles/ha) Pop. Estimate (LL,UL)	*Chelydra serpentina* Captured (m,f,j) Density (turtles/ha) Pop. Estimate (LL,UL)	*Trachemys scripta elegans* or other non-native (m,f,j)
Tommy Thompson Park	0.242	118 (49,49,20) 1.69 153 (126, 194)	32 (14,15,3) 0.46 43 (30,77)	9 (5,4,0)
Humber	0.316	56 (22,33,1) 0.72 89 (62,146)	47 (20,27,0) 0.60 153 (84, 411)	11 (5,6,0)
Toronto Islands	0.231	29 (13,14,2) 0.13 54 (31, 131)	33 (12,16,5) 0.15 52 (34, 108)	9 (4,5,0)
Frenchman's Bay	0.142	35 (24,11,0) 0.31 74 (44, 166)	3 (2,1,0) 0.03 n.a.	4 (2,2,0)
Duffin's Marsh	0.117	10 (4,6,0) 0.06 13 (6, 107)	28 (13,15,0) 0.15 169 (32, 6627)	0
Rouge Marsh	0.078	8 (5,3,0) 0.08 n.a.	18 (8,10,0) 0.18 75 (28, 2941)	2 (1,1,0) 1 *Graptemys pseudogeographica* (0,1,0),
Hydro Marsh	0.144	16 (11,5,0) 0.49 51 (19,1980)	5 (3,2,0) 0.15 7 (1, 255)	0
Mimico Creek	0.167	8 (4,4,0) 0.26 10 (4, 85)	6 (3,2,1) 0.20 6 (1, 54)	2 (1,1,0)
Carruther's Marsh	0.133	9 (4,5,0) 0.35 19 (7, 725)	6 (2,4,0) 0.23 n.a.	0
Colonel Sam Smith	0.20	9 (5,4,0) 1.8 8 (5,18)	2 (1,1,0) 0.40 n.a.	2 (0,2,0) 1 *Pelodiscus sinensis* (0,1,0)
Highland Creek	0.022	0	0	1 (0,1,0)
TOTAL		298 (141,134,23)	180 (78,93,9)	42

Growth

We recaptured 12 snapping turtles in the Humber marshes that bore the signs of having been previously marked in 2003 from the de Solla et al. (2008) study, and we were able to positively identify the notch codes and match data from six of these turtles (Table 3). Each turtle showed evidence of carapace lengthening (range 2 mm to 40 mm) and increased mass (range 0.86 kg to 5.07 kg) over that 15-year time period.

Discussion

Population sizes and density

Population densities of 20–40 Painted turtles per ha are most typical although the range is 9.9–289 turtles/ha (COSEWIC, 2018) and snapping turtles densities range between 0.5 and 66 turtles/ha (COSEWIC, 2008). However, densities are sensitive to area size. When estimating wetland size, many studies only consider the water body size and not the surrounding terrestrial landscape that is required to support the wetland. The population densities of painted turtles found in our study were low in comparison to many sites in Ontario and elsewhere (COSEWIC, 2018), and that is cause for concern. However, within each complex there were individual wetlands where turtle densities were markedly higher. For example, Goldfish pond, a very small 0.05 ha isolated wetland within the Tommy Thompson Park wetland complex, has very high densities of painted turtles (28 Painted turtles or 560 turtles per ha, Dupuis-Desormeaux et al., 2018).

It is more difficult to compare the population densities of snapping turtles because reliable estimates from other sites are difficult to obtain. Browne (2003) estimated 4.3 snapping turtles per ha at Point Pelee (1385 turtles/322.1 ha). DeCatanzaro and Chow-Fraser (2010) only captured 38 snapping turtles from 77 wetlands from a variety of sites along Georgian Bay, Lake Erie and Lake Ontario. In an inland wetland complex in the Greater Toronto Area snapping turtle densities averaged five turtle per ha but varied within individual wetlands from 17 turtles per ha to 1.2 turtles per ha (Dupuis-Desormeaux et al., 2019). In Cootes Paradise, a 250-ha coastal river marsh of Western Lake Ontario, numbers of Snapping

Table 3
- Growth data for six *Chelydra serpentina* snapping turtles first captured in 2003 and recaptured in 2018 in the Humber marshes.

Sex	SCL 2003 (mm)	SCL 2018 (mm)	Growth (mm/y)	Mass 2003 (kg)	Mass 2018 (kg)	Growth (kg/y)
m	395	429	2.26	17.50	21.30	0.253
m	370	410	2.67	13.15	18.22	0.338
f	301	329	1.87	7.70	9.20	0.1
f	290	295	0.33	6.60	7.46	0.057
f	311	332	1.4	7.20	8.30	0.073
f	347	349	0.13	7.50	10.42	0.195

turtles have plummeted from 941 to 177, representing a decrease in density from 3.8 snapping turtle per ha to 0.7 turtles per ha (Piczak et al., 2019), chiefly because of road mortality. At these low densities, Piczak et al.'s (2019) population viability analysis (PVA) models suggest that the snapping turtle population is at risk of local extirpation. Although we lack road mortality data, given that our current study has estimates of densities in each wetland complex that are even lower than those at Cootes Paradise, we should also consider the possibility that the snapping turtle population along the Toronto lakeshore wetlands may not be viable in the long-term. We suggest collecting road mortality data as well as data on other anthropogenic causes of mortality to eventually be able to perform a similar PVA analysis.

Relative abundance

The relative abundance of captured painted turtles to snapping turtles varied considerably between individual sites with some sites having a predominance of snapping turtles, which is usually associated with wetland sites of intermediate or lower water quality (deCatanzaro and Chow-Fraser, 2010; Galbraith et al., 1988; Glorioso et al., 2010). Overall, the capture ratio of painted to snapping turtles for the Toronto waterfront wetlands was 1.65:1 (298:180) which is similar to other disturbed sites in Ontario, such as Point Pelee National Park (Browne and Hecnar, 2007) where this ratio was 1.9:1 (800:421) and at the Heart Lake Conservation Area (Dupuis-Desormeaux et al., 2019) with a ratio of 1.74:1 (233:134). Our capture ratio was also similar to intermediate water quality ponds in Pennsylvania where ratios were of 1.3:1 and where, in some cases, snapping turtles were the most abundant species in individual wetlands (Hughes et al., 2016; Winchell and Gibbs, 2016; Bodie and Semlitsch, 2000; Galbraith et al., 1988).

Capture ratios and actual in situ population ratios can differ significantly year to year depending on trapping methods and other external factors that can affect trapping success (Congdon and Gibbons, 1996). Hence, we emphasize that our study results represent only a snapshot of the true populations within the Toronto lakefront wetlands. Smith et al. (2006) studied the composition of a turtle community of seven species in an Indiana lake that underwent extensive urban development during a 20-year period and found that the population of painted (*Chrysemys picta,* no subspecies specified) turtles declined significantly during development whereas other species including the snapping turtle did not. Smith et al. (2006) attributed the drop in painted turtle population to differential injury and mortality rates due to anthropogenic causes, mainly shoreline development and increase usage of motorized watercraft. If this differential response to urbanization is similar for Toronto wetlands, then we can speculate that painted turtles were once relatively more abundant than we have found here. DeCatanzaro and Chow-Fraser (2010) in a study of 77 coastal marshlands in the Great Lakes found an 11:1 ratio of painted (*C. picta*) to snapping turtles (419:38) and relatively greater abundance of snapping turtles in wetlands of intermediate water quality. However, they suspected that their trapping methods might have been biased against the capture of large snapping turtles. Painted turtle populations, like other turtle populations, are sensitive to marginally higher levels of adult mortality (Midwood et al., 2015; Congdon et al., 2003). Toronto has a well-documented high density of subsidized turtle and turtle egg predators, including raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), red fox (*Vulpes vulpes*), coyote (*Canis latrans*), and American crow (*Corvus brachyrhynchos*) (Rosatte et al., 1992). We cannot rule out that preferential predation of the smaller painted turtle may be affecting the observed structure of these aquatic turtle communities (Marchand and Litvaitis, 2004; COSEWIC, 2018).

The CPUE data showed a drop to 0.122 turtles per trap day in all-turtles captured rate in 2019 (in the East section) compared to from 0.254, 0.200, 0.259 in previous years in the West and Central sections. These CPUE are not outside the reported norms for other hoop-trap studies (Browne and Hecnar, 2007; COSEWIC, 2018). However, we speculate that the lesser capture rate in the East section may be indicative of a smaller density of turtles in those wetlands possibly due to these wetlands being less suitable to turtle communities. The West and Central sections have also benefitted from extensive restoration efforts such as addition of carp-excluding devices (which improves water quality and emergent vegetation, see Lougheed et al., 1998), structural habitat, aquatic planting, turtle nesting habitat and water-level management by the Toronto and Region Conservation Authority, whereas many of the East wetlands have not had any restoration efforts (see Table 1). Many other factors can affect turtle capture rates, including bait selection (Mali et al., 2014), ambient temperature (Crawford et al., 1983), weather patterns (Cagle, 1950) and trap placement so we hesitate to place emphasis on the restoration efforts as we have not quantified these efforts enough to analyze differences. However, these preliminary results could be explored further in future research. As well, it should be noted that both 2017 and 2019 were record high water levels in Lake Ontario, peaking at 75.93 m in 2017 and 76.03 m in 2019, versus the average levels in May and June of 75.02 m and 75.06 m historically (International Great Lakes Datum, 2019). These elevated water levels proved challenging for setting traps as the natural shoreline was often flooded, especially in 2019, therefore having to set traps in suboptimal locations could have contributed to lower CPUE for 2019. Repeating the surveys over additional years would give us a better understanding of catchability.

Reproductive potential

In assessing turtle demographics, we would expect that the number of captured individuals of reproductive age should greatly exceed those in the juvenile classes (Stearns, 1992; Ernst and Lovich, 2009). However, the predominance of adult painted females (92.5% of all females) was exceptionally high as was the adult to juvenile ratio of 12.5:1 (276:22). These results were outside the reported ranges of other studies using similar trapping methods ranging from 0.81 to 5 adults per juvenile (Browne and Sullivan, 2017; Marchand and Litvaitis, 2004; Mallet, 1975; Bayless, 1975; Ernst, 1971) and could be indicative of potentially poor recruitment into the future adult cohort (Zweifel, 1989). These results also contrast with a survey in a wetland complex using the same trapping methods within the Greater Toronto Area where 67% of female Painted turtles (59 of 88 females) were of breeding size and the adult to juvenile ratio was 4.9:1 (194:39) (Dupuis-Desormeaux et al., 2019). Snapping turtle adult females outnumbered the non-reproductive females, and a third of the females were not yet of breeding size and thus this population was showing potential recruitment into the adult class. This result was similar to another study in Maryland that found between 18 and 30% of females captured were not of reproductive size (Cain et al., 2017).

Potential effects of water level fluctuations and invasive common reed

Coastal wetlands have nutrient and habitat variation based on normal fluctuating lake levels that have led to both a diverse and productive biodiversity (Grabas et al., 2019; Strayer and Findlay, 2010). Lake Ontario water levels are artificially managed and annual winter drawdowns exact a toll on native macrophyte vegetation, benthic invertebrates and shift taxa to those resistant to drawdown effects (Carmignani and Roy, 2017). These drawdowns also increase stress on semi-aquatic animals, such as exposing turtles to freezing during hibernation (COSEWIC, 2008), and others that depend on aquatic food resources or refugia (beaver- Smith and Peterson,1991; muskrat- Toner and Farrell, 2010; shorebirds- DesGranges et al., 2006; frogs- Giese et al., 2018). Climate change will likely exacerbate water level fluctuations by increasing variability in precipitation and stressing water resource management (Gronewold and Rood, 2019). Severe lake level fluctuations have been documented elsewhere as potentially fatal for turtles as they travel to seek resources in other wetlands (Aresco, 2005) or die of starvation (Lovich et al., 2017). Painted turtles in Lake Ontario may be more affected by water level fluctuations than snapping turtles because snapping turtles can thrive on a diet of fish, crayfish and carrion whereas painted turtles depend more heavily on benthic invertebrates and submergent vegetation (Moldowan et al., 2015; Ernst and Lovich, 2009). Also, high densities of non-native common carp (*Cyprinus carpio*) reduce macrophyte cover (Lundholm and Simser, 1999) by increasing water turbidity (Chow-Fraser, 1999) which limits painted turtle foraging opportunities. Water level fluctuations also disrupt native cattail (*Typha latifolia*) marshes and promote invasive European common reed (*Phragmites australis*) (Wei and Chow-Fraser, 2006), which in turn reduce herpetofauna recruitment, available habitat and threaten to strand smaller turtles such as painted turtles (Markle et al., 2018; Misfud, 2014; Bolton and Brooks, 2010). European common reed has been expanding rapidly in Lake Ontario wetlands (Tulbure and Johnston, 2010; Wilcox et al., 2003,) and was a dominant species in many wetlands we surveyed and is of great concern to local conservation authorities (Bourgeau-Chavez et al., 2013). Anecdotally, at one of the specific wetlands within our study sites, Cell-1 of Tommy Thompson Park, visual surveys had documented annual sightings of painted turtles from 2004 to 2012, but none in 2013, one in 2014, and none in 2015 (Dupuis-Desormeaux et al., 2018). Coincidently, the first appearance of European common reed on vegetation surveys of Cell-1 was in 2009 (5% of shoreline of Cell-1) and by 2013 the invasive reed had encircled the wetland (95% coverage of Cell-1 shoreline, Toronto Regional Conservation Authority data). A single female painted turtle was captured in Cell-1 in 2016 in a small wetland pocket of native vegetation devoid of European common reed or common carp but was not subsequently recaptured in 2017 or 2018.

Scarcity of Blanding's and map turtles

Our capture results also showed a scarcity of Blanding's and map turtles and low recruitment potential as we only captured adult females. Johnson (1983) had noted a paucity of Blanding's turtles using visual surveys almost 40 years ago. Blanding's turtles have suffered from past anthropogenic habitat loss, illegal collection from the pet trade (COSEWIC, 2016), and further habitat loss due to the effects of the invasive European common reed (Markle and Chow-Fraser, 2018). This turtle species is known for having a low annual reproductive output as well as a late sexual maturity (Congdon et al., 2001). It is also particularly vulnerable to road and rail mortality because of its life history trait of frequenting multiple bodies of water throughout a season (Edge et al., 2015) and making extensive movements between these wetlands (Dupuis-Desormeaux, 2018; Markle and Chow-Fraser, 2014). Most surveyed wetlands in this study are immediately surrounded by a matrix of roads and development and not conducive to long overland journeys. It is estimated that up to 400 Blanding's turtles are killed on roads annually in Ontario (COSEWIC, 2016). The case of the low abundance of map turtles can also be attributed to habitat loss and degradation (COSEWIC, 2012), including degradation of critical aquatic overwintering habitat as well a low recruitment and late age to sexual maturity. Map turtles are particularly vulnerable to boat mortality, shoreline development (Rizkalla and Swihart, 2006) and water level fluctuations (Tessier and Lapointe, 2009), which are all common in the Lake Ontario wetlands we surveyed.

Resilience and propagule pressure of non-native species

Non-native turtle species were discovered in most wetlands surveyed. It is unsurprising that in an urban setting with >5 million people that long-lived pets would find themselves being released into the local habitat (Stringham and Lockwood, 2018) and that is likely the source of the majority of the non-native turtles we have found. In many countries, the red-eared slider is considered an invasive species and has the potential to displace local turtles (Maceda-Veiga et al., 2019), and outcompete native turtles (Cadi and Joly, 2003; Pearson et al., 2015; Lambert et al., 2019) to the point of even becoming perceived as a native turtle due to its abundance (Lovich and Yamamoto, 2016). Red-eared sliders could already be reproducing in southern Ontario although some researchers have found low overwintering survival even at Canada's southernmost point (Browne and Hecnar, 2007). More recent niche models predict that red-eared sliders will be found in up to 50% of the Great Lakes Basin by 2050 (Spear et al., 2018). We discovered one red-eared slider nesting on August 16th, 2019, which was too late for eggs to successfully hatch at this latitude. This mistimed laying may indicate that this species will find it difficult to successfully establish in the Toronto region under current climactic conditions. However, we did capture a few juvenile red-eared sliders with PL of between 98 mm and 150 mm, aging them at approximately 3 years old. Although we suspect pet releases, we cannot rule out that they may have been the result of successful nesting and overwintering in the wild. With regards to the softshell turtle sighted at Tommy Thompson Park, it is unclear if this large female was a native or non-native species, either way we suspect that it was probably a released animal. Also, of note was the sighting of this female softshell on shore digging test holes on August 19th, 2019 in an area of open gravel. We unfortunately disturbed this female and no nest was found; but the behaviour was indicative of potential nesting. The mistimed nesting attempt may also indicate that this turtle is not native to Ontario because nesting in August would be adapted to a more southerly range (Ernst and Lovich, 2009). However, these non-native species might adapt well to climate change should the warm summer days stretch later into the fall months (Ficetola et al., 2009; Zenni and Nuñez, 2013).

Connectivity

Given the documented movements of VHF tracked turtles in the Toronto harbour between Tommy Thompson Park and the Toronto Islands (Dupuis-Desormeaux et al., 2018) and the movement documented from recaptured turtles in this study between Tommy Thompson Park and the Humber marshes, we could argue that the West and Central portion of the Toronto waterfront wetlands (from Colonel Sam Smith Park to the Toronto Islands and Tommy Thompson Park) are occasionally connected. It is yet unclear if the individual wetlands of the East portion of the lakefront wetlands (from Highland Creek to Carruther's Marsh) are ecologically connected to each other or to the Central section.

Sex ratios

Road mortality is a major reason underlying the decline in turtle populations as both the number of individuals and the community composition can be negatively affected. Both male and female turtles are at risk of being killed while attempting to cross a road (Fahrig and Rytwinski, 2009; van der Ree et al., 2011; Carstairs et al., 2019). However, there is evidence that different life histories between male and female turtles, where female turtles are often attracted to nesting in the gravel substrate of roadside shoulders, leading to differential road mortality and skewed sex ratios (Haxton, 2000; Aresco, 2005; Steen et al., 2006). There seems to be some evidence that turtle populations across North America are becoming male-biased (Marchand and Litvaitis, 2004; Gibbs and Steen, 2005). However, many other factors can cause sex-ratio skews including climate change, sampling bias, skewed primary sex ratios, differential immigration and emigration, and differential maturity of the sexes (Lovich and Gibbons, 1990; Lovich et al., 2014). At our wetland complex sites, we found no sex-ratio skew in the aggregate populations of painted or snapping turtles. Although many of the coastal wetlands are surrounded by an urbanized land-use matrix, no roads directly bisect the studied wetlands. The even sex ratios in this study contrasted with male-skewed sex ratios found in a small bisected wetland in the Greater Toronto Area (Dupuis-Desormeaux et al., 2017, 2019). At the individual wetland level, only Frenchman's Bay showed a statistically significant male painted turtle skewed sex ratio, but we hesitate to place too much emphasis on this result given the limited data and the trapping difficulties in 2019. We suggest returning to this wetland in future years to confirm any sex skew and combining the data with a road mortality survey. Although all of our captured Blanding's turtles were female, the low number of total captures precludes us commenting on sex ratios. However, strongly female-biased ratios for Blanding's turtles have been reported elsewhere (Ruane et al., 2008; Congdon and van Loben Sels, 1991; Joyal et al., 2000; Pappas et al., 2000; Browne and Hecnar, 2007). Finally, although all specimens of captured map turtles were females, there were too few captured to discuss sex ratios for this species.

Limitations

The limitations of this study are varied and are discussed individually as they arose in each section; however, it is useful to summarize the most important ones here. Firstly, as discussed, we assume that our trapping methods are unbiased with regards to sex and age class (except for very young turtles) although there is some evidence to the contrary (Ream and Ream, 1966; Tesche and Hodges, 2015). Secondly, trapping effort varied between wetlands. For most wetlands, we have only one short period of trapping, often a two-week stretch in a single year that varied within the seasonal trapping window (mid-May to mid-August) from one wetland to another. Thirdly, population estimates, community assemblages, reproductive classes results based on a limited capture data are meant as a first approximation and will need to be further refined through future repeated CMR studies.

Conclusion

Our data showed that turtles along the coastal marshes of the Toronto region continue to persist. Painted and snapping turtles are represented in most wetlands, but in low numbers. In the case of the painted turtle, this species may also be showing signs of low recruitment into the adult population. Low densities of snapping turtles are potentially cause for concern. In the case of the map and Blanding's turtles, these two species are only sparsely represented in the available habitat. We urge continued research and monitoring in order to get a deeper understanding of the dynamics of these populations over time.

Management considerations

It is difficult for us to know what the past density of turtles might have been and how the current density and community structure is affecting ecological integrity. We suggest investigating proactive measures that would actively grow and protect the turtle community and increase the role of turtles in the ecosystem. First, we recommend measures that target recruitment such as reducing nest and hatchling predation by building dedicated nesting beaches (Roosenburg et al., 2014) away from predators or equipped with predator deterrent apparatus (Quinn et al., 2015). Second, we recommend headstarting in which eggs are removed from vulnerable nests and hatched in a controlled environment, then hatchlings are reared in captivity for a year or two (to reduce juvenile mortality risks) and subsequently released. Headstarting has been shown to greatly increase juvenile survival (Spinks et al., 2003; Mitrus, 2005; Spencer et al., 2017; Buhlmann et al., 2015). Although headstarting does not address the root causes of the decline in turtle populations, it does offer one way to rebalance the equation in favour of recruitment (Bennett et al., 2017), especially if paired with the continuing investment in restoring and creating wetland habitat in the Toronto region. Third, protection from subsidized predators may even be more important to long-term population growth than headstarting alone (Mullin et al., 2020). Control and removal of subsidized predator has been shown to positively impact turtle populations (Munscher et al., 2012; Barton and Roth, 2007; Spencer and Thompson, 2005). Finally, we urge land managers to limit the encroachment of invasive species (such as European common reed) and restore native wetland vegetation communities to a reasonable facsimile of the conditions in which Lake Ontario's native turtles evolved.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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