Species loss and shifting population structure of freshwater turtles despite habitat protection

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ABSTRACT

Changes to population and community structure can have important ecological consequences and raise conservation concerns when causes are anthropogenic; however, signs of stress may not always be apparent. Turtles are long-lived and presence of adults may suggest healthy populations when lack of recruitment is actually threatening persistence. We observed and captured turtles for two years in Point Pelee National Park, Ontario, Canada, and compared our results with those collected 30 years earlier to determine if (1) species relative abundance, (2) sex ratios, and (3) age structure changed over three decades. Extirpation of the spotted turtle since 1972–1973 has altered the park’s species assemblage. Evidence also suggests that Blanding’s turtles have declined. Sex ratios were similar between time periods for all species except for the painted turtle which has become significantly more male-biased. Size structure for Blanding’s and snapping turtles shifted towards larger and presumably older age classes. Our results suggest that limited juvenile recruitment caused the size shift. Heavy predation on turtle nests from a dense raccoon population appears to be the main factor limiting recruitment. Despite protecting a sizable fragment of turtle habitat for a century, Point Pelee has lost one species and only one other species has a large healthy population. Our study illustrates that habitat protection provides no guarantee for species persistence when multiple threats exist and highlights the necessity for monitoring populations of long-lived species.

1. Introduction

The structure of populations has important ecological and conservation implications and can ultimately affect the structure of communities. For example, skewed sex ratios can result in smaller effective population size and can thus lower recruitment and alter the age structure of a population (Primack, 1998; Smith and Smith, 2001). In general, broad-based age structure pyramids indicate growing populations whilst top-heavy pyramids indicate insufficient recruitment and declining populations (Bodenheimer, 1958; Alexander, 1958; Smith and Smith, 2001). Collectively, altered population structure or species losses translate to changes in community structure (i.e. richness, evenness: see Smith and Smith, 2001). Although populations can be naturally dynamic, changes occurring because of human actions are of conservation concern (Meffe and Carroll, 1997; Primack, 1998). Populations of some species may be more vulnerable to anthropogenic change because of their life histories (Congdon and Dunham, 1997; Klemens, 2000).

Turtles (Class: Testudines) are considered to be of particular conservation concern because their life history includes low reproductive output, late maturity, and habitat requirements of wetlands and terrestrial environments (Congdon
and Gibbons, 1996; Klemens, 2000). However, serious declines may easily go unnoticed because adult turtles can live many decades after recruitment problems start, thereby masking impending local extinctions with their presence (Klemens, 2000). Conservationists therefore must be vigilant of suspected problems and detect evidence of decline before populations are at serious risk of extirpation (Gibbons, 1997). It is generally considered that important threats to turtles include habitat loss, population isolation, subsidized predators, road mortality, collection as pets, interactions with exotic species, human recreation, disease, and effects of contaminants (Garber and Burger, 1995; Klemens, 2000).

Habitat protection is the cornerstone of biological conservation (Meffe and Carroll, 1997; Primack, 1998). Although managing fragments of natural areas as preserves may provide habitat for the faunas they initially support, species persistence may continue to be threatened through species relaxation, isolation effects, and from other external and internal threats (Janzen, 1983, 1986; Primack, 1998; Rivard et al., 2000).

Point Pelee National Park was once the location of greatest turtle species diversity in Canada (Table 1). However, there are concerns that turtle populations in the park may be declining. Although these populations are protected from additional habitat loss because they are in a National Park, this alone does not protect them from other threats. We examined the status of freshwater turtle populations in Point Pelee National Park by comparing our trapping data from 2001–2002 with those collected in 1972–1973 (Rivard and Smith, 1973a, b). We used the same basic methods, measurements, and traps in the same general locations as did Rivard and Smith (1973a, b) to facilitate comparison. Rivard and Smith (1973a) were concerned that high levels of predation on turtle nests (primarily by raccoons, Procyon litor) and the park’s isolation might threaten its turtle populations.

We also focussed special attention on Blanding’s turtle (Emydoidea blandingii) because it is now considered a ‘species at risk’ in many parts of its range and observations within the park suggest that it may be declining in numbers (warden records). Blanding’s turtle juveniles were also under-represented in the park in 1972–1973 (Rivard and Smith, 1973a). Other studies on Blanding’s turtles have noted under-representation of juveniles (Gibbons, 1968; Graham and Doyle, 1977; Kofron and Schreiber, 1985; Congdon et al., 1993; Herman et al., 1995; Joyal et al., 2000; Rubin et al., 2004). All of these studies except for Herman et al. (1995) and Rubin et al. (2004) suggested the lower numbers of juveniles observed were likely because they were not detected. However, McMaster and Herman (2000) noted that juvenile Blanding’s tend to be more visible than adults, and young juveniles are more visible than older juveniles and subadults.

Our general goal was to determine if population and community structure of turtles changed over three decades at Point Pelee National Park. Our specific objectives were to compare species occurrence, relative abundance, sex ratios, and population size structure between 2001–2002 and 1972–1973 (Rivard and Smith, 1973a, b). Considering the longevity of turtles and continuing conservation concerns in the park we expected changes in species relative abundance and possible species loss. If heavy predation by raccoons on turtle nests is limiting juvenile recruitment we expect a shift in size structure to larger and older turtles.

### 2. Methods

#### 2.1. Study site

Point Pelee National Park in southwestern Ontario (42° 10’N, 82° 30’W) is a small (16 km²) heavily used (up to 500,000 visitors/y) protected area. The park forms the southernmost portion of Canada’s mainland and acts as a functional ‘island’ because 80% of its perimeter is surrounded by water (Lake Erie) and the other 20% by agricultural land. Point Pelee is highly isolated from other natural areas because its setting is within one of the most densely populated (by humans) and heavily altered landscapes in eastern North America. The park contains one of the few remaining sizable fragments of Carolinian forest in Canada (15.9% of park) and one of the few remaining large deep freshwater coastal marshes in the Great Lakes (43.2% of park). The marsh is recognised as a wetland of international importance (Ramsar, 2002). Turtles use ponds in the marsh, swamp thicket/forest, wet meadows, and artificial canals within the park, and nest in beaches, old fields, and along roadsides. The park has a cool (long-term daily average 9.2 °C), moist (908 mm annual total precipitation), temperate climate which is strongly moderated by Lake Erie. Point Pelee has been a protected site for nearly a century.

#### 2.2. Data collection and analyses

We conducted extensive visual surveys from 29 April to 21 June 2001 and 1 April to 31 May 2002. Based on visual surveys, we selected 14 trapping sites. Turtles were captured during surveys or trapping sessions between 5 May and 24 August 2001 and 1 April and 22 August 2002. We used a variety of methods (hoop, basking, and wire cage live traps; and hand captures) to reduce potential trapping bias (Ream and Ream, 1966; McKenna, 2001; but see Gibbs and Steen, 2005). Traps were checked every one to two days. We also included a small

<table>
<thead>
<tr>
<th>Table 1 – List of turtle species recorded in Point Pelee National Park</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific name</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Chrysemys picta</td>
</tr>
<tr>
<td>Graptemys geographica</td>
</tr>
<tr>
<td>Emydoidea blandingii</td>
</tr>
<tr>
<td>Clemmys guttata</td>
</tr>
<tr>
<td>Glyptemys insculpta</td>
</tr>
<tr>
<td>Sternoterus odoratus</td>
</tr>
<tr>
<td>Chelydra serpentina</td>
</tr>
<tr>
<td>Apalone spinifera</td>
</tr>
<tr>
<td>Terrapene carolina</td>
</tr>
<tr>
<td>Trachemys scripta</td>
</tr>
</tbody>
</table>

a COSEWIC, 2005.
b Endangered in Nova Scotia and Threatened in Ontario.
c Status tracked in Ontario by the OMNR-NHIC.
d Introduced to Point Pelee, but special concern in Canada.
number of live ‘by catch’ turtles from a concurrent fish trapping study in the park.

We marked all adult turtles captured by filing marginal scutes to provide a unique code for identification of individuals (Cagle, 1939). Snapping turtles (Chelydra serpentina) were marked using a slightly different notch code system to avoid working near their heads. We weighed (to nearest g), took standard measurements (midline and total carapace and plastron lengths, width, height, vent to tail tip length, shell to tail tip length, carapace curved width; to nearest mm) and recorded ID for each captured individual. We also recorded the age class, sex, abnormalities, injuries, signs of parasitism or disease, and determined if females were gravid. Turtles were then released at the site of capture.

To determine if community structure changed between 1972–1973 and 2001–2002, we used Spearman’s rank correlation to compare ranked abundance of species captured by Rivard and Smith (1973a,b) to our results. Our study was comparable to Rivard and Smith (1973a,b) because we used similar trapping methods (visual surveys, hand captures, hoop traps [we also used basking and cage traps]), recorded similar data (date, location, trap method, sex, standard measurements) and conducted surveys and trapping in the same general locations in the park.

Basic hoop trap design was the same in both studies. However, Rivard and Smith’s (1973a) traps were slightly larger (90 cm long, 47.5 cm diameter vs. 82 cm long, 44 cm diameter) and had a larger mesh size (5 cm vs. 2.5 cm). The trap size difference would not likely affect the catch greatly; however, small juveniles would be more likely to escape from Rivard and Smith’s (1973a) traps because of the larger mesh size. We also determined catch per unit effort for the hoop traps in both studies. We excluded recaptures so that ‘trap happy’ or ‘trap avoiding’ individuals would not bias the estimate.

We also compared the ratio of relative abundance of snapping and Blanding’s turtles to painted turtles (Chrysemys picta) between time periods using G-tests with Williams correction applied (Sokal and Rohlf, 1995). The ratio from 1972 to 1973 was used to generate the expected numbers for 2001–2002.

We observed population structure by determining sex ratios and age/size structure. Because adult turtles cannot be aged accurately by counting rings on plastral scutes (Ross, 1989) we instead used size (carapace length) and assumed that turtles tend to grow larger as they age (Zweifel, 1989; Ernst et al., 1994). Most turtles are considered to have indeterminate growth but growth rate slows with aging (Ross, 1989; Zweifel, 1989; Ernst et al., 1994). Although the relationship between age and size may not always be reliable (see Congdon et al., 2003), it can still provide insight on population structure when the exact age of individuals cannot be determined. We compared carapace lengths between time periods using a Mann–Whitney U-test. In addition, we used the Kolmogorov–Smirnov two sample test to compare both shape and central tendency of carapace length distributions between time periods. Because of the longevity of turtles, we expected that size distributions for individual species would shift towards larger size if recruitment was limited. Differences in sex ratios were compared using G-tests with Williams correction applied (Sokal and Rohlf, 1995). We compared sex ratios for each species among trap types to determine if traps produced biased sex ratios. Comparisons of the 2001–2002 sex ratio to a 1:1 ratio were made using data with all trap types pooled. We compared sex ratios between 2001–2002 and 1972 using just the hoop trap data to ensure changes in sex ratio were not a result of different sampling techniques. We restricted analyses of sex ratios and size structure to the three most common species (painted, snapping, and Blanding’s) because of low numbers (<5) of individuals for the other species in one or both time periods (Sokal and Rohlf, 1995). All statistical analyses were conducted using Systat 9 or by hand (G-tests) following Sokal and Rohlf (1995).

3. Results

We observed and trapped individuals of six of the seven native species that inhabited Point Pelee National Park historically (painted, snapping, Blanding’s, map, stinkpot, and spiny softshell) plus the introduced pond slider (Table 1). We did not find any spotted turtles (Clemmys guttata) despite extensive searches. We observed 865 turtles during the visual surveys in 2001 (Fig. 1). Only surveys from 2001 are presented because in 2002 we targeted spotted and Blanding’s turtle habitat instead of searching all sites evenly. These numbers must be interpreted as an activity index rather than an estimation of absolute population size because individual turtles may have been counted more than once and some species were easier to observe than others.

We captured 1977 turtles (474 recaptures) in 2001 and 2002 combined (Table 2). Two spiny softshells and three pond sliders were observed and one pond slider was captured and removed.

In 1972–1973, Blanding’s turtles were more abundant than map turtles, a spotted turtle was captured, and no spiny softshells were observed (Table 2). Catch per unit effort was lower for painted, snapping, and Blanding’s in 2001–2002 than 1972 and slightly higher for map and stinkpot turtles (Table 3). Relative abundance of Blanding’s to painted turtles was significantly lower in 2001–2002 than in 1972–1973 (G = 147.99, 1 df, p < 0.001). However, snapping turtle relative abundance compared to that of the painted turtle did not change (G = 0.52, 1 df, p > 0.05).

![Fig. 1 – Number of each species observed during visual surveys in 2001.](image-url)
Sex ratios differed greatly for painted, snapping, and Blanding’s turtles among the different trap methods used (Table 4). Compared to a 1:1 sex ratio painted and snapping were male-biased (2.7 males:1 female, \( G = 161.76, 1 \text{ df}, p < 0.001 \) and 1.8 males:1 female, \( G = 34.92, 1 \text{ df}, p < 0.001 \), respectively). Painted turtles were significantly more male-biased in 2001–2002 than in 1972 (\( G = 37.85, 1 \text{ df}, p < 0.001 \)). Snapping turtle sex ratios were not significantly different between 1972 and 2001–2002 (\( G = 1.18, 1 \text{ df}, p > 0.05 \)). Blanding’s and map turtles both had female-biased populations (1 male: 2.32 females, \( G = 13.41, 1 \text{ df}, p < 0.001 \) and 1 male:2.6 females, \( G = 34.08, 1 \text{ df}, p < 0.001 \), respectively). Blanding’s sex ratio did not significantly change over the 30 year period (\( G = 0.55, 1 \text{ df}, p > 0.05 \)). Stinkpot sex ratios did not differ significantly from a 1:1 ratio (\( G = 0.38, 1 \text{ df}, p > 0.05 \)).

The shape of carapace length distributions differed significantly between time periods for painted (\( D = 0.178, N_{2002} = 800, N_{1972} = 123, p = 0.003 \)), snapping (\( D = 0.305, N_{2002} = 800, N_{1972} = 123, p < 0.001 \)), and Blanding’s turtles (\( D = 0.605, N_{2002} = 800, N_{1972} = 123, p < 0.001 \)). Snapping (Fig. 2) and Blanding’s turtles (Fig. 3) both exhibited a clear shift towards larger size classes since 1972–1973, but the painted turtle distribution shifted slightly towards smaller classes (Fig. 4). Median carapace lengths were significantly smaller for painted turtles (\( U = 55458.5, N_{2002} = 800, N_{1972} = 123, p = 0.006 \)) and significantly larger for snapping (\( U = 12053, N_{2002} = 420, N_{1972} = 93, p < 0.001 \)) and Blanding’s turtles (\( U = 618.5, N_{2002} = 85, N_{1972} = 47, p < 0.001 \)) in 2001–2002 compared to 1972–1973. For both snapping and Blanding’s turtles there were proportionately fewer individuals in juvenile size classes in 2001–2002 compared with 1972–1973 (Figs. 2 and 3) whilst there were proportionately more juvenile-sized painted in 2001–2002 (Fig. 4).

### 4. Discussion

#### 4.1. Community structure

Our study revealed that changes in turtle community structure occurred over the past thirty years. Although seven species were captured at Point Pelee between 1972–1973 and 2001–2002 (Table 2), the species composition was significantly different in the two time periods (Spearman rank correlation indicated that these species assemblages were marginally correlated with each other (\( r_S = 0.901, n = 7, p < 0.05 \)). Two spiny softshells observed are included. No species were captured in 2001–2002 that were not captured in 1972–1973.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Painted</td>
<td>1</td>
<td>1</td>
<td>133</td>
<td>800</td>
</tr>
<tr>
<td>Snapping</td>
<td>2</td>
<td>2</td>
<td>93</td>
<td>421</td>
</tr>
<tr>
<td>Blanding’s</td>
<td>3</td>
<td>4</td>
<td>46</td>
<td>85</td>
</tr>
<tr>
<td>Map</td>
<td>4.5</td>
<td>3</td>
<td>4</td>
<td>172</td>
</tr>
<tr>
<td>Stinkpot</td>
<td>4.5</td>
<td>5</td>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>Spotted</td>
<td>6</td>
<td>7</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Spiny Softshell</td>
<td>7</td>
<td>6</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 2 – Species rank and number of individuals captured at Point Pelee

<table>
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<tr>
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<tbody>
<tr>
<td>Painted</td>
<td>1</td>
<td>1</td>
<td>133</td>
<td>800</td>
</tr>
<tr>
<td>Snapping</td>
<td>2</td>
<td>2</td>
<td>93</td>
<td>421</td>
</tr>
<tr>
<td>Blanding’s</td>
<td>3</td>
<td>4</td>
<td>46</td>
<td>85</td>
</tr>
<tr>
<td>Map</td>
<td>4.5</td>
<td>3</td>
<td>4</td>
<td>172</td>
</tr>
<tr>
<td>Stinkpot</td>
<td>4.5</td>
<td>5</td>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>Spotted</td>
<td>6</td>
<td>7</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Spiny Softshell</td>
<td>7</td>
<td>6</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Spearman rank correlation indicated that these species assemblages were marginally correlated with each other (\( r_S = 0.901, n = 7, p < 0.05 \)). Two spiny softshells observed are included.

#### Table 3 – Catch per unit effort and sex ratios (M:F) for hoop traps in 1972 and 2001–2002

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Painted</td>
<td>100</td>
<td>0.192</td>
<td>2.3:1</td>
<td>462</td>
<td>0.143</td>
<td>4.7:1</td>
</tr>
<tr>
<td>Snapping</td>
<td>91</td>
<td>0.174</td>
<td>1.9:1</td>
<td>324</td>
<td>0.1</td>
<td>2.2:1</td>
</tr>
<tr>
<td>Blanding’s</td>
<td>28</td>
<td>0.054</td>
<td>1.3:1</td>
<td>31</td>
<td>0.01</td>
<td>1:1:1</td>
</tr>
<tr>
<td>Map</td>
<td>1</td>
<td>0.002</td>
<td>0:1</td>
<td>12</td>
<td>0.004</td>
<td>0:12</td>
</tr>
<tr>
<td>Stinkpot</td>
<td>2</td>
<td>0.004</td>
<td>0:2</td>
<td>17</td>
<td>0.005</td>
<td>1:1:1</td>
</tr>
</tbody>
</table>

There were 522 trap days in 1972 and 3237 trap days in 2001–2002. Recaptures were not included in this estimate.

#### Table 4 – Turtle captures for each trap type

<table>
<thead>
<tr>
<th>Species</th>
<th>Trap</th>
<th>M:F</th>
<th>Males</th>
<th>Females</th>
<th>Juveniles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Painted</td>
<td>Hoop</td>
<td>4.7:1</td>
<td>373</td>
<td>79</td>
<td>10</td>
</tr>
<tr>
<td>Painted</td>
<td>Hand</td>
<td>1.1:1</td>
<td>54</td>
<td>50</td>
<td>26</td>
</tr>
<tr>
<td>Painted</td>
<td>Basking</td>
<td>1.5:1</td>
<td>109</td>
<td>72</td>
<td>16</td>
</tr>
<tr>
<td>Snapping</td>
<td>Hoop</td>
<td>2.2:1</td>
<td>213</td>
<td>97</td>
<td>14</td>
</tr>
<tr>
<td>Snapping</td>
<td>Hand</td>
<td>1:1:1</td>
<td>41</td>
<td>45</td>
<td>4</td>
</tr>
<tr>
<td>Blanding’s</td>
<td>Hoop</td>
<td>1:1:1</td>
<td>15</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>Blanding’s</td>
<td>Hand</td>
<td>1:4:3</td>
<td>10</td>
<td>43</td>
<td>0</td>
</tr>
<tr>
<td>Map</td>
<td>Hoop</td>
<td>0</td>
<td>12</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Map</td>
<td>Hand</td>
<td>0</td>
<td>12</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Map</td>
<td>Basking</td>
<td>1:2:1</td>
<td>45</td>
<td>94</td>
<td>5</td>
</tr>
<tr>
<td>Stinkpot</td>
<td>Hoop</td>
<td>1:1:1</td>
<td>7</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Stinkpot</td>
<td>Hand</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

Numbers of male, female, and juvenile turtles caught for each species using different trap types. Sex ratios significantly differed between trap types for each species (G-values ranged from 9.06 to 51.05) except for painted turtles between hand and basking (G = 2.90), map between hoop and hand, and stinkpot between hoop and hand (G = 3.23). Totals in the table differ from those reported in Section 3 because wire cage and fishnet captures are not included above.
native species occurred historically in Point Pelee, our results suggest that only six species are extant and only one has a large healthy population (painted turtle). Extirpation of the spotted turtle from a large healthy population in only a few generations demonstrates the severe stress on these populations.

We are confident in the accuracy of species ranks based on 2001–2002 capture data because ranks concurred with those from visual surveys and rough population size estimates based on mark-recapture (Browne, 2003). Ranking (most to least) was painted, snapping, map, Blanding’s, stinkpot, then spiny softshell. The low captures of map turtles by Rivard and Smith (1973a,b) likely resulted because they did not use basking traps (see Browne and Hecnar, 2005). However, the change in rank between Blanding’s and map turtles is plausible based on Rivard and Smith’s (1973a) visual reports (19 map and 63 Blanding’s turtles). Further evidence of a Blanding’s turtle decline over the past 30 years includes: the ranking of Blanding’s below map turtles, decreased catch per unit effort, and the reduced proportion of captured Blanding’s to painted turtles.

Rivard and Smith (1973a) predicted that continuing decline of spotted turtles, and lack of a rescue effect because of the park’s isolation, would eventually lead to local extinction. This appears to be the case. Considering historical evidence of decline in Point Pelee and lack of observations since 1992 (despite intensive targeted searches), the spotted turtle is likely extirpated from the park (Hecnar and Hecnar, 2005a). Natural recolonisation is unlikely and a recent analysis concluded that repatriation potential for this species at Point Pelee was not feasible (Hecnar and Hecnar, 2005b).

The rarity of spiny softshells in the park can be explained by only occasional entry of individuals from a ‘lake-based’ population in Lake Erie (M’Closkey and Hecnar, 1997; Hecnar and Hecnar, 2005b). Although introduced pond sliders are of conservation concern (Harding, 1997), their low numbers at Point Pelee and low over-winter survival in the region (S. Hecnar, pers. obs.) indicate that they are not a threat.

Painted and snapping turtles are habitat generalists (Ernst et al., 1994) and occurred in almost every pond in the park. Their adaptability may account for their ability to maintain larger population sizes.

Blanding’s and spotted turtles have undergone dramatic population declines within the past 100 years. Both species were once very abundant in Point Pelee (Patch, 1919) but now only Blanding’s persists in very low numbers. Reduced habitat quantity and quality for spotted and Blanding’s turtles over the past century likely played a major role in their decline. Much of the swamp forest, and associated shallow wetlands preferred by spotted and Blanding’s turtles (Bury and Germano, 2003), were lost in the early 1900s when canals were excavated to drain the land for farming (Hecnar and Hecnar, 2005a,b).
Hoop traps yielded male-biased sex ratios for snapping and Blanding's turtles. Sex ratios in different habitats to closed canopy upland forest (Smith and Bishop, 2002). These successional changes would reduce habitat quality by decreasing basking opportunities and resulting in cooler microclimates for nest sites. Concentration of turtles into the relatively few remaining shallow wetlands would also put them at greater risk of efficient predators such as raccoons (Brown, 2003).

Raccoons are considered the greatest predator to turtles of all life stages (Ernst et al., 1994). Populations of these generalist predators typically increase in human modified habitats (Garrott et al., 1993) especially when regional extirpation of large carnivores occurs (Rogers and Caro, 1998). A recent study of the park’s raccoon population (Phillips and Murray, 2005) revealed that its density was amongst the highest reported in the literature and four times higher than the overall average for rural Ontario. The elevated density of raccoons confirmed both early (Rivard and Smith, 1973a) and more recent observations (Brown, 2003) implicating the raccoon as the most important predator on turtle nests. The proportion of turtle nests lost to raccoon predation in 2001–2002 ranged from 63% to 100% among locations in the park (Brown, 2003).

Other potential causes of decline exist. Point Pelee is a small but heavily-used park. The small size, attractive appearance, and relatively terrestrial habits of spotted turtles makes them susceptible to road mortality and collection for pets (Harding, 1997). Pesticide use has also resulted in high concentrations of DDT and its metabolites in the former apple orchards (Crow, 1999) adjacent to Blanding’s ‘hotspots’ within the park.

4.2. Sex ratios

Hoop traps yielded male-biased sex ratios for snapping and painted turtles, female-biased for map turtles, and equal sex ratios for Blanding’s and stinkpot turtles. Basking traps were less male-biased than hoop traps for the painted turtle and less female-biased for the map turtle. Although there may be slight sex biases in these trap techniques, we used a variety of trap techniques and do not believe that it seriously affected our interpretation (see Gibbons and Steen, 2005). However, hand captures most likely favoured capture of females because many captures were made at nesting sites. Hand captures for the painted turtle had equal sex ratios likely because a number of captures were made by dip net (not in nesting sites) and this population is likely male-biased.

Unequal sex ratios may be natural for these populations and do not necessarily indicate problems unless they alter effective population size and overall recruitment. Sex bias in populations can develop if mortality differs between sexes (Aresco, 2004; Steen and Gibbs, 2004; Gibbs and Steen, 2005). For example, female turtles may have a higher risk of road mortality or predation because they travel long distances during nesting migrations (Ernst et al., 1994; Hall et al., 1999; Steen and Gibbs, 2004; Gibbs and Steen, 2005). The small size of painted turtles may make them particularly vulnerable in this regard. Their patterns of nesting migration and propensity for ovipositing on shoulders of roads in the park places female painted turtles at greater risk of mortality than male painted turtles or other species (Brown, 2003). Park records reveal that painted turtles are killed by vehicles more often than other turtle species in Point Pelee. As well, while the snapping and Blanding’s turtle sex ratios have not changed over the past 30 years, the painted turtle sex ratio has become more male-biased. Map turtle populations are male-dominated in most areas (Ernst et al., 1994). It is unclear why the Point Pelee map turtle population is female-dominated.

Chemical contaminants have the potential to alter sex ratios because they can affect reproduction and development of reptiles (Bergeron et al., 1994; Guillette et al., 1996; Bishop et al., 1991; de Solla et al., 1998). High levels of organochlorine contaminants are well documented in Point Pelee’s herpetofauna (Russell and Haffner, 1997; Russell et al., 1999) however effects on the park’s turtles has not yet been studied.

Climatic warming may also influence sex ratios in turtles with temperature-dependent sex determination if average annual temperatures rise several degrees (Janzén, 1994). However, the role of climate warming can be ruled out at Point Pelee judging by the patterns of sex ratio change among species and because the park’s mean annual temperature has increased only 0.5 °C from 1940 to 2002 (Environment Canada weather records).

4.3. Age/size structure

The shift in size structure towards larger classes for Blanding’s and snapping turtles could be caused by either limited juvenile recruitment or changes in growth rates.

Changes in growth could be caused by increased productivity associated with environmental change (e.g. temperature or food). As noted above, mean annual temperature increased only slightly at Point Pelee over the past 60 years. Gibbons and Tinkle (1969) noted differences in sizes of adult painted turtles among three sites in the same region of Michigan which they attributed to differences in diet (smallest-herbivorous, largest-carnivorous). Conceivably, a change to a more productive diet through time could also result in larger turtles. Although data are lacking to test this hypothesis, there are no apparent changes in the nature of food resources over time at Point Pelee. If climate warming or changes in food resources resulted in increased growth of Blanding’s turtles, we would also expect similar results in other sympatric species having broad habitat and dietary overlap such as the painted turtle. Point Pelee’s painted turtles show the opposite size pattern over time. This contrary pattern weakens the temperature change or food quality argument.

Considering the decreased proportion of juvenile-sized turtles in 2001–2002 relative to 1972–1973 and the reduced catch per unit effort, lack of recruitment is most likely responsible for the shift in size/age structure for the Blanding’s and snapping turtles at Point Pelee. Our use of traps with a smaller mesh size and the relative visibility of juvenile Blanding’s turtles adds additional support to the lack of recruitment hypothesis.

The top-heavy age structure of Blanding’s turtles at Point Pelee is consistent with many other areas within its range (Gibbons, 1968; Graham and Doyle, 1977; Kofron and Schreiber, 1985; Congdon et al., 1993; Herman et al., 1995; Joyal et al., 2000; Rubin et al., 2004). Nonetheless, the size shift in...
Historical surveys indicate that Point Pelee originally had a diurnal situations. Wheeler et al. (2003) also observed shifts to Pelee, and concluded that the low proportions of juveniles urban populations of Blanding's turtles that resembled those observed.

This could be an alternative explanation for the pattern we observed. Congdon and van Loben Sels, 1993; Congdon et al., 2001). Differences in size among adult cohorts can be explained by the length of the juvenile stage [when growth is relatively rapid] (Congdon and van Loben Sels, 1993; Congdon et al., 2001). This could be an alternative explanation for the pattern we observed.

Rubin et al. (2004) found size structure patterns in isolated urban populations of Blanding's turtles that resembled those in Pelee, and concluded that the low proportions of juveniles (relative to a rural population) reflected lack of recruitment in urban situations. Wheeler et al. (2003) also observed shifts towards larger size/age classes in declining populations of hellbenders (Cryptobranchus alleganiensis), a long-lived salmonid, which they also attributed to limited juvenile recruitment.

Recruitment problems in Point Pelee are likely occurring because of elevated predation on eggs, hatchlings, and juveniles. Predation by raccoons is most likely responsible, but tilling in agricultural fields adjacent to the park would also destroy any nests in these areas.

The significant shift towards smaller size classes for painted turtles can be explained by the increased male bias in sex ratio over time and because male painted turtles are generally smaller than females (Ernst et al., 1994). The overall distribution of painted turtle size structure indicates that it has changed little over the past 30 years. Blanding's turtles experienced a non-significant decrease in male-bias, but we were not concerned about the shift in sex ratio affecting our interpretation because male Blanding's turtles are generally larger than females. Therefore, if the shift towards more females had any impact on the size structure it simply made our analysis more conservative.

Recovery of turtle populations from decline is especially slow and difficult because of their life history traits (Klemens, 2000). Once declines are detected, management efforts to restore populations may take decades before noticeable increases occur (Klemens, 2000). Therefore, it is important that managers respond promptly to population declines before recovery becomes difficult or impossible (Klemens, 2000).

5. Conclusions

Historical surveys indicate that Point Pelee originally had a diverse assemblage of turtle species, but serious conservation concerns were evident by the 1970s. Over the past 30 years, one species has been extirpated (spotted turtle) and all but one species (painted turtle) have either small populations or altered age structure. Decreased catch per unit effort of the three most common species in the park is consistent with an overall pattern of decline. Shifts in size structure over three decades provide evidence that recruitment is limiting populations of Blanding's and snapping turtles. Heavy predation on turtle nests by a dense population of raccoons is likely the major factor limiting recruitment. Other potential threats to turtles in the park include road mortality, habitat succession, and possibly chemical contamination. Our study highlights how life history characteristics of long-lived taxa such as turtles can mask impending decline when they are not monitored and demonstrates that habitat protection provides no guarantee for long-term species persistence in isolated preserves that are subjected to multiple threats.

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