Ready for bed: pre-hibernation movements and habitat use by Fowler's Toads (*Anaxyrus fowleri*)

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Abstract
We used radio-tracking to investigate movement patterns and habitat use of Fowler's Toads (*Anaxyrus fowleri*) during late summer and early fall in a relatively undisturbed lakeshore dune and beach habitat at Long Point, Ontario. Small radio transmitters were fitted to 11 adult toads with an external harness made from fine surgical plastic tubing wrapped around the body behind the front limbs. We located radio-tagged toads morning and evening, for a maximum of 9 days, recording their locations using Global Positioning System units. Initially, the toads were located on the upper beach or in the fore-dunes during the day, either dug in under the sand or hiding beneath debris; in the evening, they were generally active on the lower beach close to the water line. After a storm and the onset of cooler autumn weather, the toads tended to move further from the water line. They also curtailed their nightly activity and retreated deeper into the sand. As this sort of behaviour was not observed during the summer, we interpret it as pre-hibernation movement to more stable sites away from the beach where the animals can burrow deeply into the sand to lie dormant during the winter.

Key words: Fowler's Toad; *Anaxyrus fowleri*; radio-tracking; amphibian; habitat use; behaviour; movement; spatial ecology; hibernation; Long Point; Ontario

Introduction
Compared with their spring movements to aquatic breeding sites, the autumnal movements of temperate zone, pond-breeding amphibians to overwintering sites are not well understood (Miwa 2017). However, there is evidence that anurans may alter their habitat preferences late in their active season and begin to seek particular sites for hibernation that they would otherwise tend not to use (Koskela and Pasanen 1974; Bull 2006; Lee and Park 2009; Yu and Guo 2010; Ludwig *et al.* 2013). For example, Canadian Toads (*Anaxyrus hemiophrys*) in Minnesota are known to hibernate deep inside earthen mounds on the prairie (Tester and Breckenridge 1964), whereas Western Toads (*A. boreas*) in Alberta may overwinter in peat hummocks, squirrel middens, cavities under spruce trees, or other such sheltered sites (Browne and Paszkowski 2010a). In both cases, particular habitat features allow the animals to retreat deeply into the ground to escape inhospitable surface conditions. The animals' use of these habitats suggests that they alter their behaviour to seek out such sites as winter approaches (Browne and Paszkowski 2010b).

At its northern range limit, Fowler's Toad (*Anaxyrus fowleri*) is a shoreline beach and sand dune specialist (Breden 1988; Green 2005). At night, during summer, individuals forage along wet, sandy shores. By day, they either seek refuge under debris or bask in the warm sand of the fore-dunes that line the beach (Marchand *et al.* 2017). However, such shore-facing sites are highly vulnerable to disturbance during winter storms and are, therefore, unlikely to provide sufficient protection for overwintering animals. To survive the winter, the toads must be able to dig deeply enough into the ground to escape penetrating ground frost at sites that are sheltered from severe weather and protected from flooding.

Thus, they should have quite different microhabitat preferences for overwintering sites compared with summer refuge sites and should begin their pre-hibernation movements to such sites coincident with particular environmental conditions as summer turns into fall. The opportunity to study such movements arose during the course of a radio-tracking study of Fowler's Toads toward the end of their active season at Long Point, Ontario, when a severe storm brought a significant change in the weather.

Methods
Study site
The Big Creek National Wildlife Area (Figure 1) is at the western base of Long Point, Ontario, on the north shore of Lake Erie (42°34'N, 80°28'W). Inland from the lake lies a sandy beach largely devoid of vegetation, then dunes and marsh. The fore-dunes facing the beach are vegetated largely with American Beachgrass (*Ammophila breviligulata* Fernald) and Riverbank Grape (*Vitis riparia* Michaux), whereas the dune tops and back-dunes feature a variety of forbs, willow shrubs (*Salix* spp.), and Eastern Cottonwoods (*Populus del-*

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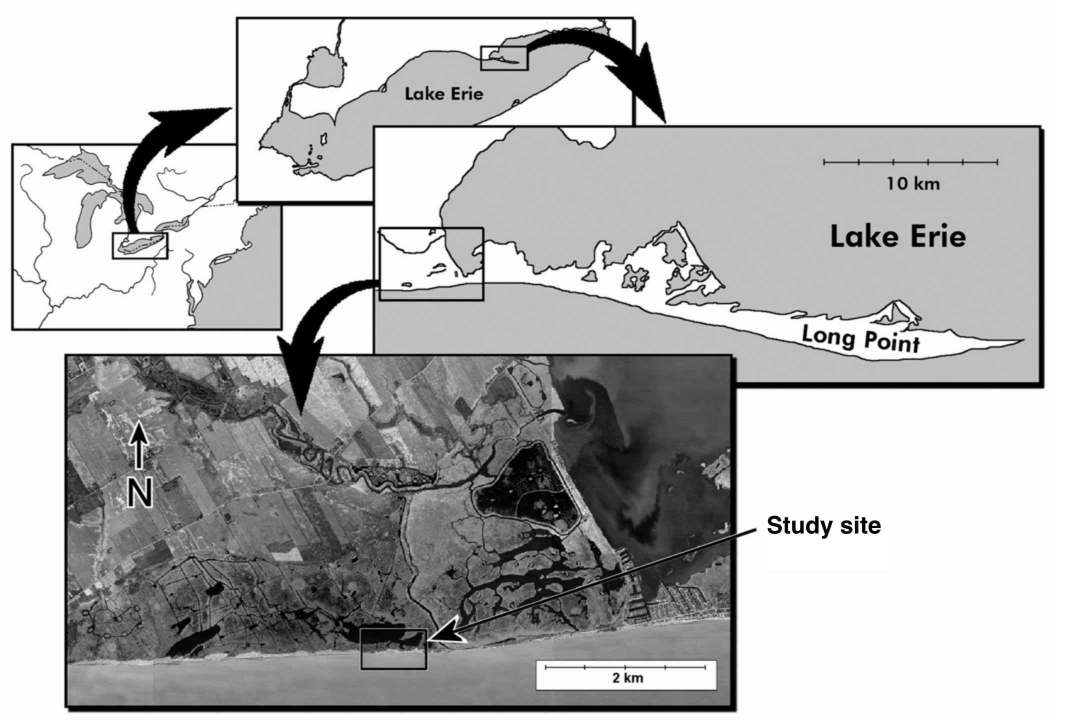

FIGURE 1. Location of the study site at Big Creek National Wildlife Area, Long Point, Ontario (42°34'N, 80°28'W). Aerial photo courtesy of Ontario Ministry of Natural Resources and Forestry.

toides W. Bartram ex Marshall). Historically, marshland located just north of the dunes and dominated by cattails (*Typha* spp.) and Common Reeds (*Phragmites australis* (Cavanilles) Trinius ex Steudel) served as spring breeding habitat for the toads (Green 1989, 2005). We obtained temperature and wind speed data for the study period (30 August to 8 September 2008) from the records of the LONG POINT (AUT) weather station, located about 33 km to the east, near the tip of Long Point (Environment Canada 2013).

Radio-tracking

We used radio-tracking (Marchand *et al.* 2017) to locate animals in the morning and evening from 30 August to 8 September 2008. We tagged adult toads with an external 0.51-g BD-2 radio-transmitter (Holohil Systems Ltd., Carp, Ontario, Canada) attached to a harness made of plastic surgical tubing with monofilament fishing line threaded through it to enable us to tie it around the toad's body (Figure 2). We attached the harness behind the toad's front limbs, rather than around the waist (Bartelt and Peterson 2000), so that it would not interfere with the animal's ability to dig into the ground. Toads were captured and tagged in the evening when they were active and tracked beginning the following morning.

We measured the snout-to-vent length (SVL) of each individual using dial calipers, noted its sex, photographed it for later identification, and assigned it an identity number for reference. As toads have specific patterns of blotches and spots on their backs (Schoen *et al.* 2015), we could readily identify each individual by comparing it to its photograph. We released all toads at the point of capture immediately after they had been tagged.

We located the radio-tagged toads every morning, when they were dormant, and evening, when they were usually active on the beach, using an HR2600 Osprey receiver (H.A.B.I.T. Research, Victoria, British Columbia, Canada) and a three-element Yagi antenna. In the morning, we checked to determine that transmitters were still properly attached to the tagged toads. Usually, we could do this visually without disturbing the animal, as the resting toads were most often at or close to the surface of the sand, with the transmitter's antenna clearly visible. If neither the toad nor its transmitter was visible at the surface, we carefully pushed aside the sand to locate it and register how deeply the toad had buried itself, with minimal disturbance to the animal. In the evening, we captured all tagged toads that were active to check the condition of the harness. We removed the harness if we saw any signs of abrasion and tagged a different toad if we could find one. We tagged an initial three toads on the first evening of the study and three more on the second evening. Thereafter, we tracked up to seven toads at a time.

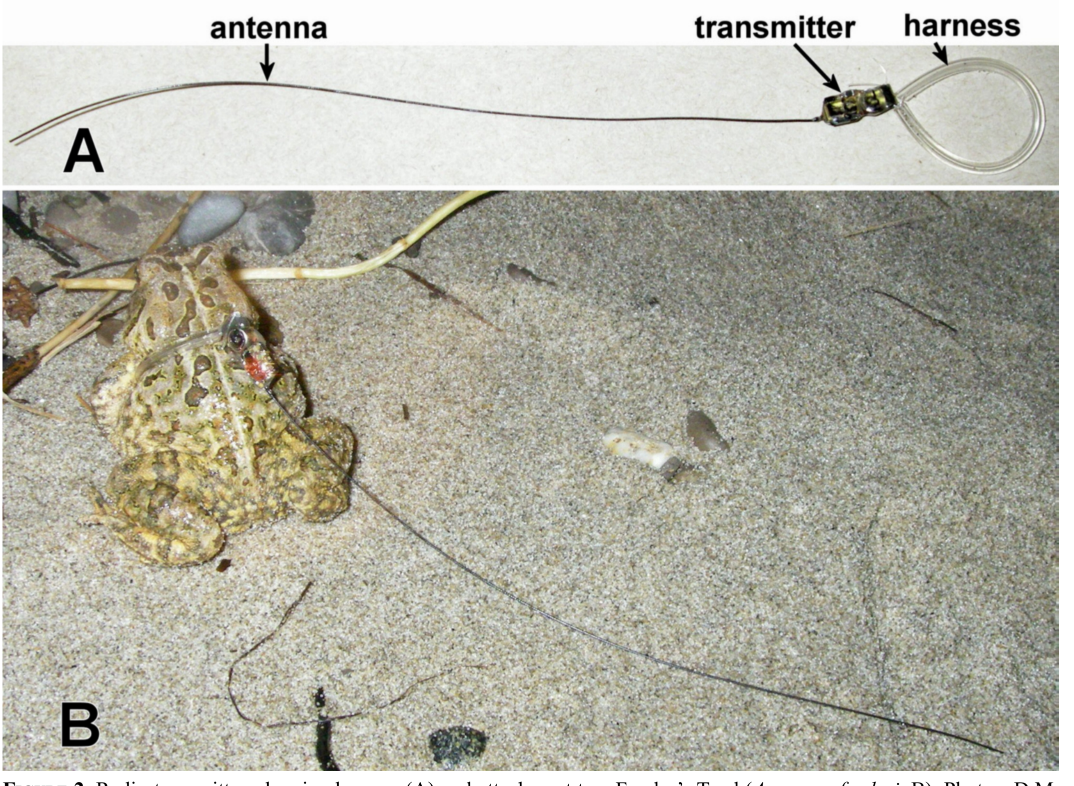

FIGURE 2. Radio-transmitter, showing harness (A) and attachment to a Fowler's Toad (*Anaxyrus fowleri*; B). Photos: D.M. Green.

Mapping

We mapped the locations of radio-tagged toads as universal transverse mercator (UTM) coordinates (NAD 83 datum) with accuracy better than 3 m using a Magellan Mobile Mapper 6 global positioning system unit and Mobile Mapper software (MiTAC Digital Corp., San Dimas, California, USA). We saved all coordinates as .shp files to download into ArcPad 7.1.1.12 software (ESRI Inc., Redlands, California, USA). We used a geo-referenced aerial photo of the region dated 2006 as the base map.

Analysis

We calculated distances travelled by the toads between mapped locations, including total straight-line distance, distance parallel to the water line, and distance perpendicular to the water line. The beach runs in an east–west direction, so distances travelled by the toads east or west parallel to the water line were calculated as the difference between each capture's easting; distances travelled north or south, perpendicular to the water line, were calculated as the difference between each capture's northing. We calculated the toads' daily average movements by correcting for the number of days over which the distances were travelled. We also computed the average distances the toads moved over 24 h (night-to-night and day-to-day) to provide estimates of nighttime activity and distances between daytime refuges. To test whether the toads tended to change the location of their daytime refuge sites to areas further away from the lake in response to the change in the weather following the storm, we used mixed effects linear regression to compare distances of refuge sites away from the Lake Erie water line, with timing (prestorm versus post-storm) as a fixed effect and the individual toads as a random effect.

Results

Weather conditions during the study

During the first five days of the study, the weather remained clear and dry with daytime high air temperatures around 24°C, nighttime lows around 19°C, light winds under 20 km/h, and very little surf on the lake (Figure 3). On the evening of 4 September 2008, a strong storm with south winds up to 57 km/h brought waves high up the beach that altered or obliterated many of the minor features of the beach, including beach pools. Toads were inactive during the storm. The weather became variable after that, with alternating periods of sun and clouds, some showers, occasional thunderstorms, and winds up to 37 km/h. The temperature rose to 25°C as the storm hit, then fell to 15°C before oscillating between 17°C and 20°C for several days afterward.

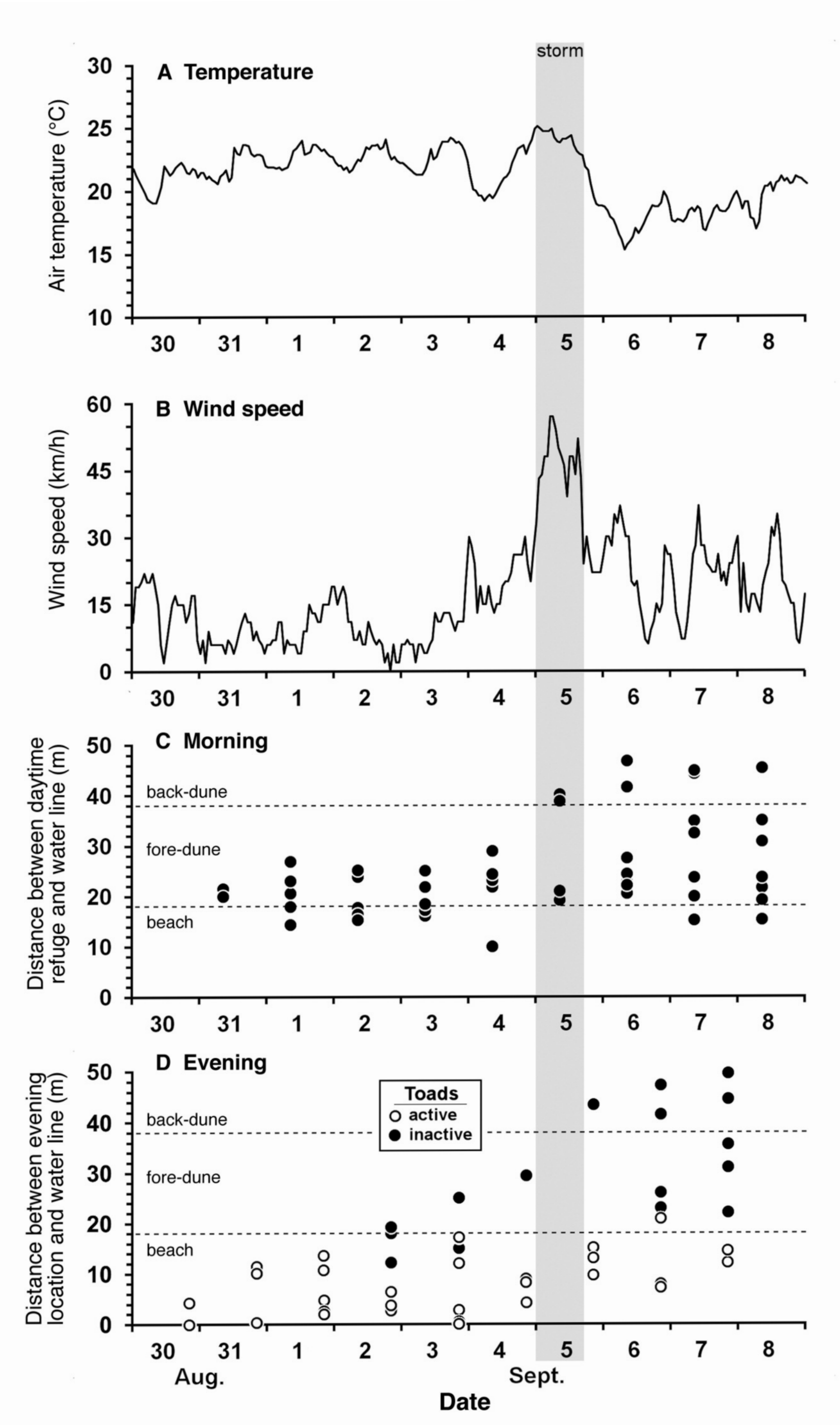

FIGURE 3. Weather conditions and locations of Fowler's Toads (*Anaxyrus fowleri*) relative to the Lake Erie water line at Big Creek National Wildlife Area, Long Point, during the study period (30 August to 8 September). The timing of a storm accompanied by high waves on the beach is indicated by the grey bar. A. Air temperature. B. Wind speed. C. Distance of daytime refuges of toads from the water line. D. Distance of evening locations of toads from the water line.

Toad movements and habitat use

We located and radio-tagged a total of 11 toads (Table 1), consisting of four females (mean ± SE SVL = 64.8 ± 3.0 mm) and seven males (SVL = 58.2 ± 0.4 mm). We were able to track two of these toads continuously for all nine days but the average number of tracking days was 4.7 per toad. Four toads managed to shed their transmitters, one after only a day, but we found two of these animals again, two and four days later. Four toads, with their transmitters, disappeared and could not be relocated. Three toads that had worn the harnesses for five days or more showed signs of abrasion behind the parotoid glands. Six transmitters were recovered at the end of the study.

For the most part, the toads moved within a limited area mainly travelling to and along the lower part of the beach on the damp sand at night and retreating to hiding places in the dry sand at the top of the beach and fore-dune during the day. Total distances travelled by toads during the study period ranged from 34 m to well over 600 m (Table 1). Daily average movements ranged from 14.2 m/day to about 125 m/day. Movements parallel to the water line ranged from about 11 m to over 440 m. Long-distance displacements of over 100 m by three toads occurred while they were active at night on the lower and upper beach. Toad 5 used the same hiding place consistently during the day for several days before embarking on an extensive trek 273 m westward. Toad 9 also exhibited long-distance movements parallel to the water line, traversing 441 m in two days, and then used the same refuge site for the next three days. Two toads were relatively sedentary: toad six moved only 26.7 m parallel to the shore over eight days, whereas toad eight moved 17.3 m over six days. Toads were found largely in areas characterized by relatively un-vegetated dunes and the absence of invasive Common Reeds.

Movements perpendicular to the water line were constrained by the width of the beach, but tended to increase after the storm as toads ventured further away from water to find daytime refugia (Figure 3). Before the storm, toads were located by day in refuge sites on the upper beach and fore-dune, on average 20.0 ± 0.9 m (n = 26) from the water line. Some of the animals used particular refuge sites, such as a hollow under a driftwood log, over many days or buried themselves in the sand to a depth of 3–5 cm, generally no deeper than the surface layer of dry sand. Most often, however, animals were found partly buried in dry sand with head and back exposed.

Following the storm, we noted a tendency for the animals to dig deeper into sand at refuge sites farther from the water line. Toad 3, for example, moved to the back-dune immediately after the storm was over, 11.3 m further from the water line, and dug down 60 cm into the sand. Toads 1, 6, and 8 also descended over 30 cm into the sand. Toad 9 moved 10.5 m further from the water line and toads 10 and 11 found refuges sites farther inland than any of the refuges used by any toads before the storm. The animals' daytime refuge sites were found an average of 29.2 ± 2.1 m (n = 25) from the water line after the storm, a significantly greater distance than before the storm (mixed effects linear regression: $F_{1,42.8}$ = 22.2, $P < 0.001$).

Discussion

Movement behaviour

Our results corroborate observations that Fowler's Toads inhabiting lakeshore habitats move on a daily basis between lakeside foraging sites at night and sand dune refuge sites during the day (Breden 1988; Marchand *et al.* 2017). Generally, the toads move very little, but there are occasional movements over larger distances, consistent with a generalized, fat-tailed Lévy-type distribution of movement distances (Marchand *et al.* 2017). Because the toads are evidently capable of travelling over 200 m in a day, dispersal movements

TABLE 1. Movements of Fowler's Toads (*Anaxyrus fowleri*) at the Big Creek National Wildlife Area, Ontario, over 10 days in August and September 2008.

Toad no.	SVL, mm	Sex	No. of days tracked	Distance moved, m		Extent of movement, m	
				Total	Mean/day	East–west*	North–south*
1	57.1	♂	9.0	229	25.4	57.1	22.9
2	62.2	♀	9.0	496	55.1	102.1	24.4
3	72.6	♀	9.0	164	18.2	40.2	45.2
4	66.1	♀	2.0	34	17.0	10.9	20.3
5	58.5	♂	4.0	377	94.3	298.1	19.7
6	58.4	♂	8.0	130	16.2	26.7	39.1
7	59.4	♂	2.0	78	39.0	71.7	13.3
8	59.7	♂	6.0	85	14.2	17.3	21.9
9	58.3	♀	5.0	623	124.6	442.2	17.0
10	57.8	♂	4.0	174	43.4	76.2	32.4
11	56.8	♂	4.5	78	17.4	26.7	49.6

Note: SVL = snout-to-vent length.
*East–west movement was parallel to the Lake Erie water line and north–south was perpendicular to the water line.

of many kilometres along the lakeshore in a season are feasible (Smith and Green 2006).

Pre-hibernation behaviour

After the storm, the toads appeared to be readying themselves for winter dormancy. Several animals appeared to respond to changes in weather conditions by shifting their movement and refuge-seeking behaviour to sites away from the more dynamic fore-dunes facing the beach to the protected back-dunes on the leeward side. We also observed that once individuals shifted their refuge sites further from the beach, they were less likely to resume their nightly nocturnal activity, foraging along the lakeshore beach. Instead they buried themselves deeper into the sand. None of these observed behaviours was apparent during summer (Boenke 2011).

It is possible that the high waves on the beach during the storm may have, in part, triggered this response. Natterjack Toads (*Epidalia calamita*) in Britain have been observed to shift refuge sites in response to tidal inundation (Denton and Beebee 1993). More probably, however, the combination of environment conditions, such as colder temperatures, increased rainfall, and decreased day length that appears to evoke pre-hibernation movements in other anurans (Koskela and Pasanen 1974; Miwa 2017) also contributed to the behavioural changes seen in these toads. Fowler's Toads at Long Point are not active in the spring at temperatures below 14°C (Green 1989, 2005); thus, the nighttime low temperatures following the storm approached the lower limits of the toad's normal activity range.

Based on our findings, it seems apparent that the active season for Fowler's Toads may typically come to an end in early to mid-September at the latitude of Long Point. As these toads typically emerge from hibernation in early to mid-May (Green *et al.* 2016), their active season lasts only about four months, compared with eight months of winter dormancy. Shifting their refuge habitat preferences to sites more likely to enable overwinter survival would appear to be a favoured adaptive response.

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