The observed decline of Western Toads (*Anaxyrus boreas*) over several decades at a novel winter breeding site

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Abstract

The Western Toad (*Anaxyrus boreas*) population of the Atlin Warm Springs in northwestern British Columbia has persisted since at least 1924. An extraordinary feature of the population has been winter breeding in late February to early March, while nearby cold-water populations breed in late-May. Metamorphosis of tadpoles, enhanced by the warm water, occurs as early as late-March. In 2008, Amphibian Chytrid Fungus (*Batrachochytrium dendrobatidis*) was documented in toadlets at the warm springs. Until 2005, as many as eight egg clutches and 25 breeding adults had been observed at the warm springs, after which the population declined. In 2017, novel spring breeding occurred in a cooler pond in the spring complex. Future observations will help determine whether the population is recovering and whether breeding phenology and habitat use have changed.

Key words: Amphibian Chytrid Fungus; *Anaxyrus boreas*; *Batrachochytrium dendrobatidis*; breeding population; breeding habitat; northwestern British Columbia; Western Toad; warm springs

Introduction

Since at least 1924, the Western Toad (*Anaxyrus boreas*) population of the Atlin Warm Springs has received substantial attention from biologists and naturalists, inspired by the relatively dense population that bred in a small and discrete habitat near the town of Atlin, British Columbia. The population occurs at the most northerly latitude of the species' range (Matsuda *et al.* 2006; Slough and Mennell 2006; Slough 2013). Cook (1977) collated some of the records of Western Toads from Yukon and northern British Columbia, and Slough (2009) summarized additional observations and specimens collected from 1924 to 2009. Additional observations to 2012 were contributed by B.G.S. to the COSEWIC assessment and status report on the Western Toad, Non-calling population (COSEWIC 2012). An unusual feature of the warm springs population was that breeding occurred in late February through early March, while adjacent cold-water populations congregated to breed in a 2-week period from late May through early June after ice breakup (Slough and Mennell 2006).

Local residents of Atlin and Whitehorse have traditionally observed toadlets at the springs over the Easter holidays (i.e., shortly after the vernal equinox on 21 March). Early breeding, in late March, has also been reported for Western Toad populations at warm springs in Utah (Thompson 2004). Some toads in Utah did not hibernate and were active year-round. It is not known whether the toads of the Atlin Warm Springs hibernate or remain active in winter.

Methods

The Atlin Warm Springs is a cluster of geothermal springs that arise near Warm Bay on the east side of Atlin Lake in northwestern British Columbia (59.404°N, 133.575°W), 20 km south by southwest of the town of Atlin, and about 650 m from the lake (Figure 1). A second set of springs is located about 300 m to the west, and both drain into Atlin Lake. There are several underground sources of spring water, although most of the water emerges in three primary source pools. The largest source pool (≤10 m in diameter and 1 m deep) and several smaller pools (<0.5 m in depth), drain into a common stream. The largest pool was mechanically excavated for bathing.

The water is clear and odourless. Water temperature is 29°C at the large source pool, with pool and drainage stream temperatures 23–27°C at breeding sites in March and up to 29°C in summer. A single cooler spring-fed pond (15°C in winter) lies at a slightly lower elevation in the centre of the warm springs complex (spring 2017 breeding site in Figure 1). Shallow tufa (calcite) basins are present where the stream cascades downslope and runs underground for about 30 m. The tufa deposits are porous and may provide hibernacula, hiding places, and foraging habitat for Western Toads.

Annual growth of vegetation in the springs begins in March. Vegetation consists of green algae, Small Duckweed (*Lemna minor* L.) and introduced Small-leaved Watercress (*Nasturtium microphyllum* Boenninghausen ex Reichenbach). Lake Chub (*Couesius plumbeus*) in-

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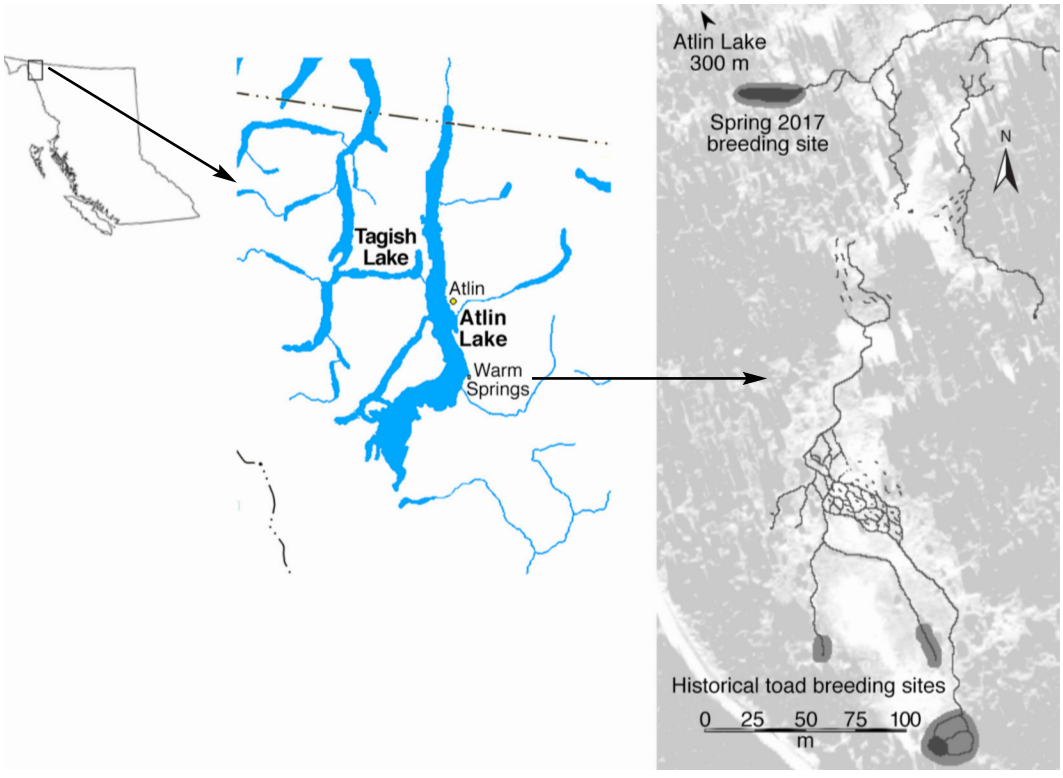

FIGURE 1. Atlin Warm Springs complex, northwestern British Columbia (59.404°N, 133.575°W), showing historical winter and 2017 spring breeding sites (grey shading). Breaks in streams indicate underground flow. Forest and meadows shown in background of spring complex with Imagery ©2018 DigitalGlobe, map data ©2018 Google.

habit the springs. We have observed Red Marshworm (*Lumbricus rubellus*), a potential prey of the Western Toad, to be abundant in the meadows surrounding the springs. Goldfish (*Carassius auratus*) were introduced to the western springs in about 2000 (S. Badhwar pers. comm. 11 March 2007), and Red Cherry Shrimp (*Neocaridina davidi*) were introduced to the eastern springs between October and December 2015 (A.dB. pers. obs.). Lake Chub and Red Cherry Shrimp are absent from the cooler pond.

Between 1996 and 2018, we searched for Western Toads in the Atlin Warm Springs using visual encounter surveys of the source springs, streams, and surrounding meadows (Table 1). The breeding sites and meadows encompassed about 1 ha and were surveyed in 1–2 h. Adults were rarely found far from water or outside of the breeding season. They may have dispersed from the site to other summer foraging habitats, or they may have gone underground into crevices created by the tufa. We also solicited observations from Environment Yukon and Environment Canada based out of Whitehorse. In addition, observations were made by A.dB. during a study of Lake Chub and Cherry Shrimp in 2017.

Results

Numerous observations of Western Toads at the Atlin Warm Springs from 1924 through 2005 indicate that a healthy breeding population persisted for at least 80 years (Table 1). After 2005, breeding activity and sightings of adults became sporadic, suggesting a population decline. Amphibian Chytrid Fungus (*Batrachochytrium dendrobatidis* [*Bd*]) was detected on Western Toad juveniles and adults from adjacent Atlin Lake in 2007 and on toadlets from the warm springs in 2008 (Slough 2009). Since 2005, observations have consisted of two clutches of eggs in 2008, one toadlet and one adult in 2012, and one toadlet in 2014. There has been no other evidence of breeding at the historical breeding sites within the springs in other years between 2006 and 2018. Three dead adult Western Toads were found in or near the springs on 7 March 2005, where at least four aggregations of recently hatched tadpoles were present. There was no obvious trauma to the dead toads.

Breeding behaviour, involving ≥25 adults and ≥8 egg clutches, was observed between 7 and 22 March in five years between 1998 and 2005 (Figure 2). Records of newly hatched larvae suggest that oviposition occurred during or before 4–10 March. Larvae that were

TABLE 1. Western Toad (*Anaxyrus boreas*) observations at the Atlin Warm Springs, northwestern British Columbia (59.404°N, 133.575°W), 1996–2018. Larval stages after Gosner (1960). Absence of data for some years indicate that the site was not visited.

Date	Eggs	Tadpoles	Terrestrial stages
Early April 1996	0	Numerous	0
22 March 1998	0	Wide range of stages (26–45), from early to near metamorphosis	0
12 February 1999	0	0	0
13 March 1999	≥8 clutches	Newly hatched (stage 20)	1 dead yearling; ≥6 adults, including 4 calling males and spawned female
9 March 2001	0	Early to mid-stages (20–30+)	≥25 breeding in 4 areas
7 March 2005	0	≥4 recently hatched aggregations (stage 26+)	1 male and 3 dead adults (1 frozen on land, 2 in stream)
21 March 2005	0	To stage 40	0
21 March, 3 June 2006	0	0	0
12 March, 19 April 2007	0	0	0
10 March 2008	0	~ 500 tadpoles (stages 26–30). Estimated: 2 clutches	0
10 May 2008	0	0	100s metamorphs (stages 44–46)
27 April 2009	0	0	0
6 April 2010	0	0	0
15 March, 2 July 2011	0	0	0
12 August 2012	0	0	1 adult, 1 toadlet (S. Stotyn, S. Cannings)
18 March 2013	0	0	0
28 June 2014	0	0	1 toadlet (S. Stotyn, S. Cannings)
20 June 2016	0	0	0 (S. Stotyn, S. Cannings)
16 May 2017	0	0	0 (J. Hobbs)
17 June 2017	0	3 aggregations, possibly from one egg clutch, downstream from traditional breeding sites	2 adults (A.dB., E. Titley)
25 February, 31 March, 27 May 2018	0	0	0 (B.G.S., A.dB.)

Sources: Observations by B.G.S. unless noted. Presence/absence data to 2012 were previously presented by Slough (2009) and COSEWIC (2012).

near metamorphosis (stage 45; Gosner 1960) observed on 22 March 1998 placed oviposition in mid-February using developmental times of Olson (2005). However, development may be more rapid in the warm water of the springs compared with cold-water habitats, as egg and tadpole development are largely temperature dependent (Matsuda *et al*. 2006). Western Toad eggs reportedly hatch within 3–12 days (Olson 2005) or 7–10 days (Matsuda *et al*. 2006) across the species' range. Goettl (unpubl. data 1996 as cited in Loeffler 2001) reported Western Toad eggs hatching in 5–7 days at 19°C with completion of metamorphosis 45 days post-breeding in the Southern Rocky Mountain population. Maxell *et al*. (2002) have reported time to hatching of ≤7 days in Montana, with metamorphosis ≤42–49 days post-oviposition. Metamorphosis may take up to three months in some systems (Olson 2005).

At least three clusters of tadpoles (possibly from one egg clutch) were observed at the only cooler pond within the Atlin Warm Springs complex on 17 June 2017, long after the late March to early April metamorphosis, which follows winter breeding (Figure 2). The tadpoles were not handled on site, but, from photographs, they appear to be at Gosner stage ≥30, indicating breeding in late May, as is typical for regional cold-water populations. Two adults were observed in terrestrial meadow habitat adjacent to the historical warm springs breeding habitat.

Discussion

Batrachochytrium dendrobatidis must be considered a factor contributing to the local population decline of Western Toads observed from 2006 to 2018. The fungus causes the infectious disease chytridiomycosis, a global threat to Western Toads across the range of the species (summarized in COSEWIC 2012). Water temperatures in the warm springs (average of 26°C in winter) are near the thermal maximum for *Bd* growth (26–28°C; Stevenson *et al*. 2013); however, the thermal tolerance of *Bd* strains is variable and the fungus is known to be adaptable to temperature conditions (Voyles *et al*. 2017). A temperate strain of *Bd* from

FIGURE 2. Western Toad (*Anaxyrus boreas*) tadpoles in the Atlin Warm Springs, northwestern British Columbia (59.404°N, 133.575°W), on 7 March 2005 (a) and 17 June 2017 (b). Photos: B. Slough (a) and A. deBruyn (b).

California grew well at 2–27°C and following freeze and heat shock treatments (Voyles *et al.* 2017). The Atlin Warm Springs are not likely a refuge from *Bd*.

The recovery of the Western Toad population of the Atlin Warm Springs may be limited by life cycle and reproduction. Females mature at 4–6 years of age, and most breed only once in their lifetime (summarized in COSEWIC 2012).

Climate change and severe weather are expected to have a low impact on Western Toad populations in British Columbia (Environment and Climate Change Canada 2016), although the predicted increase and frequency of droughts may threaten small wetland breeding sites and micro-sites used for rehydration (Provincial Western Toad Working Group 2011). Climate warming is expected to affect the phenology of breeding, larval development, and hibernation. In 2005, a single stochastic cold weather event during breeding did not appear to be the cause of mortalities and the subsequent population decline. In fact, March 2005 was relatively mild: daily mean −1.1°C, versus a long-term mean of −5.5°C for 1981 to 2010 (Environment and Climate Change Canada 2018; data from Atlin, British Columbia weather station, 20 km north-northwest of the Atlin Warm Springs). Nonetheless, activity during freezing temperatures, such as movements from hibernacula to breeding sites, places Western Toad at risk of exposure.

Amphibians including Western Toads are known to exhibit adaptive responses to climate change, such as

adjusting breeding phenology in response to warmer temperatures (Blaustein *et al*. 2001; Urban *et al*. 2014). Other plastic responses include enlarged clutch size, more rapid growth and development rate, and increased survival. This plasticity is possibly shared by the Atlin Warm Springs population of Western Toads.

We can only speculate on the cause of the novel spring and cool-water breeding observed in 2017. Was the warm springs Western Toad population extirpated and re-colonized by individuals with cold-water breeding patterns and habitat preference, or did surviving toads switch phenology and habitat in response to unknown factors in the warm springs? Western Toad tadpoles were observed at four sites on Atlin Lake in 2017 (Hobbs 2018), where the population appears healthy. The aggregating behaviour of cold-water tadpoles along shallow shorelines, where the water is sun-warmed, has not been observed at the warm springs.

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