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EGG MASS DRIFT INCREASES VULNERABILITY DURING EARLY DEVELOPMENT OF CASCADES FROGS (*RANA CASCADAE*)

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Many anuran species exhibit oviposition site selection. Female selection of oviposition sites may influence the success of offspring and increase overall fitness (Resetarits 1996). Egg mass placement (location and attachment substrate) may be determined by a number of factors including detectability by predators, water velocity, risk of desiccation or flooding, and temperature (Stebbins and Cohen 1997). Some lentic breeding anurans do not always attach their egg masses to substrates (Briggs 1987; Olson 2005; Reaser and Pilliod 2005; Wind 2005), making them vulnerable to involuntary displacement. The movement of egg masses to areas of sub-optimal conditions (for example, colder water or desiccation from stranding) may affect hatching success and overall survival of individuals (Licht 1971; Sype 1974). Here, we document high occurrences of egg mass displacement in a high-elevation breeding population of *Rana cascadae* (Cascades Frog).

This study was conducted at 2 lentic sites in the upper Deep Creek drainage within the Trinity Alps Wilderness, Trinity County, California. Echo Lake (elevation 2215 m, surface area 1.14 ha, depth 5.1 m), a relatively small tarn contained in a steep, narrow cirque, was surveyed from 2003 to 2005. Snowmelt Pond (elevation 2226 m, surface area 0.23 ha, depth 1.47 m), a temporary pond on a narrow rocky shelf 200 m north of Echo Lake that dries completely by late October, was surveyed from 2004 to 2006. Both water bodies have exposed shorelines surrounded with sparse sub-alpine vegetation. Silt dominates the littoral zones, which have limited submerged vegetation (for example, sedges and grasses) during the *R. cascadae* breeding season. This area typically receives deep annual winter snowpack, and both water bodies can remain completely frozen from early November to mid-June.

Routine visual encounter surveys for egg masses (Crump and Scott 1994) at both water bodies were conducted each year during July and early August as part of a study on *R. cascadae* breeding ecology. Egg masses were individually marked by injecting color combinations of visual implant fluorescent elastomer (Northwest Marine Technology Inc., http://www.nmt-inc.com) into the center of each mass. Numbered pin flags were used to mark single, isolated egg masses. We recorded attachment substrate and water depth for each egg mass. When an egg mass drifted from its oviposition site, we measured the straight-line distance between the initial and new location. Water temperature and depth were measured at both initial and displacement locations for a subset of egg masses. We used a Wilcoxon Rank Sum test to determine if water temperature and depth differed between the oviposition site and displacement location.

Thirty-seven *R. cascadae* egg masses were detected at Echo Lake and Snowmelt Pond from 2003 to 2006 (Table 1). All egg masses were oviposited in shallow, open areas with full exposure to sunlight. Twenty-five egg masses (68%) were initially attached to various substrates: grass (n = 13), rock (n = 5), grass and rock (n = 3), and wood (n = 4). Twelve egg masses (32%) were not attached to any substrate. We observed egg mass displacement at both sites and in all years of the study. Of the 37 egg masses detected, 51% were displaced from their original oviposition sites (Table 1). The overall median displacement distance was 2 m (range 1.1 m to 90.6 m). Oviposition substrate type did not appear to influence the likelihood of displacement, and we observed drifting of both initially attached and unattached egg masses. Oviposition sites were found to be significantly warmer than displacement locations

TABLE 1. A summary of Cascades Frog egg mass drift by site and year. Median distance displaced was measured as the minimum straight-line distance between initial and final locations of individual egg masses. SMP = Snowmelt Pond. ECH = Echo Lake.

Site; year	Total no. egg masses	No. egg masses displaced	Proportion displaced	Median distance displaced (m)	Displacement range (m)
SMP; 2004	14	11	0.79	1.5	1.1–34.9
SMP; 2005	7	2	0.29	35.3	33.7–36.8
SMP; 2006	3	1	0.33	Could not relocate	—
ECH; 2003	4	1	0.25	90.6	90.6
ECH; 2004	6	3	0.50	66	33.8–66.0
ECH; 2005	3	1	0.33	Could not relocate	—
Totals	37	19	0.51	2	1.1–90.6

(Wilcoxon Rank Sum: $n = 11$, $Z = 1.74$, $P = 0.04$). On average, the difference in water temperature from oviposition sites to displacement locations was $-1°C \pm 0.46$ (s) and ranged from $-4.1°C$ to $+0.8°C$. Oviposition sites were also significantly shallower than displacement locations (Wilcoxon Rank Sum: $n = 16$, $Z = -2.67$, $P = 0.004$). On average, the difference in depth from oviposition sites to displacement locations was -0.44 m $\pm$ 0.2 (s), and ranged from -2.4 m to $+0.19$ m.

We observed displacement of 1 egg mass that resulted in mortality. On 2 August 2005, this egg mass was relocated 36.8 m from its oviposition site where it became snagged on a pile of small sticks in flowing water within the outlet stream. On 15 August 2005, we observed tadpoles that we assumed were from this egg mass in a shallow pool located 37.2 m downstream of the pond. However, on 20 August 2005, the outlet stream was dry and desiccated tadpoles were found at the bottom of the pool.

R. cascadae, like many high elevation or northern latitude frogs, typically breed in areas within a pond or lake that thaw earliest (Sype 1974; Briggs 1976; Bull 2005; Wind 2005). This suggests that frogs select oviposition sites based on the earliest availability of the site rather than the availability of substrate or vegetation. The reason for the large variation in egg mass attachment for this study is unclear; however, variation in attachment substrate has been observed with other high elevation ranids including *R. luteiventris* (Columbia Spotted Frog; Reaser and Pilliod 2005) and *R. muscosa* (Mountain Yellow-legged Frog; Pope 1999). The observed high incidence of displacement, even when egg masses were attached to substrates, indicates that during the breeding season available substrates often may be ineffective at immobilizing egg masses at ''preferred'' oviposition microsites.

The high occurrence of *R. cascadae* egg mass displacement from original oviposition sites observed during the study is likely a natural phenomenon resulting from wind-driven surface drift. Wind is the primary force that moves water at all depths in lentic systems and this can have profound consequences for the chemistry, biology, and spatial distribution of lentic organisms, especially small or immobile life stages (Horne and Goldman 1994). Our results indicate that displaced egg masses can be carried to deeper and cooler waters compared to their original oviposition sites, and cooler water temperatures may slow embryonic development (Sype 1974). In the sub-alpine environment of the Trinity Alps Wilderness, breeding occurs relatively late in the year (July) compared to lower elevation sites (May) with the entire annual active season being less than 5 mo. For example, during the 4 y of this study, *R. cascadae* breeding began at Echo Lake and Snowmelt Pond 55 days $\pm$ 4.3 (s) later than the lowest elevation breeding site (1976 m, 1 km air distance) within the same drainage (JMG, unpubl. data). Because of this truncated active period, even a slight reduction in embryo development time at these 2 study sites could result in lower hatching success, delayed metamorphosis, and lower post-metamorphic survival. In addition to having late open-water availability, water temperatures remain colder for longer periods of time at these 2 study sites because they have higher catchment volumes relative to other breeding sites in the same basin (JMG, unpubl. data). Egg masses laid at the study sites likely have slower rates of development and consequently newly metamorphosed frogs have a shorter foraging period prior to overwintering (JMG, unpubl. data).

We suggest that researchers, based on our observations, account for the possibility of egg mass displacement when conducting egg mass surveys or studies of oviposition site selection of lentic-breeding amphibians, especially at exposed high-elevation sites. Egg mass surveys can be useful for species that breed only once per season or for cryptic species in which adult frogs are difficult to detect. Surveys for egg masses have been shown to be an accurate and affordable means for monitoring the effective population size of Wood Frogs (*R. sylvatica*), another lentic-breeding anuran (Crouch and Paton 2000). However, our observations suggest that drift of *R. cascadae* egg masses, and possibly the egg masses of other lentic-breeding amphibians, may occur often (up to 79% of the time) in medium to large water bodies. Although many high-elevation anurans in medium to large water bodies oviposit in shallow water, egg masses may be carried by wind action to cooler, deeper water locations that are not typically surveyed for egg masses. Site productivity and effective population size could be underestimated if researchers do not account for egg mass drift in survey protocols. Increased detectability of egg masses could be accomplished by expanding search efforts to sub-optimal areas, and/or increasing sampling frequency in conjunction with marking individual egg masses.

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