

# Responses of Foothill Yellow-legged Frog (*Rana boylei*) Larvae to an Introduced Predator

David J. Paoletti<sup>1</sup>, Deanna H. Olson<sup>2</sup>, and Andrew R. Blaustein<sup>1</sup>

**The consequences of species introductions into non-native habitats are a major cause for concern in the U.S. Of particular interest are the effects of predation by introduced fishes on native amphibian communities. We sought to determine whether Foothill Yellow-legged Frog (*Rana boylei*) larvae could recognize non-native Smallmouth Bass (*Micropterus dolomieu*) as a predatory threat. Through a series of laboratory experiments, we examined the initial and overall behavioral responses of larvae to native predators (Rough-skinned newts, *Taricha granulosa*), introduced predators (*M. dolomieu*), and native non-predatory fish (Speckled Dace, *Rhinichthys osculus*). Each experiment examined a different potential mode of detection including chemical cues; visual cues; or a combination of chemical, visual, and mechanical cues. Initially, larvae of *R. boylei* responded with an increase in activity levels when exposed to visual cues of *M. dolomieu*. Analyses of overall responses suggested that individual larvae of *R. boylei* require multiple cues to facilitate predator detection. When exposed to multiple cues of their native predator, larvae responded with a significant reduction in activity levels. Those larvae exposed to cues of the non-native predator displayed similar behaviors relative to control cues. Consequently, larvae of *R. boylei* appear to be especially vulnerable to predation by non-native *M. dolomieu*.**

THE consequences of species introductions into non-native habitats are a major cause of concern. An introduced species may alter native habitats, cause economic damage, carry pathogens, compete with natives for resources, or prey on them (Vitousek et al., 1997; Mack et al., 2000; Kiesecker et al., 2001; Muir and Jenkins, 2002). These introductions are particularly prevalent in aquatic systems. From 1950 to present, the number of introduced aquatic species has more than tripled in the United States (USGS, 2009). Muir and Jenkins (2002) have documented up to 140 aquatic non-native species in the Great Lakes alone. According to the U.S. Geological Survey's Nonindigenous Aquatic Species Database, over 42% ( $n = 675$ ) of introduced aquatic species are fishes (USGS, 2009), with many of these introductions being intentional.

In the U.S. Pacific Northwest, non-native fishes have been stocked in a variety of habitats from rivers to sub-alpine lakes to backyard ponds. Schade and Bonar (2005) conducted surveys of 12 western states from 2000–2002 and found that of the most widely distributed and abundant non-native fishes ( $n = 15$ ), almost all were introduced for sport fisheries. Species such as Rainbow Trout (*Oncorhynchus mykiss*), Brook Trout (*Salvelinus fontinalis*), Channel Catfish (*Ictalurus punctatus*), and Smallmouth Bass (*Micropterus dolomieu*) have been, and continue to be, stocked in many areas of the western U.S. for recreational purposes.

Introduced species are one of the leading causes of amphibian population declines worldwide (Kats and Ferrer, 2003), in addition to a myriad of other factors such as habitat loss, disease, environmental changes, and pollutants (Blaustein and Wake, 1990; Alford and Richards, 1999; Stuart et al., 2004; Pounds et al., 2006). In the western U.S., predation by introduced fishes has been implicated in affecting distributions of several amphibian species (for example, Cascades Frogs, *Rana cascadae* [Fellers and Drost, 1993]; Mountain Yellow-legged Frogs, *Rana muscosa* [Bradford et al., 1993; Knapp and Matthews, 2000]; and Long-toed Salamanders, *Ambystoma macrodactylum* [Tyler et al., 1998]). Eggs and larvae of many species are completely dependent on water for periods ranging

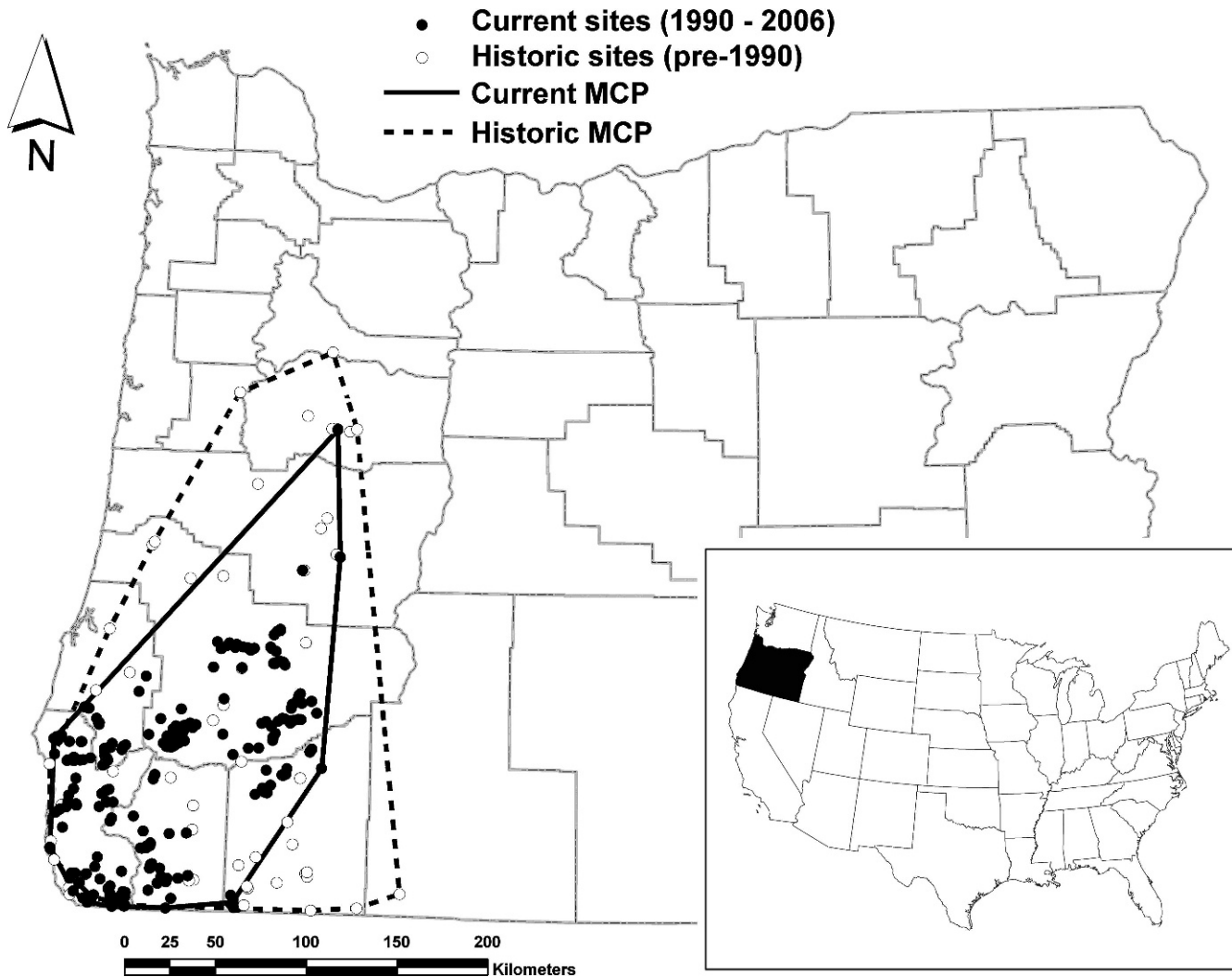
from two months to four years, depending on the species (Jones et al., 2005). Hence, these pre-metamorphic stages may be particularly susceptible to the effects of novel fish predators.

In Oregon, the distribution of the Foothill Yellow-legged Frog (*Rana boylei*) appears to be influenced by introduced *M. dolomieu* in some river systems. *Rana boylei* is a native stream-dwelling frog listed as a “Sensitive Species” in the state, where its range has been reduced to 43% of historical locations (Fig. 1; Olson and Davis, 2007). In the Umpqua River system, *M. dolomieu* was introduced as recently as the mid-1960s, where their distribution has rapidly expanded (Simon and Markle, 1999). This spread is particularly evident in Cow Creek, a major tributary of the South Umpqua River in Douglas County, Oregon (Fig. 2). As *M. dolomieu* have spread upstream through Cow Creek, a coincident reduction of *R. boylei* has been observed (Borisenko and Hayes, unpubl; Rombough, unpubl.). In the federal Conservation Assessment for *R. boylei* in Oregon, Olson and Davis (2007) proposed a variety of causes for the decline of this species, including habitat loss, pollutants, change in hydrologic regimes, and introduced species including *M. dolomieu*. However, these potential factors in the frog's decline in Oregon remain unstudied.

We investigated possible mechanisms behind declines of *R. boylei* in Cow Creek, Oregon, by experimentally assessing their responses when exposed to *M. dolomieu*. We chose a laboratory setting for our experiments in order to maintain consistent environmental conditions between experimental treatments, including the chemical composition of the water, while eliminating a majority of the biotic and abiotic variation that might confound interpretations of larval behavior in the field. Amphibian larvae often “recognize” predators via waterborne chemical cues (Kats and Dill, 1998). Upon detection of a potential threat, larvae often respond with antipredator behaviors such as refuge use or a reduction in activity levels (Petranka et al., 1987; Kiesecker et al., 1996). We have observed both of these behaviors in *R. boylei* during field observations; upon our approach they often took cover by retreating under cobble, and have been

<sup>1</sup>Environmental Science Graduate Program, 104 Wilkinson Hall, Oregon State University, Corvallis, Oregon 97331; E-mail: (DJP) paolettd@onid.orst.edu; and (ARB) blaustea@science.oregonstate.edu. Send reprint requests to ARB.

<sup>2</sup>USDA Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, Oregon 97331; E-mail: dedeolson@fs.fed.us. Submitted: 11 September 2009. Accepted: 27 October 2010. Associate Editor: G. Haenel.



**Fig. 1.** Past and present distributions of *Rana boylei* in Oregon, USA. Modified from Olson and Davis (2007). MCP = Minimum Convex Polygon of species range from known site locations.

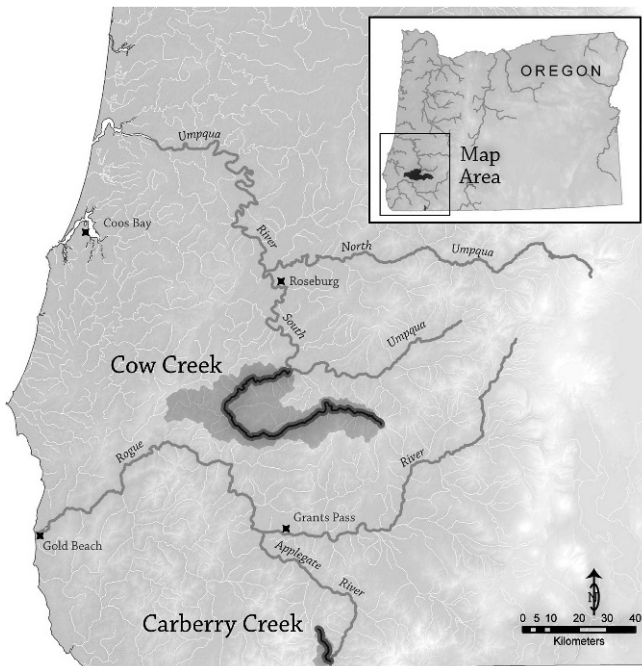
observed motionless when in close proximity to a native predator, the Rough-skinned Newt (*Taricha granulosa*; Jones et al., 2005). The newt appeared to be a stealthy predator, slowly stalking its prey, although no studies of their predation behavior under natural conditions are known to us. It is possible that the more rapid predatory behavior of introduced bass is novel to *R. boylei*.

We conducted Experiment I to determine if chemical cues alone are sufficient for larvae of *R. boylei* to detect a potential threat. Kats et al. (1994) showed that amphibian larvae may change antipredator behaviors based on their developmental stage. To determine if these ontogenetic differences were evident in *R. boylei*, Experiment Ia was conducted using early-stage larvae, whereas Experiment Ib focused on the responses of late-stage larvae. Because chemical cues may be insufficient to detect a potential threat in the stream environment in which larvae of *R. boylei* live, we designed Experiment II to determine the role visual cues play in response to predator stimuli. In a lotic environment, amphibian larvae may need to use several modes of detection in tandem to identify a potential threat. Experiment III was designed to expose larvae of *R. boylei* to chemical, visual, as well as mechanical (i.e., water movement) cues of the stimulus animal concurrently.

We hypothesized that larvae of *R. boylei* would respond to cues of a native predator by reducing activity levels and/or increasing refuge use, whereas those exposed to cues of the non-native, unfamiliar predator would display activity levels similar to larvae exposed to control cues. Studies examining the effects of introduced species on native amphibians are numerous, but to our knowledge only one (Kupferberg, 1997) has been conducted investigating the effects of non-native species (American Bullfrog, *Lithobates catesbeianus*, formerly *Rana catesbeiana*) on *Rana boylei*. Our study is the first attempt to determine empirically the effects of *M. dolomieu* on larval behavior of *R. boylei*. Absence of an appropriate antipredator response by larvae may directly impact *R. boylei* where their populations overlap with *M. dolomieu*.

#### MATERIALS AND METHODS

Eggs of *R. boylei* were collected on 13 June 2008 from an area populated by *M. dolomieu* (Cow Creek, Douglas Co., OR; 42°52'3"N, 123°34'32"W). On 24 June 2008, a second set of eggs was collected from a bass-free area (Carberry Creek, Jackson Co., OR; 42°4'6"N, 123°10'7"W; Fig. 2). Larvae from these populations will be referred to as BASS and BASSLESS



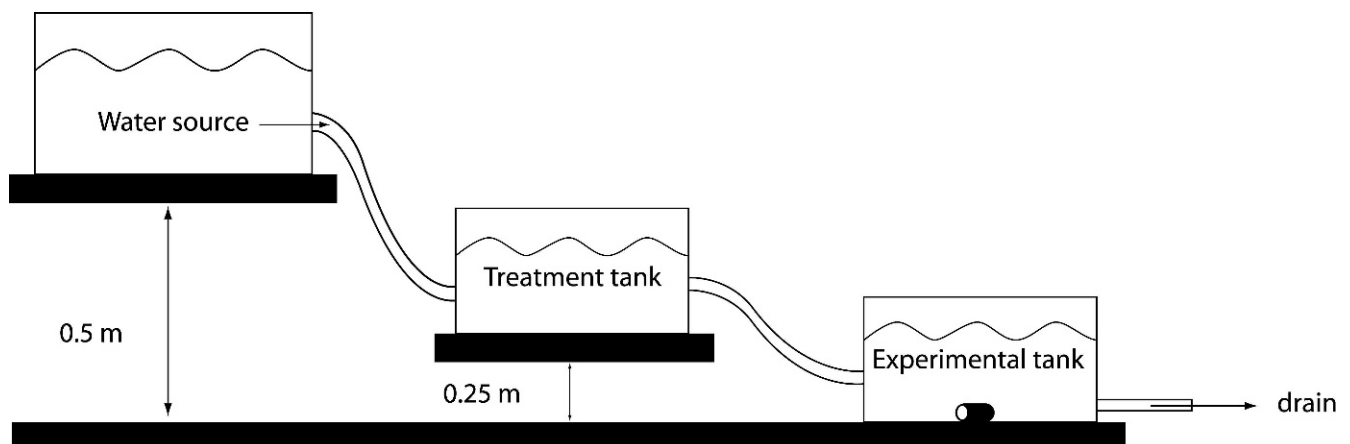
**Fig. 2.** Location of foothill yellow-legged frog (*Rana boylei*) study site and egg-collection sites at Cow Creek, Douglas County, and Carberry Creek, Jackson County, Oregon, USA.

hereafter. Eggs were transported to Oregon State University and maintained in aerated, 38-L aquaria filled with dechlorinated water. Animals were exposed to a natural 14L:10D photoperiod at a constant temperature of 16°C. Upon hatching, larvae were fed a mixture of fish flakes (TetraFin) and ground rabbit chow *ad libitum*. Source animals for the stimulus cues were collected from Cow Creek and tributaries of the South Umpqua River. These included: *T. granulosa*, Speckled Dace (*Rhinichthys osculus*), and *M. dolomieu*. We compared larval responses between treatments, exposing them to native and non-native predators, and to *R. osculus*, a non-predatory native minnow which served as our “positive fish control.” All animals were maintained in the conditions listed above at Oregon State University. *Rhinichthys osculus* were fed fish flakes and tubifex worms; *T. granulosa* and *M. dolomieu* were fed earthworms and crickets *ad libitum*. Sated

larvae may exhibit reduced activity levels, making it difficult to discern between inactivity due to satiation or the presence of a potential threat. In each experiment, food was withheld from all animals 24–48 h prior to experimental trials to avoid the effects of satiation. Blinds around test tanks prevented disturbance of animals during experimental observations.

**Experiment 1a: Detection via chemical cues by early-stage larvae.**—Early-stage larvae (Stage 20–24; Gosner, 1960) were exposed to one of four chemical cue treatments: Control (no cue); Positive Control (non-lethal, native *R. osculus*); Native Predator (*T. granulosa*); and Non-native Predator (*M. dolomieu*). Individual larvae ( $n = 104$ ) were randomly assigned to one of the four treatments and were not re-used in trials to address this objective. In addition, larvae from BASS and BASSLESS populations were alternately tested. There were a total of 13 larvae for each population (13 replicates  $\times$  4 treatments = 52 animals tested per population = 104 total). Chemical cues were supplied through a series of gravitational “flow-through” tanks (Fig. 3; similar to those in Petranks et al., 1987) and were designed to simulate the stream environment in which these animals are found. Three clear plastic tanks were arranged in a linear fashion, in sequentially descending heights. Filtered, dechlorinated water was supplied via a 144-L source tank. Water was gravity-fed through 2.5 cm polyvinyl chloride (PVC) tubing into a “treatment tank” (23  $\times$  37  $\times$  16 cm). This tank held the animal responsible for supplying the chemical cue treatment. From here, water was gravity-fed to a third tank, the “experimental tank” (23  $\times$  37  $\times$  16 cm), which held a single frog larva. A 5-cm (2.5 cm diameter) piece of black plastic pipe was affixed to the bottom of the tank to provide a standardized potential refuge for larvae. A drain pipe was inserted to maintain a constant water height of 11 cm (mean flow rate = 2.0 L/min). Four of these systems ran concurrently, with each of the four treatment tanks supplying one of the four cues. The cue assigned to each treatment tank was randomly assigned. Experimental tanks were rinsed thoroughly between each replication.

Prior to running each trial, animals supplying the cue were placed in the treatment tank, and a randomly selected larva was placed in the experimental tank and allowed to acclimate for ten minutes. After this the valve from the source tank was slowly opened, followed by the treatment



**Fig. 3.** Design of flow-through tanks addressing the potential response of larvae of *Rana boylei* from Cow Creek, Oregon, USA, to chemical cues of native and non-native predators, and native non-predators. Animals supplying chemical cues were placed in the treatment tank, and larvae were placed in the experimental tank.



tank valve. Observations began immediately and locations of larvae were recorded during “spot-checks” conducted every two minutes for ten minutes. A grid divided into six quadrants (10 × 10 cm each) was placed under each experimental tank to track movement (Garcia et al., 2009). Grids were designed to be large relative to larval body size to ensure that any movement captured was deliberate. For example, an early-stage larva would have to travel the equivalent of ten body-lengths in order to cross one gridline, therefore providing a highly conservative representation of activity levels. Furthermore, this grid size approximates larval movements observed in their natural environment. At each observation we recorded the location of each larva, whether there was movement, number of gridlines crossed following their previous position, and whether or not they were utilizing the refuge. The experiment was conducted over three days.

**Experiment 1b: Detection via chemical cues by late-stage larvae.**—Methods were identical to those listed above, using late-stage larvae (Stage 30–37; Gosner, 1960). Over 70% of these individuals were stages 34 to 36. There were nine replicates for each population (9 replicates × 4 tanks = 36 animals tested per population = 72 total).

**Experiment II: Detection via visual cues.**—We used four pairs of 9.5-L glass tanks, with an opaque divider placed between each pair. Glass tanks were used instead of plastic tanks from the previous experiment to allow for maximum visibility. Beneath one of each pair was placed a six-square grid (4.5 × 10.5 cm each) which allowed the observer to track tadpole movement. In addition to these gridlines, the treatment tank was divided into three sections (4.5 × 21 cm each) situated relative to the treatment tank—Near Section, Middle Section, and Far Section. Late-stage larvae (stages 33–40; Gosner, 1960) from the BASSLESS population were exposed to one of four different visual cues: Control (no animal); Positive Control (native *R. osculus*); Native Predator (*T. granulosa*); and Non-native Predator (*M. dolomieu*). A total of 40 larvae were tested (10 replicates × 4 tank-pairs = 40 animals), none of which were re-used within the study.

All animals were randomly assigned to a treatment, as well as their position within each of the four pairs (i.e., left- or right-hand tank). Randomly selected treatment animals and larvae were placed into tanks and allowed 15 minutes to acclimate. Opaque dividers were then slowly removed from in between each pair of tanks to allow animals to see one another, and observations began immediately. Observations were taken every two minutes for ten minutes. During every observation, we recorded within which section each larva was located, whether there was movement, and number of gridlines crossed from their previous position. The experiment was conducted over one day.

**Experiment III: Detection via chemical/visual/mechanical cues.**—This experiment was designed to reflect the same exposure to cues larvae might receive in the side pools of streams in which they are often found. Four plastic tanks (50 × 32 × 14 cm) were divided in half width-wise by fiberglass mesh to separate larvae from the treatment animal. A 5-cm (2.5 cm diameter) piece of black plastic pipe was affixed to the bottom of the larva half to provide potential refuge. A nine-square grid (8.3 × 10.7 cm) was positioned under the larva half to monitor movement (or lack thereof). Late-stage larvae (Stage 31–37; Gosner, 1960) from BASS and BASSLESS

populations were alternately tested by exposing them to one of four different treatments (Control, Dace, Newt, or Bass). There were eight replicates for each population (8 replicates × 4 tanks = 32 animals tested per population = 64 total).

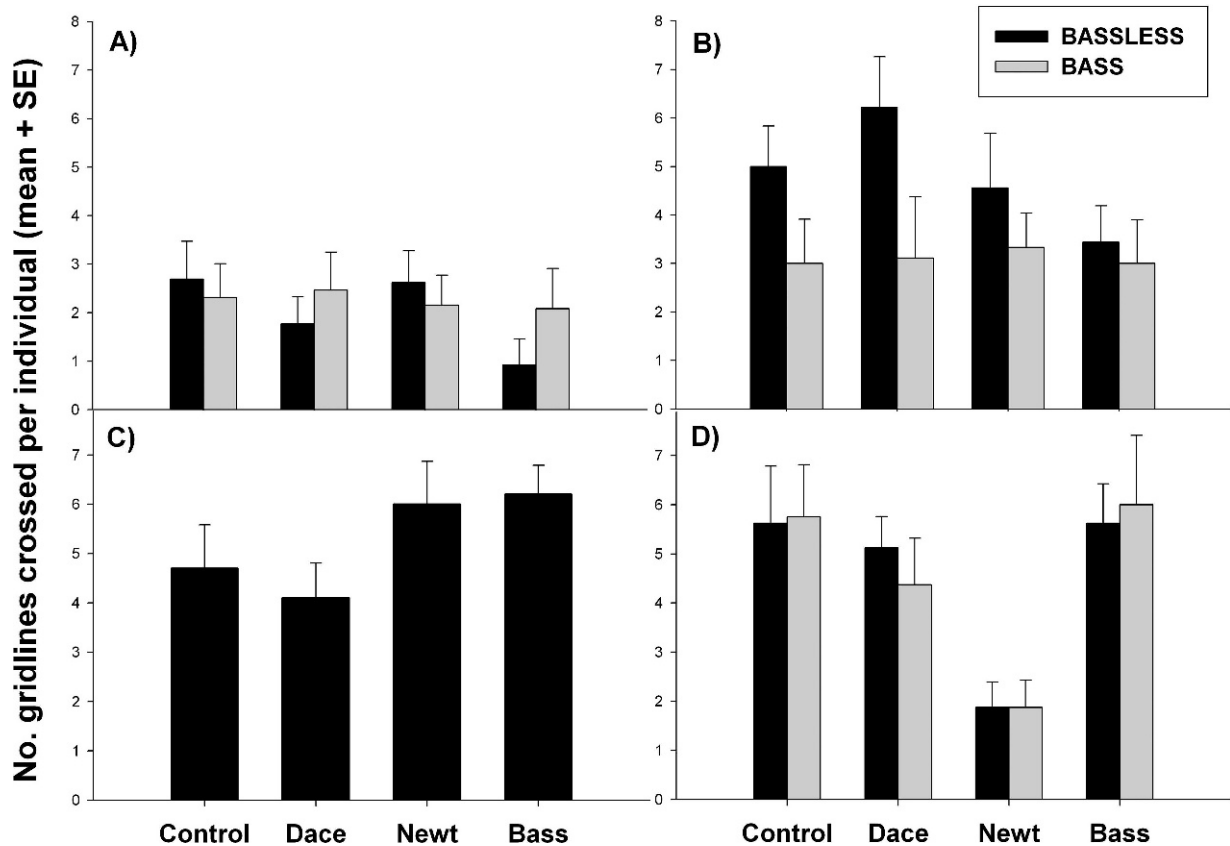
Orientation of tanks was randomly assigned, as was the treatment. Treatment animals were randomly selected and placed in their pre-designated half of the tank. Following a ten-minute acclimation period, larvae were gently placed in the center of their half and observations began immediately every two minutes for ten minutes. We recorded the location of each larva, whether there was movement, number of gridlines crossed following their previous position, and whether or not they were utilizing the refuge. Ten individuals used in this study were randomly selected from larvae used in previous experiments. The experiment was run over two days.

**Statistical analysis.**—We examined initial and overall responses of larvae to treatments. Initial responses were activity data from the first two observations (the first four min of a trial); overall responses were data from all five observations over ten minutes. The sum of the number of gridlines crossed across observations for a single larva was used as an indicator of activity level in analyses. For all experiments, we tested for differences in activity levels between the four treatment groups using a full generalized linear model (GLM) examining the effects of population, treatment, and their interaction. A GLM was selected to account for non-normality of the observations and potential heteroscedasticity. A Poisson distribution was applied when data appeared non-normal; otherwise a Gaussian distribution was used. Drop in deviance Chi-square tests were used to test the statistical significance of population, treatment, and their interaction. One-way ANOVAs and Welch modified two-sample t-tests were applied to population and treatment means to assess which populations or treatments were responsible for significant main effects indicated by the GLM. In Experiment II, the proportion of the overall 10 min time spent in each section was analyzed using a Contingency Table Analysis, with the Control treatment used as our baseline for comparison. Tank size and grid size varied among experiments, and the chemical cue concentrations in Experiment I may have differed from those in Experiment III. Hence, each experiment should be considered independently. Analyses were performed using S-Plus 8.0 statistical software (Insightful Corp.; <http://www.insightful.com>).

## RESULTS

In Experiment Ia, examining the responses of early-stage larvae to chemical cues, analyses of initial responses revealed no differences among treatments ( $df = 3$ ,  $P = 0.38$ ), but in analyses of overall responses, we found an interaction between population and treatment (Poisson distribution,  $df = 3$ ,  $P = 0.06$ ). Follow-up one-way ANOVAs indicated a difference at the treatment level ( $df = 3$ ,  $P = 0.05$ ; Fig. 4A) but not between the two populations ( $df = 1$ ,  $P = 0.38$ ). However, no significant differences between pairs of treatments were detected (*post hoc* Welch t-tests, 6 comparisons conducted,  $P > 0.17$ ).

In Experiment 1b, where we examined late-stage larvae responses to chemical cues, we found no differences among treatments initially ( $df = 3$ ,  $P = 0.80$ ) or overall ( $df = 3$ ,  $P = 0.47$ ). However, in *post hoc* analyses, when all treatment data



**Fig. 4.** Average number of gridlines crossed per treatment for each experiment testing the overall response of larvae of *Rana boylei* from Oregon, USA, to potential native predators (Rough-skinned Newts, *Taricha granulosa*), non-native predators (Smallmouth Bass, *Micropterus dolomieu*), and non-predatory native fish (Speckled Dace, *Rhinichthys osculus*). Larvae from locations with bass (BASS) and without bass (BASSLESS) were tested. (A) Experiment Ia: Detection via chemical cues by early-stage larvae. (B) Experiment Ib: Detection via chemical cues by late-stage larvae. (C) Experiment II: Detection via visual cues. (D) Experiment III: Detection via chemical/visual/mechanical cues. When exposed to all sensory cues, larvae reduced activity levels when exposed to *T. granulosa*.

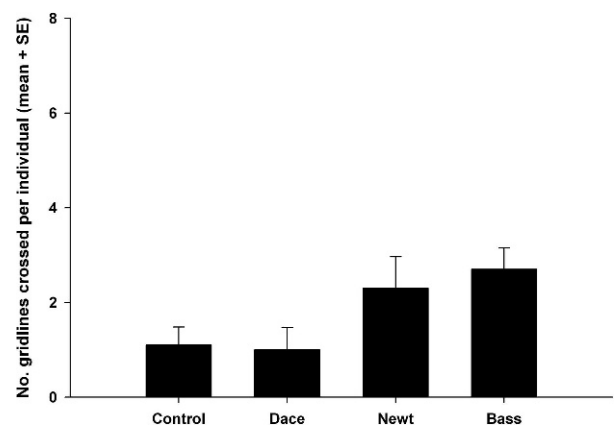
were combined, late-stage larvae from the BASSLESS population moved more often (Welch t-test,  $t = -2.52$ ,  $df = 70$ ,  $P = 0.01$ ), and traveled greater distances (Welch t-test,  $t = -2.53$ ,  $df = 70$ ,  $P = 0.01$ ), than individuals from the BASS population (Fig. 4B).

In Experiment II, examining visual cues, we found initial responses differed among treatments ( $df = 3$ ,  $P = 0.03$ ; Fig. 5). *Post hoc* t-tests revealed differences in number of gridlines crossed between larvae exposed to Bass (mean = 2.7) versus the Control (mean = 1.1;  $t = 2.73$ ,  $P = 0.01$ ), as well as Bass (mean = 2.7) versus Dace (mean = 1.0;  $t = 2.61$ ,  $P = 0.02$ ). In analyses of overall responses, we found no differences in activity levels among treatments ( $df = 3$ ,  $P = 0.14$ ; Fig. 4C). Compared to the Control treatment, larvae did not exhibit a preference in tank Section when visually exposed to the other three treatments ( $\chi^2_{0.05,2}$ ,  $P > 0.25$  for all tests).

In Experiment III, where we examined a combination of stimuli, we did not detect an initial response ( $df = 3$ ,  $P = 0.55$ ), but overall, we found that when larvae of *R. boylei* were exposed to *T. granulosa*, the native predator, larvae from both BASS and BASSLESS populations responded strongly by decreasing both the frequency of movements ( $F_{3,60} = 6.02$ ,  $P < 0.01$ ) and the average number of gridlines crossed ( $F_{3,60} = 7.77$ ,  $P < 0.01$ ; Fig. 4D). Larvae exposed to Control, Dace, and Bass cues responded similarly to one another, exhibiting higher activity levels relative to larvae exposed to *T. granulosa*. Throughout all trials, only two larvae were observed utilizing refuge; therefore data on refuge use were disregarded.

## DISCUSSION

We found no behavioral differences among treatments when larvae of *R. boylei* were exposed to chemical cues only (Experiments Ia and Ib). The overall activity level differences in Experiment Ia were influenced by larvae exposed to Bass



**Fig. 5.** Experiment II: Initial response in average number of gridlines crossed by late-stage (Stage 33–40; Gosner 1960) larvae of *Rana boylei* from Oregon, USA, to visual cues of potential native predators (Rough-skinned Newts, *Taricha granulosa*), non-native predators (Smallmouth Bass, *Micropterus dolomieu*), and non-predatory native fish (Speckled Dace, *Rhinichthys osculus*).

cues. However, our follow-up analyses revealed no significant relationship. In some systems, chemical cues alone are often sufficient for predator detection in amphibians (Petranka et al., 1987; Kiesecker et al., 1996). However, many of these studies focused on amphibian larvae from lentic environments (but see Sih and Kats, 1994; Jowers et al., 2006). The stream environment in which larvae of *R. boylei* live could moderate their reliance on chemical cues alone to detect potential threats.

Although tadpole activity levels did not differ at the treatment level in Experiment Ib, late-stage larvae from the BASSLESS population exhibited higher activity levels overall relative to late-stage larvae from the BASS population. Eggs from the BASSLESS population were collected from a higher elevation (707 m) compared with those from the BASS population (273 m), which likely results in a shorter larval period. Since larvae of *R. boylei* do not overwinter, increased activity levels may be necessary at higher elevations to acquire the resources necessary to speed development and metamorphose prior to the onset of cooler weather. These results may reveal population-level differences in life history and behavior that were previously unknown for the species.

In Experiment II, larvae exhibited an initial response to visual cues within the first few minutes of the experiment, but not an overall response. The initial response was reflected as increased activity of the Newt- and Bass-exposed larvae. This is not surprising given that both *M. dolomieu* and *T. granulosa* were occasionally observed behaving aggressively towards larvae (for example, *T. granulosa* and *M. dolomieu* followed larvae and lunged at them). Over the longer course of the observation period, this response dampened, suggesting that visual cues alone were not a sustained stimulus for antipredator behaviors. Our results agree with those of similar studies examining the role of visual cues for predator detection by amphibian larvae (Stauffer and Semlitsch, 1993; Kiesecker et al., 1996; Hickman et al., 2004).

Results of Experiment III, examining combined sensory cues, indicated that multiple cues may be necessary to elicit a sustained antipredator response in larvae of *R. boylei*. Larvae from both BASS and BASSLESS populations significantly reduced their overall activity levels when placed in the same tank as their native predator, *T. granulosa*. *Micropterus dolomieu* readily detect motion to capture prey (Sweka and Hartman, 2003), and we observed *M. dolomieu* lunging at larvae during several observations. However, those larvae placed in the same tank as *M. dolomieu* did not show any difference in activity levels relative to controls which supports our original prediction that larvae exposed to the cues of a non-native, unfamiliar predator would display activity levels similar to larvae exposed to control cues. Therefore, the failure to reduce activity levels to avoid detection in the presence of *M. dolomieu* could increase predation events on larvae of *R. boylei*.

It is unclear why larvae did not utilize refuge during trials. In the field we regularly witnessed larvae of *R. boylei* retreating between stones and under cobble upon our approach. We can only surmise that larvae avoided artificial refugia used in laboratory trials due to some quality of the material used or the tube-design of the refugia. In future studies, the use of natural cover objects could be tested.

The ability to adapt behaviorally to an unfamiliar predator is contingent upon a range of factors such as time spent in sympatry, experience, amount of predation pressure, and

the behavioral plasticity of the species. Our findings contribute to the growing body of work examining the responses of native amphibians to introduced predators. Analogous studies examining other native U.S. Pacific Northwest amphibians suggest that species differ greatly in their responses to predators. For instance, 10 of the 21 studies we reviewed (Paoletti, 2009) reported no response to the chemical cues of an introduced predator. Our results suggest that after approximately 40 years of coexistence (approx. 20 generations; Hayes et al., 2005), *R. boylei* lack the ability to respond to *M. dolomieu* as a threat. On the other hand, Kiesecker and Blaustein (1997), found that in approximately 30 generations (McAllister and Leonard, 2005), larvae of the Red-legged Frog (*Rana aurora*) developed the ability to detect and avoid non-native American Bullfrogs (*L. catesbeianus*), a potential predator. The behavioral responses witnessed in this study emphasize the difficulty in predicting how a naïve, native species might respond to an unfamiliar predator. In the brief 40 years the two species have coexisted, *M. dolomieu* may have not exerted selection pressure strong enough to modify behavioral patterns of *R. boylei*. Given the chance, *M. dolomieu* will readily consume larvae and adults of *R. boylei* (pers. obs.). However, we do not know whether *R. boylei* is the preferred prey or simply an opportunistic food source.

Several studies have shown that amphibian larvae respond to the chemical cues of injured conspecifics, or those chemicals emitted from predators that have consumed conspecifics (Laurila et al., 1997; Chivers and Mirza, 2001). Like many ranids, larvae of *R. boylei* are found in loose aggregations until metamorphosis (pers. obs.). It is possible that an individual cannot maintain the vigilance necessary to detect predators, and so rely on the alarm cues produced by one or a few group members to detect a predatory threat. Our study focused on the response of an individual tadpole to the cues of the treatment animal, without the aid of group effects or supplemental dietary cues produced by predators. In addition, our study monitored larval behavior in an artificially homogeneous habitat. The transmission and detection of chemical, visual, and mechanical cues may be altered by the physically heterogeneous habitat in which larvae are normally found. Therefore, the strength of the responses elicited by stimulus animals in the experiments reported herein should be considered highly conservative.

Our results indicate that *M. dolomieu* are capable of directly affecting populations of *R. boylei* in areas where they overlap. Removal of non-native fish has led to recovery of local amphibian populations in some areas (Hoffman et al., 2004; Vredenburg, 2004). Despite being recognized as an introduced species by Pacific Northwestern state agencies, *M. dolomieu* remains an actively managed sport fishery. Because of this and the difficulty involved with removal, eradication is not a feasible option. If larvae of *R. boylei* are unable to avoid predation by an unfamiliar predator, as our findings show, then local populations may disappear before they are able to adapt. It is therefore critical to understand the behavioral responses of native wildlife when faced with a novel predator. Developing the ability to predict these responses could aid fisheries managers when developing stocking plans to mitigate amphibian declines at the regional level.

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