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Habitat Assessment of a Newly Established Breeding Pond for the Population of Western Toads, Anaxyrus boreas, at the Bernard Field Station

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Habitat assessment of a newly established breeding pond for the population of Western toads, *Anaxyrus boreas,* at the Bernard Field Station

A Thesis Presented

by

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Table of Contents

Abstract

This study was the first research endeavor ever conducted concerning the population of Western toads, *Anaxyrus boreas*, at the Bernard Field Station. Despite the current lack of information regarding this population, they will become a concern in future years because they are threatened by habitat destruction. Preceding this study, a single breeding pond has been available to this population, which has been in use for the past 20 to 30 years. However, it is likely that the current breeding pond will be destroyed and the will be land developed for human use. In order to provide these toads with another breeding site, a new pond was constructed. Its suitability as an aquatic habitat was assessed on the basis of temperature, light intensity, algal growth and sediment levels in comparison to conditions at the old breeding pond. When tadpoles were raised in the laboratory in various water treatments, those reared in water from the new pond showed no decrease in survivorship or growth rate. The only significant difference in growth was between laboratory-raised and field animals. Tadpoles living in the field were both smaller in length during the larval period as well as smaller in mass at metamorphosis. Additionally, 75% of the tadpoles translocated to the new site completed full metamorphosis. Therefore, the new pond is both hospitable and conducive to tadpole development, a positive sign for future conservation efforts.

Introduction

Study Species

The Western toad, *Anaxyrus boreas,* is only one of three amphibian species that has been discovered and identified at the Bernard Field Station (BFS), the site where this research was conducted. This species of toad has never been closely monitored or studied at the field station, thus virtually nothing is known about the adult population size (including number of reproductively active females), the population trends over recent years, or dispersal behavior. This thesis research project marks the first serious effort to learn about this species during its breeding season. Previously, the only human intervention with regard to the toads' lifecycles has been to regularly supplement the water level of the temporary pond which has existed as a breeding site for 20 to 30 years.

Also known as the California toad, *A. boreas* (formerly *Bufo boreas,* Crother *et al.* 2008), inhabits the Pacific Coast of North America from Southern Alaska to Baja, California, and as far east as the Rocky Mountains. These toads are primarily found in desert springs, meadows, woodlands, mountain wetlands, and around ponds, lakes and slow-moving rivers. They are both terrestrial and freshwater species as adults, and dig burrows in loose soil (or inhabit burrows built by other small creatures) or shelter under rocks and logs, but must spawn eggs in shallow bodies of water (IUCN website). Whereas they prefer damp areas, they can travel far from water, especially after breeding. Adult toads were only spotted once during the duration of the experiment, primarily because they do not need to incubate or guard their eggs and secondly because they are active most often at night. When not breeding and foraging, Western toads hibernate for a few months during the winter but remain active from January through October. Adults are typically between 5.5 and 13 centimeters long with a cream colored dorsal stripe. They lack cranial crests and have dusky yellowish, tan, gray and greenish coloring with dark wart blotches that can be tinged with rust coloration. Males are smaller than females and have smoother skin (USGS website). In the wild, adult toads have a relatively long life-span and can live for up to 10 years. They are skilled hunters eating primarily insects and arthropods and defend themselves from predators by camouflage and secreting toxins from the glands on their bodies (SacZoo website).

The breeding season of the Western toad can extend from January through July depending on local temperature and rainfall conditions. Females lay eggs in shallow temporary ponds, lakes or pools of slow-moving rivers. Breeding is synchronous and each female can lay up to a maximum of 16,500 eggs, but typically lay an average of 12,000 eggs. The eggs are laid in continuous strands that are usually caught in vegetation and tangled together as the female moves throughout the pond while laying her eggs (Morey 1988). Offspring survival is low—as few as 1% of all the tadpoles laid survive to adulthood (SacZoo website). To mate, males grasp females from behind and fertilize her eggs as she lays them. Approximately 14 to 17 days after the eggs are laid, tadpoles emerge. They tend to concentrate in dense schools at the warmest, shallowest edges of the water.

Reproductive success is difficult to determine in female toads. Depending on the altitude of her habitat, female Western toads may not breed annually but may breed every 2-3 years instead (Bull 2008). In mountainous, forested terrain in Northeastern Oregon, it was hypothesized that most females laid clutches every few years because annual breeding was too costly and it took several summers to accumulate required nutrients. One theory is that this breeding strategy may lead to greater reproductive success because each clutch is larger than the size of a clutch laid by an annually breeding female, and can benefit from increased resources accumulated by the female. On the other hand, breeding is uncertain for toads from year to year as breeding sites can be erratic and highly affected by seasonal climate and temperature changes. Additionally, tadpoles and eggs are subjected to predation and desiccation. Therefore, annual breeding despite clutches likely being smaller in size may lead to greater reproductive success just because they are laid more frequently (Bull 2008). Because nothing is known about the number of females residing at the BFS, it cannot be predicted how often they breed. Although, if frequency of breeding is dependent primarily on elevation as Bull suggests, it may be possible to assume that this group of females breeds annually.

Known predators of Western toad tadpoles are garter snakes, *Thamnophis sirtalis*, the backswimmer, *Notonecta* spp., and the giant waterbug, *Lethocerus americanus.* Only one of these species, the backswimmer, is found at the BFS and has been noted to reside in pHake Lake, but not the vernal pools (BFS website). Other potential predators can include fish and birds but often these organisms find the tadpoles unpalatable because of chemicals within tadpoles' skin (Kiesecker *et al.* 1996). The existing breeding pond (and it was later noted the newly constructed pond as well), contains numerous species of crustaceans, notably daphnia, *Daphnia magna,* and fairy shrimp, *Branchinecta lindahl.* Overall, the tadpoles seem to inhabit a relatively safe area in terms of predation threat, a benefit of breeding in temporary ponds.

Once tadpoles complete metamorphosis, they inhabit terrestrial landscapes and disperse from the bond. Metamorphosis in anuran species involves radical changes in morphology and ecology between the life stages. They begin as aquatic herbivorous larvae that breathe via gills and morph to become terrestrial carnivorous juveniles that use lungs to breathe and feed primarily on insects (Alford and Harris 1988). This change is represented by the development of hind-legs followed by fore-legs as tadpoles grow in body length and overall size. Once tadpoles have developed all four legs, their tail gets progressively shorter until it is lost altogether.

Little information is known about the biology of these newly metamorphosed and juvenile toads in part because they are so small and adept at camouflage which makes tracking them with tags or by visual sighting very challenging. Nor is it known how far they typically disperse from breeding sights and the mortality risks they face during dispersal. In a study conducted in the Rocky Mountains of Northeastern Oregon, researchers found that juvenile (1 year old) toads dispersed up to 2,700 m away from their original breeding site and to areas always associated with water (Bull 2009). Mortality after dispersal was primarily due to disease, desiccation, predation, vehicles, and trampling. Dispersal is highly variable dependent upon the region and availability of water, a requirement for juveniles who are still highly susceptible to desiccation at this point in their lifecycle. Toadlets, newly metamorphosed toads, were also found to be highly vulnerable for many of the same reasons as juvenile toads: they died in large numbers due to desiccation in dry streambeds, predation and disease but also because of high density competition within the vicinity of the breeding ponds. It was suggested by the authors that 95-99% of the toadlets in their study population died (Bull 2009). The habitat at the BFS is protected and though it is used by many community members and students for the purpose of scientific research, it is mostly vehicle traffic-free within the fence enclosure. However, water resources are limited which likely restricts the dispersal of the toadlets and juveniles from their breeding site.

Study Site

The Bernard Field Station is a protected natural habitat of approximately 75 acres north of the Claremont Colleges. It has been used as an academic resource since its creation in 1976. The land is primarily coastal sage scrub, grassland, live oak forest, and Riversidian alluvial fan scrub and contains an artificial lake (pHake Lake), as well as vernal pools (BFS website). The climate can be described as Mediterranean: sunny, warm and relatively dry with 90% of the annual rainfall occurring within the winter through the early spring months.

In the fall of 2009, a site for building a new breeding pond for the Western toad was established. Building of this new pond occurred over the winter months and was completed in January of 2010. The creation of this new pond was necessitated by a threat to the toad's only other breeding site on the Bernard Field Station. The original breeding pond is situated on a portion of land in the western-most part of the field station on a tract of 11 acres of land that was purchased by Harvey Mudd College in 2008. This temporary pond which is filled by rainfall and supplemented by manual filling with a tap water hose during the breeding season, eventually evaporates and is dry for the rest of the year. This pond is the only pond located within the Field Station and has been an available breeding site for a small population of toads for the past 20 to 30 years. The plan of action for this land is hotly debated and is still unknown but the pond will likely be destroyed and the land will be developed for human use in the near future.

A Need for Conservation

This study was designed to learn more about the Western toads at the BFS with the hope of establishing a new breeding site that will be available to them once the old site is gone. Western toads are identified on the IUCN Red List of Endangered Species as a "near threatened" species because they are in significant decline. In general, amphibian species are in serious decline across the globe. Of the 6000 species of amphibians, 32% are threatened in contrast to 12% of bird and 23% of mammal species. This percentage of endangered amphibians world-wide constitutes the largest proportion of an entire class of animals that is on the brink of extinction (Gascon *et al.* 2007). Thus specialists from around the world gathered at the Amphibian Conservation Summit in Washington D.C. in September 2005 to address this issue. They created the Amphibian Conservation Action Plan, a novel inter-disciplinary approach to the question of species decline, presenting information about the diverse causes of decline and what measures must be taken to slow and reverse the losses. A declaration released after the summit strongly insists upon four urgent interventions that are critical to the conservation of amphibians: a need to expand understanding of the causes of decline, continued documentation of amphibian diversity and how it is changing, the development and implementation of long-term conservation programs, and immediate response to future emergencies and crises.

Biologists are particularly concerned about amphibian populations because of their unprecedented large-scale decline, due in part to their physiology which makes them vulnerable to environmental changes and risks. The skin of amphibians is exposed and permeable, their eggs are delicate and unprotected and thus able to absorb toxins in the environment, as ectotherms they are easily affected by temperature differences, and their life-cycle which is both terrestrial and aquatic makes them vulnerable to changes in both types of habitats. The causes of this general trend of population decline are often very difficult to pin-point on a case by case basis when studying threatened populations; in some cases, entire species have disappeared without apparent reason, never to be found again (Gascon *et al.* 2007). Among varying regions and populations, amphibians may be exposed to a number of hazardous factors including habitat destruction, diseases, heightened exposure to UVB radiation, and chemical pollution (Bancroft and Blaustein 2007). In several species, including California Treefrogs and European common toads, hatching success is decreased when eggs are exposed to UVB-light than when shielded. For other species, heightened UVB exposure can cause developmental delays and stunt growth. Disease, another primary threat to anuran populations, is easily transmitted when species including the Western toad breed synchronously and remain in dense communities throughout metamorphosis. One such deadly and mysterious pathogen is Chytridiomycosis. Little is known about this disease including how animals become infected and how it is spread, except that it has the ability to destroy entire populations in the wild even causing extinction in some species (Gascon *et al.* 2007). Global climate change is closely related to UVB exposure and disease outbreak—as temperatures increase and water levels decline, eggs are exposed to more harmful rays and are also more susceptible to disease (Bancroft and Blaustein 2007). As is the case at the Bernard Field Station, 90% of threatened amphibian species are impacted by habitat loss and degradation (Gascon *et al.* 2007).

To mitigate the problem of habitat destruction, animal relocations are an important option available to conservation biologists. By definition, they are the intentional movement by humans of a population of animals from one location to another. Types of relocations include introducing species to an altogether new habitat, re-introducing species to an historical habitat site from which they have previously become extinct, translocations that involve moving animals from one part of their range to another area within the same range and supplementations by which individuals are added to an existing population to bolster it (Fisher and Lindenmayer 2001). Translocation is a popular conservation technique that has been used in the past, with varying levels of success. It is difficult to determine what constitutes a successful translocation and it is relatively unknown how many animals must be moved and for how many years in order to establish a viable new population at a new location (this also is variable among different species). In the past, translocations of some amphibians have been successful whereas for other species, particularly endangered toad populations, translocations have done nothing to boost their bleak population outlook (Dodd and Seigel 1991). The purpose of this research was not to determine if translocation could be an effective tool for conservation of the toad population at the Bernard Field Station, as there is not enough information known about the existing population of toads, nor is there the capability to follow this project over the course of several years. It is however, the first tangible study conducted on the toads and attempts to determine the ability of the tadpoles to survive in varying aquatic environments. Among the three experimental water treatments in which tadpoles were raised within the laboratory setting, body length, time to reach metamorphosis and survival rates were compared across treatments as well as against the animals in their natural habitat in the field. A small subset of the field population was relocated to the newly constructed breeding pond and survivorship of these animals was estimated. Conservation is the ideological driving force behind this study, but the goal was merely to establish preliminary information about the Western toad species and the habitat sites available to them at the Bernard Field Station.

Materials and Methods

Habitat Locations and Field Measurements

Field work was conducted at two study sites within the Bernard Field Station. Both sites are ephemeral ponds and are henceforth referred to as “old” and “new” ponds. The old pond, located west of pHake Lake, has existed as a seasonal breeding pond for the Western toad for 20 to 30 years. At its deepest point, the water is approximately 30 centimeters deep and at maximum water level, the pond’s circumference is approximately 36 meters around although this is highly variable. The pond is surrounded by grass, bushes, and leaf-debris vegetation, offering fairly dense shelter and coverage for newly metamorphosed toads. During the breeding season, the water level is primarily derived from rainfall and supplemented by manual filling with a hose. By contrast the new pond was constructed on a rise to the south of pHake Lake. It is a much more exposed area and is surrounded by rocks and sparse, low-lying vegetation. In order to build this pond, the area was excavated by work crews with bobcat machinery to remove all shrubbery and rocks from the area. A 14 x 18 m thick rubber liner was placed along the floor of the pond, which is surrounded by a natural sloping lip and is approximately 46 centimeters deep at the center deepest point. A berme was constructed and fortified with boulders to divide the pond into two unequally sized and completely distinct halves. Finally, the liner was covered with a topsoil layer of 15 centimeters of soil and decomposed granite, and rainfall was responsible for filling the pond with water. The final part of construction which was later added to the new pond was a low-lying temporary wall built to completely enclose the smaller half of the pond. The wall was intended to temporarily trap metamorphosed toads in order to estimate survivorship. It was built by placing cinder blocks approximately 30 centimeters apart, and then they were covered with heavy duty plastic sheeting. Gravel and rocks were poured on either side of the plastic-covered cinderblock wall to ensure the plastic would not be lifted by wind. The wall was placed 0.5-1 meter from the edge of the water to provide the metamorphs shelter on land including rocks and untreated wooden boards as they transition to being primarily terrestrial animals.

Soil composition of the two ponds is very different. The old pond has a much firmer soil foundation which originally was heavy clay-based soil and was deposited from a construction site. Therefore is not like the natural alluvial-soil present at the BFS. Because this pond is so shallow in parts and there is no lining to prevent water from draining away, it shrinks considerably when temperatures are high. The new pond was formerly a vernal pool therefore its soil base is a combination of hard-pan clay mixed with alluvial soil. After the completion of construction in January 2010, sediment particles remained suspended in the water for much longer than anticipated. Thus, the pond was murky, and sediment only finally settled on the larger half of the pond in the middle of March, 2010, just weeks before the study was concluded. The smaller side of the new pond remained opaque, whereas the old pond was consistently clear and transparent. Additionally, the liner and natural slope surrounding the new pond prevent most water from draining away, maintaining a more stable water level than in the old pond. In order to attempt to quantify some of the ecological differences at the two study sites, temperatures, light intensity, algal growth and sediment levels were measured. All statistical analyses were performed using Statview, version 4.5 and SuperANOVA, version 1.11.

Air and water temperatures were measured with a Fisher Scientific dual channel thermometer every 2-6 days at the shallowest and deepest points in each pond. The temperatures at each site were averaged across four categories: old shallow, new shallow, old deep, and new deep. Average temperatures at each of these four sites were tested for independent correlations with time, as measured in Julian Days, and with average air temperatures. A 2-way ANOVA was performed in order to test for the effects of the independent factors pond (old and new) and depth (shallow and deep) and the interaction between pond and depth, on the dependent variable, water temperature.

To determine whether or not there was a significant difference in amounts of suspended matter present in the two ponds, water samples were collected from each site. A filtration system was set up and 4,000 mL of water sample was filtered through Whatman 27 cm filter paper. Prior to filtration, the filter paper was dried in an oven, weighed and then re-dried and re-weighed after the water samples had been filtered, allowing the filter paper to catch all sediment. Filtrations for each water treatment were repeated a total of ten times and mass differences calculated between initial and final masses of the filter paper. An unpaired t-test was performed to analyze an effect of water source on the mass differences of the filter papers.

Light intensity was the third measurement taken in order to compare differences in habitat between the two ponds. Light intensity was measured with a Smart Luxmeter (range of 0 to 50,000 Lux) at the shallowest (approximately 3.5-4 cm in each pond) and deepest (approximately 14.5 cm in the old pond and 31.5 cm in the new pond) depths at each site, once a week for 6 weeks. Because the light intensities were highly dependent on time of day and weather conditions, the data was presented in graphical form showing changes over time (as measured in Julian Days) according to pond and depth level.

We also attempted to quantify algal growth at each site. Twelve cube-shaped cages with 8 cm x 8 cm plexi-glass plate bases and fine mesh siding (to prevent tadpoles from eating the algae) were constructed. Six were deployed at each pond in both shallow and deep areas and left undisturbed for weeks. Unfortunately, the majority of replicates in the old pond were destroyed by being crushed (possibly by coyotes) and so it was not possible to quantify the relative amounts of algae present on the plates. Of the replicates that survived, there was clearly a visible difference between the old and new sites; old plates were covered in green growth and new plates were largely filled with silt.

Tadpole Care in the Laboratory

Following winter rains, the old pond was monitored daily for signs of egg strands. The first egg strands were seen on Tuesday, January 26, 2010. On Saturday, January 30th, the last new egg strands were discovered; during this period of 5 days, the toads only skipped 1 night of spawning. Female Western toads lay thousands of eggs in strands that are tangled within vegetation in the pond and are amassed on top of each other. Unfortunately, it was impossible to determine the number of breeding females and how many total egg strands were laid. The strands are long (spanning a distances of 2 meters or more around the edges of the pond) and delicate with the eggs encased in slippery gelatin-like transparent strands. On each day when new clusters of eggs were spotted, they were carefully lifted, de-tangled and condensed to a smaller area. Cages of sturdy plastic mesh were constructed and placed over the top of the eggs in order to easily track the developmental progress of strands within each cage, as well as to protect the eggs from damage. There were three primary cages, each containing thousands of eggs and one smaller cage containing only about 100 eggs that never developed or matured normally. Each day, the egg strands were photographed to visually monitor physical changes in egg shape. After approximately a week's time, the strands began to disintegrate and shred as eggs elongated in shape. Two weeks after strands were laid, initial tadpole movement was seen with the majority of eggs hatching as tadpoles by week three. Once the majority of eggs had become tadpoles, the cage coverings were removed.

Three weeks after eggs were laid in the pond, tadpoles were collected to bring back to be raised in the laboratory setting. Within the laboratory, 10 tadpoles were placed into each of 36 plastic shoeboxes. Animals were raised in three different water treatment conditions, water from the old pond, water from the new pond and dechloraminated tap water, with twelve replications per treatment. Treatment boxes were randomly arranged side-by-side across two bench tops and filled with equal volumes of water. They were exposed to a 12:12 h light:dark photoperiod at approximately 22-23 ^{o}C. Temperatures within the individual boxes remained relatively constant ranging from 21 ^{o}C to 22.5 ^{o}C. The tadpoles were raised for a total of 8 weeks from February 13th until their final release to the wild on April 8th, 2010. They were fed twice-daily on an as-needed basis with boiled organic lettuce. Their water was changed every 2 days and replaced with a fresh supply. Each day, tadpoles were counted and deaths documented. Dead tadpoles were immediately removed from the boxes. It was noted in 4.2% of boxes with new pond water, 0.83% of boxes with old pond water and 7.5% of boxes with tap water that cannibalism had occurred. Several tadpoles were also noted to have edemas, or swelled bodies. These tadpoles typically died in earlier stages of growth and this affected 17.5% of animals raised in new water, 13.3% of those raised in old water, and 19.2% of animals from tap boxes. After 3 weeks of development, all tadpoles were noted to have developing hind legs. Fore-legs were first seen after 4 weeks. Once tadpoles had developed all four legs, they were removed from their boxes and placed into larger tanks of new pond water, old pond water and tap water. The tanks provided the animals with both water to swim in and an elevated portion covered only in moist paper towels. They were given access to lettuce and fruit flies as a food source. The number of tadpoles with four legs was carefully noted and tracked. Once the tadpoles completely lost their tails, they were weighed before being released back into the field. The majority of metamorphosed animals were released at the new pond where untreated wooden boards were placed around the edges near to the water so as to provide them with increased shelter.

Measuring Tadpole Growth and Survivorship

Tadpole survivorship was tracked in the field in addition to within the laboratory treatments. Approximately 400 tadpoles were transferred from the old pond to the small, enclosed side of the new pond. This translocation occurred only after raising tadpoles in the new pond water in the laboratory for a number of weeks so as to be certain that the water would neither hinder their growth nor kill them. As of the last day of this study (April 18th, 2010), 300 of 400 originally released tadpoles or 75% had metamorphosed (it is highly likely that more metamorphs would have been found even after this date). Unfortunately it is not known how many of the original 400 animals survived, as the pond was very opaque and the tadpoles swam too fast and were too elusive for all to have been recaptured and counted.

The tadpoles raised in the laboratory were photographed over the course of 4 weeks every 7-10 days to monitor the growth of their body lengths. Six boxes were randomly chosen to be photographed per water treatment. Each week, all the animals in the selected boxes were placed in petri dishes atop 1 mm x 1 mm graphing paper and photographed on a light table. The body lengths of the animals were then measured and mean body lengths were calculated per shoebox as well as per overall water treatment. Because some of the boxes experienced total mortality, replacement boxes were substituted in later weeks. Samples of 100 tadpoles were also collected from the old pond in order to photograph and measure body length to compare to the growth of the laboratory-raised tadpoles. In the last 2 weeks of photographing, once tadpoles had been transferred to the new pond, they were also sampled and measured. The last week of photographing on April 2nd was only to compare body lengths of tadpoles from the new and old ponds as most of the tadpoles from the laboratory had already undergone metamorphosis. Tadpoles caught with four legs were excluded from the measurements of body length as their body sizes decrease because their tails progressively shorten. By this final week of measuring body lengths, 51% of the captured tadpoles from the old pond had four legs and 24% had four legs from the new pond sample. Whereas tadpoles with four legs are easier to catch because they swim more slowly and closer to the surface, the percentage of animals with four legs in our random samples may be a good estimate of the number of four-legged animals actually present in the field.

To analyze the growth in body lengths of tadpoles raised in the laboratory and tadpoles living in the field over the course of 5 weeks, a series of ANOVA tests were performed. One-way ANOVAs tested for the effect of water treatment on body length for each of the 5 weeks. Where significant effect of treatment was found, Tukey-Kramer HSD post-hoc tests were run to determine between which specific treatments there were significant differences in body lengths. In order to compare the body lengths of the laboratory-raised tadpoles with the body lengths of the tadpoles from the field sites, an unpaired t-test was used to analyze the data from the first week because the laboratory-raised tadpoles could be pooled into one category, laboratory treatment versus field. For weeks two, three and four, Tukey-Kramer HSD post-hocs were needed to calculate significant differences between the three laboratory treatments and the field. In the fourth week, tadpoles in the field treatment were collected from the new pond in addition to the old pond to be measured. Post-hoc tests distinguished significant differences among both laboratory treatments and field treatments for this week.

Before metamorphs were released to the field, they were weighed so as to test for an effect of water treatment on body mass at metamorphosis. A one-way ANOVA was performed to compare the body masses of metamorphs from old pond, new pond and tap water treatments. Additionally, once metamorphosed animals had been spotted at the new pond, they were captured every other day for a week, and brought back to the lab to be weighed. The body masses of the captured metamorphs from the field were compared to the masses of the released laboratory-raised metamorphs using an independent samples t-test (because no significant difference was found between body masses at metamorphosis between laboratory water treatments, the metamorphs were then pooled as one inclusive category of laboratory-raised animals for this analysis).

At the end of the experimental research time, all remaining animals were released to the new pond. Mortality of the tadpoles in each shoebox was carefully documented daily throughout 8 weeks of raising the tadpoles in the laboratory. The percentages of surviving animals were calculated per water treatment type each week on a cumulative basis over all the weeks. A 2-way ANOVA was performed to test for significant effects of time and treatment type as well as an interaction between these two independent variables on the percentage of surviving tadpoles at the end of every week. Once the animals had developed four legs (first noted on March 15th, 2010) the number of tadpoles developing four legs was noted everyday for 25 total days until the end of the experiment. The percentage of animals with four legs was calculated for each box in all three treatments after every day. A 2-way ANOVA was again used to test for a significant effect of time, treatment type and an interaction between these two factors on the daily percentage of animals developing four legs within new pond, old pond and tap water treatments. By the time the laboratory-raised animals were released, 41.7% of tadpoles raised in new pond water, 14.2% of tadpoles raised in old pond water and 35.8% of tadpoles raised in tap water had reached full metamorphosis. Remaining tadpoles that were released had both four legs and full tails, or had yet to develop four legs.

Results

Field Data:

Sediment Levels at New and Old Pond Sites

The amount of suspended matter filtered from water samples from the new pond was over twice as much as from water collected from the old pond (t= 3.753, df= 18. P= 0.0015; Figure 1).

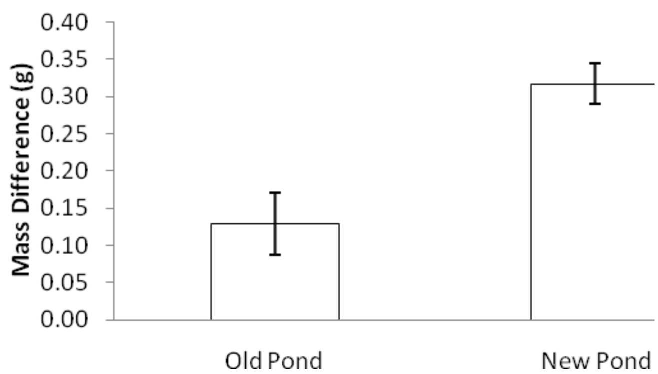

Figure 1. Mean (± SE) mass differences (g) of filtered water samples taken from the old and new ponds (N = 10 for each pond).

Temperature Analyses

There were significant relationships between mean water temperatures and Julian Days at all four sample sites: old shallow, new shallow, old deep and new deep (Figures 2 and 3). Temperatures at old deep showed a strong positive correlation with Julian Days (r= 0.587, P= 0.001) as did temperatures at old shallow, new shallow and new deep (r= 0.700, P<0.0001; r= 0.698, P<0.0001; r= 0.680, P<0.0001 respectively).

There was no significant effect of pond (old and new), nor of depth (shallow and deep) on water temperature (F= 0.323, df= 1, 107, P= 0.5711 and F= 1.939, df= 1, 107, P= 0.1666 respectively). Additionally there was no significant interaction effect of pond and depth on mean water temperatures (F= 0.009, df= 1, 107, P= 0.9229).

Mean air temperatures and water temperatures measured at old shallow, old deep, new shallow and new deep each showed highly significant correlations (r= 0.782, P<0.0001; r= 0.740, P<0.0001; r= 0.722, P<0.0001; r= 0.705, P<0.0001 respectively; Figures 4 and 5).

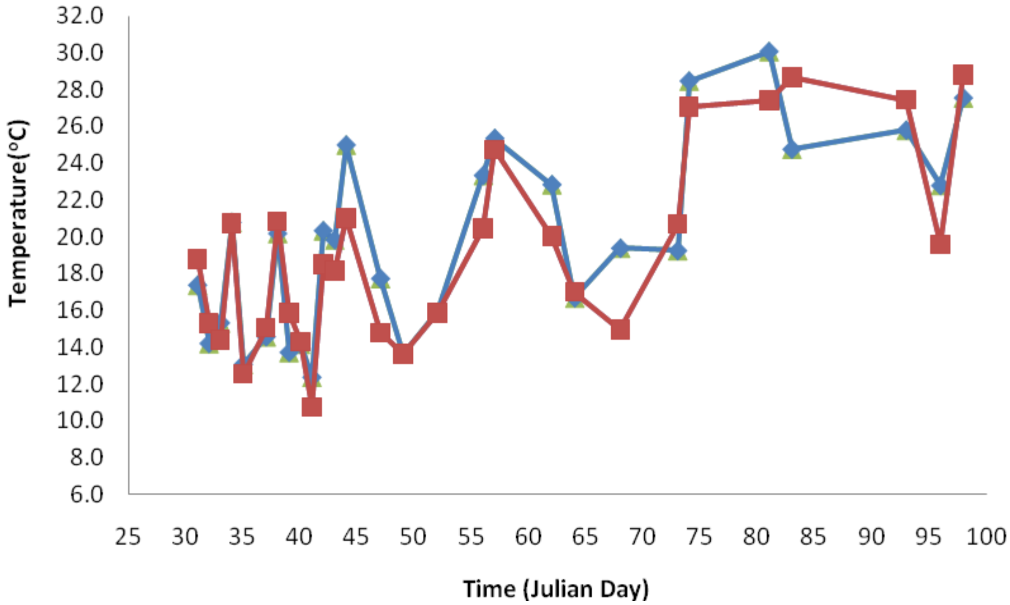

Figure 2. Mean water temperatures (^{o}C) at **old** and **new** pond shallow depths with respect to Julian Days (N = 28 days).

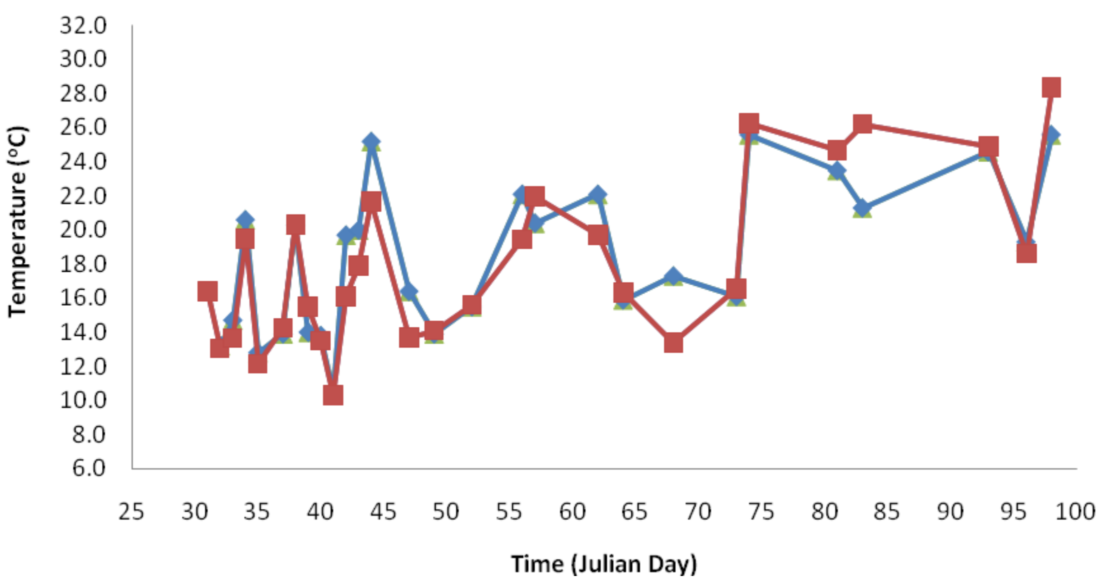

Figure 3. Mean water temperatures (^{o}C) at **old** and **new** pond deep depths with respect to Julian Days (N = 28 days).

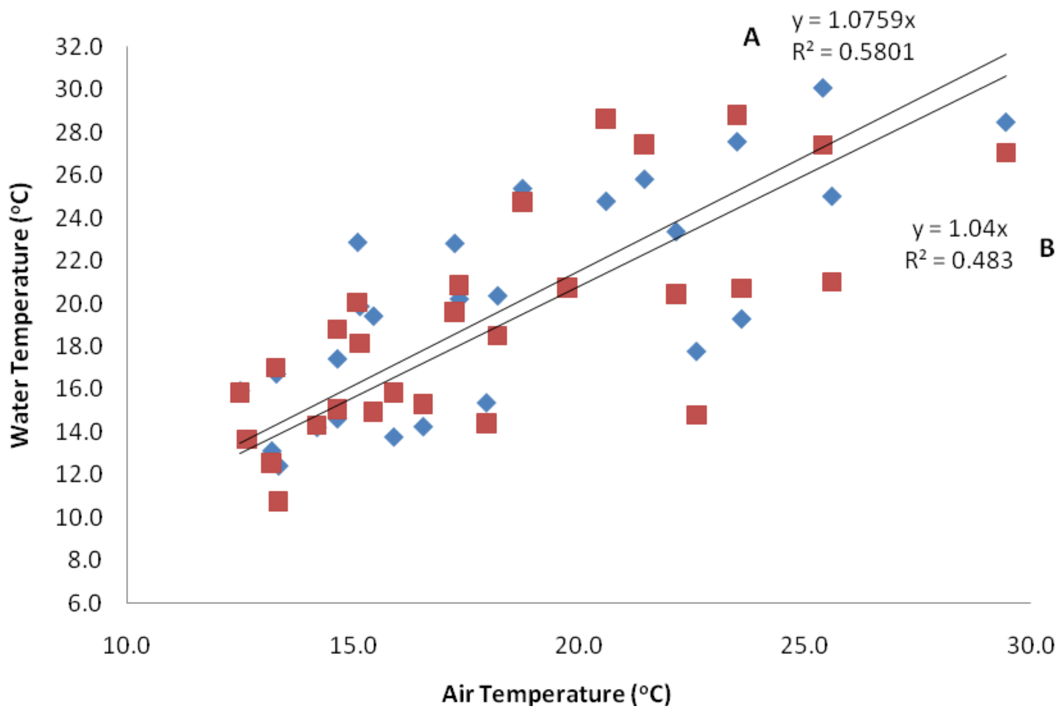

Figure 4. Correlations of mean air temperatures (°C) with mean shallow water temperatures (°C) at old and new ponds. Different letters denote the linear fit lines of both old (A, r^2= 0.580) and new (B, r^2= 0.483) sites.

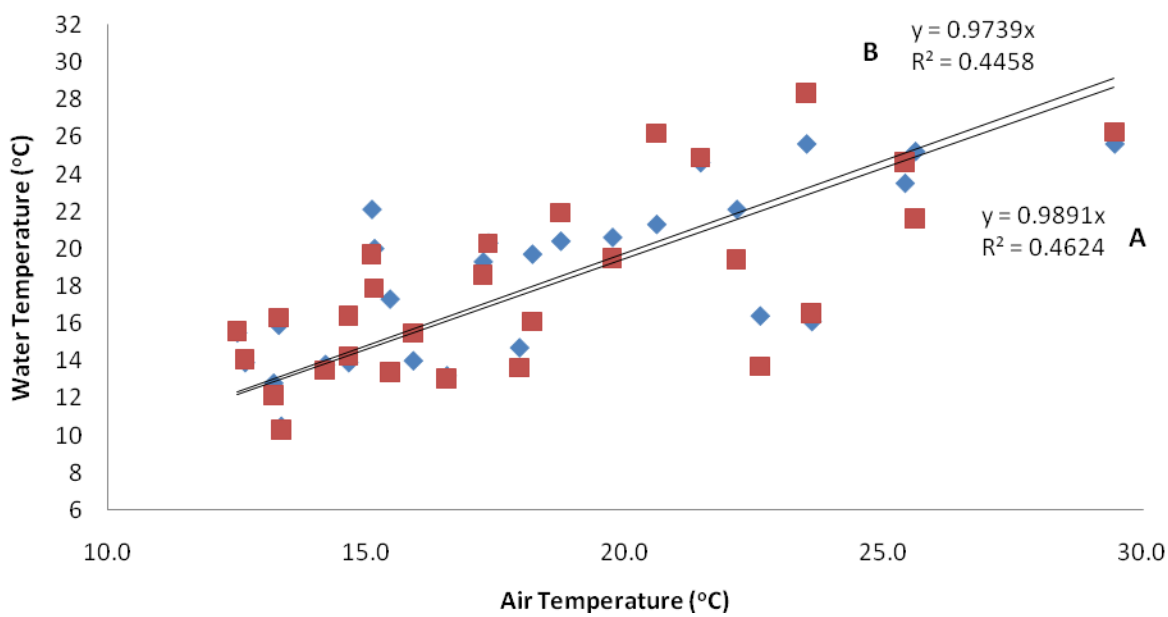

Figure 5. Correlations of mean air temperatures (°C) with mean deep water temperatures (°C) at old and new ponds. Different letters denote the linear fit lines of both old (A, r^2= 0.462) and new (B, r^2= 0.446) sites.

Light Intensity Differences

Light intensity measurements were taken at each pond at both shallow and deep water depths. The changes in light intensity at each site are graphically represented over time (Figure 6).

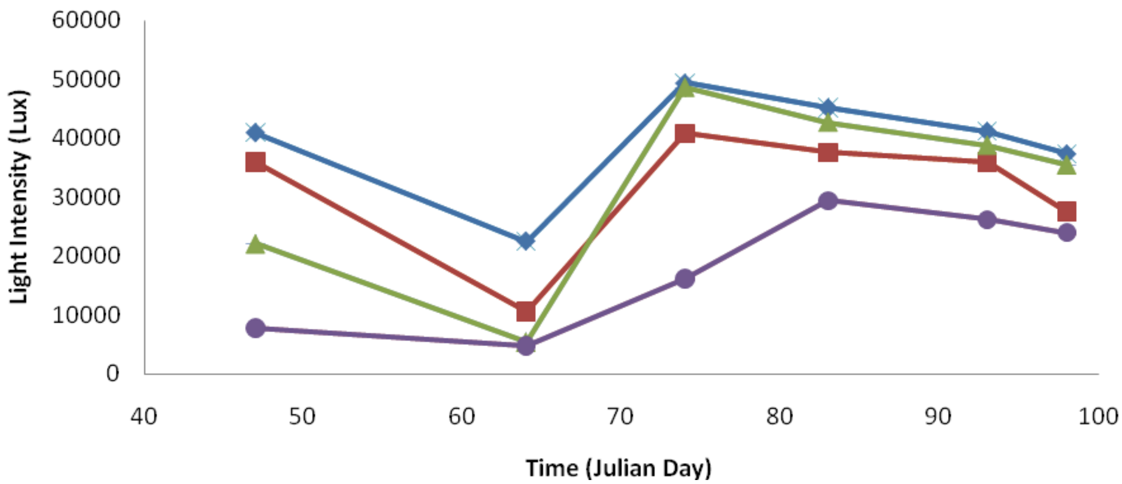

Figure 6. Light intensities (Lux) at depths of: **old shallow**, **new shallow**, **old deep** and **new deep** with respect to Julian Days (N = 6 days).

Animal Data:

Body Length Comparisons of Tadpoles

Each week for a total of 5 weeks, tadpoles were photographed to compare body length measurements between water treatments within the laboratory. During the first week, there was no significant difference in the mean body lengths of tadpoles between the three treatments ($F= 1.407$, $df= 2, 15$, $P= 0.2755$; Figure 7).

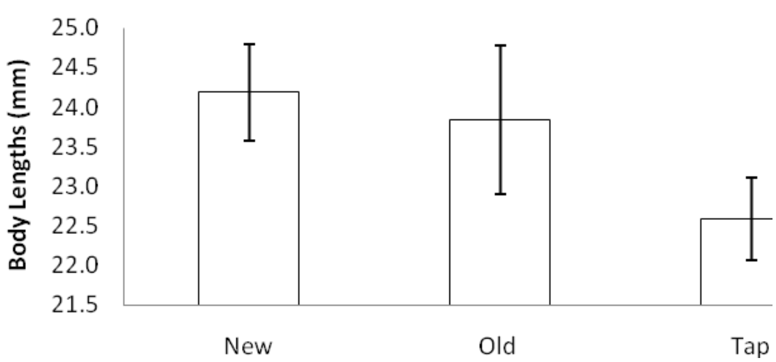

Figure 7. Mean (± SE) body length measurements (mm) of tadpoles according to water treatment after week one (New N = 47, Old N = 56, Tap N = 46).

After the second week, the overall differences in body lengths of laboratory-raised animals were significantly different according to water treatment type (F= 16.284, df= 2, 17, P= 0.0001). Tadpoles in the new treatment boxes had significantly longer bodies than those in both old and tap treatments and tadpoles raised in old pond water had significantly smaller bodies than tadpoles raised in tap water (Tukey-Kramer HSD, P<0.05; Figure 8).

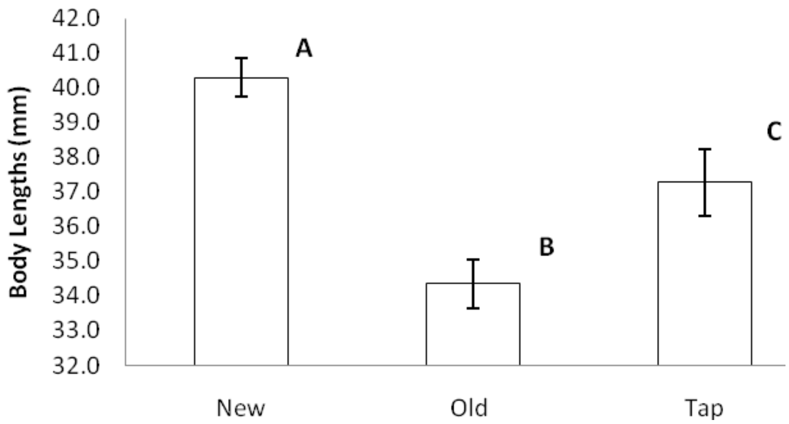

Figure 8. Mean (± SE) body length measurements (mm) of tadpoles according to water treatment type after week two (New N = 45, Old N = 55, Tap N = 46). Different letters denote significant differences based on Tukey-Kramer HSD post-hoc analyses (P<0.05).

By the third week, there was also a significant difference in body lengths of animals raised in the different laboratory water treatments (F= 5.274, df= 2, 16, P= 0.0174). Tadpoles raised in the old and new treatments showed a significant difference in body lengths, with animals in old pond water being smaller (Tukey-Kramer HSD, P<0.05). Animals raised in the tap water treatment were not significantly different in size than those raised in either new or old pond water (Figure 9).

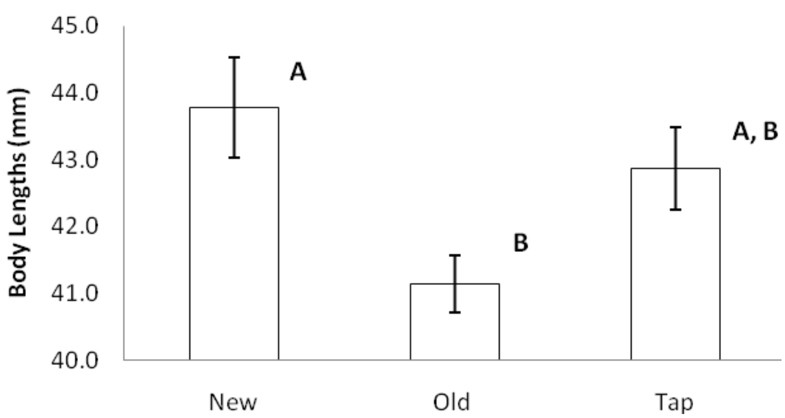

Figure 9. Mean (± SE) body length measurements (mm) of tadpoles according to water treatment after week three (New N = 46, Old N = 48, Tap N = 46). Different letters denote significant differences based on Tukey-Kramer HSD post-hoc analyses (P<0.05).

During the fourth week of comparing body length measurements, tadpoles were not significantly different in size between the new, old and tap water treatments (F= 1.824, df= 2, 15, P= 0.1955; Figure 10).

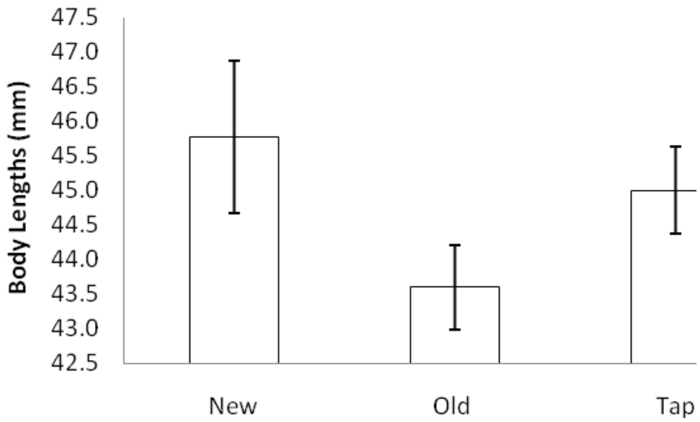

Figure 10. Mean (± SE) body length measurements (mm) of tadpoles according to water treatment type after week four (New N = 33, Old N = 42, Tap N = 31).

The fifth week of body length comparisons was calculated only between field tadpoles from both the old and new ponds as most of the laboratory-raised animals had already reached metamorphosis. This body length comparison excludes animals that were caught with four legs. Tadpoles from the old pond were not significantly different in body length from tadpoles collected from the new pond (F= 2.450, df=1, 116, P= 0.1202; Figure 11).

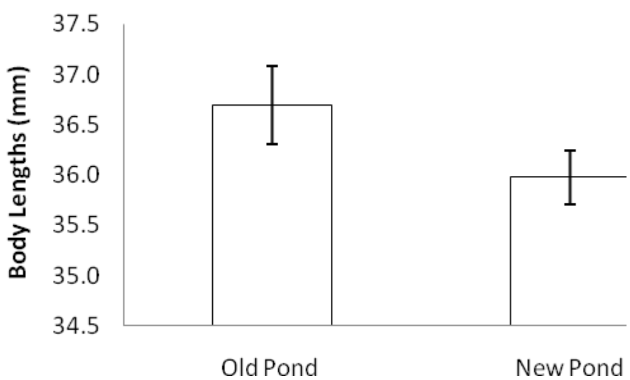

Figure 11. Mean (± SE) body length measurements (mm) of tadpoles captured from the old and new ponds after week five (Old Pond N = 48, New Pond N = 69).

In addition to comparing the body lengths of the laboratory-raised tadpoles within their respective treatments each week, the body lengths of the tadpoles collected from the field were also compared to the laboratory-raised animals every week during these same 4 weeks. The first week of measurements showed that tadpoles raised in the laboratory had significantly longer bodies than animals living in the old pond (t= -20.05, df= 119, P<0.0001; Figure 12).

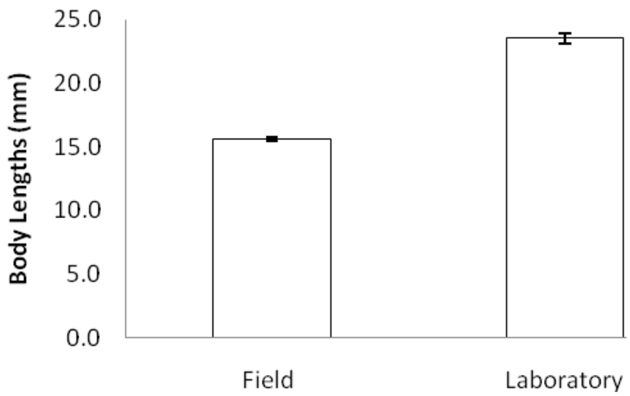

Figure 12. Mean (± SE) body lengths (mm) of laboratory-raised tadpoles (regardless of water treatment) and of tadpoles inhabiting the old pond at week one (Field N = 103, Laboratory N = 149).

In week two, there was an overall highly significant difference between all laboratory-raised animals in comparison with animals living in the field (F= 137.93, df= 2, 119, P= 0.0001). Tukey-Kramer HSD post-hoc analyses revealed that tadpoles from old pond, new pond and tap water laboratory treatments had significantly longer bodies than tadpoles from the old pond, and tadpoles raised in old pond water were significantly shorter than tadpoles raised in new pond water within the laboratory treatments (P<0.05). Animals raised in tap water, however, were not different in size than tadpoles raised in either old pond or new pond laboratory treatment boxes (Figure 13).

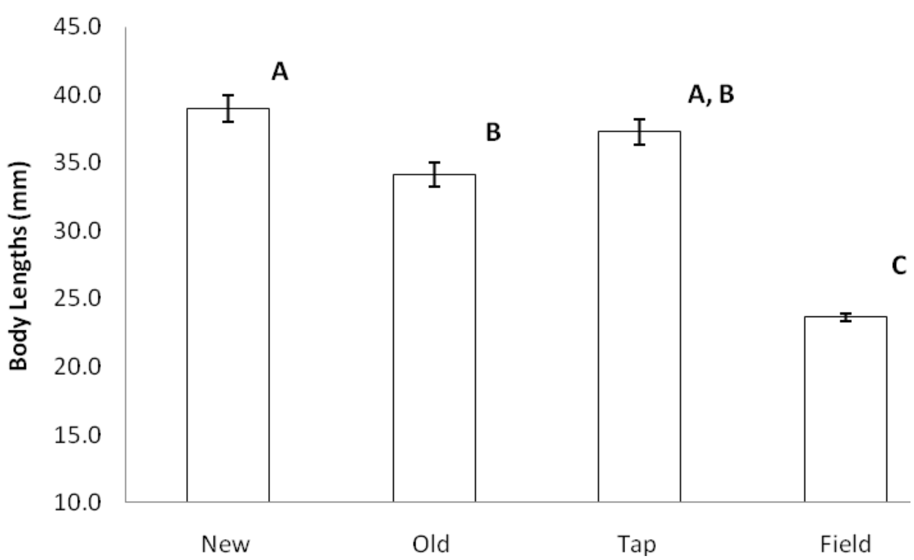

Figure 13. Mean (± SE) body lengths (mm) of laboratory-raised tadpoles (new, old and tap treatments) and of tadpoles collected from the old pond at week two (New N = 45, Old N = 55, Tap

N = 46, Field N = 103). Different letters denote significant differences based on Tukey-Kramer HSD post-hoc analyses (P<0.05).

During the third week of comparing body length measurements, there was a significant difference in body lengths between laboratory-raised tadpoles and those living in the field (F= 98.13, df= 3, 118, P= 0.0001). Tadpoles collected from the old pond were significantly smaller in size than tadpoles raised in old pond, new pond and tap water treatments although there was no difference in body length among animals from the three laboratory treatments (Tukey-Kramer HSD, P<0.05; Figure 14)

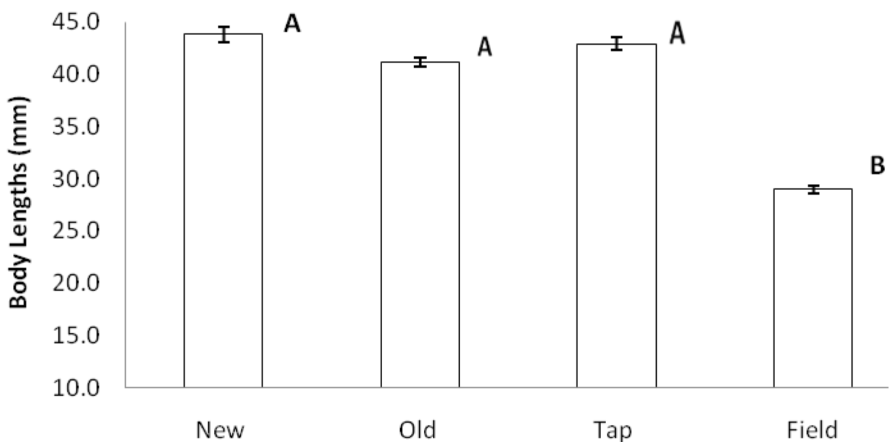

Figure 14. Mean (± SE) body lengths (mm) of laboratory-raised tadpoles (new, old and tap treatments) and tadpoles collected from the old pond at week three (New N = 46, Old N = 48, Tap N = 48, Field N = 103). Different letters denote significant differences based on Tukey-Kramer HSD post-hoc analyses (P<0.05).

During week four, tadpoles from the new pond were collected as well as from the old pond to photograph and measure in comparison to laboratory-raised animals. Tadpoles living at the ponds in the field had significantly smaller body lengths than laboratory-raised tadpoles (F= 24.469, df= 4, 164, P= 0.0001). Laboratory-raised tadpoles from all water treatments were not significantly different in size, nor were body length measurements in the old versus the new pond significantly different from each other. However, animals found in each pond were about 20% smaller than those raised in new pond water, old pond water and tap water within the laboratory (Tukey-Kramer HSD, P<0.05; Figure 15).

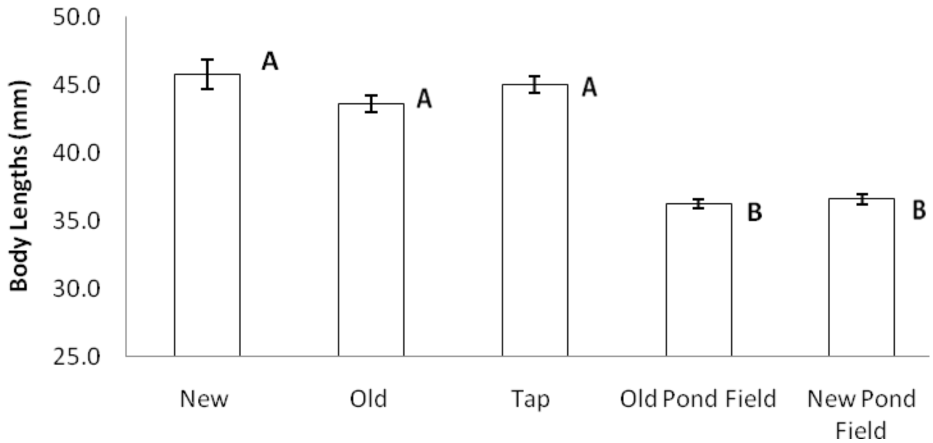

Figure 15. Mean (± SE) body lengths (mm) of laboratory-raised tadpoles (new, old and tap treatments) and of tadpoles collected from the field (old pond and new pond) at week four (New N = 33, Old N = 42, Tap N = 31, Old Pond Field N = 117, New Pond Field N = 34). Different letters denote significant differences based on Tukey-Kramer HSD post-hoc analyses (P<0.05).

Body Mass Comparisons at Metamorphosis

There was no significant effect of water treatment on the body mass of newly metamorphosed toadlets (F= 1.628, df= 2, 66, P= 0.2041; Figure 16)

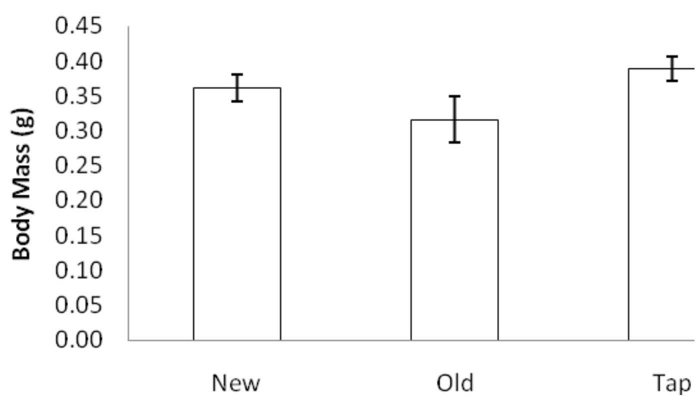

Figure 16. Mean (± SE) body masses (g) of metamorphosed toadlets within new, old and tap water laboratory treatments (New N = 34, Old N = 7, Tap N = 28).

Metamorphs raised in the laboratory were 90% larger in body mass than metamorphs captured from the new pond in the field upon completing metamorphosis (t= -22.553, df= 262, P<0.0001; Figure 17).

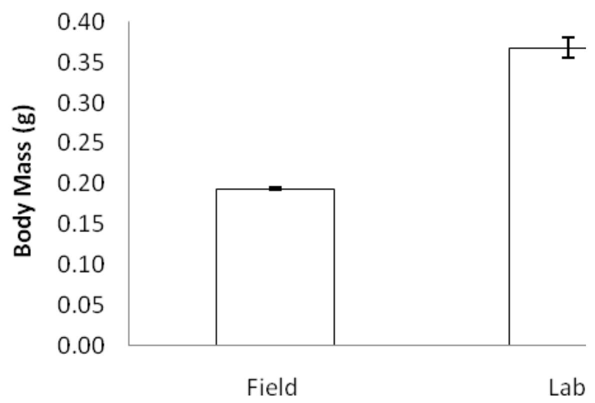

Figure 17. Mean (± SE) body masses (g) of all tadpoles to reach metamorphosis in the field and in the laboratory (Field N = 195, Lab N = 69).

Development of Four Legs in Laboratory-Raised Tadpoles

The number of tadpoles developing four legs was tracked each day for a total of 25 days. As expected, there was a highly significant effect of time on the percentage of animals with four legs (F= 59.375, 24, 675, P= 0.0001). There was also a highly significant effect of treatment type, such that over the course of 25 days in the new and tap treatment boxes combined, there was consistently a higher percentage of the total population of animals to develop four legs than was seen in the old pond water treatment boxes (F= 47.769, df= 2, 675, P= 0.0001). There was no interaction effect between the independent variables of time and treatment (Figure 18).

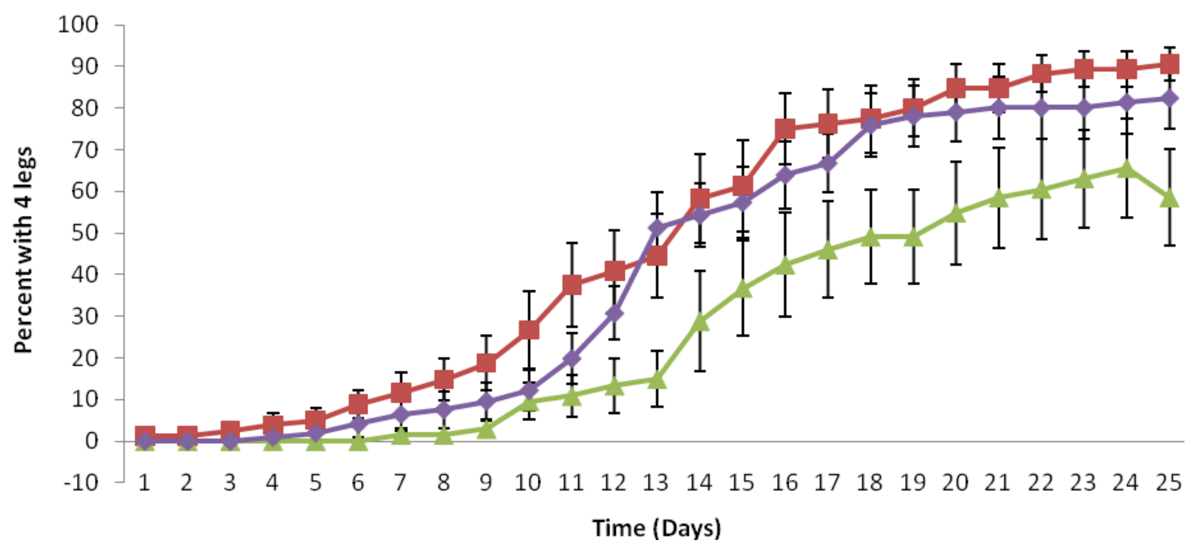

Figure 18. Mean (± SE) percentage of tadpoles with four legs in **new**, **old** and **tap** water treatments with respect to time (N = 25 days).

Survival of Tadpoles

Over the course of 8 weeks of raising tadpoles in the laboratory, mortality was noted daily and percentages of deaths calculated on a weekly basis per shoebox per water treatment type. As predicted, time had a highly significant effect on the cumulative percent survival of tadpoles (F= 8.734, df= 7, 264, P= 0.0001). Treatment type also showed a significant effect on the percentage of surviving tadpoles, with a higher percentage of tadpoles surviving in the tap and new pond treatments than in the old pond treatment due to high mortality experienced during weeks two and four (F= 7.424, df= 2, 264, P=0.0007). There was no significant interaction effect between treatment and time (Figure 19).

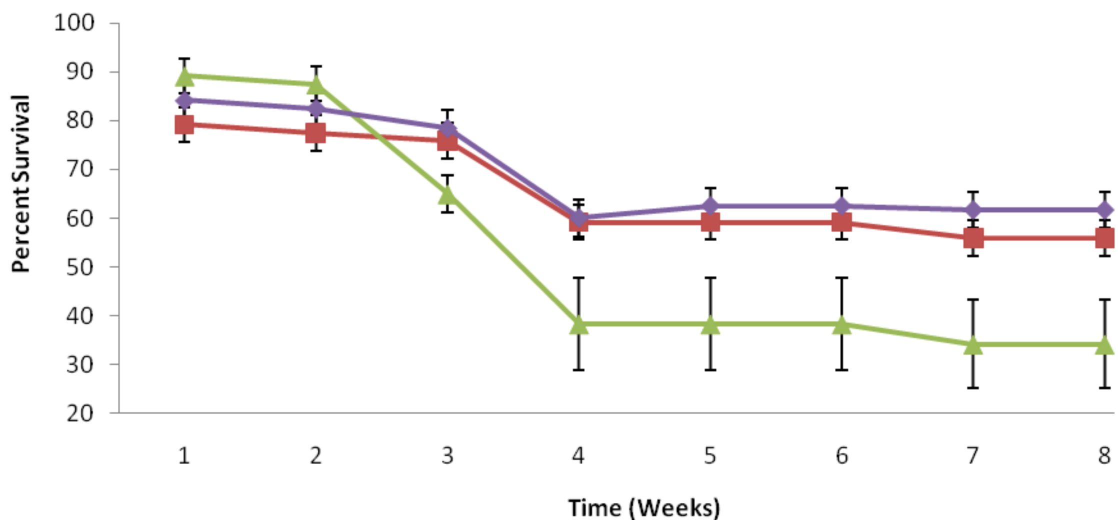

Figure 19. Mean (± SE) percentage of tadpole survivorship in **new**, **old** and **tap** water treatments over time (N = 8 weeks).

Overall, 75% of the original 400 tadpoles that were translocated to the new pond completed full metamorphosis. Of the initial 120 tadpoles reared per laboratory treatment, 42% of tadpoles raised in the new pond water metamorphed as compared to 36% in tap water and only 14% in old pond water. The high percentage of metamorphosing toadlets in the field is due in part to the date when they were translocated, which was after the period of high mortality (between weeks two and four; Figure 19) experienced in the laboratory.

Discussion

The results of my study indicate that both ponds are hospitable environments for the Western toad. When animals from the old and new ponds were captured and their body lengths measured, they showed no significant difference in size at either location, suggesting the sites were equally conducive to development. Temperatures at the two sites were very similar and light intensity measurements at the old and new ponds converged over time as more silt settled in the new pond. Of the ecological effects tested for, the only significant difference between the two sites was that the new pond had a significantly higher concentration of sediment than was found in the old pond. In the future, the amount of suspended matter can likely be decreased by draining the pond and adding a layer of decomposed granite to help prevent soil from being agitated on the pond floor and from eroding into the pond during heavy rains. Whereas a high level of sedimentation within a pond (usually caused by adjacent land use projects) is of concern to conservationists because it can represent the degradation of a freshwater habitat, the animals in this study seemed to not be highly affected.

Wood and Richardson (2009) examined the interactive effects of sediment and nutrient levels on tadpole growth. Specifically, they tested for changes in tadpole fitness as a result of higher amounts of suspended matter which affects not only food availability in ponds, but is also associated with changes in behavior and physiological costs to tadpoles. The results of their study showed that tadpoles can cope with low sediment additions but growth rates and survivorship are significantly reduced under high concentration levels. In order to escape poor aquatic environments, tadpoles have the ability to enter metamorphosis as soon as the minimum threshold size requirement is reached, and conversely if the environment is plentiful, to delay metamorphosis. However when sediment levels are high, growth rate is decreased as a result of reduced food availability and more competition among animals. Additionally, when inorganic sediment is ingested, it dilutes the nutritional value of the food so that tadpoles consumed more low-quality food to try to get sufficient nutrients. In addition to affecting food availability, turbid conditions have also been shown to disrupt foraging behavior for 24 h until normalcy is once again restored (Wood and Richardson 2009). In study subjects, it triggered fast and erratic swimming behavior (flight or fight response) which was energetically costly and also increased exposure to potential predators. A physiological concern is that sediment can clog or cause gill abrasion, thereby reducing the efficacy of gas exchange. Whereas this study raises concern about adverse effects of sedimentation on tadpole growth rate, luckily our study does not support the aforementioned results. Encouragingly, it is likely that the silt levels in the new pond are not high enough to reduce growth and survivorship.

When considering survival rates, raising animals in the laboratory was most effective in tap and new pond water. Animals raised in shoeboxes with old pond water had the highest mortality rate and the lowest percentage of the initial total of tadpoles to reach full metamorphosis. Considering that this is the same water treatment as is present in their natural habitat, our results are surprising. There were a few instances of mass mortality of entire shoeboxes of animals throughout the duration of the experiment which seemed to be more prevalent among the old pond treatment. It is not known why these deaths occurred. The only difference in the water content of the ponds is that the new pond is filled only by rain water whereas the old pond is filled by both rainfall and supplemented with tap water. However, the presence of tap water within the old pond cannot explain the mortalities because tadpoles raised in the tap water treatment in the laboratory showed high survival rates. Another potential explanation is contamination of the water source although every effort was taken to diminish the possibility of unintentionally spreading contamination or infection to the animals during the study. On the other hand, it is encouraging that the survival and growth to metamorphosis was so high for tadpoles raised in new pond water, as this pond will be their only future breeding site.

Animals raised in the laboratory compared to those in the field were consistently larger (longer in body size) and faster developing (shorter time to reach major developmental milestones—hind legs, fore-legs, completion of metamorphosis). Every week, animals collected from the field were significantly shorter in body length than laboratory-raised tadpoles. Laboratory-raised metamorphs were also 90% larger in body mass than those captured from the field at the new pond. Smith-Gill and Berven (1979) in studying amphibian metamorphosis, explain that the probability of completing metamorphosis at a certain time is dependent upon two factors, current developmental stages and differentiation rate. Differentiation rate can be measured in accordance with various environmental factors such as temperature, density and food availability. For example, temperature is one major factor determining patterns of tadpole growth and differentiation. Low temperatures slow differentiation rates more than they do growth. This increases growth at specific stages so that at any particular stage, tadpoles in colder conditions are larger than those in warmer habitats. Another major factor which determines growth and differentiation in anurans is density. High densities of tadpoles retard growth more so than differentiation, therefore at any given stage, tadpoles in dense conditions will be smaller. This notion is supported by the results of our research study whereby tadpoles raised in the laboratory were larger in size than tadpoles living in the field. Not only did laboratory-raised tadpoles not have constraints on food availability nor any threat of predation, but they were also raised at temperatures lower than the warmest temperatures experienced by the tadpoles in the field. Their larger size and faster development may also be explained by the difference in initial water temperatures experienced in the lab and in the field. From Julian days 32-41 tadpoles in the field were exposed to water temperatures as low as 10 ^{o}C, much lower than temperatures in the laboratory which were never below 20 ^{o}C. The consistency of warmer temperatures may have given the laboratory-raised animals a developmental head start or initial boost over the tadpoles in the field. To test this hypothesis, an interesting course of future study would be to observe the effects of varying temperature at different lifecycle stages on tadpoles' development. Additionally, tadpoles at the old pond were developing in areas of much higher density which is likely a major reason why they were significantly smaller than laboratory-raised animals.

Alford and Harris (1988) proposed that rates of development in anurans are set by early larval experiences and that growth rates change primarily in response to changes in resource levels. This study exposed *Bufo woodhousei* tadpoles to a number of different treatments involving high and low resource availabilities for differing amounts of time. Tadpoles exposed to high resource availability for the first 11 to 17 days then placed in low resource environments had larval periods and masses at metamorphosis indistinguishable from tadpoles reared under continuous conditions of lower resource availability. Animals exposed to lower resource levels for the first 11 to 17 days of growth then moved to conditions of high resource availability showed the same metamorphic characteristics as those grown at constant high resource levels. These results suggest that early (40% of larvae period) growth history has little to no influence on time to and size at metamorphosis of tadpoles reared in isolation. Therefore, differentiation rate is a response to changes in resource availability that can occur at any point after the initial weeks of tadpole development. One such constraint on resource availability is high population densities which was true of the habitat in which field tadpoles lived. Thus, in accordance with Alford and Harris' findings, tadpoles raised under continuous conditions of lower resource availability (i.e. high population densities which increases food competition) would result in lower body masses at metamorphosis. This finding supports the results of our study whereby metamorphs captured from the field had comparatively small body masses to those raised in the laboratory under high resource conditions.

Alford and Harris (1988), also predicted that populations of larvae with no resource limitation should undergo metamorphosis at a uniformly large size, with an individual's specific metamorphic timing determined by intrinsic growth rates (as influenced by recent growth history, i.e. changing resource levels). My laboratory-reared animals did not experience constraints on resource availability and therefore metamorphosed with similar body masses regardless of the water treatment in which they were raised. Additionally, Alford and Harris found that metamorphosing at a larger body size can increase survival of the terrestrial juveniles who in turn may reproduce earlier. Early metamorphosis has another added benefit of minimizing the risks of predation and desiccation encountered by tadpoles typically living in temporary bodies of water. Despite having been raised in the laboratory in a protected, sheltered, and ideal (with respect to food availability) habitat, it is hopeful that because the metamorphs have relatively large body sizes, this will help them to survive better in the wild.

Whereas this research project was not designed to be a study of the effectiveness of particular conservation strategies, conservation efforts are needed to aid the survival of the relatively small population of Western toads at the BFS. Amphibians are particularly susceptible to species decline because their habitats are affected by development and they are sensitive to their environment: permeable skin and high density development encourage the spread of disease and toxic poisoning and as ectotherms they are highly temperature sensitive (Dodd and Seigel 1991). Bancroft and Blaustein (2007) present a compelling argument that amphibians may not be able to adjust to the rapid climate changes which have occurred in the past decades. Many of these species exhibit seemingly maladaptive behaviors such as laying eggs in large communities in shallow waters which not only exposes them to higher levels of dangerous UVB rays but also increases the likelihood of catching and spreading disease. However, global climate change, the depletion of the ozone layer, chemical pollution of many of the world's water sources, and spread of new diseases often brought on by environmental change are all relatively new phenomena. These changes have occurred within the last decades, whereas amphibians have evolved specific reproductive behaviors over the course of millions of years. As detailed in the Amphibian Conservation Action Plan (2005), other concerns of climate change include: reduced soil moisture which will likely diminish the abundance of prey as well as eliminate habitat, and reduced snowfall occurring in conjunction with higher evaporation during the summer months which can negatively impact the duration and occurrence of seasonal wetlands which are important habitat sites and are critical to breeding success. Historically, animals have demonstrated an ability to adjust their distribution when habitats are no longer available. However, in today's world the availability of territories for animals has been vastly limited by expansions in agriculture, deforestation and urbanization. Therefore, many populations may not be able to shift their home ranges nor evolve as quickly as needed in order to survive the selection pressures of a rapidly changing environment.

So what is the best strategy to help slow or reverse global amphibian declines? There is no clear-cut answer but much literature has been published to highlight the varying strategies and degrees of success. Dodd and Seigel (1991) suggest that amphibian translocations have limited success especially in comparison to other taxa of animals. However, other studies show more encouraging data. Success itself is challenging to determine concretely. It takes many years as well as careful monitoring to determine whether the substantial addition of individuals added to the existing adult population were able to reproduce successfully and how much time was taken to reach maturity (Germano and Bishop 2009). There are a number of factors which contribute to the success of translocations: the quality of the habitat, the date animals were released, if the introduced individuals were captive or wild, the number of animals released, and the life stage of the released animals. Particularly for amphibians, the number of animals released is a primary determinant of success—when projects introduced 1000 individuals they had much better results than when populations of fewer than 1000 individuals were introduced (Germano and Bishop 2009). Transferring of eggs and tadpoles is also much easier as egg strands are easy to find and collect and are present in larger numbers. Muths, Johnson and Corn (2001) found relocations were much more successful when Boreal toad egg masses were transferred as they were not only the most cost effective solution, but were also able to withstand the trauma of being collected and transported. Their main struggle however, was that the populations of toads were so limited within their study region in the Rocky Mountains that no one population could sustain continued collection and movement of egg masses for the amount of time (several years) that repatriation efforts need in order to be effective tools. The motivation behind translocation is also an important indicator of the success of the effort. Translocations for the purpose of conservation reasons have a greater chance of succeeding than if the translocation was intended as a solution for human-wildlife conflict, which consequently had the highest failure rates in the review conducted by Germano and Bishop (2009).

The principle concern of translocation efforts is that success is hard to determine because it can take several years. Sites must be chosen carefully to prevent failures primarily caused by homing and migration by the new population. Despite the challenges associated with determining success rates and a high likelihood of failures and risks (such as introduction of disease to wild populations or captive animals potentially being unable to cope with the natural environment), amphibians also possess traits that may make them more suitable to such types of captive-release programs. They have high fecundity, often no parental care, and they can usually be bred in captivity in a cost-effective manner (Fisher and Lindemayer 2001). Dodd and Seigel (1991) stress that in order for repatriation experiments to be successful, long term and dedicated commitment is necessary. More research is needed to establish under what conditions these conservation efforts are most useful and how to achieve the highest degree of survivorship and overall success possible.

Long-term follow-up and monitoring is also essential. Publishing studies regardless of the success or failure of the project is a critical learning experience for future efforts.

This study represents only the beginning of the conservation effort needed to save the Western toad population from habitat destruction at the Bernard Field Station. It was determined that the aquatic environment was conducive to the development of the relatively small sample group of tadpoles released there as over 75% survived to complete metamorphosis. Because of these encouraging results which demonstrate the suitability of the new pond as a future breeding site, full-scale translocation is recommended within the immediate future. The toads breed only once a year and to increase the chances of a successful relocation, it is important to transfer the population at the earliest possible life stage. Egg strands are easily collected and able to withstand the stress of transportation and if tadpoles have hatched and developed at the new pond, there is a greater likelihood they will imprint upon the site and return to breed there as adults. Ideally, additional research would be conducted to determine whether or not the new pond has sufficient resources to withstand a population of thousands of tadpoles and if the terrestrial habitat surrounding the pond is suitable for juveniles. Unfortunately, the impending demolition of the old pond does not allow for the time needed in which to conduct these studies. Translocation of a species before a complete assessment of the new habitat can be determined is undeniably risky. However, nothing is comparative to the risk of losing the population of Western toads at the BFS altogether if no action is taken before their only breeding habitat is destroyed.

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Literature Cited

Alford, R. and Harris, R. 1988. Effects of Larval Growth History on Anuran Metamorphosis. The American Naturalist 131(1): 91-106.

Blaustein, A. and B. Bancroft. 2007. Amphibian population declines: evolutionary concerns. BioScience 57(5): 437-445.

Bull, E. and Carey, C. 2008. Breading Frequency of Western Toads (Bufo Boreas) in Northeastern Oregon. Herpetological Conservation and Biology 3(2): 282-288.

Bull, E. 2009. Dispersal of Newly Metamorphosed and Juvenile Western Toads (*Anaxyrus Boreas*) in Northeastern Oregon, USA. Herpetological Conservation and Biology 4(2): 236-247.

Burke, R. 1991. Relocations, Repatriations, and Translocations of Amphibians and Reptiles: Taking a Broader View. Herpetologica 47(3): 350-357.

Dodd, K. and Seigel, R. 1991. Relocation, Repatriation, and Translocation of Amphibians and Reptiles: Are they Conservation Strategies that Work? Herpetologica 47(3): 336-350.

Fisher, J. and Lindenmayer, DB. 2000. An Assessment of the Published Results of Animal Relocations. Biological Conservation 96: 1-11.

Gascon, C., Collins, J.P., Moore, R. D., Church, D.R., McKay, J.E. and Mendelson, J. R. III (eds). 2007. Amphibian Conservation Action Plan. IUCN/SSC Amphibian Specialist Group: 64pp.

Germano, J. and Bishop, P. 2008. Suitability of Amphibians and Reptiles for Translocation. Conservation Biology 23(1): 7-15.

Kiesecker, J., Chivers, D. and Blaustein, A. 1996. The Use of Chemical Cues in Predator Recognition by Western Toad Tadpoles. Animal Beahvior 52: 1237-1245.

Morey, S. 1988-1990. Western Toad, *Bufo boreas*. California Wildlife Habitat Relationships System I-III.

Muths, E., Johnson, T., and Corn, P.S. 2001. Experimental Repatriation of Boreal Toad (*Bufo boreas*) Eggs, Metamorphs and Adults in Rocky Mountain National Park. The Southwestern Naturalist 46(1): 106-113.

Smith-Gill, S. and Berven, K. 1979. Predicting Amphibian Metamorphosis. The American Naturalist 113(4): 563-585.

Wood, S. and Richardson, J. 2009. Impact of Sediment and Nutrient Inputs on Growth and Survival of Tadpoles of the Western Toad. Freshwater Biology 54: 1120-1134.

Websites:

www.bfs.claremont.edu. 2001. The Robert J. Bernard Biological Field Station. Bernard Field Station Faculty Advisory Committee.

www.saczoo.com/Document.Doc?id=372. Western Toad: *Bufo boreas*. The Sacramento Zoological Society.

http://www.npwrc.usgs.gov/resource/herps/amphibid/species/bboreas.htm. 2006. Checklist of Amphibian Species and Identification Guide: Western Toad, *Bufo boreas*. U.S. Geological Survey.

http://www.iucnredlist.org/apps/redlist/details/3179/0. 2004. *Anaxyrus Boreas*. International Union for Conservation of Nature