Report to USGS for CESU Grant:

Effects of fire suppression and exclusion on boreal toad (*Bufo boreas*) populations

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Introduction

Physical disturbances can play a major role in the creation and maintenance of landscape heterogeneity, ecosystem processes, and population and community dynamics. Pickett and White (1985) defined disturbance as “any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment.” Many natural processes (e.g., fires, floods, volcanic eruptions) and human impacts (e.g., timber harvest and mining) are considered disturbances. The effects of a disturbance depend not only on the type and magnitude of the disturbance, but also on its timing and frequency of recurrence. Catastrophic disturbances can eliminate species, reduce biotic diversity, and alter community structure (Petraitis et al. 1989; Pickett et al. 1989). In contrast, less severe disturbances may be more likely to result in increased biotic diversity by reducing abundances of competitively dominant species (Connell 1978; Petraitis et al. 1989), and/or increasing diversity of habitat. Disturbances can be integral to the functioning of ecosystems that have developed under such pressures. Wildfire is one example of a disturbance that affects systems at the landscape scale and can be important for the maintenance of biotic composition and diversity within those systems.

Wildfires create a mosaic of habitat types that benefit many species. Predictable changes in insect (McCullough et al. 1998) and bird (Hutto 1995) communities in boreal forests of the western U.S. have been documented following fires. Some species may not only benefit from fire, but may depend on conditions found in burned areas. For example, the adults of some species of jewel beetles (*Melanophila* sp.) are attracted to actively burning fires as their larvae develop only in the wood of trees freshly killed by fire (Schutz et al. 1999). Black-backed woodpeckers are also specialist on recently burned forests (Bock and Bock 1974; Murphy and Lehnhausen 1998). They enter newly burned areas and forage on wood-boring beetles, including *Melanophila* (J. Woolf, pers. com.).

Suppression of fire has changed the regular disturbance regimes that historically affected forest and prairie ecosystems across the U.S. (Frost 1998; Smith 2000). In many cases, forests that were once mosaics of varying stand ages and patterns in crown cover have been simplified into similar-aged, late successional forests. The negative effects of fire suppression (e.g., increased fuel build-up) and the resulting large, damaging fires that have burned across the western U.S. have lead to a policy of more proactive fuel reduction that includes harvest, thinning, and prescribed burning (USDA 2001). Although some researchers have examined the effects of timber harvest and prescribed burns versus wildfire with regard to small mammal communities (e.g., Ford et al. 1999; Simon et al. 2002), we do not know how these different disturbances affect other taxonomic groups such as amphibians (Pilliod et al. 2003).

Amphibian responses to disturbances are species-specific, variable, and not well understood (Pilliod et al. 2003). Kirkland et al. (1996) found American toads (*Bufo americanus*) in higher abundances in burned than unburned areas; Greenberg (2001) found that canopy gaps created by wind disturbance had no effect on amphibian numbers in the southern Appalachians; and Skelly et al. (1999) found responses to canopy closure varied by species - the abundances of some species increased while others decreased. Human disturbances such as timber harvest are frequently cited as having negative effects on amphibian species and total amphibian diversity (deMaynadier and Hunter 1995 and 1998; Dupuis 1997; Waldrick 1997). These effects, however, are not consistent across all studies or species. Some researchers have seen increased abundances of particular species, including toads, in harvested areas (deMaynadier and Hunter 1995).

Understanding how species respond to these natural disturbances is necessary for conservation and management. This is especially important for taxonomic groups such as amphibians in which dramatic declines have been documented. Extirpation of amphibian populations has been observed worldwide and is a focus of growing concern (Stuart et al. 2004). Across its range, the western toad has experienced severe declines (Carey 1993; Corn 1994; Fisher and Shaffer 1996; Stuart and Painter 1994; Ross et al. 1995). Western toad numbers in the southern portions of its range have fallen so sharply that the species is a protected in Wyoming, listed as endangered by the states of New Mexico and Colorado, and is a candidate for federal listing under the Endangered Species Act (Loeffler 2001). In Colorado and Wyoming, Corn (2003) documented the near extirpation of western toad populations at high elevations in protected locations including national parks and wilderness areas. In the northern Rockies Mountains, historic accounts portray the western toad as being common, while recent studies show this species to be far less abundant than would be expected. Within 40 random watersheds sampled in western Montana, western toad breeding was found at only 9 out of 347 potential sites (Maxell 2000). Most of those breeding sites had very few (<5) individuals; while only a couple of sites, including Jones pond at Lubrecht Experimental Forest, had more numerous populations (>15 individuals).

Multiple hypotheses have been suggested to explain the observed declines in amphibian populations. Although unlikely that a single hypothesis will explain the trends of decline throughout the range of the western toad, only one or two of the proposed hypotheses are supported. Many of the declining or extirpated populations of western toads have been at high elevations or in remote areas with minimal direct habitat loss and modification from development or other known causes (Corn 2003). Typically, habitat loss and modification are thought of in terms of discrete events (e.g., clearing of construction sites, draining wetlands, and clear-cutting forests) but do not include long-term and cumulative effects of other, less direct, anthropogenic activities (e.g., fire suppression). These types of habitat alterations may have more subtle affects on natural processes over longer periods of time. Declines in some frog and toad species in the eastern United States have been attributed to canopy closure resulting from forest succession (Skelly et al. 2002; Werner & Glennemeier 1999). By considering habitat changes over the long-term (e.g., vegetation growth resulting from decades of fire suppression), habitat modification may account for some of the declines in western toad populations that have been observed.

The U.S. Geological Survey (USGS) has documented immediate dramatic increases (up to 500%) in the numbers of western toad breeding sites in areas burned by wildfires in Glacier National Park. While these increases have been consistent for multiple fires occurring across multiple years, no increases have been documented in unburned areas of the park (Hossack et al., In Prep). These findings, along with studies of thriving populations of western toads in disturbed habitats such as the Mount Saint Helens blast zone (Crisafulli and Hawkins 1998) and observations of increased western toad abundances in burned forests in Oregon (E. Bull, pers com) and Idaho (B. Hossack, pers com; D. Pilliod, pers com) have led to the hypothesis that the western toad benefits from certain types of disturbances. If western toads are responding to disturbance, different forest management practices (specifically, fire suppression and timber harvest) may play important roles in habitat use and demographics of some populations of this species. Likewise, if certain populations of western toads rely on disturbance, thickening forests due to long-standing policies of fire suppression may be reducing suitability of habitat for those populations.

Habitat use by amphibians is closely tied to environmental characteristics (Huey 1991; Bartelt 2000). Amphibians are wet-skinned ectotherms that have little to no physiological control over their evaporative water loss or body temperature. Temperature selection by ectotherms affects their development, physiology, and behavior (Huey et al. 1979; Huey et al. 1989); thus, knowledge about the availability and distribution of related habitat characteristics is critical to understanding movement patterns and habitat use (Huey 1991).

Characteristics of terrestrial habitat available during the summer season can affect the survival, growth, and fecundity of toads (Reading and Clarke 1995; Stevens 1987). Adult toads regulate body temperature and moisture through daily and seasonal activity patterns, and through use of retreat burrows (Smits 1984; Tracy et al. 1993). Post-breeding western toads have been found to occupy a variety of different microenvironments conducive to maintenance of thermal and water balances including under rocks, logs, and bushes; in burrows; and open ground (Bartelt 2000; E. Bull, pers com). Western toads are primarily nocturnal and their microhabitat selection is believed to be closely associated with availability of cover (Bartelt 2000; Muths 2003). Disturbances change the abiotic (temperature, humidity, solar radiation and evaporative losses; Chen et al. 1993) and biotic (prey availability, availability of cover, exposure to predators) characteristics of forest patches and thus the characteristics of the micro-sites found within.

Western toads congregate at ponds in early spring to breed. After breeding, they typically disperse from these ponds into the surrounding terrestrial habitats. General movement patterns of post-breeding western toads may correspond to macro-scale (~km^2) variables such as prey abundance, forest cover, and availability of sheltered retreat sites (e.g., burrows and root holes). Movement patterns may also be related to micro-scale ($<m^2$) variables such as moisture and thermal characteristics of available retreat sites. Disturbances such as wildfire and forest management (e.g., logging and prescribed burning) can influence habitat characteristics at both of these scales. At the macro-scale, increased solar radiation resulting from canopy reduction and altered hydroperiod due to decreased transpiration can lead to warmer, wetter conditions overall. At the micro-scale, changes in moisture and thermal characteristics of retreat sites can alter the suitability of those retreat sites for use as shelter from arid conditions and thermal extremes. These differences are important because changing the characteristics or quality of microhabitats can alter the ability of the toads to travel (Preest and Pough 1989) and forage (Stevens 1987). Under optimal temperature and moisture conditions, toads exhibit more rapid reactions to prey and greater endurance; both of which can translate directly to improved body condition and increased reproductive success (Reading and Clarke 1995).

Research Questions

I. How do toads use habitat mosaics created by wildfire?
    · Are they using areas at all levels of burn severity (high severity, low/moderate severity, unburned)?
II. How do the environmental conditions of high severity burns and unburned habitat types differ with regard to temperature, and potential evaporative loss?
III. How do possible retreat sites, specifically burrows, alter these environmental conditions?

Methods

Glacier National Park was sampled the summer of 2004. Study sites within the Robert Burn of 2003 were identified by comparing detailed fire maps of the area burned (C. Key, USGS Northern Rocky Mountain Science Center) with past data on western toad breeding (USGS - unpublished data). Potential sites were chosen such that each contained the full range of burn severities that can result from wildfire (i.e., unburned, low to moderate severity burn, high severity burn) as identified by the USGS. Three study sites were selected from the potential sites identified. Selection was based on the presence of six or more adult toads. All three sites were east of the Camas Road (Glacier Route 8) between Lake McDonald and Howe Ridge. Each site consisted of a central pond or pair of ponds used for breeding by western toads and the associated terrestrial habitats surrounding those ponds (Figure 1).

Initially a 100 m grid was overlaid on the burn severity map from the Roberts Fire in Glacier National Park. We determined study sites by extending a radius from the breeding pond outward until the area encompassed included 10 grid intersections in each burn severity level. Three random points in each severity level were selected from those 10 points. This resulted in 1600 m radii for sites one and two and a 1000m radius for site three. The entire study area for each site is within the range of possible summertime movement for western toads, as single-day movements by western toads have been measured to be greater than 400m (Bartelt et al. 2004; Adams et al. 2005).

Radio Telemetry

To examine toad movement, we radio-tagged 6 to 7 toads at each study site in Glacier National Park (total = 20). Adult toads were caught at the ponds in May and June when they congregated to breed. They were located either at night by eye-shine (Corben and Fellers 2001) or during the day by slowly walking through the ponds while scanning visually. Each animal was caught by hand, weighed, measured, and fitted with a radio transmitter. Since chytrid infection is thought to possibly affect activity patterns and habitat selection by amphibians (D. Pilliod, pers com.; B. Hossack, pers com.), each animal was sampled for chytrid fungus at the time of initial and final capture by swabbing the animal's venter and preserving each swab in 95% ethanol. These samples were sent to Pisces Molecular, Boulder, Colorado, where they were tested for the presence of DNA from chytrid (*Batrachochytrium dendrobatidis)* using polymerase chain reaction (PCR) methods (see Boyle et al. 2004).

Post-breeding movement patterns and habitat use by western toads have been shown to differ between sexes; therefore individuals of both sexes were captured and marked. The ratio of males to females captured at breeding ponds in an ongoing mark-recapture study of over 300 individual toads is approximately six to one (Hossack pers. com.). Each toad was radio-tagged with an LT-2 transmitter from Titley Electronics. We attached transmitters with velcro waistbelts following the methods of Mike Young (USFS – Rocky Mountain Research Station) and Dave Schmetterling (Montana Fish Wildlife and Parks; M. Young, pers. com. 2004). Each transmitter weighed ~2.0g, had an average range of about 100-300m, and a battery life of ~20 weeks. The minimum body weight of toads used was 34 grams, ensuring that no animal would be carrying more than six percent of its body weight. Each toad caught was given a unique toe-clip mark (Martof [1953] system) so that it could be individually identified in cases of lost or failed transmitters, or in the event that an animal was recaptured for telemetry in subsequent years.

We attempted to relocate each radio-tagged animal at least once every three to five days. Relocations typically included visual contact unless an animal was in a burrow or thick vegetation. Efforts were made to avoid disturbing animals during regular relocations. We recaptured each animal at least once every 15 days for evaluation of waist belt fit. Weight and length were recorded during each recapture. Animals that developed sores from the waist belt were treated with Bactine® following recommendations of the USGS, National Wildlife Health Center (D. Earl Greene, ARMI SOP NO. 100; 16 February 2001), and their belts were adjusted to prevent further abrasion. If no radio signal was detected during a relocation attempt, we searched outward from the animal's last known location in a pattern of roughly concentric circles, increasing the radius by about 200m with each circle. Beginning in late August, animals were recaptured and their radio tags removed. Retreat site types included, under log/rock, in burrow or burned-out root hole, under bush, or on open ground.

To initially examine toad movements, we plotted toad movements in ArcGis (ESRI), calculated maximum distance moved from the initial capture location, and summarized the burn treatment, habitat (riparian, pond, forest), and microsite type for each toad relocation.

Retreat Site Characteristics

Paul Bartelt (2000) developed and tested methods for using pairs (wet/dry) of copper models to measure thermal and hydric conditions of western toad retreat sites. Each model was made of a section of copper tubing approximately the size and shape of an adult toad (3.5cm x 7cm, slightly flattened, and ends plugged with silicone) and contained a thermistor and external data logger. We built models to Bartelt's specifications, but in each substituted an I-button temperature logger (Dallas Semiconductor, DS1921G) for the thermistor and external data logger. We added a small nail to a removable plug at one end of each model to allow for access to download the I-button. Temperature was logged every 20 minutes at a resolution of 0.5ºC.

For each wet model, we buried a 500ml Rubbermaid bottle with its mouth level with the ground's surface to serve as a reservoir from which water was wicked. We placed a dry model on the ground beside each wet model (both on small pieces of plastic wrap to protect against wicking water to or from the ground). Temperatures differences between pairs of models (dry – wet temperatures) can be used to estimate a relative potential for evaporative loss by toads at that spot, while wet models provide estimates of toad body temperatures. We recorded the same habitat characteristics for each model site as were recorded for retreat sites occupied by radio-tagged toads including physical parameters and retreat site type. Cover measures were taken once a month at each model site to account for changes due to growth of vegetation during the summer. Models were checked weekly; repairs were made and water reservoirs were refilled as necessary. I-buttons were downloaded approximately once every 20 days.

A total of 108 pairs of models were deployed in the Glacier study area with 36 in each of the three study sites. We divided each study site into 3 categories based on level of burn severity (i.e., unburned, low to moderate severity, and high severity). At each site, we selected three random points within each of the burn severity categories. At each random point, we identified the closest of each of four types of potential retreat sites (i.e., under rock/log, under bush, in burrow/burned out root hole, and open ground). One pair of models was placed at each of these retreat sites.

The data from the biophysical models was manually filtered and any data of uncertain quality was removed from analyses. The events that lead to data being removed included: models being moved by small animals and wet models that were dry because either their wicking end had been pulled out of the reservoir or the reservoir had gone dry. The models were checked weekly, if the models had been compromised then data back to the previous check were removed. This lead to a fair amount of data removed, but there were 3.5 weeks (July 16th through July 22nd and July 30th through August 15th) where at least 5 of our replicate model sites were available in each treatment (e.g., open high severity). These replicate sites were averaged in order for us to compare environmental conditions at micro-sites (open and burrow) between burn treatments (high severity and unburned).

For this report we focused on presenting the data necessary to address our focal research questions. Therefore, we examined biophysical model data that allow us to examine general site characteristics (models placed in open sites in the high severity and unburned areas) and to examine how much retreat sites, specifically burrow, buffer toads from the potential for evaporative loss during the day.

Results and Discussion

Telemetry

Twenty-two (14 males, 8 females) toads were captured and radio-collared at Glacier National Park. From our original 22 toads, six (5 males, 1 female) died while collared and four (1 male, 3 females) dropped their collars. The female toads ranged in size from 66 to 171 grams (mean 105 g, standard error 12 g) and 92 to 114 mm (mean 103.5 mm, standard error 2.8 mm). The male toads ranged in size from 44 to 109 g (mean 71 g, standard error 6.1g) and 73 to 105 mm (mean 87 mm, standard error 2.9 mm). Toads were typically tested for chytrid upon initial capture. Of these initial tests three of nine (or 33% of the males) males tested positive for chytrid and four of seven females (57% of the females). Thus 43% of the total individuals captured had tested positive with the chytrid swipe test on initial capture. Of those animals that died by the end of June (and that we had initially tested for chytrid) only 50% tested positive for chytrid, although necropsies of dead toads indicated that chytrid was the cause of death for all toads examined.

There was not a strong difference between males and females in their maximum distance traveled from the breeding site (site of initial capture and collaring). We included animals in our summary with at least three relocations throughout the summer, but overall we did not indicate long movements. At site one several toads dropped their collars, died, and/or disappeared. Only one toad was tracked to the end of June and no toads were tracked into July (Figure 2). Sites 2 and 3 both had four toads with many locations lasting over a month (Figures 3, 4). Female toads were located between 207 to 668 m (mean 430 m, standard error 110 m) and males were located between 21 to 875 m (mean 390 m, standard error 78 m) from the breeding site during the summer. These distances for males were similar to what has been observed in Idaho where most male toads remained within 200m of the breeding site, with one-quarter of these male toads expanding their movement range to approximately 1 km (Bartlett et al. 2004). Our distances for female toad movements are shorter than expected

(Bartlett et al. 2004), but only one female (of 9 collared) was tracked into mid-July or August. This is likely biasing our distance measures for female toads compared with other studies that tracked animals longer.

Toads stayed primarily within the burned area throughout the summer. Glacier sites 1 and 3 had all three burn severities within the maximum distance traveled for the collared toads, and site 2 had high severity and low/moderate severity burns within this range. Even though all burn severity levels are within the typical summertime movement range of toads, the radio-collared toads remained within the burned areas. Most of the relocations were in high burn severity areas, only three toads were commonly relocated in the low to moderately burned areas (Figure 5). The only location of a toad in an unburned area was the last location of toad 3 (female) when the collar was located across on the east side of Lake McDonald and was ***no longer*** attached to a toad.

Toads were initially located in and around ponds in May and early June due to our bias in sampling (we visited potential breeding ponds to initially locate and capture toads). By mid-July toads that had been collared were no longer located around ponds, but were located equally in forest and riparian habitat (Figure 6).

The retreat sites used by toads at Glacier National Park were similar to those used in previous studies (in burrow, in grass, under bush, under log; Figure 7). There were no strong trends in the types of microsites used by toads in high severity versus low to moderate severity burns or unburned areas. Burrows and logs (more “closed” retreat sites) were used as often in low/moderate severity (23%) sites as in burned sites (25%).

Biophysical Models

The biophysical models were deployed the end of June in Glacier National Park. These models were often disturbed with the wet model pulled out of the water reservoir by small mammals or moved from the initial site. The dataset was parsed in order to obtain weeks with data that we are confident of its quality (thus, if a model was disturbed all data was removed until the previous check). This resulted in about a 3.5 week time period for us to examine trends in the environmental conditions among sites.

We examined general temperature and relative potential evaporative loss for the high severity versus the unburned areas with the open micro-site models. The wet model temperature daily fluctuations and averages were greater for the high severity than the unburned areas (Figure 8a; high severity wet model mean 17.3 ºC, maximum 35.4 ºC, minimum 6 ºC; unburned wet model mean 15.6 ºC, maximum 28.6 ºC, minimum 7.7 ºC). Toad locomotion and foraging is often temperature dependent, therefore we examined the number of hours (within this 3.5 week time period) that fell within different temperature ranges. Open sites in unburned areas were between 10 and 20 ºC, while there were over 100 hours during this 3.5 week time period when the high severity area experienced temperatures above 25ºC (Figure 8b). Even though these warmer temperatures may be better for toads, they could come at a cost of higher potential evaporative loss (measured here as dry – wet model temperatures). Similar to temperature, the potential evaporative loss demonstrated daily fluctuations with the highest potential evaporative loss occurring midday and lower values at night. The high severity areas had a greater average potential for evaporative loss, particularly higher peaks during the day (Figure 9a; mean in high severity 4.3ºC; mean in unburned 1.4ºC). The general daily trends demonstrate very little differences in potential evaporative loss between high severity and unburned from just before midnight until early morning (~7 am), but large differences during the day (Figure 9b).

Given the expected nocturnal foraging behavior for most toads, we limited the examination of the open habitat data to nighttime (defined here from 7 pm to 9am) when toads would be out foraging and experiencing the environmental conditions of this more open type of microsite. The wet model nighttime temperatures were warmer in the high severity (mean 17.7ºC, max 32.3ºC, min 6ºC) than in the unburned sites (mean 15.9ºC, max 25.0ºC, min 7.7ºC). During this 3.5 week timeframe that we examined, high severity sites also had 52 hours more potential foraging hours above 25ºC than the unburned sites (Figure 10). The difference in nighttime potential evaporative loss between the high severity and unburned sites was small (1.3ºC in high severity versus 0.8ºC in unburned). Thus, in the high burn severity areas toads would be able to experience more potential nighttime foraging hours within a 25 to 32ºC temperature range. The nocturnal behavior would "buffer" the animal from the high potential evaporative loss during the day and toads would be foraging when the potential cost of high evaporative loss is low (and not different between the high severity and unburned sites).

Given this potential energetic benefit of foraging in the high burn severity areas, we next wanted to examine the potential for retreat sites to buffer daytime evaporative loss. We focused this analysis on the burrows, because toads often used them in Glacier National Park and we felt it would have the highest potential to protect the animal from evaporative loss. Similar to the open sites, burrows had a daily fluctuation in temperature. Burrows in high severity areas (mean 16.5ºC, max 25.4ºC, min 8.4ºC) were warmer on average than burrows in unburned areas (mean 14.4ºC, max 20.3ºC, min 7.4ºC). The potential evaporative loss in burrows for the high burn severity areas was much lower than in open sites, but still demonstrated a daily cycling (Figure 11a). There was typically zero (and always ≤1.3ºC) potential for evaporative loss in burrows at any time throughout the day in the unburned areas (Figure 11b). If we just examine daytime (9 am to 7 pm) hours, there was very little potential evaporative loss in either the high burn severity (burrow: mean 1.3ºC, max 6.8ºC) or the unburned areas (burrow: mean 0.3ºC, max 1.3ºC). Thus, the use of retreat sites likely buffers the animal from the high potential evaporative loss during the daytime in the high burn severity areas. With behavioral hydric and/or thermal regulation during the daytime hours, these high severity areas may have little to no energetic costs during the daytime, but benefit the toads during nighttime foraging through the warmer temperatures.

Our results corroborate Bartelt et al. (2004) who demonstrated that patterns of toad movement and habitat use tended to reduce potential water loss. There are several considerations in addition to these abiotic environmental constraints that may influence foraging quality, the most obvious being prey availability. There is a large amount of variation in fire intensity and in insect responses to fire, but in several cases beetles have increased in abundance and diversity for 5 years after the fire. Additionally, ants may be more abundant in burned sites (McCullough et al. 1998). Overall, it appears that fire may create beneficial post-breeding adult foraging habitat.

Conclusions

How do toads use habitat mosaics created by wildfire?

· Some toads stay within the burned areas throughout the summer.

How do the environmental conditions of severely burned and unburned habitat types differ with regard to temperature, and potential evaporative loss?

· High burn severity areas were warmer on average and had more extreme daily cycling of temperature than unburned areas. In addition, the potential for evaporative loss was greater. Nighttime potential evaporative loss was small in both high severity and unburned areas and potential evaporative loss in the high burn severity sites was not much greater than in the unburned site.

How do possible retreat sites, specifically burrow, alter these environmental conditions?

· Burrow retreat sites are slightly cooler than open sites (on average 1ºC), have smaller diel fluctuations in temperature and have less potential evaporative loss than open sites. Average daytime potential evaporative loss was small and there was little difference between the high burn severity and unburned sites.

Overall, toads used high burn severity areas. These areas typically have warmer nighttime hours for foraging, but small differences in nighttime potential evaporative loss. They can buffer the high daytime potential evaporative loss in these areas through behavioral water and thermal regulation (through their use of retreat sites).

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