Introduced American Bullfrog consumption patterns in Grand Teton National Park

Preliminary report prepared by:

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Management brief:

- Introduced American bullfrogs are generalist predators implicated in the declines of native taxa, especially amphibians.

- In Grand Teton National Park (GRTE), bullfrogs and other non-native taxa occur at high densities throughout Kelly Warm Springs and in Savage Ditch.

- The consumptive impacts that bullfrogs have on native and non-native taxa in GRTE is not known.

- We captured ~ 550 larval, metamorphic and post-metamorphic bullfrogs along the perimeter of Kelly Warm Springs and along 7, 100-m reaches in Savage Ditch in July, August and September 2015. We then characterized ~ 100 post-metamorphic (juveniles and adults) bullfrog diets. Results to date only include diets sampled in July and August.

- For July and August, invertebrates were the prey items with the highest frequency of occurrence and small rodents (e.g., mice, voles, shrews) had the greatest proportion by weight. Non-native taxa were rare prey items.

- Preliminary diet results indicate that native species are the principal prey items of introduced bullfrogs in Kelly Warm Springs and Savage Ditch.

- Conservative estimates of Kelly Warm Springs and Savage Ditch post-metamorphic bullfrog abundance are 129 and 242 individuals, respectively. If our observed consumptive impacts are scaled up to these conservative estimates, than the bullfrog population has the potential to consume ~ 1.5 kg of prey mass per foraging bout. These estimates do not include bullfrogs in side-channels and ditches of SD.

- We will prepare a final report once September diet data have been identified and analyzed. Literature references are available upon request.

Introduction

Introduced American Bullfrogs (*Lithobates catesbeianus*; hereafter, bullfrog) are implicated in the decline of native amphibian populations through direct mechanisms like predation and indirect mechanisms such as resource competition and disease introduction (Boone et al. 2004, Kiesecker 2003, Longcore et al. 1999). They also prey upon and compete with other taxa including reptiles, birds, fish and mammals (Rosen and Schwalbe 2002, Lopez-Flores and Vilella 2003, Bury and Whelan 1984). Once established, eradication is difficult because they possess a life history engineered for invasion (Snow and Witmer 2010, Adams and Pearl 2007, Doubledee et al. 2003).

The bullfrog is the largest frog in North America and a prolific reproducer— measuring up to 20-cm and laying up to 20,000 eggs per clutch. When introduced to new habitats, both larvae and adults dominate native amphibians in physical size and fecundity (Moyle 1973, Adams and Pearl 2007). They can disperse through the water or overland (e.g. Sepulveda et al 2015, Miera 1999, Hossack et al, in review), are unpalatable to many predators, and can persist despite low haplotype diversity (Kamath el al 2015, in review) and low densities (Altwegg 2002, Govindarajulu 2004). Bullfrogs can have large food web impacts because they are generalist, opportunistic predators so they can thrive even when preferred prey decline. Documented stomach contents include terrestrial and aquatic macroinvertebrates, reptiles, amphibians, fish, birds, bats and small terrestrial mammals (Ficetola el at 2007, Pearl et al 2004, others reviewed in Kiesecker 2003).

Bullfrogs are now common throughout North America, though their native range is limited to the eastern half of the continent (Bury and Whelan 1984). They prefer temperate and warm permanent water bodies, but their large native latitudinal span indicates a wide environmental tolerance, including human-modified habitats such as cattle tanks and irrigation canals. Introductions in the western half of the continent started in the early 1900's when bullfrogs were cultivated for human consumption and escaped from captivity. More recent introductions can be traced to aquarium dumping, pest (mosquito) control, fish baiting, and hunting (Boersma et al. 2006, Boreges-Martins et al 2002, Jennings and Hayes 1985).

Unfortunately these introductions extend to multiple western national parks, including Yosemite, Big Bend, and Grand Teton, which function as important havens for native species. The presence of invasive species in these parks threatens the NPS mission to protect their unique natural and cultural resources in perpetuity. In Yosemite, bullfrog presence is associated with the extirpation of a federally-threatened species, California red-legged frog (*Rana aurora draytonii*) and the California Species of Concern, the foothill yellow-legged frog (*Rana boylii*; Thompsen 2012). Eradication efforts began in 2006 and continue today in the hope of restoring these species and protecting others. However, eradication is contentious and resource-intensive, and may not be the best option for every park given the multitude of invasive species issues that many parks face. To implement an informed, effective plan of action, it is critical for the park to evaluate the specific impacts of the bullfrog population.

Here, we report the current and potential consumptive impacts of bullfrogs in Grand Teton National Park. Bullfrogs were first documented in the 1950's in Kelly Warm Springs (hereafter, KWS), a geothermal pond near the Park's southeastern border (NPS report). Bullfrogs are now established in KWS and in Savage Ditch (hereafter SD), the irrigation canal that drains the springs. These habitats also contain multiple non-native species, including tropical and warm-water fish. It is not known if present bullfrog consumption impacts are limited to these non-natives or if they extend to native species, including native amphibians. Valley-bottom habitats adjacent to KWS and SD are one of the few areas in the Greater Yellowstone that still support breeding populations of all four of this region's native amphibian species (Ray et al. 2014). Thus, identifying current consumptive impacts of bullfrogs on native and non-native species is critical for prioritizing bullfrog control efforts and for providing insight into the potential for bullfrogs to impact native species in adjacent waters. In this study, we characterized current bullfrog diets in Grand Teton National Park and described the relative importance of native vs. non-native prey to bullfrog diets. We then used estimates of bullfrog abundance to characterize the potential consumptive impacts that bullfrogs have on native and non-native prey. Knowledge about current and potential impacts of bullfrogs is needed to prioritize invasive species threats in national parks.

Methods

Study Area. Kelly Warm Springs is an approximately 60 × 90 meter geothermal pond located on the eastern perimeter of the Antelope Flats area of the Grand Teton National Park (43.639392, -110.616304, elevation 1989 meters). This pond is a popular recreation area and a past release site for non-native aquarium species (e.g. goldfish (*Carrasius auratus*), convict ciclids (*Archocentrus nigrofasciatus*), swordtail (*Xiphophorus hellerii*), guppies (*Poecilia reticulata*), tadpole madtoms (*Noturus gyrinus*) and snails (*Melanoides tuberculata*)) (NPS report). This pond is less than 1-km overland from the Gros Ventre River, and is hydrologically connected to Ditch Creek, which flows into the Snake River.

The KWS shoreline consists of thickets of willow, grasses, and shrubs. A small portion of the perimeter is bare from regular human use. From July through September, dense mats of floating algae cover approximately half of the water's surface. During this same season, temperatures range from 20-30 °C. Substrate varies from deep mud and silt to gravel, cobble, and woody, organic debris at depths of 4 - 100 cm.

Savage Ditch drains KWS, and was originally engineered as an irrigation canal for hayfields and pasture that populated the valley prior to park designation (Marlow and Anderson 2011). It flows West/Northwest through the valley floor, a habitat now characterized by dry grassland meadow, sagebrush, and post-agricultural successionary growth in porous, cobble soil (USFWS official document). Substrate varies from deep silt-mud to cobble in silt, and is relatively shallow with an average depth of 33.6cm.

We sampled bullfrogs along the perimeter of KWS and in seven, 100-m reaches in SD (Table 1). Reaches were separated by approximately 500 m and systematically selected beginning with the most downstream point in SD where bullfrogs had been observed, about 100-m downstream of where SD intersects Ditch Creek (43.658477, -110.652243). The majority of SD is uniform in character, averaging 25.5 °C and 9.8% emergent vegetation, but markedly changes after crossing Ditch Creek, averaging 19.6 °C and 57.7% emergent vegetation.

Approach. To describe bullfrog diets and relative abundance across their summer growing season, we sampled for post-metamorphic (i.e., juvenile and adult) bullfrogs within three discrete time periods: July 14-16, August 20-21, and September 29 - October 1 2015. Sampling individuals from different stage classes across time allowed us to describe ontogenetic and seasonal differences in diet and to infer potential impacts on native amphibians. Logistical and safety concerns necessitated surveys in daylight hours only. We did not sample until air temperatures exceeded 10 °C.

We used a Smith-Root LR-24 backpack electrofisher (250 – 300 V, pulsed DC) to capture bullfrogs with dip nets. Our focus was on post-metamorphic bullfrogs, but we also captured larvae and metamorphic bullfrogs when possible. For KWS, we focused electrofishing efforts within 2-m of the perimeter. For SD reaches, we sampled in an upstream direction and focused electrofishing efforts within 2-m of each bank. We recorded time (sec) spent electrofishing each reach and KWS to estimate catch per unit effort.

For captured bullfrogs, we measured their snout-vent-length (SVL; mm) with calipers and we recorded their wet weight (g) with a handheld spring scale. We did not attempt to distinguish between juveniles and adults, as this can be difficult without dissection and size alone is not a consistent predictor. In July and August, we used gastric lavage to sample the stomach contents from a random subset of post-metamorphic bullfrogs in each reach and in KWS; where post-metamorphic refers to individuals with four legs and no tail. In September, we sacrificed bullfrogs and removed the entire stomach. All stomach contents were stored in ethanol until identification by Rhithron Associates (Missoula, Montana), who identified consumed prey to the lowest possible taxonomic unit and measured blotted wet weights of individual prey.

To estimate bullfrog abundance, we inserted 12 and 23-mm Passive Integrated Transponder (PIT) tags in the dorsal sinus of all captured metamorphic and post-metamorphic ($n = 201$) individuals in July and August. Captured bullfrogs were then returned to the middle of their respective reaches.

Analyses. We used the Amundsen modified-Costello method (1996) to assess the importance of our prey categories to bullfrog diets. Prey items were pooled to order, which was the most common denominator of taxonomic resolution for our diet data. We calculated the percent occurrence (%*O*), percent by number (%*N*), percent by mass (%*M*), and the prey-specific abundance (*PSA*) for each prey category (*i*) as follows:

$$\%O_i = \frac{100O_i}{\sum_{i=1}^{n} O_i},$$

$$\%N_i = \frac{100N_i}{\sum_{i=1}^{n} N_i},$$

$$\%M_i = \frac{100M_i}{\sum_{i=1}^{n} M_i},$$

$$PSA_i = 100 \times \frac{\sum S_i}{\sum S_{ti}}$$

where n is the total number of prey taxa found in each river at each sampling time and S_i equals the wet mass of prey i in stomachs, and S_{ti} equals the total wet mass of prey in predators that contain prey i.

To explore patterns of relative prey category importance for each month, we constructed bivariate plots of *PSA* versus %*O*. Dominant prey categories have high %*O* in the diets and high *PSA* values, while rare prey categories have low *PSA* and low %*O* values. Opportunistic feeding is represented for prey categories that have high *PSA* and low %*O* in the diets, while generalized feeding is characterized by prey categories that have low *PSA* and high %*O*. When plotted in this fashion, graphical techniques can be used to evaluate relative prey dominance and the degree of homogeneity of the diet (Amundsen et al. 1996; Chipps & Garvey 2007).

To scale our observed bullfrog consumption impacts to a population-level in SD, we estimated post-metamorphic bullfrog relative abundance as a function of distance away from KWS. We estimated the slope and intercept using an analysis of covariance (ANCOVA) with reach distance covarying with month.

Results

Abundance. We captured a total of 525 bullfrogs in July, August and September, with the number of captured bullfrogs decreasing with each successive month (Fig. 2). Bullfrog relative abundance was highest at KWS (n = 355) and decreased with distance away from KWS (Fig. 2-3). We found a significant relationship between post-metamorphic bullfrog relative abundance and distance (F_1 = 11.92, P = 0.003) and this relationship did not vary with month (F_2 = 0.66, P = 0.53). Using the relationship that Relative Abundance = Distance(-0.003) + 13.47, we estimated post-metamorphic relative abundance in SD as 242 individuals each month. We believe our estimates of relative abundance are conservative because we only recaptured 16 of 201 (8%) PIT tagged individuals. Few of these recaptures occurred in SD.

The only native amphibians we observed were Western toads (*Anaxyrus boreas*) in the most downstream reach of SD. We observed all life stages (larva, metamorphs and post-metamorphs including large adults) in July, only metamorphs in August, and only post-metamorphs in September.

Diet. We identified prey items from 23 diets in July and 41 diets in August (Table 2). In July, Coleoptera (O_i=73.9%), Gastropoda (O_i=52.2%), and Arachnida (O_i=47.8%) were the most frequently consumed prey, while Muriodea (m= 22.9g) had the greatest cumulative mass (Table 2 and Fig. 4). Non-native species were consumed infrequently and comprised 6.5% of the total prey mass in July (Table 2 and Figure 5). In August, Diptera (O_i=56.1%) and Hymenoptera (O_i=48.8%) were the most frequently consumed prey, while Muriodea (m= 129.8g) had the greatest cumulative mass (Table 2 and Figure 4). Non-native species were consumed infrequently and comprised 2.3% of the total prey mass in August (Table 2 and Figure 5). September diet data are still being identified.

Relative to SD bullfrog diets, fish comprised a larger diet proportion by mass in KWS in both July and August. These fish were non-natives and included madtoms (*N. gyrinus*), green sword tails (*X. hellerii*) and cyprinid fish (likely goldfish). Small rodents in the Muriodea family comprised a larger diet proportion by mass in SD than in KWS in both July and August. We recorded fish in individuals 50 – 98 mm SVL, while we only recorded small rodents in individuals larger than 96 mm SVL. Invertebrates had a low proportion by mass in both KWS and SD, but they were common prey items in both of these habitats and observed in all but 5 diets (7%). These five individuals were > 98 mm SVL and only had Muriodea prey items in their stomachs.

If consumed prey item mass is scaled up to a conservative estimate of post-metamorphic bullfrog population size in KWS (129) and Savage Ditch (242), then bullfrogs have the potential to consume 1.5 kg of prey mass per foraging bout.

Tables and Figures

Table 1. The downstream and upstream UTM coordinates (Zone 12 T) for surveyed reaches (1-7) in Savage Ditch and the stream distance (km) of the downstream point of each reach from Kelly Warm Springs.

Reach	Distance (km) from KWS	Downstream		Upstream	
		East	North	East	North
1	4200	527993	4834047	Ditch Creek	Ditch Creek
2	3600	528313	4833542	528385	4833469
3	3000	528697	4833083	528753	4833004
4	2400	529061	4832614	529148	4832553
5	1800	529528	4832232	529612	4832177
6	1200	530077	4832007	530168	4832025
7	600	530680	4831975	530780	4831978

Table 2. Gut contents by taxonomic order for July (A, P= 23) and August (B, P=41), including mass (g) and the frequency of occurance (Oi, expressed as %). P= the number of frogs containing prey. Bold taxa represent non-natives. The unidentified fish came from a KWS diet and was presumed a non-native.

	Taxa	Common Name	Mass (g)	O_i (%)
A.	*Arachnida*	Spiders	0.26	47.8
	Coleoptera	Beetles	1.11	73.9
	Dermaptera	Earwigs	0.12	21.7
	Diptera	Flies	0.24	34.8
	Fish	**Taxa Unidentifiable**	**0.56**	**4.3**
	Gastropoda	Snails	0.69	52.2
	Hemiptera	True Bugs	0.07	26.1
	Hymenoptera	Ants, Bees, Wasps	0.36	43.5
	Ictaluridae	**Catfish**	**1.18**	**4.3**
	Lepidoptera	Butterflies, Moths	0.66	17.4
	Muriodea	Rodents, namely voles	22.96	8.7
	Odonata	Dragonflies, Damselflies	0.12	4.3
	Poduromorpha	Springtails	0.55	8.7
	Poeciliidae	**Swordtails, Guppies**	**0.15**	**4.3**
	Thiaridae	**Tropical Snails**	**0.002**	**8.7**
B.	*Arachnida*	Spiders	0.44	31.7
	Coleoptera	Beetles	0.59	24.4
	Cyprinidae	**Carps, Minnows**	**0.49**	**2.4**
	Dermaptera	Earwigs	0.10	7.3
	Diptera	Flies	5.33	56.1
	Fish	**Taxa Unidentifiable**	**0.11**	**2.4**
	Gastropoda	Snails	0.35	21.9
	Hemiptera	True Bugs	0.06	26.8
	Hymenoptera	Ants, Bees, Wasps	0.67	48.8
	Ictaluridae	**Catfish**	**2.49**	**2.4**
	Lepidoptera	Butterflies, Moths	0.72	17.1
	Muriodea	Rodents	129.82	22.0
	Odonata	Dragonflies, Damselflies	7.76	17.1
	Orthoptera	Hoppers	2.20	9.8
	Poduromorpha	Springtails	0.0001	2.4
	Poeciliidae	**Swordtails, Guppies**	**0.01**	**2.4**
	Tetrapoda	unidentifiable animal	0.35	2.4
	Thiaridae	**Tropical Snails**	**0.39**	**12.2**
	Thysanoptera	Thrips	0.0001	2.4

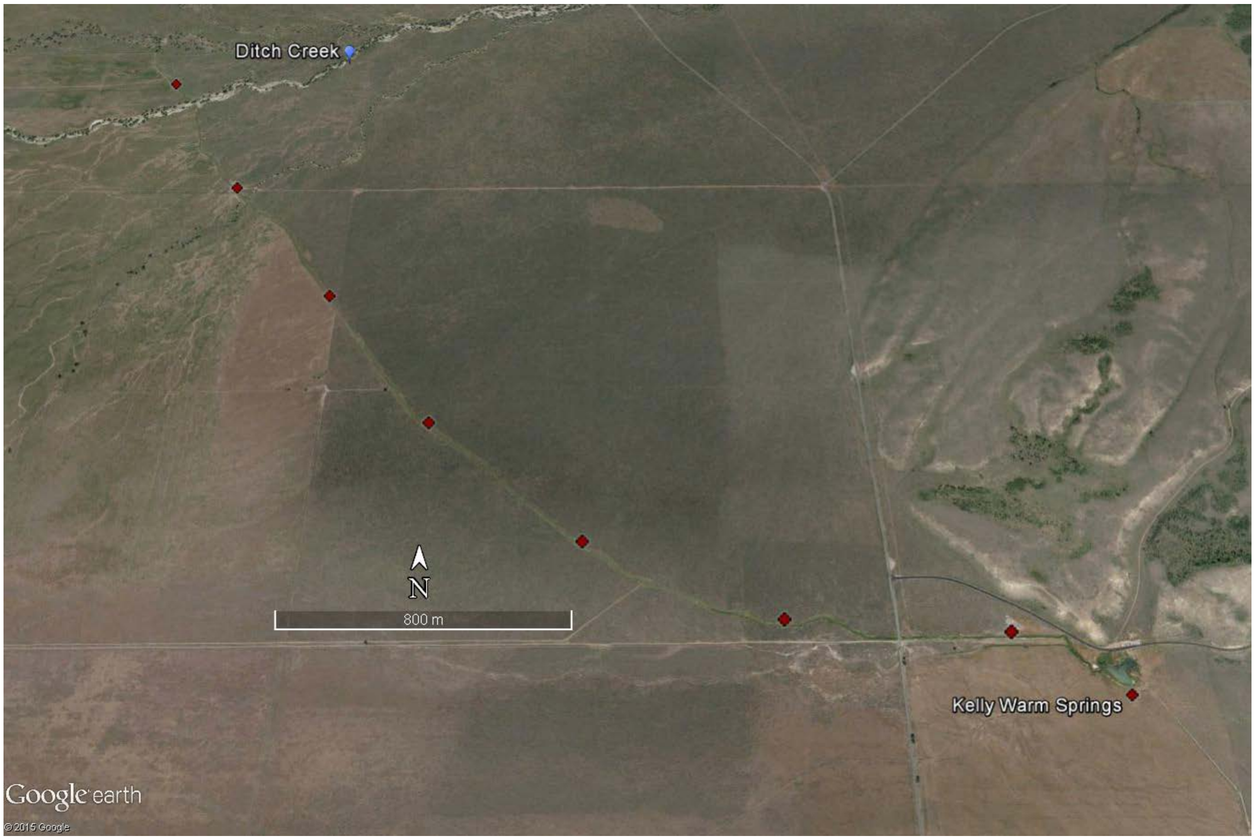

Figure 1. Map of the downstream locations of each surveyed reach in Savage Ditch and of Kelly Warm Springs. Reaches were 100-m long and separated by ~ 500 m.

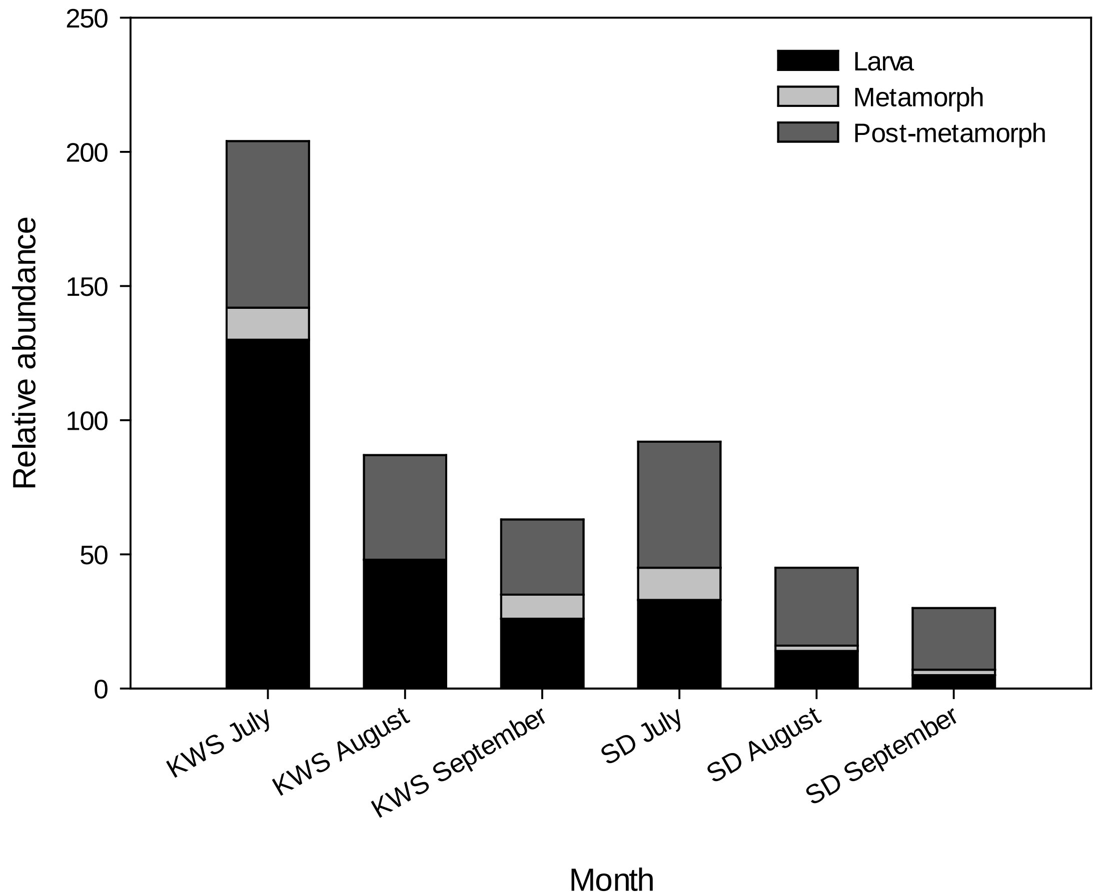

Figure 2. Relative abundance of larva, metamorphic and post-metamorphic bullfrogs each month in Kelly Warm Springs (KWS) and Savage Ditch (SD).

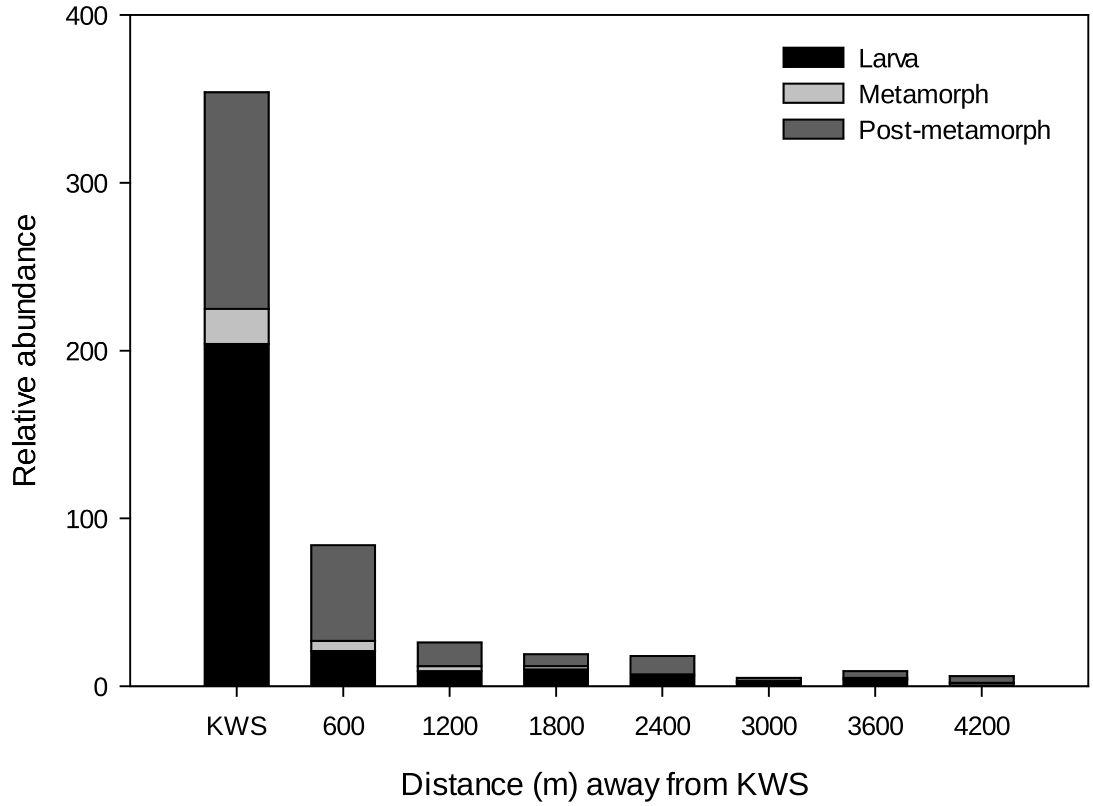

Figure 3. Relative abundance of larva, metamorphic and post-metamorphic bullfrogs in relationship to distance away from Kelly Warm Springs (KWS).

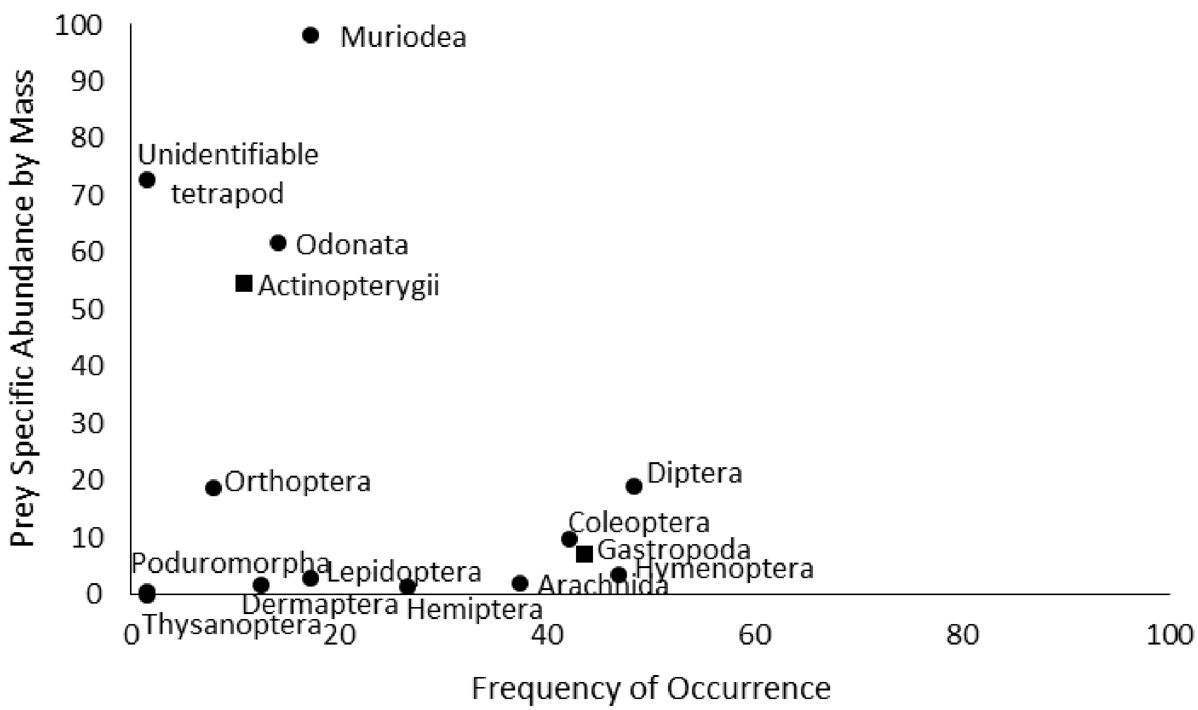

Figure 4. Biplot representation of prey-specific abundance (percent wet mass) versus percent occurrence for prey items consumed by introduced American bullfrogs in Savage Ditch and Kelly Warm Springs in July and August 2015. Squares indicate taxa that are non-native while circles indicate native taxa.

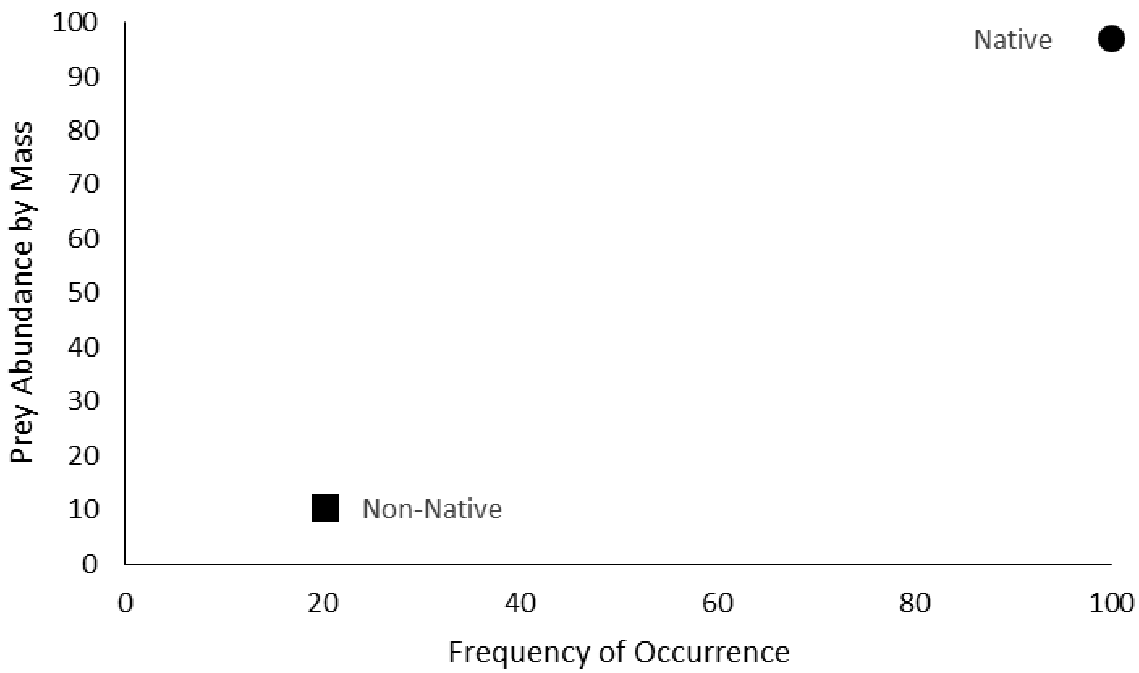

Figure 5. Biplot representation of prey-specific abundance (percent wet mass) versus percent occurrence for native and non-native prey items consumed by introduced American bullfrogs in Savage Ditch and Kelly Warm Springs in July and August 2015.