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American Bullfrogs as Invasive Species: A Review of the Introduction, Subsequent Problems, Management Options, and Future Directions

Nathan P. Snow
USDA/APHIS/WS National Wildlife Research Center, nathan.p.snow@aphis.usda.gov

Gary W. Witmer
USDA-APHIS-Wildlife Services, gary.w.witmer@aphis.usda.gov

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Nathan P. Snow and **Gary Witmer**
USDA APHIS Wildlife Services, National Wildlife Research Center, Fort Collins, Colorado

ABSTRACT: Native to the eastern United States, American bullfrogs have been introduced throughout the western U.S. and to several other countries and islands around the world. Bullfrogs are well adapted for many of the permanent water sources that occur within the U.S., and once introduced, they typically become dominant. Because of their large size and voracious appetite, bullfrogs outcompete and prey upon many indigenous species. They are hypothesized to be cause significant negative impacts, which may contribute to the endangerment and extinction of some sensitive species. There are few, if any, effective and efficient control methods to manage invasive bullfrogs. Current methods such as hand or net capture, shooting, and gigging can be labor intensive and often fail to reduce bullfrog numbers. Draining wetland habitats and broadcasting toxicants have severe negative effects on non-target species. New management options, such as locally-sprayed toxicants and multiple-capture traps, could be useful for reducing populations of invasive bullfrogs. However, researchers should make certain that non-target species are not affected by these management techniques.

KEY WORDS: American bullfrog, amphibians, introduced species, invasives, *Lithobates catesbeianus*, *Rana catesbeiana*

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INTRODUCTION

American bullfrogs (*Lithobates catesbeianus* or *Rana catesbeiana*, hereafter "bullfrogs") have been introduced throughout the western United States and the world. Their native range included the eastern U.S., extending into the Great Plains region. Bullfrogs, where introduced, are implicated in reducing various populations of native species. During 1900 - 1940, they were widely introduced into California and other western states, primarily as a food source, where they remain today (Witmer and Lewis 2001, Boersma et al. 2006). Now present in every western continental state, Hawaii, Europe, Asia, the Caribbean, and South America (Palen 2006), many introduced populations have expanded their range.

Bullfrogs directly predate indigenous frog species, which has lead to numerous frog declines (Adams 1999, Doubledee et al. 2003, Kats and Ferrer 2003). They have been able to out-compete various native *Rana* species throughout western North America, and they are a challenge to control (Hecnar and M'Closky 1997, Díaz De Pascual and Guerrero 2008). Bury and Whelan (1984) and Adams and Pearl (2007) have provided comprehensive reviews of bullfrogs and the problems they pose in the U.S. and worldwide.

Bullfrogs can be beneficial to ecosystems and for humans, but mainly where they are naturally occurring. They are an important component of aquatic ecosystems, because they are often a dominant species and can reach high population densities (Bury and Whelan 1984). Bullfrogs are often thought of as a prey species for larger predators; adults, juveniles, tadpoles, and bullfrog eggs are important food sources for a variety of aquatic and terrestrial wildlife. Bullfrogs provide some economic benefits, because some are used by humans as a food source and as research specimens (Culley 1981, Bury and Whelan 1984). However, the absence of knowledge regarding their impacts as an invasive species has resulted in little progress toward development of effective control strategies (Adams and Pearl 2007).

ECOLOGY MADE FOR INVASION

Introduced populations of bullfrogs are challenging to control because of their high mobility, generalized eating habits, and high reproductive capacity (Moyle 1973, Adams and Pearl 2007). Their large body size gives them competitive advantage over other species of smaller, native frogs (Bury and Whelan 1984). When densities are low, they have been reported to have increased survival and successful reproduction, but they can also live at extremely high densities (Altwegg 2002, Govindarajulu 2004).

Depending on body size, a female may deposit 1,000 to 40,000 eggs, which hatch in 3 - 5 days. Some females, usually only larger ones, may have two clutches of eggs in a year. In the northern portions of their range, young will overwinter as tadpoles for 1-2 years (Harding 1997), but in the southern portion, tadpoles may metamorphose during their first year (Mount 1975, Dundee and Rossman 1989). Bullfrog tadpoles are relatively large (i.e., 150 mm in length) and can occur at extremely high densities (Palen 2006). Once tadpoles metamorphose into frogs, they continue to grow and can become sexually mature in 1 - 3 years (Bury and Whelan 1984, Raney and Ingram 1941, Ryan 1953, Turner 1960).

Permanent water sources such as canals, reservoirs, marshes, ponds, and lakes are the preferred habitats of bullfrogs. In their native range, bullfrogs and other *Rana* species coexist through selective habitat preferences. Bullfrogs primarily choose the water margins, while other species selected deeper water or more inland locations (Stewart and Sandison 1972); where introduced, bullfrogs displace indigenous amphibians from those territories (Moyle 1973, Hammerson 1982, Kats and Ferrer 2003).

Bullfrogs can travel over land distances of up to 1 km to colonize new water sources (Miera 1999).

Some of the bullfrog's basic population dynamics make management options extremely limited. As some control methods are attempted, problems can be exacerbated because incomplete removal may actually increase their abundance by increasing the survival of juveniles, which serve as prey for the adults (Altwegg 2002, Werner et al. 1995, Doubledee et al. 2003, Govindarajulu 2004).

DAMAGE

Both tadpoles and adult bullfrogs are voracious feeders and can consume benthic algae and the eggs or offspring of many species of native invertebrates and vertebrates including fishes, reptiles, amphibians, water birds, and even small mammals. It is also believed that bullfrogs, once established, can compete directly with native birds, reptiles, amphibians, and fishes for limited food resources. In some cases, they also may have significant effects on aquatic vegetation. For example, tadpoles feeding on nitrogen-fixing algae can greatly influence aquatic habitats by reducing algal biomass, thereby decreasing primary production and nutrient cycling (Pryor 2003).

Declines in some indigenous species have been correlated with recent introductions of bullfrogs, thus implicating them as the cause of declines (Adams and Pearl 2007). However, some researchers have suggested that other factors (e.g., introductions of fish, alterations in habitat) taking place simultaneously with bullfrog introductions are equally, or even more, responsible for these declines (Keisecker and Blaustein 1998, Adams 1999). It has been shown that non-indigenous fish can interact with bullfrogs and the environment, which can be detrimental to native anurans (Kiesecker and Blaustein 1998, Adams et al. 2003). Regardless of differing interpretations, invasive bullfrogs are known to impact some native species via competition, predation, and habitat displacement (Boone et al. 2004, Pearl et al. 2004, others reviewed in Kiesecker 2003).

Bullfrogs may also be carriers of pathogens that can adversely affect native frog populations. Recent research has implicated introduced bullfrogs as reservoir hosts of the chytrid fungus *Batrachochytrium dendrobatidis*, which can be severely pathogenic to some amphibians (Hanselmann et al. 2004, Pearl and Green 2005, Garner et al. 2006).

MANAGING BULLFROGS

Management of bullfrog populations is difficult, in part because bullfrogs are interspersed with sensitive native species in aquatic habitats. Adult frogs are removed by trapping or hand captures, and tadpoles are destroyed by draining ponds or chemical treatment, with limited success (Bury and Whelan 1984, Moler 1994, Pitt and Doratt 2005). In some cases, habitat manipulation can be used (Adams and Pearly 2007). Because bullfrogs are extremely difficult to control and nearly impossible to eliminate, they pose a very serious challenge to restoration and conservation efforts (Boersma et al. 2006).

Adams and Pearl (2007) have suggested 3 main reasons why managing bullfrogs is extremely difficult: first, bullfrogs are well established in many parts of the western U.S.; second, their management or removal has not generated much financial support because data on their economic impacts is lacking, compared to other invasives; and third, practical control methods are few.

Hand capture, netting, gigging, and shooting are some of the methods that have been used to control bullfrogs, yet most are labor intensive and often do not reduce the bullfrog numbers to the desired level (Miera 1999). Draining ponds can potentially reduce bullfrog populations, but the effects on native species are not well understood (e.g., Maret et al. 2006). Research in California has shown promise that draining ponds every 2 years can reduce bullfrog densities enough to allow for the threatened California red-legged frog (*Rana draytoni*) to coexist (Doubledee et al. 2003). Adams and Pearl (2007) suggest that when considering draining ponds, the effect of indigenous species must be fully considered. Also, the timing of the drying event must be evaluated to avoid any rapidly-developing portion of the bullfrog population from reaching metamorphosis.

PRELIMINARY STUDIES FOR NEW CONTROL METHODS

We believe that an immediate solution is needed to reduce or eradicate localized populations of bullfrogs that serve as reservoirs for new infestations or expanding populations. Control methods potentially include (but are not limited to) chemical control and newly-designed bullfrog-specific traps.

Toxicants have potential to help in the control bullfrogs, but broadcasting toxicants in aquatic systems can be dangerous to non-target species that may be found there. We examined the efficacy of various compounds that were originally tested for controlling invasive Coqui frogs (*Eleutheradactylus coqui*) in Hawaii (Pitt and Sin 2004a,b,c; Pitt and Doratt 2005), and we also tested the active ingredient chloroxylenol (chlorodimethylphenol; Sigma-Aldrich) found in HopStop® (Pestat Pty. Ltd., Canberra, NSW, Australia), which is used on invasive cane toads (*Bufo marinus*) in Australia. In a laboratory trial, we sprayed about 4 ml of treatment solution on the entire dorsal surface of randomly-selected groups of bullfrogs, using a hand-held plastic spray bottle. Water was used as the solvent for all materials. To improve solubility, a small amount of sodium benzoate was added to the caffeine solution and a small amount of alcohol was added to chloroxylenol solution. We found 3 potential toxicants for controlling bullfrogs (Table 1). These compounds should undergo stringent testing to examine for any effects that could occur on non-target species, prior to any use in the field. Also, an effective delivery system for these compounds is necessary (e.g., local spraying versus wide broadcasting).

To help control invasive cane toads in Australia, a multiple capture trap has been developed and is being used extensively (Schwarzkopf and Alford 2006). We modified 2 of these traps so they would float on the water surface. We then tested them for 7 nights on 3 ponds along the Front Range of Colorado. We also tested multiple attractant types inside the traps. We found the most successful attractant was fishing lures (without

Table 1. Dorsally sprayed toxicant efficacy trials with bullfrogs compared to control in laboratory trials, 2008-2009. Test animals were sprayed with about 4 ml of treatment solution on their entire dorsal surface, using a hand-held plastic spray bottle.

Toxicant (concentration)	*n*	Deaths	Percent Mortality
Caffeine (10%)	5	5	100
Chloroxylenol (5%)	5	5	100
Rotenone (1%) and Permethrin (4.6%)	5	5	100
Permethrin (4.6%)	5	2	40
Rotenone (1%)	5	2	40
Calcium hydroxide (6%)	5	0	0
Citric acid (16%)	5	0	0
Potassium bicarbonate (18%)	5	0	0
Sodium bicarbonate (15%)	5	0	0
Control (water)	5	0	0

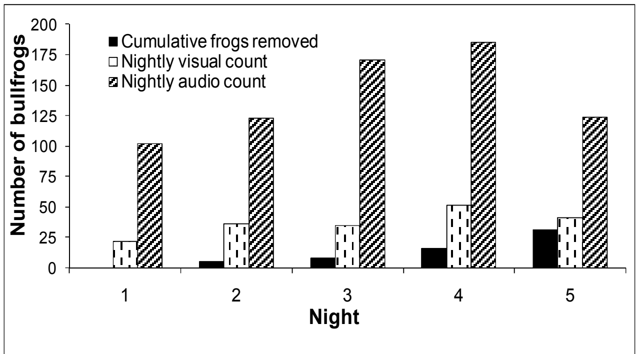

Figure 1. Bullfrogs removed and bullfrog counts (auditory and visual) at a small pond, Pueblo, Colorado, August 2009.

hooks) hanging inside the traps. The most we captured was 7 bullfrogs in a single trap overnight. While we believe that more testing should be conducted on various attractants, we think that trapping bullfrogs may be a practical method for controlling them, because little effort was needed and substantial numbers of bullfrogs were removed. Using visual and audio counts of bullfrogs as indexes of abundance, we also noticed a slight decline in the amount of bullfrogs seen or heard in a pond after 5 nights of removal via trapping (Figure 1). We suggest that more testing on the effectiveness of multiple-capture traps for removing bullfrogs, and effects of trap placement, should be conducted.

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