Removal of the American bullfrog *Rana (Lithobates) catesbeiana* from a pond and a lake on Vancouver Island, British Columbia, Canada

S. A. Orchard

BullfrogControl.com Inc., 69A Burnside Road West, Victoria British Columbia, Canada, V9A 1B6. <bullfrogcontrol@shaw.ca>.

Abstract The American bullfrog is listed as one of the 100 Worst Alien Invasive Species internationally because it is adaptable, prolific, competitively exclusive, loud, and predatory. An expectation of profits from the sale of frog legs for human consumption has led to bullfrogs becoming established on most continents as well as on islands in western Canada and the western United States, Hawaii, throughout the Caribbean, Crete, Indonesia, Japan, Singapore, Sri Lanka, and Taiwan. The ecological impact of bullfrogs on islands can be profound especially where ecologically vital freshwater resources may be limited. While the problems created by bullfrogs are well-documented, there have been few technological advances in their effective control and management. In 2006, a programme was initiated to design, field test, and refine new equipment and tactics to capture individual bullfrogs at rates to exceed replacement. The programme also hoped to demonstrate that bullfrog eradication is a feasible and practical option. The principal manual capture technique is modified fisheries electro-shocking tailored specifically for capturing juvenile (<80 mm body length) and adult (>80 mm body length) bullfrogs. Bullfrog tadpoles are not hunted directly but collected as they reach the latter stages of metamorphosis or have recently transformed. Clear patterns have emerged from comparative data sets collected between 2007 and 2009 that identify some basic units of bullfrog eradication, including logistical and time sequence requirements for successful removal of all age-classes from a single lake or pond after only one successful spawning. The two case studies presented here illustrate patterns useful for interpreting catch results and for predicting the time, effort, and costs in carrying out complete site eradications. In both examples, 'site eradication', i.e. reducing numbers of all bullfrog age-classes at one site from hundreds or thousands to zero, was carried out by one two-person team and achieved over three years with only a few nights effort per site per year. The cost of running this programme is currently $400/night/2-person team. At Amy's Pond (0.4 km perimeter distance), 1587 adult and juvenile bullfrogs were collected after 23 nights of effort spread over 3 years for a total cost of CAN$9200. At Glen Lake (2 km perimeter distance), 1774 bullfrogs were collected after 41 nights of effort spread over 3 years for a total cost of CAN$16,000.

Keywords: Amphibian management, eradication, control, site eradication, electro-frogging, cost-effective

INTRODUCTION

Populations of alien invasive American bullfrogs, (*Rana (Lithobates) catesbeiana),* are now established in western North America, western Europe, south and east Asia, and Central and South America. Historically, live bullfrogs were exported from their native range in eastern North America to establish new wild populations supplying international markets for frog meat. Bullfrogs acclimatise readily to habitats ranging from temperate to tropical. Rapid population growth rates coupled with migration outward from source population leads eventually to bullfrogs in all habitable lakes and ponds. The result is potentially catastrophic for native species that are prey to this large, abundant and aggressive non-native predator. Eradication of bullfrog populations has been proposed out of concern for the sustainability of native ecosystems and species diversity, but also because of human objections to the noise produced by choruses of large male bullfrogs and their consequent effects on property values. Continental bullfrog populations can spread out geographically over wide areas. However, island populations are area-constrained, often with relatively few vital freshwater spawning 'sites' available and surrounding habitat that is bounded on all sides by a barrier of saltwater. Islands therefore have advantages if bullfrog eradication is to be attempted. Once eradication is achieved, islands should also be easier to keep bullfrog-free.

Vancouver Island is the largest island on the west coast of North America (32,134 km^2). Its cool mountainous interior, vast tracts of rocky terrain and thick forest restrict or inhibit bullfrog dispersal. However, bullfrogs have been released and are spreading from multiple disjunct pocket populations along the low, warm, coastal zone of south-eastern Vancouver Island. They have also been introduced to smaller, adjacent islands, and have for many decades populated regional Vancouver on the adjacent mainland coast (Fig. 1).

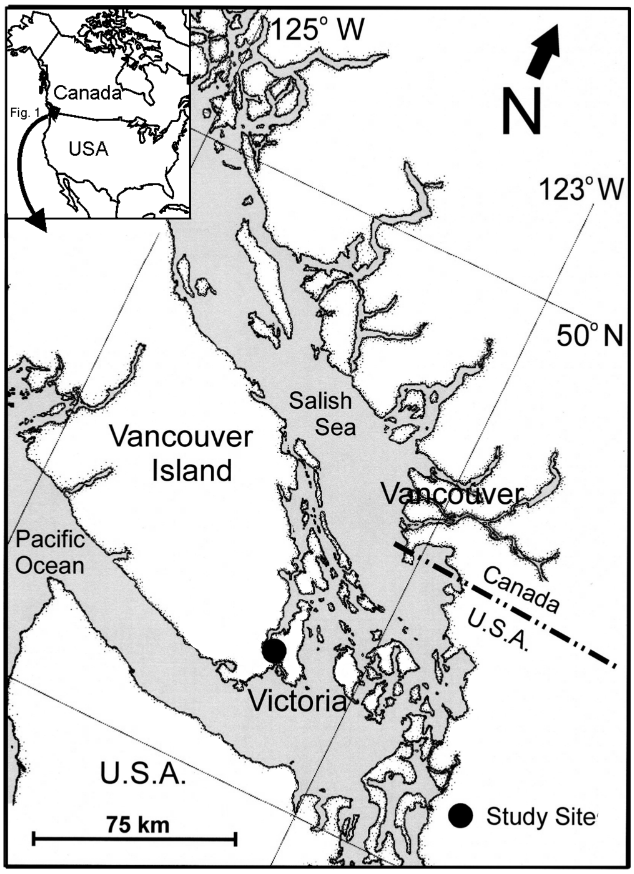

Fig. 1 Location of case study sites on the Saanich Peninsula, Vancouver Island, British Columbia, Canada.

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There are few published case studies of bullfrog eradication, and the few successful examples were laborious and costly (Adams and Pearl 2007; Kraus 2009). In England in 1996, the eradication of bullfrogs from only a few small ponds cost approximately US$70,000, including the earth-moving equipment that ultimately destroyed freshwater habitat (Banks *et al* 2000; CABI Bioscience 2005). In Germany between 2001 and 2004, bullfrogs were eradicated from five ponds with help from a volunteer force of 20 as well as the local fire department and an 'electro-fish' team. Cost estimates for this project were US$80,230/pond/year for five ponds or US$409,000 annually (Reinhardt *et al* 2003; Nehring and Klingenstein 2008). These European case studies utilised large work forces and heavy equipment beyond the budgets of many agencies. Other attempts at managing or eradicating invasive bullfrog populations have used netting, barrier fencing, seining, shooting, gigging (spearing), pitfall traps, and pond draining. These technologically unsophisticated attempts have been mostly ineffectual, excessively labour-intensive, and unable to keep pace with the bullfrogs' prolific reproduction and mobility. Such attempts are particularly difficult where populations have grown to maturity and have dispersed geographically before any control efforts were attempted. A general impression is then formed that bullfrog eradication may be feasible through the intense countervailing efforts of a large and dedicated workforce, but the time-consuming exertions required also make these measures exorbitantly expensive and generally impractical (Adams and Pearl 2007; Krause 2009).

In this paper I describe cost-effectiveness of methods used to remove bullfrogs from a pond and a lake on Vancouver Island, British Columbia, Canada. For the purposes of this study, I use the following definitions:

A 'bullfrog site' is a discrete body of standing water – generally a lake, pond, or pool – where some or all life stages of bullfrogs are present. When all sites are identified regionally and brought 'under control' by the eradication programme then eradication is inevitable because standing water is vital for population sustainability and growth.

'Productive sites' have the essential elements of: 1) permanent water that does not freeze to the bottom of become anoxic in winter; and 2) summer surface temperatures that reach and exceed 25° C. for an interval of weeks in mid- to late summer to facilitate reproduction. Permanent water is a requirement because, at this latitude, bullfrog tadpoles will commonly take 24 to 36 months to reach metamorphosis.

'Non-productive sites' are either: 1) impermanent pools that trap and kill bullfrog tadpoles before they metamorphose; or 2) too cool in summer for reproduction to occur, e.g., <25° C. Non-productive sites are useful only to migrating bullfrogs as way stations or as over-wintering sites.

STUDY SITES

The two case studies presented here are drawn from preliminary results of a long-term regional control program that encompasses a cluster of lakes and ponds at the isthmus of the Saanich Peninsula, at the extreme southern end of Vancouver Island, including the City of Victoria (Fig. 2). The particular significance of the case studies presented is that the sites are dissimilar in size and habitat characteristics, but comparable in their stage of bullfrog colonization. In both instances, fieldwork began shortly after the arrival of adult bullfrogs and after one spawning had occurred at each site. It was unknown at the start how many tadpoles would reach metamorphosis and how much time and effort would be required to capture them all post-transformation. The innovative manual capture technique developed specifically for this program was, at that stage, untested. At the end of the third field season (2007 – 2009) it was possible to quantify material costs, time and effort required to de-populate both sites using the 'electro-frogger' technique.

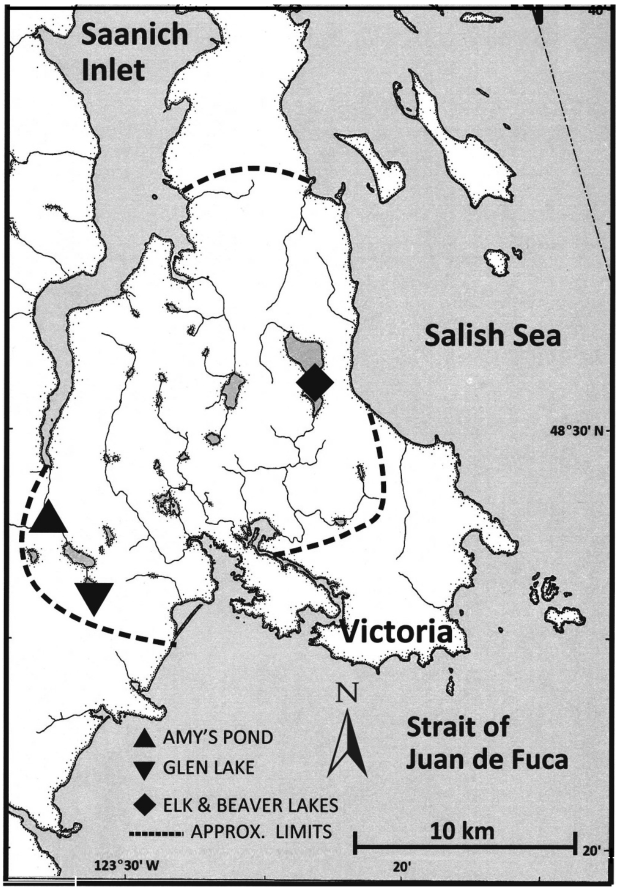

Fig. 2 Site of the founding bullfrog population (diamond) and current approximate distribution limits of bullfrogs on the Saanich Peninsula, British Columbia, including the case study sites Amy's Pond and Glen Lake.

1. Amy's Pond

At Amy's Pond the margins were essentially bare of aquatic and emergent vegetation throughout the summer. This meant that despite somewhat turbid water, there was good visibility at the surface and accessibility to the margins. With a perimeter distance of only 0.4 km, many circuits of Amy's Pond could be made in a single three-hour evening session and virtually every individual of every post-larval age-class present could be located and captured on any given night.

2. Glen Lake

Glen Lake had a perimeter distance of about 2 km, or five times the margin of Amy's Pond. It was also much more florally complex with many species of aquatic, floating, and emergent plants, as well as riparian shrub and tree thickets. These all provided effective cover for bullfrogs, impeded vision during searches, and interfered with the ability to manoeuvre during approach and capture. Unlike at Amy's Pond, only one thorough circuit of Glen Lake could be completed per evening and this only when bullfrog numbers were very low. While bullfrog densities were high, only a portion of the lake margin could be cleared per evening session.

MATERIALS AND METHODS

For this programme, one two-person team is the minimum manpower unit so what follows are the requirements to equip, transport, and fund one team. Transportation includes a utility vehicle and a very sturdy inflatable rowboat. Essential field equipment includes a modified fisheries electro-shocker, 'electro-frogger' pole, powerful spotlights, and two chest freezers, with one modified to maintain a temperature slightly above freezing. The freezers were used in a two step euthanasia procedure.

On southern Vancouver Island, the field season began in April and ended around the beginning of October. Fieldwork was weather-dependent and incompatible with excessive wind (> 15 km/hr) or rain. As explained, the case studies are part of a larger regional programme that encompassed many more sites. Regionally, we worked every night with suitable weather, which amounted to 93 nights in 2007 (19 sites/4,479 bullfrogs), 114 nights in 2008 (20 sites/3,430 bullfrogs), and 125 nights in 2009 (28 sites/3872 bullfrogs). Costs averaged about $400/night/team or CAN$37,200 in 2007, CAN$45,600 in 2008, and CAN$50,000 in 2009. The programme also included daytime site assessments, examination and measurement of the catch, dissections, data compilation and analysis, and write-up of results. On-going annual maintenance costs included permits and licences, liability insurance, and automobile insurance, as well as routine costs such as fuel, facilities, utilities, website, public relations and equipment repair and replacement.

In 2006, a prototype electrode-fitted pole (electro-frogger) was developed and field tested, and more refined, patent-pending versions have been employed since 2007. During the summers of 2007 to 2009, a two-person team applied this manual capture technique for four-hour sessions on every evening that weather permitted. A four-hour session included loading and unloading equipment, so the time locating and capturing bullfrogs was approximately three hours. Teams worked at night from an inflatable boat, with one person to manoeuvre and position the boat while the second person located and caught juveniles (< 80 mm body length) and adults (> 80 mm) frogs. Pond and lake margins were scanned by spotlight to detect bullfrogs by their eye reflections. Vocalisations from adult male bullfrogs also independently identified their whereabouts. Bullfrogs were dazzled and transfixed by the spotlight's beam as we approached. Then the electrode-fitted pole was used to generate a subsurface concentrated electrical field of < 50 cm diameter near the target bullfrog. The electrical field stunned and temporarily paralysed juvenile and adult bullfrogs for 30 seconds to one minute, which was enough time to get them into a container. The technique is humane, species-specific and only targets one bullfrog or small groups of bullfrogs in very close proximity to one another. Capture rates, on any given night, are influenced by each site's habitat characteristics, weather, and bullfrog density and demographics.

For euthanasia, bullfrogs were placed into a chest freezer modified to lower their core body temperature to just below 2° C. After at least 12 hours they are transferred to a conventional deepfreeze that quick-freezes the now cold-stupified bullfrogs. They remain in the second freezer for at least 48 hours. Cold is a natural anaesthetic for amphibians and freezing leaves an uncontaminated, chemical-free carcass that can be safely used to feed injured wildlife, donated to high schools for educational dissections, or composted.

RESULTS

In the spring of 2007, Amy's Pond and Glen Lake were at the same initial stages of bullfrog colonisation. At Amy's Pond, few adults were present, there were a few new arrivals, and there had been one successful spawning 12 to 24 months previously, which produced many tadpoles. Around mid-summer 2007, this single cohort of bullfrog tadpoles began to metamorphose and on 30 August we collected 237 transforming or recently transformed juveniles and five adults. Transformations continued throughout the remainder of the summer, but the number of juveniles captured per evening declined markedly with each subsequent visit in 2007 (Fig. 3a).

Fieldwork re-commenced in April 2008 (Fig. 3b) as the over-wintered remnant of the same cohort became active and began to complete their transformations. By the end of the 2008 season, we could find no bullfrogs of any age-class.

Our 2009 results confirmed that the metamorphosis event that began mid-summer 2007 was essentially over by mid-summer 2008. Spawning was prevented from 2007 onward by clearing the pond of all adults prior to the mid- to late-summer spawning period. By 2009, Amy's Pond was tadpole-free, though there was a small but persistent influx of juveniles and young adults from adjacent lakes and ponds.

Ultimately, we removed 1587 bullfrogs from Amy's Pond by investing 3 hours of collecting effort in each of 23 nights spread over 3 consecutive summers. By the end of the 2008 season, bullfrog numbers had been reduced to zero and all bullfrogs encountered thereafter were the result of immigration or release. The total cost for this three-year (23 nights) effort was CAN$9200 (Table 1).

Like Amy's Pond, Glen Lake was in the earliest stage of bullfrog colonisation in 2007 with just one successful spawning. By mid-summer 2007, bullfrog tadpoles first noted in late-2006 had begun to metamorphose. On 25 July, we collected 59 bullfrogs (Fig 4a), all but one of which was either in the latter stages of metamorphosis or had just recently completed transformation. From 25 July to 16 August, we concentrated on one end of the lake where the number of juveniles was high and the conditions were especially difficult due to extensive patches of cattail, rushes, water lilies, various floating aquatic plants, and willow thickets. By 17 August, one end of the lake was clear of bullfrogs and efforts were moved to the opposing end, which was also heavily vegetated. Tadpole metamorphosis followed a pattern similar to Amy's Pond, commencing in mid-summer 2007 with transformations continuing throughout that summer (Figs. 3a, 4a).

Table 1 Comparison of site characteristics with time and cost of achieving 'site eradication'

Sites	Perimeter	Littoral/ Riparian	Nights/year	Catch/year	Cost/year	3-year total catch/cost
Amy's Pond	0.4 km	Florally barren	8/2007 10/2008 5/2009	871 661 55	$3200 $4000 $2000	1587/$9200
Glen Lake	2.0 km	Florally abundant & complex	16/2007 16/2008 9/2009	1376 366 32	$6400 $6400 $3600	1774/$16,400

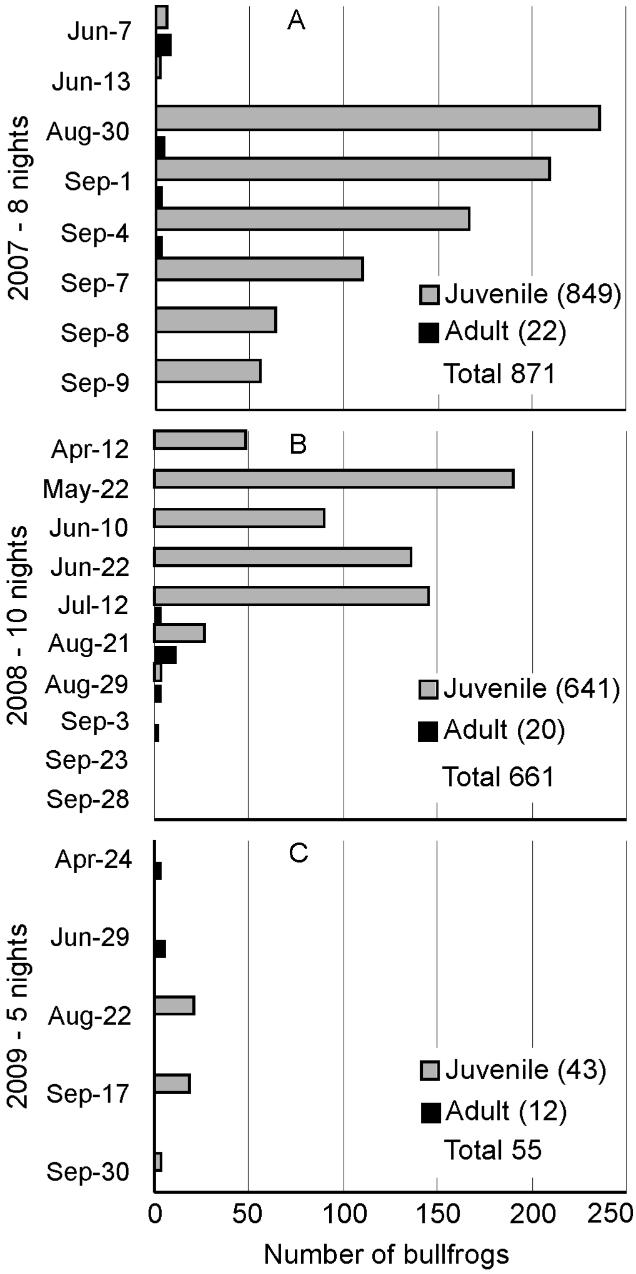

Fig. 3 Amy's Pond chronology and nightly capture results 2007- 2009 (n = 1587).

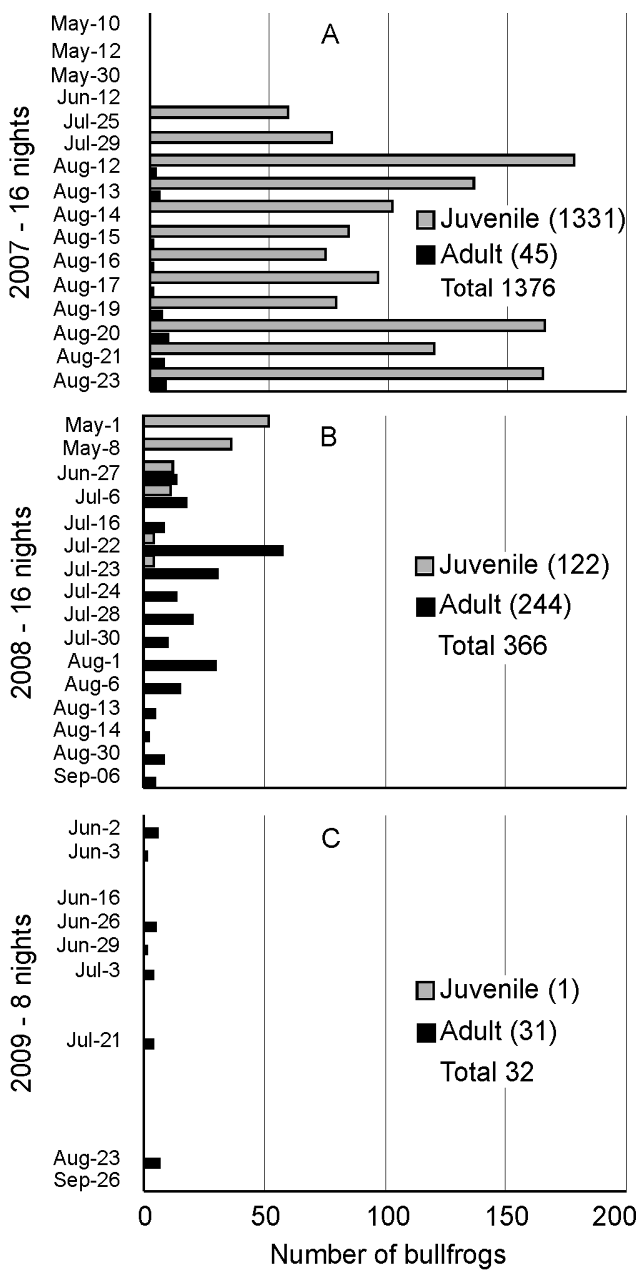

Fig. 4 Glen Lake chronology and nightly capture results 2007 - 2009 (n = 1774).

The 2008 season (Fig. 4b) began with a resumption of metamorphosis that tapered off to near zero by mid-summer. Adults recorded from 27 June onward undoubtedly included a few immigrants but were primarily Glen Lake juveniles whose body lengths had grown rapidly to young adult size (>80 mm body length) before we were able to locate and capture them.

In 2009, there were only a few newly arriving adults and juveniles. Total costs for this three-year (41 nights) effort was CAN$16,400 (Table 1).

DISCUSSION

By the end of the 2009 field season, all age-classes of bullfrogs had been successfully removed from both sites. Excluding repopulation through natural immigration or human translocation, both Amy's Pond and Glen Lake were then free of bullfrogs.

The two case studies are comparable because both had only one spawning per site. Without knowing how many eggs were produced by each of the two adult females there was nevertheless remarkable similarity in the timing and interval of tadpole transformation, and in the numbers of metamorphs/juveniles ultimately captured. If it is assumed that each female produced thousands of eggs, then there must have been considerable mortality in the tadpole stage to have resulted in only about 1,500 metamorphs/juveniles taken from each site. This is one reason to ignore the tadpole stage and concentrate on capturing the post-metamorphic stages if tadpole mortality is consistently high.

Another similarity between these case study results is a pattern of asynchronous cohort transformations from tadpole to juvenile that stretches over 12 months and two calendar years. For example, for each cohort there was an induction stage to this incremental metamorphosis that commenced about mid-summer of one year and continued throughout the remainder of the active season, e.g., July to October. However, some of this tadpole cohort did not metamorphose before the onset of winter, completing transformation the following spring in a protracted conclusion stage, e.g., April to August that peaked in spring. If this pattern proves to be consistent, a manual capture technique that targets only post-metamorphic stages will, by necessity, require two calendar years or more to clear a

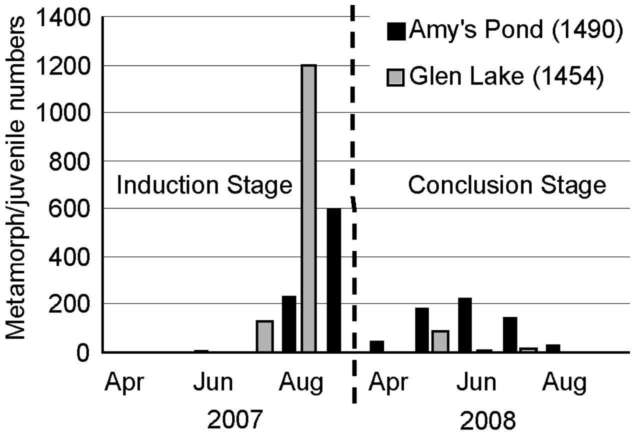

Fig. 5 Comparative capture results of the metamorph/juvenile size-classes (<80 mm body length) from Amy's Pond and Glen Lake. Both sites exhibited a 2-stage incremental cohort metamorphosis.

lake or pond of all bullfrogs. If spawning has occurred in two or more consecutive years then the removal process will take three or more calendar years to complete. At Amy's Pond, 57% (849) of our 2-year total of 1490 metamorphs/juveniles were captured during the induction stage in 2007 and the remaining 43% (641) during the conclusion stage in 2008. In Glen Lake, 92% (1332) of our 2-year total of 1454 metamorphs/juveniles were captured during the induction stage in 2007 and the remaining 8% (122) during the conclusion stage in 2008 (Fig. 5).

The electro-frogger manual capture technique demonstrated a capacity to collect as many as 241 bullfrogs per three-hour session at Amy's Pond and 181 per three-hour session at Glen Lake (Fig. 3, 4).

CONCLUSIONS

1. The manual capture 'electro-frogger' technique, when competently and diligently applied and when coupled with various pieces of essential accessory equipment, successfully located and captured juvenile and adult bullfrogs at rates that far exceeded replacement.

2. The 'electro-frogger' does not place all individuals of the population at risk simultaneously because the tadpole stage is largely unaffected. However, as tadpoles transform from landlocked aquatic larvae to semi-aquatic juveniles they rise to the surface and become vulnerable to capture.

3. At the latitude of Vancouver Island, adult bullfrogs can be successfully located and removed as they emerge from winter torpor (April – May) and prior to the spawning season (July – September). This means that with appropriate intensity of effort, bullfrog reproduction can be prevented within the first few weeks of the first year of an eradication programme and similarly prevented in subsequent years.

4. A singe two-person team can eradication bullfrogs from small to medium-sized water bodies but the number of nights per year required per year will vary depending upon perimeter distance and habitat characteristics at each site as well as the age-class complexity of the bullfrog population. An additional team would not have reduced the number of nights or number of years required to bring Amy's Pond under control. However, the number of nights per year spent on the much larger Glen Lake would have been significantly reduced by adding a second team. The number of years, however, remains independent of the number of teams deployed since each cohort of tadpoles begins to metamorphose in one calendar year and finishes in the next.

5. Where bullfrogs have spawned more than once in the same year, at the same site, the number of resultant juveniles will be numerically greater than reported here. However, they can still be removed within two years from the onset of metamorphosis if sufficient effort is applied in terms of increasing the number of field nights per year and/or increasing the number of teams active per site per night. Where there has been multiple spawning in each of two or more consecutive years, then it will take three to four years to achieve the same result with appropriate proportional increases in the intensity of effort.

6. The case studies presented here represent an environmental situation characteristic of a particular latitudinal range and climatic regime. Results from southern British Columbia should be directly relevant to bullfrog invasions in Europe, northern Asia, western United States, and possibly southern South America. It would be helpful to have comparative data sets from subtropical and tropical regions where bullfrogs are active year-round and the tadpoles reach metamorphosis within 12 months. Conceivably, a comparable programme in warmer climates with no winter dormant period would move along much faster than in these case studies, in which case site eradication through manual electro-frogging may be achievable in as little as 12 months.

7. The proposition that bullfrog eradication is neither feasible nor practical is contradicted by this study. Furthermore, the technique used is time-efficient, cost-effective, humane, and safe for personnel and the environment.

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