American bullfrog management on Vancouver Island

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Claire Errico
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Executive Summary

The American bullfrog (*Lithobates catesbeianus*) is an invasive amphibian native to the eastern region of North America that is now located throughout the south west coast of British Columbia due to ill-fated frog’s legs operations. Brought to Vancouver Island in the 1930’s, the American bullfrog has spread throughout the south island and threatens to establish in the Greater Victoria Water Supply Area causing concern among the area’s management team in regards to the impacts on water quality and native ecology. Proposed management strategies include eradication, habitat modification, education, and increased water treatment through filtration.

There is very little information on the public health and turbidity impacts of the American bullfrog. There is no information on how high densities affect turbidity in their native range and in areas where they have established as invasive species. Much of the research on pathogens carried or distributed by the American bullfrog that is available is vague and is not directly tied to human health. There is preliminary research available that suggests that the American bullfrog can act as a carrier for *E.coli.*, but that research has yet to progress further than controlled tests in well controlled situations. From a water quality perspective, there is not enough information at this point to justify management of the species. Little work has been done, likely because it is not seen as a threat to water quality parameters in its native range.

However; ecologically, current research strongly suggests that the American bullfrog has a negative impact on the growth and development of the pacific tree frog (*Pseudacris regilla*) and the blue-listed northern red legged frog (*Rana aurora*) but these impacts may be mitigated through habitat modification (Govindarajulu, 2004). Due to the complex relationships between invaders and indigenous environments the biggest risk associated with bullfrogs on southern Vancouver Island is the potential for a trophic cascade of unknown impacts on ecosystem services if bullfrogs were to eliminate or severely reduce the population numbers of indigenous species. From the perspective of a responsible land and resource management, this threat to native species and predator-prey systems is enough to justify management of the species, especially regarding the vulnerable classification of the red-legged frog.

Of the management options available, the recommended method is a combination of habitat modification, bullfrog population control, and education to protect native species and ecosystems and to prevent further dispersal of the species. Complete eradication and filtration treatment plants are not necessary at this point without solid information on the impacts of the species. The existing infrastructure and treatment regime of chlorination and UV treatment is sufficient to kill or neutralize any pathogenic or bacterial threat that may emerge as a result of bullfrog establishment within the watershed.

Keywords: invasive species, threat, watershed, turbidity, pathogen, ecology, environment, risk, strategy, protection, cost, eradication, education, habitat modification, filtration
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Introduction

Invasive species are introduced to new environments regularly, such as the American bullfrog in the Greater Victoria Watershed Area, and there are significant risks associated with the uncertainty of their impacts. Do risks associated with establishment and dispersal of invasive species justify spending on species management? Since globalization began, “120,000 non-native species of plants, animals and microbes have invaded the United States, United Kingdom, South Africa, and Brazil” (Pimentel et al., 2001) and while some of these species have been beneficial to humans such as wheat (*Triticum spp.*) and corn (*Zea mays*), others cause a great deal of damage to resources and infrastructure. Invasive weeds represent a 12% agricultural loss ($33 billion) in the United States per year and in Australia, the European rabbit (*Oryctolagus cuniculus*) is responsible for loss of pasture land and agricultural land costing approximately $200 million per year (Pimental et al., 2001). The invasive European zebra mussel (*Dreissena polymorpha*) population in the Canadian Great Lakes has grown so large that it “reduces food and oxygen for native species” (Pimentel et al., 2001) and has been known to “invade and clog water intake pipes and water filtration plants” (Pimental et al., 2001). The costs associated with the zebra mussel have already exceeded $5 billion in damage. Water security and economics becomes a significant concern when dealing with invasive aquatic species.

Worldwide there are several cases that demonstrate the damage that invasive amphibian species can have on native ecosystems. The brown tree snake (*Boiga irregularis*) in Guam, between 1963 and 1986, was responsible for the extinction of 10 of 11 indigenous bird species (Atkinson, 1996). In South Africa, the red eared slider (*Trachemys scripta elegans*) has had a significant impact on 12 indigenous terrapin species (Pimental et al., 2001). In Australia the Cane toad (*Bufo marinus*) has had devastating effects on local ecology (Shine & Wiens, 2010). The American bullfrog (*Lithobates catesbeianus*) has invaded widely yet the impacts are relatively unknown. The bullfrog has invaded Argentina, Uruguay, the south Pacific, the Caribbean, Japan, and Europe and is known for its voracious appetite (Akmentins & Cardozo, 2010)(Laufer et al., 2008)(Snow & Witmer, 2011). In many of these places, little is known about their impacts although they have been established for decades (Snow & Witmer, 2011). One of the main concerns regarding invasive species (terrestrial or aquatic) is that “a complex of ecological factors allows alien species to become abundant and emerge as ecological threats in their new ecosystems” (Pimental et al., 2001).

In the case of the American bullfrog, studies have suggested that it could be devastating to local ecosystems and in turn cause problems associated with water quality as has occurred with other invasive species, but nothing conclusive has emerged. The main challenge in evaluating the impact of the American bullfrog on water supply is that it is incredibly difficult to know how damage to an ecosystem through competition or predation relates to the effectiveness of ecosystem service provided. This is a big concern for water managers, especially with increasing human population levels depending on a water supply that remains the same. Invasive species could create a trophic cascade of effects that are unknown or unrecognized until it is too late to manage them at a cost effective level.
Risk Assessment

From a management perspective, invasive species can “include organisms that generate both public health and environmental concerns, risk assessments for these species provide opportunities to integrate human health and ecological risk issues” (Anderson et al., 2004). Currently the Invasive Species Council is working with organizations such as the Convention on Biological Biodiversity, the World Health Organization for Animal Health and the International Plant Protection Convention to develop standards and risk assessment strategies based on “sound scientific principles” (Anderson et al.,2004). Decisions on whether or not to manage for invasive species “cannot be made on the basis of science alone” (Anderson et al., 2004) and decision makers must also “weigh legal, economic, administrative, social, and cultural values” (Anderson et al., 2004) when deciding how to move forward with invasive species management. One way to address this could be through a willingness-to-pay analysis of the general public regarding bullfrog management and dispersal prevention.

This paper will address whether management is justified on southern Vancouver Island by existing scientific information on water quality concerns such as turbidity and public health, and implications for native species and environments related to bullfrog establishment. The approach will consist of a review of existing literature, expert interviews, and analysis of each. By looking at current management concerns and strategies of the Capital Regional District regarding the American bullfrog in the Greater Victoria Water Supply Area and associated literature regarding the American bullfrog, I also assessed whether species management is necessary from a water quality, ecological and cost perspective view on southern Vancouver Island and what further study is needed on the subject to direct management decision making. Vancouver Island is located off the southwest coast of British Columbia in the temperate rainforest. The southern island is in the rain shadow of the Washington states Olympic mountain range. The dominant biogeoclimatic zone is coastal western hemlock with a minor component of coastal Douglas-fir zone in the southeastern portion where the influences from the Olympic peninsula rain shadow are the highest. The majority of residents on Vancouver Island live in the drier coastal Douglas-fir zone and it is there where the American bull frog population occurs.

Species information

In their home range, American bullfrogs have been shown to have negative effects on ecology but population levels are well controlled by predators such as the channel catfish, yellow perch, eastern newt, large diving beetle, Virginia opossum, eastern painted turtle, common snapping turtle, red billed gull, and double crested cormorant (Behler, 1979). Local predators may include the great blue heron, racoons, barred owls, red tailed hawk, or the bald eagle (Behler, 1979). It is also possible that because they are new to the ecosystems, local predators do not see bullfrogs as prey or find them unpalatable (Roach, 2004). There is no information available on whether they present a risk to water quality in water bodies where they are established at high densities in their home range. This is likely because they do not present a threat in those areas because they evolved with the ecosystem and population controls are in effect.

The American bullfrog is native to eastern North America. They are currently found throughout southwestern British Columbia in the following physiographic provinces: the coast and mountains, the Georgia depression, and the southern interior. They prefer to live in permanent, warm, shallow, open
ponds with vegetative cover in which they can hide from predators. They can also be found in marshes, slow moving streams and temporary wetlands which they use as travel corridors between permanent habitats (Corkan & Thoms, 2006).

American Bullfrogs breed in the late spring and early summer, with the female laying egg masses of approximately 20,000 eggs in a sheet on the surface of a permanent pond (Pauly et al, 2009). These egg masses may sink and attach to submerged vegetation but they also gather into a distinct softball-sized ball that becomes only partially submerged. Eggs typically hatch 3-5 days later, depending on water temperature (McKercher & Gregoire, 2011). The tadpoles are much larger than native amphibian tadpoles and on Vancouver Island usually metamorphose after two years due to the cooler climate. Tadpoles can be identified by their long bodies, short tails, and orange or bronze eyes. Juvenile bullfrogs emerge near the end of the second spring and are typically larger than the adults of other frogs in this region. They can be identified by a large ear drum partially surrounded by a ridge or a groove and can be green or brown with black spots on the back and on the top of their snouts (Corkan & Thoms, 2006). In some cases, juveniles can also be identified by a distinct ‘yep’ that individuals let out when startled. Mature adults are similar to the juveniles with the ridge around the eardrum and can be green, dark brown or tan coloured. The main difference is that the males have a distinct yellow throat with grey mottling and females have a whitish throat with grey mottling.

American bullfrog adults and juveniles are carnivorous and have a local reputation in the southern Vancouver Island Region of eating whatever will fit in their mouths. They typically dine on aquatic insects, insects, and other smaller amphibians. Tim Goater at Vancouver Island University is currently doing a diet study of bullfrogs from the southern Vancouver Island population and has found the remains of crayfish, aquatic insects, native amphibians, and small mammal bones (Goater, 2012).

Area information
Southern Vancouver Island off the southwest coast of British Columbia is located in the rain shadow of the Olympic Peninsula in Washington State. The main population of American bullfrogs is located in the lower elevation (0-100m) coastal Douglas fir biogeoclimatic zone. The area of concern is the Greater Victoria Water Supply Area (GVWSA) which consists of the Sooke and Goldstream water catchment areas. These basins provide the primary and secondary water supply for the Greater Victoria region which covers the Saanich Peninsula to the

Figure 1: Distribution of American bullfrog on Vancouver Island (from: http://web.uvic.ca/bullfrogs)
outskirts of Sooke supplying approximately 300,000 industrial and private customers (Ussery, 2012).

The GVWSA is predominantly coastal western hemlock and largely above the elevation distribution of the American bullfrog. However, there are many small streams and wetlands within the catchment areas which could provide the bullfrog with easy dispersal pathways. Currently the area of concern is the southern area around the Humpback reservoir near Goldstream Park (Ussery, 2012). This area is the focus of the existing bullfrog removal program because it is the closest population to the catchment area as it is on the border of the defined watershed area.

The American bull frogs were introduced to Southern Vancouver Island in the 1930s via an ill-fated frog leg farm in Saanich (Govindarajulu, 2004). When the business did not work out, the couple running the farm let the remaining frogs free into local waterways. Since then, the bullfrog population has grown and occupies ponds throughout the greater Victoria area (Govindarajulu, 2004).

Criteria

The Vancouver Island Health Authority (VIHA) follows the parameters laid out by the Guidelines for Canadian Drinking Water Quality (GCDWQ). The American bullfrog has the potential to impact the taste and odour through increased turbidity, to be a carrier or vector for disease or bacteria that may be harmful to humans such as \textit{E.coli}., and to have irreversible damaging effects on indigenous ecosystems.

Turbidity

Turbidity could be affected by increased tadpole/juvenile bullfrog populations stirring up increased amounts of sediments due to their increased size and the lower number of sediments. Native frog populations do not significantly contribute to these problems because they are much smaller and their population levels are controlled through predation and inter/intra specific competition. Congregation of bullfrogs around water intakes and waste buildups could be another contributor to increased turbidity if there is a dramatic increase in population size (Buckland, 2012). Turbidity is measured using Nephelometric Turbidity Units (NTU) which is a measure of scattered light off of particles in the water.

“Treated water must have <0.1 NTU at all times. Where possible, filtration systems should be designed and operated to reduce turbidity levels to as low as possible, with a treated water turbidity target of less than 0.1 NTU at all times. Where this is not achievable:

- Chemically assisted filtration: ≤0.3 NTU in at least 95% of a) measurements made or b) the time each calendar month never to exceed 1.0 NTU
- Slow sand or diatomaceous earth filtrations: ≤1.0 NTU in at least 95% of a) measurements made or b) the time each calendar month never to exceed 3.0 NTU
- Membrane filtration ≤0.1 NTU in at least 99% of a) measurements made or b) the time each calendar month never to exceed 0.3 NTU

Turbidity problems can come from inorganic and organic particles such as metals (through adsorption to organics and clays), decomposed plant and animal debris and microorganisms.
Elevated turbidity levels can also cause issues with pathogens because particles may harbour microorganisms and protect them from treatment.”

- (Health Canada, 2012)

**Pathogens**

Another concern is whether or not the American bullfrog is a carrier or distributor of pathogens that could be harmful to humans. This could occur directly or indirectly. Directly, the bullfrogs themselves could be the carriers or distributors into the water supply area. Indirectly, bullfrogs could lead to increased turbidity that could create more desirable environments for existing pathogens such as *Giardia* or *Cryptosporidium* which already occur in the local environment and are tested for regularly in the water supply (Buckland, 2012)(Health Canada, 2012).

**Ecological Impacts**

On the broad scale, the main concern for water managers is the potential for unknown, cascading effects on water quality as they relate to ecosystem services provided by the environment. Concern for the local environment stems from the bullfrogs’ ability to eat many types of prey and the fact that it is a carrier for chytrid fungus *Batrachochytrium dendrobatidis*. This could be devastating to native amphibians. Due to its ravenous reputation, there are those who think it feeds on local amphibian populations enough to be detrimental to local amphibian’s numbers. Most of the concern revolves around the northern red-legged frog (*Rana aurora*) which is blue listed (threatened) in British Columbia and has a COSEWIC (Committee on Status of Endangered Wildlife in Canada) status of special concern (“B.C. frog watch”) (COSEWIC 2004). The other main species of amphibian that the bullfrog may feed on includes the pacific tree frog (*Pseudacris regilla*), and the rough skin newt (*Taricha granulosa*). All of these species have the potential to share wetland habitat with the American bullfrog but there has not been any conclusive evidence that the presence of the bullfrog in these habitats will contribute to population decline. There is also concern with the fact that the American bullfrog carries the chytrid fungus which is currently being studied as potentially linked to amphibian decline (Hayes & Jennings, 1986) (Boone et al., 2007) (Ghirardi et al., 2011) (Gahl et al., 2012). To evaluate the literature on the subject it is important to discuss the habitats and life cycles of the locally impacted species.

**Pacific Tree Frogs**

The Pacific tree frog is the smallest and most common frog in British Columbia. It is found in the coast and mountains, the Georgia depression, the southern interior, the central interior, and the southern interior mountains physiographic provinces. These frogs can be found in any wet or damp area on the south coast of BC including marshes, mountain meadows, woodlands, brush, small streams and disturbed areas such as roadside ditches (Corkan & Thoms, 2006).

Eggs are laid in late spring and early summer in shallow ponds (<0.5 m deep) that can be either seasonal or permanent. When laid, the eggs are attached to submerged vegetation. Tadpoles remain in the pond.

*Figure 2- Pacific Tree Frog*
and metamorphose into juveniles by the end of the summer. Juveniles and adults live in marshes, forests and logs and can be found in disturbed, wet urban areas and gardens. During dry weather, the adults burrow or take refuge in cool tree cavities or other shaded areas. The tadpoles are the smallest of the local amphibians and hatch in the mid-summer. Juveniles are very small and look very similar to the adults. They have a dark eye mask from the tip of their noses to the shoulder and can range in colour from mottled tan, to reddish brown, to many shades of green. These frogs also have toe pads that are characteristic of tree frogs. Tadpoles are herbivorous, feeding on algae and the adults are insectivores, feeding on aquatic and terrestrial insects (Corkan & Thoms, 2006).

**Northern Red-legged Frogs**
Northern red-legged frogs are currently blue listed (vulnerable to human activity) in British Columbia and are listed under COSEWIC as being of special concern ("B.C. frog watch") (COSEWIC, 2004). They are a mid-sized frog and are found throughout the coast and mountain, and Georgia depression physiographic provinces in British Columbia. They are typically found in cool, well shaded and deep ponds as well as in forested wetlands of all types, and coniferous and deciduous forests (Corkan & Thoms, 2006).

![Figure 3- Red-legged frog](image)

Adults breed in slow streams and deep ponds in the late winter and early spring. The eggs are attached to submerged vegetation or pond bottom and the tadpoles are usually the first to emerge in the late spring where they move into warmer parts of the pond where they metamorphose by the end of the summer or early fall. Juveniles and adults live on the shaded pond margins, forested wetland edges, or under logs and other forest debris. Tadpoles are difficult to identify and in the Vancouver Island area are often identified through their relative size and presence of adults in the area, although this is very unreliable. Adults look similar to Pacific tree frogs but are generally larger and have two distinct dorsolateral folds that the local tree frogs do not. Adults also have gold eyes that look to the side and the underside of their lower abdomen and hind legs are translucent red, with a mottled cream to yellow groin. Their diet is similar to that of the pacific tree frog with tadpoles feeding on algae, and juveniles and adults feeding on aquatic and terrestrial insects (Corkan & Thoms, 2006)).

**Other**
Other amphibious species that may come into contact with the American bullfrog are the western toad and the rough skin newt. These species are considered low risk because the western toad prefers forested non-persistent wetlands and damp forested habitats, and there is no indication that the rough skin newt is a preferred species of the American bullfrog. This could be due to the toxic skin of the rough skin newt.

**Cost of Management**
For the purpose of this paper, management costs will consider the following management scenarios: eradication of American bullfrogs from the management area, habitat modification, water treatment, and community education programs. These scenarios were identified as being the most likely response
to invasive species establishment. The costs of each option will be case specific and I will address ease of execution as well. This refers to the resources required to achieve the desired result versus the assumed resources available and what the assumed resources are.

One way to mitigate the cost of management on the regional district or other land managers could be through the implementation of a willingness-to-pay survey. This type of survey asks users or non-users in the general public how much they would be willing to pay to protect a certain value. In this case the value would be water quality or indigenous species/environment conservation. These types of surveys have been conducted throughout the world and suggest that people would be willing to pay for non-use values to be protected (Cerda, 2011).

**Eradication**

Eradication refers to the complete removal of the species from the management area. This result is very difficult to achieve and so has been broken down into partial eradication and complete eradication. Partial eradication refers to controlling population size through various strategies including capture programs and egg mass removal (Buckland, 2012). A desired result in this case would be removal of 90-99% of adults and juveniles and complete removal of egg masses. This is unlikely unless all habitats are known and carefully monitored. Complete eradication refers to removal of all individuals in the population from a defined area. The eradication area refers to the management area from which the species will be removed. In this case the desired result is removal of 100% of the population. There may also be an additional population control area as a buffer around the eradication area.

Eradication efforts would include detailed preliminary research into the existing habitats and identify currently inhabited and at risk areas, depending on the scope of the project and size of the area, this could be a very significant portion of the total overall cost.

In 2011 the Capital Regional District spent $22,187 on monitoring and removal of the Humpback reservoir and adjacent bull frog population (Buckland, 2011). This is the direct amount paid by the regional district and consists mostly of field work. An external contractor is used for the removal of bull frogs and this cost does not include the funding required for that. This program is currently being used to keep the bullfrogs out of the watershed area. In 2011 a bullfrog was confirmed in a wetland within the watershed boundary and numbers appear to be increasing yearly despite the removal program. For complete eradication, monitoring and removal efforts would likely need to be doubled. Currently there is one individual that monitors and removes the bullfrogs with seasonal, part time assistance. To obtain the response time needed for complete eradication, there would likely need to be another team to ensure rapid response time to sightings which would double the internal cost (Buckland, 2012). This brings the estimate up to approximately $44,375. Dr. Govindaraju (2004) cites an eradication effort that cost upwards of $76,000.00 for the initial effort, not including the long-term monitoring that would be required.

It is important to address that this is the cost for an un-established, transitory population and better represents the type of action that would be required on the boarders of the eradication area once eradication has been achieved. This is likely what most of Vancouver Island would be facing because
there are few established populations on the Island. Eradicating an established population would require more resources and more expertise and man power.

**Habitat Modification**
American bullfrogs prefer warm, shallow persistent habitats on Vancouver Island and habitat modification has been identified as a means to control the population and provide cover for native species (Govindarajulu, 2004). Habitat modification refers to changing existing water ways and migration corridors with heavy machinery or through introduction of shading to make the habitat less favourable to bullfrogs and more favourable for native amphibians. Low impact modification includes increasing shade or removing protective cover by hand. High impact modification refers to use of heavy machinery to increase depth, increase shading, or break up wet travel corridors. The desired result in this case is to eliminate 100% of the bullfrog population from modified habitats and establish or increase native amphibian populations.

Modification that would be required / reasonable on Vancouver Island could range from requiring detailed plans and heavy machinery, to requiring one person doing very little work. Types of modification may include: increased shading, aquatic plant removal, and altering drainages. The cost of each of these treatments depends on the resources required. Some examples of rates of required labour include:

- Machine and operator: $150/hr.
- Engineer/resource professional to develop plan: $150/hr.
- People: $11~$23/hr.

Rates from Forest Industrial Relations Ltd. (2001) projected forward using a 2.5% inflation rate

Total project cost would depend on the scope of the project and would need to be assessed on a project by project basis.

**Education**
Education would consist of incorporating public education programs on the risks of invasive species to prevent the movement of eggs and tadpoles as bait into waterways or for backyard ponds. IT could also be done in conjunction with species dispersal tracking by teaching people how to recognize American bullfrogs. Ignorance of the associated risks of setting the species free is what allowed the population to establish in the first place and public education could go a long way into assisting population control and reporting for better research. This would include education of adults and youth through naturalist programs and workshops that many communities already offer.

Comparatively, education costs would be significantly lower because these could be easily built into existing community natural education programs such as youth summer workshops, nature clubs etc. which would incur little or no extra cost. Educating the general public not to move around tadpoles or mature frogs, how to recognize the frogs and the risks associated with invasive species would go a long way in preventing further dispersal. Education could also be as small as putting up notices in bait shops for the cost of the piece of paper.
- Incorporating into existing programs:
  - 1 person 2 hrs. to plan: $22-$46 (depending on wage)
- Partnerships with existing naturalist groups:
  - 1 person 4 hrs. per club: $44-$92
- Public notices in shops:
  - 1 person 1 hr. to develop: $22-$46
  - Cost of supplies: negligible ($10 max)
    - Rates from existing recreational postings

**Filtration**

Types of drinking water filtration include: chemically assisted filtration, slow sand or diatomaceous earth filtration, and membrane filtration (Health Canada, 2012). Chemically assisted filtration utilizes chemical mixing, coagulation, flocculation (removal of colloids via clarifying agent), sedimentation, and rapid gravity filtration (Health Canada, 2012). The main identifying feature is the addition of a chemical agent that enlarges the particles to assist in removal as water moves through the filter. Slow sand filtration utilizes sand filters with a developed layer of bacteria, microorganisms, and algae that remove contaminants as the water passes through the sand and is typically used in low turbidity situations (Health Canada, 2012). Diatomaceous filtration uses a thin layer of diatomaceous earth (3mm) and passing water through to filter low turbidity water (Health Canada, 2012). Membrane filtration refers to reverse osmosis, nano-filtration, ultrafiltration, and microfiltration. These systems are most frequently used in the water industry today with the type of filter used depending on the innate water quality (Health Canada, 2012).

The Capital Regional District currently does not have a filtration facility opting instead to use a combination of ammonia, chlorine, and ultra violet light treatment to kill any pathogens that may be present in the water. While effective for removing pathogens from the water supply, these will not work together as well if the level of turbidity were to increase.

Costs of developing a filtration plant include land costs, operational costs and maintenance costs. Costs can differ dramatically depending on local availability of technology, materials, and land. Without doing a full financial analysis it is difficult to determine the true cost of filtration. There are not many examples for the Vancouver Island region because no communities on the island currently utilise filtration technology for their water supplies. Although due to a change to the VIHA water standards, many island communities are looking into the financial feasibility of filtration facilities. Preliminary numbers for a proposed filtration plant in Nanaimo do not give the total estimated costs but do state that “the project will be funded from senior government grants, development cost charges, water user rates, and borrowing of up to $22.5 million [and will cost] $1.8 million a year to operate” (City of Nanaimo, 2013) suggesting the total project cost will be much higher.
Methods

Literature Review
A literature review was conducted of the existing research on the American bullfrog population on Vancouver Island. Very little work has been done on this population in particular with the majority of it being conducted by Dr. Govindarajulu. Studies are currently being conducted by Dr. Tim Goater of Vancouver Island University on the diet of the southern Vancouver Island bull frog population and by Stan Orchard on the distribution patterns and rate of the population increase in the Victoria – Sooke-Saanich area. Literature on water quality and turbidity was reviewed and treatment feasibility was also reviewed. Joel Ussery and Nigel Buckland of the Capital Regional District also provided information they have acquired on their current American bullfrog control program in the Sooke Watershed and adjacent areas including yearly costing information.

Interviews
Interviews were conducted in person and via email with Nigel Buckland (Wildlife Biologist, Capital Regional District) and Joel Ussery (Resource Manager, Water Protection, Capital Regional District) from April 2010 to February 2013, to identify what aspects of bull frog management they feel are most important to the Capital Regional District. The author worked as a contributor to the bullfrog control program and had the opportunity to learn about the program on site. Tim Goater was interviewed via email to discuss preliminary findings in his work although no conclusions have been drawn on the outcomes.

Results

Water Quality
From a drinking water quality perspective, there is little information on the impact of American bullfrogs or other amphibians on water turbidity levels. No information is available on whether or not it has any impact on water quality in its native range in the eastern United States. This could be due to the fact that it has not been much of a concern thus far or there is no clear concern to speak of so it hasn’t been studied. The other concern would be if a bullfrog population were able to trigger an algal bloom. This would only occur if the population of bullfrogs in a single pond were so large it resulted in an increased nutrient load. The increased amount of decaying biomass could release nutrients including nitrogen and phosphorus, important nutrients supporting algal blooms (Diersing, 2009). In turn, this would increase turbidity, increasing the likelihood harmful bacteria would be found within the water supply. Without appropriate modeling it is uncertain whether a population would be able to produce enough biomass or waste to do this. The other mechanism would be if bullfrogs were to outcompete or prey on native tadpoles, leaving no primary consumers to control the algal population. Seale (1980) found that tadpoles feeding on algae are “regulatory consumers” meaning that species present appear to feed on different algae types to maintain balance among them and prevent a bloom from occurring.
From a public health perspective there are studies suggesting that bullfrogs are able to carry a strain of *E. coli* for up to 14 days that could be harmful to humans (Grey et al., 2007). The relative impact of this on a water supply would depend on the population size and the amount of *E. coli*. bullfrogs shed. As per Amborski et al. (1976)(See Figure 3) bullfrogs are also capable of carrying *Enterobacter, Streptococcus, Staphylococcus, Klebsiella, Shigella*, which are harmful to humans or have known harmful strains which could be released into the water supply with possible negative effects.

It is important to consider while looking at this information that this study was done in Louisiana, the bullfrog’s home range, a much different climate from the temperate west coast of British Columbia. Another consideration for this is the available treatment currently available. In the Greater Victoria Water Supply Area water is treated with a mixture of UV and chlorination. This kills any bacteria that may be in the water, preventing harmful impacts on the general public (Zimmer & Slawson, 2002).

**Ecological Impacts**

The ecological impacts of the American bullfrog on native frog species on Vancouver Island are currently being studied by Dr. Govindarajulu to understand how they affect local ecosystems. Jennings and Hayes (1986) remark that there is little data and too many factors involved in the decline of frog species in western North America in order for scientists and land managers to blame any single factor such as bullfrogs. Adams and Pearl (2007) suggest that little work is being done because of the low economic impacts of the bullfrog.

Bullfrogs do act as carriers/vectors for *Batrachochytrium dendrobatidis*, a fungal infection that attacks amphibian skin and can lead to mortality because of the permeable nature of their skin (Gahl et al., 2012). The skin acts as a secondary respiratory organ which makes it especially sensitive to changes in the environment. The chytrid fungus has been linked to amphibian decline in North America and other parts of the world (Lötters et al. 009). It has also been demonstrated that hibernating bullfrogs are capable of carrying pathogenic psychrophiles, bacteria that contribute to disease and deaths among amphibian populations (Amborski et al. 1976)

In their native range, overwintering bullfrogs have been shown to have a negative effect on the populations of other frog species sharing the same habitat (Boone, Little, & Semlitsch, 2004). Dr.Govindarajulu was unable to demonstrate a significant impact on native larval development in natural ponds due to differences caused by bullfrogs, however in artificial ponds there was a demonstrated negative effect on the “development rate of [pacific tree frog and red-legged] frog tadpoles” (2004).

<table>
<thead>
<tr>
<th>Organisms</th>
<th>Positive frogs (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Achromobacter</em> sp.</td>
<td>6</td>
</tr>
<tr>
<td><em>Acinetobacter</em> sp.</td>
<td>12</td>
</tr>
<tr>
<td><em>Aeromonas hydrophila</em></td>
<td>3</td>
</tr>
<tr>
<td><em>Plesiomonas shigelloides</em></td>
<td>1</td>
</tr>
<tr>
<td><em>Alcaligenes faecalis</em></td>
<td>8</td>
</tr>
<tr>
<td><em>Bacillus cereus</em></td>
<td>12</td>
</tr>
<tr>
<td><em>Bacillus megaterium</em></td>
<td>4</td>
</tr>
<tr>
<td><em>Bacillus subtilis</em></td>
<td>1</td>
</tr>
<tr>
<td><em>Citrobacter freudii</em></td>
<td>4</td>
</tr>
<tr>
<td><em>Enterobacter</em> sp.</td>
<td>15</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>4</td>
</tr>
<tr>
<td><em>Flavobacterium</em> sp.</td>
<td>9</td>
</tr>
<tr>
<td><em>Klebsiella</em> sp.</td>
<td>1</td>
</tr>
<tr>
<td><em>Mesorococcus</em> sp.</td>
<td>2</td>
</tr>
<tr>
<td><em>Proteus mirabilis</em></td>
<td>6</td>
</tr>
<tr>
<td><em>Proteus morganii</em></td>
<td>7</td>
</tr>
<tr>
<td><em>Proteus rettgeri</em></td>
<td>1</td>
</tr>
<tr>
<td><em>Proton vulgaris</em></td>
<td>4</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>9</td>
</tr>
<tr>
<td><em>Pseudomonas alcaligenes</em></td>
<td>2</td>
</tr>
<tr>
<td><em>Pseudomonas fluorescens</em></td>
<td>6</td>
</tr>
<tr>
<td><em>Pseudomonas putida</em></td>
<td>6</td>
</tr>
<tr>
<td><em>Pseudomonas sp. (not identified further)</em></td>
<td>11</td>
</tr>
<tr>
<td><em>Serratia</em> sp.</td>
<td>1</td>
</tr>
<tr>
<td><em>Shigella</em> sp.</td>
<td>1</td>
</tr>
<tr>
<td><em>Staphylococcus epidermidis</em></td>
<td>1</td>
</tr>
<tr>
<td><em>Staphylococcus sp. (not identified further)</em></td>
<td>2</td>
</tr>
<tr>
<td><em>Streptococcus</em> sp.</td>
<td>6</td>
</tr>
<tr>
<td><em>Unclassified gram negative bacteria</em></td>
<td>3</td>
</tr>
</tbody>
</table>

*Figure 4- Amborski, Carr, & Culley, 1976*
was also found that bullfrogs did not affect survival rate of the native tadpoles in both the natural and artificial (controlled) environment (Govindarajulu, 2004). Keisecher (1997) was able to show that northern red-legged frogs tadpoles sharing habitat with non-native predatory bullfrogs seek cover when presented with chemical cues from them where as northern red-legged frogs that do not share habitat with the bullfrogs do not. In another study, bullfrogs were shown to only have negative impacts on the population of Pacific tree frogs, not red-legged frogs or western toads indicating variable reactions to the invasive amphibian (Preston et al., 2012).

In a study done by Chivers et al. (2000) it was found that adult pacific tree frogs in Oregon that co-habit with American bullfrogs “show strong avoidance of chemical cues of bullfrogs” and those that do not co-habitate with American bullfrogs do not respond to their chemical cues. This suggests that the biggest risk to the Pacific tree frog populations is new ingress of bullfrogs to ponds formerly free of them.

Research shows that bullfrogs could present a threat to native frogs but is inconclusive. In artificial cases there is a threat to development but in natural cases, a threat has yet to be demonstrated due to insufficient study. There are studies that suggest bullfrogs have a negative impact on native frogs, but no conclusive work has been conducted and further study is needed (Doubledee et al., 2003).

**Discussion**

*Table 1- Management Concern Summary*

<table>
<thead>
<tr>
<th>Public Health</th>
<th>Results</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential for <em>E. coli</em>, <em>Enterobacter</em>, <em>Streptococcus</em>, <em>Staphylococcus</em>, <em>Klebsiella</em>, <em>Shigella</em></td>
<td>Preliminary work suggests that bullfrog tadpoles could be carriers for <em>E. coli</em>. but this is inconclusive in a natural setting. Other work compiled by the CRD suggests bullfrogs could be carriers for other pathogens but this chance is very low and there is no information on what role amphibians play in bacterial infections in humans.</td>
<td>Low</td>
</tr>
<tr>
<td>Turbidity</td>
<td>Increase in population of bullfrogs will contribute to increased turbidity of water supply or an algal bloom</td>
<td>Low</td>
</tr>
<tr>
<td>Amphibians appear to act as regulatory consumers, which would prevent a bloom from occurring. It is unlikely that the population would grow to the size that turbidity could be affected No information regarding turbidity related to high densities in the bullfrogs home range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecology</td>
<td>Potential of predation on native species Carriers of the chytrid fungus killing native frog populations</td>
<td>Moderate</td>
</tr>
<tr>
<td>Native species living with bullfrogs are able to pick up on their chemical cues and avoid predation. There were minor differences in development in artificial ponds but no negative impacts have been observed in natural habitats. There is ample evidence that bullfrogs act as carriers of the chytrid fungus although work has not been conducted on Vancouver Island to determine the extent of the potential impacts</td>
<td>The existing information is incomplete. More study is needed to determine what the impact of the American bullfrog is on native frog populations through competition and predation. The effects of the Chytrid fungus on native amphibian populations also needs to be addressed before the risk associated with bullfrogs can be lowered.</td>
<td></td>
</tr>
</tbody>
</table>
Water Quality
From a water quality point of view there does not appear to be a threat from the American bullfrog at this time. However that is not saying there will not be emerging water quality impacts as the bullfrogs spread and the population grows. There is little existing information on the impacts bullfrogs have on water quality including turbidity and public health and few studies have been done to address it, likely due to the low risk. There is no information available from the bullfrog’s home range demonstrating a link between high bullfrog densities and turbidity issues. Most of the information available is from controlled situations that do not account for unknown variables that can occur in a natural setting. In an analysis done for the Capital Regional District numerous pathogens are identified as being associated with the American bullfrog but acknowledge that at the time of review, no peer reviewed studies focusing on the “role of amphibians, including bullfrogs, as biological sources of bacterial infections in people” (Stitt et al., 2009) had been conducted.

The other consideration is whether bullfrogs could impact turbidity and public health on Vancouver Island. There is currently no evidence that directly links bullfrog biomass density to turbidity problems in their home range. This could be because there are no turbidity issues associated with bullfrogs or because they do not occur within water supply areas. It is also possible that the populations are better controlled through predation and competition. On southern Vancouver Island the bullfrog population is steadily increasing closer to the watershed area. The population encroaching on the watershed grows each year and in 2011, 3 were removed from within the watershed boundary (Buckland 2011). Nigel Buckland and Joel Ussery feel that it is inevitable that bullfrogs will establish in the watershed eventually, although they are going to try to delay that for as long as they can due to the unknown nature of the ecological and water quality effects. In other communities on Vancouver Island, bullfrogs are not a concern to municipal governments at this point, with Victoria being the only community at this time with an active bullfrog eradication program (Goater, 2012). From a public health perspective the risk of E.coli being a problem for the CRD is low because they have mechanisms in place that could deal with any minor instance of E.coli that may occur.

Ecological Impacts
From an ecological perspective, management of the American bullfrog population is justified. Non-native species can have unpredictable, far reaching effects on native species through predation and competition and the American bullfrog is no different (Lowe, 2002). This unpredictability is what water managers should try to mitigate within water supply systems. Due to the conservation status of the red legged frog, land managers have a responsibility under the B.C. wildlife act. Best practices for amphibian conservation (as applied to the red-legged frog) describe maintenance of natural processes and meta-population dynamics as key component of species protection (Ovaska et al., 2004). Because the species has a conservation status of ‘vulnerable’, species protection should be a serious consideration. This also includes prevention of “habitat degradation...by controlling...spread of exotic species” (Ovaska et al., 2004). Management of bullfrogs would falls under this umbrella of protection of vulnerable species. The B.C. Conservation Status Report recommends “control and eradication of non-native species...including bullfrogs” (Wind, 2007). While there are still questions to resolve regarding the role of bullfrogs in western temperate ecosystems, scientists are making progress
determining the effect bullfrogs can have on native amphibians. The other concern is that bullfrogs will spread the chytrid fungus which has the potential to decimate the Vancouver Island frog and toad population due to the limited habitat available. If bullfrogs were to successfully remove one or more of the native amphibian species from the local environment, the resulting impacts on the remaining portion of the ecosystem are unknown.

Cost
The cost of bullfrog management on Vancouver Island at this point is fairly low and further management would be relatively low impact compared to what the impact would be if the population was left unchecked. The uncertainty surrounding impacts on water quality need to be addressed and further study needs to occur to ensure the local bullfrog populations will not be detrimental or destructive for local native ecosystems on the west coast.

Comparison
Of the proposed management strategies, not all are viable strictly as a means to manage the impacts of the American Bullfrog. For example the establishment of a filtration plant with so little known about the impacts of bullfrogs on public health does not make sense. The relative risks are not high enough as there is little conclusive information the bullfrog carries any human pathogens and the relative risk is very low. This should only be done with conclusive information backed up by solid, applicable research.

Eradiation on the other hand may seem to be an appealing option as the initial cost is much lower than that of filtration but it is important to consider that once eradication is achieved there will need to be a plan to maintain it, and it may take a long time to achieve complete eradication, especially on the mainland. Partial eradication is an alternative, utilizing population control methods such as collecting egg masses and capturing adults. This would be more realistic in areas where the population has become established as capturing juveniles of the species can be challenging and complete eradication may not be possible without resorting to extreme, environmentally damaging methods.

Habitat modification is a good alternative for areas that are closer to urban centers and could be done by volunteers depending on the scale of the project. Planning is critical in this case because modifications will not only impact the American bullfrog but other species, natural drainage patterns, and if it occurs within a community watershed, could significantly increase turbidity and sedimentation temporarily. Depending on the level of modification required, there is also the potential for pollution via gas and fluids from machinery. Another potential issue with machinery is site damage and degradation from compaction on wetland margins. Most of these issues can be addressed through proper planning and preparation but as the changes would be occurring in persistent wetlands, there will always be risk of damage or compaction to other habitats, soils, and water quality.

Education is a low hanging fruit that would be easily worked into existing programs. On its own, education likely would not be very effective management of invasive populations. Coupled with another management strategy such as population control or habitat modification, it could be an effective way of preventing new populations from becoming established. Which strategy (if any) to adopt also depends on the relative ease of execution due to availability of resources and what resources are available...
compared to what are needed. This would need to be considered on a case by case basis for each regional district on Vancouver Island.

Table 2: Bullfrog Management Strategy Comparison

<table>
<thead>
<tr>
<th>Management Strategy</th>
<th>Cost (yearly)</th>
<th>Positive</th>
<th>Negative</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eradication</td>
<td>$22,000 +</td>
<td>Direct removal ensures species under control</td>
<td>Could be difficult to maintain Total eradication could be hard to achieve.</td>
<td>Could work well on newly established or transitory populations but would require lots of resources for established large populations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Job creation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitat Modification</td>
<td>$100-$2000</td>
<td>Can be a long term solution</td>
<td>May contribute to site degradation due to the persistent nature of bullfrog inhabited wetlands Chance for pollution from machinery to occur in sensitive areas. May require long term maintenance</td>
<td>Level of modification would need to be assessed individually for each wetland or corridor Would be best used in high risk areas where risk to water quality or native ecosystems is the highest.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can be a low impact way to prevent further colonization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td>$25-$1000</td>
<td>Can be incorporated into existing programs</td>
<td>Low impact</td>
<td>Best use would be in conjunction with another management strategy such as population control. Alone would only help to prevent human assisted migration and establishment of new populations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does not require a lot of resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filtration</td>
<td>$25 million +</td>
<td>Could address other water quality issues associated with turbidity or sedimentation problems</td>
<td>Cost prohibitive for most smaller communities Long planning horizon</td>
<td>A solution for larger problems, not a good solution for managing unknown risk factors</td>
</tr>
</tbody>
</table>

Conclusion

From a water quality perspective, management of the American bullfrog is unnecessary at this point. There is no information or evidence suggesting that bullfrog population densities are related to increases in turbidity and public health concerns and uncertainty can be mitigated through existing water treatment facilities. Further study is required regarding the potential for public health impacts of bullfrogs, including their abilities to act as carriers for harmful pathogens such as *E.coli*.

Ecologically, studies show that American bullfrogs represent a threat to indigenous frog species through competition and predation (Keisecher, 1997). Species management guidelines for the blue listed red-legged frog indicate that species habitat and meta-populations should be protected from degradation, including risks to the population from invasive species (Wing, 2007). The preservation of species and environments is enough justification for species management actions to prevent further dispersal of American bullfrogs.
While preliminary information is available that there may be a connection between bullfrogs and *E. coli*, this has yet to be conclusively proven. Not managing the bullfrog population may be tempting from an economic standpoint because, as Adams and Pearl (2007) pointed out, the information still is not there to justify spending money on them. Management should be based on ecological concerns as there is insufficient evidence that the American bullfrog can have a negative impact on water quality at this time.

**Recommendations**

Based on the analysis, recommendations for bullfrog management on southern Vancouver Island include:

1. Evaluate the existing population, including mapping the current distribution, projected expansion, and modeling of population demographics.
2. Conduct or encourage further research into the potential impacts on public health due to habitation in a water supply area and remaining current with ongoing research.
3. Control the existing population dispersal through public education, removal of egg masses, and removal of juveniles and adults from key, water supply or ecologically important areas.
4. Modify habitat in key areas such as water supply areas and known red-legged frog habitat where there is already an established population and eradication is impractical.

Until more information is available on the impact bullfrogs have on public health or native wetland ecology, management should be preventative and focus on key important areas, such as protection of red-legged frogs. As more information becomes available it will be possible to adapt and adopt a more aggressive management strategy or a more passive strategy depending on results from further analysis.
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