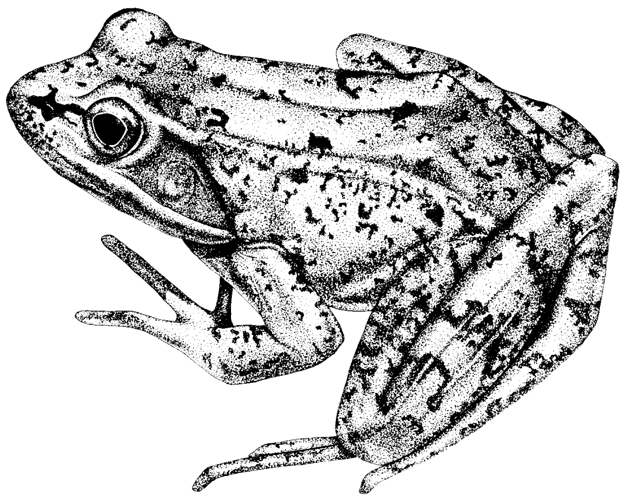
COSEWIC
Assessment and Update Status Report

on the

Red-legged Frog
Rana aurora

in Canada



SPECIAL CONCERN
2004

COSEWIC
COMMITTEE ON THE STATUS OF
ENDANGERED WILDLIFE
IN CANADA

COSEPAC
COMITÉ SUR LA SITUATION
DES ESPÈCES EN PÉRIL
AU CANADA

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

COSEWIC 2004. COSEWIC assessment and update status report on the Red-legged Frog *Rana aurora* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 46 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Previous report:

Waye, H. 1999. COSEWIC status report on the red-legged frog *Rana aurora* in Canada *in* COSEWIC assessment and status report on the red-legged frog *Rana aurora* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-31 pp.

Production note:
COSEWIC would like to acknowledge Kristiina Ovaska and Lennart Sopuck for writing the status report on the Red-legged Frog *Rana aurora*. This report was prepared under contract with Environment Canada and was overseen and edited by David Green, the COSEWIC Amphibians and Reptiles Species Specialist Subcommittee Co-chair.

For additional copies contact:

COSEWIC Secretariat
c/o Canadian Wildlife Service
Environment Canada
Ottawa, ON
K1A 0H3

Tel.: (819) 997-4991 / (819) 953-3215
Fax: (819) 994-3684
E-mail: COSEWIC/COSEPAC@ec.gc.ca
http://www.cosewic.gc.ca

Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur la situation de *Grenouille à pattes rouges* (*Rana aurora*) au Canada — Mise à jour.

Cover illustration:
Red-legged Frog — Illustration by Andreé Jenks

Catalogue No. CW69-14/340-2005E-PDF
ISBN 0-662-39849-1
HTML: CW69-14/340-2005E-HTML
0-662-39850-5

Recycled paper

COSEWIC
Assessment Summary

Assessment Summary – November 2004

Common name
Red-legged Frog

Scientific name
Rana aurora

Status
Special Concern

Reason for designation
A large proportion of the known Canadian distribution of this species occurs in the densely populated southwestern part of British Columbia. Habitats are becoming increasingly lost and fragmented due to land conversions and other human activities. Introduced Bullfrog and Green Frog, which are spreading rapidly, have replaced this species at many sites and appear to adversely affect the use of wetland breeding sites and reproductive success. Populations of this species, and other amphibian species that require extensive habitat, are inherently vulnerable to habitat fragmentation which can be expected to exacerbate isolation effects and local extinctions.

Occurrence
British Columbia

Status history
Designated Special Concern in April 1999. Status re-examined and confirmed in May 2002 and in November 2004. Last assessment based on an update status report.

COSEWIC
Executive Summary

Red-legged Frog
Rana aurora

Species information

The Red-legged Frog (*Rana aurora*) is one of six species of ranid or “true” frogs (family Ranidae) native to western North America. Two subspecies are recognized: the Northern Red-legged Frog (*R. a. aurora*), which occurs in Canada, and the California Red-legged Frog (*R. a. draytonii*). It is a moderate-sized frog, averaging 50 – 70 mm in length as adults, with relatively long legs and webbed feet.

Distribution

The distribution of the Northern Red-legged Frog extends from southwestern British Columbia to northwestern California. In Canada, the species occurs throughout Vancouver Island, on several of the islands in the Strait of Georgia, and on the adjacent mainland of southwestern British Columbia where its range overlaps with that of the rare Oregon Spotted Frog (*R. pretiosa*). In 2001 the species was documented from several localities on Graham Island, Queen Charlotte Islands, evidently introduced.

Habitat

The Red-legged Frog is an inhabitant of moist, lower elevation forests and requires both aquatic breeding habitats and terrestrial foraging habitats. The frogs breed in ponds, ditches, springs, marshes, margins of large lakes, and slow-moving portions of rivers, typically where emergent vegetation is abundant. Metamorphosed individuals are largely terrestrial and inhabit a variety of forest types but are most abundant in older, moist stands. Clearcuts are barriers to movement, especially during dry conditions.

Biology

The Red-legged frog breeds during a short period in early spring. Male frogs call mostly from under water and consequently breeding choruses can remain undetected. Clutches contain up to 1300 eggs. Eggs usually hatch in late spring, and tadpoles transform in July – August. The greatest mortality occurs during the tadpole stage.

Adult frogs migrate between aquatic breeding sites and terrestrial foraging habitats, sometimes over many kilometers. Hibernation occurs either under water or on land.

Population sizes and trends

Although no recent population estimates are available for any locality, there is no compelling reason to suspect that the number of breeding adults in Canada is small enough to trigger any of COSEWIC's quantitative criteria. Surveys since 1997 suggest that the species remains widespread within its known range. In the Lower Fraser Valley, there is some evidence that pollutants might contribute to the paucity of these frogs within agricultural areas, but habitat is also likely to be a factor. Only a few records are available from the mainland coast north of Vancouver and the northern limits of the species' distribution and its patterns of abundance there are unknown. Population trends for the Red-legged Frog are unknown as available presence/absence data do not necessarily reflect patterns of abundance.

Limiting factors and threats

The Red-legged Frog reaches the northern limits of its natural distribution in southern British Columbia. Human-induced threats include habitat fragmentation, draining of wetlands, loss and modification of forest habitats, removal of riparian vegetation, pollution of breeding habitats with pesticides, herbicides, and fertilizers, and the introduction non-native sport fish and bullfrogs to aquatic habitats. The distribution of this species overlaps the most populated parts of the province, where the lower elevation areas extensively used by this species have seen the most development. Habitat modification continues. Habitat fragmentation is of particular concern in view of the species' seasonal migrations between forested areas and wetland breeding sites.

Special significance of the species

Declines in amphibian populations worldwide have featured prominently in popular literature and news coverage. Because of its relatively large spatial requirements and close association with moist forests, stream banks, and wetlands, the Red-legged Frog is emblematic of wilderness values, forest ecosystem health and the need to consider landscape-wide habitat connections.

Existing protection or other status designations

In British Columbia, the Red-legged Frog is on the provincial blue list of species at risk (i.e., species considered particularly sensitive or vulnerable to human activities or natural events). *Rana aurora* is included in the Identified Wildlife Management Strategy (IWMS), Version 2004, which contains specific guidelines for habitat management. However, much uncertainty exists on how these guidelines will be implemented. The Act does not apply to private lands, including vast tracts of private forestry land on Vancouver Island within the core area of the species' range. The British Columbia Wildlife Act prohibits the collection, possession, and trade of all native vertebrates, including amphibians. This law has limited effectiveness in protecting frogs, because it is difficult to enforce and does not cover damage to habitats.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5th 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal agencies (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government members and the co-chairs of the species specialist and the Aboriginal Traditional Knowledge subcommittees. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(NOVEMBER 2004)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and it is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for atleast 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A wildlife species for which there is inadequate information to make a direct, or indirect, assessment of its risk of extinction.

* Formerly described as “Vulnerable” from 1990 to 1999, or “Rare” prior to 1990.
** Formerly described as “Not In Any Category”, or “No Designation Required.”
*** Formerly described as “Indeterminate” from 1994 to 1999 or “ISIBD” (insufficient scientific information on which to base a designation) prior to 1994.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

Update
COSEWIC Status Report

on the

Red-legged Frog
Rana aurora

in Canada

2004

TABLE OF CONTENTS

List of figures

SPECIES INFORMATION

Name and classification

The Red-legged Frog belongs to the large, nearly cosmopolitan family of Ranidae or "true frogs" (Amphibia: Anura: Ranidae: *Rana: Rana aurora* Baird and Girard, 1852). The genus *Rana* consists of over 250 described species distributed throughout the world, with the exception of southern South America, Australia, and Antarctica (Duellman and Trueb 1996). As currently composed, the genus *Rana* may be polyphyletic, and its systematics require further investigation (Crother 2000).

Six species of frogs of the genus *Rana* are native to the west coast of North America: *Rana aurora*, *R. boylii* (Foothill Yellow-legged Frog), *R. cascadae* (Cascades Frog), *R. muscosa* (Mountain Yellow-legged Frog), *R. pretiosa* (Oregon Spotted Frog), and *R. luteiventris* (Columbia Spotted Frog). These species form the *R. boylii* species group, which molecular evidence suggests is a well-defined, monophyletic group, about 8 million years old (Macey *et al*. 2001). Relationships within the *R. boylii* group are incompletely understood, but recent mitochondrial DNA sequencing suggests that *R. aurora*, *R. cascadae*, and *R. muscosa* might be closely related (Macey *et al*. 2001).

Rana aurora is divided into two geographically separated subspecies: *R. a. aurora* (the Northern Red-legged Frog), which occurs from British Columbia south to northern California, and *R. a. draytonii* (the California Red-legged Frog), which occurs from northern California to Baja California, Mexico. The two forms differ in their morphology, behaviour, and genetics (Hayes and Miyamoto 1984), but whether they are sufficiently distinct to warrant the recognition of two separate species is still to be resolved (Crother 2000).

Description

The Northern Red-legged Frog is a moderate-sized frog with snout-vent length of adults usually from about 50 to over 70 mm (Green and Campbell 1984); females attain a somewhat larger body size than do males and may be up to about 100 mm long (Nussbaum *et al*. 1983). As is typical of most other North America ranids, these frogs have a smooth to somewhat rugose skin, a dorsolateral fold along each side of the body extending from near the eye to near the groin, relatively long legs when compared to other groups of frogs, and webbed feet. The back of the Red-legged Frog is brownish, flecked with small black spots with indistinct edges; the dorsal surface of the limbs is often banded with black (Figure 1a). A dark mask typically extends from the eye to the jaw line and is bordered from below by a cream-coloured band. The throat and chest are gray or white with black flecking, whereas the undersides of the hind legs and the lower portion of the trunk are reddish, giving the species its common name. The brightness of the red varies both geographically and with ontogeny (Altig and Dumas 1972); small juveniles may lack the red colour altogether or show only a faint reddish or yellowish tint on the underside of the legs.

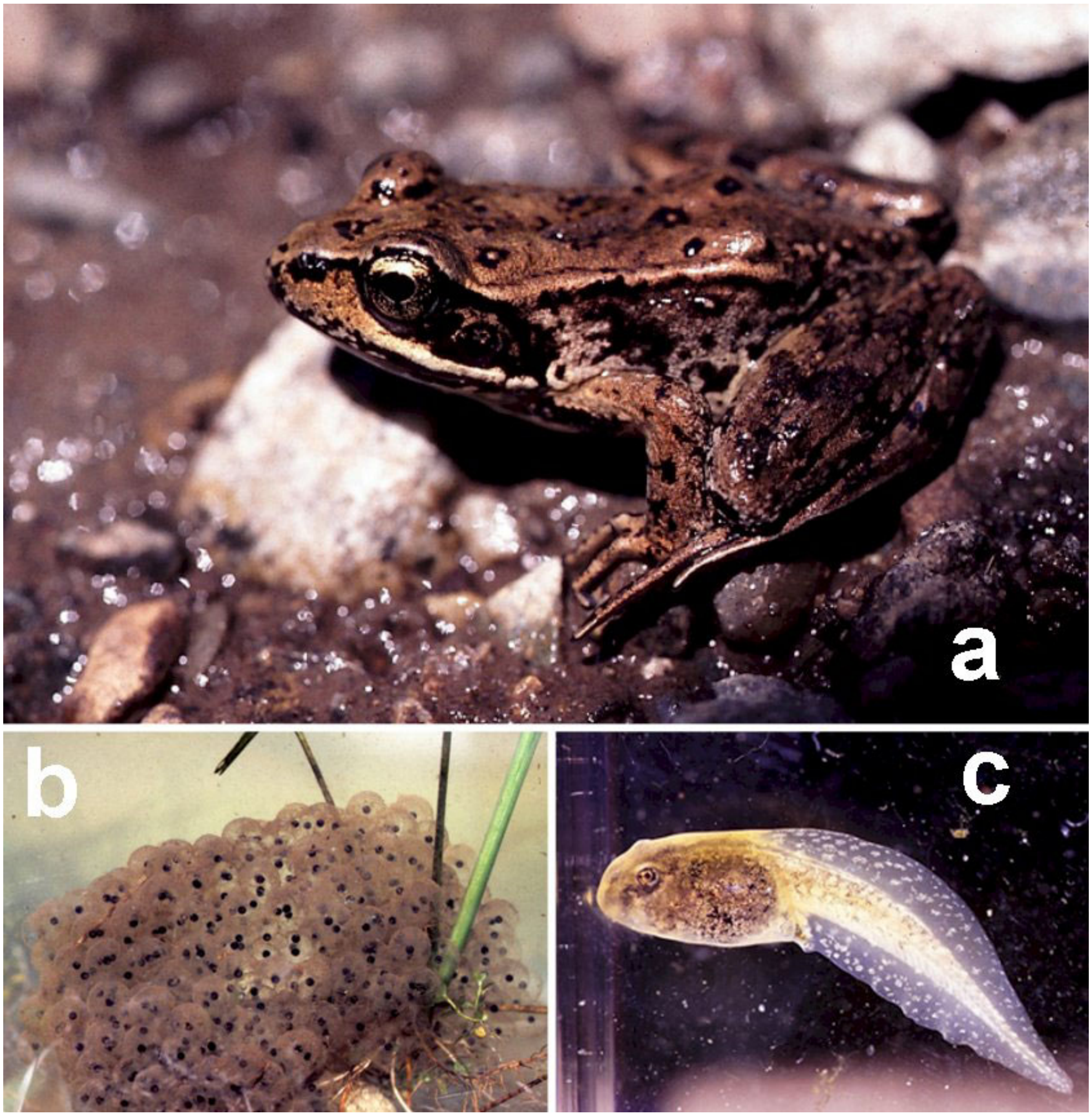


Figure 1. Red-legged Frog, *Rana aurora*: a. adult (Rocky Point, Vancouver Island, B.C.), b. Egg-mass (Vedder Creek, B.C.), c. Tadpole (Vedder Creek, B.C.). Photographs by Kristiina Ovaska.

Tadpoles are tan or greenish brown, and the trunk, tail, and fins are typically covered with gold- or brass-coloured flecking or blotches; the white underside often has a pinkish tinge. They can attain a relatively large size (up to about 70 – 80 mm) immediately before metamorphosis. The tail is relatively short (about 1.5 times or less the length of the body), and the dorsal fin is relatively tall (taller than the tail musculature at its widest point), resulting in a stubby appearance (Figure 1c; Corkran and Thoms 1996).

In British Columbia, the Red-legged Frog may be confused with the Oregon and Columbia spotted frogs, which have a similar body form and reddish underside of the hind limbs and the lower portion of the trunk; the two spotted frogs cannot be reliably distinguished from each other based on morphology. The Red-legged Frog is sympatric with the Oregon Spotted Frog in the lower Fraser Valley, whereas it is largely allopatric with the Columbia Spotted Frog. Potential for overlap with the Columbia Spotted Frog exists at the southeastern and northern distributional limits of the Red-legged Frog on the mainland (see section on Canadian Distribution), and specimens from these areas should be examined carefully. Adults of the Red-legged Frog can be distinguished from the spotted frogs by the presence of greenish and black mottling in the groin area, longer legs (the heel extends beyond the snout when pressed against the body), less extensive webbing on the hind feet, lateral rather than upward orientation of the eyes, and pronounced dorsolateral folds (Nussbaum *et al*. 1983, Leonard *et al*. 1993). The tadpoles of the Red-legged Frog have a shorter tail and taller dorsal fin than those of the spotted frogs; the dorsal fin of the Red-legged Frog typically has distinct gold-coloured flecks, which are usually absent from tadpoles of the spotted frogs (Corkran and Thoms 1996).

More detailed information on the appearance of this species and its distinguishing characteristics can be found in Altig and Dumas (1972) and various field-guides (Nussbaum *et al*. 1983, Green and Campbell 1984, Stebbins 1985, Leonard *et al*. 1993, Corkran and Thoms 1996).

DISTRIBUTION

Global range

The distribution of the Northern Red-legged Frog extends from southwestern British Columbia south to northwestern California (Figure 2). This species occurs throughout western Washington and Oregon west of the Cascade Mountains to the Pacific coast. In northwestern California, the Northern Red-legged Frog is replaced by the California Red-legged Frog (*R. aurora draytonii*), the range of which extends south to Baja California, Mexico. An isolated population in southeastern Alaska is the result of a recent introduction (K. MacAllister, pers. comm.). A population in the Queen Charlotte Islands is probably also introduced (see below). Most of the global distribution of the Red-legged Frog is in the United States with about one quarter being in Canada.

Canadian range

In Canada, the Red-legged Frog occurs in southwestern British Columbia, where it is found throughout Vancouver Island, on several of the islands in the Strait of Georgia, and on the adjacent mainland (Figure 3). Populations in these areas are geographically isolated from each other by stretches of ocean; the extent of the open ocean between Vancouver Island and the mainland is the shortest (less than 1 km) through offshore islands in the Johnstone Strait. The mainland portion is contiguous with the species' range in Washington State.

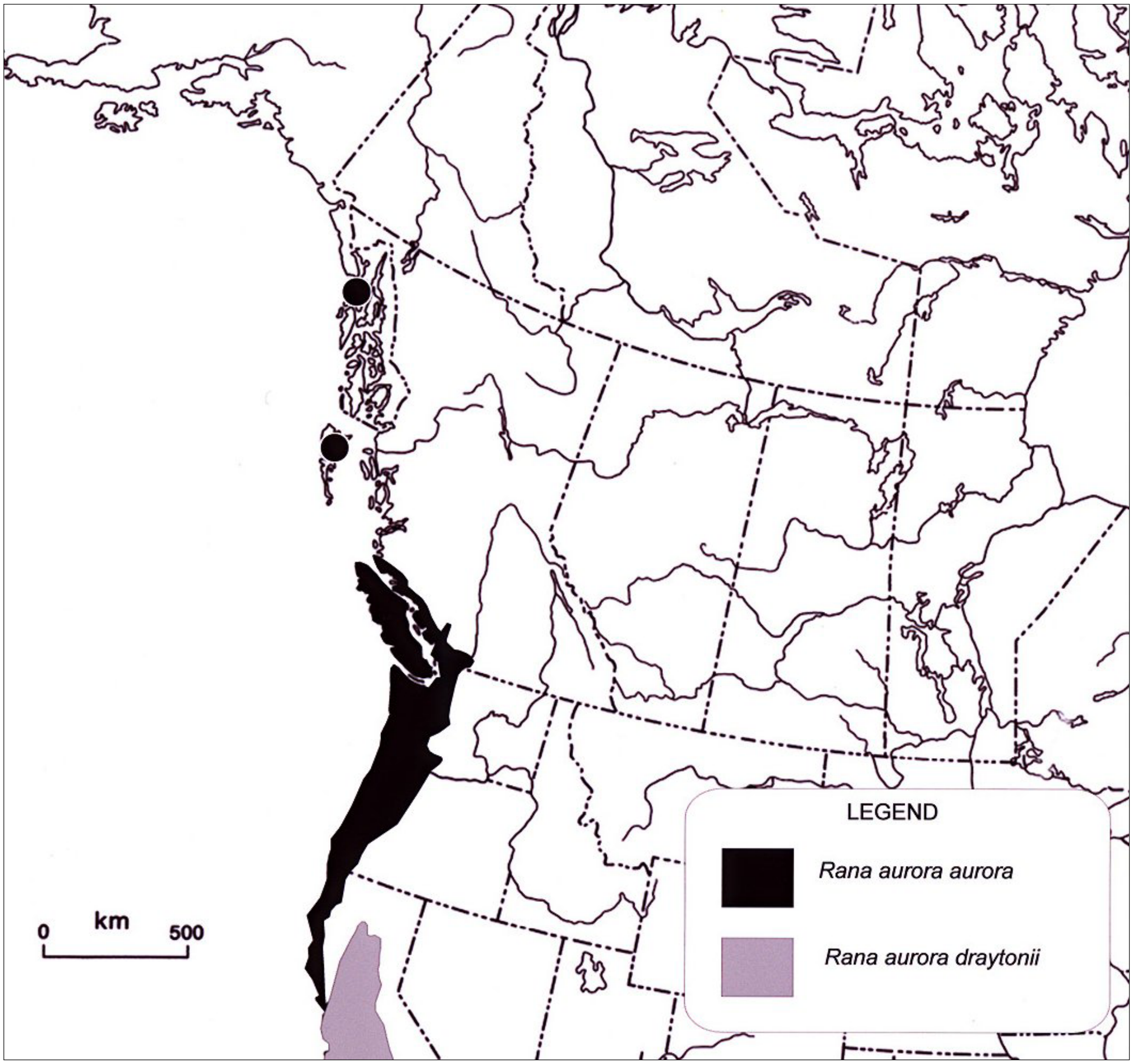


Figure 2. North American distribution of the Northern Red-legged Frog. Distribution in the United States based on a maps provided by R. Nauman and K. MacAllister; BC distribution based on Figure 3.

Vancouver Island comprises the bulk (over 50%) of the species' known Canadian range. On the mainland, the species' distribution extends through the lower Fraser Valley east to near Hope and north along the coast to Bramham Island in the vicinity of Cape Caution. In the north, an isolated record exists from near Kitimat on the central coast (RBCM #1199, 12000). Specimens associated with the Kitimat record could not be located but were probably misidentified and represent the Columbia Spotted Frog, which is known from the area. In the southwest, a record from the Manning Park (RBCM #816, 817) probably also represents the Columbia Spotted Frog; unfortunately, these specimens could also not be located.

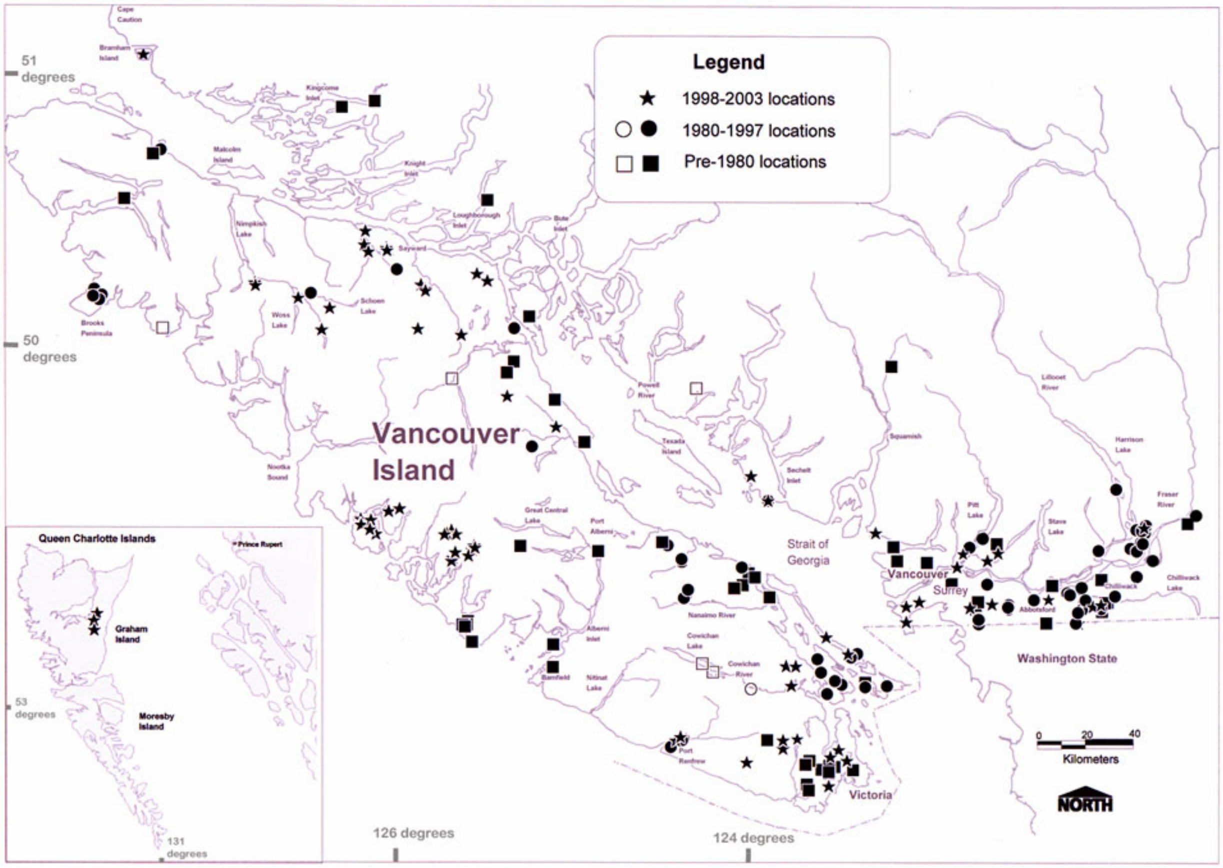


Figure 3. Locality records for the Red-legged Frog in British Columbia, 1887 – 2003. Open symbols represent approximate locations.

There are only a few records north of Vancouver along the mainland coast. The northernmost record (excluding the Kitimat record) is from Bramham Island, where students of the Coastal Ecosystem Foundation studied the ecology of the Red-legged Frog in the late 1990s (W. Meggill, pers. comm.). There are no museum specimens associated with this record. Three museum records exist from north of Powell River (from the Kingcome area and Loughborough Inlet near Powell River; CMC #1879, 1886A, B). The identification of these specimens has been confirmed (in September 2003, by Dr. Francis Cook, Researcher Emeritus, Canadian Museum of Nature). The rugged coastal forests north of Powell River and along the central coast have not been surveyed systematically for amphibians, and the limits of this species on the mainland remain unknown.

In 2001, the Red-legged Frog was documented from the Queen Charlotte Islands (Haida Gwaii) (Ovaska *et al*. 2002). The species was found at 10 localities in the vicinity of Port Clements, Graham Island, including both settled and remote areas. It is possible that this population is a result of human introduction, similar to the deliberate release of individuals of the Pacific Treefrog (*Pseudacris regilla*), which is now widespread on the islands (Reimchen 1991). However, the possibility that the Red-legged Frog is an overlooked native species cannot be ruled out conclusively without further investigation.

Other distribution records for the Red-legged Frog obtained since 1998, after the preparation of the COSEWIC status report by Waye (1999), are from within the known portions of the species' Canadian distribution on Vancouver Island and the Lower Mainland (Figure 3).

HABITAT

The Red-legged Frog is an inhabitant of moist, lower elevation forests and requires both aquatic breeding habitats and terrestrial foraging habitats in a suitable spatial configuration to complete the different phases of its life cycle. Hibernation can occur either on land on the forest floor or in water (Licht 1969), but little is known of specific requirements for over-wintering sites.

Elevation

The species has been recorded from sea-level to elevations up to 860 m in Washington and to 1427 m in Oregon (Leonard *et al*. 1993). The highest locality record from British Columbia is from 1040 m (E. Wind, unpublished data), but most records from the province are from below 500 m. In the Clayoquot Sound area on the west coast of Vancouver Island, Beasley *et al*. (2000) found the Red-legged Frog more frequently in wetlands below 500 m (30% were occupied) than in those above 500 m (14% were occupied); the highest locality for this species was at 710 m. Wind (2003 and unpublished data) surveyed 236 wetlands ranging in elevation from sea-level to 1200 m for amphibians. The mean elevation where this species was found was 515 m, but most sites were lower (mode = 180 m).

Aquatic breeding habitats

The Red-legged Frog breeds in a variety of permanent and temporary water bodies, including potholes, ponds, ditches, springs, marshes, margins of large lakes, and slow-moving portions of rivers (Blaustein *et al*. 1995 and references therein). Abundant emergent vegetation is typically present at breeding sites (Adams 1999, Ostergaard and Richter (2001). Within breeding sites, females deposit their eggs in quiet waters in areas that receive sunlight for at least a part of the day (Licht 1969).

In the Puget Lowlands, Washington State, the most common wetlands where this species was found had shallow slopes and a southern exposure; these habitat attributes together explained 63% of the variation in wetland occupancy (Adams 1999). Breeding habitats that were in permanent water bodies tended to be large wetlands with structural complexity. Also in Washington State, Ostegaard *et al*. (2003) found this species breeding in storm water storage ponds (i.e., small natural or modified catchment areas used for storage of storm water run-off). Its presence was positively correlated with wetland complexity, measured as the ratio of coverage by emergent vegetation to open water, and percentage of forest cover in the surrounding area. Egg-masses were most numerous in ponds with over 30% forest cover within 200 m from the shore. In Clayoquot Sound, Vancouver Island, the Red-legged Frog was more frequently found in bogs and fens than in other types of wetlands that included marshes, swamps, and shallow water areas of larger water bodies (Beasley *et al*. 2000).

Adams (2000) found that the survival of tadpoles of the Red-legged Frog in experimental enclosures was highly variable among sites but tended to be lower in permanent than temporary wetlands. The difference was possibly due to habitat gradients or indirect effects of native or exotic predators. These results suggest that permanent water bodies, which harbour more predators, may sometimes act as sink habitats rather than as source habitats for recruits to the population. Caution should be exercised in inferring the suitability of breeding sites from presence/absence type of data, where survival characteristics of the young are unknown.

Terrestrial foraging habitats

Metamorphosed individuals spend a large proportion of their life in terrestrial habitats, and adults are often encountered on land in the vicinity of wetlands or along forested stream banks (Blaustein *et al*. 1995 and references therein). Outside the breeding season, adults of the California Red-legged Frog remained within 130 m or less from their aquatic breeding sites (Bulger *et al*. 2003). The Northern Red-legged Frog is less closely tied to water bodies and riparian habitats than is the more aquatic California Red-legged Frog (Hayes and Miyamoto 1984). However, in one study on northern Vancouver Island, individual, radio-tracked frogs were relatively sedentary and typically remained within 36 m or closer to the edge of forest streams (Chan-McLeod 2003a; see section on Movements and Dispersal). When conditions are suitable, these frogs can be encountered on the forest floor far from water bodies; distances of 200-300 m away from water have been noted on rainy nights (Nussbaum *et al*. 1983).

The Red-legged Frog occupies a variety of forest types and ages but appears to be most abundant in older, moist stands (reviewed in Waye 1999 and Blaustein *et al*. 1995; also see Section “Limiting Factors and Threats” for interactions with forestry). In the Washington Cascade Range, this species was most abundant in mature stands and least abundant in young stands (Aubry and Hall 1991). Its abundance was negatively correlated with elevation and increasing slope. Captures were also associated with moderately moist conditions in older forest stands; very wet old-growth stands appeared to be somewhat less suitable. Within a younger set of chronoseries in second-growth Douglas Fir-dominated forest, Aubry (2000) found that this species was more abundant in stands that were near rotation age (50 – 70 years) than in younger stands, where only very few captures occurred. The near-rotation-age stands had a closed canopy and 30 – 45 m tall trees; the herb and shrub layer had re-established, but the abundance of coarse woody debris was depressed from old-growth conditions. In a study in Washington and Oregon, this species was most abundant at lower elevation habitats with relatively flat slopes, but there was no relationship to stand age (classed as old growth, mature, young) (Bury *et al*. 1991). It is possible that the association of the species with forest age varies geographically, with forest type, or with moisture or other conditions.

On Vancouver Island and the Gulf Islands, distribution records and anecdotal observations suggest that the species is commonly found in second growth forests, and occasionally occurs in suburban gardens and seasonal ponds in pasture- and agricultural lands adjacent to forested areas. On Vancouver Island, Wind (2003) found the species in wetlands within both recently logged and older forest. Relative abundance and survivorship characteristics were not studied (see section "Limiting Factors and Threats: Interactions with Forestry Practices" for a review of effects of logging on this species). "Presence/absence" data are inadequate for determining patterns of abundance and whether particular habitats might act as dispersal sinks, where populations are maintained by immigration rather than through recruitment through reproduction.

Dispersal habitats

Dispersal habitats are defined here as habitats that frogs must traverse to access different seasonal habitats during their life-cycle, such as between terrestrial foraging and aquatic breeding habitats, as well as those habitats that connect subpopulations or spatially separated units. Riparian areas have been postulated as corridors or conduits for movements of the Red-legged Frog across inhospitable habitats, but little evidence of such use exists. Migration movements of the California Red-legged Frog took place overland across a variety of habitats at distances up to 500 m away from water bodies; no associations with particular vegetation communities or topography were found (Bulger *et al*. 2003). These authors concluded that dispersal habitats were ubiquitous and widely distributed, making their protection difficult. However, habitats that retain moisture during periods of drought probably are more valuable for dispersal than are clearcuts.

On northern Vancouver Island, experimentally displaced adults were attracted to riparian areas along wider (3 m in width) streams but not to narrow streams (< 1.5 m in width) (Chan-McLeod 2003b). However, the frogs avoided non-forested parts of creeks in clearcuts and did not use them as travel corridors; whether they would travel along creeks with riparian buffer zones was not investigated. The permeability of clearcuts to movements increased on rainy days, while clearcuts acted as barriers to movements on hot, dry days. In another experiment on northern Vancouver Island, displaced frogs moved across clearcuts along random trajectories and failed to use residual tree-patches as stepping-stones; however, directional movements towards larger residual tree patches occurred from short (5 – 50 m) distances away (Chan-McLeod and Moy, in review). The authors suggested that open habitats, such as clearcuts, could act as habitat sinks, where dispersing or migrating frogs may be subject to mortality from predation or desiccation.

These frogs have been noted to move across roads, especially on rainy nights (Nussbaum *et al*. 1983). Road mortality can be considerable where dispersal routes are across highways or main roads (Beasley, 2003; B. Beasley, pers. comm.).

Trends

Over the past century, habitats of the Red-legged Frog have been altered by human activities over most of the species' range in British Columbia. Habitat degradation and loss are extensive on southern and eastern Vancouver Island, the Lower Fraser Valley, and parts of the Sunshine Coast. The rate and permanency of habitat alteration are highest in these areas, as a result of agriculture, urbanization, forestry, and introduction of exotic species. Of particular concern is the exotic Bullfrog (*R. catesbeiana*), which adversely affects populations of the Red-legged Frog (Govindarajulu 2003; see Section "Limiting Factors and Threats: Introduced Species"). Although the highest abundance of both the Bullfrog and the Green Frog (*Rana clamitans*), another exotic species, is associated with human settlements, these species have started to spread to wetlands in rural areas, degrading their quality as breeding sites for the Red-legged Frog. Within the range of the Red-legged Frog, the Bullfrog is known from most of the Lower Mainland, southeastern Vancouver Island from Victoria to Parksville, and from some of the Gulf Islands (Govindarajulu 2003). The Green Frog in known from several localities on southeastern Vancouver Island and the Lower Mainland and may also adversely affect native species of amphibians, but potential interactions have not been studied.

Habitat alteration on the more remote areas on northern and western Vancouver Island and the mainland coast north of Powell River result primarily from forestry activities on crown lands. The impacts of forestry activities on crown lands subject to the Forest and Range Practices Act are potentially less severe and of shorter duration than impacts of other human activities, provided that wetlands are protected and forests are allowed to regenerate. However, road-building activities in particular have the potential to permanently degrade wetlands and cause collision mortality.

Vancouver Island: Urban and agricultural areas covered about 4% (about 1200 km^2) of the total area of the island in 1989 (BC Ministry of Forests 1991) and are expanding rapidly. Agriculture and urbanization result in severe and long-term changes to habitats. Low-elevation forested and wetland habitats (< 500 m asl) overlap extensively with areas of human habitation on southern and eastern Vancouver Island. These habitats have been permanently degraded and fragmented by the drainage of wetlands, pollution of water bodies, and removal of forest cover. The human population on southern Vancouver Island grew by 2.7% from 1996 – 2001 and continues to expand rapidly (Statistics Canada 2003). Recently, a new double-lane highway was constructed inland from the coast between Campbell River and Nanaimo, which has facilitated increased development in these areas.

Logging has affected a large proportion of the low-elevation forests inhabited by the Red-legged Frog. Based on satellite imagery, about 45% of the land area of the island consisted of immature forest in 1989 (BC Ministry of Forests 1991). Logging activity is thought to be responsible for most of the immature forest in this area where wildfires, pest outbreaks, and blow-down are relatively uncommon (MacKinnon and Eng 1995). Logging activity has continued at a high rate over the past 14 years. In 1999, satellite imagery indicated that about 70% of low- to mid-elevation forests (excluding Mountain Hemlock and “muskeg” forests and bare ground) are immature (Sierra Club 2003). The southeastern portion of the island, from Campbell River to Victoria, consists mainly of private forestry lands, which have been logged extensively; almost all old-growth forest at low- to mid-elevations has been removed. The northern and western portions of the island are crown land, and more old-growth habitat remains. However, most of the area consists of a mosaic of recent clearcuts, young forests, and patches of old-growth. The exceptions are protected areas (see section on Protection and Ownership, below).

The effects of logging on frogs are likely medium-term, and habitats are expected to improve as second-growth forests mature and wetlands recover. However, on the south island, logging of low elevations second-growth forests is in progress, and the regenerated habitats are again being degraded. Recently developed Identified Wildlife habitat guidelines are expected to provide provisions to protect some of the remaining habitats in mature second-growth and old-growth forests (see section on Protection and Ownership, below).

Lower Mainland: The Lower Mainland, an area along and adjacent to the Lower Fraser River Valley from Vancouver to Hope, covers about 10% of the Canadian range of the Red-legged Frog. This region was likely an important component of the species’ range in British Columbia in the past, because it once provided productive and extensive low-elevation forested and wetland habitats. Prior to the early 1800s, the Fraser Valley contained vast forests of giant trees with extensive swamps and wetlands along the river courses (Boyle *et al*. 1997). Since European settlement, much of the old-growth forest has disappeared and wetlands have decreased from about 10% of the area to only 1% in 1990 (Boyle *et al*. 1997). Habitat degradation in the Lower Mainland has been severe over the past century, with many permanent landscape modifications. Urban development and agriculture continue to expand in this region, which is one of Canada’s fastest growing areas. The human population on the Lower Mainland grew by 8.3% from 1996 – 2001 (Statistics Canada 2003), and this growth is shifting from Vancouver to outlying communities in the Fraser Valley between Surrey and Chilliwack. Consequently, there is intense pressure to develop lands in this region, including remnant mature forest stands and wetlands. Agriculture in the Fraser Valley has resulted in extensive habitat loss from wetland drainage, pollution, and forest removal. Remaining habitats are highly fragmented, posing threats to populations of the Red-legged Frog, particularly where habitat losses continue and exotic species are spreading.

South-Central Coast (Sunshine coast north to Bramham Island/Rivers Inlet): On the Sunshine Coast, residential development along coastal regions between Gibsons and Powell River has increased over the past decade with consequent alteration and loss of wetlands and adjacent forest cover. Areas subject to forestry are also extensive, especially in low-elevation habitats along the coast (Sunshine Coast Regional District 2003; forest cover map).

Permanent habitat losses are relatively minor in areas of the coast north of Powell River, where the human population is very low. Forestry occurs mainly on crown lands and is most extensive between Powell River and Knight Inlet, especially at low-elevations and on islands. Large tracts of old-growth forest are still present north of Knight Inlet (BC Ministry of Forests 2003). The Central Coast Region of British Columbia has been poorly surveyed for amphibians, and the northern distributional limits of the Red-legged Frog (north of 51° N) along the coast are unknown. Although the Central Coast region may be less productive for the species due to a harsh climate and rugged terrain, this area is relatively undisturbed and potentially could represent a significant component of the provincial population of the species. Surveys in this area are required to clarify distributional patterns.

Protection/ownership

Parks and other protected areas: On Vancouver Island, about 13% of the land-base is protected. A total of 24% of the island is privately owned, 75% of which is private forestry lands (Sierra Club 2003, van Kooten 1995). Most of the private forestry lands and urban/agricultural developments are found in southeastern quarter of Vancouver Island. This region appears to be an important area for the Red-legged Frog. The majority of historic locations occur there, and although the records probably reflect observation bias, it is possible that the abundance of low-elevation forests and wetland breeding sites also contributes to the pattern. Yet, this region contains relatively little protected land. In 2003, the Gulf Islands National Park Reserve was established off the southeastern coast of Vancouver Island. The new park is composed mainly of lands that were already protected as provincial or regional parks, but some new acquisitions were also included. Several areas within this park contain habitat for the Red-legged Frog. On the western and northern parts of Vancouver Island, most of the land is crown land and used mainly by forestry companies for logging.

On the Lower Mainland very little of the land base is protected, and much of it consists of small parks surrounded by urban and rural developments. Many of the known sites for the Red-legged frog in the Fraser Valley are located within these parks and, even though the land is protected, habitat degradation and fragmentation are of concern (Waye 1999). Wetland areas on the Lower Mainland are threatened by encroaching urban development, which can result in direct habitat loss, habitat degradation due to fragmentation, contamination from pollutants entering storm drains, changes in drainage patterns, and introduction and spread of exotic species (Schaefer 1994; R. Rithaler, pers. comm.).

The Sunshine Coast and south-central coast contain relatively few protected areas and the majority of the land base is zoned for forestry activities. The main existing or proposed parks in this region are Cape Caution/Bramham Island, Ahnuhati, Smokehouse, Broughton, Desolation Sound, and Tetrahedron. The Sunshine Coast currently only has 3.6% of the land base protected compared to 12% for the province as a whole (Sunshine Coast Regional District 2002).

Forestry Regulations and Guidelines: The Forest and Range Practices Act provides some provisions for the protection of habitats of the Red-legged Frog through measures described in the Riparian Management Area Guidebook and General Wildlife Measures (GWMS) contained in the Identified Wildlife Management Strategy. The Riparian Guidebook recommends that buffer zones of undisturbed forest cover be retained around larger wetlands and streams. However, smaller wetlands (<0.5 ha) are used extensively by the Red-legged Frog and are not addressed by the provisions in the Riparian Guidebook.

The Identified Wildlife Management Strategy contains guidelines for the protection and management of the Red Legged Frog through the establishment of Wildlife Habitat Areas (WHAs) and associated General Wildlife Measures (GWMs). Priority for WHA establishment will be networks of small ephemeral and perennial wetlands (a minimum of three wetlands that are within 300 m of each other), especially in areas where frogs are known to occur (Maxcy 2003). The size of WHAs is usually less than 10 ha. Other characteristics of potential WHAs will include high structural complexity of aquatic and terrestrial habitats, a humus substrate in the wetland, forest/vegetation cover surrounding wetlands, absence of predatory fish and the Bullfrog, low- to mid-elevation (<850 m asl), and presence of water until late summer. To date no WHA's for this species have been put into place, and none are currently proposed.

At present, the Identified Wildlife Management Strategy does not stipulate the percentage of wetlands that need to be protected from forestry activities to maintain the viability of frog populations in a particular region. General Wildlife Measures address the appropriate placement of logging roads to reduce collision mortality, maintenance of hydrological regimes and emergent vegetation in wetlands, and retention of forest cover and coarse woody debris in areas surrounding wetlands. Although habitat protection provided by these measures is potentially considerable, many uncertainties surround their implementation, the measures are largely untested, and their effectiveness is presently unknown.

The Forest and Range Practices Act also contains more general protection measures such as restrictions on the size of clearcuts and provisions for Wildlife tree patches/retention areas that may serve to protect habitats for the Red-legged Frog. Any protection measures for wildlife habitat on private forestry lands, which cover large tracts of the species' habitat on southern Vancouver Island and the Lower Mainland, are currently undertaken on a voluntary basis only.

Urban planning and protection initiatives: Municipal and regional governments in the Lower Mainland, Vancouver island, and Sunshine Coast have prepared land use plans, by-laws, and zoning regulations, which offer some protection for wetland habitats. Developers are required to follow by-laws, mitigate impacts, and protect wildlife habitat, where possible. Recently, a set of province-wide Best Management Practices (BMPs) for amphibians and reptiles was developed by the Ministry of Water, Land and Air Protection (Ovaska *et al* 2003). BMPs provide guidelines and specific measures that developers and local governments can use to protect or restore habitats for these animals. Unfortunately, protected areas and restoration projects in urban and rural settings tend to be small, and habitats are often highly fragmented. They are probably of limited benefit for the Red-legged Frog, which requires relatively large areas of forest surrounding wetlands.

In 2003, the municipality of Delta (south of Vancouver) became the first municipality in British Columbia to assess the distribution and status of amphibians in the community. They have developed detailed "In-Stream Works Windows" designed to protect amphibians and their habitats in riparian areas (R. Rithaler, pers. comm.). Conservation organizations such Ducks Unlimited, Nature Trust of BC, and The Land Conservancy are actively acquiring, protecting and restoring wetlands and adjacent terrestrial habitats in southwestern British Columbia. Some projects, such as Cheam Lake wetlands, Codd Island Wetlands, Pitt-Addison Marsh, Burns Bog, and Blaney Bog may be of sufficient size to protect both wetland and adjacent forest cover for the Red-legged Frog.

BIOLOGY

The Red-legged Frog has a biphasic life-cycle typical of aquatic-breeding amphibians in the northern hemisphere: Eggs are laid in water and develop into aquatic larvae, which then metamorphose into juveniles that leave the water. Juvenile frogs forage in terrestrial and riparian habitats for several years before reaching sexual maturity and then return to aquatic habitats to reproduce. Outside the breeding season, adults of the Red-legged Frog are highly terrestrial and can be found far from water. The use of aquatic breeding habitats increases the exposure of the vulnerable, early life history stages to contaminants, as ponds and other water bodies act as sinks for various pollutants. In fragmented landscapes, seasonal migrations of these frogs to and from breeding sites increase their vulnerability to road mortality and to predators. The modification of either their aquatic breeding sites or adjacent terrestrial habitats by human activities and land use practices can be detrimental to local populations. These frogs require sufficient space to allow for seasonal movements are therefore especially vulnerable to habitat fragmentation.

Licht (1969, 1971, 1974) and Calef (1973a, b) studied the reproductive biology and survivorship of the Red-legged Frog in southern British Columbia. These studies remain the most detailed treatments of the species' biology and natural history in Canada to date. Waye (1999) provided a comprehensive review of the general biology of this species based on the above and other studies reported up to 1997.

Reproduction

The Red-legged Frog is an explosive breeder (sensu Wells 1977), and adults congregate at breeding sites for a short period (2 – 4 weeks) in early spring, often immediately after the break-up of ice. Males are vocal but typically call from under water – as a result, breeding choruses are inaudible or only barely detectable to the human ear from above the water's surface (Licht 1969). The timing of the breeding migration and egg-laying varies both geographically and from year to year depending on air and water temperatures; water temperatures of at least 6 – 7°C appear to be to required for egg-laying to occur, but temperatures frequently drop below this value during embryonic development (Licht 1974, Brown 1975). In southern British Columbia, breeding has been reported from February to April, but it is typically completed by the end of March (Licht 1969, Calef 1973b). While males are capable of breeding multiple times during each breeding season, their mating success appears to be highly variable (Calef 1973a). Adult females reproduce each year (Licht 1974). Sexual maturity by both sexes is attained at three or more years of age (Licht 1974).

As in most aquatic-breeding anurans, fertilization is external. Females lay their eggs in a large (20 – 30 cm diameter) gelatinous cluster, which they often attach to submerged vegetation (Leonard *et al*. 1993; Figure 1b). The egg masses are typically entirely submerged, about 30 – 90 cm below the surface of the water (Licht 1969). The clutch size is relatively large (up to 1300 eggs; Leonard *et al*. 1993) and shows a positive correlation with the body size of the female (Licht 1974). The average clutch size in marshes near Vancouver was 680 eggs (range: 243 – 935 eggs; Licht 1974); at another site on the lower mainland (Marion Lake) it was 531±19 eggs (mean±SE; Calef 1973b).

The duration of the incubation and larval period is temperature-dependent and highly variable under natural conditions. Hatching can take place as soon as about nine days from oviposition (under constant temperature of 18.3°C; Storm 1960) but usually takes much longer under the variable temperature regimes encountered under field conditions in the spring (6 – 7 weeks in Oregon, Storm 1960; 35 days in Washington, Brown 1975). In southern British Columbia, hatching typically occurs during the first half of May (Calef 1973b). The duration of the larval period is about 11 – 14 weeks (Calef 1973b). Most tadpoles transform from early July to early August, but the timing of metamorphosis varies both annually and with location (Licht 1969, Calef 1973b); Calef (1973b) found that tadpoles continued to metamorphose until early October at one site. Over-wintering by tadpoles has been documented for the California Red-legged Frog under some situations (Fellers *et al*. 2001), but there is no evidence of this phenomenon for the Red-legged Frog.

Survival

The Red-legged Frog exhibits a Type III survivorship curve, which occurs when juvenile mortality is extremely high. Annual survivorship of those individuals that survive the critical early period then increases greatly. For this species the greatest mortality occurs during the tadpole stage, whereas embryonic mortality and that of metamorphosed individuals is relatively low (Calef 1973b, Licht 1974). Licht (1974) reported survival rates of over 90% for embryos from oviposition to hatching and less than 1% for tadpoles from hatching to metamorphosis in marshes near Vancouver. Calef (1973b) reported 5% survival through the tadpole stage at another lower mainland site (Marion Lake); small tadpoles were particularly vulnerable, and most mortality occurred within the first 3 – 4 weeks from hatching. In Licht's (1974) study, the overall survival rate of metamorphosed juveniles to the end of the growing season was 4.8% from the egg stage and 5.3% from the tadpole stage. Survival of the these recruits to the population over their first year as frogs was estimated to be relatively high at 52%, based on mark-recapture data over one year; the annual survival of adults was also high at 69%. The high embryonic survival of the Red-legged Frog contrasted with that of the syntopic Oregon Spotted Frog (R. pretiosa), in which most early mortality occurred in the egg-stage, often due to stranding of the eggs laid in shallow water. Survivorship of other life history stages was similar for the two species (Licht 1974).

While fungal infections and desiccation due to fluctuating water levels contribute to embryonic mortality, predation is thought to be the main source of mortality of tadpoles of the Red-legged Frog (Calef 1973b, Licht 1974). Experiments in field enclosures where numbers of predators (Rough-skinned Newt *Taricha granulosa*) were manipulated emphasized the importance of predation as a mortality factor for tadpoles (Calef 1973b).

Little is known of the demography of the Red-legged Frog. Adult males greatly outnumber females at breeding sites, but outside the breeding season the sex ratio appears to be even (Calef 1973a). Adults live for multiple years, but their longevity under field conditions is unknown; a lifespan up to 15 years has been reported in captivity (McTaggart Cowan 1941). Populations of many aquatic-breeding anurans fluctuate widely from year to year (Pechmann and Wilbur 1994), and this species is probably no exception. Waye (1999) pointed out that populations of the Red-legged Frog are likely to withstand 1 – 2 years of low recruitment through the survival of adults for multiple years.

Predators and parasites

Predators of tadpoles of the Red-legged Frog include predatory fish such as the introduced Rainbow Trout (*Salmo gairdneri*), salamanders such as the Rough-skinned Newt and Northwestern Salamander (*Ambystoma gracile*), and various invertebrates such as dragonfly larvae (family Odonata) and the Giant Water Bug (*Lethocerus americanus*) (Calef 1973b). Leaches prey on anuran tadpoles and eggs (Licht 1974), and the Rough-skinned Newt has been observed to feed on eggs of the California Red-legged Frog (Rathbun 1998). The introduced Bullfrog is a predator of both larvae and adults. Various other vertebrate and invertebrate predators that include metamorphosed frogs and tadpoles in their diets are often present in aquatic habitats occupied by this species, including the Raccoon (Procyon lotor), Great Blue Heron (*Ardea herodias*), Belted Kingfisher (*Megaceryle alcyon*), and the Common Garter Snake (*Thamnophis sirtalis*) (Licht 1974).

The Red-legged Frog is a host for various parasites and disease-causing organisms. Infection by the parasitic yeast *Candida humicola* alters the behaviour of tadpoles of this species and increases their susceptibility to predation (Lefcort and Blaustein 1995). In western United States, infections by the parasitic trematode *Ribeiroia ondatrae* are linked to limb abnormalities in several amphibian species (Johnson *et al*. 2002). Johnston *et al*. (2002) found a relatively high frequency of limb malformations (mean of 10.8%) in metamorphs of the Red-legged Frog, which were associated with Ribeiroia infection. The parasite was found at 5 of the 11 sites sampled where this frog was present. The Red-legged Frog is susceptible to infections by iridoviruses, a group of pathogens that infect invertebrates and ectothermic vertebrates. An iridovirus identical to that in sympatric fish species has been isolated from the Red-legged Frog, suggesting that fish (native and introduced) may act as reservoirs of viruses pathogenic to amphibians (Mao *et al*. 1999).

Physiology

The Red-legged Frog is adapted to breeding in cold conditions (Licht 1971). Adults are active early in the spring when air and water temperatures are low, and males may call at water temperatures as low as 4 – 5° C (Licht 1971, Calef 1973a, Brown 1975). The eggs can withstand exposure to similarly low temperatures, although egg-laying typically occurs in somewhat warmer water (see Section on Reproduction, above). The thermal tolerance of young embryos (up to Gosner developmental stage 11) ranges from 4 to 21°C (Licht 1971). Both the lethal maximum and minimum are the lowest reported for North American *Rana*, and the pattern most closely resembles that of the cold-adapted Wood Frog (*Rana sylvatica*) from Alaska. The thermal tolerance of embryos increases as development proceeds; hatching occurs at Gosner developmental stage 21 in this species. In nature, the eggs are protected within a gelatinous mass and are typically submerged in water; both factors buffer them from thermal fluctuations (Licht 1971). Because these frogs breed at night very early in the spring, it is unlikely that young embryos will ever be exposed to temperatures above the lethal limits in British Columbia.

The eggs of the Red-legged Frog are relatively large, with large yolk supplies, when compared to other species of *Rana* (Licht 1971). This trait appears to be an adaptation to northern climates and to breeding at low temperatures. A correlate of a large egg size is a slow embryonic developmental rate. The adaptive significance of large eggs in these frogs is unknown but may relate to advantages gained by correspondingly larger larvae, which can better escape predation.

These frogs are not known to be freeze-tolerant, as are the Wood Frog and a few other northern anurans. Instead, they over-winter in the bottom of pools or on the forest floor, presumably in microhabitats that are buffered from below-freezing conditions.

Movements and dispersal

Adults undertake seasonal migrations between aquatic breeding sites and terrestrial foraging habitats in the spring, and metamorphs disperse away from the breeding sites from late summer to early autumn each year. Migrations to and from hibernation sites may also occur, but it is possible that hibernation takes place within foraging or breeding areas. The spatial extent of seasonal migrations and dispersal patterns for the Red-legged Frog are poorly known. In Washington, five female frogs equipped with radio-transmitters moved relatively long distances (up to 80 m day) during the spring migration period from breeding sites to foraging areas (Shean 2002). In contrast, their movements were shorter (< 3 m/day) and unidirectional while at the breeding site. The summer foraging sites were up to 312 m away from the breeding sites in straight-line distance. In Oregon, four adult frogs were found in April – May at a straight-line distance of 1.1 – 2.4 km from their capture points the previous December, indicating that at least some individuals undertake relatively long migration movements (Hayes *et al*. 2001). The migration movements of the California Red-legged Frog took place overland through routes that were up to 500 m from water (Bulger *et al*. 2003). The frogs traveled distances of 200 – 2800 m over several months over the wet season in winter to reach their breeding grounds. Interestingly, only a relatively small proportion (11 – 22%) of the breeding population migrated; most frogs remained in the vicinity of the breeding sites year-round. The California Red-legged Frog is more aquatic than the Northern Red-legged Frog and somewhat dissimilar in its ecology, morphology, and genetics from its southern form – therefore, these observations may not be applicable to the northern subspecies.

Within breeding sites in southern British Columbia, individual adult males typically moved distances of 100 – 300 m within and between weed-beds (Calef 1973a). Individual males showed site-fidelity to particular breeding sites from year to year, and about 20% of the males marked in one year were recaptured the following year. Furthermore, about 58% of the recaptured males returned to the same weed-bed, and many others occupied adjacent weed-beds within 100 m of their original capture locations. Site-fidelity of females is less well documented, most likely due to difficulties in obtaining sufficiently large sample sizes of females rather than differences in their behaviour.

Within terrestrial habitats on northern Vancouver Island, Chan-McLeod (2003a, b) and Chan-McLeod and Moy (in review) studied movements of adults of the Red-legged Frog in relation to various logging patterns. Frogs that were experimentally released under individual trees or into small forest patches within a logged matrix (cut area surrounding the patches) during the non-breeding season from May to October either remained in these patches, moving at average rates of less than 10 m/day, or left the patches and moved through the habitat, including the logged matrix, at average rates of 50 – 60 m/day. No tendencies to move towards the direction of original capture sites some distance away were found. In another experiment, frogs that were released at the clearcut – old growth forest edge moved straight-line distances of up to 221 m in 3 days and 191 m in two days across the clearcut under favourable, wet conditions (Chan-McLeod 2003b).

In the uncut forest on northern Vancouver Island, individual frogs occupied small home ranges in forested riparian areas along streams and typically moved only short distances when monitored in May – June (for 3 – 41 days) and in September – October (for 3 – 13 days; Chan-McLeod 2003a). At four sites, the average daily movements of radio-tracked 68 adults were less than 5 m between locations. Individual frogs were site-tenacious and moved back and forth within a small, defined area. The frogs remained within 36 m or closer to the water's edge. Two of the frogs undertook directional, longer movements. One frog moved about 260 m along the riparian channel within a period of three weeks in early summer; another moved perpendicular to the stream at least 200 m. These results suggest that although typically sedentary in riparian habitats, these frogs are capable of and occasionally undertake relatively long-distance movements. Chan-McLeod (2003a) suggested that, although infrequent, longer movements might be important for connecting subpopulations and maintaining spatial structure of metapopulations.

Young juveniles remain on the shores of breeding habitats for some time after transformation (Licht 1969), but nothing is known of the dispersal movements of metamorphs into the terrestrial habitat. Movements of older juveniles, until maturation several years later, are also unknown.

The potential of a rescue effect for Canadian populations due to dispersal from nearby U.S. populations is very limited. There are several records from near the U.S. border on the Lower Mainland but most of these date from before 1960 and it is unknown whether these populations still exist. Dispersal across the border from the US could potentially occur through the lowlands west from the Columbia Valley near Cultus Lake, but this area is highly fragmented and heavily modified by agriculture, residential developments, and roads. Some forested areas remain in the immediate vicinity of the border. Immediately east of the Columbia Valley, the high peaks of the Cascade Mountain Range pose barriers to dispersal.

Nutrition and interspecific interactions

The diet of the Red-legged Frog consists of a wide variety of small invertebrates. In marshes in southern British Columbia, the dominant prey items of adults and juveniles, in terms of percentage of stomachs where present, were spiders (Arachnida), beetles (Carabidae, Staphylinidae, Chrysomelidae, and Curculionidae), leaf hoppers (Cicadellidae), damsel bugs (Nabidae), and minute moss beetles (Limnebiidae) (Licht 1986). Adult flies (Muscidae) and fly larvae of the family Syrphidae were also numerically abundant in some stomachs. Newly metamorphosed frogs had consumed spittlebugs (Cercopidae), spiders, leafhoppers, slugs, larvae of syrphid flies, and various other small prey. Metamorphosed frogs foraged in the riparian habitat, typically very close (within 1 m) to the water's edge, but moved further into the terrestrial habitat during and after rains, foraging in patches of dense vegetation and along margins of rain-puddles.

Licht (1986) reported on the diet and foraging behaviour of adults and juveniles of the Red-legged Frog and Oregon Spotted Frog from marshes where the two species were syntopic. The Red-legged Frog foraged mostly on land on terrestrial prey, whereas the Oregon Spotted Frog commonly foraged in water and included a larger proportion of aquatic prey in its diet. The availability of food appeared not to be a factor limiting growth of either species. Barnett and Richardson (2002) found complex, indirect effects on the development of tadpoles of these two species in the presence and absence of a predator (dragonfly larvae) and each other in artificial pond experiments. Exposure of the Red-legged tadpoles to the odonate predator or tadpoles of the Oregon Spotted Frog resulted in increased body size at metamorphosis; developmental time also decreased in the presence of Spotted Frog tadpoles. Tadpoles of both species exhibit avoidance behaviour when exposed to a caged odonate predator.

Tadpoles of the Red-legged Frog respond behaviourally to alarm cues from injured conspecifics and predators. They also alter their pattern of development in response to chemical cues of predators but in a complex way. Kiesecker *et al*. (2002) found that tadpoles exposed to predators fed a diet of conspecific tadpoles metamorphosed earlier and at smaller body size than did control tadpoles.

Tadpoles of the Red-legged Frog feed largely on filamentous green algae. Experiments in enclosures indicated that feeding by tadpoles of this species altered both the composition and abundance of periphyton (Dickman 1968). Dickman (1968) suggested that feeding by tadpoles might initiate seasonal succession of periphyton in water bodies, which in turn could result in widespread effects within the food-web.

Behaviour and adaptability

Because males call from under water, even large breeding concentrations may remain undetected, unless special techniques such as hydrophones or snorkelling are used. Adults show fidelity to particular breeding sites and may attempt to return to them across modified landscapes where the risk of mortality is high, such as across busy roads. Where sufficient forest cover remains, these frogs can be found near human habitations and in backyard pools. Their ability to use a variety of habitats for breeding and other seasonal activities facilitates their occupancy of human-modified landscapes. However, their tolerance limits and exact spatial requirements, particularly in terrestrial habitats, are largely unknown.

POPULATION SIZES AND TRENDS

Population size

The number of adult frogs may vary from hundreds to thousands at breeding sites depending on the size and characteristics of the wetland, but little quantitative information is available. Although population estimates for this species are largely unavailable, there is every indication that there are more breeding adults in Canada than would trigger any of the COSEWIC numerical criteria. Waye (1999) summarized what is known of population sizes of the Red-legged Frog in British Columbia and

United States. Two mark-recapture studies at breeding sites were carried out in 1968 – 1970 in southern British Columbia (Licht 1969, 1971, 1974, Calef 1973a, b). At Marion Lake, near Squamish, the number of egg-masses, an index of the number of breeding females, was 618 and 620 in two years, respectively; the average number of adult males was estimated to be 1770 (SE = 280) and 3600 (SE = 775) in the two years (Calef 1973a, b). In marshes near Vancouver, the number of egg-masses was 6 and 33 in two years, respectively; the average estimated number of adults of both sexes was 531 frogs (SE = 19; Licht 1969, 1974). No information exists on current population sizes in these or other breeding sites in the province, or on densities in terrestrial habitats.

Populations of the Red-legged Frog are likely to undergo high year-to-year or longer-term fluctuations in size, similar to those reported for many other species of aquatic-breeding anurans (Pechmann and Wilbur 1994). However, populations have not been monitored over multiple years, and the magnitude of multi-year fluctuations is unknown.

Population distribution and persistence

On Vancouver Island, the species is relatively widely distributed, based on historical and recent records (Figure 3). The island appears to remain a stronghold of the species' Canadian distribution, although habitats continue to be modified by forestry, urban developments, agriculture, and other human activities, and by the spread of introduced species. Recent (since 1998) systematic surveys of wetlands for aquatic-breeding amphibians, including the Red-legged Frog, have been conducted in Clayoquot Sound on the west coast of the island (Beasley *et al*. 2000), on forestry lands on southeastern and northern parts of the island (Wind 2003), and near Victoria (Govindarajulu 2003 and unpublished data). A research project on interactions of this species with forestry activities was carried out on northern Vancouver Island (Chan-McLeod 2003a). Additional locality records are available from researchers working on other amphibian species (Western Toad: Davis, pers. comm.), from the public through the provincial Frog Watch Program, and from serendipitous encounters by various field workers.

In Clayoquot Sound, the Red-legged Frog was located in 26% of the 148 wetlands surveyed in 1998 – 1999 (Beasley *et al*. 2000). Its frequency of occurrence was similar to that of the Pacific Treefrog (33%) and Rough-skinned Newt (22%). The Northwestern Salamander was the most frequently encountered amphibian (found in 61% of the wetlands), whereas the Western Toad was rare (found in 1% of the wetlands). The Red-legged Frog was unevenly distributed among the four watersheds surveyed; it was not found in one watershed, and its frequency of occurrence ranged from 18 – 50% in the remaining three watersheds.

Wind (2003) surveyed 116 wetlands on northern and 97 wetlands on southeastern Vancouver Island; these wetlands were located both in forested and recently logged areas. Amphibians were detected in 41% of all wetlands surveyed. Overall, the Red-legged Frog was found at 21% of the wetlands, including sites in both recently logged

(0-5 years) and older forest (>150 years). It was the most frequently encountered amphibian in the southeast, followed by the Pacific Treefrog and Rough-skinned Newt. In the north, however, the Northwestern Salamander was by far the most frequently encountered amphibian, followed by the Red-legged Frog and Pacific Treefrog; the difference between the north and southeast possibly reflected higher elevations of the sites surveyed in the north.

Govindarajulu (2003 and unpublished data) surveyed wetlands on the Saanich Peninsula near Victoria on southern Vancouver Island as a part of her dissertation study on the effects of the Bullfrog on native amphibians. She located the Red-legged Frog at 15 lakes and ponds, most of which were on the west side of the peninsula and lacked Bullfrogs. Several other wetlands, especially on the east side of the peninsula, supported Bullfrogs only. This distribution pattern, together with experimental studies of interactions between the two species, suggest that the Red-legged Frog is in the process of being displaced from this area by the Bullfrog (see section "Limiting factors and threats"). The Bullfrog may be influencing the distribution of the Red-legged Frog over a wider area along the east coast of Vancouver Island, as well as on the Lower Mainland.

Only sporadic distribution data are available for other areas of Vancouver Island. For example, the species continues to be found in Jordan Meadows, a large wetland complex on southwestern Vancouver Island from where the Western Toad, for unknown reasons, has disappeared over the past decade (Davis and Gregory 2003). However, no quantitative data on abundance are available for the Red-legged Frog at this site, and the population should be monitored for epidemic disease, which can affect a multitude of amphibian species, spread rapidly, and decimate populations. Many parts of Vancouver Island, such as most of the west coast, mountains in the central part of the island, and the far north have not been surveyed systematically for amphibians, and the present status of populations remain unknown.

Little information exists on the current distribution and abundance of the species in most areas of mainland British Columbia. An exception is the Delta area south of Vancouver, where the Corporation of Delta has assessed fish and amphibian distributions and status within watersheds throughout the district based on historical records and new survey data (R. Rithaler, pers. comm.). The Red-legged Frog occurred in 10 of 23 watersheds within Delta in 1990 – 2002; there were no known disappearances from entire watersheds when this pattern was compared to pre-1990 records (Rithaler 2002, 2003). The species is considered to be uncommon within the district, although it is regularly observed within certain areas (R. Rithaler, pers. comm.). The introduced Bullfrog and Green Frog are widespread in Delta and have been recorded from 18 and 17 watersheds, respectively, in 1990 – 2002 (Rithaler 2002, 2003). Habitat modifications, particularly the removal of riparian vegetation and channel deepening, appear to have contributed to the expansion of these introduced species and the disappearance of the Red-legged Frog from particular wetlands in Delta (R. Rithaler, pers. comm.).

De Solla *et al*. (2002a, b) studied effects of agricultural pollutants on amphibians in the Lower Fraser River Valley. The Red-legged Frog was primarily found at the periphery of the farmlands in the Sumas Prairie area during surveys in mid-1990s, and subsequent studies using experimental enclosures suggested that poor hatching success in contaminated water might contribute to this pattern (De Solla *et al*. 2002a). During two other surveys in the mid-1990s, the species was found at 14 sites in the Lower Fraser Valley but not at 25 sites where apparently suitable habitat existed (Haycock 1996 and Knopp 1996, cited in Waye 1999). Haycock (1998) carried out additional surveys of wetlands for amphibians throughout the Fraser River Lowlands in and summarized records from Knopp (1996, 1997) for the same area. Whereas the Oregon Spotted frog (*Rana pretiosa*) has virtually disappeared, the Red-legged Frog was found at 50% of the sites surveyed and was considered a common amphibian species in the Fraser River Lowlands. However, much habitat has been lost or seriously degraded in this area.

Only a few old (1940s) locality records exist from the Sunshine coast and farther north, and the species' past and current distribution there is virtually unknown.

Population trends

Over the past several decades, the California Red-legged Frog has undergone precipitous population declines, including local extirpations, over most of its range in California (reviewed in Stebbins and Cohen 1995). While exploitation and habitat loss have undoubtedly contributed to the declines, especially in human-modified landscapes, declines in more remote areas are incompletely understood. Wind-borne transport of agricultural pesticides appears to be an important contributing factor (Davidson *et al*. 2002).

Whereas population trends of the California Red-legged Frog have received much attention, relatively little is known of population trends of the Northern Red-legged Frog. Since the mid-1970s population declines have occurred in the southern portion of its range in the Willamette Valley, Oregon (Blaustein *et al*. 1994b), but it appears to remain relatively common in at least some areas of Washington State, including human-modified landscapes (Ostergaard *et al*. 2003).

In British Columbia, the species' range overlaps with heavily urbanized and modified landscapes in the Lower Fraser Valley and on southern and southeastern Vancouver Island, where draining of wetlands, clearing of forest cover and riparian vegetation, and pollution have most likely contributed to the loss of breeding sites and local populations over the past century. Habitats continue to be lost and fragmented at an alarming rate in these areas (see section of "Habitat trends"), and introduced predators and competitors, such as the Bullfrog, often compromise the quality of remaining habitats (Govindarajulu 2003). However, populations and distribution trends have not been monitored systematically, and there is little documentation of population declines or disappearances.

Limited distribution records suggest that the species continues to be found throughout most of its known range in British Columbia (Figure 3). Distribution records from 1997 to present suggest that the species remains relatively widespread within portions of its range on Vancouver Island (see section “Population distribution and persistence”, above). However, “presence/absence” data collected for these surveys do not necessarily reflect patterns of abundance, and even large population declines could go undetected using solely this type of data. In the Lower Fraser Valley, there is some evidence that agricultural pollutants might contribute to the paucity of these frogs within agricultural edges in the Sumas Prairie (De Solla *et al*. 2002a), but the loss of both aquatic and terrestrial habitats is also likely to be a factor. No information exists on recent or historical population trends on the Sunshine Coast or areas north of Powell River.

Waye (1999) suggested that surveys of both historic sites and other localities with suitable habitat should be undertaken in different parts of the species’ range in British Columbia to fill in many uncertainties about distributional trends and the status of this species. Such surveys have not been undertaken to date, although several recent amphibian surveys on Vancouver Island, as a part of various projects, have contributed to our knowledge of its frequency of occurrence within wetlands. Future surveys should target the Sunshine Coast and the Lower Fraser Valley, where relatively little recent information on the species exists. Intensive monitoring of population trends at selected sites, either those with historic data or where populations of other species have undergone declines, would also be desirable.

LIMITING FACTORS AND THREATS

In British Columbia, the distribution of the Red-legged Frog is restricted to relatively low elevations. Most records are from elevations below 500 m, although the species has been reported from localities up to 1040 m in elevation. The species reaches the northern limits of its natural distribution in southern British Columbia. Its present northern distributional limits are probably a result of the glacial history of the area and not a reflection of its physiological or ecological tolerance limits, as attested by two isolated northern populations, in Haida Gwaii and southeast Alaska – the Alaska population and possibly also the Haida Gwaii population are the result of recent introductions. The species may still be expanding its range northwards along the Pacific coast, but altitudinal barriers (and possibly interactions with the Columbia Spotted Frog or other species) pose limits to its range expansion inland.

Throughout the species’ Canadian range, populations are threatened by human activities and land-use practices. Anthropogenic threats include habitat fragmentation, draining of wetlands, loss and modification of forest habitats, removal of riparian vegetation, pollution of breeding habitats, and the introduction of exotic and other non-native organisms to aquatic habitats. Epidemic disease is a concern for anuran populations in general, and synergistic interactions among various factors, human-induced and natural, are probably common and can affect amphibians in unpredictable ways. Global climate change can exacerbate all these effects.

Habitat loss and fragmentation

The distribution of the Red-legged Frog in Canada overlaps the most populated parts of the province in the Lower Fraser Valley and on the southern and eastern Vancouver Island (Figure 3). Over the past century, habitats in these areas have been lost due to draining of wetlands and the conversion of forests to agricultural lands and urban developments. Most of the development has been in lower elevation areas extensively used by this species. Urban development, in particular, continues to expand at a rapid rate in the southwestern part of the province, including parts of Vancouver Island, Lower Fraser Valley, and the Gulf Islands (see Section on “Habitat trends”). Within less populated parts of the species’ range (on the northern and western Vancouver Island, Sunshine Coast, and areas northward along the coast), forestry activities are extensive and continue to modify habitats.

In addition to habitat loss and alteration, human activities contribute to increased need for roads and to fragmentation of habitats. Habitat fragmentation is of particular concern for these frogs that undertake seasonal migrations and require forested areas for foraging, in addition to wetland breeding sites. Many amphibian populations are organized spatially as some form of metapopulations, and dispersal is essential for maintaining the viability of such populations (Marsh and Trenham 2001 and references therein). In other areas, habitat fragmentation has been shown to contribute to local declines and disappearances of forest-dwelling, pond-breeding amphibians that rely on dispersal among habitats and subpopulations (*R. sylvatica, Ambystoma maculatum*; Gibbs 1998). Green (2003) compared population trend data and demographic parameters of a large number of amphibian species and populations and concluded that “curtailment of recolonizations in an obligately dispersing species with highly fluctuating populations and high frequencies of local extinctions, such as pond-breeding amphibians, is likely to be affected rapidly and catastrophically by habitat fragmentation“ (p. 341). These considerations apply to the Red-legged Frog in general, although details of its population fluctuations and dynamics in space and time are unknown.

The loss of habitats to agriculture and urbanization are more or less permanent, whereas the effects of forestry are more temporary, provided that the forest cover is allowed to regenerate and wetlands are not degraded. However, vast tracts of land over much of the species’ Canadian range are affected by forestry. Therefore, the responses of this species to forestry activities and its ability to co-exist on forestry lands are of utmost importance in assessing threats to populations and their vulnerability within the species’ Canadian range.

Effects of forestry practices

Logging results in generally drier conditions and alters the microclimate and structure of the forest floor, and hydrology of wetlands. The concern is that these changes create unsuitable conditions for frogs, resulting in reduced opportunities for foraging and hibernation, in barriers to dispersal and migration movements, and in fragmentation of habitats. If wetlands are altered or drainage patterns changed, the reproductive success could be affected. The Red-legged Frog is associated with moist forest conditions and is frequently found in older forests; however, it is not restricted to older forest age-classes (reviewed in Blaustein *et al*. 1995). In Oregon, Cole *et al*. (1997) detected no effects attributable to logging, burning, herbicide application on the capture success of the Red-legged Frog; however, capture rates varied greatly both among years and sites, making comparisons problematic. In southern Washington, this species was more abundant in mature than in young forest stands (Aubry and Hall 1991). In another study in Washington, in managed, second-growth Douglas Fir (*Pseudotsuga menziesii*) forest, this species was more abundant in rotation age stands (50 – 70 years) than in all younger stands, where only a few captures took place (Aubry 2000). These stands also had the highest species richness of amphibians. Aubry (2000) concluded that maximizing the percentage of rotation age forest in managed stands is beneficial for this and other species of amphibians.

In the Clayoquot Sound area on the west coast of Vancouver Island, Beasley *et al*. (2000) found that the percentages of occupancy of wetlands by aquatic-breeding amphibians, including the Red-legged Frog, was similar in areas disturbed by past logging and in undisturbed areas. However, wetlands surrounded by clearcuts were more likely to dry up in the summer than were those in more undisturbed areas. The relative abundance of amphibians or their survivorship characteristics in the two types of habitats were not investigated.

On northern Vancouver Island, Chan-McLeod (2003b) investigated the effects of clearcut logging on movements of the Red-legged Frog. Radio-tagged frogs were introduced to experimental plots at the clearcut – old growth forest interface, and their movements were monitored for a period of several weeks outside the breeding season in the summer and autumn. New clearcuts (less than 12 years old) posed barriers to movements of the frogs, which moved mostly towards and within the forest. The use of clearcuts for movements varied depending on weather, and permeability of clearcuts was greatest during wet, cool conditions and least during dry, hot conditions. Most movements into the clearcut occurred during rainy days. The frogs failed to use unbuffered (without a fringe of trees) creeks as movement avenues within clearcuts. In another experiment on northern Vancouver Island, Chan-McLeod and Moy (in review) investigated the use of residual trees and patches of trees (ranging in size from 0.07 ha to 2.7 ha) within a logged matrix by this species; the logging patterns were a result of standard variable-retention, operational procedures. Over a 3-day period of the trials, individual frogs that were experimentally released at the bases of residual, single trees or in small tree patches were more likely to leave than were individuals released in larger tree patches. In addition to large patch size, the presence of a stream within the patch was associated with an increased residency time by frogs. While moving through the logged matrix, individual frogs did not use the residual tree patches as stepping stones, but rather entered the patches more or less at random; directional movements towards a patch occurred only from short (< 20 m) distances away. The authors suggested that residual trees grouped together in patches of 0.8 ha to 1.5 ha, especially when located at sites with streams, facilitate movements of these frogs.

The above studies indicate that logging, whether clearcut or variable-retention, alters movement patterns and poses barriers of varying permeability to movements of the Red-legged Frog. These effects can be mitigated to some degree by adjusting the spatial configuration of cut areas and the size and location of residual tree patches. However, the retention of larger areas of older forest is also desirable and may be essential for the long-term persistence of populations. The effects of logging on foraging success and survivorship of this species have not been studied.

Pollutants

Pools, ponds, and other wetland habitats act as sinks for various pollutants, resulting in the exposure of aquatic-breeding amphibians to contaminants during critical periods in the early development (Vitt *et al*. 1990). Amphibians from heavily cultivated areas show mutagenic effects and developmental abnormalities in eastern Canada (Bonin *et al*. 1997), and wind-borne agricultural pesticides have been implicated in the population declines of the California Red-legged Frog and several other aquatic-breeding amphibians in California (Davidson *et al*. 2002). Contamination of aquatic breeding sites with nitrate and nitrite, resulting from run-off of fertilizers and sewage, has recently been recognized as a problem for amphibians (reviewed in Rouse *et al*. 1999, Halliday 2000). The exposure of early developmental stages to even low concentrations, considered safe for humans, can result in behavioural changes, developmental abnormalities, or mortality (Marco and Blaustein 1999, Marco *et al*. 1999). Tadpoles of the Red-legged Frog suffered acute effects when raised in water with nitrite (Marco *et al*. 1999).

In British Columbia, the range of the Red-legged Frog overlaps agricultural and farm lands in the Lower Fraser Valley, and poor water quality appears to affect hatching success (De Solla *et al*. 2002a). De Solla *et al*. (2002a) examined survivorship and development of two species, the Red-legged Frog and the Northwestern Salamander, in the intensively farmed Sumas Prairie area where these amphibians occupy drainage canals and other aquatic habitats that are exposed to agricultural run-off. Hatching success of both species was reduced in enclosures within agricultural sites (up to 9% and 34% in two years, respectively) when compared to that within reference sites at the periphery of the agricultural area (85% or higher). However, when reared in the laboratory in water from these sites, the hatching success was not significantly different between the two types of sites. The authors suggested that laboratory conditions failed to adequately mirror conditions in the field, where water quality could be poorer due to constant influx of contaminants, lack of artificial aeration, and variable temperature regimes. They concluded that high ammonia concentrations and low concentrations of dissolved oxygen were likely factors for the observed differences in hatching success under field conditions. In contrast, residues of organochlorine pesticides, which were widely used in the area in the 1970s, and polychlorinated biphenyls (PCBs) appear not to be a problem for this species (De Solla *et al*. 2002b). Concentrations of these compounds in the eggs of the Red-legged Frog from the Sumas Prairie area were relatively low and similar among agricultural and reference sites.

A wide range of chemical substances present in the environment potentially interferes with hormone signals during sensitive developmental periods of amphibians (Crump 2001). Exposure to sex steroids or their mimics can alter the operational sex ratio and reproductive characteristics, whereas exposure to thyroid hormones or their mimics can alter developmental timing and metamorphosis. Where it occurs in the vicinity of populated areas and farmlands, the Red-legged Frog is potentially exposed to endocrine-disrupting compounds, but whether these substances are a problem for this species has not been studied.

Introduced species

The introduction and spread of non-native species, particularly sport fish and the Bullfrog (*Rana catesbeiana*), are of concern for the persistence of native amphibian populations throughout western North America and are thought to be a contributing factor to declines in some areas (Hayes and Jennings 1986, Stebbins and Cohen 1995). The modification of habitats by human activities, including altered hydrological and temperature regimes and forest clearing, creates conditions suitable for the establishment and spread of the Bullfrog and other exotic species. The occurrence of the Red-legged Frog shows a negative correlation with introduced fish in the Puget Lowlands of Washington State, and in enclosure experiments tadpoles failed to survive in the presence of predatory fish (Adams 1999, 2000). Predatory sport fish have been introduced to permanent water bodies throughout the range of the Red-legged Frog in British Columbia, and restocking of lakes remains common. Many of the stocked lakes originally lacked fish; as a result native amphibians using these lakes are poorly adapted to survival in the presence of predatory fish (Wind, manuscript in review).

Both adults and tadpoles of the Bullfrog have been shown to prey on native anurans and their life stages, but the adverse effects of the Bullfrog on the Red-legged Frog are probably largely indirect and involve complex interactions. Using experimental enclosures, Kiesecker and Blaustein (1997, 1998) demonstrated a shift in microhabitat use and activity by Red-legged Frog tadpoles in the presence of Bullfrog larvae or adults: Red-legged Frog tadpoles reduced their activity and increased the time spent in shelters when exposed to Bullfrogs or their chemical cues. Developmental timing and body size at metamorphosis were also altered in the presence of Bullfrogs, but survivorship to metamorphosis was reduced only if the tadpoles were exposed to a combination of factors (either Bullfrog larvae and adults, or bullfrogs and fish, Smallmouth Bass, *Micropterus dolomieui*; Kiesecker and Blaustein 1998). When exposed to chemical cues from Bullfrogs, Red-legged Frog tadpoles from areas of syntopy (where they had co-occurred with the Bullfrog since its introduction about 60 years previously) showed behavioural differences when compared to tadpoles from allopatric populations; these differences included reduced activity and increased use of shelters. The authors inferred that tadpoles from allopatric populations failed to recognize the Bullfrog as a threat and thus behaved inappropriately in their presence, so increasing their risk of mortality from predation. Kiesecker *et al*. (2001) showed that the dispersion of food affects interactions of tadpoles of the Red-legged Frog with the Bullfrog: adverse effects on growth and survivorship of the Red-legged Frog in the presence of Bullfrogs occurred only when food was distributed in a clumped pattern but not when it was widely scattered. The above studies emphasize the complexity of the interactions of native anurans with Bullfrogs.

Negative effects of the Bullfrog on native frogs have been inferred from correlations of Bullfrog population increases with population declines of native species (Hayes and Jennings 1986). However, in wetlands in the Puget Lowlands, Washington State, Adams (1999) found that the presence of the Red-legged Frog was more closely correlated with habitat structure, including pond permanence, and the presence of introduced fish than with the presence of the Bullfrog. In enclosure experiments, the survival to metamorphosis of both the Red-legged Frog and the Pacific Treefrog (*Pseudacris regilla*) in permanent pools tended to be low when compared to temporary pools, regardless of the presence or absence of Bullfrog tadpoles (Adams 2000). Adams (2000) suggested that the effects of the Bullfrog on the Red-legged Frog were largely indirect and might augment other factors, such as changes in hydrology and the presence of both native and introduced fish predators in breeding habitats.

In British Columbia, the Bullfrog is presently found in the Lower Fraser Valley, where they were first recorded in the 1940s, on southern and southeastern Vancouver Island from Victoria north to Parskville, and in the southern Okanagan Valley (Govindarajulu 2003). On the Saanich Peninsula on southern Vancouver Island, a dramatic range expansion of the Bullfrog has occurred within the past six years since monitoring began in 1997. Control efforts, consisting of the removal of adults in an attempt to reduce the breeding population, are in progress along the periphery of the distribution and are hoped to limit further spread of the species. In addition to disturbed areas, Bullfrogs occupy relatively undisturbed water bodies, such as small, wooded lakes in the vicinity of Victoria. A study is in progress to investigate the effects of Bullfrogs on native amphibians, including the Red-legged Frog, through field and enclosure experiments, but complete results were unavailable at the writing of this report (P. Govindarajulu, pers. comm.). Preliminary results show that on the Saanich Peninsula the Red-legged Frog is mainly found in lakes and ponds that lack Bullfrogs, possibly indicating past displacement; the two species presently co-occur in a small number of water bodies in this area.

Epidemic disease

Outbreaks of epidemic disease, including new, emergent diseases caused by chytrid fungi and iridoviruses, are an important, widespread factor threatening amphibian populations. Skin disease caused by a chytrid fungus has been implicated in amphibian declines worldwide and can have devastating effects on populations over a large area over a relatively short period (Daszak *et al*. 1999). This disease appears to be caused by a single species of the fungus (*Batrachochytrium dendrobatidis*), which is capable of infecting a wide range of amphibian species (Nichols 2003). A number of species of *Rana* are known hosts to the fungus, but there are no reports of infections for the Red-legged Frog (Speare and Berger 2002). In British Columbia, this fungus has been isolated from both the Northern Leopard Frog and Oregon Spotted Frog (L. Friis, pers. comm.), but to date no outbreaks of chytridiomycosis has been reported from the province. Other pathogenic microorganisms infecting amphibians include *Aeromonas* bacteria, which cause red-leg disease in stressed animals, and various pathogenic iridoviruses.

Atmospheric changes

Some amphibians have been shown to be sensitive to exposure to ambient ultraviolet-B radiation (UV-B: 280 – 320 nm in wavelength) during early development, and elevated UV-B levels, resulting from stratospheric ozone depletion and habitat modifications, have been suggested as a contributing factor to amphibian population declines (Blaustein *et al*.1994a). Hatching success of the Red-legged Frog was unaffected by ambient UV-B levels in studies conducted in Oregon (Blaustein *et al*. 1996) and British Columbia (Ovaska *et al*. 1997). However, in the same study, hatching success of this species was reduced under slightly elevated UV-B regimes, while the sympatric Pacific Treefrog (*Pseudacris regilla*) showed no similar reduction in survival and appeared to be more tolerant. Belden and Blaustein (2002) found that the exposure of embryos of the Red-legged Frog to ambient UV-B levels affected subsequent larval growth and development, although direct mortality did not occur. These effects included smaller body size of exposed tadpoles one month after hatching and retarded early growth rate. The authors concluded that such sublethal effects may already occur in nature under the present, ambient UV-B levels.

Global climate change is predicted to be associated with drier summers, increased incidence of droughts, and alterations in hydrological conditions (Gates 1993). All these factors are expected to stress amphibian populations, influencing their movement and activity patterns, and resulting in loss and deterioration of breeding habitats. Drying of breeding wetlands and increased barriers to movements are likely to be most important effects of global climate change to populations in British Columbia. Water temperatures would have to increase considerably to directly affect embryonic survival, even of cold-adapted species such as the Red-legged Frog, in British Columbia (see section on Physiology). However, these northern populations will become increasingly important as reservoirs of genetic variation, if declines occur farther south within the species' range.

Interactions and synergistic effects

Under natural conditions, individual stressors rarely act alone but interact with other stressors and background conditions, which modify and sometimes enhance their effects. For example, Kiesecker and Blaustein (1998) experimentally demonstrated synergistic interactions between two invasive organisms (the Bullfrog and fish) and between different life-stages of the Bullfrog (adults and larvae) on survivorship of the Red-legged Frog. Synergistic effects have been shown to occur for various anurans between pathogenic fungi and UV-B radiation (Kiesecker and Blaustein 1995) and among various pollutants, the competition intensity, the predator environment, and the hydroperiod of the breeding sites (Boone and Semlitch 2001, 2002). Global climate change is likely to accentuate habitat fragmentation and interact with other threat factors.

Other amphibians that are sympatric with the Red-legged frog have exhibited declines. The Western Toad, *Bufo boreas*, has disappeared from several localities on Vancouver Island for reasons that are largely unknown (Davis and Gregory 2003), however there is no evidence of similar declines of the Red-legged frog from these localities. The Oregon Spotted Frog, *Rana pretiosa*, has declined throughout its range in western North America, including British Columbia. It is presently known from only a few localities in the Lower Fraser Valley. Loss and degradation of breeding habitats due to agriculture, urban developments, and other human activities and invasion of aquatic habitats by introduced, invasive plants and animals are thought to be largely responsible for the declines of this species in British Columbia (Haycock 2000).

SPECIAL SIGNIFICANCE OF THE SPECIES

Frogs in general have a benevolent public image, and the declines of their populations worldwide have featured prominently in popular literature and news coverage. In the north temperate zone, ranid frogs (of the family Ranidae) have been affected more severely than other groups of amphibians (in terms of number of species with documented declines; Crump 2003). Many of the declines in western North America have involved species of *Rana*. Population declines of these frogs may be indicative of broader ecosystem deterioration and signal impending ecological problems. Because of the value of ranid frogs as indicator species, population trends of the Red-legged Frog and other native *Rana* warrant documentation and public concern. Because of its relatively large spatial requirements and its close association with moist forests, stream banks, and wetlands, the Red-legged Frog could be viewed as an emblem for wilderness values and forest ecosystem health. This species also could also be viewed as a representative of amphibians with biphasic life-cycles that include both terrestrial and aquatic habitats, reflecting the importance of landscape-wide habitat connections.

The Red-legged Frog is the only native ranid or “true frog” on Vancouver Island and the Sunshine coast, and it has a relatively small overall range in North America. It is of scientific interest as a member of the western North American *Rana boylii* group, which reflects the genetic, historical, and geographical complexity of this region. Amphibians in general play important roles in the ecosystem both as consumers of invertebrates and as prey for birds, mammals, and other larger organisms. The ecological role of the Red-legged Frog in forest ecosystems is incompletely understood, but because of its local abundance and widespread distribution within its range, its role could be considerable in both aquatic and terrestrial ecosystems. Its role as a consumer of insect pests could be of public interest.

Frogs feature in the mythology and art of the Coastal Salish, Haida, and other First Nations groups of western Canada, but it is unknown whether the Red-legged Frog in particular holds special significance to aboriginal peoples.

EXISTING PROTECTION OR OTHER STATUS

The Red-legged Frog has the global heritage status of G4T4 (“apparently secure”, both for the species *R. aurora* and for the subspecies *R. a. aurora*). In the United States, its national heritage status is N4 (“apparently widespread”; designated in November 1996). Its status in the different states is as follows: California S2? (“imperiled?”); Oregon S3 (“vulnerable to extirpation or extinction”); Washington S4 (“apparently widespread”) (NatureServe 2003).

In Canada the species was listed federally as “special concern” by COSEWIC in 2002. Under the new Species At Risk Act (SARA), there are no immediate habitat protection requirements for species with this status. A management plan is required, but the guidelines for these plans have not yet been released (K. Nelson, pers. comm.). To date (August 2003), efforts in British Columbia have focused on meeting the requirements for species listed as threatened, endangered, or extirpated, for which a recovery plan is mandatory under SARA (RENEW 2003).

In British Columbia, the Red-legged Frog is on the provincial blue list of species at risk. Blue-listed species are “taxa of Special Concern” that “have characteristics that make them particularly sensitive or vulnerable to human activities or natural events” (BC Species and Ecosystems Explorer 2003). As a result of the COSEWIC assessment, *Rana aurora* was added to the list of Identified Wildlife included in the identified Wildlife Management Strategy (IWMS) Version 2004. IWMS Version 2004 contains specific guidelines for management of Red-legged Frog habitat. Because much of the Canadian distribution of the Red-legged Frog coincides with lands used for forestry, these management guidelines are potentially of critical importance for protecting this species. However, these guidelines are not applicable to a large area of private forestry lands on southeastern Vancouver Island.

The British Columbia Wildlife Act prohibits the collection, possession, and trade of all native vertebrates, including amphibians. This law has limited effectiveness in protecting frogs, because it difficult to enforce and does not cover damage to habitats.

SUMMARY OF STATUS REPORT

This report provides a summary of the biology, distribution, and vulnerability of Canadian populations of the Red-legged Frog, focusing on new information that has become available since the preparation of the first status report by Waye (1999). This species has a restricted Canadian distribution in southwestern British Columbia, where it occurs on Vancouver Island, several of the islands in the Strait of Georgia, and the adjacent mainland. A new population was discovered on Graham Island, Queen Charlotte Islands in 2002; this population probably originates from a human introduction.

Wetland surveys and serendipitous observations since 1998 suggest that the Red-legged Frog remains relatively widespread on Vancouver Island and parts of the mainland British Columbia. Vancouver Island remains a stronghold for the Canadian populations of this species. Little is known of its distribution and status on the Sunshine Coast and coastal areas north of Powell River on the mainland, and the northern limits of the species' distribution remain unknown. Surveys of the south and central coast north of Vancouver (up to Rivers Inlet) are required, as this area still contains vast tracks of forest relatively undisturbed by human activities and might provide a refuge for the frogs. At present it is unknown whether this area forms an important component of the species' range or whether it is peripheral to their distribution.

The Canadian population of the Red-legged Frog numbers in the tens of thousands or perhaps more adults, but there is no detailed information on population sizes or trends in any area. The distribution of the species appears to be shrinking in areas where the introduced Bullfrog is established, suggesting declines or even local extirpations in disturbed habitats in parts of the southern Vancouver Island. In contrast, in some areas on Vancouver Island where the Western Toad has undergone local extinctions over past decade, the Red-legged Frog remains apparently abundant. However, declines could go unnoticed because (1) surveys that have included this species have been at the "presence/not detected" level, and there are no recent estimates of abundance, and (2) most areas within the species' range have not been surveyed systematically or at all. In the past, extensive loss of wetland and forest habitats have resulted in local declines and disappearances from populated areas on southern and eastern Vancouver Island and the Lower Mainland. Habitats continue to be lost and fragmented at an alarming rate.

Populations of the Red-legged Frog are vulnerable because (1) a large proportion of the species' known Canadian distribution overlaps with the densely populated southwestern part of the province; (2) populations are vulnerable to clearcut logging, in particular, and forestry activities are converting old growth and mature second-growth forest into young seral stages at a rapid rate; (3) introduced species, particularly the rapid spread of the Bullfrog, appear to adversely affect the use of wetland breeding sites and reproductive success; (4) ranid frogs appear to be particularly susceptible to disease, and chytrid fungi has been isolated from two other species of *Rana* in British Columbia; (5) habitats are becoming increasingly fragmented due to land conversions, draining and other human activities. Populations of this species are inherently vulnerable to local extinctions and habitat fragmentation –alteration of habitats and global climate change can be expected to exacerbate isolation effects and local extinctions and adversely affect amphibian species that require much space, such as the Red-legged Frog.

Draft guidelines for managing Identified Wildlife have been prepared for this species under the BC Forest and Range Practices Act. The measures in the guidelines will become mandatory on public forestry lands in the near future and will help protect habitats and populations. The Identified Wildlife Management Strategy contains guidelines for the protection and management of the Red Legged Frog through the establishment of Wildlife Habitat Areas (WHAs) and associated General Wildlife Measures (GWMs). However, much uncertainty exists on how the guidelines will be implemented; furthermore, the guidelines are not mandatory on private lands, such as the vast tracts of private forests on Vancouver Island.

TECHNICAL SUMMARY

Rana aurora
Red-legged frog — Grenouille a pattes-rouge
Range of Occurrence in Canada: BC

Extent and Area Information	
• *Extent of occurrence (EO) (km²)* **[based on map Fig. 3]**	53,000 km²
• *Specify trend in EO*	Appears to be stable
• *Are there extreme fluctuations in EO?*	No
• *Area of occupancy (AO) (km²)* **[no more than 10% of EO is likely habitable]**	ca. 5,000 km²
• *Specify trend in AO*	Decline
• *Are there extreme fluctuations in AO?*	Unknown
• *Number of known or inferred current locations*	ca. 100
• *Specify trend in #*	Unknown
• *Are there extreme fluctuations in number of locations?*	Unknown
• *Specify trend in area, extent or quality of habitat*	Decline
Population Information	
• *Generation time (average age of parents in the population)*	3 – 4 years
• *Number of mature individuals*	Tens of thousands, perhaps more
• *Total population trend:* **[appears to be declining or extirpated in areas where Bullfrogs and Green Frogs are established]**	Probable decline
• *% decline over the last/next 10 years or 3 generations.*	Not applicable
• *Are there extreme fluctuations in number of mature individuals?* **[fluctuations are the norm for pond-breeding anurans]**	Undocumented but probable
• *Is the total population severely fragmented?*	Yes
• *Specify trend in number of populations*	
• *Are there extreme fluctuations in number of populations?*	no
• *List populations with number of mature individuals in each:* • Vancouver Island • Lower Mainland British Columbia coast (from Lower Fraser River Valley to Sunshine coast and to Powell River area) • Several small islands in the Strait of Georgia **Each of the above areas has numbers in the thousands or tens of thousands**	
Threats (actual or imminent threats to populations or habitats)	
• Introduction and spread of non-native species (sport fish, Bullfrog, Green Frog) • Loss, fragmentation, and modification of breeding habitats and surrounding terrestrial foraging habitats due to urbanization, agriculture, and forestry	
Rescue Effect (immigration from an outside source)	
• *Status of outside population(s)?* **USA:** N4 "apparently widespread" (1996) California: S2? "imperiled?" Oregon: S3 "vulnerable to extirpation or extinction" Washington: S4 "apparently widespread"	
• *Is immigration known or possible?*	Possible on Lower Mainland only
• *Would immigrants be adapted to survive in Canada?*	Yes
• *Is there sufficient habitat for immigrants in Canada?*	Yes
• *Is rescue from outside populations likely?*	insignificant
Quantitative Analysis	Not applicable

Current Status
COSEWIC: Special Concern British Columbia: Blue list "Special Concern"

Status and Reasons for Designation

Status: Special Concern	**Alpha-numeric code:** Not applicable
Reasons for Designation: A large proportion of the known Canadian distribution of this species occurs in the densely populated southwestern part of British Columbia. Habitats are becoming increasingly lost and fragmented due to land conversions and other human activities. Introduced Bullfrog and Green Frog, which are spreading rapidly, have replaced this species at many sites and appear to adversely affect the use of wetland breeding sites and reproductive success. Populations of this species, and other amphibian species that require extensive habitat, are inherently vulnerable to habitat fragmentation which can be expected to exacerbate isolation effects and local extinctions.	
Applicability of Criteria **Criterion A** (Declining Total Population): insufficient evidence to quantify declines **Criterion B** (Small Distribution, and Decline or Fluctuation): distribution is larger in extent than cutoff values for this criterion although declines and population fluctuations are inferred. **Criterion C** (Small Total Population Size and Decline): despite inferred declines, population fluctuations, and the fragmentation of the range, total population size remains large and decline rate cannot be quantified. **Criterion D** (Very Small Population or Restricted Distribution): total population size and area of occupancy too great to trigger this criterion. **Criterion E** (Quantitative Analysis): not applicable	

ACKNOWLEDGEMENTS

Laura Friis provided access to summaries of locality records, greatly facilitating the preparation of this report. Laura Friis, Kathy Paige, and Kari Nelson patiently answered all our queries. We thank Ann Chan-McLeod, Elke Wind, Purnima Govindarajulu, Ted Davis, Barb Beasley, and Rob Rithaler for generously sharing with us their reports, results of work in progress, and unpublished data. Kelly McAllister and Rick Nauman provided us with drafts of their distribution maps that were useful for the preparation of Figure 2. Kelly Sendall provided access to specimens at the Royal British Columbia Museum. Michèle Steigerwald provided information on specimens at the Canadian Museum of Nature, and Francis Cook kindly inspected specimens there. D. Fraser, P. Gregory, D. Rivard, and D. Green provided helpful review comments on an earlier version of this report.

Funding for the preparation of this status report provided y the Canadian Wildlife Service, Environment Canada.

INFORMATION SOURCES

Adams, M.J. 1999. Correlated factors in amphibian decline: exotic species and habitat change in western Washington. Journal of Wildlife Management 63:1162–1171.

Adams, M.J. 2000. Pond permanence and the effects of exotic vertebrates on anurans. Ecological Applications 10:559–568.

Altig, R. and Dumas, P.C. 1972. *Rana aurora*. In: Reimer, W.J. (editor), Catalogue of American Amphibians and Reptiles 160. American Society of Ichthyologists and Herpetologists.

Aubry, K.B. 2000. Amphibians in managed, second-growth Douglas-fir forests. Journal of Wildlife Management 64:1041–1052.

Aubry, K.B. and Hall, P.A. 1991. Terrestrial amphibian communities in the southern Washington Cascade Range. In: L.F. Ruggiero, K.B. Aubry, A.B. Carey and M.H. Huff (technical coordinators): Wildlife and Vegetation of Unmanaged Douglas-Fir Forests. Pp 327–338.

Barnett, H.K. and Richardson, J.S. 2002. Predation risk and competition effects on the life-history characteristics of larval Oregon spotted frog and larval red-legged frog. Oecologia-Berlin 132:436–444.

BC Ministry of Forests. 1991. Vancouver Island's Forests. Landsat 5 thematic mapper imagery, map prepared by British Columbia Ministry of Forests Inventory Branch, January 1991.

BC Ministry of Forests. 2003. Central Coast Land and Resource Management Plan: Protection Areas & Option Areas. http://srmwww.gov.bc.ca/rmd/lrmp/cencoast/protection.htm (Accessed August 2003).

BC Species and Ecosystem Explorer. 2003. Government of British Columbia, Ministries of Sustainable Resource Management and Water, Land and Air Protection. http://srmapps.gov.bc.ca/apps/eswp/ (accessed September 2003).

Beasley, B. 2003. The SPLAT project update: monitoring amphibian movements and mortality on the Pacific Rim highway. Unpublished report prepared for Pacific Rim National Park Reserve and Ecosystem Services, Western Canada Services Centre of Parks Canada.

Beasley, B., Addison, C. and Lucas, K. 2000. Clayoquot Sound amphibian inventory, 1998-1999. Unpublished report, Long Beach Model Forest Society and the Ministry of Environment, Lands and Parks, Ucluelet, BC.

Belden, L.K. and Blaustein, A.R. 2002. Exposure of red-legged frog embryos to ambient UV-B radiation in the field negatively affects larval growth and development. Oecologia (Berlin) 130:551–554.

Blaustein, A.R., Beatty, J.J., Olson, D.H., and Storm, R.M. 1995. The biology of amphibians and reptiles in old-growth forests in the Pacific Northwest. USDA Forest Service, General Technical Report PNW-GTR-337. 98 pp.

Blaustein, A.R., Hoffman, P.D., Hokit, D.G., Kiesecker, J.M., Walls, S.C., and Hays, J.B. 1994a. UV repair and resistance to solar UV-B in amphibian eggs: a link to population declines? Proceedings of National Academy of Science (USA) 91:1791–1795.

Blaustein, A.R., Wake, D.B., and Sousa, W.P. 1994b. Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. Conservation Biology 8:60–71.

Blaustein, A.R., Hoffman, PD., Kiesecker, J.M., and Hays, J.B. 1996. DNA repair activity and resistance to solar UV-B radiation in eggs of the Red-legged Frog. Conservation Biology 10:1398–1402.

Bonin, J., Ouellet, M., Rodrigue, J., DesGranges, J-L., Gagné, F., Sharbel, T.F., and Lowcock, L.A. 1997. Measuring the health of frogs in agricultural habitats subjected to pesticides. In Amphibians in Decline: Canadian Studies of a Global Problem (D.M. Green, editor). Herpetological Conservation 1:246–257.

Boone, M.D. and Semlich, R.D. 2001. Interactions of an insecticide with larval density and predation in experimental amphibian communities. Conservation Biology 15:228–238.

Boone, M.D. and Semlich, R.D. 2002. Interactions of an insecticide with competition and pond drying in amphibian communities. Ecological Applications 12:307–216.

Boyle, C.A., Lukowich, L., Schreier, H. and Kiss, E. 1997. Changes in land cover and subsequent effects on Lower Fraser Basin ecosystems from 1827 to 1990. Environmental Management 21(2): 185 –196.

Brown, H.A. 1975. Reproduction and development of the red-legged frog, *Rana aurora*, in northwestern Washington. Northwest Science 49:241–252.

Bulger, J.B., Scott, N.J., and Seymour, R.B. 2003. Terrestrial activity and conservation of adult California red-legged frogs *Rana aurora draytonii* in coastal forests and grasslands. Biological Conservation 110:85–95.

Bury, R.B., Corn, P.S., and Aubry, K.B. 1991. Regional patterns of terrestrial amphibian communities in Oregon and Washington. In: L.F. Ruggiero, K.B. Aubry, A.B. Carey and M.H. Huff (technical coordinators): Wildlife and Vegetation of Unmanaged Douglas-Fir Forests. Pp. 341–350.

Calef, G.W. 1973a. Spatial distribution and "effective" breeding population of red-legged frogs (*Rana aurora*) in Marion Lake, British Columbia. Canadian Field-Naturalist 87:279–284.

Calef, G.W. 1973b. Natural mortality of tadpoles in a population of *Rana aurora*. Ecology 54:741–758.

Chan-McLeod, A.C.A. 2003a. Refining the funnel trapping protocol for monitoring amphibians and movement patterns of red-legged frogs. Unpublished progress report prepared for Weyerhaueser Company, Nanaimo, BC.

Chan-McLeod, A.C.A. 2003b. Factors affecting the permeability of clearcuts to red-legged frogs. Journal of Wildlife Management 67:663–671.

Chan-McLeod, A.C.A. and Moy, A. (in review). Evaluating residual tree patches as stepping stones and short-term refugia for anurans. Unpublished manuscript.

Cole, E.C., McComb, W.C., Newton, M., Chambers, C.L., and Leeming, J.P. 1997. Response of amphibians to clearcutting, burning, and glyphosate application in the Oregon Coast Range. Journal of Wildlife Management 61:656–664.

Corkran, C.C. and Thoms, C. 1996. Amphibians of Oregon, Washington, and British Columbia. Lone Pine Publishing, Vancouver, BC.

Crother, B.I. 2000. Scientific and standard English names of amphibians and reptiles of North America north of Mexico, with comments regarding confidence in our understanding (by Committee on Standard English and Scientific Names). SSAR. http://www.herplit.com/SSAR/circulars/HC29/Crother.html (accessed September 2003).

Crump, D. 2001. The effect of UV-B radiation and endocrine-disrupting chemicals (EDCs) on the biology of amphibians. Environmental Review 9:61–80.

Crump. M. 2003. Conservation of amphibians in the New World tropics. Pp. 53–69, *in*: Semlitsch, R. (editor), Amphibian Conservation. Smithsonian Institution, Washington DC.

Daszak, P., Berger, L., Cunningham, A.A., Hyatt, A.D., Green, DE., and Speare, R. 1999. Emerging infectious diseases and amphibian population declines. Emerging Infectious Diseases 5:735–748.

Davidson, C., Shaffer, H.B., and Jennings, M.R. 2002. Spatial tests of the pesticide drift, habitat destruction, UV-B, and climate-change hypotheses for California amphibian declines. Conservation Biology 16:1588–1601.

Davis, T.M. and Gregory, P.T. 2003. Decline and local extinction of the Western Toad, *Bufo boreas*, on southern Vancouver Island, British Columbia, Canada. Herp. Rev. 34:350–351.

De Solla, S.R., Pettit, K.E., Bishop, C.A., Cheng, K.M., and Elliott, J.E. 2002a. Effects of agricultural runoff on native amphibians in the lower Fraser River Valley, British Columbia, Canada. Environmental Toxicology and Chemistry 21:353–360.

De Solla, S.R., Bishop, C.A., Pettit, K.E., and Elliot, J.E. 2002b. Organochloride pesticides and polychlorinated biphenyls (PCBs) in eggs of red-legged frogs (*Rana aurora*) and northwestern salamanders (*Ambystoma gracile*) in an agricultural landscape. Chemosphere 46:1027–1032.

Dickman, M. 1968. The effect of grazing by tadpoles on the structure of a periphyton community. Ecology 49:1188–1190.

Duellman, W.E. and Trueb, L. 1996. Biology of Amphibians. McGraw-Hill Book Company, New York.

Fellers, G.M., Launer, A.E., Rathbun, G., Bobzien, S., Alvarez, J., Sterner, D., Seymour, R.B., and Westphal, M. 2001. Overwintering tadpoles in the California red-legged frog (*Rana aurora draytonii*). Herpetological Review 32:156–157.

Gates, D.M. 1993. Climate Change and Its Biological Consequences. Sunderland, MA. Sinauer Assoc, Inc.

Gibbs, J.P. 1998. Distribution of woodland amphibians along a forest fragmentation gradient. Landscape Ecology 113:263–268.

Govindarajulu, P. 2003. Survey of bullfrogs *Rana catesbeiana* in British Columbia. http://web.uvic.ca/bullfrogs (accessed August 2003).

Green, D.M. and Campbell, R.W. 1984. The Amphibians of British Columbia. Victoria, B.C. British Columbia Provincial Museum. Handbook No. 45.

Green, D.M. 2003. The ecology of extinction: population fluctuation and decline in amphibians. Biological Conservation 11:331–343.

Halliday, T. 2000. Nitrates and amphibians. Froglog 38:3.

Haycock, R. 1996. Oregon Spotted Frog project. Unpublished report prepared for B.C. Ministry of Environment, Lands and Parks, Victoria, B.C. (cited in Waye 1999).

Haycock, R. 1998. Amphibian survey with special emphasis on the Oregon Spotted Frog *Rana pretiosa*. Selected wetland sites: Fraser Lowlands and corridors to Interior Plateau. Unpublished report prepared by Hyla Environmental Services for BC Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, B.C.

Haycock, R. 2000. COSEWIC assessment and status report on the Oregon Spotted Frog, *Rana pretiosa,* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa.

Hayes, M.P. and Jennings, M.R. 1986. Decline of ranid frog species in western North America: are bullfrogs (*Rana catesbeiana*) responsible? Journal of Herpetology 20:490–509.

Hayes, M.P. and Miyamoto, M.M. 1984. Biochemical, behavioral and body size differences between *Rana aurora aurora* and *R. a. draytoni*. Copeia 1984:1018-1022.

Hayes, M.P., Pearl, C.A., and Rombough, C.J. 2001. *Rana aurora aurora* (northern red-legged frog). Movement. Herpetological Review 32:35–36.

Johnson-Pieter, T.J., Lunde, K.B., Thurman, E.M., Ritchie, E.G., Wray, S.N., Sutherland, D.R., Kapfer, J.M., Frest, T.J., Bowerman, J., and Blaustein, A.R. 2002. Parasite (*Ribeiroia ondatrae*) infection linked to amphibian malformations in the western United States. Ecological Monographs 72:151–168.

Kiesecker, J.M. and Blaustein, A.R. 1995. Synergism between UV-B radiation and a pathogen magnifies amphibian embryo mortality in nature. Proceedings of the National Acaddemy of Science USA (Ecology) 92:11049–11052.

Kiesecker, J.M. and Blaustein, A.R. 1997. Population differences in responses of red-legged frogs (*Rana aurora*) to introduced bullfrogs. Ecology (Washington DC) 78:1752–1760.

Kiesecker, J.M. and Blaustein, A.R. 1998. Effects of introduced bullfrogs and smallmouth bass on microhabitat use, growth, and survival of native red-legged frogs (*Rana aurora*). Conservation Biology 12:777–787.

Kiesecker, J.M., Blaustein, A.R., and Miller, C.L. 2001. Potential mechanisms underlying the displacement of native red-legged frogs by introduced bullfrogs. Source: Ecology (Washington DC) 82:964–1970.

Kiesecker, J.M., Chivers, D.P., Anderson, M., and Blaustein, A.R. 2002. Effect of predator diet on life history shifts of red-legged frogs, *Rana aurora*. Journal of Chemical Ecology 28:1007–1015.

Knopp, D. 1996. Wetlands of the Fraser Valley – amphibian survey. Unpublished report prepared by B.C.'s Wild Heritage Consultants for B.C. Ministry of Environment, Lands and Parks, Victoria, B.C.

Knopp, D. 1997. Oregon Spotted Frog in the Fraser River Lowlands. Unpublished report prepared by B.C.'s Wild Heritage Consultants for B.C. Ministry of Environment, Lands and Parks, Victoria, B.C.

Lefcort, H. and Blaustein, A.R. 1995. Disease, predator avoidance, and vulnerability to predation in tadpoles. Oikos 74:469–474.

Leonard, W.P., Brown, H.A., Jones, L.L.C., McAllister, K.R., and Storm, R.M. (coordinating editors). 1993. Amphibians of Washington and Oregon. Seattle. Seattle Audobon Society.

Licht, L.E. 1969. Comparative breeding behavior of the red-legged frog, (*Rana aurora aurora*) and the western spotted frog (*Rana pretiosa pretiosa*) in southwestern British Columbia. Canadian Journal of Zoology 47:1287–1299.

Licht, L.E. 1971. Breeding habits and embryonic thermal requirements of the frogs, *Rana aurora aurora* and *Rana pretiosa pretiosa* in the Pacific northwest. Ecology 52:116–124.

Licht, L.E. 1974. Survival of embryos, tadpoles, and adults of the frogs *Rana aurora aurora* and *Rana pretiosa* sympatric in southwestern British Columbia. Canadian Journal of Zoology 52:613–627.

Licht, L.E. 1986. Food and feeding behavior of sympatric red-legged frogs, *Rana aurora* and spotted frogs, *Rana pretiosa*, in southwestern British Columbia. Canadian Field-Naturalist 100:22–31.

Macey, J.R., Strasburg, J.L., Brisson, J.A., Vredenburg, V.T., Jennings, M., and Larson, A. 2001. Molecular phylogenetics of western North American frogs of the Rana boylii species group. Molecular Phylogenetics and Evolution 19:131–143.

MacKinnon, A. and M. Eng. 1995. Old Forests: Inventory for Coastal British Columbia. Cordillera: A journal of British Columbia Natural History, Summer 1995:20-33.

Mao, J., Green, D.E., Fellers, G., and Chinchar, V.G. 1999. Molecular characterization of iridoviruses isolated from sympatric amphibians and fish. Virus Research 63:45-52.

Marco, A. and Blaustein, A.R. 1999. The effects of nitrate on behavior and metamorphosis in Cascades frogs (*Rana cascadae*). Environmental Toxicology & Chemistry 18:946–949.

Marco, A., Quichano, C., and Blaustein, A.R. 1999. Sensitivity to nitrate and nitrite in pond-breeding amphibians from the Pacific Northwest, USA. Environmental Toxicology & Chemistry 18:2836–2839.

Marsh, D.M. and Trenham, P.C. Metapopulation dynamics and amphibian conservation. Conservation Biology 15:40 – 49.

McTaggart Cowan, I. 1941. Longevity of the red-legged frog. Copeia 1941:48.

Maxcy, K.A. 2003 (Draft). Red-legged Frog (*Rana aurora aurora*). Pp 107 – 118 in Paige, K. (editor). Standards for Managing Identified Wildlife. Ministry of Forests and Ministry of Water, Land and Air Protection. Victoria, B.C.

NatureServe Explorer. 2003. http://www.natureserve.org/explorer/sumvert.htm (accessed July 2003)

Nichols, D.K. 2003. Tracking down the killer chytrid of amphibians. Herpetological Review 34:101–104.

Nussbaum, R.A., Brodie, E.D. Jr., and Storm, R.M. 1983. Amphibians & Reptiles of the Pacific Northwest. Northwestern University Press of Idaho, Moscow. 332 pp.

Ostergaard, E.C. and Richter, KO. 2001. Stormwater ponds as surrogate wetlands for assessing amphibians as bioindicators. http://www.epa.gov/owow/wetlands/bawwg/natmtg2001/richter/richter.pdf (Accessed August 2003)

Ovaska, K., Davis, T.M., and Novales Flamarique, I. 1997. Hatching success and larval survival of the frogs *Hyla regilla* and *Rana aurora* under ambient and artificially-enhanced solar UV radiation. Canadian Journal of Zoology 75:1081–1088.

Ovaska, K., Hyatt, L., and Sopuck, L. 2002. *Rana aurora*. Geographic distribution. Herpetological Review 33:318.

Ovaska, K., Sopuck, L., Engelstoft, E., Matthias, L., Wind, E. and MacGarvie, J. 2003. Best Management Practices for Amphibians and Reptiles in Urban and Rural Environments in British Columbia. Prepared for BC Ministry of Water, Land and Air Protection Nanaimo, BC.

Pechmann, J.H.K. and Wilbur, H.M. 1994. Putting declining amphibian populations in perspective: natural fluctuations and human impacts. Herpetologica 50:65–84.

Rathbun, G.B. 1998. *Rana aurora draytonii* (California red-legged frog). Egg predation. Herpetological Review 29:165.

Reimchen, T.E. 1991. Introduction and dispersal of the Pacific treefrog, *Hyla regilla*, on the Queen Charlotte Islands, British Columbia. The Canadian Field-Naturalist 105:288–290.

RENEW 2003. RENEW Recovery Handbook. Working draft, 30 April 2003.

Rithaler, R.C. 2002. Delta Watersheds: Fish and Amphibian distributions. (1:25,000 map; created 13 October 2001, amended 28 January 2002). Available from the Corporation of Delta, 4500 Clarence Taylor Crescent, Delta BC V4K 3E2.

Rithaler, R.C. 2003. Amphibians in Delta. (1:90,000 map; created 12 August 2002, amended 18 August 2003). Available from the Corporation of Delta, 4500 Clarence Taylor Crescent, Delta BC V4K 3E2.

Rouse, J.D., Bishop, C.A., and Struger, J. 1999. Nitrogen pollution: An assessment of its threat to amphibian survival. Environmental Health Perspectives 107:799–803.

Schaefer, V. 1994. Urban biodiversity. Chapter 22 *in* Biodiversity in British Columbia: Our Changing Environment (L.E. Harding and E. McCallum, eds.) Environment Canada, Canadian Wildlife service, Ottawa, ON. 425 p.

Shean, J.T.S. 2002. Post-breeding movements and habitat use by the Northern Red-legged Frog, *Rana aurora aurora*, at Dempsey Creek, Thurston County, Washington. Thesis for Master in Environmental Studies, Evergreen State College, Olympia, Washington, U.S.A.

Sierra Club, 2003. Vancouver Island: How much has been logged? http://www.sierraclub.ca/bc/Campaigns/VancouverIsland/vimaps.html (accessed September 2003).
Speare, R. and Berger, L. 2002. Global distribution of chytridiomycosis in amphibians. World Wide Web - http://www.jcu.edu.au/school/phtm/PHTM/frogs/chyglob.htm (accessed August 2003).
Statistics Canada. 2003. Lower Mainland and southern Vancouver Island, population change 1996-2001. http://geodepot.statcan.ca/Diss/Highlights/Page9/Vancouver_e.jpg (accessed August 2003).
Stebbins, R.C. 1985. A Field Guide to Western Reptiles and Amphibians. Second edition, revised. Houghton Mifflin, Boston.
Stebbins, R.C. and Cohen, N.W. 1995. A Natural History of Amphibians. Princeton Univ. Press, Princeton, New Jersey.
Storm, R.M. 1960. Notes on the breeding biology of the red-legged frog (*Rana aurora aurora*. Herpetologica 16:251–259.
Sunshine Coast Regional District. 2002. Sunshine Coast regional issues assessment. Final report. July 18, 2002.
Sunshine Coast Regional District. 2003. Sunshine Coast Habitat Atlas; forest cover map. http://habitat.scrd.bc.ca/images/HA_Forest_Cover.pdf
Van Kooten, G.C. 1995. Modeling public forest land use tradeoffs on Vancouver Island. Journal of Forest Economics 1: 191–218. http://www.urbanfischer.de/journals/jfe/content/1995/van%20Kooten.pdf (accessed October 2003).
Vitt, L.J., Wilbur, H.M., Caldwell, J.P., and Smith, D.C. 1990. Amphibians as harbingers of decay. BioScience 40:418.
Waye, H. COSEWIC status report on the Red-legged Frog (*Rana aurora*) in Canada. 1999. Unpublished report prepared for COSEWIC. 27 pp.
Wells, K.D. 1977. The social behaviour of anuran amphibians. Animal Behaviour 25:666–693.
Wind, E. 2003. Aquatic-breeding amphibian monitoring program. Analysis of small wetland habitats on Vancouver Island. Annual Progress Report 2002. Unpublished report prepared for Weyerhaueser BC Coastal Group, Nanaimo, BC.
Wind, E. (in review). Effects of nonnative predators on aquatic ecosystems. Unpublished report prepared for the Ministry of Water, Land and Air Protection, Victoria, BC.

BIOGRAPHICAL SUMMARY OF REPORT WRITERS

Kristiina Ovaska, M.Sc., Ph.D. has studied the behaviour and ecology of amphibians as a part of her dissertation and post-doctoral work and as a consultant over the past 20 years. In British Columbia, her amphibian studies have addressed social behaviour and population dynamics of plethodontid salamanders, interactions with forestry practices, effects of UV-B radiation on hatching success of aquatic-breeding amphibians, and effects on endocrine-disrupting compounds on amphibian metamorphosis and tadpole behaviour. She has also carried out various surveys for amphibians, including species at risk. She has also studied community ecology of salamanders in Washington State and courtship behaviour and ecology of tropical frogs in the West Indies and Panama. She is the author of 8 COSEWIC status reports and 5 RENEW recovery strategies for amphibian, reptile, and mollusc species, and over 40 publications in refereed scientific literature, most of them on amphibians.

Lennart Sopuck, MSc. has studied a wide variety of wildlife species over the last 25 years, including several species at risk, and specializes in research on the effects of human activities on wildlife. He is co-author of the RENEW recovery strategy for the Coastal Giant Salamander and for two species of terrestrial gastropods. He has participated in studies of plethodontid salamanders on Vancouver Island, including population monitoring and the effects of variable-retention forest harvesting practices. He is co-author of a report that describes best management practices to assist land developers in the protection of amphibians and reptiles in rural and urban environments in British Columbia.

AUTHORITIES CONTACTED

Researchers:

(Contacted in July – September 2003 for locality records and results of ongoing and recent studies)

Beasley, Barb. Consultant. Ucluelet, BC.
Chan-McLeod, Ann. Dept. of Forest Sciences, Forest Sciences Centre, University of British Columbia, Vancouver, B.C.
Davis, Ted. Lecturer, Camosun University College, Victoria, BC.
Govindarajulu, P. Ph.D. candidate, Department of Biology, University of Victoria, Victoria, BC. (August 2003)
Knopp, Denis, Consultant, B.C.'s Wild Heritage Environmental Consultants, Chilliwack, B.C.
Meggill, W. Research Associate, Department of Zoology, University of British Columbia, Vancouver, BC. (August 2003)
Shean, J.T. Graduate student. Evergreen State College, Olympia, Washington, U.S.A.; (September 2003)
Wind, Elke. Consultant . E. Wind Consulting, Nanaimo, BC.

BC Ministry of Air, Land and Water Protection personnel:

(Contacted for information on policies and management measures, or locality records in July – August 2003)

Friis, Laura. Small Mammal and Herpetofauna Specialist, Biodiversity Branch, Victoria.
Nelson, Kari. Species at Risk Biologist, Biodiversity Branch, Victoria.
Paige, Kathy. Biodiversity Monitoring and Reporting Section, Victoria.
Vennesland, Ross. FIA Species at Risk Recovery Biologist, Surrey BC.

Other institutions or individuals contacted:

Conservation Data Centre, Victoria, BC (contacted for locality records in August 2003).

MacAllister, Kelly. US Fish and Wildlife (contacted in August 2003 for information on the status of the species in Washington and for distribution information in the United States).

Rithaler, R. Corporation of Delta, Delta B.C.(contacted in September 2003; provision of maps and information on amphibian distribution and status in Delta).

COLLECTIONS EXAMINED

Many of the records for *Rana aurora* were obtained from data files compiled by Laura Friis (BC Ministry of Air, Land and Water Protection) in July 2003. These files contain information associated with records from the following sources:

- Canadian Museum of Nature
- Royal British Columbia Museum
- Cowan Vertebrate Museum, University of British Columbia
- BC Frog Watch Program
- Various surveys and observations contributed by researchers, consultants, and private individuals

We contacted the following additional sources for locality information:

- Royal Ontario Museum
- Various researchers (see “Authorities Consulted”, above)

The web-based records from the following collections in the United States were searched in September 2003:

- Museum of Vertebrate Zoology, University of California, Berkley, California (no specimens)
- California Academy of Sciences, San Francisco, California (no specimens)
- Museum of Comparative Zoology, Harvard University (1 specimen MCZ a-1538 from Edmonton, Alberta, which was misidentified and was *Rana sylvatica*).

We attempted to examine specimens from the Royal British Columbia Museum that were associated with outlying records (RBCM 1199, 1200, Kitimat; RBCM 816, 817, Manning Park); these specimens could not be located. An additional suspicious specimen (RBCM 297, Garibaldi) had been discarded in 1959.