The Canadian Field-Naturalist

Evidence of successful hatching by introduced Red-eared Slider (*Trachemys scripta elegans*) in British Columbia, Canada

Aimee M. Mitchell[1, 2,*], Vanessa L. Kilburn[1, 3, 4], Rebecca Seifert[1], and Deanna MacTavish[1]

[1]Coastal Painted Turtle Project operated by Coastal Partners in Conservation Society, 4-2422 Hawthorne Avenue, Port Coquitlam, British Columbia VC3 6K7 Canada

[2]Athene Ecological, 103-1516 East 1st Avenue, Vancouver, British Columbia V5N 1A5 Canada

[3]Ecorana Environmental Ltd., 3601 Hillcrest Avenue, North Vancouver, British Columbia V7R 4B7 Canada

[4]Toucan Ridge Ecology & Education Society (T.R.E.E.S.) Research Center, Middlesex, Stann Creek, Belize, Central America

[*]Corresponding author: wptrecovery@gmail.com

Mitchell, A.M., V.L. Kilburn, R. Seifert, and D. MacTavish. 2022. Evidence of successful hatching by introduced Red-eared Slider (*Trachemys scripta elegans*) in British Columbia, Canada. Canadian Field-Naturalist 136(2): 122–132. https://doi.org/10.22621/cfn.v136i2.2653

Abstract

Globally, competition and disease from introduced Red-eared Slider (*Trachemys scripta elegans*) is a threat to co-existing native turtles. Red-eared Slider has been introduced throughout south coastal British Columbia (BC), mainly as pet turtle releases. Urban centres receive the most individuals, particularly in the Lower Mainland area outlying Vancouver, on southern Vancouver Island, and on the Sunshine Coast. The range of Red-eared Sliders in BC overlaps that of the Threatened Pacific Coast population of Western Painted Turtle (*Chrysemys picta bellii*). Herein we report on a survey for both species, noting presence, assessed population sizes, and nesting activity. Across 19 sites in the south coast occupied by both turtle species, we found the median abundance of Red-eared Sliders to be 2.5 times larger than that of Western Painted Turtles (Mann–Whitney $U = 104$, $n_1 = n_2 = 19$, Z-Score = −2.2188, $P = 0.02642$, two-tailed). There had been no evidence of Red-eared Sliders successfully hatching in the wild in BC until our study. We observed complete development, with 19 neonates from three different nesting sites between 2015 and 2017. Thus, Red-eared Slider is indeed established and able to breed in BC and thus competition and disease introduction from the species likely contributes to the decline of the Pacific Coast population of Western Painted Turtle, particularly at sites with low painted turtle numbers. The scale and mechanisms of impact requires further investigation.

Key words: Red-eared Slider; Western Painted Turtle; invasive species; reproduction; population status; northern climates; British Columbia

Introduction

Red-eared Slider (*Trachemys scripta elegans*) is a widely introduced turtle species that negatively impacts native turtles and ecosystems globally but may not necessarily be able to reproduce and spread in northern climates (Ficetola *et al.* 2009). Originally from the Mississippi Valley, USA and Caribbean basin, Red-eared Slider is an aquatic emydid turtle that occupies a variety of lentic habitats. Because of human activity, they now occur on every continent except for Antarctica, making this species the world's most widespread freshwater turtle (Ernst and Lovich 2009).

The International Union for the Conservation of Nature's (IUCN) Invasive Species Specialist Group has assigned Red-eared Sliders a Vertebrate Pest Category rating of Extreme in Australia, where a risk assessment has been conducted (GISD 2018) and has categorized it as one of the world's 100 worst invasive species (Lowe *et al.* 2000). Although introductions of various other emydid turtle species have occurred Canada-wide, Red-eared Sliders are now the most widespread non-native turtle in Canada and the most abundant non-native turtle in British Columbia (BC; Bury and Matsuda 2012).

Like many other introduced species, Red-eared Sliders commonly are associated with human-modified habitats and urban centres, attributable to the more frequent release of pet store turtles into these ecosystems (Bury 2008; Lambert *et al.* 2013). Red-eared Sliders tend to thrive in urban and human-modified habitats due to the species' generalist nature with respect to diet, habitat, and the availability of food in urban waterbodies (Ferronato *et al.* 2009; Thomson *et al.* 2010). This success in urban environments also may be attributed to the species' ability to tolerate

A contribution towards the cost of this publication has been provided by the Thomas Manning Memorial Fund of the Ottawa Field-Naturalists' Club.

high levels of radioactive, thermal, chemical, and organic pollution (Gibbons 1990).

Globally within its introduced range, Red-eared Slider is considered invasive only in regions where it is capable of repeated, successful reproduction (Ficetola *et al.* 2009; Thomson *et al.* 2010). For example, introduced Red-eared Sliders reproduce readily in warmer Mediterranean climates where they have been introduced. At higher latitudes, successful embryo development and hatchling survival are limited by temperature and moisture (Ficetola *et al.* 2009). Red-eared Slider reproduction has been observed throughout Europe in both Mediterranean and more continental climates (Lever 2003; Cadi *et al.* 2004; Çiçek and Ayaz 2015; Dordević and Andelković 2015), in California (Spinks *et al.* 2003; Thomson *et al.* 2010), and also in southern Ontario where full details on successful reproduction are being compiled into a manuscript (S. Gillingwater pers. comm. 23 February 2021). A recently emerged hatchling also was reported from Vancouver Island, BC (C. Miller Retzer pers. comm. 6 October 2020).

In their native range, Red-eared Slider nest May through July, laying 1–30 eggs per clutch and commonly two or sometimes three clutches per season (Tucker 1997). They require 60–80 days to hatch in native conditions, but in colder summers incubation can exceed 100 days; hatchlings overwinter in the nest in some areas (Tucker 1997; Ultsch 2006; Costanzo *et al.* 2008), although most hatchlings emerge in autumn (Ernst and Lovich 2009). Unfavourable climate restricts embryo development and hatchling overwintering survival (Packard *et al.* 1997; Tucker and Packard 1998; Kleewein 2015). At the northern limit of its native range in Illinois, Red-eared Sliders do not extend beyond areas where the ground frequently freezes to a depth of 12 cm (Ernst and Lovich 2009). Minimum temperature for complete embryo development is 21°C (viability minimum) with an optimal minimum of 25°C (Greenbaum 2002). Further, this species exhibits a temperature-dependent sex ratio with eggs incubated at temperatures below 27°C producing only males, while those incubated above 30°C produce only females (Ernst and Lovich 2009). Temperature-dependent sex ratios may limit population growth and spread in their introduced range where temperatures do not reach minima needed for successful development (Cadi *et al.* 2004).

In Europe, where Red-eared Sliders occupy the same wetland as native European Pond Turtle (*Emys orbicularis*), the introduced turtle outcompetes the native species for basking space (Cadi and Joly 2003; Lambert *et al.* 2013). Cadi and Joly (2004) also found that in sites of mixed species, European Pond Turtles showed higher mortality rates and increased weight loss compared to Red-eared Sliders. In the upper Midwest of the United States north of the confluence of the Ohio and Mississippi Rivers where other subspecies of painted turtles occur with Red-eared Sliders and the sliders are native, painted turtles are almost always less abundant than the sliders (Dreslik and Phillips 2005). Disease transmission also is a concern, and this may be the most significant impact of introduced Red-eared Slider on native turtles (Hays *et al.* 1999; Thomson *et al.* 2010).

It has been assumed that Red-eared Sliders do not reproduce successfully in BC water bodies based on numerous incidental field observations from local biologists and naturalists who have found stalled embryo development upon excavating nests. Therefore, it was presumed that populations were being sustained without reproduction through ongoing pet turtle releases (P. Govindarajulu and K. Welstead pers. comm. 4 July 2012). However, in the warmest summers of south coastal BC where the climate is mild, current environmental conditions could allow for successful reproduction in some localities. Further, with predicted climate change, many regions will experience warmer temperatures and changes in precipitation levels that may allow introduced Red-eared Sliders to more readily reproduce. Here we report on the reproductive efforts of introduced Red-eared Sliders sympatric with native Western Painted Turtle (*Chrysemys picta bellii*) along the south coast of BC.

Methods

Study area

Our area of study included the Lower Mainland and Fraser River Valley (LM/FV; in the Greater Vancouver and Fraser Valley Regional Districts), the Sea-to-Sky area (Squamish/Whistler), and the Upper Sunshine Coast (Powell River area) between Saltery Bay and Lund, including Texada Island (collectively south coast north, SCN; Figure 1). Other than differences in geographical location and therefore slight longitudinal and possibly climatic differences, these regions differed with respect to human population density, land use, and the degree of human disturbance. The LM/FV is heavily populated in the Greater Vancouver area with decreasing population density moving east from Vancouver into the Fraser Valley where agriculture is the primary land use. The SCN has similar population density to the Fraser Valley areas but with minimal agriculture. All survey site information including waterbody name, region, global positioning system (GPS) location, and location and species of turtles observed were deposited with the BC Conservation Data Centre.

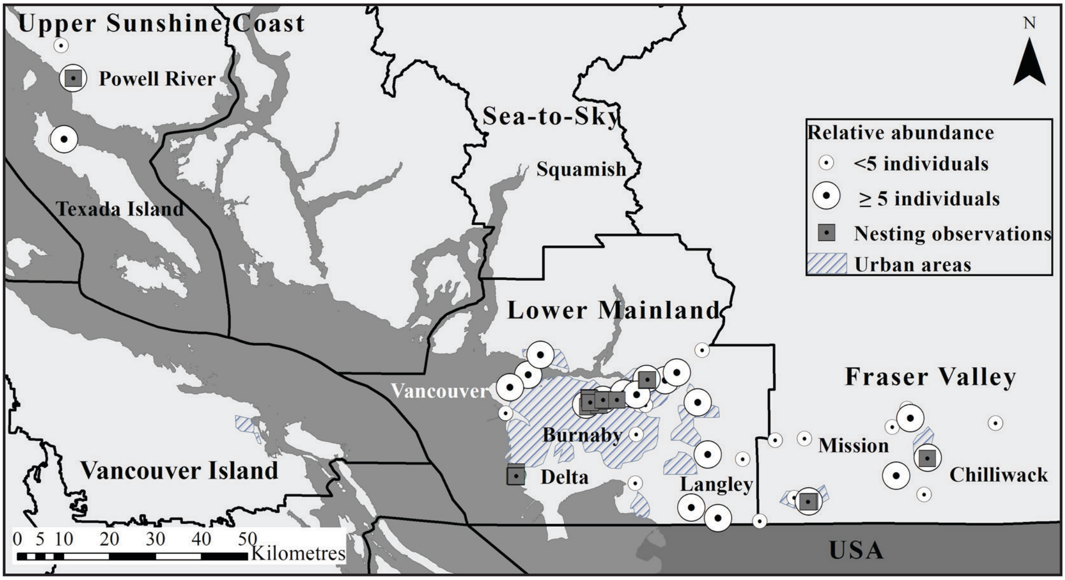

FIGURE 1. Distribution and relative abundance of Red-eared Slider (*Trachemys scripta elegans*) and their nests in south coastal British Columbia, 2008–2018.

Distribution and abundance of turtles

We conducted Western Painted Turtle and Red-eared Slider surveys at waterbodies with historical occurrence records and other waterbodies of unknown occupancy status that met the biophysical features and attributes of suitable turtle habitat. This habitat included lakes, ponds, marshes, river channels, sluggish streams, and sloughs with emergent or floating vegetation, vegetative mats, bottom substrates with organic material, submerged or emergent logs, large woody debris or rocks, and warm shallow water margins (ECCC 2018). Surveys were conducted in April–May and September–October, 2009–2018. We visually searched for basking turtles on logs, rocks, or shoreline areas using binoculars and/or a spotting scope. Because both emydid turtle species have similar ectothermic requirements and basking behaviour, we assumed that there was an equal likelihood of detecting either species if present (Peterman and Ryan 2009).

These surveys were conducted either by foot from vantage points along the shore or by kayak. Unless the presence of Western Painted Turtles was confirmed on the first visit, we attempted at least three surveys at each site deemed suitable over the course of the field season, following BC Ministry of Environment Resource Information Standards Committee (RISC) guidelines (MELP 1994). However, some sites were surveyed only once or twice if on an earlier visit the site was deemed unsuitable for turtles, if access was restricted, or the waterbody condition changed substantially between surveys. We attempted to conduct all surveys between 0900 and 1500 on warm sunny days of zero precipitation early in the breeding season (April and May) when turtles are likely to bask (MELP 1994). We generally avoided surveying on cloudy or rainy days or on hot days (>25°C) in the summer (mid-July through mid-August) when Western Painted Turtles in this region are rarely observed basking (see Lefevre and Brooks 1995; Semproni and Ogilvie 2007; Engelstoft and Ovaska 2008).

We summarized our detection data from the basking surveys as maximum abundance for each site using the maximum number of Red-eared Sliders and Western Painted Turtles observed on any one survey at a site through all survey years to avoid double counting individuals. For data analyses we grouped all sites into three regional categories: LM/FV sites were classified as either LM/FV urban (n = 17) or LM/FV rural (n = 19) depending on whether the site was located within a major city surrounded by residential or commercial infrastructure ("urban") or outside of city limits ("rural"); sites north of LM/FV (Squamish/Whistler, Upper Sunshine Coast, Texada Island; n = 6) were grouped into a third regional category: SCN. Using an online calculator (Social Science Statistics 2018) we performed two-tailed Mann-Whitney U-tests on the maximum abundance of both species with all regions combined where either one or both species were observed (n = 42 sites) and with all regions combined with sites where both species were detected (n = 19 sites). These tests were also conducted within each region where both species were detected with a sufficient sample size of sites (n = 10 for rural and n = 7 for urban). The tests determined if there was a difference in abundance of the two turtle species.

Red-eared Slider reproduction

Nesting surveys—We conducted nesting surveys for both Western Painted Turtles and Red-eared Sliders at sites where Western Painted Turtles were observed from our detection surveys between mid-May and mid-July, 2009–2018 in the LM/FV, on the Sunshine Coast, and on Texada Island, following a standardized protocol (Coastal Painted Turtle Working Group 2011). However, Red-eared Sliders often deposit eggs later in the summer (into August) compared to Western Painted Turtles (A.M.M. pers. obs. 2009) so we continued to respond to reports of nesting Red-eared Sliders to track nesting observations past the standard nesting monitoring season for Western Painted Turtles. We did all nesting surveys in the late afternoon and evening, as turtle nesting activity is known to peak around 1800 (Bowen *et al.* 2005). We searched suitable potential upland habitat for evidence of nesting activity, which is usually visible as test holes, depredated and emerged nest holes, and eggshell remains from predation (Engelstoft and Ovaska 2008). Potentially suitable nesting habitat consists of exposed, south-facing, sandy soil with little or no vegetation on flat or gentle slopes with limited understorey and canopy cover (Klemens 2000; Semlitsch and Bodie 2003; Marchand and Litvaitis 2004). Although nesting female painted turtles may travel up to 650 m from water to nest, we concentrated our searches within the first 150 m from the water's edge where most nesting activity occurs (Christens and Bider 1986).

During nesting surveys, we recorded data on the survey site (description and GPS coordinates, Universal Transverse Mercator [UTM] Zone 10U), date with start and end times, species of turtles observed, numbers of individuals, nesting substrate, distance of the nest from the water, and numbers of eggs deposited (for actual nesting attempts). Completed nests were marked with exact UTM positions and maps of the nesting sites were created using ArcGIS (ESRI, Redlands, California, USA) Desktop 10.3 to plot their precise location. We installed iButton temperature loggers (Embedded Data Systems, Lawrenceburg, Kentucky, USA) when possible, at nest sites from 2009 to 2013. We placed an iButton in a nylon cover and buried it at the level of the nest chamber (average 25 cm depth). Completed Red-eared Slider nests were protected with hardwire mesh exclosures to prevent predation and allow us to monitor hatching success and prevent escape.

Due to distance between occupied sites, time and labour constraints, lack of nesting evidence at many occupied sites, and access constraints, our nesting surveys and the sites annually monitored changed over time. By the summer of 2018, we had reduced our nesting surveys for Red-eared Sliders and Western Painted Turtles to three sites where we repeatedly saw nesting attempts. Besides summer monitoring, we checked known nests periodically throughout the year for signs of disturbance and predation. In both the fall and the spring, we monitored nests frequently for signs of emergence. We also responded to incidental reports from other biologists working in the region and public reports of Red-eared Sliders depositing eggs, although these nests could not always be located.

Embryonic development monitoring—To determine how quickly Red-eared Slider eggs develop in south coastal BC, we excavated and examined nests from a subsample of sites where dates for egg deposition were known. However, in other cases, eggs and fully developed hatchlings were found via excavation by Sandhill Crane (*Antigone canadensis*) or by incidental observations from previously undetected nests, where the egg deposition date was not known and the period of development could not be determined. All eggs were dissected and embryos preserved in ethanol.

For each embryo, we recorded egg condition, yolk condition (hardened yolks versus unhardened yolks to determine viability), and stage of development by comparing with descriptions and photos in Greenbaum (2002). To determine if there was an increase in the frequency of later developmental stages overtime, we first summarized the number of eggs classified in two developmental range categories: ≤ stage 21 and stage 22–26 (with stage 26 being completed development and hatched). We then calculated a 2×2 χ^2 statistic using two 5-year time periods: 2008–2012 and 2013–2017. Because successful reproduction seemed evident, any known Red-eared Slider nests deposited after 2017 were removed to reduce the likelihood of Red-eared Slider recruitment.

Results

Distribution and abundance of Red-eared Sliders

Red-eared Sliders were present in all regions of our study area, with sites in the LM/FV having higher abundances than in SCN (Figure 1). Median abundance of Red-eared Sliders and Western Painted Turtles were 4.5 and 1 per site, respectively, at the 42 sites (three regional categories combined: LM/FV urban, LM/FV rural, and SCN) where either or both turtle species were observed basking. Overall Red-eared Sliders were significantly more abundant in our study region than Western Painted Turtles ($U = 208.5$, $n_1 = n_2 = 42$, $Z = 3.38263$, $P < 0.001$).

When limited only to sites where both turtle species were observed ($n = 19$), a significantly higher abundance of Red-eared Sliders (median = 5) continued to be found (Western Painted Turtles: median = 2; $U = 104$, $n_1 = n_2 = 19$, $Z = –2.2188$, $P = 0.02642$; Figure 2). No significant difference was found in abundance of the two species in the LM/FV rural sites (median abundance of 5 and 2, Red-eared Slider and Western Painted Turtle, respectively; $U = 24$, $n_1 = n_2 = 10$, $Z = −1.92762$, $P = 0.0536$; Figure 2). Both species were observed at too few sites in the SCN region ($n = 2$) to test for differences in abundance (Figure 2). Significantly more Red-eared Sliders than Western Painted Turtles were found at the urban LM/FV sites that contained both species (median 16 and 3, respectively; $U = 8.5$, $n_1 = n_2 = 17$, $Z = −1.98052$, $P = 0.0477$; Figure 2). Thus, in south coastal BC, the majority of introduced turtles occupy urban sites in the Lower Mainland in close proximity to human populations, becoming scarcer with distance from urban centers (Figures 1 and 2).

Red-eared Slider reproduction

We documented 28 incidental nests in the LM/FV and SCN regions from 2008 to 2018 with 15 nests confirmed and their development tracked (Figure 1). Seven nests (of the 15) were intensively monitored because the egg deposition dates were known (Table 1). We found 93% (14/15) had some portion of eggs that were fertile (vascularized and/or with an embryo present) and 80% ($n = 12$) had eggs with embryos that developed to at least stage 21 of a maximum 26 (Greenbaum 2002). Of these 12 nests that reached a late stage of development, complete embryonic development and hatchling emergence occurred in 33% ($n = 4$ nests) between 2014 and 2017 at three different sites (Table 1).

Of all the eggs that we tracked for development (Table 1), 87% (113/130 eggs) were fertile (vascularized and/or with an embryo present) and of the fertile eggs, 74% (84/113) developed to at least stage 21 (Figure 3). From 2008 to 2012, the majority (75% or 18/24) of viable eggs developed only to a maximum of stage 21, five eggs advanced to stage 22–25, and only one egg had completed development (> stage 26). However, during 2013–2017 more than half the viable eggs (56% or 45/89) advanced to stage 22–25 or completed development (Table 1, Figures 3 and 4). In 2014, we first began to observe complete embryonic development and hatchling emergence, with the first record occurring at Reifel Migratory Bird Sanctuary with six healthy neonates (Table 1, Figure 4). Significantly more of the viable eggs developed to at least stage 22–26 in 2013–2017 than in 2008–2012 ($n = 113$, $\chi^2_1 = 4.98$, $P = 0.0255$).

We recorded hatchlings in nests annually into 2017 at three sites both in the LM/FV (Reifel Migratory Bird Sanctuary and Burnaby Lake), and in the SCN (Cranberry Lake in the Upper Sunshine Coast), for a total of 19 neonates observed between 2014 and 2017 (Table 1). Further, we observed juvenile Red-eared Sliders (>1 year after hatching until breeding age of 4–5 years for males and 8–10 years for

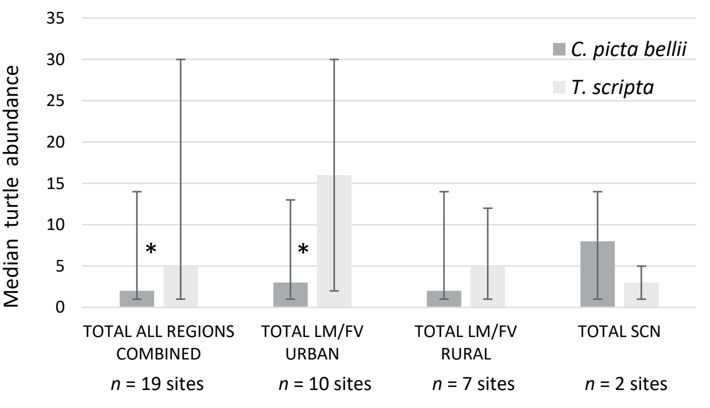

FIGURE 2. Median abundance (bars show maxima and minima) of Western Painted Turtle (*Chrysemys picta bellii*) and Red-eared Slider (*Trachemys scripta elegans*) observed basking at the same waterbody, south coastal British Columbia, 2009–2018. Regions were Lower Mainland/Fraser Valley (LM/FV) in the Greater Vancouver and Fraser Valley Regional Districts ('rural' sites outside of city limits and 'urban' sites within a major city surrounded by residential or commercial infrastructure), and South Coast North (SCN) in the Upper Sunshine Coast (Powell River area) between Saltery Bay and Lund, including Texada Island (see Figure 1). An asterix indicates a significant difference ($P < 0.05$) in abundance between the two turtle species (Mann-Whitney U-tests, see text).

TABLE 1. Red-eared Slider (*Trachemys scripta elegans*) nests and egg development in south coastal British Columbia, 2008–2018. N/A = not applicable; N/R = not recorded.

Site	Year	Annual nest number	Cumulative nest number	Date laid	Number of eggs	Number fertilized	Number of embryos	Developed to which embryonic stage* (x number of eggs)
Reifel Island Bird Sanctuary†	2008	1	1	04-Jun	Min. 1	Min. 1	Min. 1	21
Mill Lake	2012	N/A	N/A	N/A	N/A	N/A	N/A	Completed development - Juvenile
Burnaby Lake	2012	1	2	8-Jul	>2	N/R	N/R	N/R
Reifel Island Bird Sanctuary†	2012	2	3	23-May	9	9	3	23 (x3), <12 (x6)
Reifel Island Bird Sanctuary	2012	3	4	08-Jul	N/R	N/R	N/R	N/R
Reifel Island Bird Sanctuary†	2012	4	5	N/R	7	7	7	23 (x1), 22 (x1), 21 (x5)
Reifel Island Bird Sanctuary†	2012	5	6	N/R	6	6	0	<12 (x6)
Burnaby Lake	2012	6	7	12-Jul	>12	N/R	N/R	N/R
Lafarge Lake	2012	7	8	19-Jul	>1	N/R	N/R	N/R
Mill Lake	2012	8	9	16-Jul	N/R	N/R	N/R	N/R
Deer Lake	2012	9	10	N/R	N/R	N/R	N/R	N/R
Reifel Island Bird Sanctuary†	2013	1	11	12-May	10	5	1	22–23 (x1), <12 (x4)
Reifel Island Bird Sanctuary†	2013	2	12	25-May	8	5	2	19–20 (x2), <12 (x3)
Reifel Island Bird Sanctuary†	2013	3	13	22-Jul	13	11	11	19–20 (x7), <12 (x4)
Burnaby Lake†	2013	4	14	N/R	16	16	16	24–25 (x16)
Sardis Pond	2013	5	15	N/R	N/R	N/R	N/R	N/R
Burnaby Lake	2014	1	16	N/R	N/R	N/R	N/R	N/R
Lafarge Lake	2014	2	17	N/R	N/R	N/R	N/R	N/R
Reifel Island Bird Sanctuary	2014	3	18	26-May	9	5	1	25 (x1), <12 (x4)
Reifel Island Bird Sanctuary	2014	4	19	24-Jun	12	11	11	23 (x7), 21 (x4)
Reifel Island Bird Sanctuary‡	2014	5	20	N/R	Min. 6	6	Min. 6	>26 (x6)
Reifel Island Bird Sanctuary†	2015	1	21	N/R	Min. 3	3	Min. 3	>26 (x3)
Burnaby Lake†	2015	2	22	N/R	Min. 4	4	Min. 4	>26 (x4)

TABLE 1. *Continued.*

Site	Year	Annual nest number	Cumulative nest number	Date laid	Number of eggs	Number fertilized	Number of embryos	Developed to which embryonic stage* (x number of eggs)
Lafarge Lake	2017	1	23	N/R	N/R	N/R	N/R	N/R
Cranberry Lake†	2017	2	24	N/R	14	12	10	>26 (x6), 21 (x4), <12 (x2)
Cranberry Lake†	2017	3	25	N/R	12	10	8	21 (x8), <12 (x2)
Reifel Island Bird Sanctuary‡	2017	N/A	N/A	N/A	N/A	N/A	N/A	Completed development - Juvenile
Burnaby Lake	2017	4	26	N/R	N/R	N/R	N/R	N/A
Burnaby Lake	2018	5	27	11-Jun	15	15	15	Nest removed
Burnaby Lake	2018	6	28	20-Jun	9	9	9	Nest removed

*Embryonic stage according to Greenbaum (2002).
†Nests monitored for development.
‡First confirmed completed development.

females; ECCC 2018) at two sites: one in 2012 (Mill Lake) and another in 2017 (Reifel Migratory Bird Sanctuary; Table 1).

Summer temperatures (data not shown) within nests at Reifel Migratory Bird Sanctuary and at Burnaby Lake in 2012 reached or exceeded the minimum viability threshold for completed embryonic development of Red-eared Slider (average 23°C) in 51% of the three daily readings (n = 299) and 71% of the three daily readings (n = 260) throughout the summer period, respectively. In 2013, summer temperatures exceeded those in the previous year at Burnaby Lake and were above the optimal minimum (average 26°C) for the species in 37% of the three daily readings throughout the period (n = 260). No temperature readings were taken at nests after 2013.

Discussion

Our survey results show that Red-eared Sliders appear to be more abundant in many sites throughout the LM/FV than the native Western Painted Turtle, particularly in urban areas. Without historical data we cannot determine whether the original Western Painted Turtle populations were always small and disjunct or whether Red-eared Sliders have affected Western Painted Turtle abundance over the last few decades since their introduction. Still, there is sufficient evidence from studies outside of Canada to suggest Red-eared Sliders contribute to population declines in Western Painted Turtles; indeed the threat impact of invasive species, including Red-eared Slider, is listed as high in the final Recovery Strategy for the species (ECCC 2021). While the Committee on the Status of Endangered Wildlife in Canada initially assessed the status of the Pacific Coast population of Western Painted Turtle in 2006 as Endangered, it reassessed this species in 2016 and recommended a downlisting to Threatened, its current legal status (SARA Registry 2021).

Red-eared Sliders are successfully hatching in south coastal BC; coupled with their distribution and relatively high abundance in the region, there is a potential for significant or severe consequences for Western Painted Turtle populations in the LM/FV. Many regions in BC are already experiencing warming temperatures—with direct evidence of increased substrate temperatures at turtle nesting sites in some years over the past decade—and with climate change models predicting an increase of 1–2°C in air temperatures by 2050 (Rodenhuis 2009; PCIC 2010; Carlson 2012; Mitchell 2014). However, we were not able to make any direct correlations between temperature changes observed at nesting sites after 2013, the last year temperature loggers were deployed, and our

FIGURE 3. Red-eared Slider (*Trachemys scripta elegans*) embryonic developmental stages (Greenbaum 2002): a. stage 21, b. stage 23, and c. stage 24–25. Photos: Aimee Mitchell.

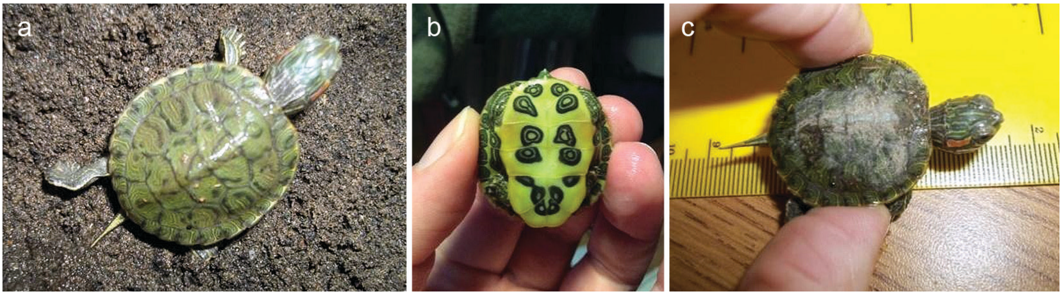

FIGURE 4. Red-eared Slider (*Trachemys scripta elegans*) neonates stage >26, fully developed, and emerged from the egg, Nest 5 laid in 2014 and discovered in early 2015. Photos: Aimee Mitchell.

subsequent observations of increased later stages of development over time.

As the climate shifts towards conditions more favourable for Red-eared Slider reproduction, recruitment to existing populations will also likely increase and distribution expand to areas where conditions are currently less favourable for Red-eared Sliders. This predicted population increase is likely to accelerate as Red-eared Sliders have a large reproductive capacity, commonly producing up to three clutches per season (Tucker 1997). However, reproductive output of Western Painted Turtle may also increase. On occasion, we observed Western Painted Turtles producing three clutches per season in our study area (A.M.M. pers. obs. 15 July 2019); others (Iverson and Smith 1993; St. Clair *et al.* 1994) have reported multiple clutches occur in warmer parts of the species' range.

Red-eared Sliders are known to outcompete native turtles in other areas where they have been introduced (e.g., Cadi and Joly 2003, 2004; Lambert *et al*. 2013). Red-eared Sliders are more aggressive and outcompete smaller native turtles at basking sites (Cadi and Joly 2003; Lambert *et al.* 2013), which often are limited in many of the more urbanized sites where both species coexist in BC. Also, there could be competitive advantage based on the size of juvenile turtles. Red-eared Slider hatchlings are generally larger at nest emergence than Western Painted Turtle hatchlings although there is some size overlap (Ernst *et al.* 1994; Tucker 2000). We also found differences in the size of turtle hatchlings (unpubl. data): average carapace length and weight was 35.1 mm and 6.1 g for Red-eared Slider hatchlings (n = 6) and 27.1 mm and 4.7 g for Western Painted Turtle hatchlings (n = 12). Thus, compared to Western Painted Turtle hatchlings, Red-eared Slider hatchlings are less likely to be predated upon by aquatic predators with gape size limitations such as herons, fish, and invasive frogs (Ernst *et al.* 1994; Tucker 2000).

Red-eared Sliders bred and raised under unhygienic captive conditions are known to harbour pathogens (Hidalgo-Vila *et al.* 2009) that might transfer to native turtles, as many turtle pathogens are not host-specific (Verneau *et al.* 2011). Thomson *et al.* (2010) and Silbernagel *et al.* (2013) suggest that disease transfer from released pet Red-eared Sliders is a significant threat to native turtles, and disease is implicated in declines of native turtle populations in Europe (Cadi and Joly 2004). Ten Red-eared Sliders captured and euthanized during our study had a bacterial respiratory condition (A. Walton pers. comm. 15 August 2014). In addition, one Western Painted Turtle was rescued from a site dominated 30:1 by Red-eared Sliders in the Lower Mainland and subsequently required treatment for several weeks for a respiratory illness.

Conclusions

We documented the distribution and relative abundance of Red-eared Slider populations across south coastal BC as well as successful reproduction of the species in the wild. Since monitoring began in 2009, we have observed a shift over time from only partially developed Red-eared Slider embryos to successful hatching and emergence (nests laid in 2014 and emerged in 2015). We suspect that with continued climate change, conditions will become more suitable for successful reproduction at more localities and the frequency of successful development and emergence will increase at sites where emergence has already been documented. The predicted increase in abundance and distribution of Red-eared Sliders throughout south coastal British Columbia is a conservation concern and may impact the native federally listed Pacific Coast population of Western Painted Turtle although the exact mechanism remains to be explored. In the interim, we suggest the elimination of both Red-eared Slider adults and their nests to limit further recruitment, as part of a precautionary conservation approach.

Author Contributions

Writing – Original Draft: A.M.M. and R.S.; Writing – Review & Editing: V.L.K. and A.M.M.; Conceptualization: A.M.M.; Investigation: A.M.M., V.L.K., and D.M.; Methodology: A.M.M.; Formal Analysis: A.M.M. and V.L.K.; Funding Acquisition: V.L.K. and A.M.M.

Acknowledgements

Funding for the surveying and monitoring aspects of this study included Environment and Climate Change Canada's Habitat Stewardship Program and Habitat Conservation Trust Foundation. Provincial biologists from the Ministry of Forests, Lands and Natural Resource Operations and Rural Development, Kym Welstead and Connie Miller Retzer, and Purnima Govindarajulu (of the Ministry of Environment), provided in-kind support, field assistance, and resources. Besides our funding sources, we thank all our partners, volunteers, and landowners that assisted in reporting and tracking observations. Of particular importance was the contribution to the identification and tracking of nests by staff at the Reifel Migratory Bird Sanctuary in Delta, British Columbia, especially Kathleen Fry. Veterinarian Dr. Adrian Walton, of Dewdney Animal Hospital, generously provided valuable information and guidance regarding turtle health and potential impacts of introduced turtles on wild individuals, including diagnosing respiratory illnesses in both species of turtles that were removed from sympatric sites through the course of this study. Ontario Species at Risk Herpetologist Scott Gillingwater provided important information on invasive turtle breeding and survival observations for eastern Canada. R. Bruce Bury and Brent M. Matsuda provided much appreciated consultation and review.

Literature Cited

Bowen, K.D., R.-J. Spencer, and F.J. Janzen. 2005. A comparative study of environmental factors that affect nesting in Australian and North American freshwater turtles. Journal of Zoology 267: 397–404. https://doi.org/10.1017/s0952836905007533

Bury, R.B. 2008. Do urban areas favor introduced turtles in Western North America? Pages 343–345 *in* Urban Herpetology: Herpetological Conservation Volume 3. *Edited by* J.C. Mitchell, R.E. Jung Brown, and B. Bartholomew. Society for the Study of Amphibians and Reptiles, Salt Lake City, Utah, USA.

Bury, R.B., and B.M. Matsuda. 2012. [Abstract] Invasive and native turtles in the Pacific Northwest: distribution, ecology and management challenges. *In* Abstracts from the 2012 Annual Meeting of the Society for Northwestern Vertebrate Biology in Cooperation with NW Partners in Amphibian and Reptile Conservation and Pacific Northwest Native Freshwater Mussel Workgroup, Held at the Best Western Hood River Inn, Hood River, Oregon, March 20–23, 2012. Northwestern Naturalist 93: 165–186. https://doi.org/10.1898/1051-1733-93.2.165

Cadi, A., V. Delmas, A.C. Prevot-Juillard, P. Joly, C. Pieau, and M. Girondot. 2004. Successful reproduction of the introduced slider turtle (*Trachemys scripta)* in the south of France. Aquatic Conservation: Marine and Freshwater Ecosystems 14: 237–246. https://doi.org/10.1002/aqc.607

Cadi, A., and P. Joly. 2003. Competition for basking places between the endangered European pond turtle (*Emys orbicularis galloitalica*) and the introduced red-eared slider (*Trachemys scripta elegans*). Canadian Journal of Zoology 81: 1392–1398. https://doi.org/10.1139/z03-108

Cadi, A., and P. Joly. 2004. Impact of the introduction of the red-eared slider (*Trachemys scripta elegans*) on survival rates of the European pond turtle (*Emys orbicularis*). Biodiversity and Conservation 13: 2511–2518. https://doi.org/10.1023/b:bioc.0000048451.07820.9c

Carlson, D. 2012. Preparing for climate change: an implementation guide for local governments in British Columbia. Prepared by West Coast Environmental Law. Accessed 9 June 2022. https://www.protectthegreatbearsea.com/sites/default/files/publications/WCEL_climate_change_FINAL.pdf.

Christens, E., and J.R. Bider. 1986. Reproductive ecology of the painted turtle (*Chrysemys picta marginata*) in southwestern Quebec. Canadian Journal of Zoology 64: 914–1020. https://doi.org/10.1139/z86-138

Çiçek, K., and D. Ayaz. 2015. Does the red-eared slider (*Trachemys scripta elegans*) breed in Turkey? Hyla 1: 4–10.

Coastal Painted Turtle Working Group. 2011. Western Painted Turtle, Habitat Acquisition Trust. Accessed 9 June 2022. https://hat.bc.ca/western-painted-turtles.

Costanzo, J.P., R.E. Lee, Jr., and G.R. Ultsch. 2008. Physiological ecology of overwintering in hatchling turtles. Journal of Experimental Zoology Part A: Ecological Genetics and Physiology 309: 297–379. https://doi.org/10.1002/jez.460

Dordević, S., and M. Andelković. 2015. Possible reproduction of the red-eared slider, *Trachemys scripta elegans* (Reptilia: Testudines: Emydidae), in Serbia, under natural conditions. Hyla 1:44–49.

Dreslik, M.J., and C.A. Phillips. 2005. Turtle communities in the upper Midwest, USA. Journal of Freshwater Ecology 20: 149–164. https://doi.org/10.1080/02705060.2005.9664948

ECCC (Environment and Climate Change Canada). 2021. Recovery Strategy for the Western Painted Turtle (*Chrysemys picta bellii)* Pacific Coast population in Canada [final version]. *Species at Risk Act* Recovery Strategy Series. Environment and Climate Change Canada, Ottawa, Ontario, Canada.

Engelstoft, C., and K. Ovaska. 2008. Western Painted Turtle surveys on Galiano, Pender, and Vancouver Island, 2008, including surveys in selected CRD regional parks. CRD Regional Parks and the Habitat Acquisition Trust, Victoria, British Columbia, Canada. Accessed 9 June 2022. https://static1.squarespace.com/static/5e3c5b7e5460c55405a6d4d6/t/61bbd68314b87472f29cca2c/

Ernst, C.H., and J.E. Lovich. 2009. Turtles of the United States and Canada. Second Edition. Johns Hopkins University Press, Baltimore, Maryland, USA.

Ernst, C.H., J.E. Lovich, and R.W. Barbour. 1994. Turtles of the United States and Canada. Smithsonian Institution Press, Washington, DC, USA.

Ferronato, B.O., T.S. Marques, I. Guardia, A.L.B. Longo, C.I. Piña, J. Bertoluci, and L.M. Verdade. 2009. The turtle *Trachemys scripta elegans* (Testudines, Emydidae) as an invasive species in the polluted streams of southeastern Brazil. Herpetological Bulletin 109: 29–34.

Ficetola, G.F., W. Thuiller, and E. Padoa-Schioppa. 2009. From introduction to the establishment of alien species: bioclimatic differences between presence and reproduction localities in the slider turtle. Diversity and Distributions 15: 108–116. https://doi.org/10.1111/j.1472-4642.2008.00516.x

Gibbons, J.W. 1990. Life History and Ecology of the Slider Turtle. Smithsonian Institution Press, Washington, DC, USA.

GISD (Global Invasive Species Database). 2018. Species profile: *Trachemys scripta elegans*. Accessed 31 December 2018. http://www.iucngisd.org/gisd/species.php?sc=71.

Greenbaum, E. 2002. A standardized series of embryonic stages for the emydid turtle, *Trachemys scripta*. Canadian Journal of Zoology 80: 1350–1370. https://doi.org/10.1139/z02-111

Hays, D.W., K.R. McAllister, S.A. Richardson, and D.W. Stinson. 1999. Washington state recovery plan for the western pond turtle. Washington Department of Fish and Wildlife, Olympia, Washington, USA. Accessed 31 December 2018. http://wdfw.wa.gov/publications/00398/.

Hidalgo-Vila, J., C. Diaz-Paniagua, N. Perez-Santigosa, C. de Frutos-Escobar, and A. Herrero-Herrero. 2008. *Salmonella* in free-living exotic and native turtles and in pet exotic turtles from SW Spain. Research in Veterinary Science 85: 449–452. https://doi.org/10.1016/j.rvsc.2008.01.011

Hidalgo-Vila, J., C. Díaz-Paniagua, A. Ribas, M. Florencio, N. Pérez-Santigosa, and J.C. Casanova. 2009. Helminth communities of the exotic introduced turtle, *Trachemys scripta elegans* in southwestern Spain: transmission from native turtles. Research in Veterinary Science 86: 463–465. https://doi.org/10.1016/j.rvsc.2008.08.003

Iverson, J.B., and G.R. Smith. 1993. Reproductive ecology of the painted turtle (*Chrysemys picta*) in the Nebraska Sandhills and across its range. Copeia 1: 1–21. https://doi.org/10.2307/1446291

Kleewein, A. 2015. Investigating temperature tolerance in wild broods of *Trachemys scripta elegans* (Reptilia: Testudines: Emydidae) in Austria. Hyla 1: 28–35.

Klemens, M. 2000. Turtle Conservation. Smithsonian Institution Press, Washington, DC, USA.

Lambert, M.R., S.N. Nielsen, A.N. Wright, R.C. Thomson, and H.B. Shaffer. 2013. Habitat features determine the basking distribution of introduced red-eared sliders and native western pond turtles. Chelonian Conservation and Biology 12: 192–199. https://doi.org/10.2744/CCB-1010.1

Lefevre, K., and R.J. Brooks. 1995. Effects of sex and body size on basking behavior in a northern population of painted turtle, *Chrysemys picta*. Herpetologica 51: 217–224.

Lever, C. 2003. Naturalized Reptiles and Amphibians of the World. Oxford University Press, New York, New York, USA.

Lowe, S., M. Browne, S. Boudjelas, and M. De Poorter. 2000. 100 of the world's worst invasive alien species: a selection from the Global Invasive Species Database. Accessed 9 June 2022. http://www.iucngisd.org/gisd/pdf/100English.pdf.

Marchand, M.N., and J.A. Litvaitis. 2004. Effects of landscape composition, habitat features, and nest distribution on predation rates of simulated turtle nests. Biological Conservation 117: 243–251. https://doi.org/10.1016/j.biocon.2003.07.003

MELP (Ministry of Environment, Lands and Parks). 1998. Inventory methods for pond-breeding amphibians and painted turtle: standards for components of British Columbia's biodiversity No. 37. Ministry of Environment, Lands and Parks, Resources Inventory Branch, Surrey, British Columbia, Canada. Accessed 6 June 2022. https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nr-laws-policy/risc/pond.pdf.

Mitchell, A. 2014. Western Painted Turtle site enhancement and climate monitoring summary 2009–2014. Habitat Conservation Trust Foundation Project 0-307: monitoring and restoring degraded habitats for coexisting species. BC Ministry of Forests, Lands and Natural Resource Operations, Surrey, British Columbia, Canada.

Packard, G.C., J.K. Tucker, D. Nicholson, and M.J. Packard. 1997. Cold tolerance in hatchling slider turtles (*Trachemys scripta*). Copeia 2: 339–345. https://doi.org/10.2307/1447753

PCIC (Pacific Climate Impacts Consortium). 2010. Climate summary for the South Coast Region. University of Victoria, Victoria, British Columbia, Canada.

Peterman, W.E., and T.J. Ryan. 2009. Basking behavior of emydid turtles (*Chrysemys picta*, *Graptemys geographica*, and *Trachemys scripta*) in an urban landscape. Northeastern Naturalist 16: 629–636. https://doi.org/10.1656/045.016.n412

Rodenhuis, D.R., K.E. Bennett, A.T. Werner, T.Q. Murdock, and D. Bronaugh. 2009. Hydro-climatology and future climate impacts in British Columbia. Pacific Climate Impacts Consortium, University of Victoria, Victoria, British Columbia, Canada.

SARA (*Species at Risk Act*) Registry. 2021. Species summary: Western Painted Turtle (*Chrysemys picta bellii*), Pacific Coast population. Government of Canada, Ottawa, Ontario, Canada. Accessed 19 July 2021. https://species-registry.canada.ca/index-en.html#/species/902-634

Semlitsch, R.D., and J.R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology 17: 1219–1228. https://doi.org/10.1046/j.1523-1739.2003.02177.x

Semproni, M., and F. Ogilvie. 2007. Western Painted Turtle (*Chrysemys picta bellii*) presence/not detected survey Lower Mainland Region Summer 2007. BC Ministry of Environment, Surrey, British Columbia, Canada.

Silbernagel, C., D.L. Clifford, J. Bettaso, S. Worth, and J. Foley. 2013. Prevalence of selected pathogens in western pond turtles and sympatric introduced red-eared sliders in California, USA. Diseases of Aquatic Organisms 107: 37–47. https://doi.org/10.3354/dao02663

Social Science Statistics. 2021. Mann-Whitney *U* Test Calculator. Accessed 9 June 2022. https://www.socscistatistics.com/tests/mannwhitney/default.aspx.

Spinks, P.Q., G.B. Pauly, J.J. Crayon, and H.B. Shaffer. 2003. Survival of the western pond turtle (*Emys marmorata*) in an urban California environment. Biological Conservation 113: 257–267. https://doi.org/10.1016/S0006-3207(02)00392-0

St. Clair, R.J., P.T. Gregory, and J.M. MacCartney. 1994. How do sexual differences in growth and maturation interact to determine size in northern and southern painted turtles? Canadian Journal of Zoology 72: 1436–1443. https://doi.org/10.1139/z94-190

Thomson, R.C., P.Q. Spinks, and H.B. Shaffer. 2010. Distribution and abundance of invasive red-eared sliders (*Trachemys scripta elegans*) in California's Sacramento River basin and possible impacts on native western pond turtles (*Emys marmorata*). Chelonian Conservation and Biology 9: 297–302. https://doi.org/10.2744/ccb-0820.1

Tucker, J.K. 1997. Natural history notes on nesting, nests, and hatchling emergence in the red-eared slider turtle, *Trachemys scripta elegans*, in west-central Illinois. Biological Notes - Illinois Natural History Survey 140: 1–13.

Tucker, J.K. 2000. Body size and migration of hatchling turtles: inter- and intraspecific comparisons. Journal of Herpetology 34: 541–546. https://doi.org/10.2307/1565269

Tucker, J.K., and G.C. Packard. 1998. Overwinter survival by hatchling sliders (*Trachemys scripta*) in west-central Illinois. Journal of Herpetology 32: 431–434. https://doi.org/10.2307/1565459

Ultsch, G.R. 2006. The ecology of overwintering among turtles: where turtles overwinter and its consequences. Biological Reviews 81: 339–367. https://doi.org/10.1017/S1464793106007032

Verneau, O., C. Palacios, T. Platt, M. Alday, E. Billard, J.-F. Allienne, C. Basso, and L.H. Du Preez. 2011. Invasive species threat: parasite phylogenetics reveals patterns and processes of host switching between non-native and native captive freshwater turtles. Parasitology 138: 1778–1792. https://doi.org/10.1017/S0031182011000333

Received 13 October 2020
Accepted 3 February 2022
Associate Editor: W.D. Halliday