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Removal as a Control Method for *Trachemys scripta elegans* and the Response of *Chrysemys picta bellii*

by

Jacob Swanson

An undergraduate honors thesis submitted in partial fulfillment of the

requirements for the degree of

Bachelor of Science

in

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and

Environmental Science

Thesis Adviser

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Portland State University

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Abstract

The red-eared slider is considered one of the most ubiquitous freshwater turtles globally. Several key ecological advantages and life history traits of this species jointly impact growth rates and survivorship of native freshwater turtles where sympatry occurs. Evaluation of current management actions for red-eared slider turtles is limited, resulting in a paucity of information to guide management for the species and conservation of declining native freshwater turtles. We used previously collected mark-recapture and removal sampling data from sites with sympatric populations of red-eared slider and western painted turtles. We examined the effects of control (trapping and removal) of red-eared sliders on (1) red-eared slider abundance (2) western painted turtle abundance and body condition (3) community composition. The estimated population size of western painted turtles decreased over time, though with wide confidence intervals, in Peninsula Drainage Canal and increased substantially in Smith and Bybee. However, in Smith and Bybee the estimated population size of red-eared sliders increased, despite continuous removal of the species. We did not detect a difference in the average body condition for western painted turtles as more red-eared sliders were removed. We also showed moderate evidence that management actions can change community composition by removing red-eared sliders, increasing the proportion of western painted turtles relative to red-eared sliders within the community. The questions we set out to answer are imperative to the management of these species and our study highlights the need to make improvements to mark-recapture study design and more systematic sampling to enable rigorous conclusions.

Introduction

Biological invasions have long been recognized as a contributing factor to the global decline in biodiversity and have heavily benefited from human activity and ecosystem modification (Bravener et al. 2013; Chapin et al. 2000; Pejchar and Mooney 2009). Once established in novel habitats, invasive species can displace or even permanently replace native species (Dupuis-Desormeaux et al. 2022). Particular attention is warranted towards the red-eared slider (*Trachemys scripta elegans*) a freshwater turtle species native to the south-central United States. At present, *T. s. elegans* is recognized as the most commonly introduced freshwater turtle worldwide (García-Díaz et al. 2017; Seebens et al. 2017) and has been listed by the International Union for Conservation of Nature (IUCN) as one of the "world's worst invasive species" (Lowe et al. 2000). Given *T. s. elegans* ubiquitousness, investigating current management actions where the species has successfully invaded novel environments is paramount to be able to effectively inform both conservation of native freshwater turtles where sympatry occurs and invasive species management for the species.

The introduction of *T. s. elegans* outside their native geographic range is due to human-mediated pet releases into novel environments. The turtle then successfully fills niches where many native turtle populations are declining (Dupuis-Desormeaux et al. 2022). Previous studies have shown the several ecological advantages *T. s. elegans* can have over freshwater turtles globally such as greater tolerance for human activity (Lamber et al. 2013), broader thermal tolerance (Rödder et al. 2009; Heidy Kikillus et al. 2010; Masin et al. 2014), thermoregulatory advantages (Costa 2014; Polo-Cavia et al. 2008), and superior feeding kinematics (Nishizawa et al. 2014). Further, *T. s. elegans* life history traits have evolved to reach sexual maturity earlier, have greater fecundity, and higher annual oviposition than most freshwater turtles (Gibbons 1990; Pleguezuelos 2002). These factors yield *T. s. elegans* as a strong competitor where sympatry with other species of freshwater turtles occurs.

Several studies including both field and controlled experiments have reported the effects of introduced *T. s. elegans* on native turtle populations. For example, competition for key ecological resources such as basking habitat (Cadi & Joly 2003; Polo-Cavia et al. 2010; Lambert et al. 2018; Lambert et al.

2019), and food resources (Pearson et al. 2015) may lead to both the decline in fitness and increased mortality of native freshwater turtles (Cadi & Joly 2004). Additionally, there is growing concern amongst conservation biologists as previous studies have documented pathogenic prevalence (Silbernagel et al. 2014; Hidalgo Vila et al. 2009), host transmission (He´ritier et al 2017; Brenes et al. 2014), parasitic outbreaks, and spillover effects (Iglesias et al. 2015), where sympatry occurs between introduced *T. s. elegans* and native freshwater turtles. These factors likely contribute to the global decline in freshwater turtle populations (Standford et al. 2020).

In the Pacific Northwest (PNW) there are two native freshwater turtles, the western painted turtle (*Chrysemys picta bellii*) and the northwestern pond turtle (*Actinemys marmorata*). In Oregon, both *C. p. bellii* and *A. marmorata* are classified as "Sensitive-Critical" on Oregon's State Sensitive Species List (ODFW 2021) and are identified Species of Greatest Conservation Need (SGCN) in the State Wildlife Action Plan, also known as the Oregon Conservation Strategy (OCS) (ODFW 2016). Concern about the decline and future of *A. marmorata* throughout its range motivated a listing petition under the federal Endangered Species Act (ESA) of 1973, as amended in 2012. In 2015 the U.S. Fish and Wildlife Service (USFWS) concluded that listing of the species may be warranted. After conducting a species status assessment, the USFWS announced on September 30, 2023, their proposal to list *A. marmorata* as "threatened" under the ESA. In Washington State, *A. marmorata* has been listed as an endangered species under State ESA since 1993 (Hays et al. 1999).

Introduced *T. s. elegans* breeding populations have been well established in Oregon and pose a significant threat to Oregon's native freshwater turtle species. Oregon is just one of two states in the United States that have enacted regulation outlawing the possession, release, sale, and purchase of *T. s. elegans*. The Oregon Department of Fish and Wildlife (ODFW) considers the control or eradication of invasive turtle species (e.g., *T. s. elegans*, *Chelydra serpentina* and others) in the OCS as a conservation goal and Best Management Practice (BMP) for conserving Oregon's native freshwater turtle species (ODFW 2015). Further, an interagency management effort in Oregon has implemented invasive species control regimes for invasive turtle species which involves trapping using baited traps followed by humane euthanasia.

Invasive species management strategies can be diverse in their methodologies and their success can vary widely across taxa. Trapping is one of the most advocated and successful management practices for removing invasive species (Muller & Schwarzkopf 2017; Nogales et al. 2004; El-sayed et al. 2006) because traps operate for long periods, commonly use attractants that improve removal rates (Alam and Hasanuzzaman 2016) and have lower non-target risks than biocontrol agents. Methods to control or eradicate invasive species using trapping methods have been well documented across taxa including insects (Leza et al. 2021), invertebrates (Hein et al. 2006; Hein et al. 2007; Duncombe & Therriault 2017), amphibians (Muller and Shwartzkopf 2018; Kamoroff et al. 2020), and fish (Gaeta et al. 2015; Knapp & Meathews 1998). Yet, the response of invasive species populations to removal does not always produce the desired results. For example, Nishibori et al. 2023 performed a long-term removal study for *T. s. elegans* using trapping and muddling methods to examine the potential for reduction in annual catch rate by continuous removal. They found the annual catch rate did not decrease over the extent of the study and only a minimal effect on population growth was observed. Moreover, a decline in annual catch rate was only detected when the trapping efforts were conducted in a drained reservoir, which is a method that poses many management implications and is not always feasible. For some other taxa, trapping has even been shown to increase population size due to juveniles being released from conspecific predation or competition (Zipkin et al. 2009; Grosholz et al. 2021), and similar overcompensatory response is possible for *T. s. elegans.* Studies that have examined the effects of population removal for *T. s. elegans* are still limited and the existing studies focus on interspecies competition (Lambert et al. 2018; Lambert et al. 2019; Costa

2014; Pearson et al. 2015). Further, no studies have investigated the response of native turtle abundance to the removal of *T. s. elegans*, resulting in a paucity of information to guide management for these species.

Here, we hypothesized that when *T. s. elegans* are removed, *C. p. bellii* populations will respond with increased population size and increased mass, and *T. s. elegans* population size will decrease with removal. We used mark-recapture and removal data for sympatric populations of *T. s. elegans* and *C. p. bellii*, to examine the effects of trapping and removal of *T. s. elegans*. Population models were created to infer abundance estimates for both species populations at two sites to answer the following questions (1) Do current management actions for *T. s. elegans* decrease the species abundance (2) What is the response of *C. p. bellii* populations to *T. s. elegans* removal? In short, the overarching goal for this study is to help inform current invasive species management for *T. s. elegans*, and current management strategies at sites where sympatry of *T. s. elegans* and *C. p. bellii* occurs.

Methods

This study used multi-year mark-recapture datasets for *C. p. bellii* and removal datasets for *T. s. elegans* provided by ODFW and Laura Guderyahn Earth, Environment and Society PhD student at Portland State University.

Study Sites

Guderyahn for their dissertation performed comprehensive surveys throughout the Willamette watershed to assess the demographics and health of Oregon turtle populations. They provided a mark-recapture dataset for Smith and Bybee Wetlands Natural Area where they collected biometric data for *C. p. belli* and *T. s. elegans* to be analyzed for the present study. The Smith and Bybee Wetlands Natural Area is one of the largest protected urban wetlands in the United States at approximately 800 hectares (Figure 1A). The preserve is located in North Portland, Oregon near the confluence of the Columbia and Willamette rivers. The site is managed by Metro, the regional governing authority for the greater Portland Metropolitan Area. In 2003, Metro replaced an earthen dam with a new water control structure at Smith and Bybee Lakes and now manages the landscape to mimic historic hydrology, restoring the network of wetlands within the slough (Jenkins et al. 2008). This site is considered a Priority Turtle Conservation Area that may support the largest population of *C. p. belli* in the state of Oregon.

ODFW performed mark-recapture at Peninsula Drainage Canal as part of a larger effort to monitor *C. p. bellii* populations within the Willamette Valley Ecoregion. Peninsula Drainage Canal is in Northeast Portland, Oregon in the Columbia Slough Watershed (Figure 1B) and is a part of the Portland Metro levee system managed by Multnomah County Drainage Districts. Peninsula Drainage Canal is considered a closed system that is not hydraulically connected to the Columbia River, Lower Columbia Slough, or the interior drainage systems and receives only inputs from rainfall. Peninsula Drainage Canal is approximately 1.5 km in length and 7.86 ha in surface area. In the surrounding landscape there are two golf clubs and mixed agricultural, industrial, and residential areas. This site is designated as a Special Habitat Area by the City of Portland as it likely supports the second largest population of *C. p. bellii* in the city.

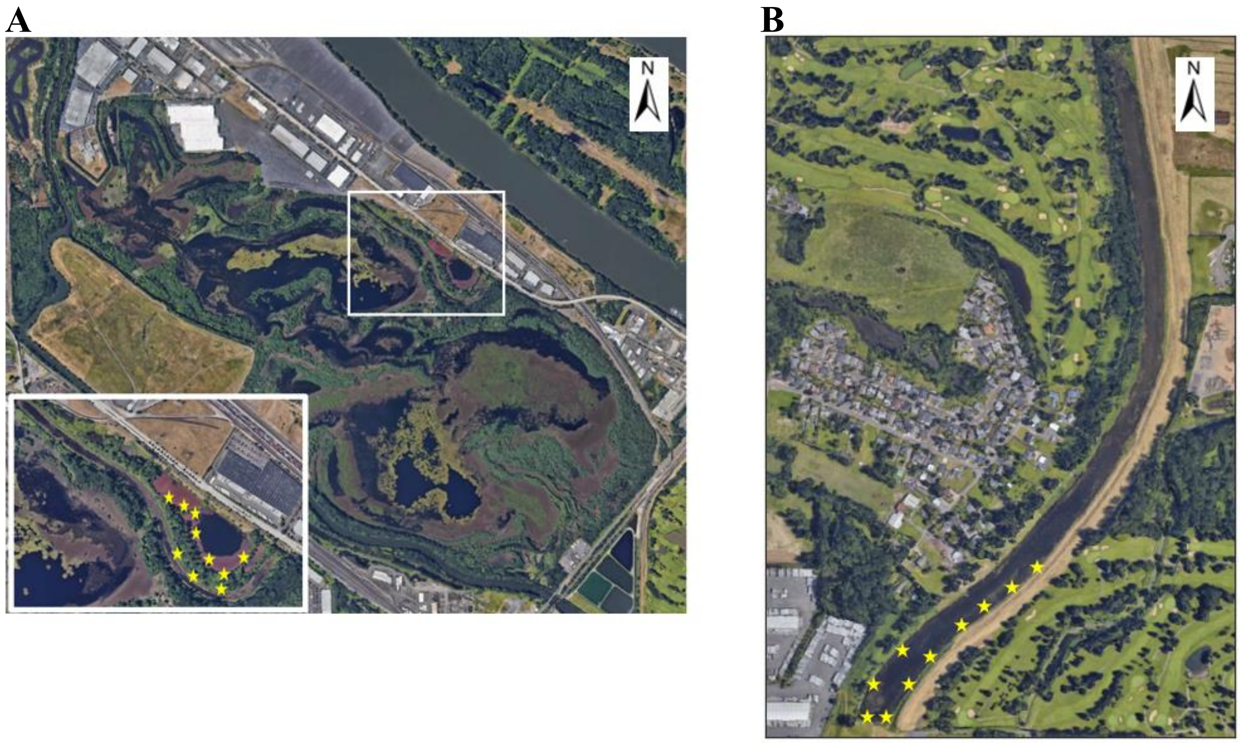

Figure 1. Study sites in Portland, Oregon (A) Smith and Bybee Wetlands Natural Area (lat 45°37’N; long 122°45’W) (B) Peninsula Drainage Canal (lat 45°35'N; long 122°38'W). Yellow stars represent trap locations (Maps prepared used ArcGIS pro 3.1.2).

Mark-Recapture

ODFW deployed submersible hoop, opera, and minnow traps, baited with canned sardines. The number of traps and the trap types varied by trap occasion. ODFW selected trap sites based on a preliminary visual survey, during which they determined the areas being actively used by turtles within the canal. ODFW trapped a total of 8 trap nights from 24 May-2016 to 22 September-2016, 3 trap nights in June-2018, 2 trap nights in July-2019, and 6 trap nights from 30 July-2020 to 11 September-2020. Guderyahn deployed submersible funnel traps of various sizes, baited with either canned sardines or canned wet cat food. The same number and types of traps were placed in the same locations during each trapping event. Their study was performed in a subarea in the northeastern part of the Smith and Bybee Wetlands Natural Area that was accessible by foot and is located near the Smith and Bybee Wetlands Natural Area public parking lot. Guderyahn trapped a total of 12 trap nights from 21 June-2021 to 9 July-2021, 12 trap nights from 27 September-2021 to 15 October-2021, 12 trap nights from 3 May-22 to 21 May-22, and 12 trap nights from 5 October-2022 to 23 October-2022. For both ODFW and Guderyahn’s study, all traps were rebaited approximately every 24 hrs. All captured *C. p. bellii* were processed in the field and released to their points of capture on the same day. All captured *T. s. elegans* were processed and then transferred to ODFW to be humanely euthanized in accordance with agency policy. All captured *C. p. bellii* > 80 mm carapace length were provided with a unique notch identification number using a handheld metal file following the Holland (1994) system. Shell measurements of carapace length and plastron length were taken with dial calipers to the nearest 0.1mm. Body mass was measured using an Ohaus Scout Balance scale to the nearest gram. Sex for adult turtles was determined by visually assessing secondary sexual characteristics. Age class was delineated using carapace length, where turtles reach sexual maturity at ≥ 100 mm carapace length (Holland 1991).

Population Estimation

We used trap event which was the total cumulative trap days per trap session. Each trap event occurred over 4 days for Guderyahn's study, and 1-3 days for the ODFW study, respectively. Trap events were pooled for each year to calculate population estimates, because population-based estimates can be more robust and accurate when pooling data for multiple sample events as it increases sample size (Nicola et al. 1999) as opposed to calculating population estimates for each trap event. Population estimates for *C. p. bellii* were calculated using the Schnabel Mark-Recapture method with the Chapman correction for small sample sizes for years when more than two trap events occurred (R package 'FSA', function 'mrClosed', method 'Schnabel'; Schnabel, 1938; Spinks et al. 2003). In 2020 at Peninsula Drainage Canal there were only two trap events, and for this reason we had to use the Lincoln-Petersen method with the Chapman correction for small sample size to infer population estimates for *C. p. bellii* for this year (R package 'FSA,' function 'mrClosed', method 'Petersen') (Lincoln 1930; Ogle 2016).

The Leslie-depletion method was used to calculate the population size for *T. s. elegans* (R package 'FSA', function 'depletion', method 'Leslie') (Ogle 2016; Rose et al. 2013) when the catchability coefficient (q) was ≥ 2. In 2016 at Peninsula Drainage Canal, we used the DeLury method to estimate the population size for *T. s. elegans* because q was < 2, violating the assumptions of the Leslie-depletion method. The Leslie-depletion method creates a model that regresses the catch per unit effort (CPUE; number of individuals captured per trap-night) against the cumulative number of individuals captured. The Delury method regresses CPUE against cumulative effort (Delury 1947). As CPUE declines with the cumulative number of individuals caught or cumulative effort, a regression can be used to estimate the initial population size (Leslie & Davis 1939; Delury 1947).

Turtle Relative Abundance

To show the effects of removing *T. s. elegans* on the turtle community composition at Peninsula Drainage Canal we used a general linear mixed effects model (R package 'lme4', function 'glmer'). Our model regressed the proportion of *C. p. belli* to *T. s. elegans* against the number of *T. s. elegans* removed in each year with year as a random effect.

C. p. bellii Body Condition

To examine the physical response of *C. p. bellii* to the continuous removal of *T. s. elegans* we used linear models (R package 'lme4', function 'lm'; Lambert et al. 2019) to show the annual change in the total adult *C. p. bellii* population body condition. Our linear model regressed body mass against plastron length. We also incorporated year and sex as fixed effects in our model. This model tested the difference in the residuals between study year and sex (Lambert et al. 2019). We assessed the significance ($\alpha < 0.05$) of each fixed effect in our model using likelihood ratio tests to test whether our more complex model was significantly better than the simpler model (Lambert et al. 2019). Non-significant fixed effects were not incorporated in our model to increase power to detect differences in the variables with stronger effects.

Results

Mark Recapture and Removal Sampling

A total of 108 unique *C. p. bellii* and 74 *T. s. elegans* were captured at Peninsula Drainage Canal in 2016, 2018, 2019, and 2020 (Table 1 & 2). Out of the 107 *C. p. belli* captured, 27 individuals were recaptured. *C. p. bellii* recaptures occurred almost exclusively within the same trap event, with only 2 turtles recaptured in a later trap event during the same year.

At Smith and Bybee, a total of 64 unique *C. p. belli* and 53 *T. s. elegans* were captured between 2021-2022. Out of the 64 *C. p. bellii* captured, 7 individuals were recaptured. Similar to what occurred at Peninsula Drainage Canal, *C. p. bellii* recaptures occurred almost exclusively within the same trap event and only 3 turtles were recaptured in 2022.

Table 1. Site, species, mean carapace length, juvenile:adult ratios, and total number of turtles captured and recaptured in 2016, 2018-2020

Site	Year	Species	Total Captures	Total Recaptures	Mean Carapace (mm)	Juvenile:Adult
Peninsula Drainage Canal	2016	*C. picta bellii*	25	0	167	0.04
Peninsula Drainage Canal	2018	*C. picta bellii*	21	9	141	0.24
Peninsula Drainage Canal	2019	*C. picta bellii*	2	2	136	0.50
Peninsula Drainage Canal	2020	*C. picta bellii*	86	16	199	0.01
Smith and Bybee	2021	*C. picta bellii*	14	0	158	0.09
Smith and Bybee	2022	*C. picta bellii*	27	7	168	0.02

Table 2. Site, year, species, mean carapace length, juvenile:adult ratios, and total number of turtles captured and recaptured

Site	Year	Species	Total Captures	Mean Carapace (mm)	Juvenile:Adult
Peninsula Drainage Canal	2016	*T. scripta elegans*	20	198	0.05
Peninsula Drainage Canal	2018	*T. scripta elegans*	12	199	0.00
Peninsula Drainage Canal	2019	*T. scripta elegans*	8	190	0.00
Peninsula Drainage Canal	2020	*T. scripta elegans*	34	183	0.08
Smith and Bybee	2021	*T. scripta elegans*	26	188	0.04
Smith and Bybee	2022	*T. scripta elegans*	27	186	0.00

Population Estimates

The estimated population size of *C. p. bellii* decreased from 2016-2020 with wide confidence intervals in Peninsula Drainage Canal and increased substantially in Smith and Bybee (Table 3). At Peninsula Drainage Canal the Schnabel method estimated *C. p. bellii* population size was 178 turtles (95% confidence interval [CI] 38-178) in 2016, and the Lincoln-Petersen method estimated 141 ([CI] 130-208) in 2020. Our population estimate in 2016 was the upper confidence limit due to zero recaptured turtles which led our model to assume a large population. At Smith and Bybee the Schnabel method estimated *C. p. bellii* population size was 17 turtles ([CI] 11-40) in 2021, and 135 turtles ([CI] 83-234) in 2022.

The estimated population size of *T. s. elegans* increased from 2021- 2022 with wide confidence intervals (Table 3), despite continuous removal of the species. At Peninsula Drainage Canal the DeLury method estimated *T. s. elegans* population size was 20 ([CI] 20-138, $R^2 = 0.66$, $q = 0.03$) in 2016. CPUE declined as cumulative effort increased, but the model did not exhibit a significantly negative slope ($p > 0.05$; Figure 2) so we cannot conclude that trapping and removal resulted in a reduction in the number of

T. s. elegans at this site. Further, we were unable to calculate population estimates for *T. s. elegans* at Peninsula Drainage Canal in 2018, 2019, and 2020 due to the requirements for removal methods not being met (i.e., < 2 trap events). At Smith and Bybee the Leslie-depletion method estimated *T. s. elegans* population size was 27 turtles ([CI] 26-123, $R^2 = 0.09$, q = 0.03) in 2021, and 43 turtles ([CI] 27-88, $R^2 = 0.44$, q = 0.02) in 2022 (Table 4). Though CPUE declined as cumulative catch increased, we cannot conclude that the trapping resulted in a reduction in the number of *T. s. elegans* at this site in either year trapping was performed ($p > 0.05$; Figure 3 & 4).

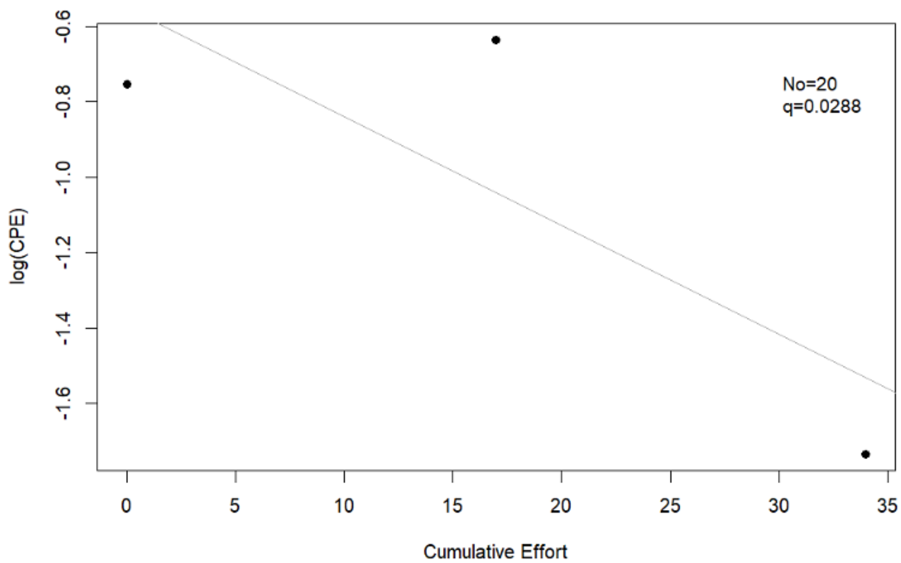

Figure 2. 2016 Peninsula Drainage Canal DeLury model for *T. s. elegans* ($R^2 = .66$, q = 0.03, $p > 0.05$).

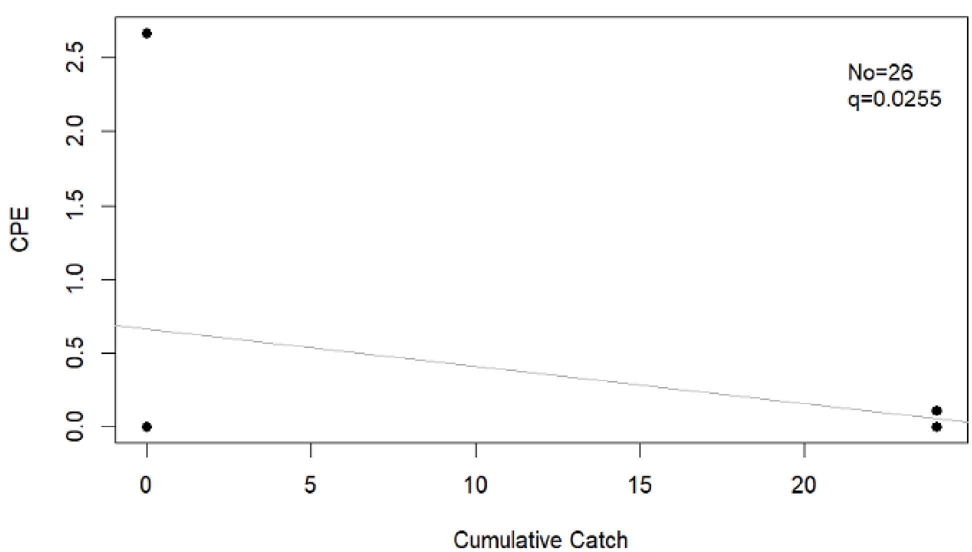

Figure 3. 2021 Smith and Bybee Leslie-depletion model for *T. s. elegans* ($R^2 = .09$, q = 0.03, $p > 0.05$).

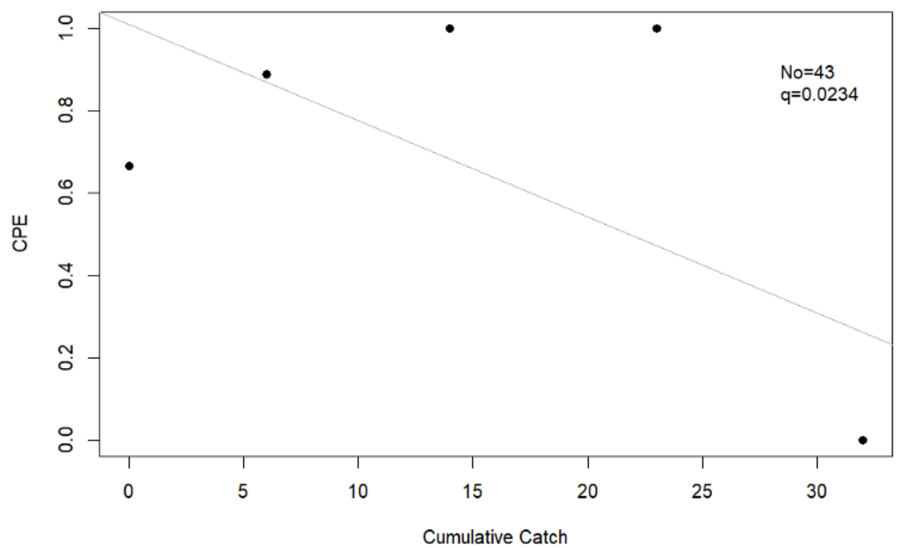

Figure 4. 2022 Smith and Bybee Leslie-depletion model for *T. s. elegans* (R^2 = .44, q = 0.023, p > 0.05)

Table 3. Population estimates for C. picta bellii at two sites in Portland, Oregon

Site	Year	Estimation Method	Population Estimate
Peninsula Drainage Canal	2016	Schnabel	178 (CI: 38,178)
Peninsula Drainage Canal	2020	Lincoln-Peterson	141 (CI: 130,208)
Smith and Bybee	2021	Schnabel	17 (CI: 14, 40)
Smith and Bybee	2022	Schnabel	135 (CI: 83,234)

Population estimates were derived using FSA software.

Table 4. Population estimates for T. scripta elegans at two sites in Portland, Oregon

Site	Year	Estimation Method	Population Estimate
Peninsula Drainage Canal	2016	DeLury	20 (CI: 20, 138)
Smith and Bybee	2021	Leslie-depletion	27 (CI: 26, 123)
Smith and Bybee	2022	Leslie-depletion	43 (CI: 27, 88)

Population estimates were derived using FSA software.

Turtle Relative Abundance

The general linear mixed effects model of the turtle community showed there was moderate evidence that continuous *T. s. elegans* removal affected the turtle community composition (GLM: z = 1.57, p = 0.12). Generally, there was an increasing trend of the proportion of *C. p. bellii* to *T. s. elegans* relative abundance from 2016-2020, with a greater proportion of *C. p. bellii* within the turtle community with continuous *T. s. elegans* removal (Figure 5). However, this trend was not consistent among years due to 2019 being a low capture year with only 2 *C. p. bellii* and 11 *T. s. elegans* captured.

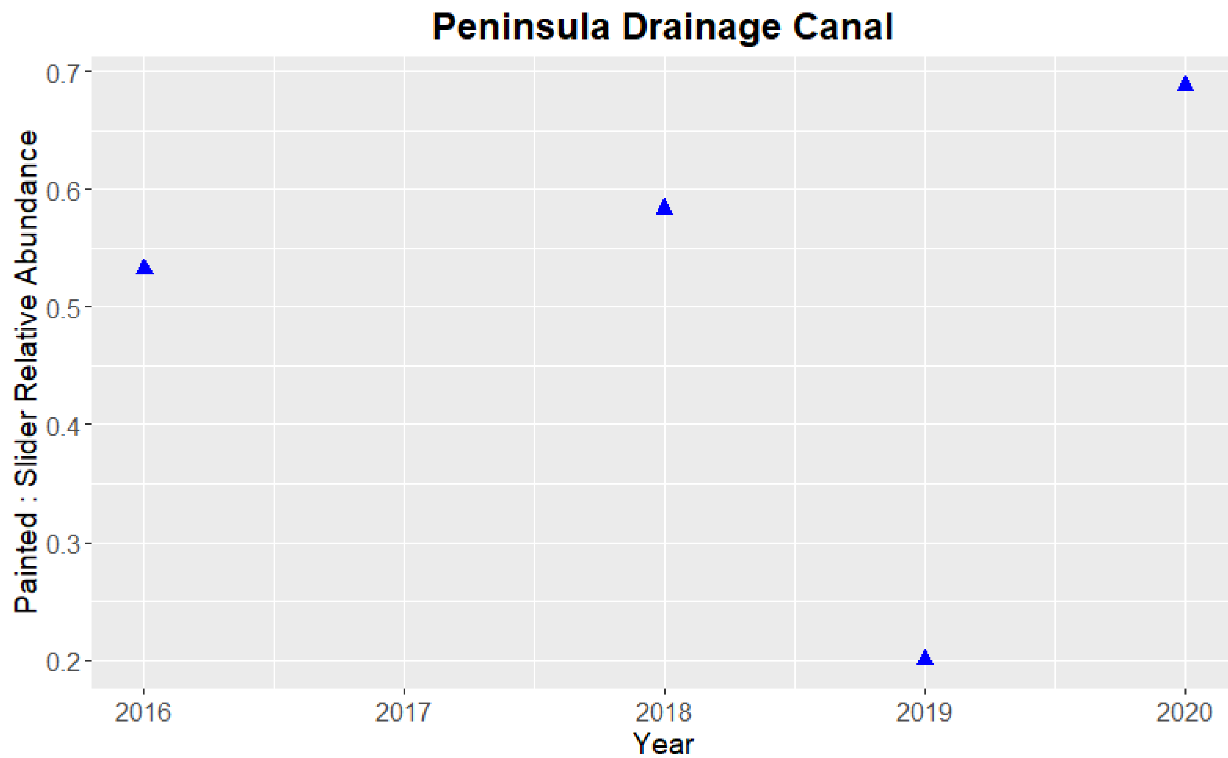

Figure 5. Change in the turtle community composition shown as the relative abundance of *C. p. bellii* (Painted) to *T. s. elegans* (Slider) regressed against the number of *T. s. elegans* removed. Generally, there is more *C. p. bellii* within the turtle community with continuous *T. s. elegans* removal, apart from 2019.

C. p. bellii Body Condition

In our linear regression model, we used the total adult population body condition because we had few unique turtles recaptured in subsequent years at either site. We used year as our "treatment" to represent the effects of continuous *T. s. elegans* removal on *C. p. bellii* body condition. At Smith and Bybee our model showed there was moderate evidence that year had a significant effect in our model ($p = 0.07$; Figure 6A). Plastron length ($p < 0.001$) and sex ($p < 0.001$) had a significant effect in our model ($R^2 = 0.95$). The average mass for female *C. p. bellii* in 2021 (774.00 g ± 473.18 SD) and 2022 (874.06 g ± 314.63 SD) was greater than male *C. p. bellii* in 2021 (505.33 g ± 191.21 SD) and 2022 (506.89 g ± 169.65 SD). There were no reported gravid female turtles in any year of Guderyahn's study. The difference in body mass between female and male turtles is expected as this freshwater emydid turtle is sexually dimorphic, where female turtles are typically larger than males (Rowe 1997; Ernst et al. 1994). At Peninsula Drainage Canal, year ($p = 0.008$) and plastron length ($p < 0.001$) had a significant effect in our model ($R^2 = 0.92$; Figure 6B). Sex did not have a significant effect ($p = 0.14$) and was not incorporated in our model. There was no detectable difference in the average body condition with respect to plastron length for *C. p. bellii* with continuous *T. s. elegans* removal at Smith and Bybee (56.87 g ± 47.83 SD), or Peninsula Drainage Canal (39.72 g ± 31.32), respectively.

A

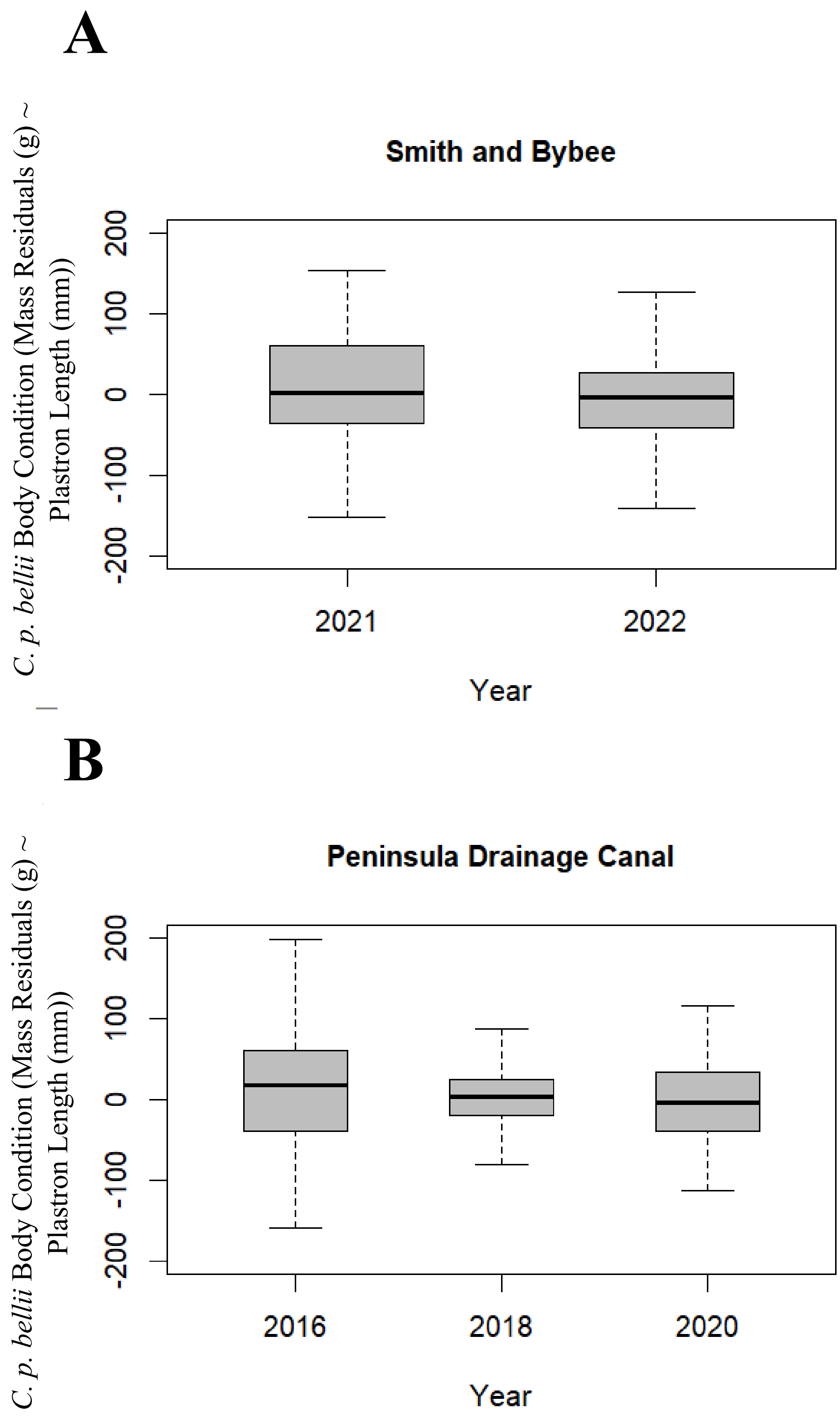

Figure 6. Change in overall adult *C. p. bellii* body condition with continuous *T. s. elegans* removal overtime at (A) Smith and Bybee (B) Peninsula Drainage Canal. Body condition is represented by the residuals of mass (g) regressed against plastron length (mm).

Discussion

Controlling T. s. elegans populations

This study attempted to answer several questions imperative to management and conservation of native and introduced freshwater turtles by investigating the potential for removal as a control method for *T. s. elegans,* and the response of *C. p. bellii*. To our knowledge, our study is the first to examine the effects of the introduction of *T. s. elegans* on native *C. p. bellii*. The population estimates calculated in this study may be unreliable due to low sample size and should be considered rough approximations. Our results suggest that *T. s. elegans* populations may respond to management actions (e.g., trapping and removal) with compensatory population growth. Here, we posit two possible explanations.

(1) *T. s. elegans* may respond to removal by a process known as the "hydra effect," named after the mythical multi-headed serpent that can grow two heads for each head removed. This outcome is driven by overcompensation, the process that refers to a population's ability to increase in response to mortality (Grosholz et al. 2021; Abrams & Matsuda 2005). This phenomenon typically will cause a rapid increase in a stage-specific density in the population (Grosholz et al. 2021). In our study, there were few juveniles, and zero hatchlings captured at either site reducing the likelihood that the results were driven by the hydra effect in this population. We believe that the adult skew we found in the population could either be due to low recruitment for this species because of poor egg hatching success at Smith and Bybee (Lloyd & Warner 2019), or there could be significant trap bias by age-class misrepresenting the juvenile:adult ratios. The number of turtles captured in specific age-classes can vary by trap type often biasing population demographics (Tesche and Hodges 2015). Additionally, hatchlings are notoriously difficult to capture (Tesche and Hodges 2015; Mazerolle et al. 2007; Pike et al. 2008; Ream and Ream, 1996). It is likely that these age-classes were able to elude capture merely because of the trap types that were used or because these age-classes were not using the areas where traps were present. It will be important for management to incorporate methods that will increase the capture probabilities for hatchling and juvenile turtles to be able to accurately estimate population demographics and detect the potential of this species to overcompensate in response to removal.

(2) At Smith and Bybee we suspect the subarea where *T. s. elegans* were removed was not a closed population, which would violate the assumptions of removal methods for population-based inference. As management continued to remove individuals, the change in turtle density may have caused turtles inhabiting other subareas within Smith and Bybee to immigrate into the newly less populated area. *T. s. elegans* will invade and repopulate an area that has been harvested in a relatively short period (Mali et al. 2016). Further, *T. s. elegans* have been shown to shift their spatial distribution away from removal sites to other areas with suitable habitat in response to removing conspecifics from the turtle community (Lambert et al. 2019). There may have been habitat connectivity between the nearby ponds at Smith and Bybee, and *T. s. elegans* individuals responded to removal by invading the newly depopulated area.

The results from the present study can provide insight into the effects of current management on introduced *T. s. elegans* populations. However, there is still the need for further research on this topic to be able to effectively inform management for this species. We suggest future studies use a Before-After-Control-Impact (BACI) design to investigate the potential for removal as a control method for this species.

C. p. bellii Response

We investigated how *C. p. bellii* may respond to the removal of *T. s. elegans* by looking at two response variables. First, we inferred population estimates and assessed how the population changed with continuous *T. s. elegans* removal. At Smith and Bybee the C. *p. bellii* population size may have grown in response to *T. s. elegans* removal. The mark-recapture at Smith and Bybee was a short-term study, and it is unlikely that we would have been able to capture recruitment within this timeframe, as *C. p. bellii* can take on average four to six years to reach the adult life stage (Gibbons 1968). Smith and Bybee is a highly connected wetland complex, as previously mentioned the subarea that was sampled at this site was likely not a closed population. Out of the 60 *C. p. bellii* individuals captured in 2022, only 3 of those turtles were recaptures from the previous sampling year. This implies that *C. p. bellii* may have responded to the removal of *T. s. elegans* by immigrating from other areas in the wetland complex as more turtles were removed, or to a naturally occurring shift in the resource quality gradient (Roe et al. 2009), or a combination of the two. Native freshwater turtles avoid using habitat with chemical stimuli of *T. s. elegans* (Polo-Cavia et al. 2009) and may change their basking behavior when *T. s. elegans* individuals are removed from the population (Lambert et al. 2018; Lambert et al. 2019). We propose that removing *T. s. elegans* can support *C. p. bellii* by increasing availability to critical resource patches (Roe et al. 2009) that may not otherwise be used by the species due to interspecific competition with *T. s. elegans*, or ecological pressures felt by high turtle densities (Lambert et al. 2019). However, at Peninsula Drainage Canal we cannot confidently conclude how *C. p. bellii* responded to *T. s. elegans* removal at the population level. Though the population estimate decreased from 2016 to 2020, the 95% confidence interval increased. Therefore, we were unable to detect any change for the *C. p. bellii* population at this site.

For our second response variable, we examined the change in *C. p. bellii* population body condition for adult turtles over time and with continuous *T. s. elegans* removal. There was no detectable difference in *C. p. bellii* body condition at either site with continuous removal of *T. s. elegans*. Our results vary from the findings of Lambert et al. 2019 who conducted an in-situ mesocosm experiment in California to assess the effects of *T. s. elegans* removal on adult *C. p. bellii* body condition using unique turtles. They found that removing *T. s. elegans* from the UCD Arboretum waterway improved *C. p. bellii* body condition as it likely relieved behavioral and ecological pressures in sites with high turtle densities (Lambert et al. 2019). The minimal change in body condition in our study may be because *T. s. elegans* densities at our sites were not large enough to exert such pressures, there was greater resource availability relative to the turtle population, or the dietary niche overlap for *T. s. elegans* and *C. p. bellii* is modest. We suggest future studies examine the potential effects of introduced *T. s. elegans* sympatry on native freshwater turtle condition and stress in sites with high versus low turtle densities. Further, investigating dietary habits for *C. p. bellii* and *T. s. elegans* and evaluating the degree of niche overlap may reveal food preference for both species. This information can help wildlife agencies manage habitat to ensure the perpetuity of nutritional resources for native turtles.

Shift in Community Composition

We measured the change in turtle relative abundance over time with continuous *T. s. elegans* removal. The data suggest that current management actions may have changed the relative abundance of species within the turtle community to support higher numbers of native *C. p. bellii* relative to introduced *T. s. elegans*, and by decreasing turtle densities. We propose that controlling introduced *T. s. elegans* populations by trapping and removing individuals may support *C. p. bellii* populations simply through the release of pressure from a novel competitor, or a reduction in turtle densities. However, the effects of removing *T. s. elegans* on *C. p. bellii* remains unresolved and warrants further research. We suggest future studies investigate axes of competition for *T. s. elegans* and *C. p. bellii* (e.g., basking sites, and nesting habitat), and the potential influence of *T. s. elegans* on *C. p. bellii* distribution and habitat use.

Recommendations for Management

Turtles are reported as one of the most endangered vertebrate taxa on the planet (Rhodin et al. 2018), with nearly one-half of all turtles worldwide considered to be threatened by the IUCN (Araya-Donoso et al. 2022; Stanford et al. 2020). Here in the western United States, the western pond turtle is currently being reviewed to be listed as threatened under the ESA throughout its home range. Events like the proposed listing of the western pond turtle stress the importance of developing methods for wildlife managers and conservation scientists to collect reliable data that can be used to infer changes in population size and structure. Here, we recommend several ways in which management can improve mark-recapture study design to advance population monitoring programs for freshwater turtles by reviewing the available mark-recapture literature, and lessons learned from the present study.

In sites like Smith and Bybee where inter-wetland connectivity is likely high, the entire wetland complex should represent the minimum population unit to meet the closed population assumption for population-based analyses. We suggest traps be set throughout the entire wetland complex when feasible because freshwater turtles can exhibit relatively high inter-pond migration in response to changes in resource quality gradients (Roe et al. 2009) or when seeking a mate. Further, we advise that trap placement may be an important consideration to minimize trap avoidance behavior. Sufficiently dispersing traps throughout a site should be incorporated into the protocol for mark-recapture to minimize the effects of avoidant behavior, changes in habitat use and movement on capture success. Site selection for trap placement can be determined by performing preliminary surveys that reveal which areas have the highest activity or by conducting pilot studies to maximize the number of individuals captured.

Several studies have reported mark-recapture methods to improve CPUE and recapture per unit effort for freshwater turtles. Freshwater turtles have shown learned avoidance of traps (Hollender et al 2024). To account for this behavior implementing periodic trap relocation can be effective at increasing the number of individuals captured and recaptured (Hollender et al. 2022). To maintain high capture rates, switching bait type (Mali et al. 2012; Mali et al. 2014), and using fresh bait daily (Bluett et al. 2011; Mali et al. 2014) can increase capture success for long-term monitoring campaigns. Larger mouth-openings (6.5-12 cm) for hoop nets have been shown to have higher capture success than the preset tight mouth-opening for new traps, and these modifications did not introduce bias for escape probabilities (Mali et al. 2014). To maximize capture for all life-stages, adequately assess population demographics (e.g., sex/age ratios), and reduce sampling bias, investigators recommend using a mixed sampling methodology using multiple trap types when feasible (Tesche & Hodges 2015; Gamble et al. 2006; Mali et al. 2012; Koper and Brooks 1998; Ream and Ream 1966). It may also be important to consider how each life-stage may use different habitat and how this may affect capture success, specifically for hatchling and juvenile turtles.

Much more data is needed to be able to assess demographics of both native and invasive freshwater turtles in Oregon to confidently modify management and conservation objectives and approaches to support viable populations of native freshwater turtles into the future. We recommend a regular annual sampling schedule. We suggest management samples for a minimum of three years at a site in order to detect change in population demographics and produce data that will be able to inform site-specific management. We recommend the use of an adaptive management approach to assess which methods (e.g., trap type, bait type, trap depth, trap relocation) produce the highest capture and recapture success. Moreover, collecting data on covariates (e.g., temperature, habitat characteristics, time of year) concurrently to sampling can help inform methodology to maximize capture and recapture success, and ecological theory for Pacific Northwest freshwater turtles.

For usable population estimates, it is vital that sampling duration or frequency be contingent on the number of turtles captured and recaptured. The proportion of recaptures needed for accurate estimations varies with population size and low population sizes require more intensive trapping efforts. However, a rough guideline is that 10% of captures need to be recaptured at later trap events for tight enough confidence intervals to be used for management decisions. Further, we suggest using water year (October 1 – September 30) as opposed to calendar year (January 1- December 31) when calculating population size. Mark-recapture and removal methods for calculating population estimates assume a closed population. This novel approach considers freshwater turtle life histories traits such as breeding and hatchling emergence phenology. For this reason, water year may better meet the closed population assumption and therefore produce more reliable population-based estimates. See appendix Table A1 for more specific capture recommendations for population-based analyses for estimating populations using mark-recapture and removal methods for closed populations. We advise management when developing sampling plans to consider the parameters of the available demographic analyses to be able to produce reliable demographic estimates. We also provided the R script that were used in this study to calculate population estimates and perform body condition and community composition analyses so that management can apply these methods to future datasets.

Finally, community science can be an effective strategy to advance scientific research for wildlife through the contribution of critical data at the temporal and spatial scale that otherwise would not be feasible for professional researchers (Sun et al. 2021; Shirk et al. 2012). Investing in community science initiatives will grow management's capacity and support long-term sampling and data collection that will benefit conservation and management of freshwater turtle populations sustainably into the future.

Appendix

Table A1. Population Estimation Methods for Closed Populations

Method	Citation	No. of trap days/events	Assumptions	Estimation Failure	R Script Resource
Mark-Recapture					
Schnabel	Schnabel 1938	This method requires atleast 3 capture days/events	(1) Marks to identify individuals are not destoryed or lost (2) Returned individuals mix randomly with the unmarked population (3) Individuals have equal probability of being captured (4) Behavior is unaffected by marking or tagging process	You must have (1) Atleast 3 capture days/events (2) Enough individuals captured and recaptured to produce reliable population estimates	Ogle 2018
Schumacher-Eschmeyer	Schumacher & Eschmeyer 1943	This method requires atleast 3 capture days/events	Same as Schnabel Method	Same as Schabel Method	Ogle 2018
Lincoln-Petersen	Lincoln 1930	This method requires a single recapture	Same as Schnabel Method	You must have (1) Atleast 2 capture days/events (2) Enough individuals captured and recaptured to produce reliable population estimates	Ogle 2018
Log-Linear Model	Otis et al. 1978	This method requires atleast 3 capture days/events	This method is used when the capture probability within each sampling event is not met. Unique model that allows for four types of capture probabilities. (1) M_0 = no heterogeneity in capture probability (2) M_t = Capture probability varies form one sampling event to the next, but it is the same for each individual for any sampling event (3) M_b = Capture probability varies due to the affects of an individual being capture in a previous sampling occasion (4) M_h = Capture probabilites are not equal among individuals (5) M_{th} = Capture proability varies across sampling events and among individuals. The Akaike's Information Criterion (AIC) is then used to assess the best fitting model to your dataset	Same as Schnabel Method	Ogle 2018
Removal Sampling					
Leslie-Depletion	Leslie & Davis 1939	This method requires atleast 3 capture days/events	(1) Constant catchability over the duration of removal (2) Enough animals must be removed to substantially reduce CPUE (3) Catch removes more than 2% of the population (4) Units of effort are independent i.e., capture methods (e.g., traps) do not compete	This method will fail if less than 2% of the population is captured. The catchability coefficient, denoted as q, must be > 2%. If the catchability coefficient is less than 2%, then DeLury method is better suited for your dataset	Ogle 2013; Ogle 2018
DeLury	DeLury 1947	This method requires atleast 3 capture days/events	Same as Leslie-Depletion Method		Ogle 2013; Ogle 2018
CarleStrub (k-pass)	Carle & Strube 1978	This method requires a single recapture	(1) During all removal periods the capture probability is equal for all individuals in each removal occasion	This method will fail if the number of individuals captured on the last trap occasion is equal to or greater than the number of individuals captured on the first trap occasion	Ogle 2013; Ogle 2018

Body Condition Analysis

R Script: ..\Results\HTML\Body-Condition-Analysis.html

Community Composition Analysis

R Script: ..\Results\HTML\Community-Composition.html

Mark-recapture Population Estimate Analyses

R Script: ..\Results\HTML\Mark-Recapture.html

Removal Method Population Estimate Analyses

R Script: ..\Results\HTML\Removal-Method.html

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