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SPATIAL DISTRIBUTION AND ABUNDANCE OF COMMON SHARP-TAILED SNAKES (*CONTIA TENUIS*) ON OBSERVATORY HILL, VANCOUVER ISLAND, BRITISH COLUMBIA

CHRISTIAN ENGELSTOFT[1], KRISTIINA OVASKA[1*], LENNART SOPUCK[1], AND DAVID ROBICHAUD[2]

[1]Biolinx Environmental Research Ltd., 1759 Colburne Place, North Saanich, British Columbia, Canada V8L 5A2
[2]LGL Ltd. Environmental Research Associates, 9768 Second Street, Sidney, British Columbia, Canada V8L 3Y8

[*]Correspondence: email ke.ovaska@gmail.com

ABSTRACT: Similar to many small, secretive snakes, the natural history and population biology of Common Sharp-tailed Snakes are poorly known. Information on habitat use and patterns of abundance are particularly important for management and recovery of this species listed as endangered in Canada. We surveyed for snakes from October 2010 to March 2019 using a microhabitat-based array of 162 artificial cover-object stations. The surveys (236 array checks) resulted in 177 detections of sharp-tailed snakes, representing 106 individuals identified through pattern mapping. Body size (snout-vent length) of the snakes ranged from 82 mm to 261 mm, and most (65.1%) were adults $\geq$180 mm. The dispersion of snakes among sampling stations was aggregated over time with 42 stations used by one to 15 individuals over the course of the study, including three “hot spots” used by over ten individuals; these sites represented hibernation and possibly also egg-laying sites. Most detections were on the warmer west and south slopes of the hill and were correlated with the presence of talus but not with other habitat attributes examined. The population sampled by the array was estimated to consist of a mean of 128 snakes (6.04/ha) in 2011 and 80 (3.80/ha) in 2018 with mean annual survival rate of 52.9%. We suggest focusing survey efforts on stable talus patches with south- and west-facing aspects both to locate the species at new sites and to identify important habitats at known sites.

Key Words: Contia tenuis*; artificial cover objects; distribution; abundance; population, habitat; British Columbia*

INTRODUCTION

Common Sharp-tailed Snakes (*Contia tenuis*) are small, slender, semi-fossorial snakes patchily distributed throughout the entire northern half of their global range in Washington state and southern British Columbia. Similar to small, cryptic colubrid snakes, such as Dekay’s Brownsnakes (*Storeria dekayi*), Red-bellied Snakes (*S. occipitomaculata*), and Smooth Greensnakes (*Opheodrys vernalis*), their natural history is poorly known (Leonard and Ovaska, 1998). This is largely due to difficulties in detecting and studying them using conventional methods, including inapplicability of radio-telemetry due to their small body size. In particular, information is lacking on populations of small snakes at the northern limits of their range in Canada (Rutherford and Cairns, 2020).

In British Columbia, Common Sharp-tailed Snakes are known from disjunct populations on southeastern Vancouver Island and four smaller islands in the Strait of Georgia, and from Pemberton Valley in the southern interior of the province (Environment and Climate Change Canada [ECCC], 2020). Due to their patchy distribution, apparent rarity, and threats to their habitats from residential development and other anthropogenic factors, Common Sharp-tailed Snake was designated as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 1999, 2009), and listed as endangered under the federal *Species at Risk Act* (SARA) in 2003.

We studied the spatial distribution, movements, and patterns of abundance of sharp-tailed snakes annually from 2010 to 2018 on Observatory Hill on southern Vancouver Island. This site was selected because it provided an accessible, relatively large patch of natural habitat within altered and fragmented habitats on southeastern Vancouver Island. A better understanding of the natural history of this poorly known species is expected to help managers minimize disturbance of the snakes and their habitats and to facilitate the application of conservation measures at this and other sites across the species' northern distribution.

MATERIALS AND METHODS

Study Site

The study area was within the National Research Council's property on Observatory Hill (48.51990º N, -123.41812º W; NAD 83), located in a rural area of Saanich, within Greater Victoria, on southern Vancouver Island. The hill contains relatively undisturbed habitat, surrounded by roads, hobby farms, and residences. Most of the open and woodland habitats on the hill, totalling 73.5 ha, are designated as Critical Habitat for the species under SARA (ECCC, 2020).

Observatory Hill is within the Coastal Douglas-fir Biogeoclimatic Zone (Meidinger and Pojar, 1991; FLNROD, 2019) and is under the influence of a mild maritime climate, which may facilitate the persistence of Common Sharp-tailed Snakes at the periphery of their range in British Columbia. The steep upper reaches of the eastern, southern, and western slopes are relatively open and dry with numerous rock outcroppings and dispersed stands of Arbutus (*Arbutus menziesii*) and stunted Garry Oaks (*Quercus garryana*). The southwestern slopes were burned in the 1930s, creating seral stands of these two species. Douglas-fir (*Pseudotsuga menziesii*) forest dominates the wetter lower reaches and the northern slopes. Several large buildings and a paved road associated with the Dominion Astrophysical Observatory are located near the summit of the hill, the highest point of which is about 230 m above sea level.

Survey Methods

We used artificial cover-objects (ACOs) to survey for snakes. This method has low impact on habitat and allows for multiple searches with standardized search effort (Engelstoft and Ovaska, 2000; Dorcas and Willson, 2009). The ACOs consisted of 30 x 60 cm pieces of black UDL™ fibreglass roofing material laid flush on the ground in a semi-random, microhabitat-based pattern, as described below. We chose a microhabitat-based sampling design, because previous surveys at the site using systematic ACO placements along transects resulted in very few observations of the species.

To select survey sites, we first walked through open and woodland habitats, which were determined to provide potentially suitable habitat for sharp-tailed snakes, and mapped microhabitat features classed either as wood (decaying logs, sloughed-off bark), rock (outcrops, talus patches), or mixed wood and rock microhabitats along parallel meandering transects. We then randomly selected 50 features from this pool of 492 microhabitat features, with rock (51%), wood (37%), and mixed (12%) features represented according to their relative proportions. In addition, we included four sites where sharp-tailed snakes had been detected previously, resulting in a total of 54 sampling units, referred to as plots. Each plot consisted of three stations 10 m apart along a random azimuth centered on the selected microhabitat feature, resulting in a total of 162 stations; each station, in turn, consisted of two ACOs within ca. 1 m from each other. Prior to ACO placement, a botanist inspected the sites to minimize risk of damaging rare vascular plants, mosses, and lichens that occur on the hill. During the course of the study, we replaced any disturbed covers as detected. In areas prone to disturbance by ravens in 2018, the ACOs were protected with a piece of stucco wire laid on top of the cover-object.

The sampling area covered much of the property, but the heavily wooded northern side of the hill and an area of open bedrock on the south side were not sampled because previous surveys there over several years were unsuccessful in detecting sharp-tailed snakes (Engelstoft and Ovaska, unpubl. data). Also, we excluded a small area of woodland to the northwest to avoid disturbance of the habitat known to contain many rare plants.

We installed the ACO array on 16 – 27 September 2010 and inspected it for snakes 236 times from 4 October 2010 to 27 March 2019. Surveys took place approximately weekly during peak activity periods of the snakes in spring and early summer (late February to June) and in fall (September to early November) and less often during July and August; we did not check the ACOs in December, and there was only one check in January, during a mild winter. Checking the array took approximately 6 person-hours. In spring, we surveyed the ACOs during the warmest part of the day, aiming for sunny conditions, while in summer we surveyed them either in morning or late afternoon to avoid excessively warm conditions.

Handling and Processing of Snakes

We measured and weighed sharp-tailed snakes found, determined the sex of larger snakes, and took photographs of the underside of the snout, chin, and tail for individual identification purposes through pattern mapping. We considered individuals < 180 mm snout-vent length (SVL) to be juveniles (Govindarajulu et al., 2011). We examined the snakes on site and released them within minutes at their original capture points; a small number of snakes were retained overnight for surgical implantation of PIT (passive integrated transponder) tags; results will be reported as part of another study. We also recorded the location, species, and number of other reptiles encountered.

Habitat Description

At each ACO station, we recorded the distance to nearest opening and to forest edge, dominant tree species (within 20 m radius), and dominant shrub species (within 5 m radius). We collected habitat data at 159 ACO stations in 53 plots, after excluding all three stations at one plot (except for aspect measurements) because of restricted access during construction. We visually estimated the following microhabitat features within a 5 m-radius circular area centred on each ACO station: canopy closure (percentage cover of the sky directly above the centre of the station and 5 m away in each cardinal direction); percentage cover by different substrate types, which included boulders and rocks, talus (layers of rock including pebbles < 7.5 cm in greatest dimension), exposed bedrock with cracks and fissures, coarse woody debris (decaying logs, stumps, sloughed off bark), and deep (> 5 cm) duff; percentage cover by different vegetation layers, which included low shrubs (≤ 1 m), high shrubs (> 1 m), and herbs and grass. In addition, we recorded meso-slope and aspect for each plot, as it was

Table 1. Jolly-Seber models fit to the 2011 – 2018 Common Sharp-tailed Snake data from Observatory Hill, ranked in order fit (best to worst); i.e., the probability that the model was that which minimized information loss. Table shows model formulation, number of parameters (npar), the AICc, ΔAICc, relative likelihood (RL), and model weight.

Model Formulation	npar	AICc	ΔAICc	RL	Weight
Φ(~1) p(~semi-ann) PENT(~t0) N(~1)	6	257.18	0.00	1.00	0.45
Φ(~semi-ann) p(~semi-ann) PENT(~t0) N(~1)	7	258.38	1.20	0.55	0.25
Φ(~1) p(~semi-ann) PENT(~semi-ann) N(~1)	7	259.07	1.89	0.39	0.18
Φ(~semi-ann) p(~semi-ann) PENT(~semi-ann) N(~1)	8	260.51	3.33	0.19	0.09
Φ(~semi-ann) p(~1) PENT(~semi-ann) N(~1)	7	262.64	5.46	0.07	0.03
Φ(~1) p(~time) PENT(~t0) N(~1)	20	266.69	9.51	0.01	0.00
Φ(~semi-ann) p(~1) PENT(~t0) N(~1)	6	268.19	11.01	0.00	0.00
Φ(~semi-ann) p(~time) PENT(~t0) N(~1)	21	268.62	11.44	0.00	0.00
Φ(~1) p(~1) PENT(~semi-ann) N(~1)	6	270.55	13.36	0.00	0.00
Φ(~1) p(~semi-ann) PENT(~time) N(~1)	19	270.61	13.43	0.00	0.00
Φ(~semi-ann) p(~time) PENT(~semi-ann) N(~1)	22	271.47	14.29	0.00	0.00
Φ(~semi-ann) p(~semi-ann) PENT(~time)N(~1)	20	272.75	15.56	0.00	0.00
Φ(~semi-ann) p(~1) PENT(~time) N(~1)	19	275.27	18.09	0.00	0.00
Φ(~time) p(~semi-ann) PENT(~t0) N(~1)	20	279.93	22.75	0.00	0.00
Φ(~1) p(~1) PENT(~t0) N(~1)	5	280.41	23.23	0.00	0.00
Φ(~time) p(~semi-ann) PENT(~semi-ann) N(~1)	21	280.42	23.24	0.00	0.00
Φ(~1) p(~1) PENT(~time) N(~1)	18	284.45	27.26	0.00	0.00
Φ(~time) p(~1) PENT(~semi-ann) N(~1)	20	287.14	29.96	0.00	0.00
Φ(~time) p(~1) PENT(~t0) N(~1)	19	290.61	33.43	0.00	0.00
Φ(~1) p(~time) PENT(~semi-ann) N(~1)	21	293.31	36.13	0.00	0.00
Φ(~1) p(~time) PENT(~time) N(~1)	33	299.21	42.03	0.00	0.00
Φ(~semi-ann) p(~time) PENT(~time) N(~1)	34	302.18	45.00	0.00	0.00
Φ(~time) p(~semi-ann) PENT(~time) N(~1)	33	304.15	46.96	0.00	0.00
Φ(~time) p(~time) PENT(~t0) N(~1)	34	305.58	48.40	0.00	0.00
Φ(~time) p(~1) PENT(~time) N(~1)	32	307.96	50.78	0.00	0.00
Φ(~time) p(~time) PENT(~semi-ann) N(~1)	35	308.80	51.62	0.00	0.00
Φ(~time) p(~time) PENT(~time) N(~1)	47	356.47	99.29	0.00	0.00

the same for each of three stations/plot. We used the above features to examine associations with sharp-tailed snake detections and to provide descriptive data of high use sites.

Data Handling and Analysis

Microsoft® Excel (2007) was used for multiple regression analysis of habitat correlations, descriptive statistics, and preparation of graphs. Maps were prepared using QGIS® (ver. 3.4).

We conducted population analysis using the Jolly-Seber formulation in the program 'MARK' (White and Burnham, 1999; Cooch and White, 2013). The method allows the simultaneous estimation of the probability of detection during observational periods (p), the apparent survival between observational periods (Φ, accounts for deaths and emigration as a single process), and two abundance-related parameters called N and PENT (probability of entry). The parameter N is a global parameter that represents the total number of animals that has ever been in the study area during the survey, and is used to scale the PENT parameters, which represent the proportion of N that enters the study area, either through birth or immigration, during each observation period. We split the survey data into 16 six-month observational periods from start of 2011 to end of 2018 ("Jan-June" and "Jul-Dec" x 8 years), resulting in 16 possible p and PENT parameters and 15 possible Φ parameters, along with the global N parameter. In total, 27 formulations of the model were constructed (Table 1) using three formulations of Φ, p, and PENT in various combinations. The three formulations were: (1) parameter free to vary among all observational periods ("~time"); (2) parameter allowed to vary between semi-annual (Jan-June vs. July-Dec) periods but not among years ("~semi-ann"); and (3) parameter fixed over time ("~1"; for the PENT parameter, we evaluated an initial value, after which it was fixed, "~t0"). For each of the 27 models, we calculated AICc (small-sample-size corrected version of Akaike information criterion, AIC), ΔAICc, relative likelihood, and model weight following Burnham and Anderson (2002). Models with the lowest AICc were selected as the most parsimonious, and are shown in order of best to worst fit in Table 1. For each model, we estimated parameters using maximum likelihood. We modelled all Φ and p parameters using a logit link (they were restricted to lie between 0 and 1), modelled N using a log link, and modelled the PENT parameters using a multinomial logit link (the set of parameters must sum to 1). We fit all models using the R (R Core Team 2017) package 'RMark' (Laake, 2013), which allows models to be constructed and fed into the program 'MARK' for analysis.

RESULTS

Capture Success

The surveys resulted in 177 detections of sharp-tailed snakes from October 2010 to March 2019. The detections represented 106 individual snakes and included 55 recapture events; on 16 occasions, a snake escaped, evading individual identification. The number of captures per individual ranged from one to eight. Most individuals (79 snakes, 74.5%) were captured only once, while 27 snakes (25.5%) were recaptured at least once. Most recaptures were within the year of initial capture, but 15 (14.2%) snakes were recaptured in more than one year. The average number of checks did not vary significantly among years (ANOVA: $F_{7,8} = 2.0$; $P = 0.17$), or between semi-annual periods (Jan-Jun vs. Jul-Dec; ANOVA: $F_{1,14} = 0.6$; $P = 0.44$).

The overall capture success of sharp-tailed snakes was 0.75 detections per survey of the ACO array. Comparable values for Northwestern Gartersnakes (*Thamnophis ordinoides*; n = 1561 detections) and Northern Alligator Lizards (*Elgaria coerulea*; n = 1138 detections) were 6.61

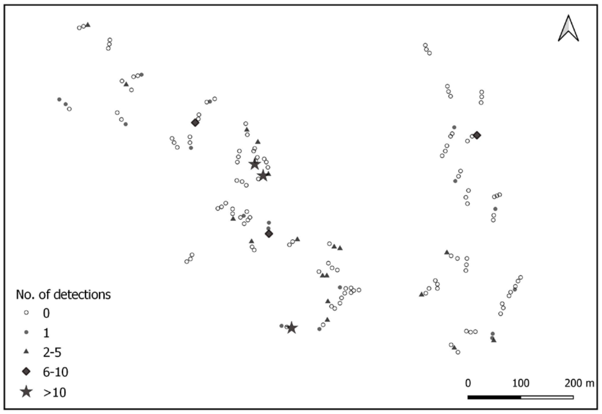

Figure 1. Dispersion of Common Sharp-tailed Snake detections among artificial cover-object stations on Observatory Hill, October 2010 – March 2019. Multiple detections of same individuals at same stations and snakes of unknown identity were omitted.

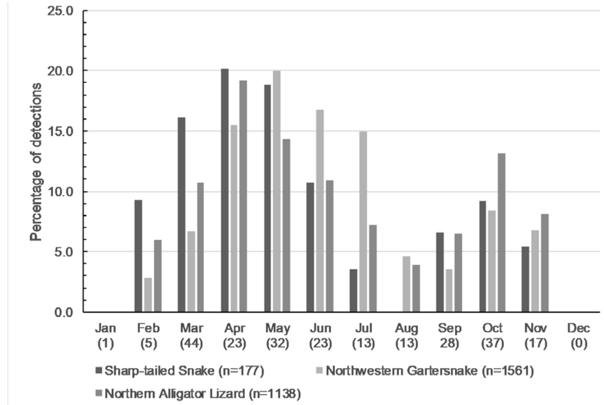

Figure 2. Seasonal pattern of detections of Common Sharp-tailed Snakes, Northwestern Gartersnakes, and Northern Alligator Lizards at the Observatory Hill study site, October 2010 – March 2019. The percentage of detections is scaled to the survey effort, shown in parentheses on x-axis (number of surveys/per month of an array of 162 artificial cover-object stations).

and 4.82 detections per survey, respectively. Other reptiles encountered less frequently on the array within the study period were Terrestrial Gartersnakes (*T. elegans*; 14 detections), Common Gartersnakes (*T. sirtalis*; one detection), and introduced Common Wall Lizards (*Podarcis muralis*; 48 detections).

Spatial Distribution of Captures

We detected sharp-tailed snakes at 42 of the 162 ACO stations during the course of the study. Snakes were most often (88.6%) found singly under an ACO, but on 17 occasions (10.8%) two snakes and on one occasion (0.6%) four snakes were found together. The number of detections per station ranged from 1 to 36 (mean = 1.08; SD = 3.76; n = 177 detections) over the entire study period. The highest number of detections of individuals per station was 15 (mean = 0.69; SD = 2.00; n = 111 detections) (Figure 1). The dispersion of snakes among the sampling stations across the study period was highly aggregated (coefficient of dispersion = 3.44 for all captures and 2.91 omitting recaptures of individuals at the same station), approximating a negative binomial distribution. There were three "hot spots", used by disproportionally high numbers of snakes (Stations 464B, 501B, and 504B with 11, 14, and 15 individuals, respectively) (Figure 1). The distribution of detections at these stations spanned from early to late in the season (464B: 15 Feb to 10 Nov; 501B: 5 Mar to 9 Oct; 504B: 1 Mar to 8 Nov). The detections at one of these stations (464B) included three of the ten very small individuals (SVL <112 mm) found during the study.

The known area of occupancy by the species on the hill, calculated as the minimum convex polygon around outermost captures, increased initially with sampling effort from 25.7 ha in 2011 to 30.9 ha in 2015 when it approached a plateau. By 2018, it was only slightly larger (31.1 ha) and encompassed 80.5% of the area sampled by the ACO stations.

Movements and Seasonal Distribution of Captures

Individual snakes were most often recaptured at the same ACO stations where they were originally caught regardless of the period between the first and last capture (mean = 337.9 days, SD = 406.2 days, n = 27 snakes). We detected only two movements by snakes among stations: one individual was found at two adjacent stations of the same sampling plot approximately 10 m away 14 days apart, from February to March 2015; another individual was found at two different plots and had moved a distance of 28 m over a period of 1,161 days, from September 2013 to November 2016.

We detected sharp-tailed snakes under the ACOs from late February to mid-November; the earliest seasonal detection was on 15 February in 2015 and latest on 10 November in 2017. Detection success showed a broad peak in spring and early summer with the highest numbers of detections per survey in March–May; a smaller peak occurred in September–November (Figure 2). More commonly encountered Northwestern Gartersnakes and Northern Alligator Lizards showed a similarly bimodal pattern of captures, but detections of these species extended further into summer (Figure 2).

Habitat Associations

A multiple regression model with ten habitat metrics as X variables and the number of individuals by ACO station as the Y variable was highly significant (ANOVA: $F_{10,148}$ = 3.5895; *P* = 0.0003), and explained 14.1% (adjusted r^2) of the variability among stations used by the snakes. The percentage of ground covered by talus was the greatest contributor to the model showing a positive association with snake detections, and the only habitat attribute that was statistically significant in univariate tests (Table 2). The results were similar when the number of detections rather than individuals by ACO station was used as the Y variable ($F_{10,148}$ = 3.3, *P* = 0.0008).

At the spatial scale of sampling plots, we detected the species most often on west- and south-facing aspects (X^2 = 7.3, df = 2, *P* < 0.026; north and east aspects combined for analysis; Figure 3). Terrain slope was uncorrelated with detections (plots with detections: mean = 26.7º, SD = 2.06º, n = 28 plots; plots with no detections: mean = 30.1º, SD = 3.6º, n = 25 plots; t = -0.89; *P* = 0.38).

Two of the three "hot spots" (ACO stations with the highest number of detections and individuals) were in openings within 30 m of forest edge, and one was in forest within 10 m of an opening. All sites had southwestern exposure on a steep (30–32º) slope with a relatively high proportion of ground covered by talus (20–30%) and over 5 cm deep duff (25–60%). Garry Oak was the

Table 2. Multiple regression with ten habitat metrics as the X variables and the number of individual Common Sharp-tailed Snakes by ACO station as the Y variable.

	Coefficients	*SE*	*t*	*P*	*Lower 95%*	*Upper 95%*
Intercept	-0.5813	0.7788	-0.7464	0.4566	-2.1203	0.9577
Distance to opening (m)	-0.2663	0.2886	-0.9227	0.3577	-0.8365	0.3040
Canopy coverage (%)*	0.0154	0.0126	1.2225	0.2235	-0.0095	0.0403
CWD (%)	0.0311	0.0338	0.9215	0.3583	-0.0356	0.0978
Talus (%)	0.0870	0.0205	4.2517	0.0000	0.0466	0.1274
Boulder & rock (%)	-0.0079	0.0128	-0.6154	0.5392	-0.0332	0.0174
Bedrock with cracks (%)	0.0046	0.0131	0.3532	0.7244	-0.0212	0.0304
Deep duff (>5 cm; %)	0.0112	0.0114	0.9850	0.3262	-0.0113	0.0338
Grass & herbs (%)	0.0126	0.0098	1.2846	0.2010	-0.0068	0.0321
Low shrubs ($\leq$ 1 m; %)	0.0068	0.0197	0.3475	0.7287	-0.0321	0.0458
High shrubs (> 1 m; %)	-0.0002	0.0117	-0.0167	0.9867	-0.0234	0.0230

*average of 5 measurements

dominant overstory species and Ocean Spray (*Holodiscus discolor*) the dominant shrub at all three hot spots.

Size-frequency Distribution

Body size (SVL) of sharp-tailed snakes at first capture ranged from 82 mm to 261 mm (mean = 182.1 mm, SD = 41.9 mm; n = 106), and the snakes weighed from 0.4 g to 8.8 g (mean = 3.7 g, SD = 1.8 g, n = 105). Of all snakes, 69 (65.1%) were adults (SVL $\geq$ 180 mm), and the size distribution was biased towards larger snakes (Figure 4). Of adults, 39 were males and 25 females, resulting in a sex ratio of 1 to 0.56 in favour of males (the sex of the remaining adults was not determined). We were able to determine the sex for 14 juveniles, of which nine were males and five were females.

Population Size and Survivorship

The AICc values for the top three models were similar, with ΔAICc < 2 (Table 1), but the parameter estimates derived from the second-best and third-best models were not well defined, thus only the top-model was used for calculation of snake abundances and abundance trends. The top model included a single survival rate for all inter-observational periods, a detection probability that varied semi-annually but not among years, a single PENT parameter that represented a constant rate of recruitment into each period, after the initial (t0) value estimated for the first survey in 2011.

Based on the parameter estimates from the top model, survival between observational periods was estimated to be 72.7% (SE = 6.9%), with 95% confidence limits ranging from 57.4% to 84.1%. As survivorship values across multiple time periods are multiplicative, this estimate was squared to yield average annual survival rates of 52.9% (SE = 7.1%). Detection probabilities during the January–June period averaged 11.7% (SE = 4.2%; CL from 5.6% to 22.8%); those in the July–December period were much lower, averaging 4.5% (SE = 1.7%; CL from 2.1 % to 9.1%). The PENT and N parameters translated into an initial population size of 127.7 snakes (SE = 56.2; CL from 56.0 to 291.3), with a net recruitment of 46.7 snakes (SE = 39.0; CL from 11.2 to 194.5) during the first period, and an average net semi-annual recruitment of 21.6 snakes (SE = 5.2, CL from 13.6 to 34.4) thereafter. After combining the recruitment and mortality, total abundances were calculated (Figure 5).

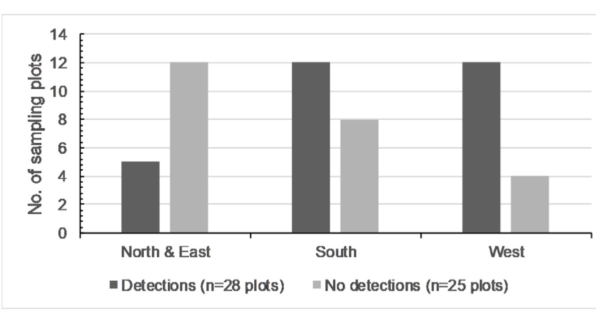

Figure 3. Aspect at ACO plots with and without Common Sharp-tailed Snake detections on Observatory Hill, October 2010 - March 2019.

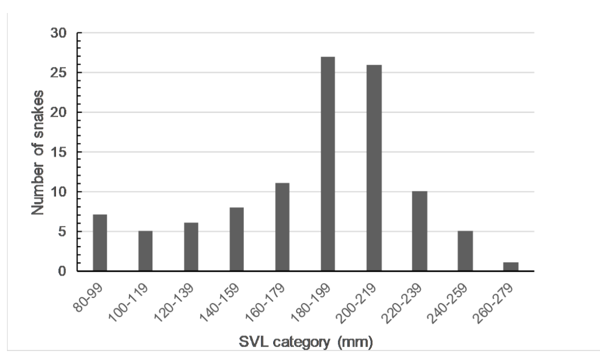

Figure 4. Size-frequency distribution of Common Sharp-tailed Snakes caught on Observatory Hill, October 2010 – March 2019. For recaptured individuals, only size at first capture is included. SVL – snout-vent length

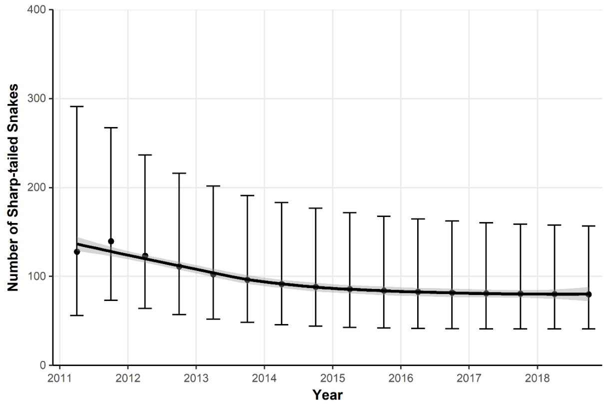

Figure 5. Estimated number of Common Sharp-tailed Snakes in the area sampled by the ACO stations by semi-annual observation period, as derived from the top-model. The mean trend was derived using a LOESS smoothing function. Error bars show the 95% confidence limits.

Based on the estimated average survival and average recruitment rates, the population appears to be on a slight negative trajectory. The 2018 abundance estimate for the area sampled by the ACO stations was estimated to be 80 snakes (SE = 28; CL from 40 to 157).

DISCUSSION

Since the assessment and designation of Common Sharp-tailed Snakes as endangered in Canada, considerable effort has been expended in attempts to locate the species and to delineate its distribution (reviewed in COSEWIC, 2009; British Columbia Ministry of Environment, 2015). However, only a few studies have addressed aspects of the species' population biology and spatial distribution. In British Columbia, Govindarajulu et al. (2011) reported on the life history and abundance of the species at two sites on Vancouver Island and two on the Gulf Islands in the Strait of Georgia, including reanalysis of data at a small (0.07 ha) North Pender Island site monitored intermittently with varying intensity over eight years (Ovaska and Engelstoft, 2008). To our knowledge, the Observatory Hill study represents the longest monitoring study anywhere within the species' distribution where sharp-tailed snakes were sampled annually using consistent methodology. The use of artificial cover-objects (Engelstoft and Ovaska 2000), together with the microhabitat-based sampling design used in this study resulted in a relatively large number of detections, allowing us to document the area of occupancy and dispersion of the snakes at the site, and to obtain information on habitat use and abundance.

Capture Success and Habitat Use

We detected sharp-tailed snakes 8.8 and 4.8 times less frequently than Northwestern Gartersnakes and Northern Alligator Lizards, respectively, suggesting lower abundance. The seasonal distribution of sharp-tailed snake captures showed a pronounced peak in spring-early summer and a smaller peak in fall, in contrast to a more even distribution of detections for the above two species. Mild conditions in some years allowed sharp-tailed snakes to emerge as early as February and remain active near the surface until November.

Sharp-tailed snakes were widely but unevenly distributed in woodland openings and their forested fringes across much of the site but were predominantly detected on the south and west slopes of the hill. Use of these warmer aspects and relatively open habitats is consistent with thermal constraints posed by the climate and similar to what has been reported for small colubrid snakes at northern latitudes (e.g., Red-bellied Snakes and Common Gartersnakes in Quebec; Retamal Diaz and Blouin-Demers, 2017). Thermal constraints may be particularly applicable to oviparous species at the northern limits of their distribution (Gregory, 2009), such as sharp-tailed snakes in British Columbia, where the availability of warm incubation sites may be limiting.

Sharp-tailed snake detections were correlated with the proportion of talus substrate in the immediate vicinity of the sampling station, but overall, the measured habitat attributes explained relatively little of the variability among ACO stations used by the snakes. Wilkinson et al. (2007) also found an association between Common Sharp-tailed Snakes and rocky substrates on Vancouver Island and the Gulf Islands. In Oregon, the only documented egg-laying site of the species was a communal site used by a number of reptile species on a south-facing talus patch (Brodie et al., 1969).

We identified three "hot spots", i.e., ACO stations used by disproportionally large numbers of individuals. All were on rocky terrain on the southwestern slope of the hill and most likely provided access to hibernation sites, based on the timing of their use by snakes early and late in the season. Winter detections of PIT-tagged snakes within 6 and 13 m of two of these stations confirmed their location adjacent to hibernation sites (Engelstoft et al., unpubl. data). In addition, the presence of very small individuals at one of the sites suggested that egg-laying occurred in the immediate vicinity. At a Washington state site, Leonard et al. (1996) similarly documented two presumed hibernation and egg-laying aggregations of Common Sharp-tailed Snakes on rocky substrates. Alternative explanations for snake aggregations include shortage of suitable cover, very favourable conditions, social attraction, or even chance, a list of functions Gregory (2004) suggested for aggregations of single and multiple species of snakes under rocks in Ontario. On Observatory Hill, the hot spots were used consistently over many years, suggesting that the sites were of ecological importance to the snakes.

Movements

We documented surprisingly few movements of snakes between sampling stations, even between stations within the same plots that were only 10 m apart. However, recapture success was low both within and among years. Sampling bias associated with artificial cover objects may have been a contributing factor, as snakes were only available for capture when thermoregulating or sheltering under the ACOs. Snakes buried within rocky substrates or under other natural cover would have been missed with this method. A bias towards specific microhabitats has been reported for Dekay's Brownsnakes that also rely heavily on cover-objects; most detections were of gravid females under woody debris at an Ontario site (Hecnar and Hecnar, 2011). Nevertheless, the results support conclusions of previous studies that Common Sharp-tailed Snakes show a high degree of site fidelity and do not undertake extensive seasonal migrations (Ovaska and Engelstoft, 2008). On Observatory Hill, the longest documented displacement distance was that for an adult male with 141 m between its two farthest captures within five years of monitoring with PIT-tag telemetry, i.e., employment of a portable scanner with an antenna on a wand to scan the ground and potential retreats for tagged snakes (Engelstoft et al., 2019 and unpubl. data). Site fidelity and similarly short movement distances have also been documented for Dekay's Brownsnakes, small, primarily nocturnal slug-eating snakes with similar ecology to that of Common Sharp-tailed Snakes (Gray, 2014).

Demography

The body size of sharp-tailed snakes detected tended towards larger, adult-sized individuals, and juveniles were greatly under-represented in the samples, comprising only 11.3% of all individuals. Govindarajulu et al. (2011) noted a similar bias at three of the four sites studied, where individuals with SVL <120 mm comprised only 3 to 7% of all captures. At the fourth site, a small (0.098 ha) talus patch, however, they comprised 40% of the captures; this patch probably provided egg-laying and neonate habitat. Juvenile snakes, particularly neonates, are often secretive and less mobile than adults and are generally rarely detected in field studies (Pike et al., 2008).

Assuming that sharp-tailed snakes using the ACO array were representative of the population and that the ACOs sampled 21.03 ha of habitat (based on 39.1 m-radius area around each station; this value is the average distance between two farthest detections of individual snakes at the site based on PIT-tag telemetry, Engelstoft et al., 2019), then the density of snakes ranged from a mean of 6.04/ha (0.0006/m^2) in 2011 (127 snakes) to 3.80/ha (0.0004/m^2) in 2018 (80 snakes). These densities are much lower than previously reported for the North Pender Island site (0.067 snakes/m^2 within a 733 m^2 area), which was also sampled with ACOs (Govindarajulu et al., 2011). However, the densities reported in the North Pender Island study represent those in a small habitat patch, potentially comparable to "hot spots" in this study, and cannot be extrapolated to a wider area. The densities are also much lower than reported for Dekay's Brownsnakes in Pennsylvania (244 – 260 snakes/ha; Gray, 2014). In general, population density tends to be greatest in the center of a species' distribution, decreasing towards the boundaries (Brown, 1984). Densities might be expected to be relatively low at the periphery of Common Sharp-tailed Snakes' distribution in British Columbia, but comparable data from the core of the species' range south of Washington State are lacking.

The mean annual survivorship on Observatory Hill (52.9%; SE = 7.1%) was slightly lower than that for all size classes combined at the North Pender Island site (0.71%; 95% CL: 0.59–0.81%; Govindarajulu et al., 2011). At both sites, populations were deemed to be stable or slightly declining, but low recapture rates resulted in high variance, and the results should be interpreted with caution.

Conservation Implications

Similar to other British Columbia sites studied (Ovaska and Engelstoft, 2008; Govindarajulu et al., 2011), the Common Sharp-tailed Snake population on Observatory Hill is small and patchily distributed across the landscape. Such populations are inherently vulnerable to disturbance and stochastic events (Irwin and Irwin, 2006). Across the species' range in British Columbia, we suggest focusing survey efforts on stable talus patches, particularly with south- and west-facing aspects, both to locate the species at new sites and to identify important habitats at known sites. While the ACO method may contain biases with respect to the proportion and segment of the population sampled, when deployed over multiple years, it allowed us to determine the area of occupancy and identify important sites, information that site managers can use to direct maintenance and other activities. The identification and protection of "hot spots" from disturbance is of considerable conservation significance for local populations at this and other sites.

Recommendations for Further Study

Detailed information on movements and seasonal habitat use by Common Sharp-tailed Snakes remain incompletely understood. In particular, information is needed on characteristics of hibernation and egg-laying habitats and on the extent that snakes use deeper forest habitats. Such information is challenging to obtain for this small and cryptic species. While ACOs are effective for detecting snakes, the data may be biased towards microsites suitable for thermoregulation at the expense of other habitat features. New methods, such as PIT-tag telemetry (Oldham et al., 2016) and environmental DNA extraction from soil samples (Matthias et al., 2021) provide exciting avenues to examine these and other aspects of the natural history of Common Sharp-tailed Snakes and other small snakes in a variety of habitats. We are currently experimenting with several PIT-tag telemetry systems, including automated detection set-ups, to investigate movements and habitat use of sharp-tailed snakes on Observatory Hill.

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