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From the Field

Assessment of Alternative Sampling Designs for Range-wide Monitoring of New England Cottontail

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ABSTRACT Monitoring within an adaptive management framework provides important insights about system responses to management and information on which management actions to adjust to improve outcomes over time. We evaluated the range-wide monitoring survey of the New England cottontail (*Sylvilagus transitionalis*) and assessed its ability to track changes in species' population status over time using data gathered under the original protocol in 2016–2017 from 204 sites in 5 states (Connecticut, Maine, Massachusetts, New Hampshire, and New York, USA). We used occupancy analysis and structured decision making to evaluate 2 questions: 1) Does the monitoring survey provide the information needed to meet monitoring goals? and 2) What changes in the monitoring protocol, survey-site selection, or field-data collection are needed to better meet monitoring goals? A power analysis applied to data from the 2016–2017 survey indicated insufficient power (<0.80) to detect a large (0.50) change in occupancy, and either increasing the number of sites sampled, the number of occupied sites sampled, or both actions were needed to increase power and enable range-wide survey objectives to be met. A revised study design was implemented in 2017–2018 that included sampling 146 of about 210 known occupied sites in 6 states (Connecticut, Maine, Massachusetts, New Hampshire, New York, and Rhode Island, USA) and provided sufficient power (0.81) to detect a small (0.30) change in occupancy. The revised study design revealed a 50% decline in the number of known occupied sites has occurred over the last decade. Our findings highlight the importance of study-design considerations in monitoring protocols and the important role of structured decision-making in making transparent, data-informed, and defendable decisions when developing, evaluating, and revising monitoring plans for cryptic and rare species such as the New England cottontail.

KEY WORDS adaptive management, monitoring, New England cottontail, occupancy, structured decision making, study design, *Sylvilagus transitionalis.*

Adaptive management is an iterative decision-making approach that seeks to reduce uncertainty about system function over time through a doing-monitoring-adjusting loop (Walters 1986). Monitoring provides knowledge about the system state and response to management that is subsequently used to adjust management actions, with the intent to further reduce uncertainty in system responses and improve management outcomes over time (Elzinga et al. 1998, Gibbs et al. 1999, Block et al. 2001). The heavy reliance on monitoring necessitates both good study design as well as periodic review to ensure the monitoring effort is capable of measuring system response to management (Lyons et al. 2008).

Occupancy monitoring for cryptic and rare species poses special challenges to adaptive management. Cryptic species are morphologically identical to each other but are separate species, whereas rare species are classified as such based on abundance and geographic range (Gaston 1994). Challenges arise when species detection or identification is uncertain in the field, a species has limited range, or abundance and geographic range are not independent (Flather and Sieg 2007).

The New England cottontail (*Sylvilagus transitionalis*), an endemic species found in 6 states in the northeastern United States, is both cryptic and rare. It is a habitat specialist closely associated with shrublands, early successional forests, and forests with a well-developed, shrubby understory (Litvaitis 1993*a*, Litvaitis et al. 2003). The New England

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cottontail was recently separated taxonomically from Appalachian cottontail (*Sylvilagus obscurus*; Chapman et al. 1992); is nearly indistinguishable from eastern cottontail (*Sylvilagus floridanus*) based on morphological characteristics of the skull (Fay and Chandler 1955), body size, mass, and ear length (Litvaitis et al. 1991); and is only distinguished reliably using genetic analysis (Litvaitis and Litvaitis 1996, Kovach et al. 2003, Sullivan et al. 2019). Surveys for the New England cottontail began formally in the late 1800s distinguishing the species from other races of cottontail (Bangs 1894) and then continued into the 1970s with establishing range and distribution (Nelson 1909, Stevens 1950, Fay and Chandler 1955, Hall and Kelson 1959, Eabry 1968, Linkkila 1971, Johnston 1972, Jackson 1973, Silver 1974, Godin 1977). Population status and trend surveys indicated population declines since 1960 (Chapman and Stauffer 1981; Hoff 1987; Cardoza 1993; Litvaitis 1993*a*, *b*), attributed to loss of early successional forest due to succession, development, and changing land use practices (Litvaitis et al. 2003, 2008). Concerted effort towards state- and range-wide surveys began in the 1990s and revealed substantial range contraction from the historical extent (Litvaitis and Jakubas 2004, Litvaitis et al. 2006) and raised concern for the species' conservation (USFWS 2006, 2009) and its genetic diversity (Fenderson et al. 2011, 2014). Habitat loss, range contraction, and population and genetic diversity declines were the impetus for the development and implementation of a coordinated, region-wide monitoring survey to meet the goals of the Conservation Strategy for New England Cottontail developed by state and federal natural resource managers to recover the species (Fuller and Tur 2012, 2017; Shea et al. 2019).

Management actions for the New England cottontail consist of maintaining existing habitat, creating new habitat, translocating rabbits, and augmenting existing populations with captive-reared rabbits (Fuller and Tur 2012, 2017). The intent of monitoring is to assess New England cottontail status and persistence within existing habitat and response to management through colonization of new habitat. Range-wide monitoring of the New England cottontail is a multi-state, coordinated survey conducted annually since 2015. Survey objectives include determining current occupancy rates of New England cottontail at locations throughout the species' range, how occupancy status changes through time via estimation of species-specific occurrence and underlying vital rates (local patch colonization and extinction), and how management activities influence changes in occupancy status at a location. Occupancy and trends in occupancy from the region-wide survey are intended to inform management and regulation decisions by state and federal agencies. After the first 2 years of implementation, low occupancy rates despite substantial survey efforts raised questions about whether the monitoring plan, as designed, was fulfilling its intended goals.

Our purpose is to review the recent range-wide monitoring survey of the New England cottontail and assess its ability to track changes in population status and trends over time. We used data gathered under the original protocol in 2016–2017 from 206 plots in 5 states (Connecticut, Maine, Massachusetts, New Hampshire, and New York, USA) to conduct occupancy analysis in conjunction with structured decision-making to evaluate 2 study design questions: 1) Does the monitoring survey provide the information needed to meet monitoring goals? and 2) What changes in the monitoring protocol, survey site selection, or field data collection are needed to better meet monitoring goals? In this way, we provide a framework for adaptive monitoring such that the monitoring effort provides reliable information on which to base adaptive management decisions. Our decision-analysis led to a revision of the original monitoring protocol; thus, we then evaluated the implementation of the revised protocol. We estimated occupancy rates of New England cottontail using data gathered under the revised protocol in 2017–2018 from 355 plots in 6 states (Connecticut, Maine, Massachusetts, New Hampshire, New York, and Rhode Island, USA).

RANGE-WIDE NEW ENGLAND COTTONTAIL SURVEY DESIGN

The range-wide monitoring survey uses occupancy as the primary means for evaluating New England cottontail dynamics (Shea et al. 2019). Occupancy is the status of an area (occupied, not occupied, unknown), and a function of the probability of detection during presence/absence surveys given one or more individuals are present. Systematic fecal-pellet surveys are conducted in winter along transects within plots or patches, in conjunction with genetic species identification, as the means for detecting New England cottontail and, over time, occupancy dynamics (Kovach et al. 2003, Brubaker et al. 2014).

Fecal-pellet surveys were conducted November to April because cold temperatures preserve DNA quality and snow cover increases visibility of pellets (Brubaker et al. 2014). Most pellet surveys were conducted >24 hours after a snowfall event, high wind event, or rain event, to allow sufficient time for rabbit activity and deposition of pellets. During a pellet survey, an observer walked parallel transects and searched up to 15 m to either side for pellet piles. Once a pellet pile was found, 1 or more pellets were collected from the pile, stored in a vial, and the UTM coordinates (or latitude and longitude) of the pile were recorded. To reduce collection of pellets from the same individual, the observer spaced collections at approximately 30-m intervals. The species origin of the fecal pellets (New England cottontail, eastern cottontail or snowshoe hare [*Lepus americanus*]) was determined using mitochondrial DNA analysis (e.g., Kovach et al. 2003, Kilpatrick et al. 2013, Sullivan et al. 2019).

In the original implementation of the monitoring protocol, the sampling frame for pellet surveys included designated survey zones within New England cottontail conservation focus areas—the total areas within each state over which management activities for cottontails are coordinated under the Conservation Strategy for the New England Cottontail (Shea et al. 2019). Survey zones comprised areas within a 5-km buffer surrounding recent historical (2009–2014) New England cottontail occurrences. Within survey zones, 4-ha plots were randomly selected in each of the 6 focal states (Connecticut, Maine, Massachusetts, New Hampshire, New York, and Rhode Island), with plot allocation across states proportional to survey zone area and monitoring capacity. Plot selection was further stratified by distance from known historical New England cottontail occurrence (Shea et al. 2019).

Occupancy Analysis

Occupancy models incorporate covariates that help determine the factors associated with probability of detection and occupancy. For the New England cottontail, factors affecting probability of detection include snow depth and days since a snowfall or high wind event (Brubaker et al. 2014). Covariates for probability of detection were measured during each pellet survey and included air temperature, days since last snowfall, days since last high wind (>25 mph) event, days since last rain, presence or absence of snow crust, and snow depth. Covariates for occupancy were measured once per year per plot or patch at a minimum of 2 transects representative of the habitat type(s) present within the plot. Covariates for occupancy included proportion of ground covered by understory vegetation (0–5%, 5–25%, 25–50%, 50–75%, and 75–100%), proportion of ground covered by dense (high stem density) understory vegetation (0–5%, 5–25%, 25–50%, 50–75%, and 75–100%), dominant understory vegetation type (native or invasive), proportion of ground covered by tree canopy (0–5%, 5–25%, 25–50%, 50–75%, and 75–100%), and dominant vegetation type (tree, shrub, or grass).

Single-season, single-species occupancy models were fit in 2 stages for data collected in the 2016–2017 surveys and in the revised 2017–2018 surveys (see below). The first stage identified the most-supported model of detection probability (based on Akaike's Information Criterion for small samples [AIC_c]) when holding the occupancy component fixed. The second stage identified the most-supported model of occupancy when using the detection probability component identified in first stage. All occupancy models were fit in R v. 3.6.1 using the package unmarked (Fiske and Chandler 2011, R Core Development Team 2017).

EVALUATION OF RANGE-WIDE SURVEY STUDY DESIGN

We used a structured decision-making approach to evaluate whether the range-wide monitoring survey was meeting its stated goals. Structured decision-making begins with problem statement(s), then identifies goals (stated as objectives), one or more performance measures for each objective, alternatives (in this case, study designs) that could be taken to meet objectives, and an evaluation of consequences and tradeoffs associated with each alternative study design (Gregory and Keeney 2002, Hammond et al. 2002, Gregory et al. 2012). Subsequently, an alternative is selected for implementation, and monitoring gathers data used to assess whether or not the objectives were met. A problem statement minimally includes a proposed action or set of actions, prediction(s) about how each action leads to outcomes, and an assessment of how those outcomes fulfill the objectives (Conroy and Peterson 2013). In the context of the range-wide monitoring survey of New England cottontail, we focused on a relatively narrow set of questions pertaining to the study design: 1) Does the monitoring survey provide the information needed to meet the 3 stated monitoring objectives?, and 2) What changes in monitoring protocol or survey site selection are needed to better meet monitoring goals?

Monitoring Objectives and Performance Measures

The objectives for the range-wide monitoring survey include determining current occupancy rates of New England cottontail at locations throughout the species range, how occupancy status changes through time via estimation of species-specific occurrence and underlying vital rates (local patch colonization and extinction), and how management activities influence changes in occupancy status at a location. We focused on current occupancy rates (objective 1 of the range-wide monitoring), because they constitute the basis for assessing trends in occupancy (objective 2) and response to management activities (objective 3), and express occupancy rates as a means objective specific to the study design: maximize the power to detect a change in occupancy of known occupied sites.

Performance measures provide benchmarks for understanding New England cottontail occupancy as well as how the aspects of study design affect the survey effort and ability to detect changes in occupancy over time. The performance measures included occupancy (ψ) and power to detect a change in occupancy as a function of the number of sites surveyed, the number of visits per site, and the probability of detection (Guillera-Arroita and Lahoz-Monfort 2012). Because we assumed fixed effort, we tracked the number of plots sampled range-wide (S sample sites) and the number of visits per site (K replicate surveys), which were considered action elements of the sampling strategy (Clemen and Reilly 2001). Detection probability (p) was fixed across all alternatives.

Alternatives

The initial study design was implemented in 2015–2016 and 2016–2017 (Shea et al. 2019). We used the 2016–2017 data, which consisted of 204 sites visited an average 3.6 times (1–4 visits per site) for a total effort of 730 site-visits, as the reference alternative. The 204 sites were stratified based on distance from known New England cottontail locations (0–1 km vs 1–5 km) and on habitat quality (high, medium, low, and very low), with the effort allocated as 40% within 1 km and 60% in the 1–5-km buffer (Table 1). The number of sites surveyed within each state was determined proportionately by the number of known New England cottontail locations and total available effort. Most states used a double-observer method whereby 2 observers independently surveyed a site on the same day, traversing the same transects in different directions, and treated each observer as a separate visit.

Table 1. Study design for range-wide monitoring of New England cottontail as implemented in 2016–2017 in 5 northeastern states in the United States, which stratified sites on distance from known New England cottontail location (0–1 km vs 1–5 km) and habitat quality (high, medium, low, and very low; habitat quality not reflected in table).

State	0–1 km	1–5 km	Total plots	Plots occupied	Naïve occupancy	Estimated occupancy (SE)
Range-wide	82	122	204	46	0.23	0.184 (0.039)
Connecticut	32	48	80	22	0.28	0.264 (0.100)
Maine	10	15	25	0	0.00	
Massachusetts	9	14	23	8	0.35	0.351 (0.100)
New Hampshire	14	20	34	5	0.15	0.125 (0.062)
New York	14	22	36	11	0.31	0.312 (0.082)

For the remaining study design alternatives, we considered changes in the monitoring protocol and survey site selection that might better meet the stated monitoring goals. We focused on the monitoring protocol and survey-site selection, because these were the factors that seemed most likely to affect survey outcomes, whereas field data collection procedures had been well established in prior work (e.g., Litvaitis et al. 2006, Brubaker et al. 2014). In particular, we were interested in the effects of focusing on known occupied sites versus unknown sites in the survey site selection. We developed alternatives that consisted of different allocations of effort to finding new sites, visiting known occupied sites, and the number of visits per site, expressed as unique combinations of number of sites sampled (183, 243, or 365) and number of visits per site (4, 3, or 2, respectively) constrained by total available effort of 730 site-visits; and a range of plausible initial occupancy rates (0.1–0.5, in 0.1 increments), based on knowledge from prior surveys (Table 2). We also examined how changes in initial occupancy rates affected the reference alternative of 204 sites visited an average of 3.6 times. We held detection probability constant at $p = 0.70$, the range-wide estimate of detection probability for 2016–2017.

Consequences and Tradeoffs

Given the alternatives and performance measures, and field data from conducting the surveys, it was possible to evaluate alternative study designs with respect to anticipated and actual outcomes for the range-wide monitoring objectives. The 2016–2017 monitoring survey (reference alternative) sampled 204 plots range-wide and detected New England cottontail in 46 of those plots (naïve occupancy = 0.23; Table 1). Model-estimated probability of occupancy ranged from 0.13 (SE 0.06) to 0.35 (SE 0.10) for models fit at the state level, and was 0.18 (SE 0.04) range-wide for the most-supported model (Table 1). The probability of detection was 0.70 (SE 0.11) range-wide.

We used simulations and power analyses to assess the power (G) of a particular study design to detect a change in occupancy between 2 surveys, where a survey is conducted annually and consecutive (year-to-year) surveys are considered independent (Guillera-Arroita and Lahoz-Monfort 2012). Type I error, denoted by α, was the probability of detecting an effect when no effect exists (false positive). We used $\alpha = 0.05$ for all analyses. Type II error, denoted by β, was the probability of not detecting an effect of a given size when an effect exists (false negative). We used $\beta = 0.20$, corresponding to a power $= 1 - \beta = 0.80$ as a minimum power for detecting differences (Cohen 1988).

Power may be increased through larger sample sizes (more sites surveyed), smaller estimation error, and larger effect size. We define the effect size as R, the proportional difference in occupancy between 2 surveys (ψ_1 and ψ_2), such that $\psi_2 = \psi_1(1 - R)$, where $R > 0$ represents a decline and $R < 0$ an increase in occupancy. The power to detect a proportional difference in occupancy is

$$G = 1 - \beta = 1 - \Phi\left(\frac{z_{\alpha/2}\sqrt{\sigma_1^2 + \sigma_2^2} - (\psi_1 - \psi_2)}{\sqrt{\sigma_1^2 + \sigma_2^2}}\right) \tag{1}$$

where σ^2, the asymptotic variance of the occupancy estimator, is

$$\sigma^2 = \frac{\psi}{S}\left\{(1 - \psi) + \frac{1 - p^*}{p^* - Kp(1 - p)^{K-1}}\right\} \tag{2}$$

a function of occupancy ψ, the number of sites surveyed S, the number of visits per site K, and the probability of not

Table 2. Alternatives considered during the evaluation of the range-wide New England cottontail monitoring survey. The Reference Alternative included the observed occupancy rate of 0.184 as well as the range of occupancy examined for alternative study designs. Survey effort reported as total site-visits. Initial occupancy defined as proportion of sites occupied.

Study design element	Reference alternative (2016–2017)	Alternative 1	Alternative 2	Alternative 3
Number of sites	204	365	243	183
Number of visits	3.6	2	3	4
Survey effort	730	730	730	730
Initial occupancy	0.1–0.5	0.1–0.5	0.1–0.5	0.1–0.5
Detection p	0.70	0.70	0.70	0.70
Observers	2	2	2	2
Observer covers	whole plot	half plot	half plot	half plot

missing the species at an occupied site $p* = 1 - (1 - p)^K$ (Guillera-Arroita and Lahoz-Monfort 2012).

We estimated power to detect a 0.1–0.5 proportional difference in occupancy for the reference alternative of 204 sites sampled 3.6 times (original protocol; Table 3). Given the observed occupancy of 0.18 and detection probability of 0.70, the study design in place for the 2016–2017 surveys had power 0.76 to detect a 0.50 decline in New England cottontail occupancy, and power 0.32 to detect a 0.30 decline in New England cottontail occupancy. Thus, only monitoring objective 1, current occupancy, was met and all subsequent monitoring objectives were unmet under the 2016–2017 study design.

Power analyses for 730 site visits across a range of occupancy values with detection probability fixed at 0.70, indicated that power increased with the number of sites surveyed, greater initial occupancy rate, and larger proportional differences in occupancy (Table 3). Modifications to study design, including increasing the number of sites surveyed and number of sample sites occupied by New England cottontail, provided power ≥0.80 to detect as little as 0.30 change in occupancy when surveying 183 sites at 0.50 initial occupancy, or surveying 365 sites at 0.40 occupancy. With <0.40 occupancy rates, insufficient power (≤0.80) was provided by all combinations of sites and visits. Relaxing R, the proportional difference in occupancy, to 0.50 provided power ≥0.80 when surveying 243 sites at 0.20–0.50 occupancy, or surveying 183 sites at 0.30–0.50 occupancy.

Decision

The power analyses indicated that increasing the number of sites sampled, increasing the number of sample sites occupied by New England cottontail, or doing both was required to achieve power ≥0.80 to detect a 0.30 to 0.50 change in New England cottontail occupancy, and would enable meeting both objective 1 and objective 2 of the range-wide monitoring survey. Given logistical constraints in total survey effort, it was deemed more feasible to increase occupancy rates rather than number of sites. Based on the results of the power analysis and logistical constraints in survey effort, we recommended a shift towards a target of 60% occupancy achieved through sampling all known occupied sites. Subsequently, the 2017–2018 survey sites were stratified based on occupancy status (known occupied vs unknown or unoccupied) and management status (habitat management conducive to New England cottontail or not managed), with all effort allocated within 2 km of known New England cottontail occupied sites (Table 4). Known occupied sites included all sites occupied by New England cottontail in any year from 2009 to 2017. We assumed total available survey effort was at capacity for each state and thus capped sample effort at 2016–2017 level, which was 204 plots visited 3.6 times on average, or total sample effort of 730 plot-visits. We also recommended 2 independent visits per plot using a single-observer method (e.g., 1 observer surveys the whole plot each visit) or a double-observer method (e.g., 2 observers each surveying a separate half of the plot each visit). The total number of

Table 3. Power estimates for the ability to detect a 10–50% change in New England cottontail occupancy, given fixed effort of 730 site-visits across varying levels of initial occupancy. The Reference Alternative is the 2016–2017 data where range-wide occupancy was 0.18 (SE = 0.04) and detection probability was 0.70 (SE = 0.11).

Occupancy	Proportional difference in occupancy	365 sites with 2 visits	243 sites with 3 visits	183 sites with 4 visits	204 sites with 3.58 visits (reference)
0.5	0.1	0.210	0.187	0.158	0.051
	0.2	0.645	0.576	0.482	0.169
	0.3	0.945	0.905	0.829	0.519
	0.4	0.998	0.994	0.977	0.863
	0.5	1.000	1.000	0.999	0.986
0.4	0.1	0.162	0.143	0.123	0.051
	0.2	0.503	0.433	0.355	0.130
	0.3	0.854	0.781	0.679	0.385
	0.4	0.984	0.962	0.911	0.721
	0.5	1.000	0.998	0.989	0.935
0.3	0.1	0.125	0.110	0.097	0.050
	0.2	0.367	0.307	0.251	0.102
	0.3	0.700	0.607	0.505	0.272
	0.4	0.925	0.862	0.769	0.545
	0.5	0.992	0.975	0.934	0.809
0.2	0.1	0.095	0.085	0.077	0.076
	0.2	0.243	0.202	0.168	0.164
	0.3	0.492	0.408	0.331	0.324
	0.4	0.758	0.657	0.551	0.539
	0.5	0.929	0.862	0.767	0.756
0.1	0.1	0.070	0.066	0.062	0.050
	0.2	0.137	0.117	0.102	0.063
	0.3	0.261	0.214	0.176	0.108
	0.4	0.440	0.358	0.290	0.190
	0.5	0.645	0.539	0.442	0.316

Table 4. Study design for the revised New England cottontail range-wide monitoring survey, which stratified sites based on occupancy and management status in 6 states in the northeastern United States during 2017–2018. Allocation of sample sites prioritized occupied sites regardless of management status, and then all unoccupied or unknown sites that were managed. Any remaining effort was allocated to unoccupied or unknown, unmanaged sites to reach the total number of sites per state.

State	Occupied Sites, Managed or Unmanaged	Unoccupied or Unknown Sites, Managed	Unoccupied or Unknown Sites, Unmanaged	Total sites[a]
Connecticut	~80	All	Balance to	130
Maine	~30	All	Balance to	50
Massachusetts	~30	All	Balance to	50
New Hampshire	~8	All	Balance to	15
New York	~60	All	Balance to	100
Rhode Island	1	All	Balance to	10
Total sites	~210	All	Balance to	355

[a] Total sites = known occupied sites/target occupancy of 0.60.

sample plots for each state was calculated as known occupied sites/target occupancy of 0.60. A greater initial occupancy (0.60) was used instead of the target occupancy of 0.50 because we assumed that not all previously occupied sites were actually occupied. The lower total number of plots sampled thus allowed for some attrition of occupied sites while still aiming to achieve target occupancy rates of 0.50 in each state. The remaining effort after sampling all known occupied sites (remaining effort = total plots – all known occupied sites) was allocated to unoccupied sites, with primary attention given to managed sites and any remaining effort to unmanaged sites.

IMPLEMENTATION OF THE REVISED RANGE-WIDE SURVEY STUDY DESIGN

The 2017–2018 monitoring survey sampled 337 plots range-wide, including 146 of approximately 210 known occupied sites, and detected New England cottontail in 103 of the plots sampled (naïve occupancy = 0.30; Table 5). Model-estimated occupancy ranged from 0.059 (SE 0.057) to 0.463 (SE 0.233) for models fit at the state level, and was 0.370 (SE 0.054) range-wide for the most-supported model (Table 5).

Detection probability ranged from 0.56 (SE 0.153) to 1.00 (SE 0.014) at the state level, and was 0.911 (SE 0.080) range-wide (Table 6). New England cottontail were detected on the first visit in 85, and on the second visit in 12, of the 102 occupied sites. The number of sites sampled and the number of visits per site had power 0.81 to detect a change in occupancy of 0.30 given the observed detection probability (0.91) and occupancy (0.370). Thus, monitoring objective 1 was met and monitoring objective 2 should be met with continuation of the 2017–2018 study design.

Of the 337 sites sampled in 2017–2018, 146 were considered (at the onset of the survey season) as known occupied by New England cottontail, meaning that this species was previously detected at the site in any year between 2009 and 2017, and 191 sites had status unknown or unoccupied for that same period of time. The 146 sites sampled constituted approximately 70% of the 210 known occupied sites heading into the 2017–2018 survey. Notably, only 72 known occupied sites were confirmed occupied in 2017–2018, an apparent 50% decline in the number of known occupied sites range-wide since the most recent surveys of the last decade (Table 5). The magnitude of decline in known occupied sites ranged from 38% (New York) to 71% (Massachusetts). New England cottontail were detected at 31 of the 191 unknown or previously unoccupied sites, which brought the total number of plots

Table 5. Effort and occupancy for the 2017–2018 New England cottontail range-wide monitoring survey with partial implementation of the revised protocol that emphasized monitoring of sites occupied by New England cottontail (NEC) between 2009 and 2017 in 6 states in the northeastern United States.

	All plots				Previously unoccupied or unknown sites		Known occupied sites*		
	Plots sampled	Plots occupied	Naïve occupancy	Estimated occupancy (SE)	No. Sampled	No. with NEC detected	No. Sampled	No. with NEC detected	Apparent decline
Range-wide	337	103	0.30	0.370 (0.054)	191	31	146	72	50%
Connecticut	109	37	0.34	0.331 (0.048)	62	10	47	27	43%
Maine	80	21	0.26	0.346 (0.069)	41	3	39	18	50%
Massachusetts	68	20	0.29	0.431 (0.124)	44	13	24	7	71%
New Hampshire	25	7	0.28	0.280 (0.129)	11	1	14	6	57%
New York	38	17	0.45	0.506 (0.11)	17	4	21	13	38%
Rhode Island	17	1	0.06	0.059 (0.057)	16	0	1	1	0%

* Sites on which New England cottontail were detected in prior surveys of 2009–2017.

Table 6. Detection and time to first detection, an indicator of how many visits were required to detect a New England cottontail given one or more was present at a site, for the 2017–2018 New England cottontail range-wide monitoring survey in states in the northeastern United States.

	Detection probability (SE)	Number of detections	First visit (Cumulative %)	Second visit (Cumulative %)	Third visit (Cumulative %)
Range-wide	0.911 (0.080)	103	85 (83%)	12 (95%)	5 (99%)
Connecticut	0.927 (0.039)	37	33 (89%)	3 (97%)	1 (100%)
Maine	0.996 (0.020)	21	18 (86%)	2 (95%)	1 (100%)
Massachusetts	0.799 (0.158)	20	19 (95%)	1 (100%)	
New Hampshire	0.971 (0.086)	7	6 (86%)	1 (100%)	
New York	0.556 (0.153)	17	8 (47%)	5 (76%)	3 (94%)
Rhode Island	1.000 (0.014)	1	1 (100%)		

occupied to 103 at the end of the range-wide monitoring survey in 2017–2018.

CONCLUSIONS

The ultimate goal of monitoring studies is to detect a change in species status should a change occur. For cryptic and rare species, detecting changes in status can be challenging, and it is especially important to understand the relationship between study design and reliability of information for decision making. Here, we evaluated the New England cottontail range-wide survey with respect to its ability to detect a change in occupancy. A power analysis applied to data from the 2016–2017 survey indicated insufficient power (0.76) to detect a large (0.50) change in occupancy. Substantially increasing the number of sites sampled, the number of occupied sites sampled, or both actions were needed to increase power and enable range-wide survey objectives to be met. A revised study design implemented in 2017–2018 that included sampling all known previously occupied sites was shown to be more robust than the original study design, with 0.81 power to detect a 0.30 change in occupancy. Our findings highlight the important role of structured decision-making in making transparent, data-informed, and defendable decisions when developing, evaluating, and revising monitoring plans for cryptic and rare species such as the New England cottontail. In particular, identifying performance measures and using power analyses provided a benchmark to understand whether or not objectives were being met. Whereas the initial study design met monitoring objective 1 by providing an estimate of occupancy, its continued implementation would not have provided the critically needed information on changes in occupancy status over time (monitoring objective 2), nor provide information on response to habitat management (monitoring objective 3). In contrast, the revised study design met objective 1 and provided a path to meet objectives 2 and 3, with greater power to detect a smaller change in occupancy, key pieces of information on which to base management decisions for the New England cottontail.

Our findings also highlight the importance of system-specific study design considerations when developing a monitoring program for rare and cryptic species. In this case, knowledge of the species prior occurrence on the landscape was critical for selection of monitoring sites, given that only a small amount of suitable habitat is occupied by remnant populations of New England cottontail (Litvaitis et al. 2006). Defining the sampling frame to focus on known occupied sites therefore was critical for a study design with sufficient power to track changes in occupancy status. Random selection of sites irrespective of occupancy status would not have yielded a robust study design for this rare species, unless a very large number of sites were surveyed—in this case, it would have required many-fold more sites than existing personpower and resources. Accordingly, the original protocol of Shea et al. (2019) may have been appropriate for an abundant, wide-spread species within its range, but lacked power to detect trends in the status of the New England cottontail, given its low occupancy and limited distribution within suitable habitat. Focusing surveys on a large proportion of occupied sites makes sense for meeting management goals as well. For declining or vulnerable populations, the proportion of previously occupied sites that remain occupied over time is of primary interest in conservation management (Olea and Mateo-Tomas 2011). If management actions reverse population declines, then the newly occupied sites will be colonized from those previously occupied, further necessitating the focus on known occupied areas and surrounding areas. Lastly, and perhaps most importantly, our process brought to light new information on the continued and severe decline of this rare species, which would not have been possible without identifying the need for and adapting the monitoring protocol.

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