USGS science for a changing world

ESTIMATING SITE OCCUPANCY AND DETECTION PROBABILITY PARAMETERS FOR MESO- AND LARGE MAMMALS IN A COASTAL ECOSYSTEM

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Background

Long-term monitoring programs for wildlife populations are being implemented world-wide in an effort to assess changes that occur across time and space. Unfortunately, many programs fail to consider two important sources of variability, spatial variation and detectability, often resulting in index-type information where the relationship between the count and the target population is unknown, making it difficult to make meaningful inferences. As part of the U.S. National Park Service's (NPS) nationwide effort to develop *science-based* monitoring programs, we used a new technique (MacKenzie et al. 2002, 2003, 2004) to estimate site occupancy and detection probabilities for medium-sized and large mammals on Cape Cod, Massachusetts. Using this approach, we demonstrate how these parameters can guide sampling effort in the design of biological inventories and develop monitoring programs that allow inferences to be made about species' distributions or population change.

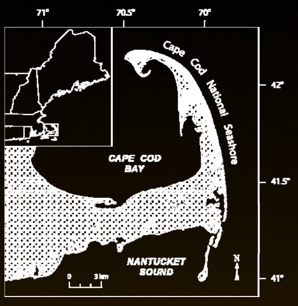
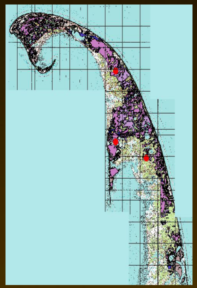


Figure 1. Map of Cape Cod, Massachusetts showing the boundary of Cape Cod National Seashore.

Site and Sample Selection



Sites were selected to include 5 of the major vegetation communities w/in Cape Cod National Seashore.

A Systematic Random sample of points was chosen using the Arcview extension "Sample" by Quantitative Designs Inc.

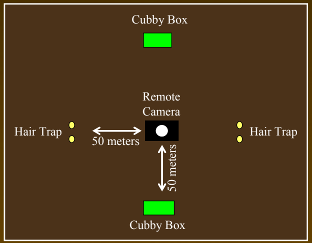
Points were randomly chosen within cells of a grid of random origin, following criteria of one point per cell.

Coordinates produced by Arcview were entered into a hand-held GPS and exact locations were marked in the field.

Techniques and Site Layout

Sites were setup to include:

- 1 Remote Camera - Active/Passive Infrared
- 2 Cubby boxes - Sooted aluminum plate housed inside a plywood box
- 2 Hair Traps – Serrated Aluminum attached to stakes
- ❖ Equipment was oriented in a configuration similar to the diagram
- ❖ Size and shape of the habitat patch occasionally prevented this exact configuration

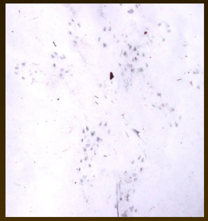


Study Area, Techniques, and Analyses

Cape Cod forms the eastern edge of Massachusetts and juts out into the Atlantic Ocean. The landform has been shaped by a combination of hurricanes, agriculture, recreation, suburban development, and fire, and the vegetation and topography are typical of Atlantic barrier islands. Our study area was limited to federal lands within the Cape Cod National Seashore, a unit of the NPS (see Figure 1). We used 3 different techniques bundled into a single sampling array to detect medium-sized and large terrestrial mammals. Remote cameras with infrared detection, hair catchers, and cubby boxes (i.e., covered track plates) were placed at randomly selected sites and detection/nondetection information was collected at each site; multiple sites were located within 5 different vegetative strata. We calculated site occupancy (ψ) and detection probabilities (p) for each species detected and used AIC model selection to assess the importance of individual sampling methods and major environmental factors on these parameters. To illustrate how detection probabilities can be used to design inventory programs, we used model-averaged detection estimates to calculate the 95% probability that a target species would be detected at least once at an occupied site in "*T*" weeks of sampling. For comparison, we then applied the recommendations developed by MacKenzie and Royle (2005) to determine the optimal number of sampling occasions (weeks, in our case) for designing a long-term monitoring program. All analyses can be performed with either the program MARK (White and Burnham 1999) or PRESENCE 2.0 (J. Hines and D. Mackenzie, http://www.mbr-pwrc.usgs.gov/software.html).

Archived Track Specimens

Virginia Opossum (*Didelphis virginiana*) prints



Long-tailed Weasel (*Mustela frenata*) prints

Results

White-tailed deer and river otter were detected only by remote cameras, whereas long-tailed weasels were detected only with cubby boxes. The remaining 7 species were detected by more than one method and included the Virginia opossum, gray squirrel, cottontail, and 4 medium-sized carnivores: coyote, striped skunk, raccoon, and red fox (Table 1). Given that the target species is present, remote cameras are at least 3 times more likely to detect coyote, striped skunk, cottontail, raccoon, and red fox than hair traps. Cameras also were equal or superior to cubby boxes for many of these same species, except for long-tailed weasels and gray squirrels. Occupancy differences were less evident among the 4 species detected by hair traps. We found that vegetation influenced detectability and site occupancy for some carnivores and that seasonality influenced detectability of opossums (Table 2). Guided by our detection probabilities, remote cameras on Cape Cod need to be deployed at least 12 weeks to confirm site occupancy for coyotes (with 95% accuracy), whereas hair traps would require twice the sampling period (Figure 2A). The probability of detecting a raccoon at least once at occupied sites approaches 95% after 6-7 weeks of sampling with remote cameras, 11 weeks with cubby boxes, and over 20 weeks with hair traps (Figure 2B). Using our model averaged estimates for coyotes on Cape Cod as a guide (Table 2), the optimal number of weeks needed to confirm occupancy per year for monitoring purposes is 12-15 for remote cameras and over 30 weeks for hair traps. The optimal number of weeks needed for raccoon is 6-7 weeks for remote cameras, 8-12 weeks for cubby boxes, and 26-34 weeks for hair traps.

TABLE 1. Parameter estimates using model, $\psi(.)\,p(.)$, from 3 detection methods on 13 sites for 43 possible sampling weeks: hair trap (HAIR), cameras (CAM), and Cubby box (CUB). Results are given for 10 mammal species: *Coyote* (CL), *Virginia Opossum* (DV), *River Otter* (LC), *Long-Tailed Weasel* (MF), *Striped Skunk* (MM), *Whitetail Deer* (OV), *Raccoon* (PL), *Gray Squirrel* (SC), *Cottontail* (SS), and *Red Fox* (VV). ψ(min) is the proportion of sites where a species was observed using all detection methods. ψ(obs) is the proportion of sites where a species was observed for the given detection method. Bold entries indicate instances where ψ(min) was not within the interval.

		CAM (T = 128)			CUB (T = 172)			HAIR (T = 187)		
Species	ψ(min)	ψ(obs)	$\hat{\psi}(.)$ [SE$\hat{\psi}$(.)]	$\hat{p}(.)$ [SE$\hat{\psi}$(.)]	ψ(obs)	$\hat{\psi}(.)$ [SE$\hat{\psi}$(.)]	$\hat{p}(.)$ [SE$\hat{\psi}$(.)]	ψ(obs)	$\hat{\psi}(.)$ [SE$\hat{\psi}$(.)]	$\hat{p}(.)$ [SE$\hat{\psi}$(.)]
CL	0.92	0.83	0.94 (0.12)	0.21 (0.04)	-	-	-	**0.54**	**1.00 (0.00)**	**0.05 (0.02)**
DV	0.39	**0.17**	**0.21 (0.14)**	**0.16 (0.09)**	0.31	Na	Na	**0.39**	**0.68 (0.21)**	**0.11 (0.03)**
LC	0.17	0.17	0.17 (0.11)	0.40 (0.11)	-	-	-	-	-	-
MF	0.23	-	-	-	0.23	0.29 (0.14)	0.19 (0.08)	-	-	-
MM	0.46	0.33	0.36 (0.15)	0.27 (0.07)	0.39	0.60 (0.19)	0.13 (0.04)	0.23	0.47 (0.25)	0.06 (0.03)
OV	0.25	0.25	0.34 (0.17)	0.16 (0.06)	-	-	-	-	-	-
PL	0.39	0.17	Na	Na	0.23	0.38 (0.19)	0.12 (0.04)	-	-	-
SC	0.31	0.31	0.34 (0.14)	0.41 (0.07)	0.08	Na	Na	-	-	-
SS	0.85	0.83	0.90 (0.12)	0.38 (0.05)	0.69	0.86 (0.12)	0.25 (0.04)	**0.31**	**0.55 (0.23)**	**0.08 (0.03)**
VV	0.39	0.25	0.28 (0.15)	0.20 (0.10)	0.15	Na	Na	-	-	-

Na – model yielded nonsensical occupancy estimates (1.0) because of low probability of detection for the given method, p<0.02

Discussion

Scientifically-defensible monitoring programs are needed that can document biodiversity and detect changes in biological systems, but it is important to first identify program objectives, account for sources of variation, test and validate the underlying assumptions, and then evaluate the proposed enumeration methods (Pollock et al. 2002). Following this guide, we tested and validated our assumptions of seasonal closure in our target populations and independence among different detection methods. Our results demonstrated that detectability is not equal to 1 nor is it likely to be constant due to a variety of factors including sampling methods, behavior and ecology of the target species, and/or local environmental characteristics. In our study, species-specific detectability varied considerably across detection methods and resulted in questionable site occupancy estimates when not accounting for this variation. As a result, we question site occupancy estimates (and resulting inferences) when detectability falls below 0.15 and we consider probabilities < 0.05 unacceptable for occupancy estimation and inference. Future studies will benefit from incorporating detection probabilities into their findings because of the potential variation in detectability. Site occupancy surveys that incorporate detection probabilities provide the necessary foundation for conducting efficient biological inventories and subsequent long-term monitoring.

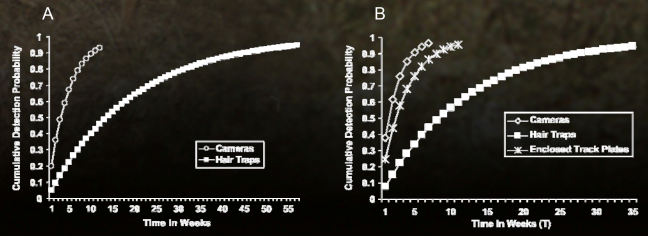


Figure 2. The probability of detecting a target species at least once (cumulative detection probability) in "T" weeks of sampling for coyotes (A) and raccoons (B) on Cape Cod, Massachusetts. Graphs based on model averaged (weekly) detection probabilities for each species and detection method were: (Coyote = A) remote cameras (p = 0.20), hair traps (p = 0.05); (Raccoon = B) remote cameras (p = 0.38), hair traps (p = 0.08), cubby boxes (p = 0.25).

Table 2: Summary of model selection results and a subset of estimates from the top models for each of 7 mammal species. Detection/nondetection data for each species was fit to a candidate model set consisting of 14 models. Occupancy probability, ψ, was modeled as constant across sites or varied according to vegetation or detection method. Detection probability, p, was modeled as constant across all sample occasions or varying among seasons, vegetation, detection methods, or an interactive effect of method*season (see text for more details). AICc weight indicates the relative support for a given model; the top 3 models for each species are presented. Only a subset of parameter estimates from remote cameras, cubby boxes, and hair traps methods are given, but model-averaged estimates are based on the full set of candidate models.

Species	Models	AIC$_c$ weight	$\hat{P}_{CAM}$	$\hat{P}_{CUB}$	$\hat{P}_{HAIR}$	$\hat{\psi}_{CAM}$	$\hat{\psi}_{CUB}$	$\hat{\psi}_{HAIR}$
Coyote	ψ(.) p(Method)	0.78	0.20		0.06	0.96		0.96
	ψ(Method) p(Method)	0.20	0.21		0.05	0.94		1.0
	Model Averaged Estimates (standard error)		0.20 (0.04)		0.05 (0.02)	0.94 (0.11)		0.96 (0.09)
Opossum	ψ(.) p(Season)	0.63				0.62	0.62	0.62
	ψ(Veg) p(Season)	0.15						
	ψ(Method) p(Season)	0.10				0.35	0.62	0.82
	Model Averaged Estimates (standard error)					0.60 (0.18)	0.63 (0.17)	0.66 (0.17)
Striped skunk	ψ(.) p(Veg)	0.50				0.62	0.62	0.62
	ψ(Veg) p(Method)	0.16	0.24	0.13	0.06			
	ψ(.) p(Method)	0.10	0.26	0.13	0.07	0.46	0.46	0.46
	Model Averaged Estimates (standard error)		0.21 (0.08)	0.13 (0.03)	0.08 (0.04)	0.60 (0.17)	0.60 (0.17)	0.58 (0.17)
Raccoon	ψ(.) p(Method)	0.49	0.38	0.25	0.05	0.85	0.85	0.85
	ψ(Veg) p(Method)	0.33	0.39	0.25	0.06			
	ψ(.) p(Season*Method)	0.08	0.38	0.25	0.08	0.90	0.86	0.52
	Model Averaged Estimates (standard error)		0.39 (0.05)	0.25 (0.04)	0.06 (0.02)	0.85 (0.10)	0.85 (0.10)	0.80 (0.14)
Gray squirrel	ψ(.) p(Method)	0.38	0.03	0.12		0.44	0.44	
	ψ(.) p(.)	0.27	0.09	0.09		0.36	0.36	
	ψ(Method) p(Method)	0.15	0.02	0.12		1.00	0.38	
	Model Averaged Estimates (standard error)		0.05 (0.04)	0.11 (0.04)		0.49 (0.25)	0.41 (0.18)	
Cottontail	ψ(.) p(Method)	0.76	0.41	0.02		0.35	0.35	
	ψ(Method) p(Method)	0.20	0.41	0.01		0.34	1.0	
	Model Averaged Estimates (standard error)		0.41 (0.07)	0.01 (0.01)		0.35 (0.17)	0.49 (0.26)	
Red fox	ψ(.) p(Method)	0.24	0.19	0.04		0.32	0.32	
	ψ(.) p(.)	0.20	0.10	0.10		0.30	0.30	
	ψ(.) p(Veg)	0.18				0.52	0.52	
	Model Averaged Estimates (standard error)		0.15 (0.09)	0.06 (0.05)		0.35 (0.17)	0.41 (0.22)	

Literature Cited

MacKenzie, D.I., J. D. Nichols, G. B. Lachman, S. Droege, R. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255.

_____, J. D. Nichols, J. E. Hines, M. G. Knutson, and A. B. Franklin. 2003. Estimating site occupancy, colonization, and extinction when a species is detected imperfectly. Ecology 84:2200-2207.

_____, L. L. Bailey, and J. D. Nichols. 2004. Investigating species co-occurrence patterns when species are detected imperfectly. Journal of Animal Ecology 73:546-555.

_____, and J. A. Royle. 2005. Designing efficient occupancy studies: general advice and tips on allocation of survey effort. Journal of Applied Ecology 74:1105-1114.

Pollock, K. H., J. D. Nichols, T. R. Simon, G. L. Farnsworth, L. L. Bailey, and J. R. Sauer. 2002. Large scale wildlife monitoring studies: statistical methods for design and analysis. Environmetrics 13:105-119.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation for populations of marked animals. Bird Study 46 Supplement:120-138.

Forthcoming Publication

O'Connell, A. F., Jr., N. W. Talancy, L. L. Bailey, J. R. Sauer, R. Cook, and A. T. Gilbert. 2006. Estimating site occupancy and detection probability parameters for mammals in a coastal ecosystem. Journal of Wildlife Management. In Press.