Lecture 09 - Patch Occupancy and Patch Dynamics

Resources

Site Occupancy

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

Tucker Jr., J.W, W.D. Robinson. 2003. Influence of season and frequency of fire on Henslow's sparrows (*Ammodramus henslowii*) wintering on Gulf Coast pitcher plant bogs. Auk 120:96-106.

Patch dynamics

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

Barbraud, C., J. D. Nichols, J. E. Hines, and H. Hafner. 2003. Estimating rates of local extinction and colonization in colonial species and an extension to the metapopulation and community levels. – Oikos 101: 113–126.

Patch Occupancy:

The Problem

Conduct "presence-absence" (detection-nondetection) surveys

Estimate what fraction of sites (or area) is occupied by a species when species is not always detected with certainty, even when present ($p < 1$)

Motivation

a. Extensive monitoring programs

b. Incidence functions and metapopulations

c. Surveys of geographic range

Important Sources of Variation

d. Spatial variation

    1) Interest in large areas that cannot be completely surveyed

    2) Sample space in a manner permitting inference about entire area of interest

e. Detection probability - even on surveyed areas in sample don't detect all animals present

Extensive Monitoring Programs

    1) State Variables:

Abundance/population size

Proportion of patches or sample areas occupied

Species richness

2) Monitoring expense/effort: a>b>c

3) Proportion of sites or areas occupied is a relatively inexpensive approach to single-species monitoring

Incidence Functions and Metapopulations

$$\Pr(\text{occurrence of species in patch}) = f(\text{patch characteristics})$$

Proportion of patches occupied: state variable in metapopulation models, e.g.,

Levins (1969, 1970)

Lande (1987, 1988)

Hanski (1992, 1994, 1997)

Proportion of patches occupied: basis for estimating patch extinction and colonization probabilities

Basic Sampling Scheme

N sites are surveyed, each at T distinct sampling occasions

Species is detected/not detected at each occasion

Detection History Data

1 = detection, 0 = non-detection

Examples:

Detections on occasions 1, 2, 4:	1101
Detections on occasions 2, 3:	0110
No detections at site:	0000

Distinct sampling occasions may be:

Repeated visits on different days

Multiple surveys on the same visit

Small time periods within a survey

e.g., detection/non-detection is recorded every minute of a 5-minute auditory survey

Maintain detection probability at a reasonable level (e.g., >0.10)

Model Parameters and Assumptions

ψ_i -probability site i is occupied

p_{ij} -probability of detecting the species in site i at time j, given species is present

f. The detection process is independent at each site

g. No heterogeneity that cannot be explained by covariates

h. Sites are closed to changes in occupancy state between sampling occasions

Probabilistic Model

Pr(detection history 1001) =

$$\psi_i \left[p_{i1} \left(1 - p_{i2}\right)\left(1 - p_{i3}\right) p_{i4} \right]$$

Pr(detection history 0000) =

$$\psi_k \prod_{j=1}^{4} \left(1 - p_{kj}\right) + \left(1 - \psi_k\right)$$

i. The product of these statements across all potential histories forms the model likelihood

j. Maximum likelihood estimates of parameters (MLEs) can be obtained

k. However, parameters cannot be site specific without additional information (covariates)

l. Parametric bootstrap for goodness-of-fit

As in MARK but see MacKenzie and Bailey (2005)

The Likelihood Function

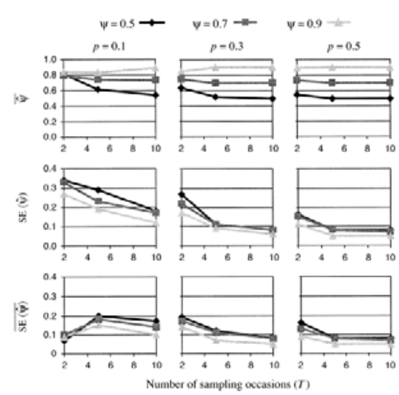
$$\mathcal{L}\left(\psi, \{p_j\} \mid N, n., \{n_j\}\right)$$
$$= \left[\psi^{n.} \prod_{j=1}^{T} p_j^{n_j} \left(1 - p_j\right)^{n.-n_j} \right] \left[\psi \prod_{j=1}^{T} \left(1 - p_j\right) + \left(1 - \psi\right) \right]^{N-n.}$$

N – total number of occupied sties

p_j – probability of detection at time j

$n.$ - total number of sites at which species was detected at least once

n_j - number of sites at which species was detected at time j



Does It Work?

Simulation study to assess how well ψ is estimated (MacKenzie et al. 2002)

T = 2, 5, 10

N = 20, 40, 60

ψ = 0.5, 0.7, 0.9

p = 0.1, 0.3, 0.5

m = 0.0, 0.1, 0.2

Generally unbiased estimates when Pr(detecting species at least once) is moderate ($p^* > 0.5$)

Bootstrap estimates of SE also appear reasonable for a similar range

Including Covariates

a. ψ may only be a function of site-specific covariates

Site-specific covariates do not change during the survey

i.e., habitat type or patch size

b. p may be a function of site and/or time specific covariates

Sampling occasion covariates may vary with each sampling occasion and possibly site

i.e., cloud cover or air temperature

Example:

Linear-logistic function: covariates for site (X_i) and sampling occasion (T_{ij})

$$\psi_i = \frac{\exp(\beta_0 + \beta_1 X_i)}{1 + \exp(\beta_0 + \beta_1 X_i)}$$

$$p_{ij} = \frac{\exp(\beta_0 + \beta_1 X_i + \beta_2 Y_{ij})}{1 + \exp(\beta_0 + \beta_1 X_i + \beta_2 Y_{ij})}$$

Average Pr(occupancy):

$$\hat{\bar{\psi}} = \frac{\sum_{i=1}^{N} \hat{\psi}_i}{N}$$

Example: Anurans at Maryland Wetlands (Droege and Lachman)

Frogwatch USA (NWF/USGS) – now PARC

Volunteers surveyed sites for 3-minute periods after sundown on multiple nights

29 wetland sites; piedmont and coastal plain

27 Feb. – 30 May, 2000

Covariates:

a. Sites: habitat ([pond, lake] or [swamp, marsh, wet meadow])

b. Sampling occasion: air temperature

Example: Anurans at Maryland Wetlands (Droege and Lachman)

American toad (*Bufo americanus*)

Detections at 10 of 29 sites

Spring peeper (Hyla crucifer)

Detections at 24 of 29 sites

Example: Anurans at Maryland Wetlands (*H. crucifer*)

- Naïve $\hat{\psi} = 0.83$

Model	ΔAIC	$\hat{\hat{\psi}}$	$\hat{SE}\left(\hat{\hat{\psi}}\right)$
ψ(hab)p(tmp)	**0.00**	**0.84**	**0.07**
ψ(.)p(tmp)	1.72	0.85	0.07
y(hab)p(.)	40.49	0.84	0.07
ψ(.)p(.)	42.18	0.85	0.07

Example: Anurans at Maryland Wetlands (*B. americanus*)

- Naïve $\hat{\psi} = 0.34$

Model	ΔAIC	$\hat{\hat{\psi}}$	$\hat{SE}\left(\hat{\hat{\psi}}\right)$
ψ(hab)p(tmp)	0.00	0.50	0.13
ψ(.)p(tmp)	0.42	0.49	0.14
ψ(hab)p(.)	0.49	0.49	0.12
ψ(.)p(.)	0.70	0.49	0.13

Software

Windows-based software

- Program PRESENCE – pwrc.usgs.gov
- Program MARK

Fit both predefined and custom models, with or without covariates

Provide maximum likelihood estimates of parameters and associated standard errors

Assess model fit

Patch Occupancy as a State Variable: Modeling Dynamics

Patch occupancy dynamics

Model changes in occupancy over time

Parameters of interest:

$\lambda_t = \psi_{t+1} / \psi_t$ = rate of change in occupancy

$1-\phi_t = Pr$(absence at time t+1 | presence at t) = patch extinction probability

$\gamma_t = Pr$(presence at t+1 | absence at t) = patch colonization probability

Patch Occupancy Dynamics: Pollock's Robust Design

Sampling scheme:

Primary sampling periods: long intervals between periods such that occupancy status can change

Secondary sampling periods: short intervals between periods such that occupancy status is expected not to change

Robust Design Capture History

History : 10 00 11 01

10, 01, 11 = presence

Interior '00' =

Patch occupied but occupancy not detected, or

Patch not occupied (=locally extinct), yet re-colonized later

Robust Design Capture History

Parameters:

ϕ_t - probability of survival from t to t+1

p^*_t - probability of detection at least once in primary period t

$$p_t^* = 1 - (1 - p_{t1})(1 - p_{t2})$$

γ_t - probability of colonization in t+1 given absence in t

$$\Pr(10\ 00\ 11\ 01) = p_1^* \left[\phi_1 (1 - p_2^*) \phi_2 + (1 - \phi_1) \gamma_2 \right] p_3^* \phi_3 p_4^*$$

Model Fitting, Estimation and Testing

Unconditional modeling:

program PRESENCE

Program MARK

Conditional modeling: can "trick" either program RDSURVIV or program MARK into estimating parameters of interest using Markovian temporary emigration models:

Fix ϕt = 1 ('site survival')

γ"t : probability of extinction

1-γ't : probability of colonization

$$\Pr(10\ 00\ 11) = \gamma''_2 (1-\gamma'_3) + (1-\gamma''_2)(1-p_2^*)(1-\gamma''_3) p_3^*$$

Main assumptions

All patches are independent (with respect to site dynamics) and identifiable

Independence violated when sub-patches exist within a site

No colonization and extinction between secondary periods

Violated when patches are settled or disappear between secondary periods => breeding phenology, disturbance

No heterogeneity among patches in colonization and extinction probabilities except for that associated with identified patch covariates

Violated with unidentified heterogeneity
(reduce via stratification, etc.)

Tests and Models of Possible Interest

Testing time dependence of extinction and colonization rates

Testing whether site dynamics reflect a first-order Markov process (i.e., colony state at time t depends on state at time t-1) vs. non-Markovian process ($\phi_t = \gamma_t$)

Building linear-logistic models and testing the effects of individual covariates
e.g., logit(ϕ_t or γ_t) = $\beta_0 + \beta_1 x_t$

Example: Modeling Waterbird Colony Site Dynamics

Colony-site turnover index
(Erwin et al. 1981, Deerenberg & Hafner 1999)

Combines colony-site extinctions and colonization in single metric

Not possible to address mechanistic hypotheses about factors affecting these site-level vital rates

Markov process model of Erwin et al. (1998)

Developed for separate modeling and estimation of extinction and colonization probabilities

Assumes all colonies are detected

Modeling Colony Dynamics with Patch Occupancy (Barbraud et al. 2003)

Approaches when:

All colonies are detected

Some colonies are missed

Two examples from the Camargue, France:

Grey heron Ardea cinerea

Purple heron Ardea purpurea

Focus on Purple heron, where some colonies may be missed

Example: Purple heron

Colonial breeder in the Camargue
(from 1 to ≈300 nests; n = 43 sites)

Colonies found only in reed beds -

Factors affecting detection (p < 1 ?)

breeds in May => reed stems grown

small nests (≈ 0.5 m diameter) with brown color (similar to reeds)

Two surveys (early May & late May) per year by airplane (100m above ground) covering the entire Camargue area, each lasting one or two days

Since 1981 (Kayser et al. 1994, Hafner & Fasola 1997)

Questions:

What is the detection probability, p^* ?

Time and area effects on colonization and extinction probabilities ?

Example: Purple Heron
Model Selection Inferences About p

No time (year) or regional variation in detection probability, p

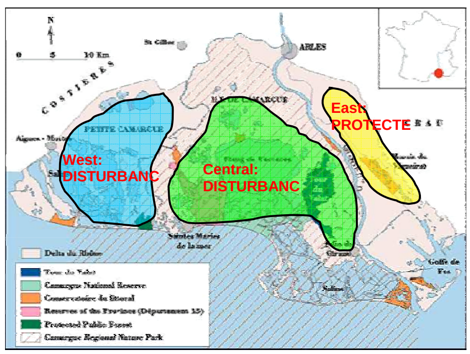
Similar detection probability for colonies that were and were not detected on the first flight of each year

$p = 0.975 \pm 0.006$

$p^* = 1-(1-p)^2 = 0.9994 \approx 1$

Study area

Divided in 3 sub-areas based on known different management practices of breeding sites (Mathevet 2000)



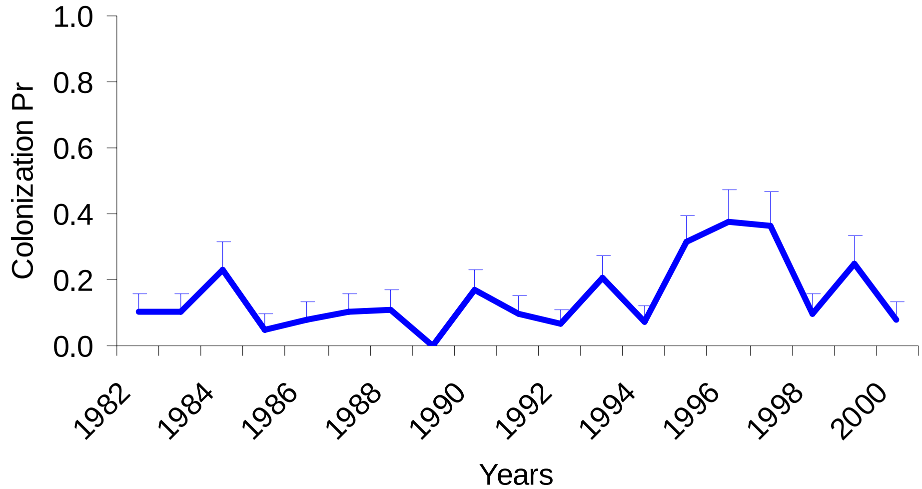
Questions about patch dynamics:

Time effects on extinction\colonization probabilities over all areas ?

Extinction\colonization probabilities higher in central (highly disturbed) area ?

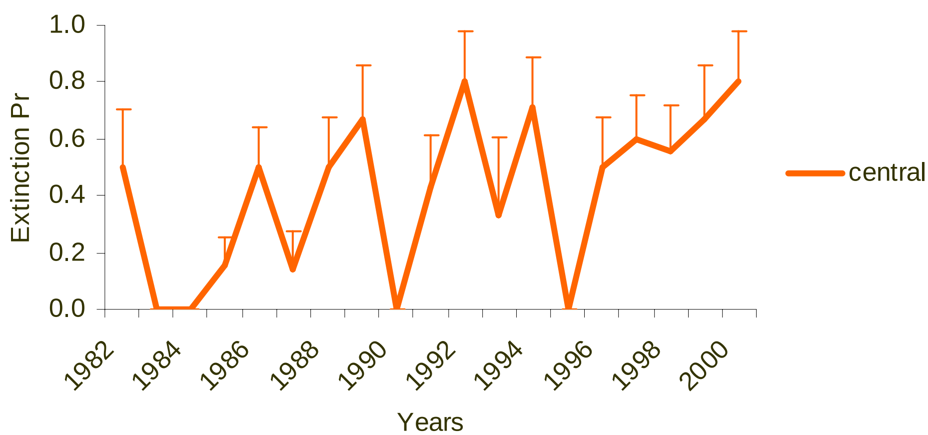
Model Selection

Model	AICc	ΔAICc	w_i	K
$[\phi_{w=e(.)c(t)}\, \gamma_t]$	**308.0**	0	0.77	**39**
$[\phi_g\, \gamma_t]$	310.4	2.4	0.23	22
$[\phi_t\, \gamma_t]$	348.5	40.5	0.00	38
$[\phi_{g*t}\, \gamma_t]$	352.5	44.5	0.00	76
$[\phi_{g*t}\, \gamma]$	356.9	48.9	0.00	60
$[\phi_{g*t}\, \gamma_g]$	357.1	49.1	0.00	60



[$\phi_{g*t}\,\gamma_{g*t}$]	405.6	97.6	0.00	114

LRT [ϕ_{g*t} γ_t] vs [ϕ_g γ_t] : χ^2_{54}= 80.5, P = 0.011



Extinction west = east = 0.137 ± 0.03

Additional Question:

Can colonization in west or east be modeled as a function of extinction in central ?

Linear-logistic models coded in SURVIV:

$$\gamma_{\mathrm{w}} = \frac{e^{\beta_0 + \beta_1 \phi_c}}{e^{\beta_0 + \beta_1 \phi_c}}$$

$$\gamma_{\mathrm{e}} = \frac{e^{\beta_0 + \beta_1 \phi_c}}{e^{\beta_0 + \beta_1 \phi_c}}$$

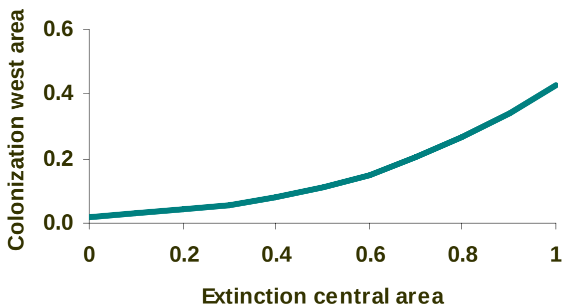
Possible in MARK?

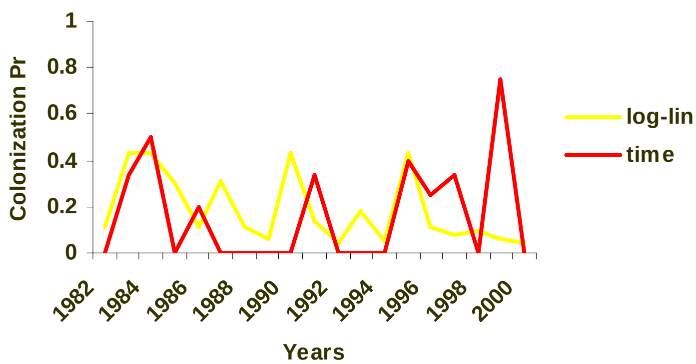
Model	AICc	ΔAICc	*K*
[$\phi_{w=e(.)}$ c(*t*) γ_t]	**308.0**	**0**	**39**
[ϕ_{abv} $\gamma_{w=f(\phi c)}$]	315.2	7.2	41
[ϕ_{abv} $\gamma_{e=f(\phi c)}$]	319.1	11.1	41

Model [ϕ_{abv} $\gamma_{w=f(\phi c)}$]

Intercept = -0.29 ± 0.50 (-1.27 to 0.69)

Slope = -3.59 ± 0.61 (-4.78 to –2.40)





Other Applications

Northern spotted owls (Franklin et al.)
(California study area, 1997-2001)

Potential breeding territory occupancy

Estimated p range (0.37 – 0.59);

Estimated λ=0.98

Inference: constant Pr(extinction),
time-varying Pr(colonization)

Tiger salamanders (Bailey et al.)
(Minnesota farm ponds and natural wetlands, 2000-2001)

Estimated p's were 0.25 and 0.55

Estimated Pr(extinction) = 0.17

Naïve estimate = 0.25

Conclusions

"Presence-absence" surveys can be used for inference when repeat visits permit estimation of detection probability

Models permit estimation of occupancy during a single season or year

Models permit estimation of patch-dynamic rate parameters (extinction, colonization, rate of change) over multiple seasons or years

Advances

D. I. MacKenzie, J. D. Nichols, N. Sutton, K. Kawanishi, and L.L. Bailey. 2005. Improving inferences in population studies of rare species that are detected imperfectly. Ecology 86:1101-1113.

J. A. Royle, Nichols, J. D. and Kéry, M. 2005. Modelling occurrence and abundance of species when detection is imperfect. Oikos 110: 353-359.

J. A. Royle. 2004. Modeling abundance index data from Anuran calling surveys. Conservation Biology 18:1378-1385.

J. A. Royle. 2004. N-mixture models for estimating population size from spatially replicated counts. Biometrics 60:108-115.

D. I. MacKenzie, and L.L. Bailey. 2005. Assessing the fit of site-occupancy models. Journal Agricultural, Biological, and Environmental Statistics. 9:300-318.