University of Wyoming
RMark Workshop
Spring 2024; February 27–29
https://github.com/gbarrile/RMark_Workshop_Sp24

Instructor: Dr. Gabriel Barrile, gbarrile@uwyo.edu

Workshop prerequisites: None, but prior courses in statistics and some familiarity with Program R will be helpful.

Description: This workshop introduces participants to fundamental models used in fish and wildlife population analysis. Although examples focus on avian systems, models covered in this workshop can be applied across animal taxa. Course content includes the parameterization of models used to estimate ecological state variables (occupancy, abundance) and population vital rates (survival, recruitment, dispersal) of both marked and unmarked populations, accounting for imperfect capture/detection probability. The workshop covers closed population models, Cormack-Jolly-Seber models, multistate models, reverse-time Pradel models, and Robust Design models with *capture-mark-recapture data*, site-occupancy models with *detection-nondetection data*, known-fate models with *biotelemetry data*, and nest survival models with data from *nest checks*. Models are fitted using the 'RMark' package in Program R. Each mini lesson will begin with an introduction to the subject material through a brief lecture followed by the application of the concepts through exercises in R (e.g., formatting data, fitting and selecting models, visualizing predicted relationships) using simulated or real datasets.

Objectives: (1) build familiarity with key statistical packages (i.e., RMark and Program MARK) used in fish and wildlife population analysis; (2) improve ability to record and format field data for suitable input into appropriate analytical tools; (3) gain comfort in fitting models to estimate demographic rates and forecast population dynamics; (4) properly interpret model outputs and generate tables and figures for reports and scientific publications; and (5) recognize the types of data needed to model specific population parameters in order to develop better study designs (e.g., number of sites, number of surveys per site, whether to tag or not tag individuals).

Required materials: laptop computer with Program MARK and Program R installed.

Helpful resources: Program MARK – 'a gentle introduction'. Go to http://www.phidot.org/software/mark/docs/book/ and select specific chapters from the dropdown menu.

All other supplemental readings constitute articles from the primary literature that are freely available online—see the 'Supplemental Readings' section below for a complete list of readings (pdfs of articles can be provided for those without access).

Relevant textbooks:

Williams, B. K., Nichols, J. D., & Conroy, M. J. (2002). *Analysis and management of animal populations*. Academic press.

Amstrup, S. C., McDonald, T. L., & Manly, B. F. (2005). *Handbook of capture-recapture analysis*. Princeton University Press.

Kéry, M., & Royle, J. A. (2015). *Applied Hierarchical Modeling in Ecology: Analysis of distribution, abundance and species richness in R and BUGS: Volume 1: Prelude and Static Models*. Academic Press.

Kéry, M., & Royle, J. A. (2020). *Applied Hierarchical Modeling in Ecology: Analysis of distribution, abundance and species richness in R and BUGS: Volume 2: Dynamic and Advanced Models*. Academic Press.

Workshop Outline

Spring 2024 RMark Workshop

Day 1 (2/27)	
08:30–10:00	Introduction
10:00–12:00	Closed Population Estimation
12:00–01:30	**Lunch**
01:30–03:00	Cormack-Jolly-Seber Model
Day 2 (2/28)	
08:30–10:00	Robust Design with Temporary Emigration
10:00–11:30	Robust Design Multi-State Model
11:30–12:30	**Lunch**
12:30–01:30	Site-Occupancy Model (Single-Season)
01:30–02:30	Site-Occupancy Model (Multi-Season)
Day 3 (2/29)	
08:30–10:30	Known Fate Model
10:30–12:30	Nest Survival Model
12:30–02:00	**Lunch and Department Seminar**
02:00–04:00	Robust Design Pradel Recruitment Model

*Schedule subject to change depending on participant interests

Supplemental Readings (not required)

Model 1 – Closed Population Estimation

Program MARK – a 'gentle introduction.' Chapter 14: Closed population capture-recapture models, written by Paul Lukacs. Go to http://www.phidot.org/software/mark/docs/book/ and select Chapter 14 from the dropdown menu.

Program MARK – a 'gentle introduction.' Appendix C: RMark – an alternative approach to building linear models in MARK, written by Jeff Laake and Eric Rexstad. Go to http://www.phidot.org/software/mark/docs/book/ and select Appendix C from the dropdown menu.

Otis, D. L., Burnham, K. P., White, G. C., & Anderson, D. R. (1978). Statistical Inference from Capture Data on Closed Animal Populations. *Wildlife Monographs*, *62*, 3–135. http://www.jstor.org/stable/3830650

Huggins, R. (1989). On the statistical analysis of capture experiments. *Biometrika*, *76*(1), 133-140. https://doi.org/10.1093/biomet/76.1.133

Model 2 – Cormack-Jolly-Seber Model

Program MARK – a 'gentle introduction.' Chapter 4: Building & comparing models. Go to http://www.phidot.org/software/mark/docs/book/ and select Chapter 4 from the dropdown menu.

Program MARK – a 'gentle introduction.' Chapter 7: 'Age' and cohort models. Go to http://www.phidot.org/software/mark/docs/book/ and select Chapter 7 from the dropdown menu.

Lebreton, J. D., Burnham, K. P., Clobert, J., & Anderson, D. R. (1992). Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. *Ecological Monographs*, *62*(1), 67-118. https://doi.org/10.2307/2937171

Muñoz, A. P., Kéry, M., Martins, P. V., & Ferraz, G. (2018). Age effects on survival of Amazon forest birds and the latitudinal gradient in bird survival. *The Auk: Ornithological Advances*, *135*(2), 299-313. https://doi.org/10.1642/AUK-17-91.1

Kanyamibwa, S., Bairlein, F., & Schierer, A. (1993). Comparison of survival rates between populations of the White Stork Ciconia 3iconia in Central Europe. *Ornis Scandinavica*, 297-302. https://doi.org/10.2307/3676791

Wei, L., Wenqin, Z., & Wang, D. (2020). Seasonal dynamic of population survival and its mechanism in Mongolian gerbils (*Meriones unguiculatus*) in the Inner Mongolia agro-pastoral ecotone. *ACTA Theriologica Sinica*, *40*(6), 571. https://doi.org/10.16829/j.slxb.150431

Model 3 – Robust Design with Temporary Emigration

Program MARK – a 'gentle introduction.' Chapter 15: The 'robust design', written by William Kendall. Go to http://www.phidot.org/software/mark/docs/book/ and select Chapter 15 from the dropdown menu.

Kendall, W. L., Nichols, J. D., & Hines, J. E. (1997). Estimating temporary emigration using capture–recapture data with Pollock's robust design. *Ecology*, *78*(2), 563-578. https://doi.org/10.1890/0012-9658(1997)078[0563:ETEUCR]2.0.CO;2

Muths, E., Scherer, R. D., Corn, P. S., & Lambert, B. A. (2006). Estimation of temporary emigration in male toads. *Ecology*, *87*(4), 1048-1056. https://doi.org/10.1890/0012-9658(2006)87[1048:EOTEIM]2.0.CO;2

Fujiwara, M., & Caswell, H. (2002). A general approach to temporary emigration in mark–recapture analysis. *Ecology*, *83*(12), 3266-3275. https://doi.org/10.1890/0012-9658(2002)083[3266:AGATTE]2.0.CO;2

Bailey, L. L., Simons, T. R., & Pollock, K. H. (2004). Estimating detection probability parameters for plethodon salamanders using the robust capture-recapture design. The Journal of Wildlife Management, 68(1), 1-13. https://doi.org/10.2193/0022-541X(2004)068[0001:EDPPFP]2.0.CO;2

Model 4 – Robust Design Pradel Recruitment Model

Program MARK – a 'gentle introduction.' Chapter 13: Time-symmetric open models: recruitment, survival, and population growth rate. Go to http://www.phidot.org/software/mark/docs/book/ and select Chapter 13 from the dropdown menu.

Pradel, R. (1996). Utilization of capture-mark-recapture for the study of recruitment and population growth rate. *Biometrics*, 703-709. https://doi.org/10.2307/2532908

Muths, E., Scherer, R. D., & Pilliod, D. S. (2011). Compensatory effects of recruitment and survival when amphibian populations are perturbed by disease. *Journal of Applied Ecology*, *48*(4), 873-879. https://doi.org/10.1111/j.1365-2664.2011.02005.x

Sanderlin, J. S., Waser, P. M., Hines, J. E., & Nichols, J. D. (2012). On valuing patches: estimating contributions to metapopulation growth with reverse-time capture–recapture modelling. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1728), 480-488. https://doi.org/10.1098/rspb.2011.0885

Korfanta, N. M., Newmark, W. D., & Kauffman, M. J. (2012). Long-term demographic consequences of habitat fragmentation to a tropical understory bird community. *Ecology*, *93*(12), 2548-2559. https://doi.org/10.1890/11-1345.1

Nichols, J. D., & Pollock, K. H. (1990). Estimation of recruitment from immigration versus in situ reproduction using Pollock's robust design. *Ecology*, *71*(1), 21-26. https://doi.org/10.2307/1940243

Model 5 – Robust Design Multi-State Model

Program MARK – a 'gentle introduction.' Chapter 10: Multi-state models. Go to http://www.phidot.org/software/mark/docs/book/ and select Chapter 10 from the dropdown menu.

Chabanne, D. B., Pollock, K. H., Finn, H., & Bejder, L. (2017). Applying the multistate capture–recapture robust design to characterize metapopulation structure. *Methods in Ecology and Evolution*, *8*(11), 1547-1557. https://doi.org/10.1111/2041-210X.12792

Converse, S. J., Kendall, W. L., Doherty Jr, P. F., & Ryan, P. G. (2009). Multistate models for estimation of survival and reproduction in the grey-headed albatross (*Thalassarche chrysostoma*). *The Auk*, *126*(1), 77-88. https://doi.org/10.1525/auk.2009.07189

Muths, E., Bailey, L. L., Lambert, B. A., & Schneider, S. C. (2018). Estimating the probability of movement and partitioning seasonal survival in an amphibian metapopulation. *Ecosphere*, *9*(10), e02480. https://doi.org/10.1002/ecs2.2480

Model 6 – Site-Occupancy Model (Single-Season)

MacKenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Andrew Royle, J., & Langtimm, C. A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, *83*(8), 2248-2255. https://doi.org/10.1890/0012-9658(2002)083[2248:ESORWD]2.0.CO;2

Tyre, A. J., Tenhumberg, B., Field, S. A., Niejalke, D., Parris, K., & Possingham, H. P. (2003). Improving precision and reducing bias in biological surveys: estimating false-negative error rates. *Ecological Applications*, *13*(6), 1790-1801. https://doi.org/10.1890/02-5078

Program MARK – a 'gentle introduction.' Chapter 21: Occupancy models – single-species, written by Brian Gerber, Daniel Martin, Larissa Bailey, Thierry Chambert, and Brittany Mosher. Go to http://www.phidot.org/software/mark/docs/book/ and select Chapter 21 from the dropdown menu.

Chibesa, M., & Downs, C. T. (2017). Factors determining the occupancy of Trumpeter Hornbills in urban-forest mosaics of KwaZulu-Natal, South Africa. *Urban Ecosystems*, *20*(5), 1027-1034. https://doi.org/10.1007/s11252-017-0656-3

Zungu, M. M., Maseko, M. S., Kalle, R., Ramesh, T., & Downs, C. T. (2020). Factors affecting the occupancy of forest mammals in an urban-forest mosaic in EThekwini Municipality, Durban, South Africa. *Urban Forestry & Urban Greening*, *48*, 126562. https://doi.org/10.1016/j.ufug.2019.126562

Abdoulaye, D., Adama, T., & Matthias, W. (2021). Research and tourism affect positively the occupancy pattern of Loxodonta cyclotis (Elephantidae) in Taï National Park, Côte d'Ivoire. *Nature Conservation Research. Заповедная наука*, *6*(1), 68-77.

Kamjing, A., Ngoprasert, D., Steinmetz, R., Chutipong, W., Savini, T., & Gale, G. A. (2017). Determinants of smooth-coated otter occupancy in a rapidly urbanizing coastal landscape in Southeast Asia. *Mammalian Biology*, *87*(1), 168-175. https://doi.org/10.1016/j.mambio.2017.08.006

Model 7 – Site-Occupancy Model (Multi-Season)

MacKenzie, D. I., Nichols, J. D., Hines, J. E., Knutson, M. G., & Franklin, A. B. (2003). Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecology*, *84*(8), 2200-2207. https://doi.org/10.1890/02-3090

Kéry, M., & Chandler, R. (2016). Dynamic occupancy models in unmarked. http://cran.nexr.com/web/packages/unmarked/vignettes/colext.pdf

Broms, K. M., Hooten, M. B., Johnson, D. S., Altwegg, R., & Conquest, L. L. (2016). Dynamic occupancy models for explicit colonization processes. *Ecology*, *97*(1), 194-204. https://doi.org/10.1890/15-0416.1

Program MARK – a 'gentle introduction.' Chapter 21: Occupancy models – single-species, written by Brian Gerber, Daniel Martin, Larissa Bailey, Thierry Chambert, and Brittany Mosher. Go to http://www.phidot.org/software/mark/docs/book/ and select Chapter 21 from the dropdown menu.

Maphisa, D. H., Smit-Robinson, H., & Altwegg, R. (2019). Dynamic multi-species occupancy models reveal individualistic habitat preferences in a high-altitude grassland bird community. *PeerJ*, *7*, e6276. https://doi.org/10.7717/peerj.6276

Ruiz-Gutiérrez, V., Zipkin, E. F., & Dhondt, A. A. (2010). Occupancy dynamics in a tropical bird community: unexpectedly high forest use by birds classified as non-forest species. *Journal of Applied Ecology*, *47*(3), 621-630. https://doi.org/10.1111/j.1365-2664.2010.01811.x

Model 8 – Known Fate Model

Program MARK – a 'gentle introduction.' Chapter 16: Known-fate models. Go to http://www.phidot.org/software/mark/docs/book/ and select Chapter 16 from the dropdown menu.

Walker, J., & Lindberg, M. S. (2005). Survival of scaup ducklings in the boreal forest of Alaska. *The Journal of wildlife management*, *69*(2), 592-600. https://doi.org/10.2193/0022-541X(2005)069[0592:SOSDIT]2.0.CO;2

Schwartz, C. C., Haroldson, M. A., White, G. C., Harris, R. B., Cherry, S., Keating, K. A., ... & Servheen, C. (2006). Temporal, spatial, and environmental influences on the demographics of grizzly bears in the Greater Yellowstone Ecosystem. *Wildlife Monographs*, *161*(1), 1-8. https://doi.org/10.2193/0084-0173(2006)161[1:TSAEIO]2.0.CO;2

Model 9 – Nest Survival Model

Program MARK – a 'gentle introduction.' Chapter 17: Nest survival models, written by Jay Rotella. Go to http://www.phidot.org/software/mark/docs/book/ and select Chapter 17 from the dropdown menu.

Rotella, J. 2007. Modeling nest-survival data: recent improvements and future directions. *Studies in Avian Biology* **34**: 145–148.

Dinsmore, S. J., White, G. C., & Knopf, F. L. (2002). Advanced techniques for modeling avian nest survival. *Ecology*, *83*(12), 3476-3488. https://doi.org/10.1890/0012-9658(2002)083[3476:ATFMAN]2.0.CO;2

Devineau, O., Kendall, W. L., Doherty Jr, P. F., Shenk, T. M., White, G. C., Lukacs, P. M., & Burnham, K. P. (2014). Increased flexibility for modeling telemetry and nest-survival data using the multistate framework. *The Journal of wildlife management*, *78*(2), 224-230. https://doi.org/10.1002/jwmg.660

Details of each model covered in this workshop

Response	System	Marked	Data	Model
Abundance	Closed	Yes	Capture-Recapture	Closed Population Estimation
Survival	Open	Yes	Capture-Recapture	Cormack-Jolly-Seber Model
Survival	Both	Yes	Capture-Recapture	Robust Design with Temporary Emigration
Recruitment and Growth	Both	Yes	Capture-Recapture	Robust Design Pradel Recruitment Model
Dispersal	Both	Yes	Capture-Recapture	Robust Design Multi-State Model
Distribution	Closed	No	Detection/Nondetection	Site-Occupancy Model (Single-Season)
Change in Distribution	Open	No	Detection/Nondetection	Site-Occupancy Model (Multi-Season)
Survival	Open	Yes	Biotelemetry	Known Fate Model
Survival	Open	Yes	Nest Checks	Nest Survival Model

*All models will be fit in the *RMark* package in Program R

In the **Response column, *Abundance* may be used interchangeably with *Density*, and *Distribution* may be used interchangeably with *Occurrence*

***In the **System** column, *Closed* may be used interchangeably with *Static*, and *Open* may be used interchangeably with *Dynamic*

****In the **Marked** column, *Yes* indicates that individual animals are uniquely identified in the dataset