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Impact of a Century of Climate Change on Small-Mammal Communities in Yosemite National Park, USA

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pear unlikely, putting the focus on elevational gradients, where range-shift gaps will develop early for the great numbers of narrow-ranged species. The lowland tropics lack a source pool of species adapted to higher temperatures to replace those driven upslope by warming, raising the possibility of substantial attrition in species richness in the tropical lowlands.

References and Notes

1. C. Parmesan, *Annu. Rev. Ecol. Evol. Syst.* **37**, 637 (2006).
2. R. Wilson, D. Gutierrez, J. Gutierrez, V. Monserrat, *Glob. Change Biol.* **13**, 1873 (2007).
3. J. Lenoir, J. Gegout, P. Marquet, P. de Ruffray, H. Brisse, *Science* **320**, 1768 (2008).
4. M. B. Bush, *Glob. Ecol. Biogeogr.* **11**, 463 (2002).
5. Materials and methods are available as supporting material on *Science* Online.
6. M. B. Bush, H. Hooghiemstra, in *Climate Change and Biodiversity*, T. E. Lovejoy, L. Hannah, Eds. (Yale Univ. Press, New Haven, CT, 2005), pp. 125–137.
7. J. A. Pounds, M. P. L. Fogden, K. L. Masters, in *Climate Change and Biodiversity*, T. E. Lovejoy, L. Hanna, Eds. (Yale Univ. Press, New Haven, CT, 2005), pp. 70–74.
8. C. L. Cardelús, R. K. Colwell, J. E. Watkins, *J. Ecol.* **94**, 144 (2006).
9. G. Brehm, R. K. Colwell, J. Kluge, *Glob. Ecol. Biogeogr.* **16**, 205 (2007).
10. A. R. Wallace, *Tropical Nature and Other Essays* (Macmillan, London, 1878).
11. T. Dobzhansky, *Am. Sci.* **38**, 209 (1950).
12. L. Hannah, R. A. Betts, H. H. Shugart, in *Tropical Rainforest Responses to Climatic Change*, M. B. Bush, J. R. Flenley, Eds. (Springer Praxis, 2007), pp. 351–366.
13. J. R. Flenley, *Clim. Change* **39**, 177 (1998).
14. M. B. Bush, M. R. Silman, D. H. Urrego, *Science* **303**, 827 (2004).
15. F. E. Mayle, D. J. Beerling, W. D. Gosling, M. B. Bush, *Philos. Trans. R. Soc. London B Biol. Sci.* **359**, 499 (2004).
16. M. Bush, M. Silman, *J. Quat. Sci.* **19**, 677 (2004).
17. D. D. Ackerly *et al.*, *Bioscience* **50**, 979 (2000).
18. J. Hansen *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **103**, 14288 (2006).
19. C. A. Deutsch *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **105**, 6668 (2008).
20. D. A. Clark, S. C. Piper, C. D. Keeling, D. B. Clark, *Proc. Natl. Acad. Sci. U.S.A.* **100**, 5852 (2003).
21. K. J. Feeley, S. Joseph Wright, M. N. Nur Supardi, A. R. Kassim, S. J. Davies, *Ecol. Lett.* **10**, 461 (2007).
22. O. L. Phillips, S. L. Lewis, T. R. Baker, Y. Malhi, in *Tropical Rainforest Responses to Climatic Change*, M. B. Bush, J. R. Flenley, Eds. (Springer Praxis, 2007), pp. 317–332.
23. L. Miles, A. Grainger, O. Phillips, *Glob. Ecol. Biogeogr.* **13**, 553 (2004).
24. S. A. Cowling *et al.*, *Philos. Trans. R. Soc. London B Biol. Sci.* **359**, 539 (2004).
25. J. W. Williams, S. T. Jackson, J. E. Kutzbach, *Proc. Natl. Acad. Sci. U.S.A.* **104**, 5738 (2007).
26. M. B. Bush, M. R. Silman, C. McMichael, S. Saatchi, *Philos. Trans. R. Soc. London B Biol. Sci.* **363**, 1795 (2008).
27. R. L. Peters, J. D. S. Darling, *Bioscience* **35**, 707 (1985).
28. G.-R. Walther *et al.*, *Nature* **416**, 389 (2002).
29. C. Ghalambor, R. Huey, P. Martin, J. Tewksbury, G. Wang, *Integr. Comp. Biol.* **46**, 5 (2006).
30. R. G. Pearson, T. P. Dawson, *Glob. Ecol. Biogeogr.* **12**, 361 (2003).
31. S. Williams, E. E. Bolitho, S. Fox, *Proc. R. Soc. London B. Biol. Sci.* **270**, 1887 (2003).
32. J. H. Christensen *et al.*, in *Climate Change 2007: Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 2007), pp. 847–940.
33. J. Kluge, M. Kessler, R. R. Dunn, *Glob. Ecol. Biogeogr.* **15**, 358 (2006).
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Impact of a Century of Climate Change on Small-Mammal Communities in Yosemite National Park, USA

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We provide a century-scale view of small-mammal responses to global warming, without confounding effects of land-use change, by repeating Grinnell's early–20th century survey across a 3000-meter-elevation gradient that spans Yosemite National Park, California, USA. Using occupancy modeling to control for variation in detectability, we show substantial (~500 meters on average) upward changes in elevational limits for half of 28 species monitored, consistent with the observed ~3°C increase in minimum temperatures. Formerly low-elevation species expanded their ranges and high-elevation species contracted theirs, leading to changed community composition at mid- and high elevations. Elevational replacement among congeners changed because species' responses were idiosyncratic. Though some high-elevation species are threatened, protection of elevation gradients allows other species to respond via migration.

Although human-driven global warming (*1*) has changed phenology of species and contributed to range expansions (*2*–*6*), contractions of species' ranges are less well documented (*7*–*10*). Models of future climate-change scenarios predict large range shifts, high global extinction rates, and reorganized communities (*11*, *12*), but model outcomes are also highly uncertain (*13*, *14*). Most studies of species' responses span only a few decades—typically from the 1960 or 1970s, which was a relatively cool period, to the present. Such results can be confounded by decadal-scale climate oscillations (*15*) and landscape modification (*8*, *16*). Furthermore, range shifts are uncertain when confounded by false absences due to limited historic sampling and inability to control for changes in detectability between sampling periods (*17*, *18*).

We quantified the impact of nearly a century of climate change on the small-mammal community of Yosemite National Park (YNP) in California, USA, by resampling a broad elevational transect (60 to 3300 m above sea level) that Joseph Grinnell and colleagues surveyed from 1914 to 1920 (*19*) (Fig. 1). Their work documented the diversity and distribution of terrestrial vertebrates in California to establish a benchmark for future comparison (*20*), and led to the concept of the ecological niche, the importance of temperature as determinant of range boundaries, and the notion that species respond uniquely to environmental changes (*21*). In contrast to most early–20th century records, the "Yosemite Transect" was densely sampled across elevations (Fig. 1) and is amply documented by specimens (n = 4354), field notes (>3000 pages), and photographs (~700) (*22*), enabling precise identification of both species and sampling sites. From daily trapping records, we estimated detectability of species in historical as well as current surveys, permitting the unbiased estimation of species' "absences" from elevational bands in both periods (*23*). The transect spans YNP, a protected landscape since 1890, and allowed us to examine long-term responses to climate change without confounding effects of land-use change, although at low to mid-elevations there has been localized vegetation change relating to seral dynamics, climate change, or both (*24*). Finally, analyses of regional weather records pointed to substantial increase of the average minimum monthly temperature of 3.7°C over the past 100 years, with notable increases from 1910 to 1945 and from 1970 to the present (*15*, *22*) (fig. S1).

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Future warming is predicted to cause substantial turnover of species within North American National Parks, including Yosemite (*25*). Given marked regional warming over the past century, we predicted that species ranges should have shifted upward (*5*, *10*). This should manifest as upward contraction of the lower range limit for mid- to high-elevation species, upward shift of the entire range or expansion of the upper limit for low- to mid-elevation species, and altered community composition within elevational bands (*9*).

Elevational ranges of species and their habitats differed markedly between the gradual western and steep eastern slopes of the transect (*19*) (Fig. 1). On the west slope, we trapped small mammals at 121 sites compared to 56 in Grinnell's time (table S1), but overall effort and elevational range (~50 to 3300 m) were comparable (*22*). There were fewer sites on the east side in both time periods (9 for Grinnell, 12 for resurveys) because of limited extent (Fig. 1). Our analyses of richness and turnover focused on species detectable by standardized trapping (37 species) or by observation (6 species; table S2). To test for elevational shifts, we applied occupancy modeling (*22*, *23*) to the 23 west slope taxa with sufficient trapping records to estimate detectability in both periods (tables S1 and S2 and Fig. 2). The best detection model in a set of 36 (table S3) was used to calculate the probability of a false absence (P_{fa}) across trapping sites, where a species was not observed in one sampling period but was in the other (Table 1). Range shifts were significant if $P_{\mathrm{fa}} \leq 0.05$. For each species we evaluated eight hypothesized relationships of occupancy, era, and elevation (fig. S2) using the 14 best detection models (table S3) to create model-averaged occupancy-elevation profiles (Fig. 2 and fig. S3). Conservatively, we excluded shifts that were statistically significant but biologically trivial (Fig. 3). In most cases where the P_{fa} test indicated an elevation shift, occupancy models agreed (Table 1 and fig. S3). Exceptions occurred when occupancy models were weak (i.e., insufficient data) or detected changes in occupancy at elevations other than range limits, or when nonstandard data (i.e., records from ad hoc collecting) were included in P_{fa} tests but not in occupancy models.

Elevation limits shifted mostly upward (Table 1 and Fig. 3A), and this occurred more frequently for lower than upper limits ($\chi^2 = 4.26$, df = 1, P = 0.039). Twelve of 28 (43%) west slope species showed significant shifts in lower limits, of which 10 increased (mean = +475 m) and two, both shrews, decreased (mean = −744 m). In contrast, upper limits changed significantly in only seven instances, with similar numbers of upward (n = 4, mean = +501 m) and downward shifts (n = 3, mean = −309 m).

High-elevation species typically experienced range contractions, whereas low-elevation species expanded their ranges upward ($\chi^2 = 8.8$, df = 2, P = 0.012), a pattern expected with increased temperature. Lower range limits contracted in 50% of the high-elevation species but in only 10% of low-elevation species, whereas 50% of low-elevation species expanded their upper range compared to none of the high-elevation species (Fig. 3B). High-elevation species contracting (Table 1 and Fig. 2A) included the alpine chipmunk (*Tamais alpinus*), Belding's ground squirrel (*Spermophilus beldingi*), water shrew (*Sorex palustris*), and pika (*Ochotona princeps*). Range collapse—increased lower limits and decreased upper limits—was observed in two high-elevation species: the bushy-tailed woodrat (*Neotoma cinerea*) and the shadow chipmunk (*T. senex*) (Fig. 2B). Parallel trends were observed on the east slope of the Sierra for *N. cinerea* and *S. beldingi* (fig. S3). Range contractions due to increases in lower-elevation limits were also observed for two species formerly at mid- to high elevations [the golden-mantled ground squirrel (*Spermophilus lateralis*) and the long-tailed vole (*Microtus longicaudus*)] (Table 1). Only one lowland species contracted—the kangaroo rat (*Dipodomys heermanni*) showed a modest increase in lower limit and a larger decrease in upper limit since Grinnell's time. Range expansions resulted from either expanded upper limits [the pocket mouse (*Chaetodippus californicus*), the California vole (*M. californicus*), and the harvest mouse (*Reithrodontomys megalotis*)] or expanded lower limits (two shrews: *Sorex monticola* and *S. ornatus*). Finally, the pinyon mouse (*Peromyscus truei*) translocated upward (Fig. 2C); both upper and lower limits increased by ~500 m, but it now also occupies montane conifer habitats on the west slope 800 to 1400 m higher after its east slope population expanded upward by ~1000 m to cross the Sierra crest.

Elevational range shifts resulted in modest changes in species richness and composition at varying spatial scales. Species richness averaged across five estimators (*26*) that account for nonobserved species (Fig. 3C, fig. S4, and table S4) declined from the Grinnell era to the present (repeated measures analysis of variance, F = 32.7 df = 1, P = 0.004). Richness estimators suggest a slight decrease across the whole transect (current-historic mean estimates = −4.4 species, −9%), but not within YNP (+1.3 species, 4%). Species richness was reduced within each life zone, with the largest change in the Lower and Upper Sonoran zones west of YNP. Community similarity between Grinnell's period and the present was high (mean similarity, S > 0.9) for the whole transect, the park alone, and most life zones. Species composition was least similar for the Transition and Hudsonian-Arctic zones, as expected given the upward expansions of formerly Sonoran zone taxa and the range shifts of high-elevation species (Table 1).

Closely related species responded idiosyncratically to climate change (Table 1), but why species vary in response is not clear. For example, some species of *Peromyscus* mice showed elevation range shifts (*P. truei*), whereas others did not (*P. boylii*, *P. maniculatus*). The same is

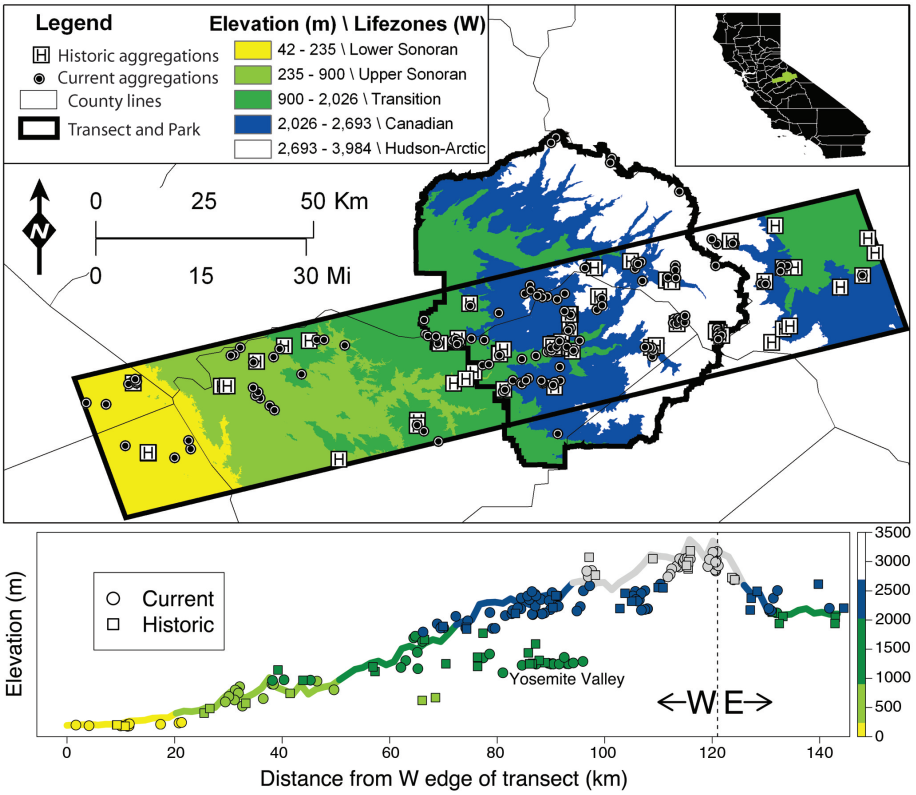

Fig. 1. Map of surveyed sites in Grinnell (Historic) and Current surveys relative to the Yosemite National Park boundary and life zones (upper panel), and to an averaged elevational profile (lower panel).

true for chipmunks (*Tamias*), ground squirrels (*Spermophilus*), voles (*Microtus*), and shrews (*Sorex*). Beyond original elevation range (high versus low), life history and ecological traits were weak predictors of which species exhibited upward shifts of their range limits (tables S5 and S6). This was especially true for high-elevation species with upward contraction of their lower range limit. However, lowland species that are short-lived and lay more litters per year (so-called fast life-style species) were more likely to expand their range upward than were their long-lived, less fecund counterparts (table S5 and fig. S5). The elevational replacements among congeners, documented so carefully in the early 20th century (*19*), are now quite different.

By applying occupancy modeling to a thoroughly documented historical record and the resurvey, we provide an unbiased comparison of changes in species' ranges at the centennial scale. Because much of the transect spans a long-protected National Park, confounding effects of land-use change are minimized. Even so, vegetation has changed within YNP over this period, in part due to fire suppression (*22*). The park was hardly pristine in the early 20th century, with ranching of introduced herbivores in Yosemite Valley and the high country recovering from historical overgrazing. As examples, expansion by *C. californicus* and west slope *P. truei* are associated with fire-related conversion of conifer to shrub habitats, whereas the downward shift of *S. monticola* could reflect recovery of their preferred wet meadow habitats. Increased prevalence of mesic small mammals following cessation of grazing has also been reported for an analogous community in the Rocky Mountains (*27*).

The preponderance of upward range shifts, leading to contraction of high-elevation species and expansions of low-elevation taxa, accords with the predicted impacts of climate warming (*5*, *8*, *9*). Although vegetation dynamics have likely contributed to changes at low to mid-elevation, habitat change at higher elevations is limited (*15*) (fig. S6). The ~500-m average increase in elevation for affected species is also consistent with estimated warming of +3°C, assuming a change of temperature with elevation of ~6°C per km. Several small-mammal taxa that responded to changing temperature also showed large range fluctuations during late Quaternary climate fluctuations (*28*), and some have declined regionally (*29*).

Table 1. Analyses of elevation change for 28 west slope species. Given are average detectability per site for Grinnell [*P*(*G*)] and current [*P*(*C*)] periods, original elevation range, changes in upper (U) and lower (L) range limit that are significant by the P_{fa} tests, the best supported form of the occupancy model (Elev, elevation; NA, not analyzed), the cumulative Akaike's Information Criterion weight for all models with those terms (*w*), and original Lifezone classification (*18*), where L and H refer, respectively, to species with mostly low- to mid-elevation ranges (<2000 m) and mid- to high-elevation ranges (>2000 m) in Grinnell's time; *P. maniculatus* covered the entire transect. Values in bold are further supported by occupancy models. See fig. S4 for elevation plots and models of individual species.

No.	Species	*P*(*G*)	*P*(*C*)	Original elevation range (m)	Range limit change (m)	Best occupancy model	*w*	Original life zone (H, L)
					Range expansions			
1	*Microtus californicus*	0.81	0.58	57–1160	+505 U	Elev	0.36	Lower–Upper Sonoran (L)
2	*Reithrodontomys megalotis*	0.99	0.87	57–1160	+112 U	Elev	0.50	Lower–Upper Sonoran (L)
3	*Peromyscus truei**	0.99	0.93	183–1220	**+589 U, +468 L**	Era*(Elev + Elev^2)	0.99	Upper Sonoran (L)
4	*Chaetodippus californicus*	0.28	0.19	193–914	**+800 U**	Era*(Elev + Elev^2)	0.32	Upper Sonoran (L)
5	*Sorex ornatus*	0.32	0.93	549–914	**−485 L**	Era *(Elev + Elev^2)	0.74	Upper Sonoran (L)
6	*Sorex monticolus*	0.99	0.97	2212–3287	**−1003 L**	Era + Elev + Elev^2	0.37	Canadian–Hudsonian (H)
					Range contractions			
7	*Dipodomys heermanni*	0.16	0.98	57–1025	+63 L, **−293 U**	Era*Elev	0.48	Lower–Upper Sonoran (L)
8	*Microtus longicaudus*	0.99	0.98	623–3287	**+614 L**	Era + Elev + Elev^2	0.74	Transition–Hudsonian (H)
9	*Zapus princeps*	0.98	0.90	1291–3185	+159 L, −64 U	Era + Elev + Elev^2	0.53	Transition–Hudsonian (H)
10	*Tamias senex*	0.95	0.71	1402–2743	+1007 L, −334 U	Elev +Elev^2	0.48	Canadian (H)
11	*Spermophilus lateralis*	0.70	0.89	1646–3200	**+244 L**	Era*(Elev + Elev^2)	0.78	Transition–Hudsonian (H)
12	*Sorex palustris*	0.39	0.23	1658–3155	**+512 L**	Era + Elev + Elev^2	0.39	Canadian–Hudsonian (H)
13	*Neotoma cinerea**	0.90	0.71	1798–3287	**+609 L, −719 U**	Era*(Elev + Elev^2)	0.83	Canadian–Arctic-Alpine (H)
14	*Spermophilus beldingi**	0.98	0.98	2286–3287	+355 L	Elev	0.32	Canadian–Arctic-Alpine (H)
15	*Tamias alpinus*	0.92	0.95	2307–3353	**+629 L**	Era + Elev	0.56	Hudsonian–Arctic-Alpine (H)
16	*Ochotona princeps*†	NA	NA	2377–3871	+153 L	NA	NA	Canadian–Arctic-Alpine (H)
					No change			
17	*Peromyscus maniculatus**	0.99	0.99	57–3287	No change	Era*(Elev + Elev^2)	0.72	Lower Sonoran–Arctic-Alpine (H)
18	*Thomomys bottae*†	NA	NA	57–1676	No change	NA	NA	Lower Sonoran–Transition (L)
19	*Spermophilus beecheyi*	0.50	0.82	61–2734	−250 U	Era*(Elev + Elev^2)	0.89	Lower Sonoran–Canadian (L)
20	*Neotoma macrotis*	0.90	0.91	183–1646	+67 U	Elev + Elev^2	0.62	Lower Sonoran–Transition (L)
21	*Peromyscus boylii*	0.98	0.97	183–2469	−122 L	Elev + Elev^2	0.60	Upper Sonoran–Transition (L)
22	*Sorex trowbridgii*	0.71	0.88	1160–2286	No change	Elev + Elev^2	0.40	Transition–Canadian (H)
23	*Microtus montanus**	0.81	0.98	1217–3155	No change	Elev + Elev^2	0.36	Transition–Hudsonian (H)
24	*Tamiasciurus douglasi**†	NA	NA	1229–3185	No change	NA	NA	Transition–Hudsonian (H)
25	*Tamias quadrimaculatus*	0.95	0.85	1494–2210	+50 U	Era*(Elev + Elev^2)	0.78	Transition–Canadian (H)
26	*Tamias speciosus**	1.00	1.00	1768–3155	+128 L, +65 U	Era*(Elev + Elev^2)	1.00	Canadian–Hudsonian (H)
27	*Thomomys monticola*†	NA	NA	1905–3155	No change	NA	NA	Canadian–Hudsonian (H)
28	*Marmota flaviventris*†	NA	NA	2469–3353	No change	NA	NA	Canadian–Arctic-Alpine (H)

* Similar trends are observed for east-side populations (see fig. S4). †These species were encountered by observation and/or specialized trapping and were not subject to occupancy analyses.

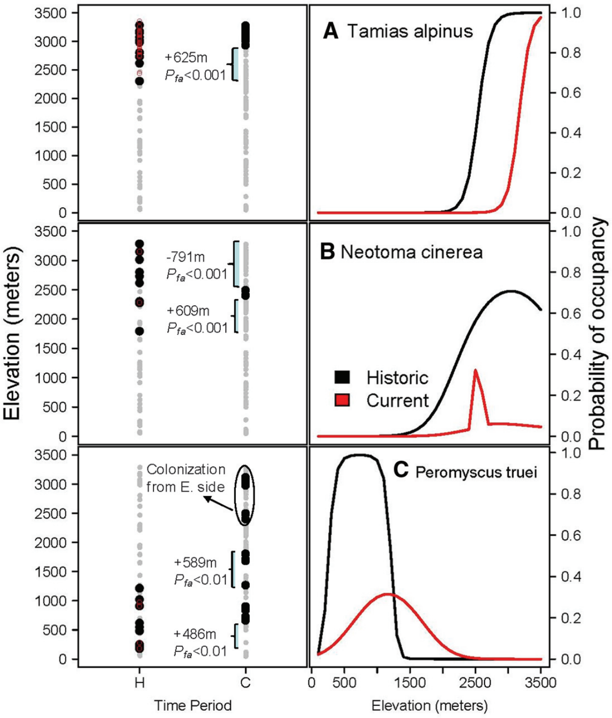

Fig. 2. Example elevation plots from the west slope transect of upward range expansion (*T. alpinus and P. truei*) (**A** and **C**), and range collapse (*N. cinerea*) (**B**). Shown are occupied (black) and unoccupied (gray) sites, probability of false absence (P_{fa}), and model-averaged occupancy-elevation profiles (table S3 and fig. S2). *P. truei* colonized high elevations west of the Sierra crest from the eastern slope. Red marks for historical elevation profile of *T. alpinus* refer to ad hoc records.

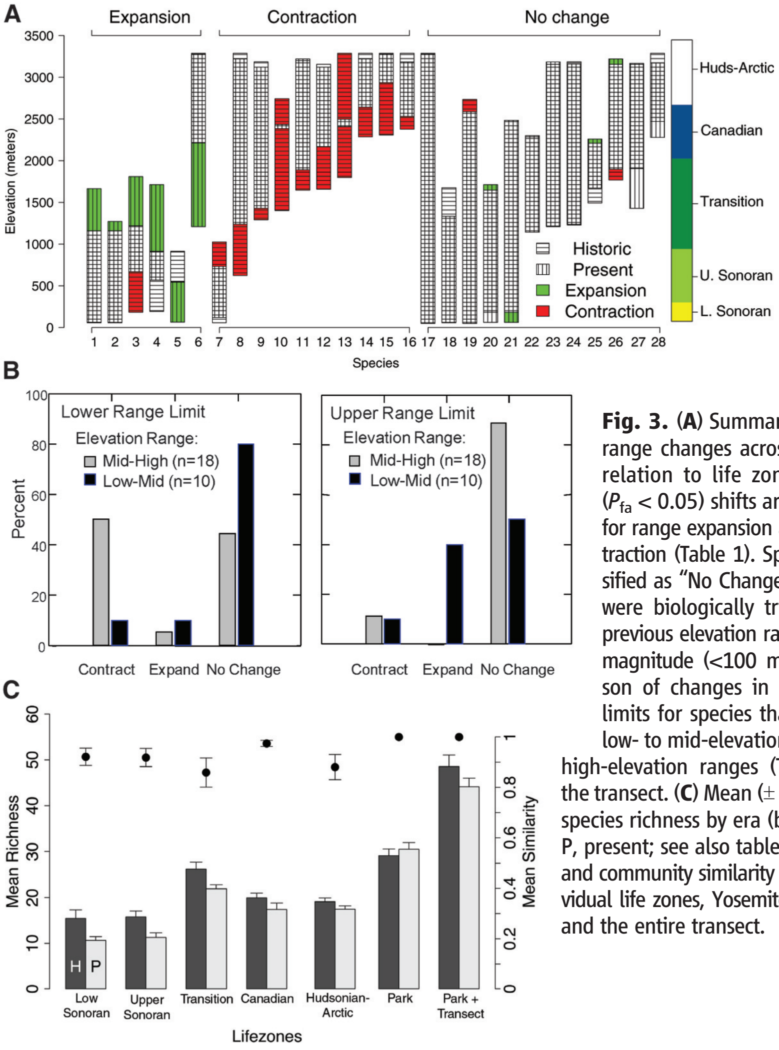

Fig. 3. (**A**) Summary of elevational range changes across all species in relation to life zones. Significant ($P_{fa} < 0.05$) shifts are colored green for range expansion and red for contraction (Table 1). Species were classified as "No Change" if range shifts were biologically trivial (<10% of previous elevation range) or of small magnitude (<100 m). (**B**) Comparison of changes in elevation-range limits for species that formerly had low- to mid-elevation versus mid- to high-elevation ranges (Table 1) across the transect. (**C**) Mean (± SE) estimates of species richness by era (bars: H, historic; P, present; see also table S4 and fig. S4) and community similarity (points) for individual life zones, Yosemite National Park, and the entire transect.

Recent trends do not bode well for several mid- to high-elevation species, including some endemic to the high Sierra (e.g., *T. alpinus*) (Fig. 3A). Nevertheless, species diversity within Yosemite has changed little, because range expansions compensated for retractions. Our results confirm that protecting large-scale elevation gradients retains diversity by allowing species to migrate in response to climate and vegetation change. The long-recognized importance of protected landscapes has never been greater.

References and Notes

1. Intergovernmental Panel on Climate Change, *Climate Change 2007: Synthesis Report Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC, Geneva, Switzerland, 2007).
2. C. Rosenzweig *et al.*, *Nature* **453**, 353 (2008).
3. C. Parmesan, G. Yohe, *Nature* **421**, 37 (2003).
4. G. R. Walther *et al.*, *Nature* **416**, 389 (2002).
5. C. Parmesan, *Annu. Rev. Ecol. Evol. Syst.* **37**, 637 (2006).
6. J. Lenoir, J. C. Gégout, P. A. Marquet, P. de Ruffray, H. Brisse, *Science* **320**, 1768 (2008).
7. R. J. Rowe, *J. Biogeogr.* **32**, 1883 (2005).
8. R. Hickling, D. B. Roy, J. K. Hill, R. Fox, C. D. Thomas, *Glob. Change Biol.* **12**, 450 (2006).
9. R. J. Wilson, D. Gutierrez, J. Gutierrez, V. J. Monserrat, *Glob. Change Biol.* **13**, 1873 (2007).
10. C. D. Thomas, A. M. A. Franco, J. K. Hill, *Evolution Int. J. Org. Evolution* **21**, 415 (2006).
11. C. D. Thomas *et al.*, *Nature* **427**, 145 (2004).
12. J. W. Williams, S. T. Jackson, *Front. Ecol. Environ* **5**, 475 (2007).
13. A. J. Davis, L. S. Jenkinson, J. H. Lawton, B. Shorrocks, S. Wood, *Nature* **391**, 783 (1998).
14. R. G. Pearson *et al.*, *J. Biogeogr.* **33**, 1704 (2006).
15. C. I. Millar, R. D. Westfall, D. L. Delany, J. C. King, L. J. Graumlich, *Arct. Antarct. Alp. Res.* **36**, 181 (2004).
16. W. Jetz, D. S. Wilcove, A. P. Dobson, *PLoS Biol.* **5**, e157 (2007).
17. J. K. Hill *et al.*, *Proc. R. Soc. Lond. B. Biol. Sci.* **269**, 2163 (2002).
18. L. P. Shoo, S. E. Williams, J. M. Hero, *Biol. Conserv.* **125**, 335 (2005).
19. J. Grinnell, T. Storer, *Animal Life in the Yosemite* (Univ. of California Press, Berkeley, CA, 1924).
20. J. Grinnell, *Pop. Sci. Mon.* **77**, 163 (1910).
21. J. Grinnell, *Am. Nat.* **51**, 115 (1917).
22. See supporting material on *Science* Online.
23. D. I. MacKenzie *et al.*, *Inferring Patterns and Dynamics of Species Occurrence* (Elsevier, San Diego, 2006).
24. A. Guarin, A. H. Taylor, *For. Ecol. Manage.* **218**, 229 (2005).
25. C. E. Burns, K. M. Johnston, O. J. Schmitz, *Proc. Natl. Acad. Sci. U.S.A.* **100**, 11474 (2003).
26. A. Chao, in *Encyclopedia of Statistical Sciences*, N. Balakrishnan, C. B. Read, B. Vidakovic, Eds. (Wiley, New York, 2005).
27. R. J. Rowe, *Am. Nat.* **170**, 242 (2007).
28. D. K. Grayson, *Quat. Sci. Rev.* **25**, 2964 (2006).
29. E. A. Beever, P. E. Brussard, J. Berger, *J. Mammal.* **84**, 37 (2003).
30. Supported by funding from the Yosemite Foundation, the National Parks Service, and NSF (DEB 0640859). Assistance was received from A. Chang, H. Shofi, K. Tsao, D. Yang, W. Monahan, R. Hijmans, and M. Koo. L. Chow (U.S. Geological Survey Yosemite) and S. Thompson (Yosemite National Park) stimulated and participated in the project. Comments from R. Colwell, M. Power, F. Hamer, and L. Shoo improved this manuscript.

Supporting Online Material

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Materials and Methods
Figs. S1 to S6
Tables S1 to S6

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Supporting Online Material for

Impact of a Century of Climate Change on Small-Mammal Communities in Yosemite National Park, USA

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This PDF file includes:

Materials and Methods
Figs. S1 to S6
Tables S1 to S6
References

SUPPORTING ONLINE MATERIAL

Materials And Methods

A. Evidence for Climate Change in Yosemite Region.

Evidence from various independent sources point to an increase in average temperature at the state level (S*1*) and locally in the area of Yosemite National Park and the transect (S*2*).

Direct evidence of warming in the area was obtained from weather station data available from NCDC (http://www.ncdc.noaa.gov/oa/ncdc.html) and WRCC (http://www.wrcc.dri.edu/). Average monthly minimum temperature in Yosemite Valley has experienced a general increase during the last century whereas maximum temperature shows slight or no increase (Fig. S1). Linear regression of monthly averages of minimum temperature for the Yosemite Headquarters station indicate a general increase of 3.9 C in January and 5.3 C in July. A similar analysis done by Millar *et al.* (S*2*) but combining data from two other stations (Sacramento, CA and Mina, NV) revealed an average increase of 3.7 C when using annual averages of minimum temperature. Millar *et al.* (S*2*) also registered changes in vegetation growth recorded in tree rings and invasion of snowfield slopes that match tightly with changes in minimum temperature and also variability in precipitation. LaDochy *et al.* (S*1*) performed an analysis of climate trends at the state level using weather station data from 1950 – 2000 and found an average warming of 1.0 C during this period. Comparison of interpolated climate surfaces for California indicate considerable spatial variation in both the magnitude and direction of climate change (*S3*).

B. Sampling Design and Field Methods

We identified the field sites visited by the 1914–1920 Grinnell Survey from a combination of their original field notes and maps that are archived at the Museum of Vertebrate Zoology (MVZ; http://mvz.berkeley.edu/Grinnell/). Written descriptions enabled us to precisely relocate and resample many of the same sites. Field teams spent a minimum of 10 days at each site, and sampled each of the major habitats within a radius of approximately 1 km (chaparral, woodland, forest, meadow, riparian, talus, etc.). Most sites were surveyed one time during the 3-year period, but several were revisited two or more times. All field notes, photographs, datasheets, and maps are archived in the Museum of Vertebrate Zoology.

During the Grinnell period, small mammals were detected by sight, or by capture in traps, or were taken by shotgun with light shot. Trapped specimens were generally caught with smaller museum special snap traps, larger rat traps, Macabee™ gopher traps, mole traps, or steel traps of various sizes. They did not use a standardized protocol for trapping. Rather, they assessed the potential species to be sampled and used the appropriate traps in suitable conditions. Grinnell et al. typically recorded what types of traps were used, for how many nights, and what species were caught on each night. Traplines were left out from 1-14 nights (mean for the west slope was 4.6 nights) and contained in average 24 mouse/rat traps (Table S1). For occupancy analyses we only include captures from mouse and rat traps with recorded effort; captures based on specialized trapping, such as gopher, mole, steel and tree traps, were excluded. Many specimens of more common species were discarded, but are recorded as such in the field notes. Most animals that were kept were preserved as study skin plus skull, but some were preserved as complete skeletons or in formaldehyde.

For the resampling effort, it was not feasible to establish a standardized trapping design for small mammals (e.g., grid or parallel lines of traps set at uniform distance intervals with a common bait) given the diversity of habitats at each site, the differences in major habitats across the elevational transect, and the range in food habits of focal taxa. Rather, we standardized trap effort (number of traps and nights trapped) for each habitat. Each mammal live trap and pitfall trap line at a site was "run" for a minimum of 4 consecutive days/nights. We used primarily Sherman live traps, supplemented with Tomahawk live traps, with a minimum of 40 traps (40 Sherman live traps, sometimes supplemented with 10 Tomahawk live traps) per trapline per night for the four consecutive nights. Traps were placed in "likely" spots within each habitat (e.g., grass tunnels of *Microtus*). Pocket gophers were trapped using commercial Macabee™ gopher traps. Pitfall traps were used for shrews. Two meandering lines, each comprising of 25 32-oz. plastic cups, were placed in the ground at approximately 10 m intervals using a 10.2 cm soil auger. These were run during the same trapping interval. The diversity of traps and methods employed and habitats visited ensured that the full range of target taxa was sampled. For all our analyses we only include captures from Sherman, Tomahawk, and pitfall cups in order to maintain consistency with historical trapping methods.

Captured animals were identified, sexed, and weighed, with reproductive data noted for most individuals. All trap lines or stations were georeferenced by hand-held GPS units, using the WGS-84 datum. Data are archived in fieldnotes for all individuals encountered, including those released as well as preserved. Voucher specimens of selected small mammals (rodents and shrews) were taken in accordance with permission granted by the National Park Service and Yosemite National Park. Specimens were archived in the collections of the Museum of Vertebrate Zoology, as were those collected during the original Grinnell-era surveys. Data for all specimens are available via the Museum's website (http://mvz.berkeley.edu) under accession numbers 13817 (2003), 13948 (2004), 14091 (2005), and 14191 (2006).

C. Data Set Construction

The trapping effort and elevational range of sampling was similar between the Grinnell and contemporary periods. A total of 311 traplines where trapping effort could be quantified were identified in Grinnell's time and 308 in the resurvey. For both periods, traplines were aggregated into sampling sites if they were within 2 km and 100 m elevation to reduce spatial autocorrelation (Table S1). The higher level of aggregation in the Grinnell period reflects our generally conservative approach to grouping traplines and greater uncertainty in the exact location and elevation of traplines (mean point-radius error of georeference for historical traplines was 323 ± 425.9 m). Accordingly, there was a larger number of both traplines (mean

4.8 vs 2.3) and traps (mean 111 vs 85) per site for the Grinnell period versus the re-survey. However, the mean number of trap-nights per site was similar; 4.1 for Grinnell survey and 3.3 for the re-survey. Most, but not all, sites were geographically matched between the Grinnell and re-survey periods.

Following aggregation, on the western slope of the transect there were 54 sites with traplines in Grinnell's time and 121 sites in the contemporary resurvey where trapping effort could be quantified, spanning elevational ranges of 57–3287 masl in the original survey and 48–3278 masl in the re-survey (Table S1). On the eastern slope there were 9 sites during Grinnell's time and 12 in the resurvey, spanning elevational ranges of 1981–2804 masl and 2155–3094 masl, respectively.

D. Estimation of the Probability of Detection, False Absence and Occupancy

We focus here on developing and comparing the elevational profiles of species occupancy in order to maximize use of available data. In reporting the past and present elevational ranges, we include additional observations and specimens for which effort was not quantifiable (e.g., specimens shot in Grinnell surveys or observational data in both periods). However, statistical analyses of detectability and occupancy across elevation are based solely on the species and sites (as enumerated above) for which trap effort and nightly detection records were quantified.

Although the overall survey methodology was similar between periods, differences in trap types and effort per site could confound interpretation of absences and, thus, overall comparisons. To control for these effects, we estimated detectability for each period and species from the temporal pattern of presence or "no-presence" records across sites, and incorporated any between-period difference in detectability into our analyses of changes in elevational range limits and profiles of occupancy probability (ψ). Given prior evidence for distinct elevational distributions of small mammals on the east versus west sides of the Sierra crest (S*4*), we used only the west slope records to estimate parameters. The analyses of detectability and ψ employed the likelihood framework and AIC model-averaging methods (S5) described in MacKenzie et al. (S*6*) and implemented in Program MARK version 5.1 (S*7*).

To estimate the probability of detection per trap night (p), we constructed 32 competing models with the following independent variables: era (Grinnell or resurvey), trend (linear decline in detections over sequential nights due to the collection of trapped individuals or to trap-shyness), trap effort (number of traps/100 and the $\log_{10}$ of the number of traps), the interaction between era and trend, and the interactions between era and trap effort variables. We also built detection models with all additive combinations of these independent variables, as well as a constant model (.). The candidate model set is listed in Table S3.

We ran each p model with a ψ_{era} term and selected the best detection model with the lowest AIC score for each species. We used the parameter values to estimate the overall probability of detection (S*6*) as $P^* = 1 - \prod_i (1 - p_i)$ for each site for each era based on its number of nights trapped and traps used. To estimate the probability of false absence (P_{fa}) across a set of sites in an elevational band where a species was detected in one era but not the other, we first calculated the probability of a false absent for each site $P_{fa(site)} = 1 - P^*_{(site)}$ and then obtained the product of these values across the set of sites in question as $P_{fa} = \prod_{site} (1 - P_{fa(site)})$.

To estimate elevational profiles of occupancy (ψ) for each era, we again constructed a set of competing likelihood models incorporating era (Grinnell or present), elevation represented as linear (elev) or quadratic (elev + elev^2) functions, and interactions between era and elevation functions. This resulted in eight competing ψ models. Five models had between-era effects: era, era+elev, era*elev, era+elev+ elev^2, and era*(elev+ elev^2). Three models had no era effects: elev, elev+elev^2, and constant (.). These are listed in Table S3 and illustrated in Figure S2.

The eight occupancy models were each run with a set of 14 detection functions that included the best model for each species (Table S3). This resulted in a total of 112 models per species in the occupancy model set. Models were compared using AIC$_c$ (corrected for small sample size) scores (S*5*). Occupancy profiles were estimated across the range of elevations sampled by model-averaging ψ at 100-m increments using the AIC weights (*w*) of the 112 models. Occupancy-elevation profiles for each species appear in Fig. S3. Finally, cumulative AIC weights were calculated for each occupancy model.

E. Estimation of Species Richness and Turnover

To estimate species richness and between-era turnover as a function of elevation, we calculated species richness for the total transect, Yosemite National Park alone, and each of the 5 lifezones proposed by Grinnell, for each time period using presence/absence data from all the mammals captured within these areas. The software EstimateS v. 8.0 was used to estimate species richness metrics from replicated sample-based incidence data and between-era turnover from similarity metrics (S*8*). This methodology allows controlling for different sampling efforts at each time period. We calculated five non-parametric estimators of total species richness that infer species not recorded: Incidence Coverage Estimator (ICE), Chao1, Chao2, Jack1, and Jack2 to estimate the asymptote of the species accumulation curve. Two similarity metrics that control for effort and correct for unobserved species were estimated using replicated presence/absence data, in practice, occurrence records across multiple sites within a lifezone, the Park, or the entire transect: “Chao-Sorensen” and “Chao-Jaccard” each estimate the probability of choosing two individuals, one from each of the two samples, which belong to a species shared between the samples (*S9,* S*10*). Following Wilson et al. (*S11*), we report the mean and standard error across the five non-parametric estimators of total richness and the two similarity indices (Table S4**).** Individual estimators follow the same trends and they are shown in Figure S4. To test the hypothesis of a change in species richness between the two time periods we employed a repeated-measures one-way ANOVA with time as a factor and lifezones as the subjects on which repeated measures were taken.

Figure S1. Changes in minimum and maximum temperatures in Yosemite Valley (WRCC-049855 37°45' 119°35' 1250 msnm) over the past 100 years. Source data from Western Regional Climate Center (WRCC: http://www.wrcc.dri.edu).

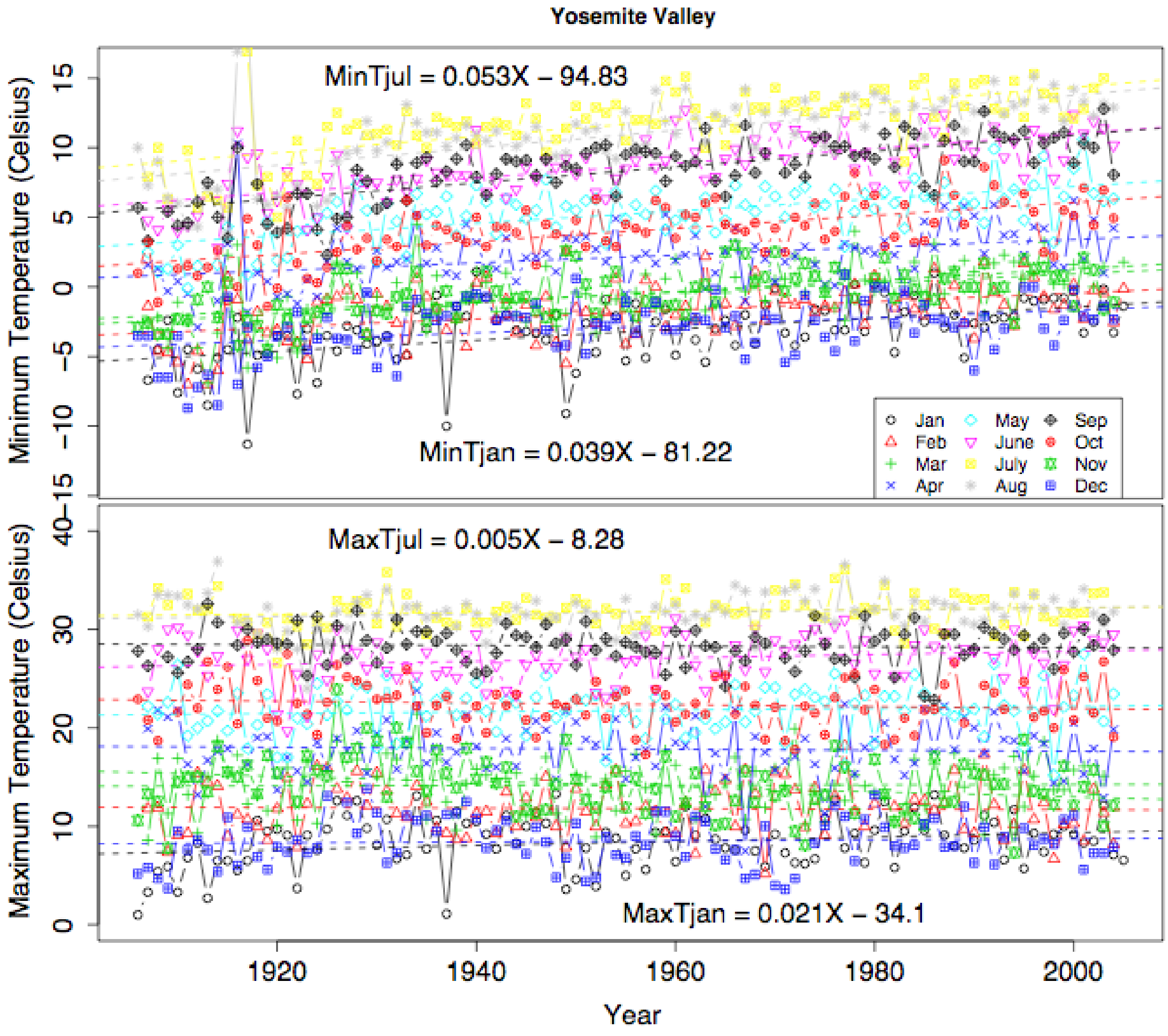


Figure S2. Eight occupancy models tested for each small mammal species with sufficient quantitative trapping data for analysis.

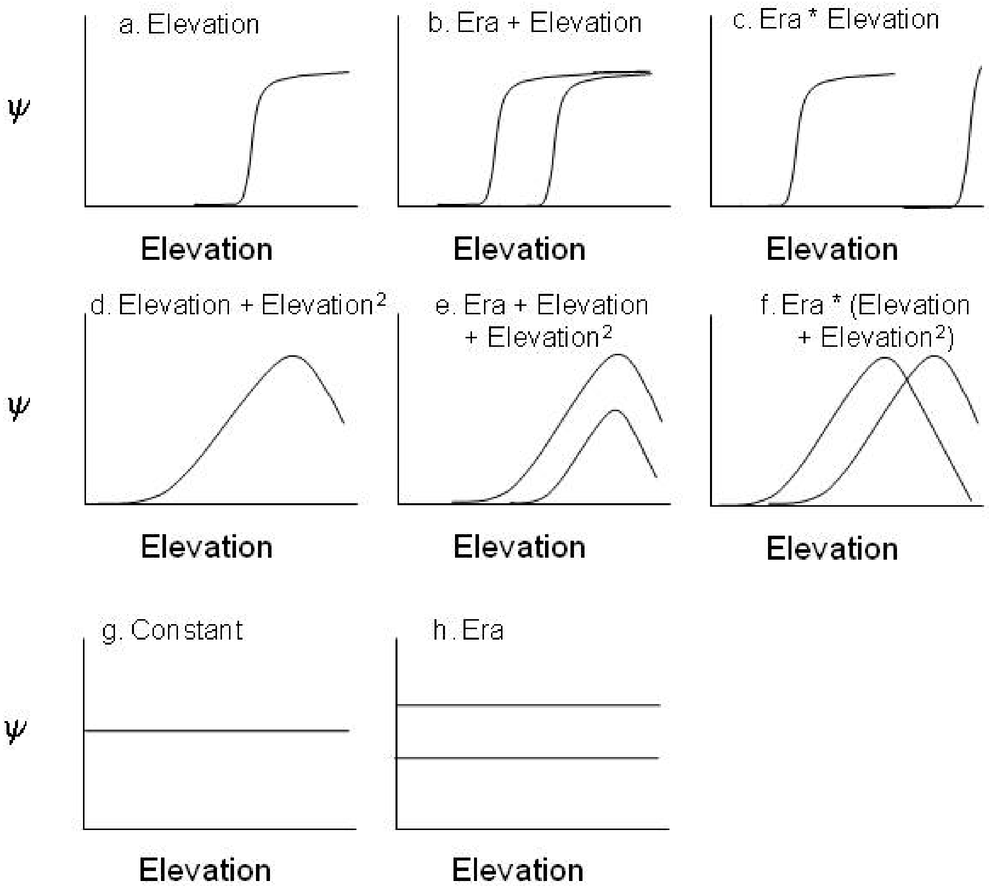
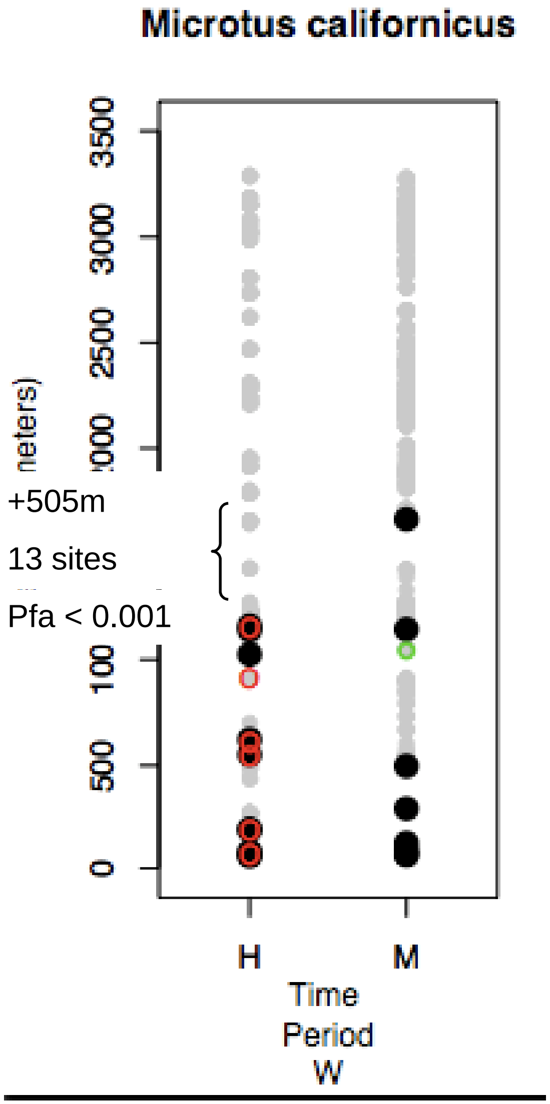


Figure S3. Comparison of elevation profiles for 28 species and occupancy results for 23 species of small mammals of the YNP transect in Table 1. Elevation plots are shown separately for the western and eastern slopes of the transect across the Sierra Nevada. Displayed are occupied (black) and unoccupied (grey) sites, results from the probability of false absence (P_{fa}) tests, and cumulative AIC weights and model-averaged occupancy-elevation profiles for historic (black) and modern (red) based on 112 models (Table S3, Fig. S2) averaged using the AIC weights. Red (historic) and green (modern) circles refer to *ad hoc* records of occurrence based on specimens collected or observed that were not part of the quantitative trapping effort.

1. *Microtus californicus*

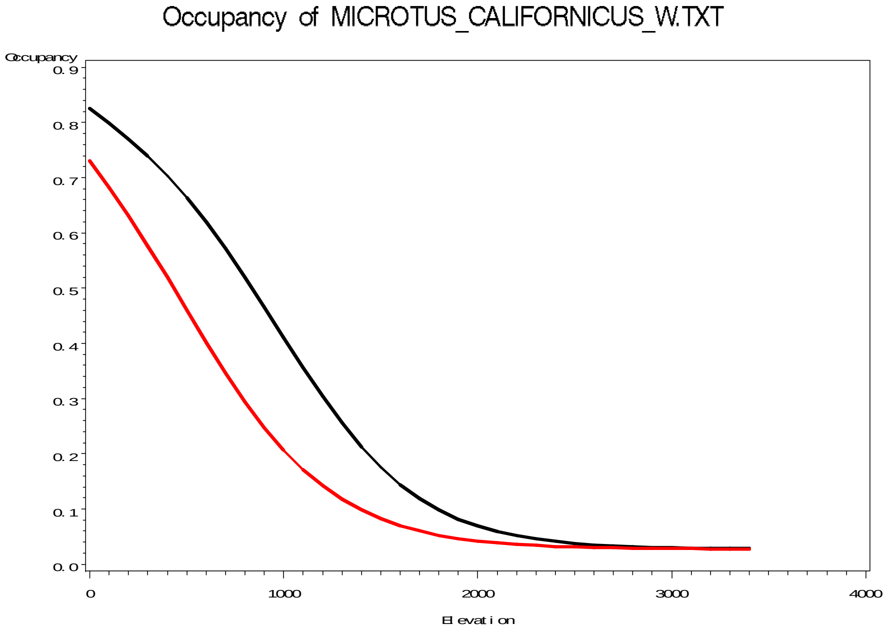


+505m

13 sites

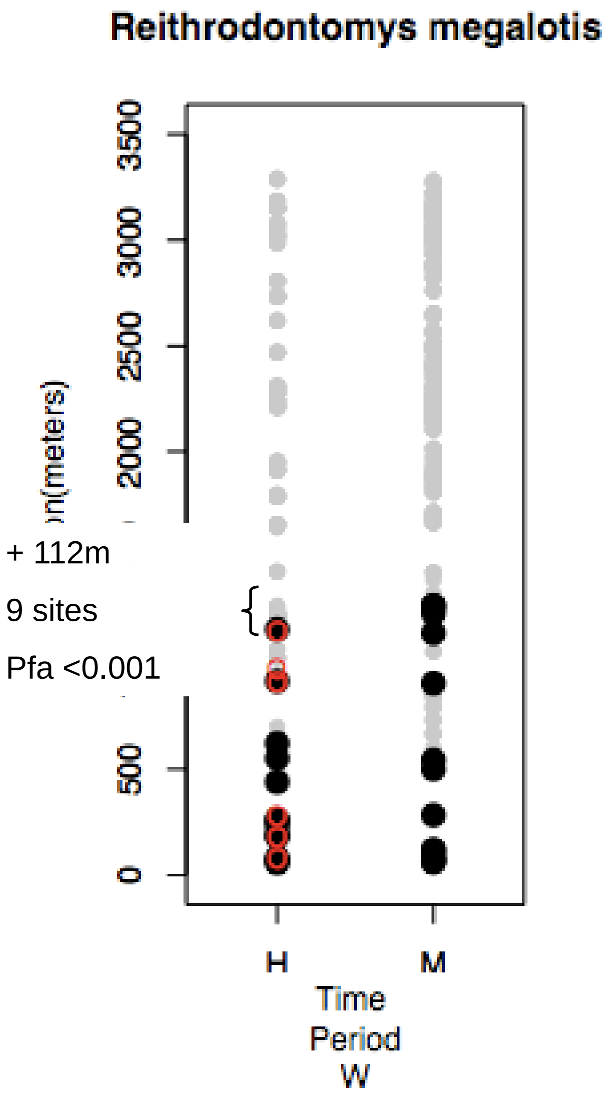
Pfa < 0.001

Occupancy models	Cumulative AIC Wt
Constant	0.00
Elev	0.36
Elev+Elev^2	0.08
Era	0.00
Era*(Elev + Elev^2)	0.01
Era*Elev	0.11
Era+Elev	0.33
Era+Elev+Elev^2	0.11



Moritz et al.

2. *Reithrodontomys megalotis*

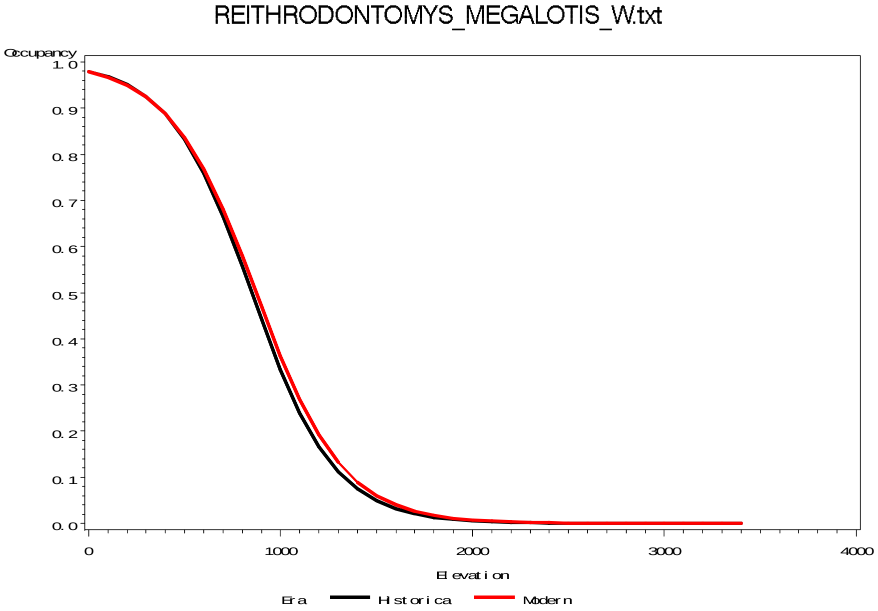


+ 112m

9 sites

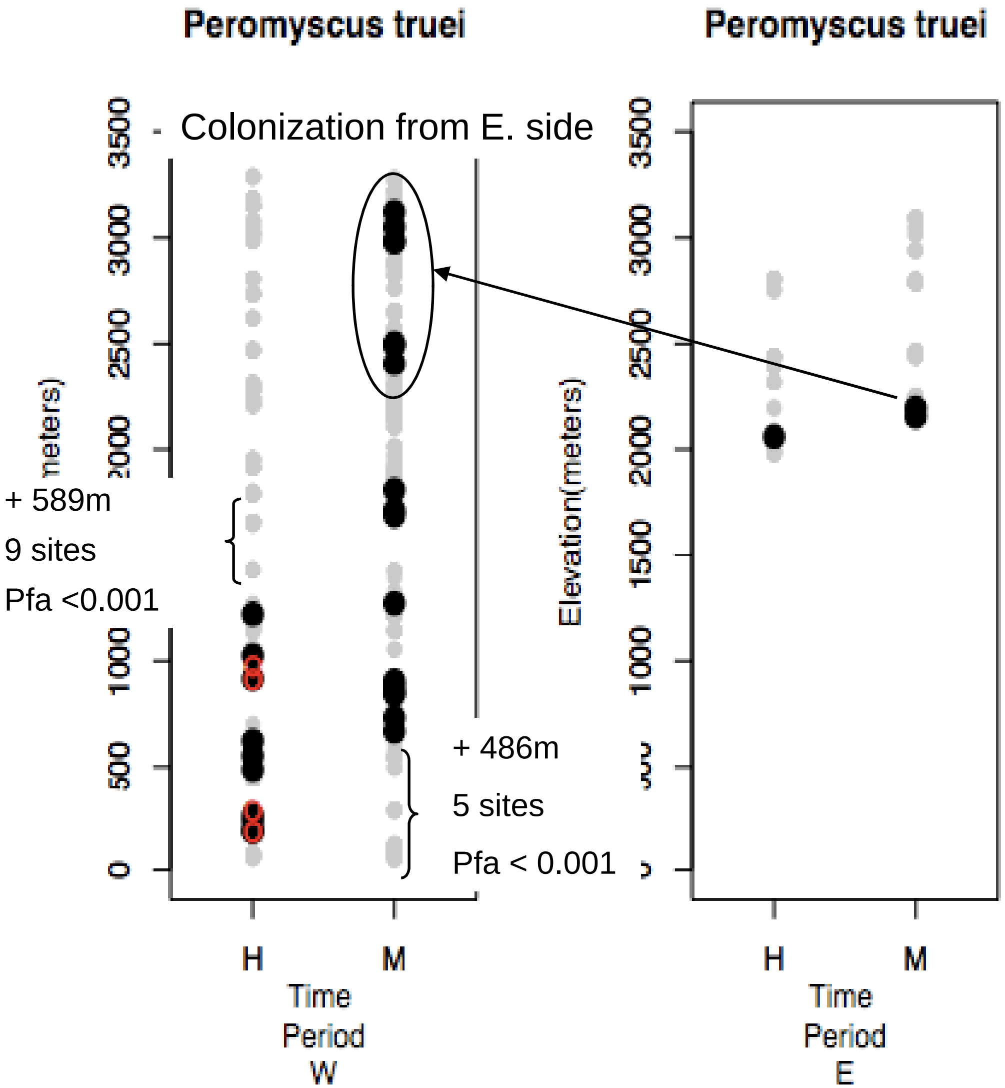
Pfa <0.001

Occupancy models	Cumulative AIC Wt
Constant	0.00
Elev	0.50
Elev+Elev^2	0.16
Era	0.00
Era*(Elev + Elev^2)	0.01
Era*Elev	0.09
Era+Elev	0.18
Era+Elev+Elev^2	0.06



Moritz et al.

3. *Peromyscus truei*



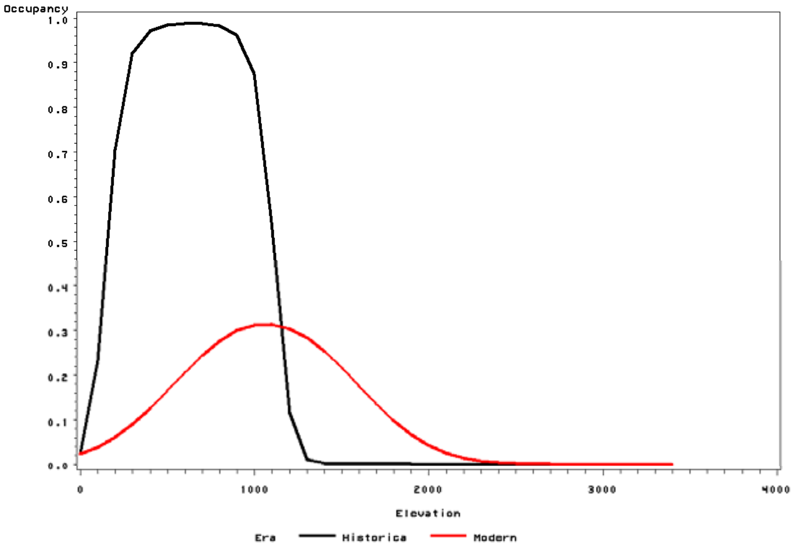
Colonization from E. side

+ 589m
9 sites
Pfa <0.001

+ 486m
5 sites
Pfa < 0.001

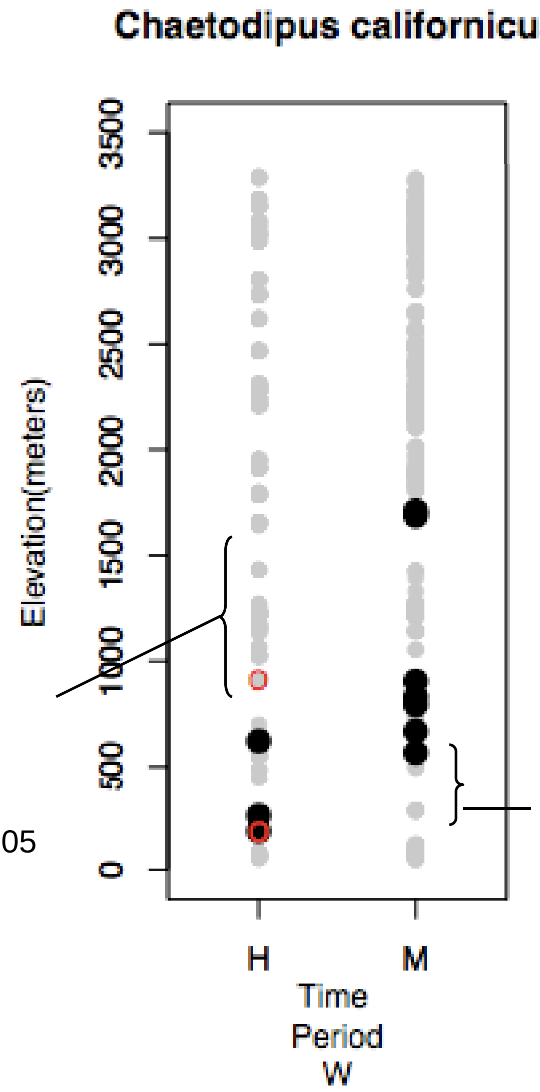
Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.00
Elev+Elev^2	0.00
Era	0.00
Era*(Elev + Elev^2)	0.99
Era*Elev	0.00
Era+Elev	0.00
Era+Elev+Elev^2	0.00

Occupancy of P_truei_W_censored.txt — no data above 2400m



Moritz et al.

4. *Chaetodipus californicus*



+ 800m

17 sites

Pfa = 0.005

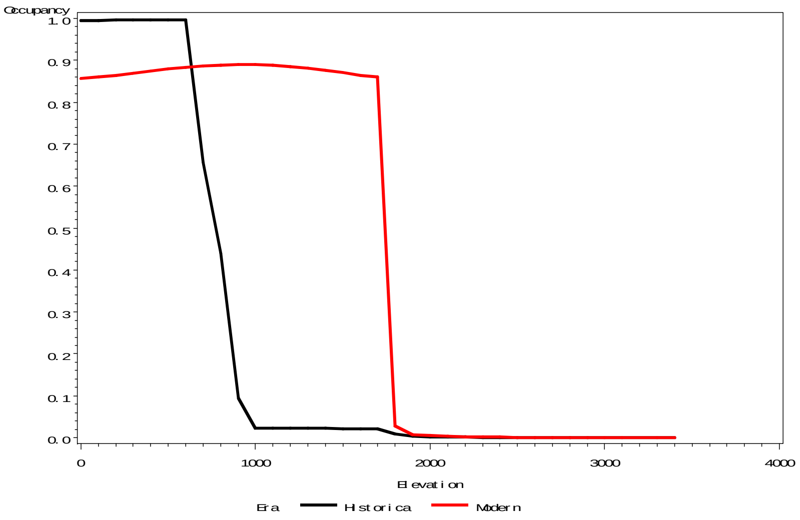
+ 385m

5 sites

Pfa = 0.24

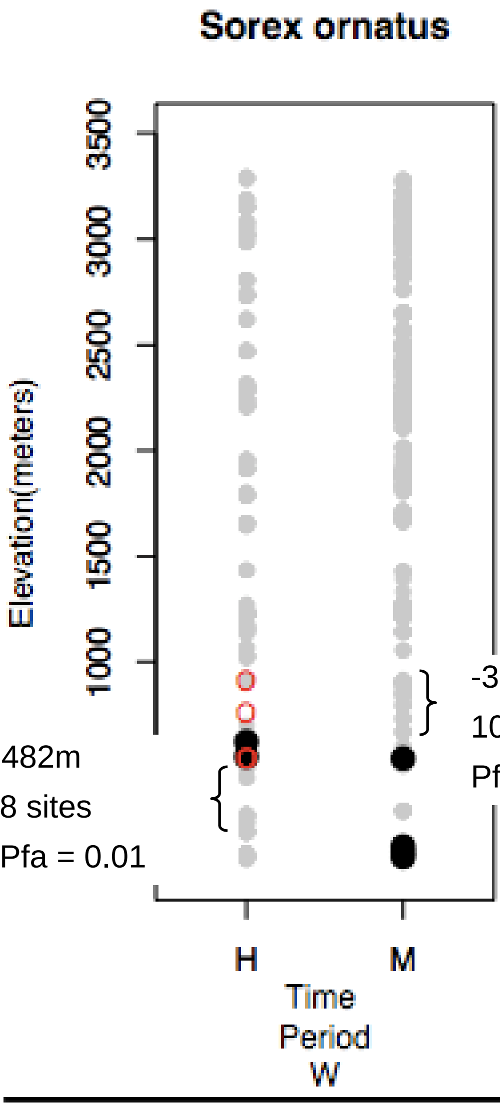
Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.01
Elev+Elev^2	0.01
Era	0.00
Era*(Elev + Elev^2)	0.32
Era*Elev	0.24
Era+Elev	0.22
Era+Elev+Elev^2	0.20

Occupancy of CHAETODIPUS_CALI.TXT



Moritz et al.

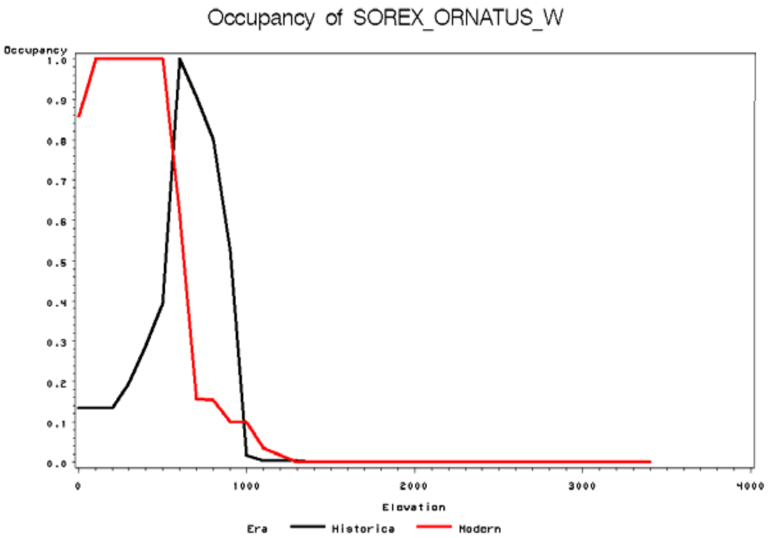
5. *Sorex ornatus*



-482m
8 sites
Pfa = 0.01

-370m
10 sites
Pfa = 0.10

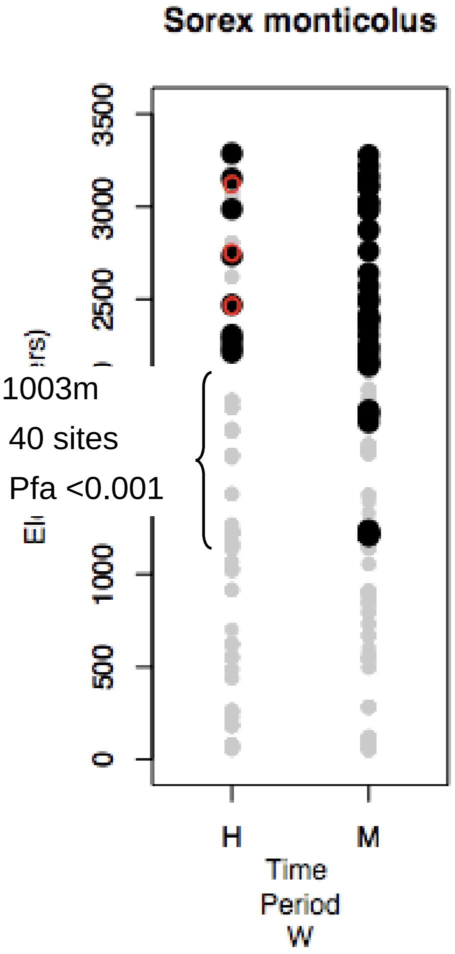
Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.02
Elev+Elev^2	0.03
Era	0.00
Era*(Elev + Elev^2)	0.74
Era*Elev	0.02
Era+Elev	0.02
Era+Elev+Elev^2	0.17



Moritz et al.

6. *Sorex monticolus*

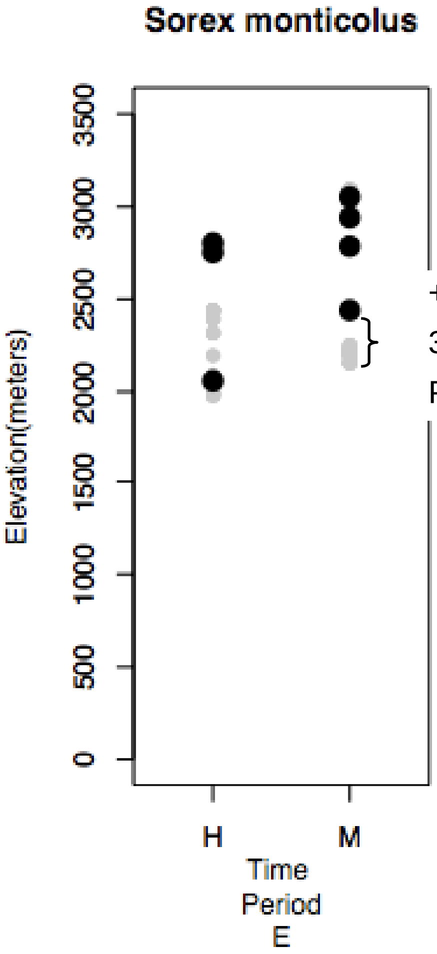
Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.00
Elev+Elev^2	0.00
Era	0.00
Era*(Elev + Elev^2)	0.28
Era*Elev	0.08
Era+Elev	0.25
Era+Elev+Elev^2	0.37



-1003m

40 sites

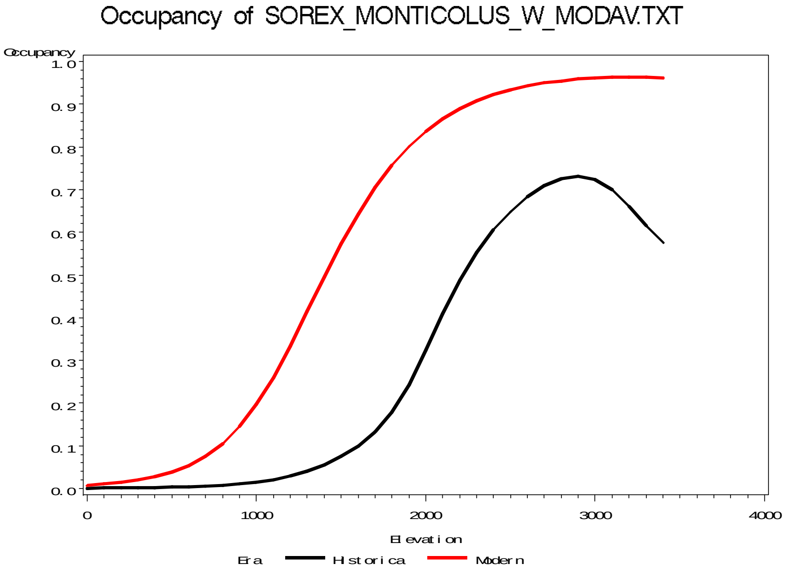
Pfa <0.001



+85m

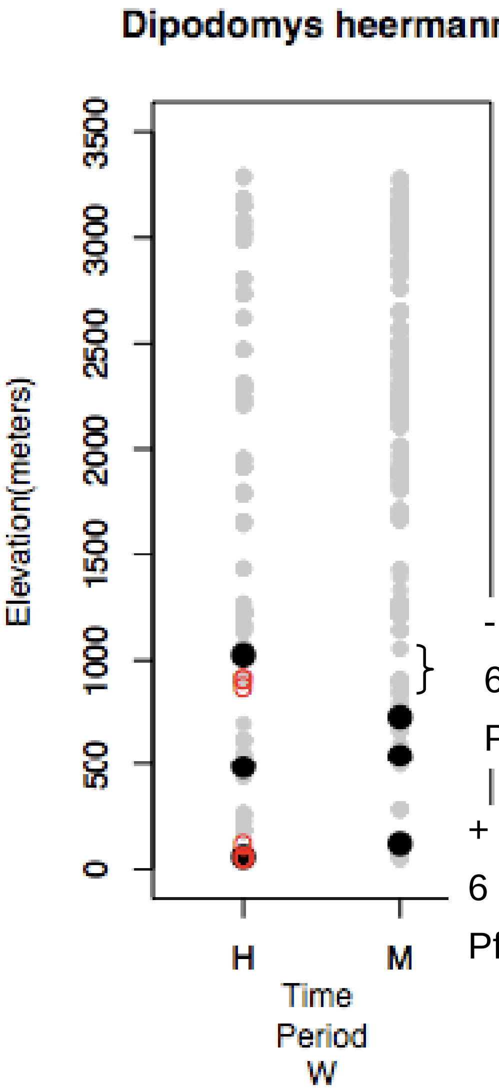
3 sites

Pfa < 0.001



Moritz et al.

7. *Dipodomys heermanni*



- 293m

6 Sites

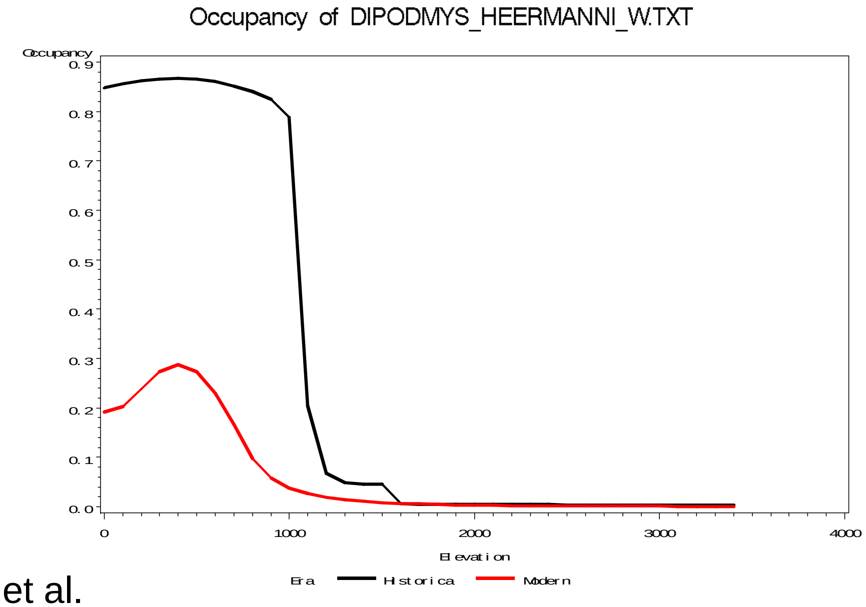
Pfa <0.001

+ 63m

6 Sites

Pfa <0.001

Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.04
Elev+$Elev^2$	0.12
Era	0.00
Era*(Elev + $Elev^2$)	0.04
Era*Elev	0.48
Era+Elev	0.03
Era+Elev+$Elev^2$	0.28



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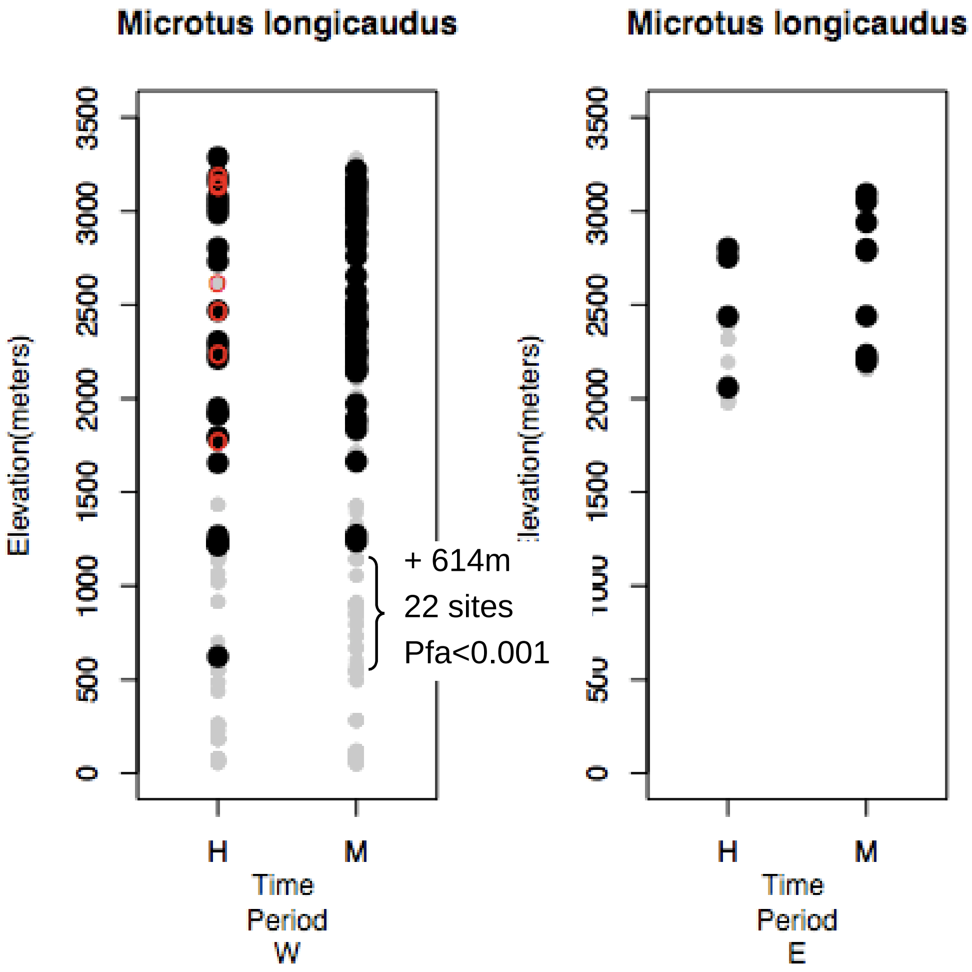
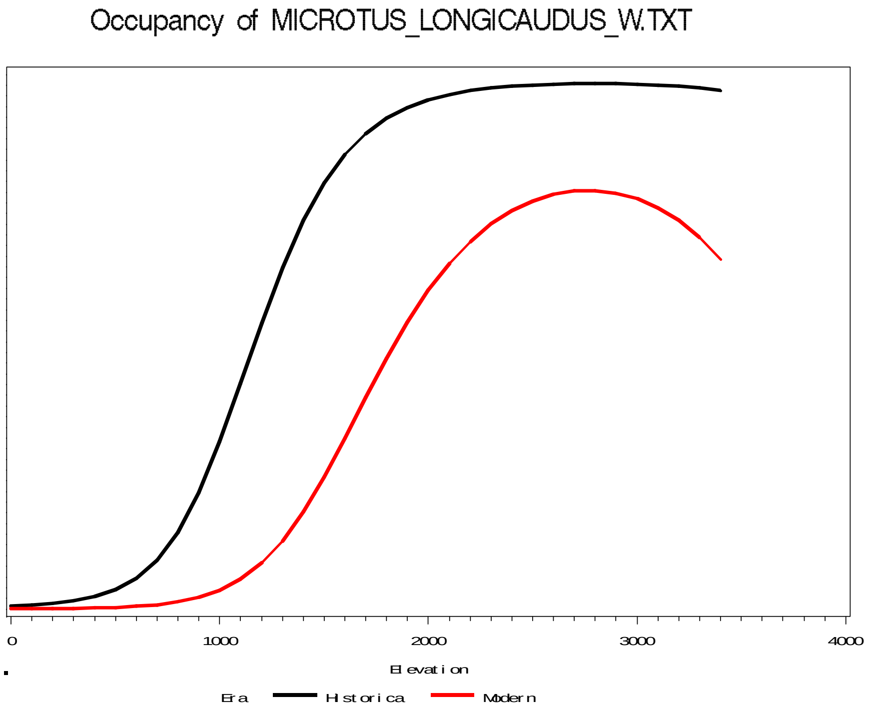
8. *Microtus longicaudus*



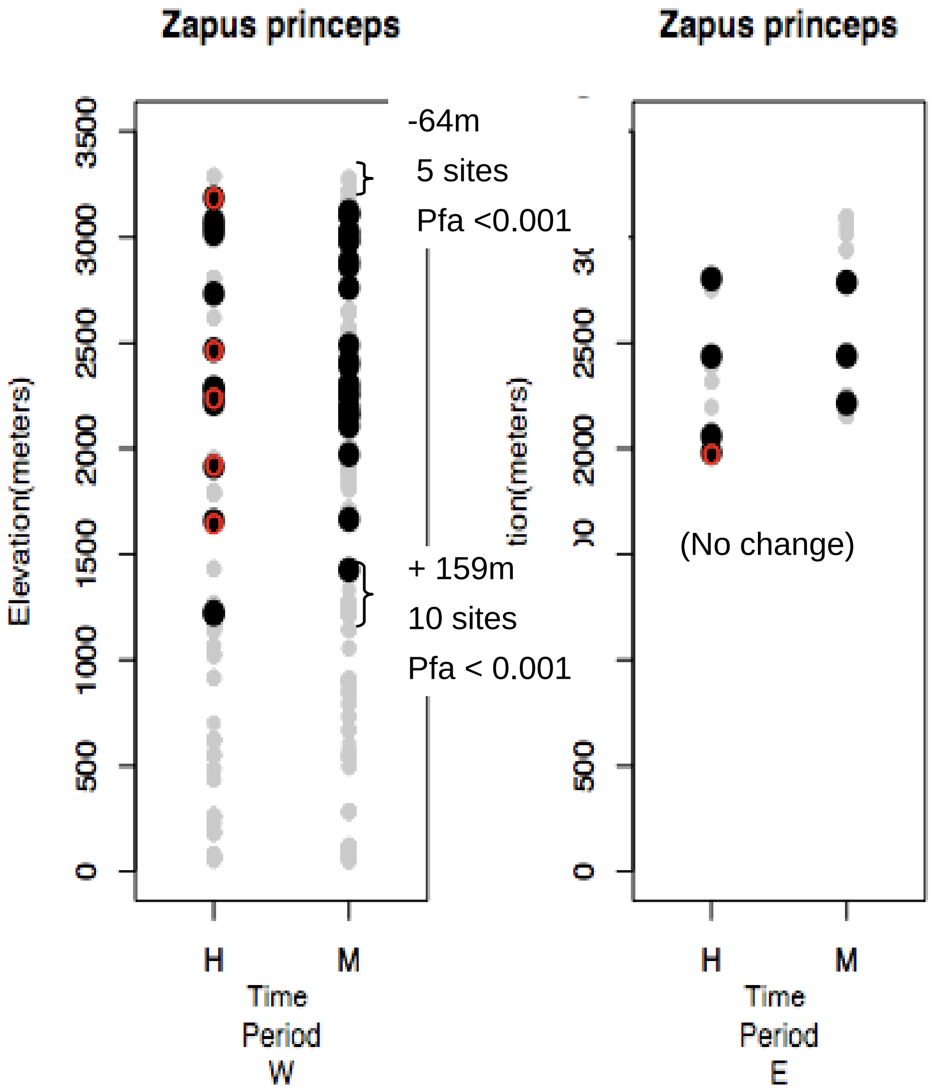
+ 614m
22 sites
Pfa<0.001

Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.00
Elev+Elev^2	0.00
Era	0.00
Era*(Elev + Elev^2)	0.19
Era*Elev	0.03
Era+Elev	0.04
Era+Elev+Elev^2	0.74



Moritz et al.

9. *Zapus princeps*



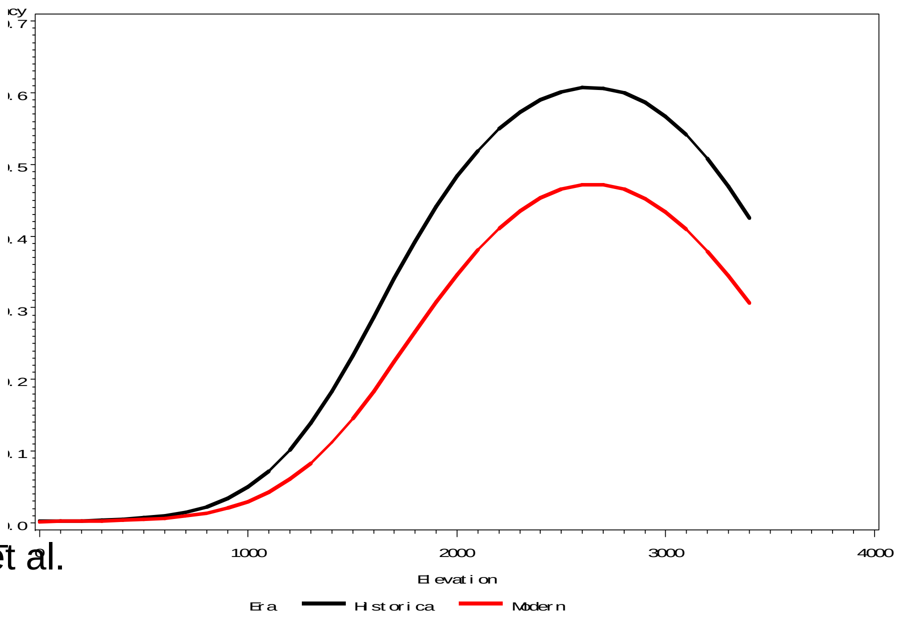
-64m
5 sites
Pfa <0.001

+ 159m
10 sites
Pfa < 0.001

(No change)

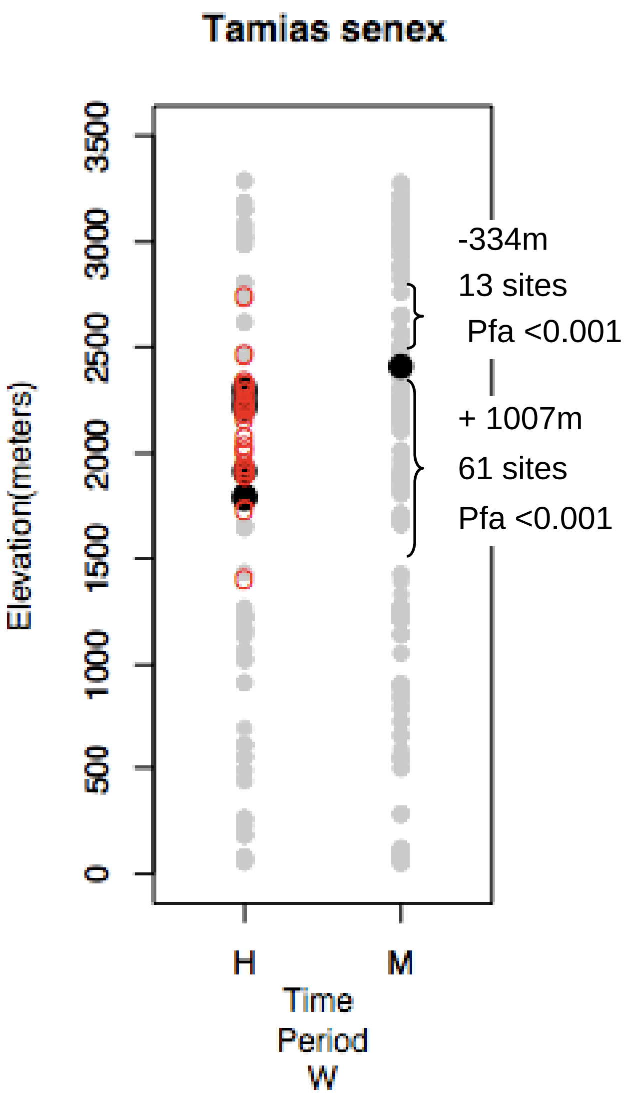
Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.03
Elev+Elev^2	0.35
Era	0.00
Era*(Elev + Elev^2)	0.06
Era*Elev	0.01
Era+Elev	0.02
Era+Elev+Elev^2	0.53

ZAPUS_PRINCEPS_W.txt



Moritz et al.

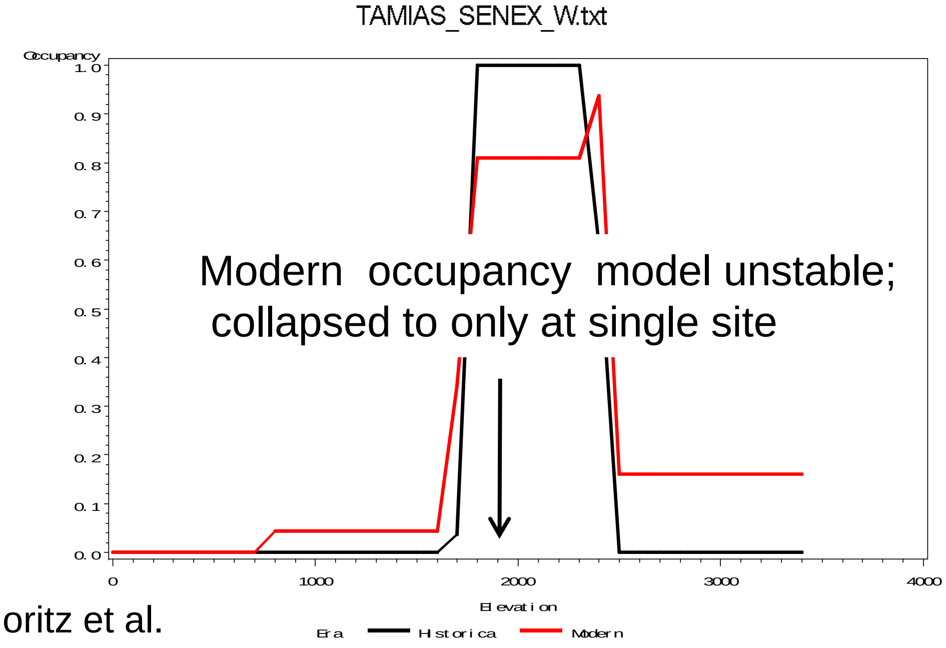
10. *Tamias senex*



-334m
13 sites
Pfa <0.001

+ 1007m
61 sites
Pfa <0.001

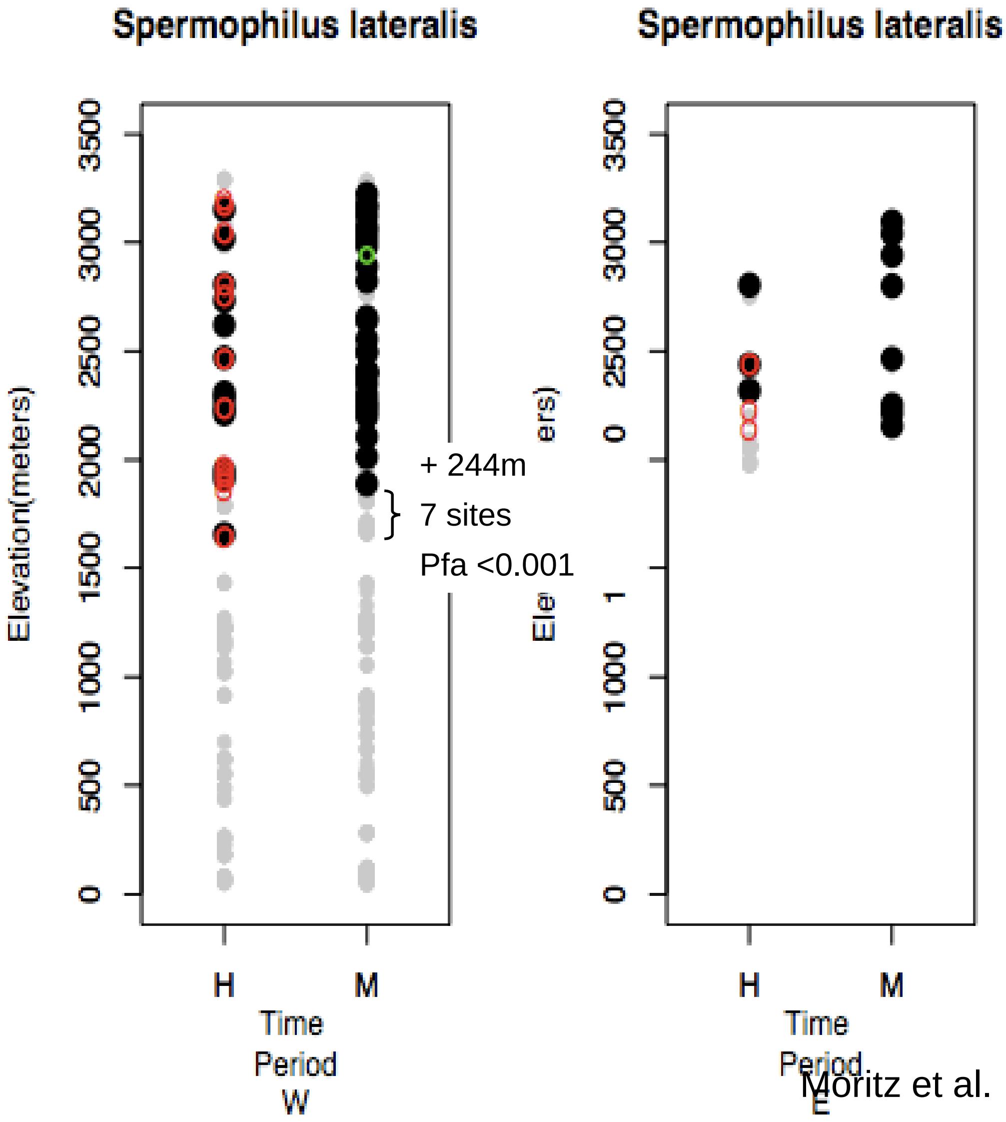
Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.00
Elev+Elev^2	0.48
Era	0.00
Era*(Elev + Elev^2)	0.19
Era*Elev	0.00
Era+Elev	0.00
Era+Elev+Elev^2	0.33



Modern occupancy model unstable; collapsed to only at single site

Moritz et al.

11. *Spermophilus lateralis*



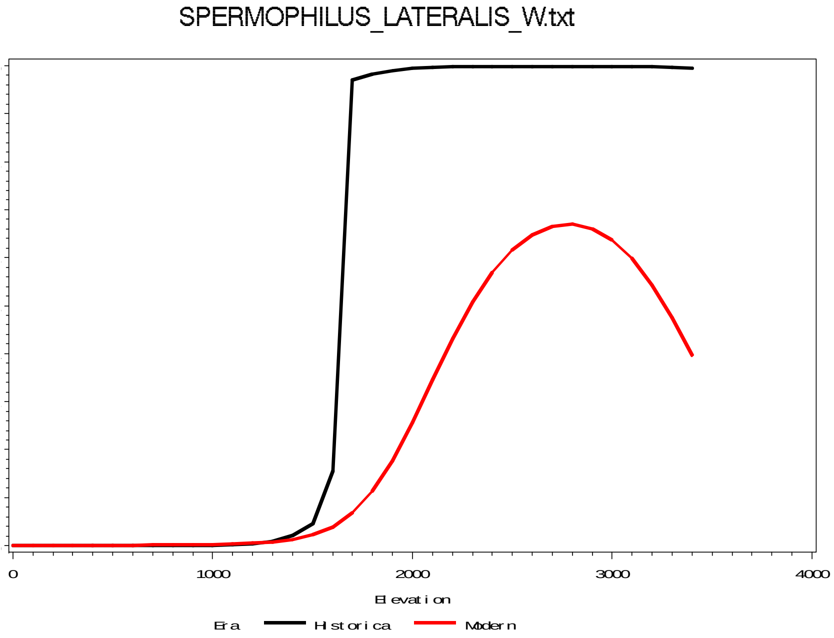
+ 244m

} 7 sites

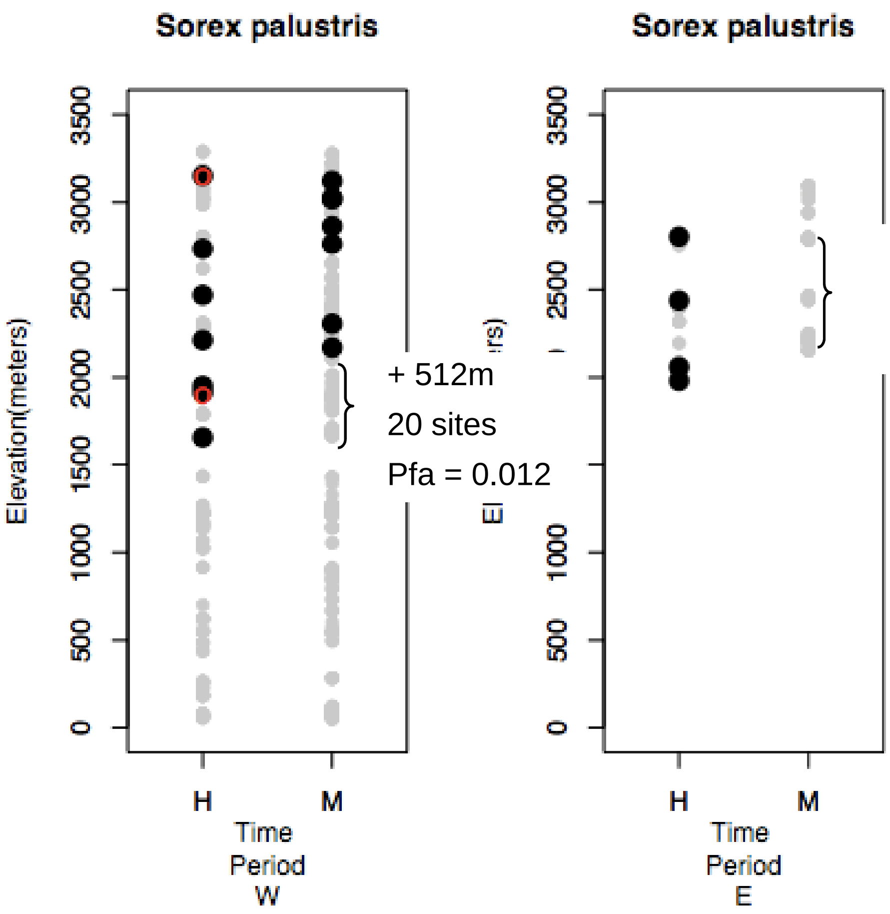
Pfa <0.001

Moritz et al.

Occupancy models	Cumulative AIC Wt
Constant	0.00
Elev	0.00
Elev+Elev^2	0.00
Era	0.00
Era*(Elev + Elev^2)	0.78
Era*Elev	0.10
Era+Elev	0.01
Era+Elev+Elev^2	0.11



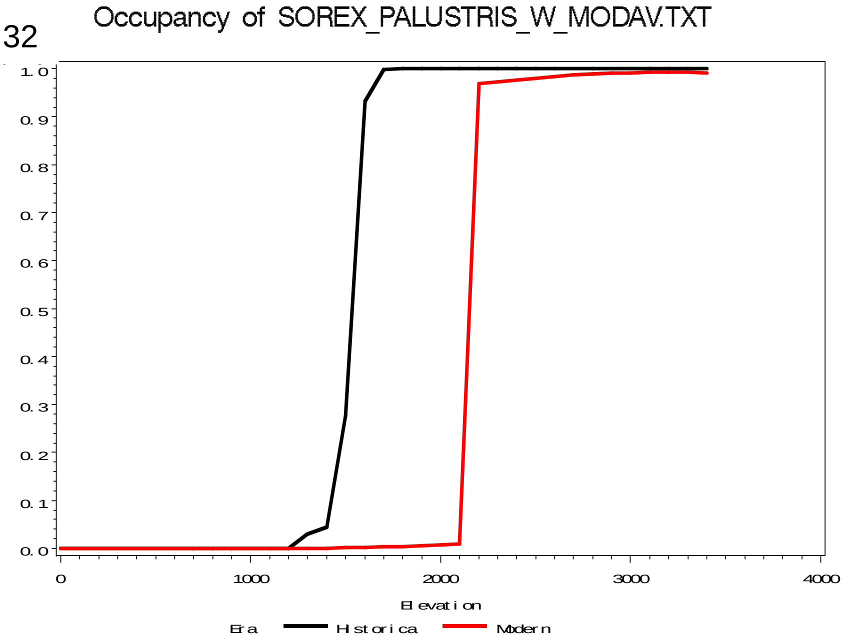
12. *Sorex palustris*



+ 512m
20 sites
Pfa = 0.012

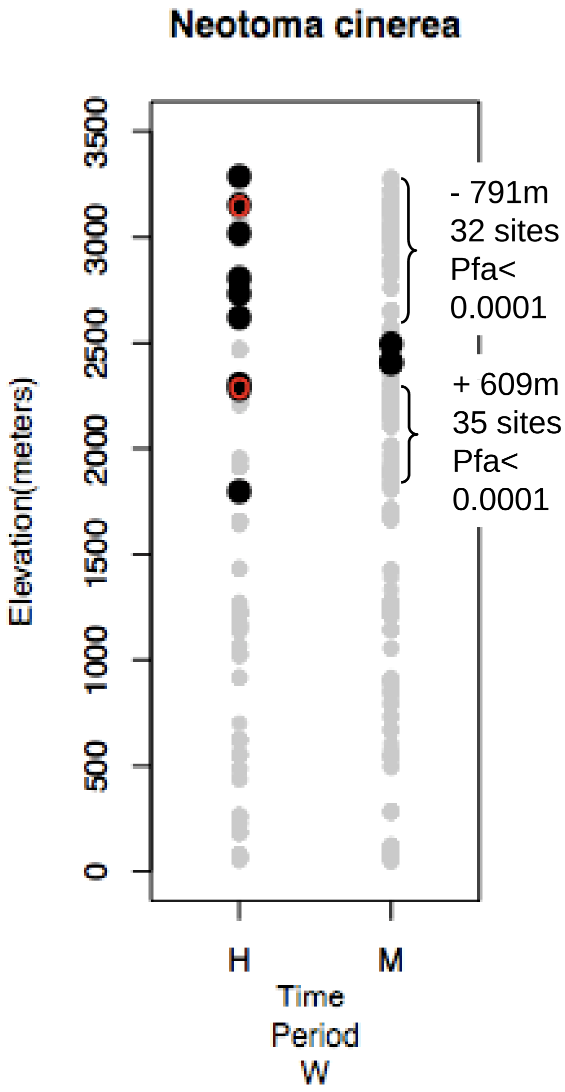
Absent
9 sites
Pfa = 0.32

Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.00
Elev+Elev^2	0.00
Era	0.00
Era*(Elev + Elev^2)	0.12
Era*Elev	0.14
Era+Elev	0.34
Era+Elev+Elev^2	0.39



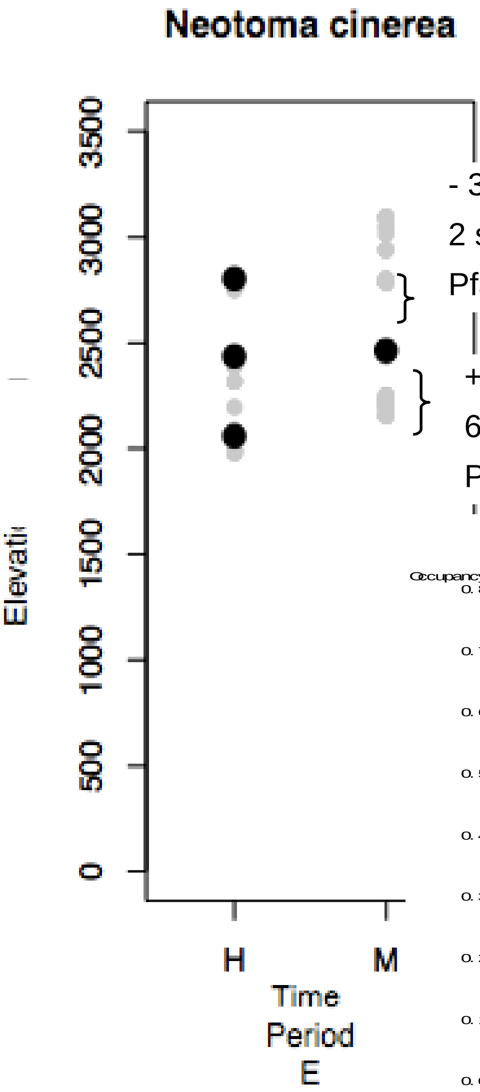
Moritz et al.

13. *Neotoma cinerea*



- 791m
32 sites
Pfa<
0.0001

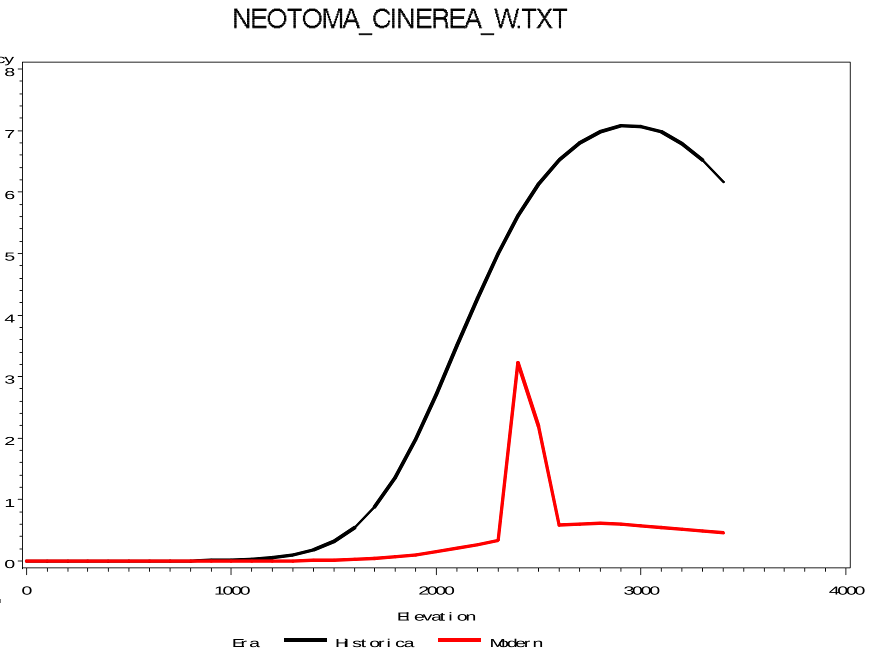
+ 609m
35 sites
Pfa<
0.0001



- 339m
2 sites
Pfa = 0.09

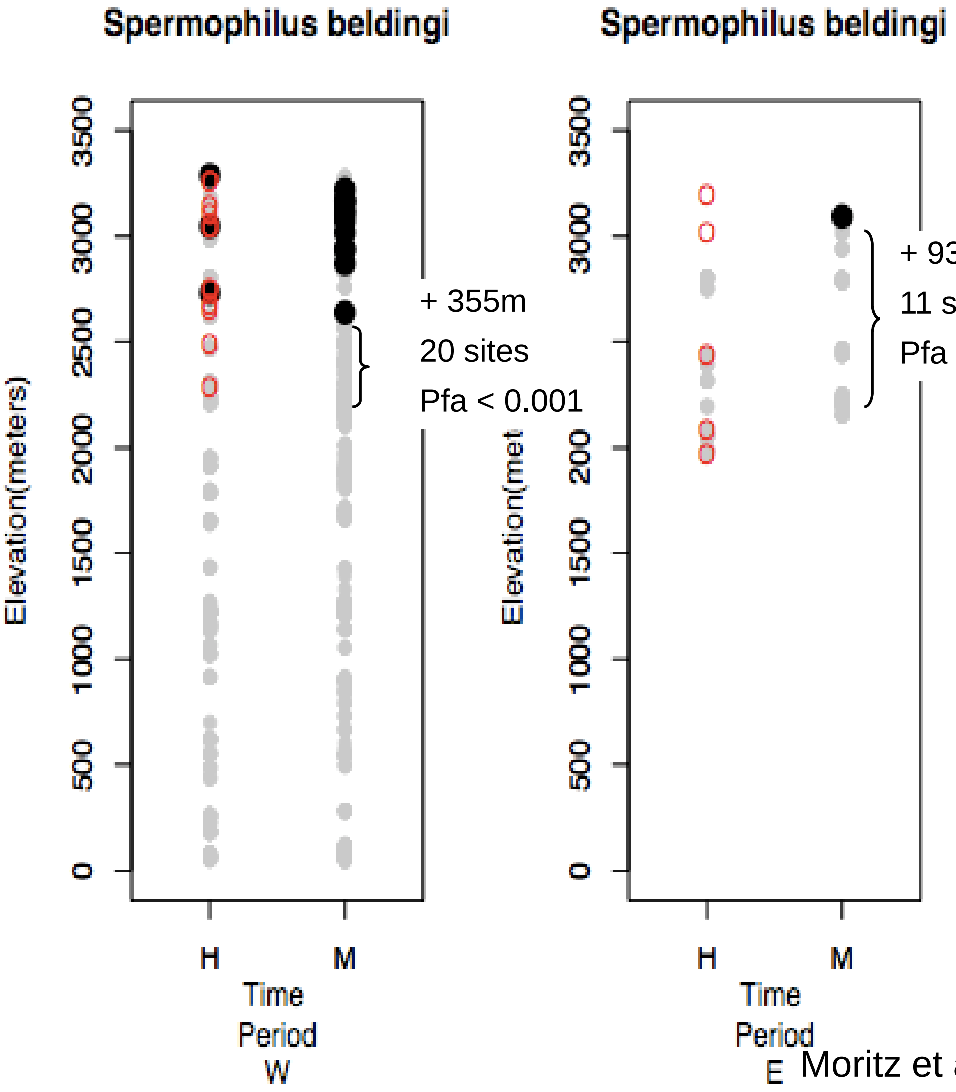
+ 406m
6 sites
Pfa < 0.001

Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.02
Elev+Elev^2	0.02
Era	0.00
Era*(Elev + Elev^2)	0.83
Era*Elev	0.02
Era+Elev	0.01
Era+Elev+Elev^2	0.10



Moritz et al.

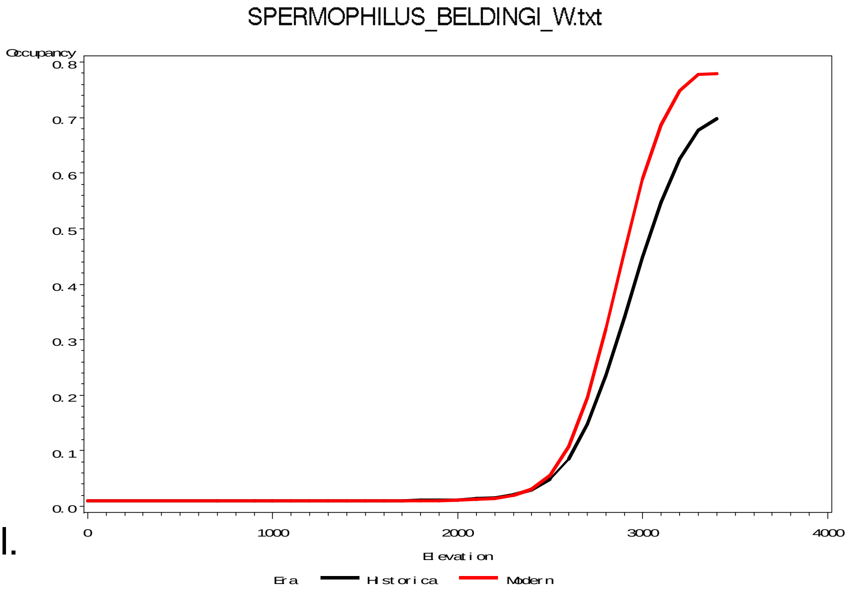
14. *Spermophilus beldingi*



+ 355m
20 sites
Pfa < 0.001

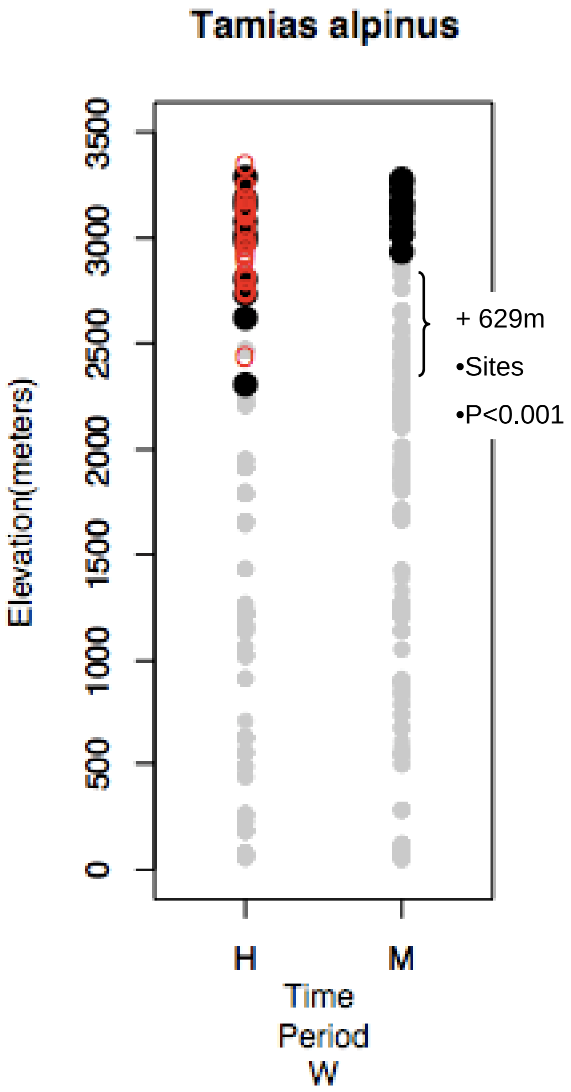
+ 939m
11 sites
Pfa < 0.001

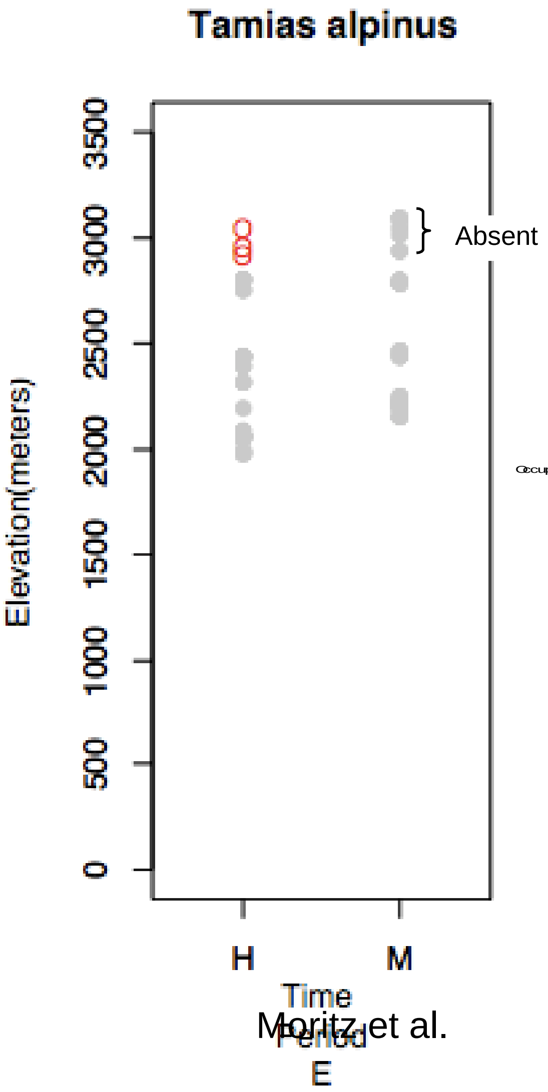
Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.32
Elev+Elev^2	0.22
Era	0.00
Era*(Elev + Elev^2)	0.02
Era*Elev	0.13
Era+Elev	0.20
Era+Elev+Elev^2	0.11



Moritz et al.

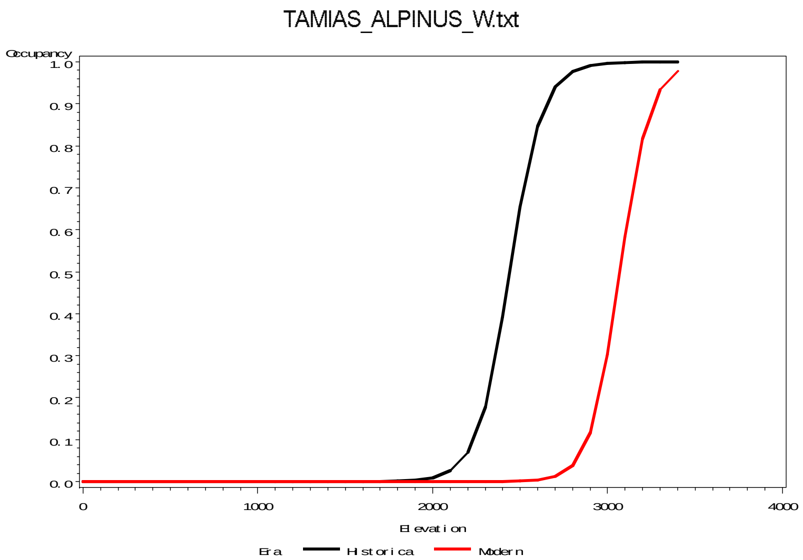
15. *Tamias alpinus*



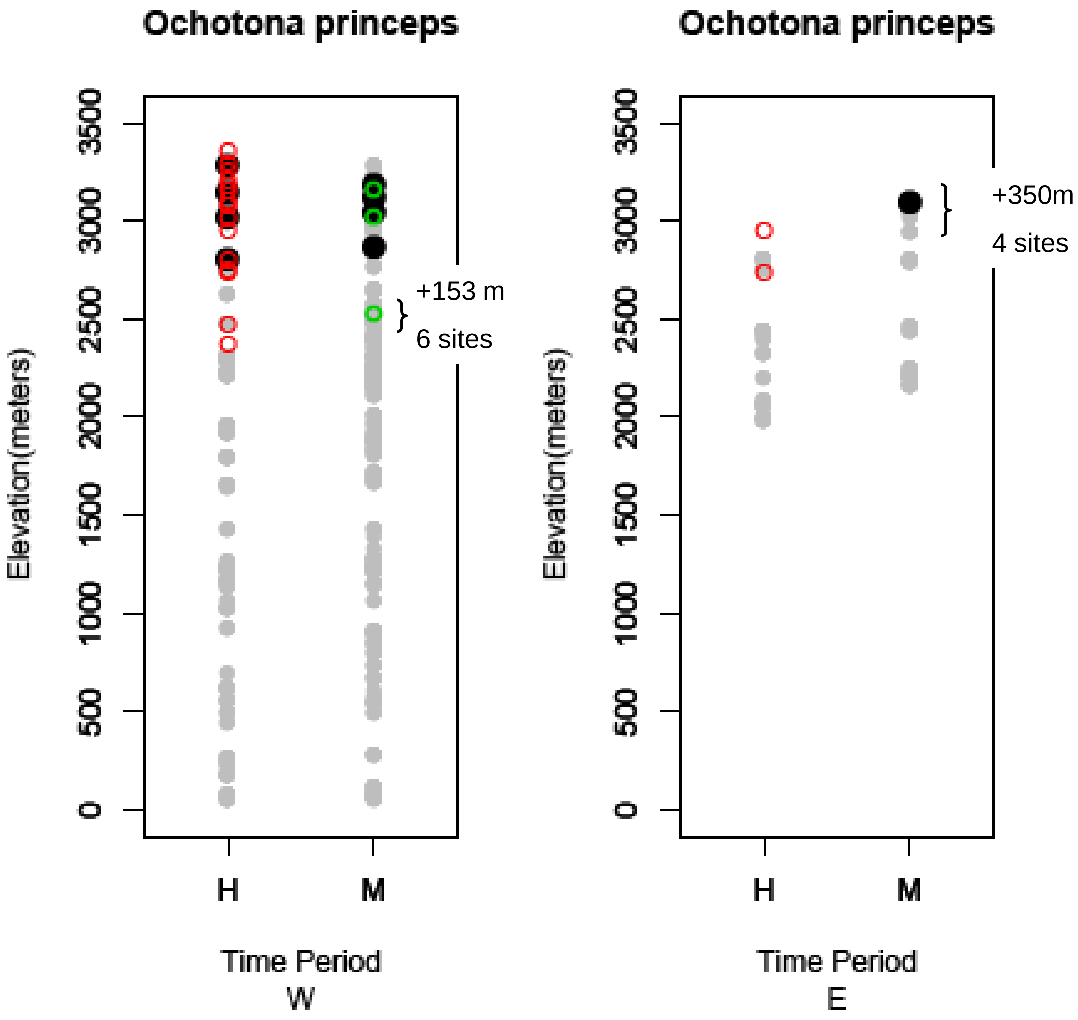


Moritz et al.

Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.00
Elev+Elev^2	0.00
Era	0.00
Era*(Elev + Elev^2)	0.06
Era*Elev	0.19
Era+Elev	0.56
Era+Elev+Elev^2	0.18



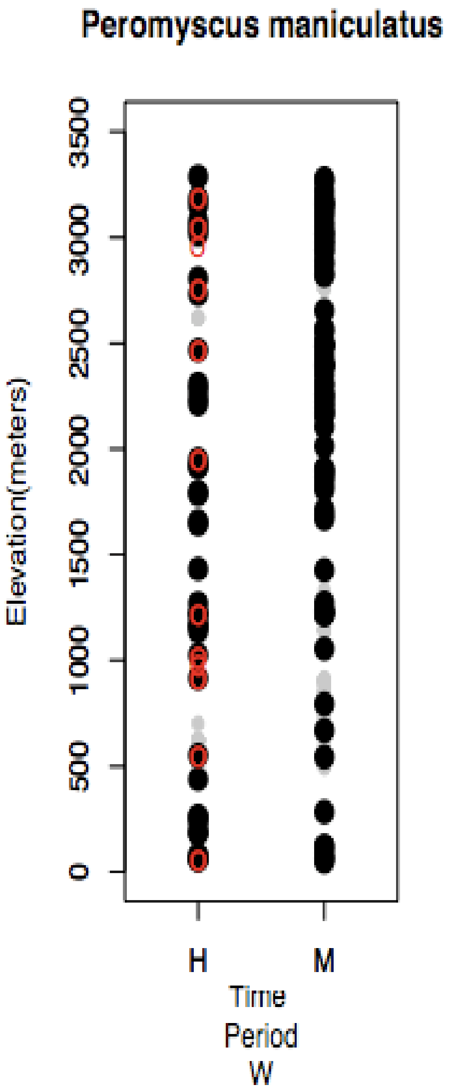
16. *Ochotona princeps*

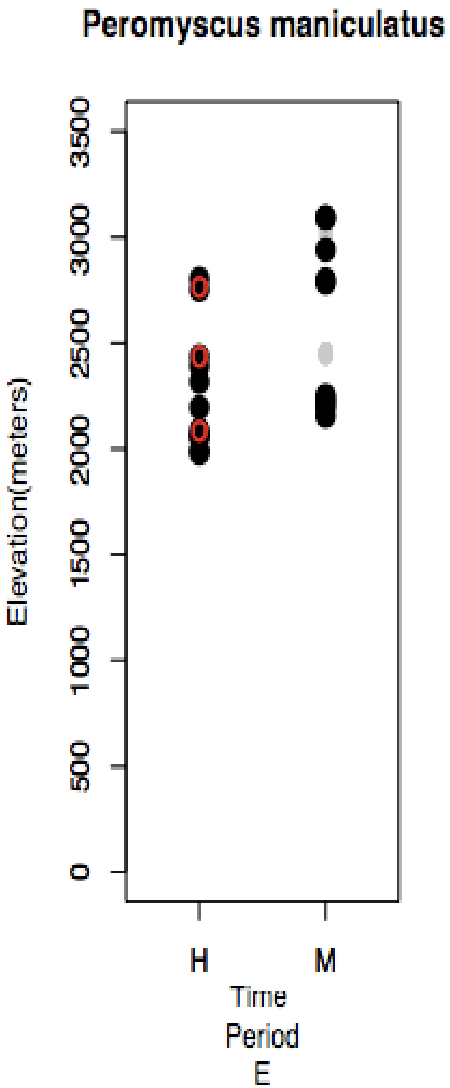


Data insufficient to analyze with occupancy models.

Moritz et al.

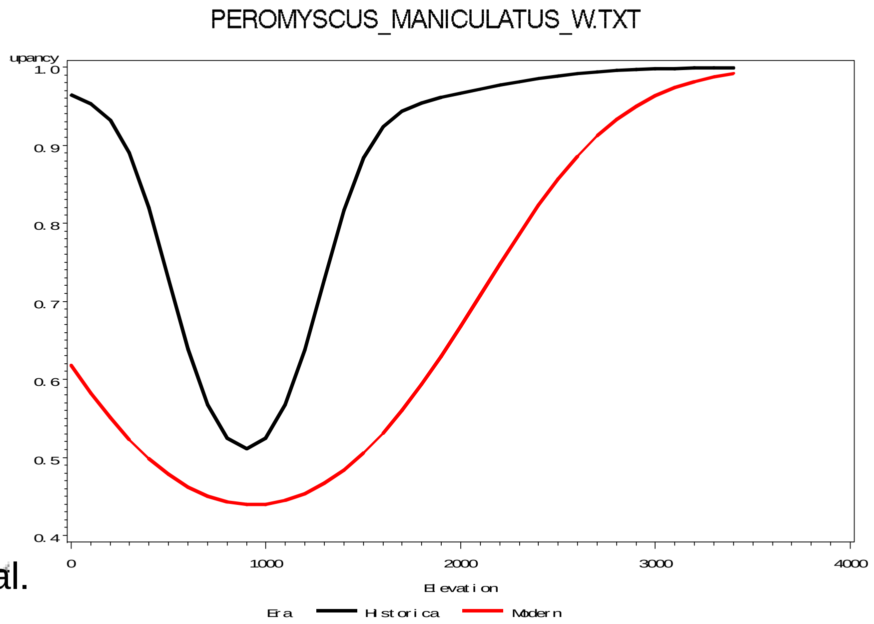
17. *Peromyscus maniculatus*



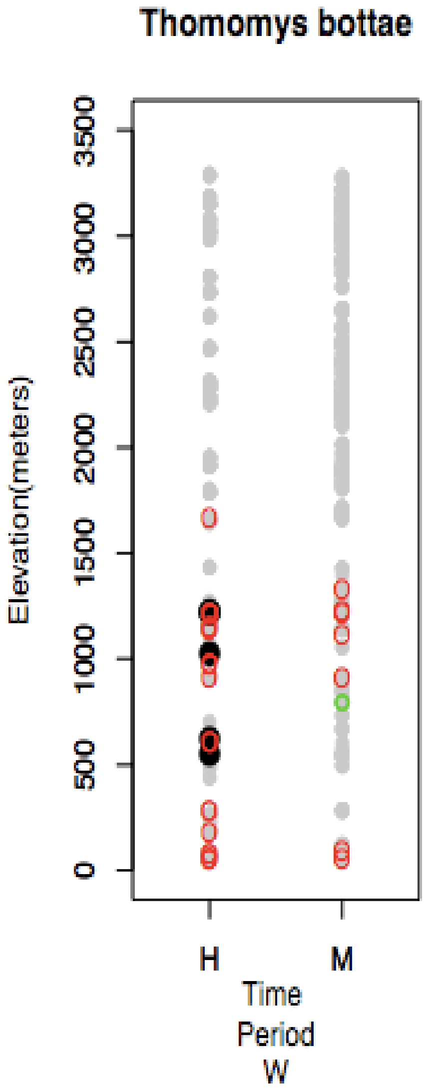


Moritz et al.

Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.00
Elev+Elev^2	0.01
Era	0.00
Era*(Elev + Elev^2)	0.72
Era*Elev	0.00
Era+Elev	0.00
Era+Elev+Elev^2	0.26



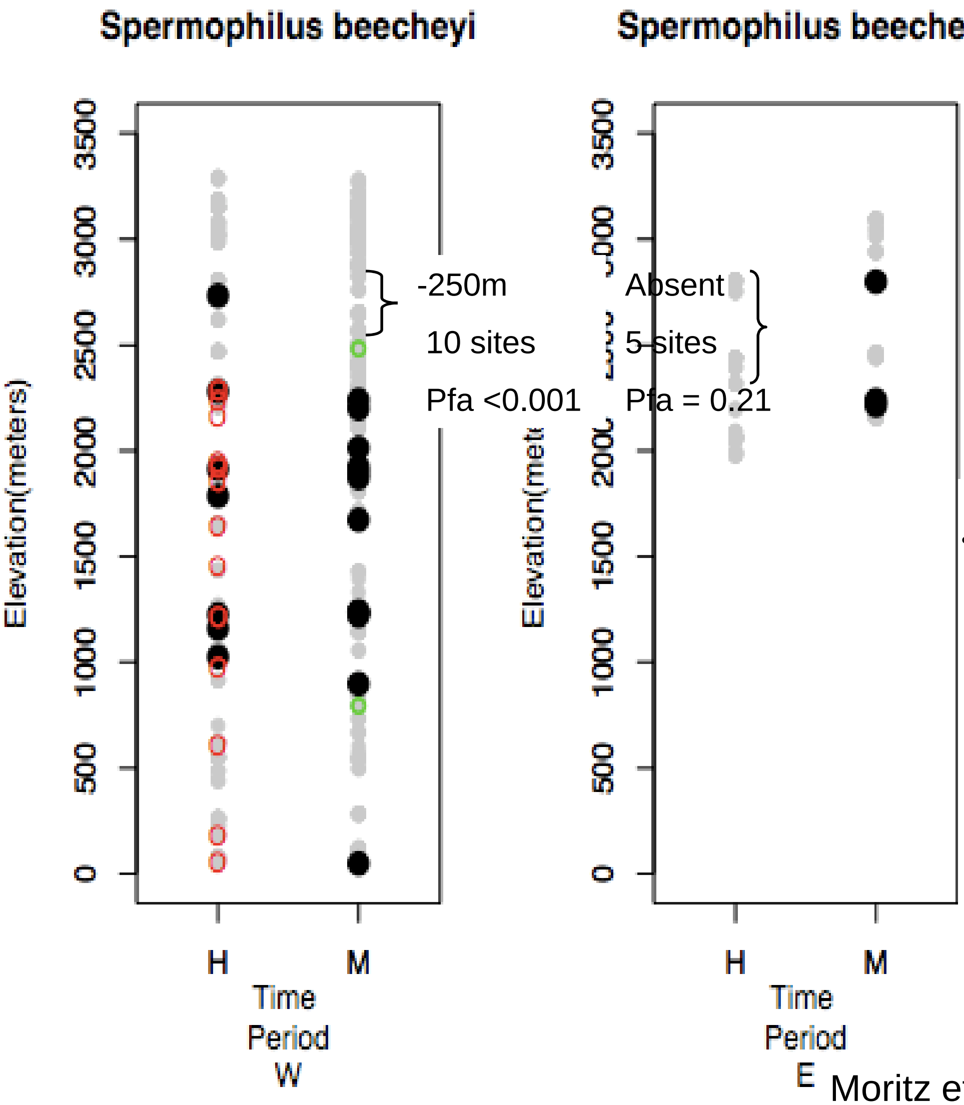
18. *Thomomys bottae*



Nonstandard trapping technique
made data unsuitable for
use with occupancy models.

Moritz et al.

19. *Spermophilus beecheyi*



-250m

10 sites

Pfa <0.001

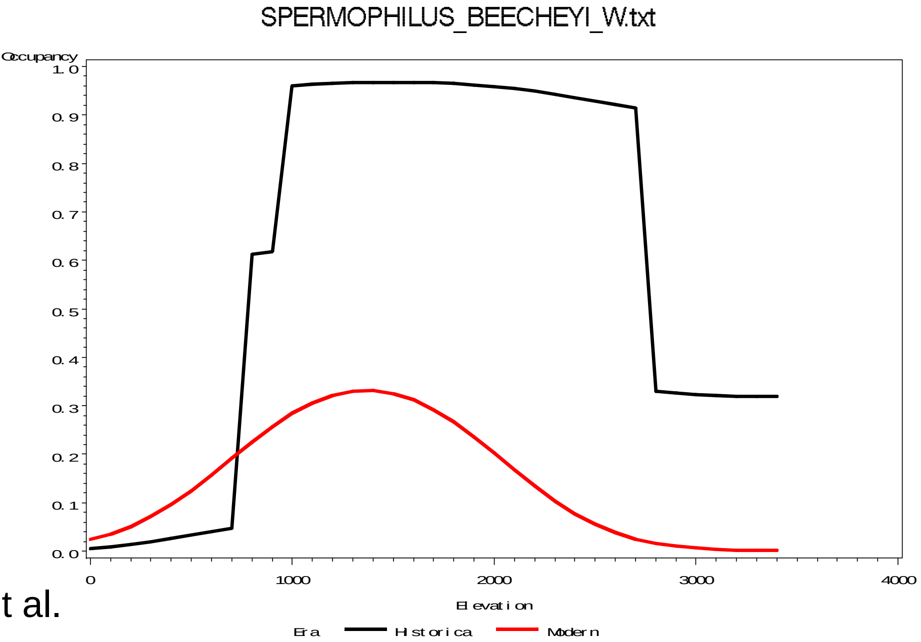
Absent

5 sites

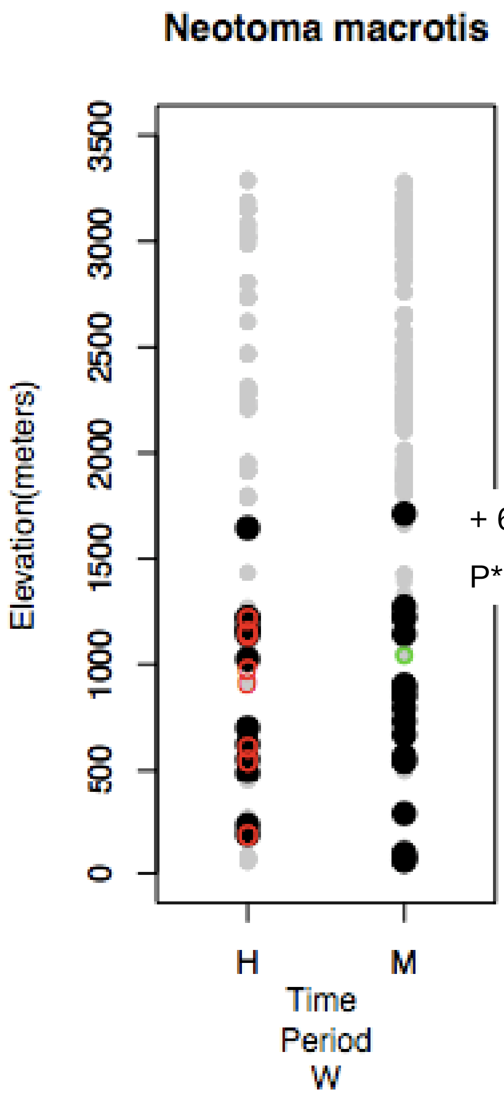
Pfa = 0.21

Moritz et al.

Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.00
Elev+Elev^2	0.03
Era	0.00
Era*(Elev + Elev^2)	0.89
Era*Elev	0.01
Era+Elev	0.00
Era+Elev+Elev^2	0.07



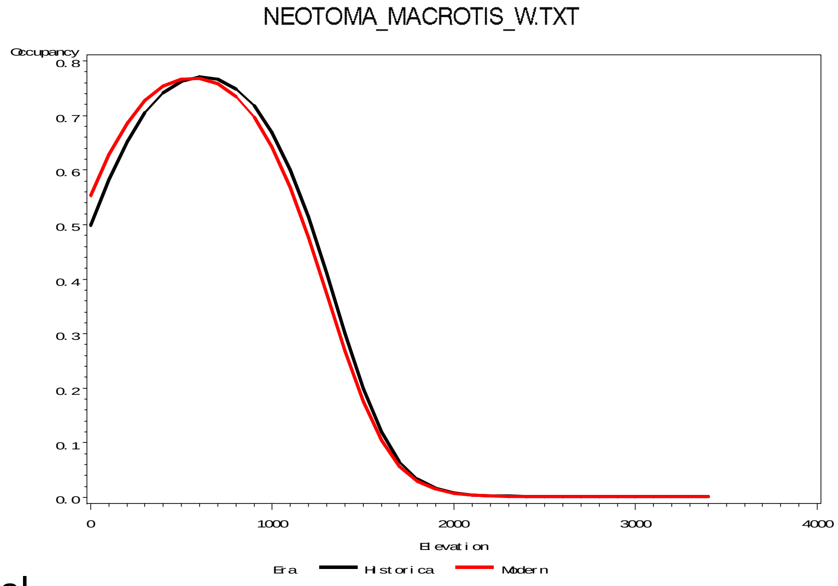
20. *Neotoma macrotis*



+ 67m

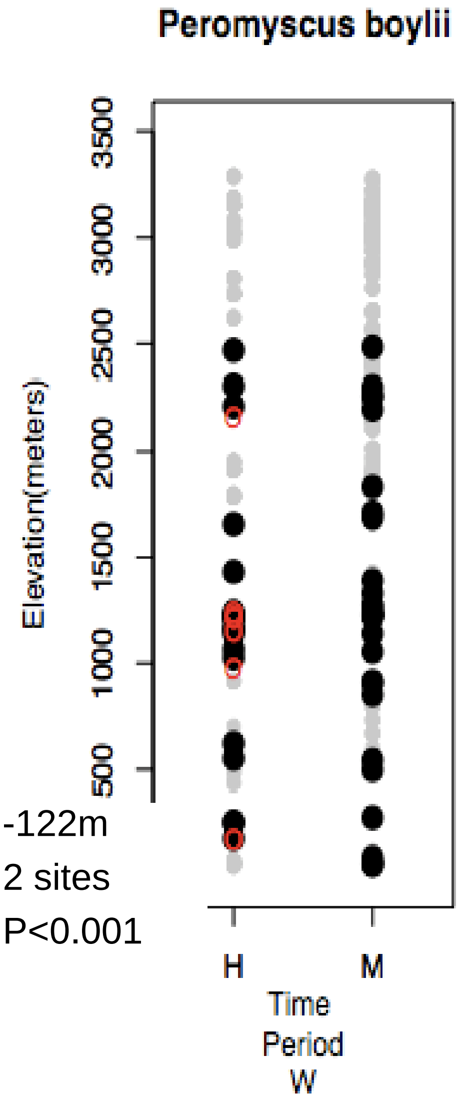
P* = 0,02

Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.03
Elev+Elev^2	0.62
Era	0.00
Era*(Elev + Elev^2)	0.10
Era*Elev	0.01
Era+Elev	0.03
Era+Elev+Elev^2	0.21



Moritz et al.

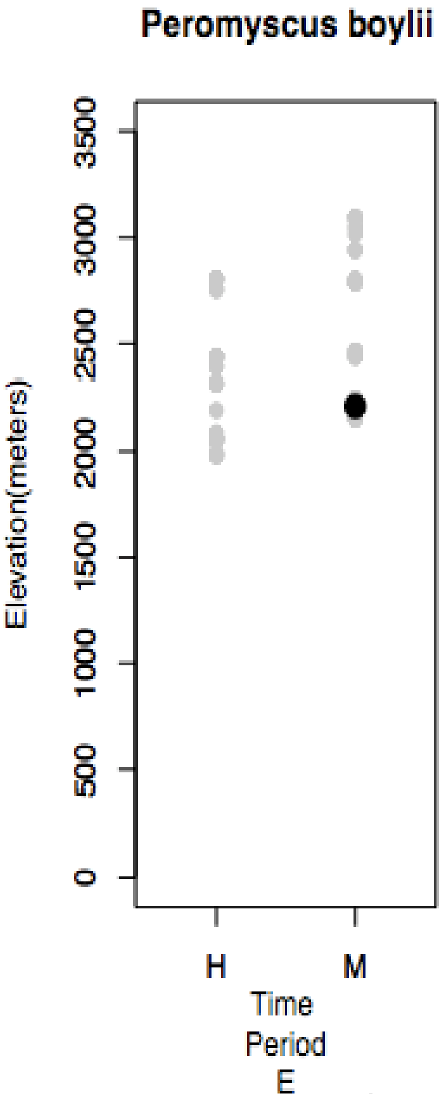
21. *Peromyscus boylii*



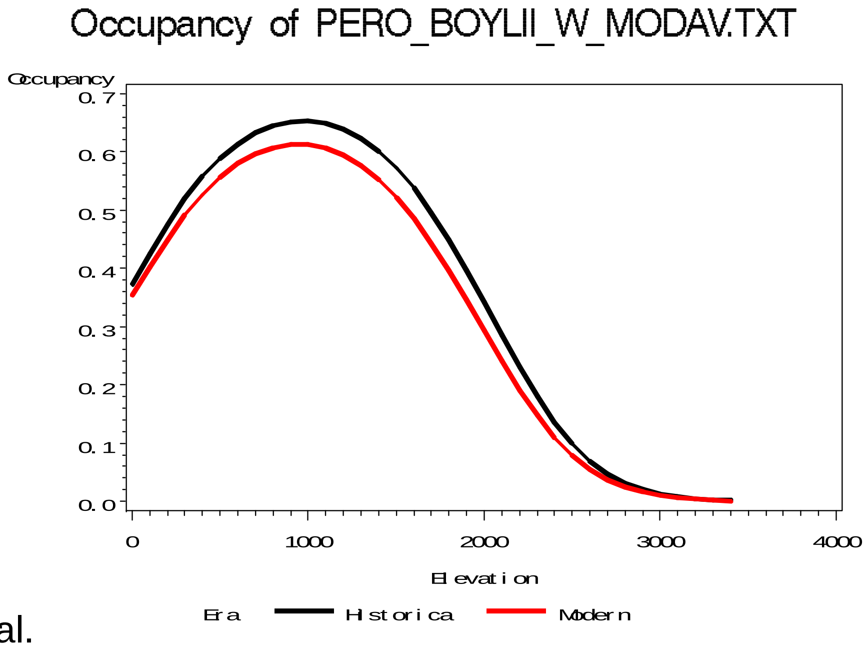
-122m

2 sites

P<0.001

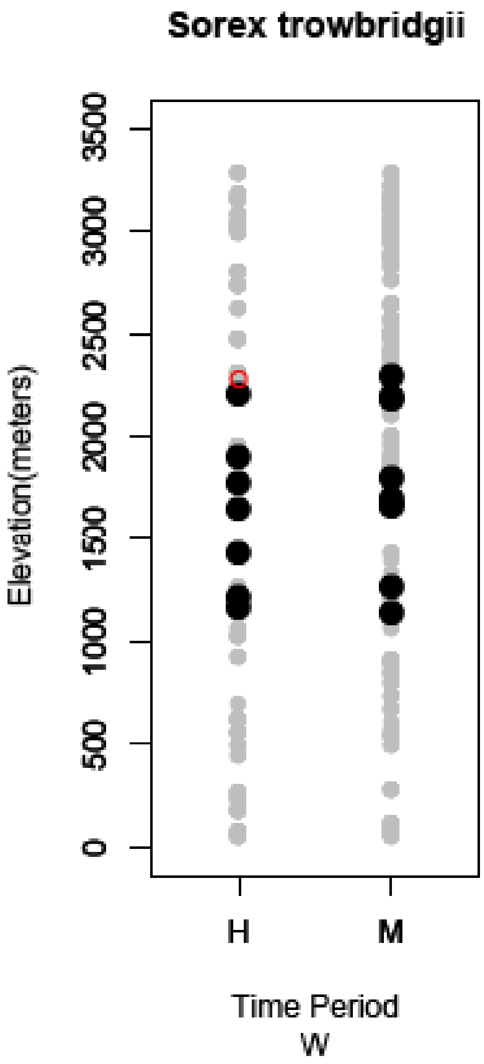


Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.00
Elev+Elev^2	0.60
Era	0.00
Era*(Elev + Elev^2)	0.08
Era*Elev	0.00
Era+Elev	0.00
Era+Elev+Elev^2	0.32

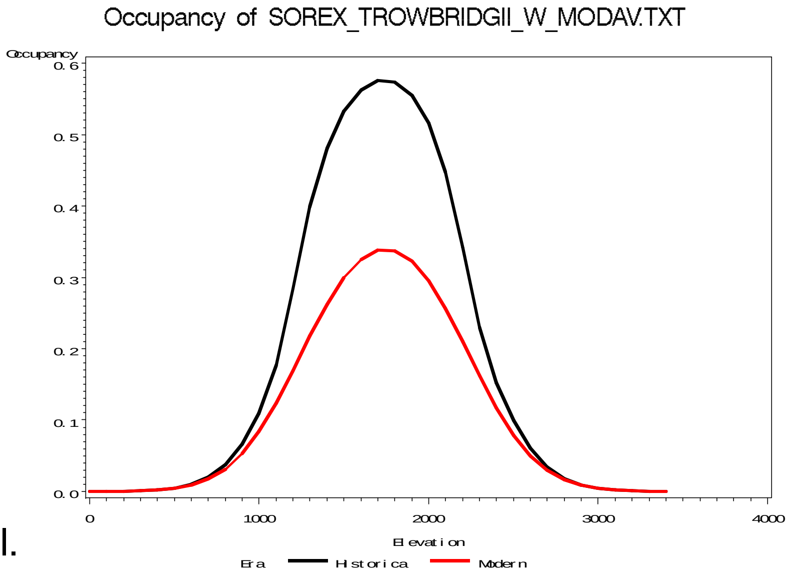


Moritz et al.

22. *Sorex trowbridgii*

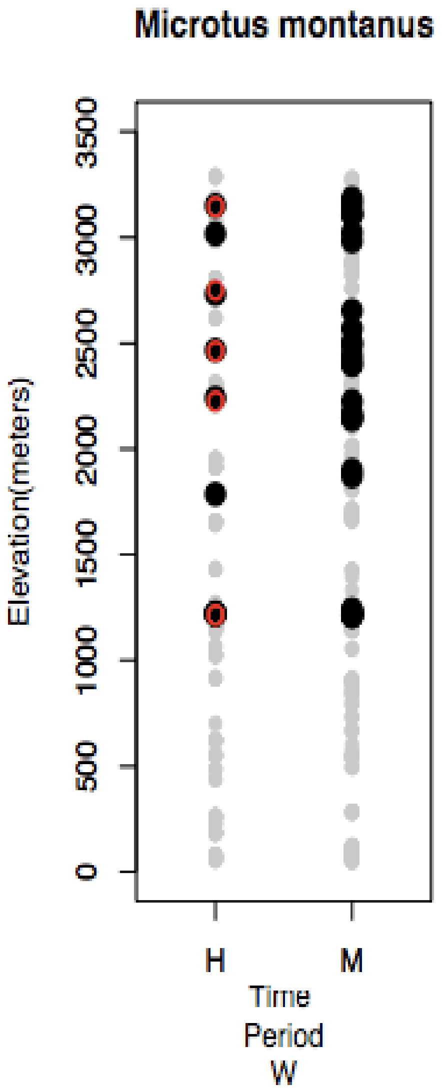


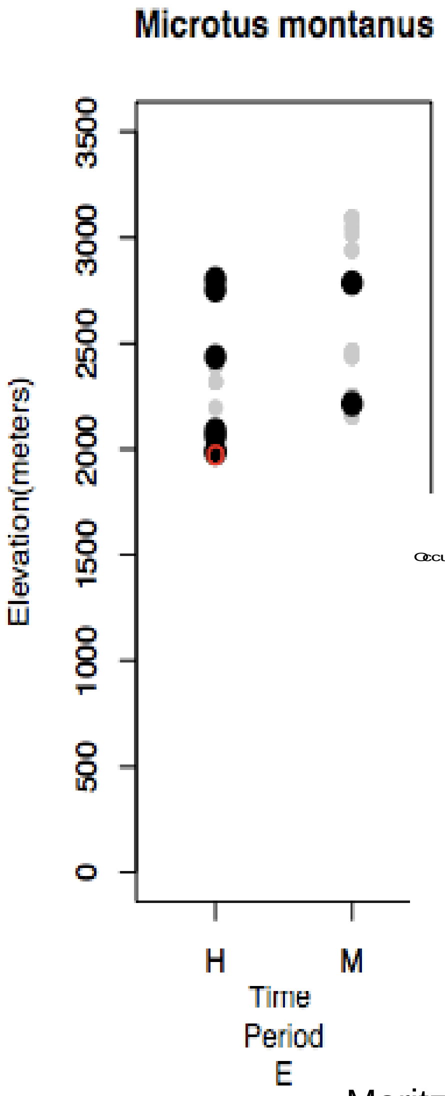
Occupancy models	Cumulative AIC Wt
Constant	0.00
Elev	0.00
Elev+Elev^2	0.40
Era	0.00
Era*(Elev + Elev^2)	0.21
Era*Elev	0.00
Era+Elev	0.00
Era+Elev+Elev^2	0.39



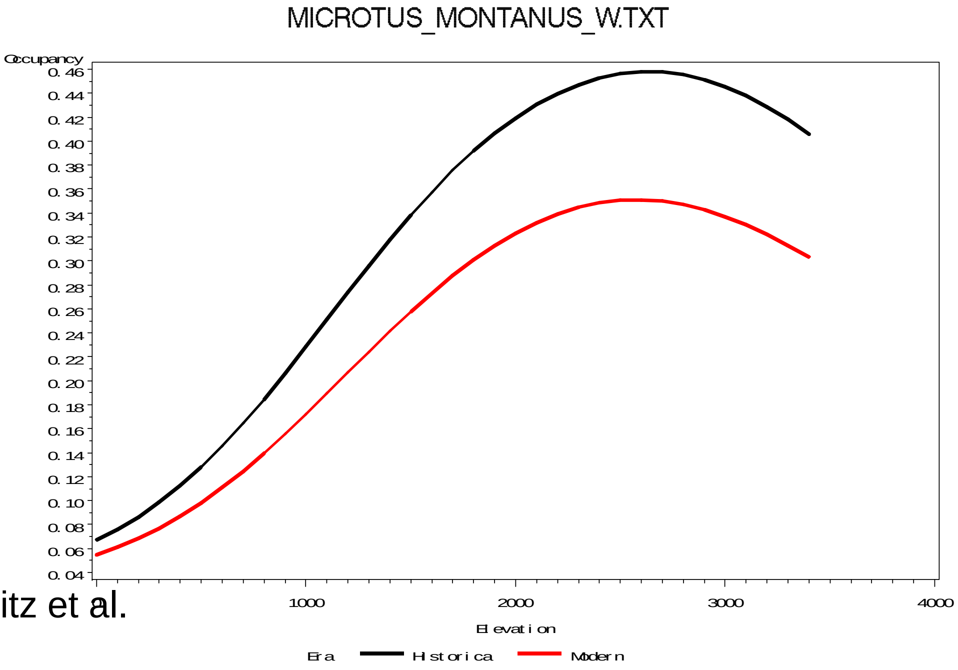
Moritz et al.

23. *Microtus montanus*



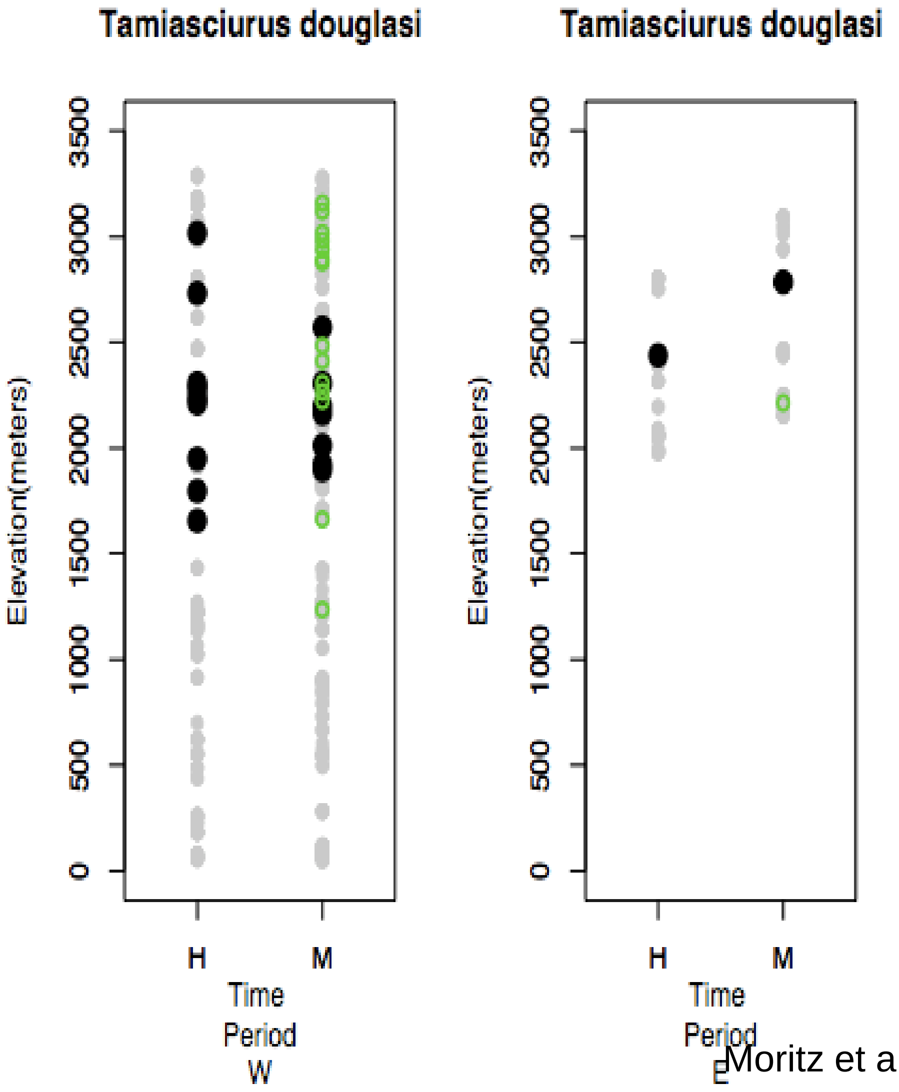


Occupancy models	**Cumulative AIC Wt**
Constant	0.01
Elev	0.14
Elev+Elev^2	0.36
Era	0.01
Era*(Elev + Elev^2)	0.04
Era*Elev	0.06
Era+Elev	0.11
Era+Elev+Elev^2	0.28



Moritz et al.

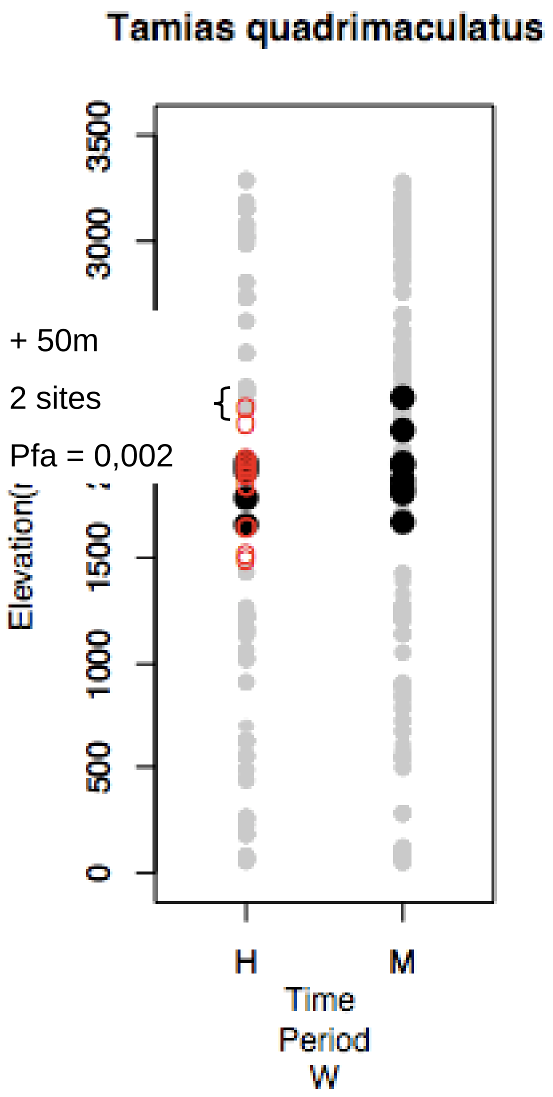
24. *Tamiasciurus douglasi*



Moritz et al.

Data insufficient to analyze with occupancy models as only one capture occurred at each site.

25. *Tamias quadrimaculatus*

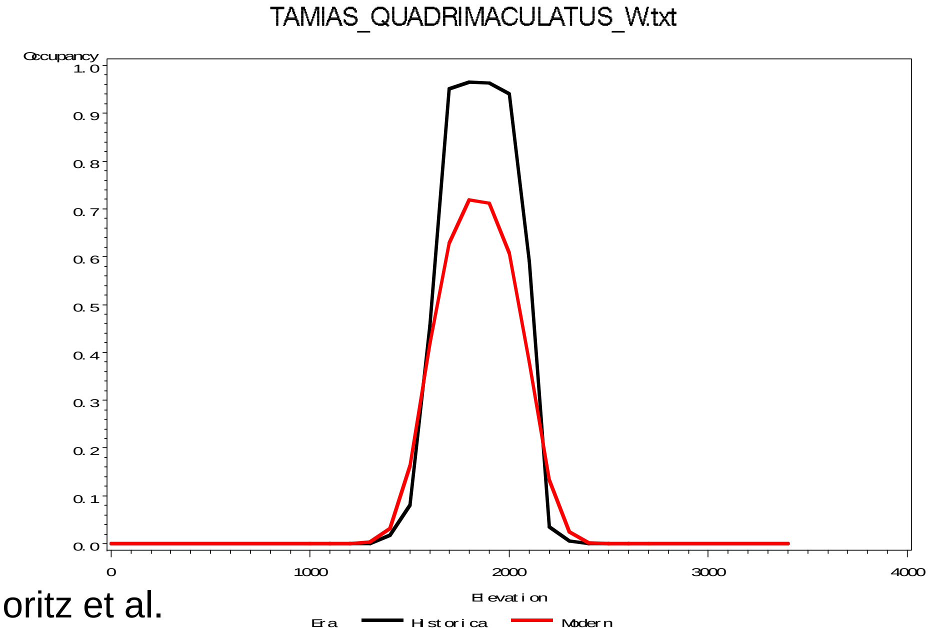


+ 50m

2 sites {

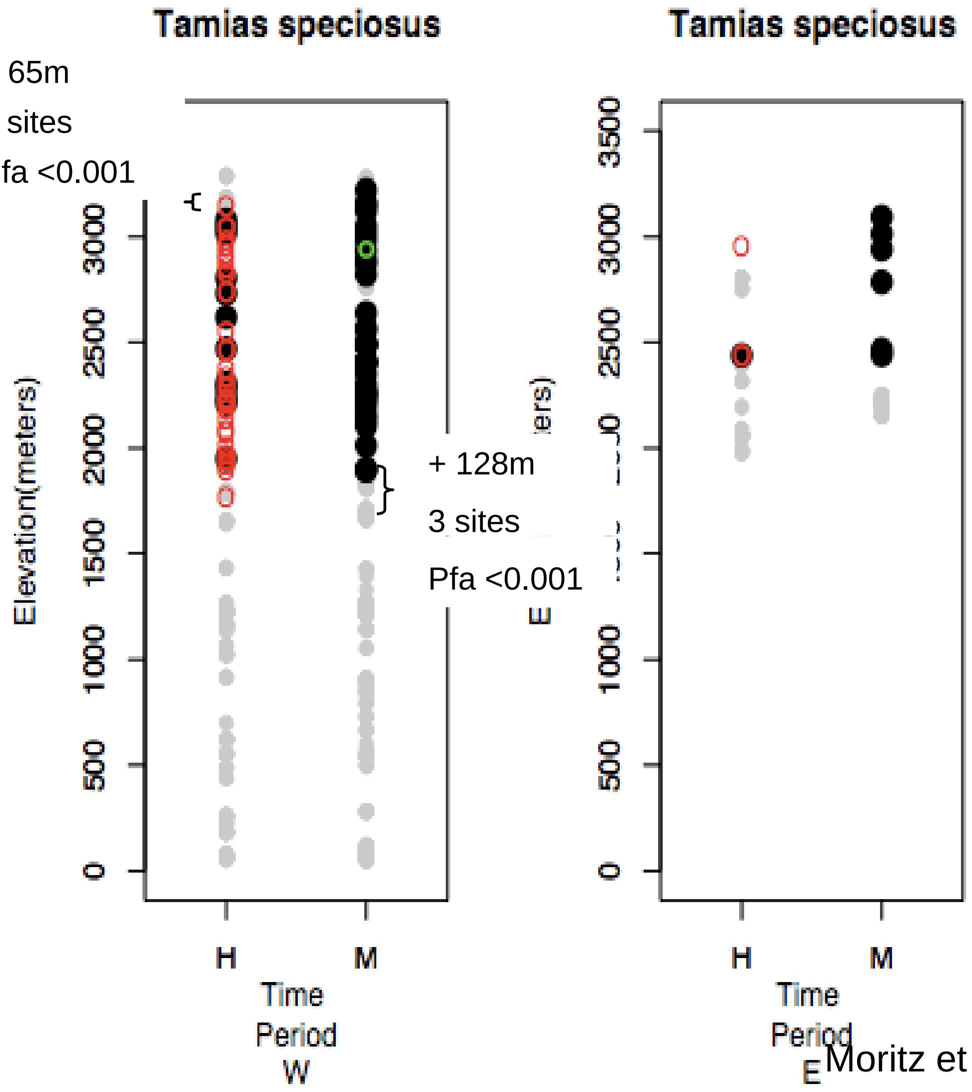
Pfa = 0,002

Occupancy models	Cumulative AIC Wt
Constant	0.00
Elev	0.00
Elev+Elev^2	0.16
Era	0.00
Era*(Elev + Elev^2)	0.78
Era*Elev	0.00
Era+Elev	0.00
Era+Elev+Elev^2	0.07



Moritz et al.

26. *Tamias speciosus*



+ 65m

2 sites

Pfa <0.001

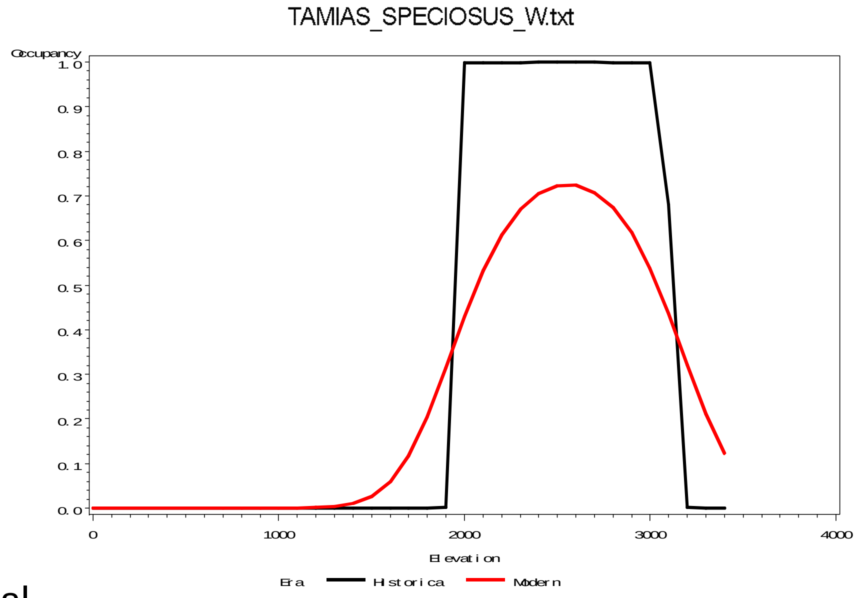
+ 128m

3 sites

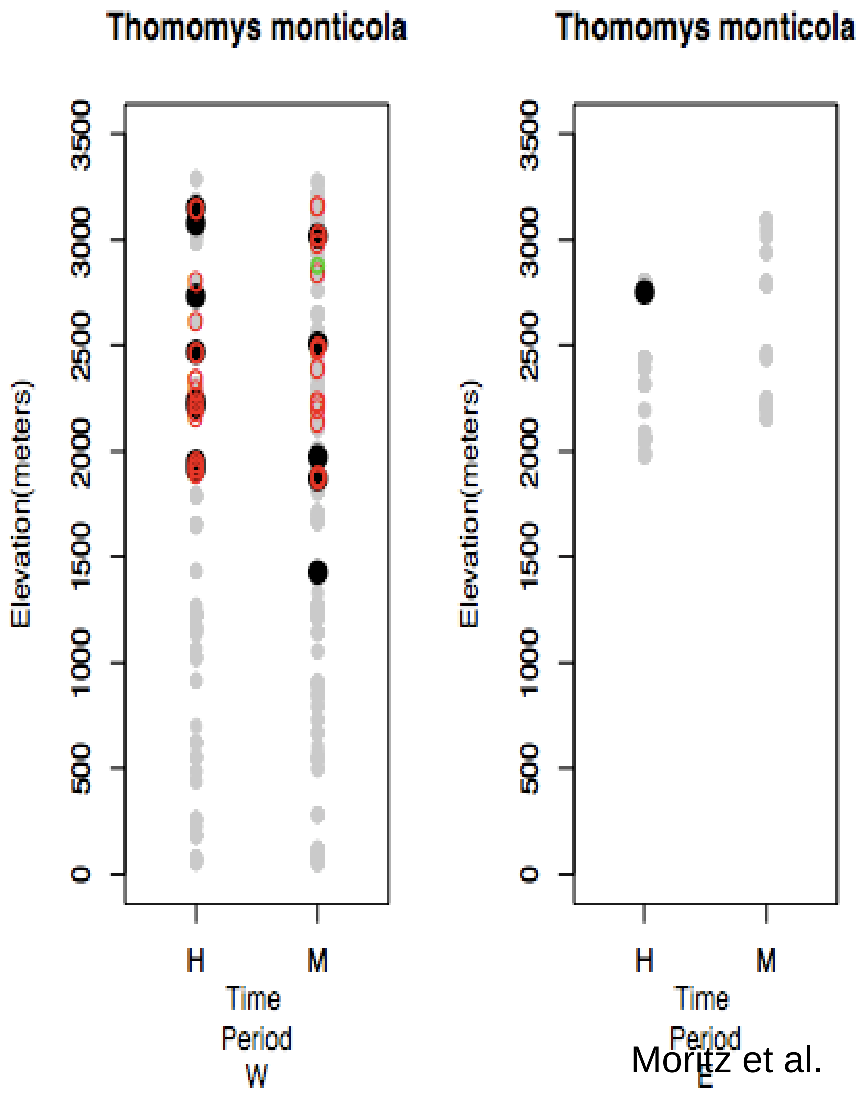
Pfa <0.001

Moritz et al.

Occupancy models	**Cumulative AIC Wt**
Constant	0.00
Elev	0.00
Elev+Elev^2	0.00
Era	0.00
Era*(Elev + Elev^2)	1.00
Era*Elev	0.00
Era+Elev	0.00
Era+Elev+Elev^2	0.00



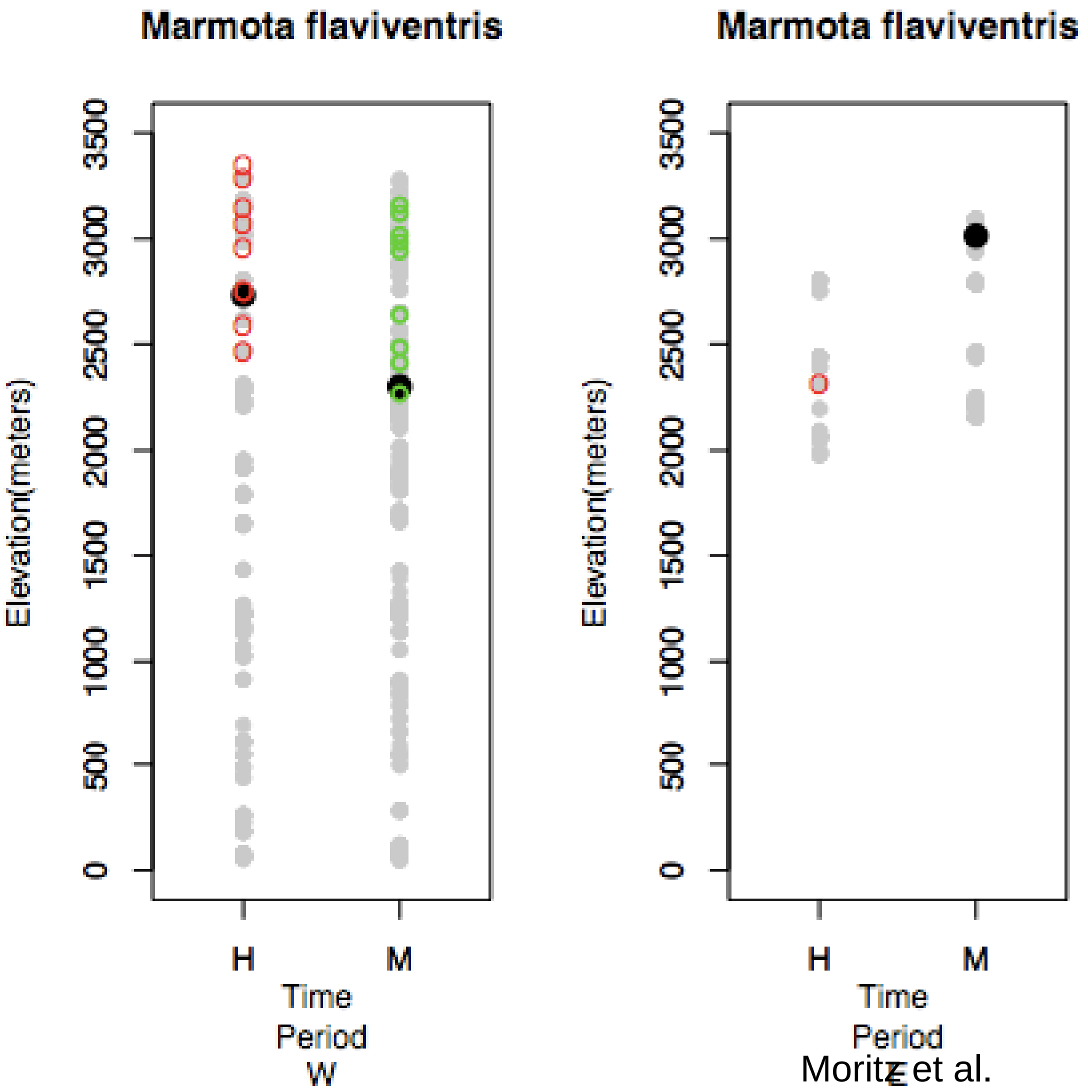
27. *Thomomys monticola*



Moritz et al.

Nonstandard trapping techniques made data unsuitable for use with occupancy models.

28. *Marmota flaviventris*



Moritz et al.

Nonstandard observation-based records made data unsuitable for use with occupancy models.

Figure S4 – Species richness estimators (+1 SD) by era for each lifezone, Yosemite National Park (Park) and the entire transect (Park&Transect). The five non-parametric estimators of total species richness are Chao1, Chao2, Incidence Coverage Estimator (ICE), Jack1, and Jack2 to estimate the asymptote of the species accumulation curve.

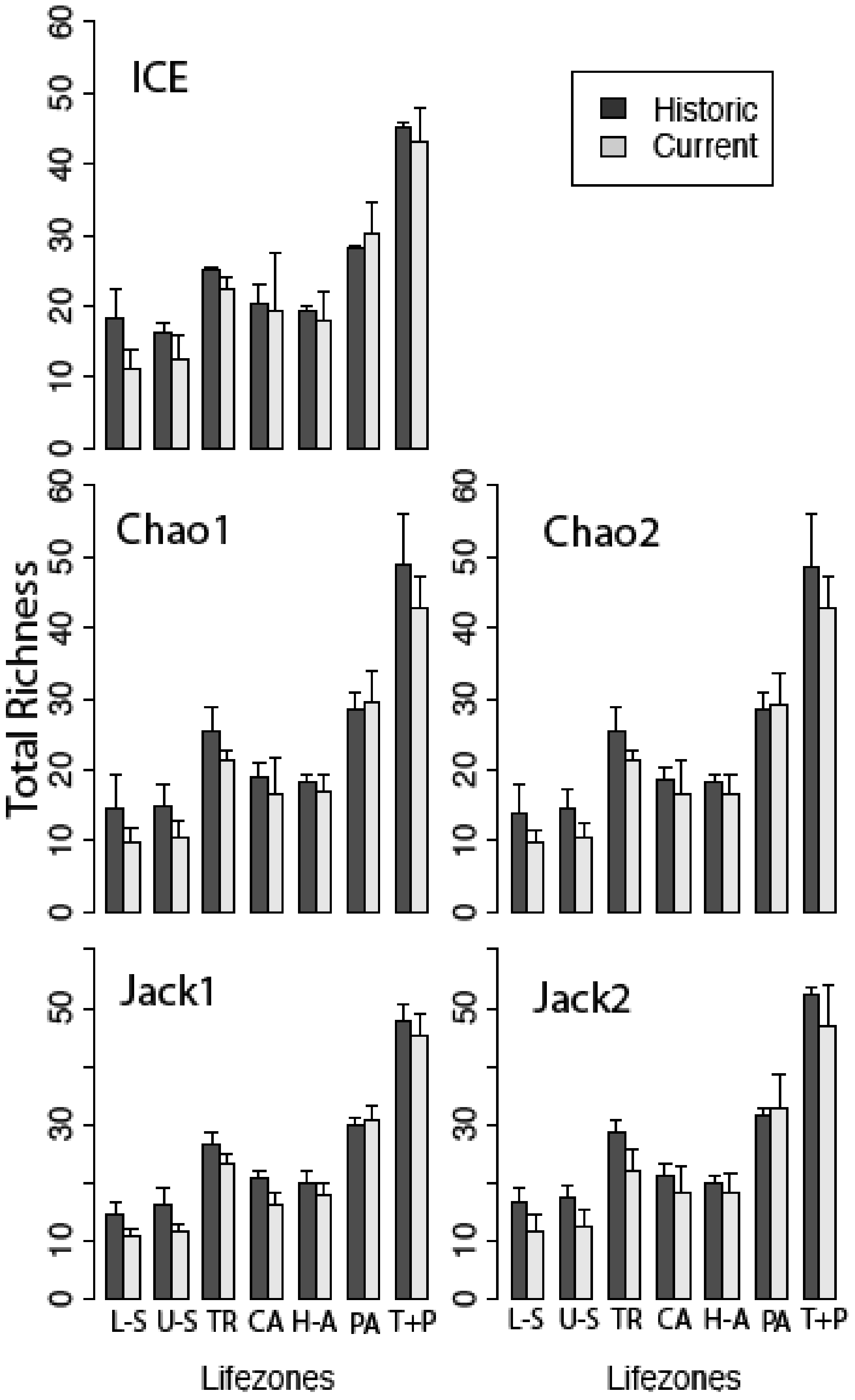

ICE
Chao1
Chao2
Jack1
Jack2
Historic
Current
Total Richness
0
10
20
30
40
50
60
L-S
U-S
TR
CA
H-A
PA
T+P
Lifezones

Figure S5. Probability of an upper limit range expansion for 10 low-mid elevation species in relation to longevity (life span in years) and litters per year derived from the best two composite posthoc logistic regression models (Life zone, Longevity; Life zone, Litters per year) in Table S5 based on an information theoretic approach to model selection. Life history data shown in Table S6. No mid-high species exhibited upwards range shifts, and the modeled probability of an upwards range expansion in relation to longevity and litter size was near zero.

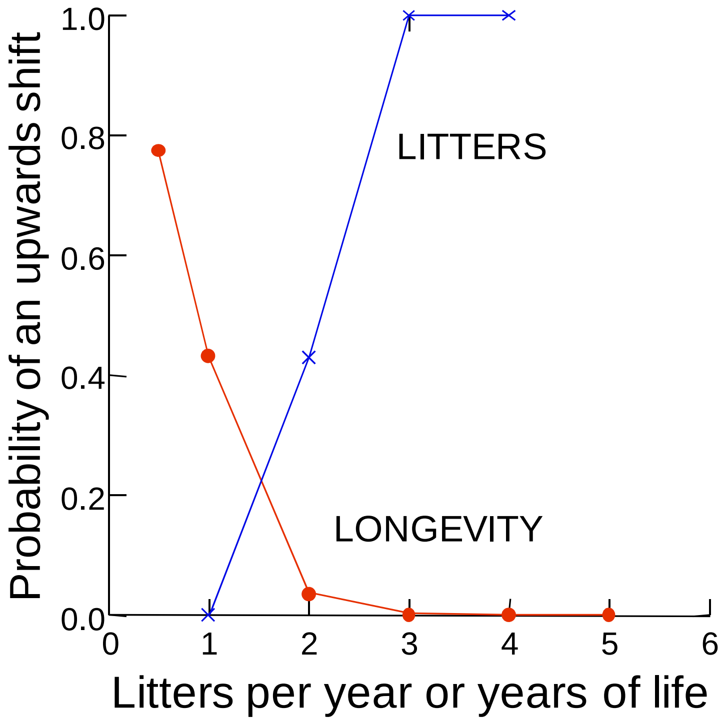


Figure S6 – Examples of photographic retakes illustrating precise location of historic sampling units and similarity of habitat.

Big Oak Flat Road, South Facing North wall of Valley showing Rockslides. Mariposa Co., California. Old picture taken by C. D. Holliger on December 30, 1914. Recent picture taken by Robert Hijmans on 2003

Lyell Canyon, Yosemite National Park, California. Old picture taken by T. Storer on July 24, 1915. Recent picture taken by Robert Hijmans on 2003.

.

Table S1. Details of effort and location for trapping sites. Elevation (Elev.), latitude and longitude refer to centroids for traplines, aggregated as described under Methods. Under Lifezone, USon, LAon and Huds-Alp refer to “Upper Sonoran”, “Lower Sonoran”, and “Hudsonian-Alpine”, respectively. Trap effort is the product of average number of nights trapped (Av. No. Nights) and the average number of traps per night.

Period	Site	No. of Traplines	Slope	Lifezone	Elev. (masl)	Av. No. Nights	Trap Effort	Latitude	Longitude
Historic	La Grange-2	1	W	Lson	57	3.0	15	37.666	-120.470
Historic	La Grange-1	5	W	Lson	69	8.3	440	37.666	-120.470
Historic	Pleasant Valley-5	6	W	Uson	274	5.9	452	37.660	-120.275
Historic	Pleasant Valley-1	12	W	Lson	277	4.6	1425	37.659	-120.287
Historic	Pleasant Valley-2	6	W	Uson	277	3.9	360	37.659	-120.287
Historic	Pleasant Valley-3	2	W	Lson	277	2.4	386	37.659	-120.287
Historic	Pleasant Valley-4	3	W	Lson	288	2.3	62	37.659	-120.287
Historic	Coulterville-1	2	W	Uson	500	2.0	271	37.711	-120.215
Historic	El Portal-5	1	W	Uson	593	4.0	60	37.674	-119.781
Historic	Mt Bullion-1	1	W	Uson	676	2.0	40	37.508	-120.044
Historic	El Portal-4	4	W	Uson	697	6.3	923	37.665	-119.807
Historic	El Portal-1	14	W	Uson	742	6.7	2897	37.674	-119.781
Historic	Coulterville-3	3	W	Transition	916	1.3	75	37.754	-120.106
Historic	Coulterville-2	8	W	Transition	1043	5.9	1389	37.743	-120.157
Historic	El Portal-3	1	W	Transition	1153	2.0	44	37.688	-119.764
Historic	Happy Isles-1	1	W	Transition	1285	3.0	102	37.732	-119.561
Historic	Cascade Creek-1	1	W	Transition	1444	4.0	148	37.728	-119.712
Historic	Cascade-1	3	W	Transition	1444	3.7	230	37.726	-119.711
Historic	Merced Grove-1	12	W	Transition	1679	4.5	1001	37.748	-119.835
Historic	Coulterville-4	3	W	Transition	1705	5.5	204	37.748	-119.835
Historic	Gentrys-1	5	W	Transition	1822	3.4	524	37.735	-119.703
Historic	Chinquapin-1	7	W	Transition	1865	4.3	835	37.652	-119.703
Historic	Aspen Valley-1	3	W	Transition	1946	4.7	544	37.830	-119.773
Historic	Crane Flat-1	2	W	Transition	1956	1.0	20	37.758	-119.798
Historic	Mono PO-1	8	E	Transition	1958	2.5	244	37.991	-119.141
Historic	Dry Creek-1	2	E	Canadian	2078	1.0	102	37.935	-118.935
Historic	Farrington-1	5	E	Canadian	2092	5.8	457	37.905	-119.102
Historic	Mono Meadow-1	6	W	Canadian	2176	5.3	825	37.657	-119.597
Historic	Mono Craters-1	1	E	Huds-Alp	2244	1.0	1	37.888	-118.960
Historic	Mono Mills-1	2	E	Canadian	2244	2.3	275	37.888	-118.960
Historic	Merced Lake-1	9	W	Canadian	2266	6.0	1257	37.740	-119.397
Historic	Indian Canyon-1	8	W	Canadian	2357	3.1	696	37.779	-119.566
Historic	Glen Aulin-1	7	W	Canadian	2455	5.0	725	37.917	-119.440
Historic	Merced Lake-2	1	W	Canadian	2503	1.0	12	37.743	-119.388
Historic	Mono Craters-2	2	E	Canadian	2684	1.0	150	37.864	-119.006
Historic	Gem Lake-1	2	E	Huds-Alp	2824	1.0	21	37.750	-119.148
Historic	Lyell Canyon-1	6	W	Huds-Alp	2966	5.1	917	37.777	-119.261
Historic	Lyell Canyon-2	1	W	Huds-Alp	3099	7.0	189	37.774	-119.260

Historic	Lyell Canyon-5	2	W	Huds-Alp	3099	3.5	178	37.773	-119.263
Historic	Mt Hoffman-1	3	W	Huds-Alp	3137	1.4	90	37.844	-119.506
Historic	Lyell Canyon-3	4	W	Huds-Alp	3201	3.6	160	37.770	-119.257
Historic	Lyell Canyon-4	3	W	Huds-Alp	3275	8.0	307	37.764	-119.251
Current	LG-1	1	W	Lson	48	4.0	80	37.625	-120.567
Current	LG-2	2	W	Lson	51	1.0	60	37.622	-120.526
Current	LG-4	2	W	Lson	61	3.0	240	37.666	-120.463
Current	LG-3	2	W	Lson	62	3.0	240	37.664	-120.479
Current	LG-5	2	W	Lson	68	4.0	320	37.669	-120.462
Current	S-1	2	W	Lson	87	5.0	400	37.511	-120.384
Current	LG-6	1	W	Lson	94	3.0	120	37.674	-120.466
Current	S-3	2	W	Lson	117	3.0	240	37.529	-120.351
Current	S-4	3	W	Lson	119	3.7	610	37.547	-120.355
Current	CPV-11	1	W	Uson	282	4.0	160	37.709	-120.221
Current	CPV-8	2	W	Uson	498	3.5	191	37.723	-120.268
Current	CPV-13	1	W	Uson	544	4.0	480	37.720	-120.179
Current	CPV-4	1	W	Uson	544	4.0	240	37.656	-120.221
Current	CPV-7	4	W	Uson	595	3.0	223	37.724	-120.260
Current	CPV-3	1	W	Uson	669	4.0	80	37.647	-120.211
Current	CPV-2	1	W	Uson	732	4.0	160	37.640	-120.217
Current	CPV-1	1	W	Uson	794	4.0	80	37.634	-120.207
Current	CPV-6	1	W	Uson	844	2.0	40	37.610	-120.178
Current	CPV-10	1	W	Uson	850	3.0	30	37.739	-120.248
Current	CPV-5	1	W	Uson	852	3.0	180	37.619	-120.187
Current	CPV-14	2	W	Uson	881	3.0	200	37.736	-120.166
Current	MD-2	1	W	Transition	901	2.0	40	37.755	-120.075
Current	MD-1	2	W	Transition	902	4.5	480	37.756	-120.090
Current	CPV-12	1	W	Transition	914	3.0	240	37.684	-120.121
Current	Ca-1	3	W	Transition	1051	2.3	460	37.723	-119.712
Current	FM-2	4	W	Transition	1140	3.3	472	37.579	-119.882
Current	YV-7	1	W	Transition	1209	4.0	335	37.741	-119.594
Current	YV-10	2	W	Transition	1211	2.0	130	37.746	-119.579
Current	YV-2	2	W	Transition	1212	3.0	150	37.722	-119.636
Current	YV-6	2	W	Transition	1216	4.0	260	37.738	-119.605
Current	YV-8	3	W	Transition	1219	3.0	234	37.561	-119.591
Current	YV-1	4	W	Transition	1223	4.3	560	37.715	-119.665
Current	YV-5	2	W	Transition	1225	5.0	400	37.731	-119.603
Current	YV-11	1	W	Transition	1228	3.0	150	37.741	-119.572
Current	YV-3	3	W	Transition	1233	4.0	420	37.731	-119.614
Current	YV-4	5	W	Transition	1236	2.2	145	37.732	-119.608
Current	YV-12	1	W	Transition	1237	3.0	240	37.733	-119.558
Current	YV-13	2	W	Transition	1269	3.0	220	37.753	-119.546
Current	FM-1	2	W	Transition	1272	3.0	210	37.566	-119.869
Current	YV-9	1	W	Transition	1330	2.0	80	37.752	-119.587
Current	F-1	1	W	Transition	1392	2.0	80	37.705	-119.733
Current	HM-1	2	W	Transition	1428	4.0	520	37.796	-119.868
Current	MG-1	5	W	Transition	1672	3.4	940	37.748	-119.839
Current	HG-1	2	W	Transition	1689	3.0	192	37.767	-119.865
Current	HG-2	1	W	Transition	1713	4.0	250	37.763	-119.860

Current	MG-2	1	W	Transition	1809	2.0	80	37.762	-119.843
Current	Ch-1	1	W	Transition	1835	4.0	440	37.648	-119.704
Current	AV-1	3	W	Transition	1872	3.0	405	37.825	-119.772
Current	Ch-2	2	W	Transition	1877	2.5	64	37.652	-119.700
Current	CF-2	11	W	Transition	1896	3.4	1199	37.757	-119.802
Current	CF-4	3	W	Transition	1899	4.0	335	37.746	-119.799
Current	CF-3	8	W	Transition	1902	4.6	967	37.751	-119.794
Current	CF-1	1	W	Transition	1951	2.0	80	37.753	-119.809
Current	Ch-3	1	W	Transition	1972	1.0	40	37.671	-119.684
Current	TF-1	1	W	Transition	2013	2.0	80	37.755	-119.743
Current	TF-2	1	W	Transition	2013	2.0	20	37.755	-119.743
Current	CF-5	2	W	Canadian	2106	3.0	200	37.758	-119.770
Current	MMe-5	3	W	Canadian	2140	3.3	440	37.665	-119.622
Current	MMe-7	2	W	Canadian	2143	4.5	445	37.670	-119.625
Current	MMe-4	1	W	Canadian	2151	4.0	320	37.662	-119.601
Current	WB-1	2	E	Canadian	2155	3.0	272	37.908	-119.116
Current	MMe-3	1	W	Canadian	2160	4.0	320	37.668	-119.597
Current	IC-2	2	W	Canadian	2164	3.0	70	37.774	-119.569
Current	MoMe-1	1	W	Canadian	2170	3.0	12	37.666	-119.668
Current	MoMe-2	1	W	Canadian	2170	4.0	320	37.666	-119.668
Current	TC-1	1	W	Canadian	2191	4.0	160	37.811	-119.713
Current	WB-2	2	E	Canadian	2195	1.0	120	37.908	-119.128
Current	ML-5	4	W	Canadian	2199	3.0	365	37.740	-119.410
Current	BC-1	6	E	Canadian	2214	4.5	771	37.900	-119.130
Current	ML-4	2	W	Canadian	2224	2.5	170	37.739	-119.402
Current	MMe-2	2	W	Canadian	2224	4.0	400	37.670	-119.585
Current	WC-1	2	E	Canadian	2236	2.0	136	37.897	-119.130
Current	ML-3	4	W	Canadian	2241	3.3	385	37.739	-119.396
Current	ML-2	3	W	Canadian	2246	3.3	280	37.732	-119.394
Current	MMi-1	1	E	Canadian	2251	2.0	100	37.888	-118.960
Current	SM-1	1	W	Canadian	2253	4.0	160	37.676	-119.652
Current	SM-2	1	W	Canadian	2258	4.0	80	37.672	-119.657
Current	ML-1	1	W	Canadian	2261	3.0	120	37.721	-119.395
Current	YC-1	3	W	Canadian	2296	3.3	430	37.850	-119.576
Current	IC-1	1	W	Canadian	2306	4.0	160	37.780	-119.564
Current	MMe-1	2	W	Canadian	2350	3.5	240	37.699	-119.586
Current	GA-4	3	W	Canadian	2389	3.7	454	37.914	-119.429
Current	GA-5	2	W	Canadian	2389	4.0	338	37.912	-119.425
Current	WW-3	1	W	Canadian	2397	2.0	160	37.845	-119.613
Current	WW-5	1	W	Canadian	2397	2.0	80	37.846	-119.633
Current	GA-2	4	W	Canadian	2405	2.5	464	37.913	-119.421
Current	WW-6	1	W	Canadian	2409	6.0	60	37.839	-119.593
Current	WW-1	3	W	Canadian	2415	4.3	815	37.868	-119.648
Current	WL-1	2	E	Canadian	2440	4.0	475	37.871	-119.171
Current	SL-1	1	W	Canadian	2446	2.0	80	37.851	-119.659
Current	WL-2	1	E	Canadian	2465	4.0	236	37.871	-119.161
Current	WW-2	1	W	Canadian	2484	4.0	320	37.857	-119.647
Current	PF-1	3	W	Canadian	2486	4.0	580	37.807	-119.564
Current	WW-4	1	W	Canadian	2489	2.0	160	37.843	-119.623

Current	GA-3	1	W	Canadian	2492	3.0	72	37.916	-119.418
Current	GA-1	3	W	Canadian	2496	2.7	416	37.902	-119.431
Current	McS-1	2	W	Canadian	2508	3.0	315	37.852	-119.628
Current	FD-1	1	W	Canadian	2556	3.0	240	37.876	-119.416
Current	SC-1	1	W	Canadian	2571	4.0	160	37.818	-119.510
Current	PF-2	1	W	Canadian	2572	4.0	40	37.814	-119.577
Current	JR-1	1	W	Canadian	2641	3.0	240	37.884	-119.363
Current	SN-1	1	W	Canadian	2655	4.0	160	37.826	-119.499
Current	GM-1	2	W	Huds-Alp	2761	3.0	150	38.163	-119.605
Current	WF-2	2	E	Huds-Alp	2787	4.5	275	37.954	-119.229
Current	WF-1	1	E	Huds-Alp	2800	4.0	160	37.954	-119.226
Current	LM-1	1	W	Huds-Alp	2823	4.0	240	37.883	-119.347
Current	TL-1	1	W	Huds-Alp	2828	4.0	120	37.905	-119.532
Current	DeM-1	1	W	Huds-Alp	2868	2.0	42	37.899	-119.348
Current	DL-1	4	W	Huds-Alp	2874	4.5	592	38.173	-119.595
Current	KM-2	6	W	Huds-Alp	2883	5.7	1394	38.122	-119.483
Current	TL-2	1	W	Huds-Alp	2936	4.0	176	37.904	-119.535
Current	KM-1	1	E	Huds-Alp	2941	4.0	160	38.130	-119.479
Current	MF-1	1	W	Huds-Alp	2941	3.0	180	37.841	-119.500
Current	DD-1	1	W	Huds-Alp	2968	2.0	118	37.908	-119.348
Current	LC-1	3	W	Huds-Alp	2983	4.0	292	37.780	-119.261
Current	LC-2	4	W	Huds-Alp	2983	3.0	459	37.778	-119.261
Current	V-2	2	W	Huds-Alp	3015	3.5	140	37.790	-119.352
Current	RC-1	6	W	Huds-Alp	3018	5.3	1471	38.061	-119.339
Current	V-1	1	W	Huds-Alp	3024	3.0	120	37.798	-119.349
Current	WF-3	3	E	Huds-Alp	3040	3.0	270	37.953	-119.262
Current	LC-3	1	W	Huds-Alp	3051	5.0	120	37.772	-119.258
Current	V-4	2	W	Huds-Alp	3073	3.0	240	37.800	-119.342
Current	WF-4	1	E	Huds-Alp	3094	3.0	240	37.963	-119.272
Current	V-5	2	W	Huds-Alp	3107	4.0	240	37.797	-119.339
Current	LC-4	13	W	Huds-Alp	3121	3.8	1710	37.768	-119.255
Current	TP-1	1	W	Huds-Alp	3149	2.0	80	37.908	-119.264
Current	V-3	4	W	Huds-Alp	3149	3.0	472	37.788	-119.344
Current	V-6	3	W	Huds-Alp	3159	3.3	317	37.797	-119.336
Current	V-8	1	W	Huds-Alp	3167	3.0	120	37.805	-119.328
Current	V-7	1	W	Huds-Alp	3184	2.0	72	37.791	-119.328
Current	LC-5	4	W	Huds-Alp	3220	3.3	610	37.764	-119.260
Current	LC-7	1	W	Huds-Alp	3264	3.0	120	37.757	-119.259
Current	LC-6	1	W	Huds-Alp	3278	3.0	240	37.765	-119.252

Table S2. Small mammal species included in analyses. Slope is east (E) or west (W), with first records marked as *. Method refers to standardized trapping (S), observation (O) or special trapping (Sp). Species included in richness analyses are listed as occurring (1) for Grinnell (G) and Present (P) surveys for the whole transect, and for Yosemite National Park alone. Species included in analyses of range limits are listed as having appropriate data for occupancy modeling (Y) or not (N). We observed all 42 of the focal taxa observed in the Grinnell period, and one new species, *Sorex tenellus*, a rare shrew encountered at two high elevation sites (ca. 3020 m) that previously was known from mid-high elevations to the north and east. We encountered two species (*Spermophilus beecheyi* and *Peromyscus boylii*) new to the east side of the transect. Within YNP, we detected all 27 species observed in Grinnell's time and three new ones – *Sorex tenellus, Chaetodipus californicus*, and *Reithrodontomys megalotis*. The last two resulted from upward range expansions.

			Richness				Range limits
			Transect		YNP		
Species	Slope	Method	G	P	G	P	Occupancy
Chaetodipus californicus	W	S	1	1	0	1	Y
Dipodomys heermanni	W	S	1	1	0	0	Y
Dipodomys panamintinus	E	S	1	1	0	0	-
Glaucomys sabrinus	W	S	1	1	1	1	-
Lemmiscus curtatus	E	S	1	1	0	0	-
Marmota flaviventris	E, W	O	1	1	1	1	N
Microtus californicus	W	S	1	1	1	1	Y
Microtus longicaudus	E, W	S	1	1	1	1	Y
Microtus montanus	E, W	S	1	1	1	1	Y
Neotoma cinerea	E, W	S	1	1	1	1	Y
Neotoma macrotis	W	S	1	1	1	1	Y
Ochotona princeps	E, W	O	1	1	1	1	N
Onychomys leucogaster	E	S	1	1	0	0	-
Perognathus inornatus	W	S	1	1	0	0	-
Perognathus parvus	E	S	1	1	0	0	-
Peromyscus boylii	E*, W	S	1	1	1	1	Y
Peromyscus californicus	W	S	1	1	0	0	-
Peromyscus maniculatus	E, W	S	1	1	1	1	Y
Peromyscus truei	E, W	S	1	1	1	1	Y
Phenacomys intermedius	W	S	1	1	1	1	-
Reithrodontomys megalotis	W	S	1	1	0	1	Y
Sorex lyelli	E, W	S	1	1	1	1	-
Sorex monticolus	E, W	S	1	1	1	1	Y
Sorex ornatus	W	S	1	1	0	0	-
Sorex palustris	E, W	S	1	1	1	1	Y
Sorex tenellus	W*	S	0	1	0	1	-
Sorex trowbridgii	W	S	1	1	1	1	Y
Sorex vagrans	E	S	1	1	0	0	-
Spermophilus beecheyi	E*, W	S	1	1	1	1	Y

Spermophilus beldingi	E, W	S	1	1	1	1	Y
Spermophilus lateralis	E, W	S	1	1	1	1	Y
Tamias alpinus	E, W	S	1	1	1	1	Y
Tamias amoenus	E	S	1	1	0	0	-
Tamias merriami	W	S	1	1	0	0	Y
Tamias minimus	E	S	1	1	0	0	-
Tamias quadrimaculatus	W	S	1	1	1	1	Y
Tamias senex	W	S	1	1	1	1	Y
Tamias speciosus	E, W	S	1	1	1	1	Y
Tamiasciurus douglasii	E, W	O	1	1	1	1	N
Thomomys bottae	W	Sp	1	1	1	1	N
Thomomys monticola	E, W	Sp	1	1	1	1	N
Thomomys talpoides	E	Sp	1	1	0	0	-
Zapus princeps	E, W	S	1	1	1	1	Y
Total		**43**	**42**	**43**	**27**	**30**	**28**

Table S3. Candidate model sets for the occupancy analysis. Initially we screened 36 detection models for each small mammal species in the Yosemite transect with trapping data combined from both the west and east slopes. This model set was then reduced to 14 detection models in the final set (= x) that incorporated either the best (lowest AICc) or near best models for each species. The 8 occupancy models were each run with the final set of 14 detection functions yielding 112 models.

Model parameter	Model terms	Final set
Detection	constant (.)	x
	era	
	era + era*log(traps)	
	era + era*log(traps) + era*traps/100	
	era + era*log(traps) + era*traps/100 + era*trend	x
	era + era*log(traps) + era*trend	
	era + era*log(traps) + traps/100	
	era + era*traps/100	x
	era + era*traps/100 + era*trend	x
	era + era*trend	
	era + log(traps)	
	era + log(traps) + era*traps/100	
	era + log(traps) + era*trend	
	era + log(traps) + traps/100 + trend	x
	era + traps/100	
	era + traps/100 + era*trend	x
	era + traps/100 + trend	
	era + trend	
	era + trend + era*log(traps)	x
	era + trend + era*traps/100	
	era + log(traps) + trend	x
	era*log(traps) + era*traps/100	
	era*log(traps) + era*traps/100 + era*trend	x
	era*log(traps) + era*trend	
	era*traps/100 + era*trend	
	log(traps)	x
	log(traps) + era*traps/100	
	log(traps) + era*trend	
	log(traps) + trend	x
	traps/100	x
	traps/100 + era*log(traps)	
	traps/100 + era*trend	x
	traps/100 + trend	x

	trend	
	trend + era*log(traps)	
	trend + era*traps/100	x
Occupancy	constant (.)	x
	elevation	x
	elevation + elevation^2	x
	era	x
	era + elevation	x
	era + elevation + elevation^2	x
	era * elevation	x
	era * (elev+ elev^2)	x

Table S4. Summary of mean and standard errors of estimates of species richness by sampling period and similarity of species assemblages between periods (see Methods). Also shown is the difference in estimated species richness between Current and Historical sampling periods as absolute numbers (C - H) and percent (%) change.

	Richness							
	Current		Historical		Difference		Similarity	
Location	Mean	SE	Mean	SE	C - H	%	Mean	SE
Transect	44.12	1.88	48.54	2.53	-4.42	-9.11	1.00	0.00
Park	30.47	1.44	29.16	1.39	1.31	4.49	1.00	0.00
Low Sonoran	10.66	0.81	15.47	1.83	-4.82	-31.12	0.92	0.03
Upper Sonoran	11.31	0.98	15.79	1.26	-4.48	-28.35	0.92	0.04
Transition	21.93	0.86	26.22	1.52	-4.29	-16.36	0.86	0.06
Canadian	17.41	1.40	19.92	1.05	-2.52	-12.64	0.97	0.01
Hudsonian-Arctic	17.46	0.73	19.11	0.78	-1.65	-8.62	0.88	0.05

Table S5. Information theoretic approach to model selection for logistic regression models relating mammal life history traits (Table S6) to the probability of an upward shift in the lower or upper limit of elevational range for 28 small mammal species. *K* is the number of parameters, AIC$_c$ is the Akaike's Information Criterion corrected for small sample size, ΔAIC$_c$ is the difference between the model and the best (lowest AIC) model, and AIC weight (w) indicates the relative explanatory ability of a model compared to others in the same model set. *Post hoc* models are given for the best single model combined with every other parameter. Higher order models were not supported by small samples sizes.

Lower Limit Range Change Models	**K**	**AICc**	**ΔAICc**	**AIC Wt (w)**
Life zone	2	35.93	0.00	0.51
Constant (.)	1	38.65	2.72	0.13
Litters per year	2	39.84	3.91	0.07
Young per year	2	40.04	4.11	0.07
Mass	2	40.41	4.48	0.05
Litter size	2	40.78	4.85	0.05
Longevity	2	40.81	4.88	0.04
Annual rhythm	3	41.18	5.25	0.04
Daily rhythm	3	41.85	5.92	0.03
Diet	4	45.01	9.08	0.01
Posthoc models				
Life zone, Mass	3	37.50	1.57	
Life zone, Young per year	3	37.72	1.79	
Life zone, Litters per year	3	37.87	1.94	
Life zone, Litter size	3	38.00	2.07	
Life zone, Longevity	3	38.45	2.52	
Life zone, Daily rhythm	4	39.37	3.44	
Life zone, Annual rhythm	4	40.18	4.25	
Lize zone, Diet	5	41.80	5.87	

Upper Limit Range Change Models	**K**	**AICc**	**ΔAICc**	**AIC Wt (w)**
Life zone	2	17.94	0.00	0.72
Longevity	2	21.19	3.25	0.14
Mass	2	23.86	5.92	0.04
Daily rhythm	3	24.74	6.80	0.02
Litters per year	2	24.81	6.87	0.02
Constant (.)	1	25.11	7.17	0.02
Young per year	2	25.75	7.81	0.01
Annual rhythm	3	26.56	8.62	0.01
Litter size	2	27.45	9.51	0.01
Diet	4	29.91	11.97	0.00
Posthoc models				
Life zone, Longevity	3	14.41	-3.53	
Life zone, Litters per year	3	16.56	-1.38	

Life zone, Mass	3	17.21	-0.73
Life zone, Young per year	3	18.51	0.57
Life zone, Litter size	3	20.41	2.47
Life zone, Daily rhythm	4	21.88	3.94
Life zone, Annual rhythm	4	22.10	4.16
Life zone, Diet	5	24.19	6.25

Table S6. Small mammal life history dataset used for tests of elevational range shift in Table S5.

Species	Mass (g)	Longevity (yrs)	Litter_size	Daily_rhythm	Annual_rhythm	Food	Litters/yr	Young/yr
Chaetodipus californicus	25	1	4	nocturnal	non-hibernator	granivore	2	6
Dipodomys heermanni	70	3	3	nocturnal	non-hibernator	granivore	2	5
Marmota flaviventris	4500	5	5	diurnal	obligate hibernator	herbivore	1	5
Microtus californicus	60	0.5	6	both	non-hibernator	herbivore	4	24
Microtus longicaudus	65	0.5	4	both	non-hibernator	herbivore	3	12
Microtus montanus	45	0.5	6	both	non-hibernator	herbivore	4	24
Neotoma cinerea	450	3	4	nocturnal	non-hibernator	herbivore	2	8
Neotoma macrotis	350	3	3	nocturnal	non-hibernator	herbivore	1	3
Ochotona princeps	130	3	4	diurnal	non-hibernator	herbivore	2	6
Peromyscus boylii	24	1	3	nocturnal	non-hibernator	granivore	2	6
Peromyscus maniculatus	18	0.5	4	nocturnal	non-hibernator	omnivore	3	12
Peromyscus truei	30	0.5	4	nocturnal	non-hibernator	omnivore	2	8
Reithrodontomys megaloti	10	0.5	4	nocturnal	non-hibernator	omnivore	2	8
Sorex monticolus	4	0.5	6	both	non-hibernator	insectivore	2	9
Sorex ornatus	4	0.5	5	both	non-hibernator	insectivore	2	8
Sorex palustris	15	0.5	6	both	non-hibernator	insectivore	2	12
Sorex trowbridgii	6	0.5	4	both	non-hibernator	insectivore	2	8
Spermophilus beecheyi	700	3	6	diurnal	obligate hibernator	omnivore	1	6
Spermophilus beldingi	300	3	6	diurnal	obligate hibernator	herbivore	1	6
Spermophilus lateralis	250	3	4	diurnal	obligate hibernator	omnivore	1	4
Tamias alpinus	35	2	4	diurnal	facultative hibernator	granivore	1	4
Tamias quadrimaculatus	80	2	4	diurnal	facultative hibernator	granivore	1	4
Tamias senex	80	2	4	diurnal	facultative hibernator	granivore	1	4
Tamias speciosus	50	2	4	diurnal	facultative hibernator	granivore	1	4
Tamiasciurus douglasi	250	4	5	diurnal	non-hibernator	granivore	2	8
Thomomys bottae	120	2	6	both	non-hibernator	herbivore	2	12
Thomomys monticola	90	2	4	both	non-hibernator	herbivore	1	4
Zapus princeps	30	2	4	nocturnal	obligate hibernator	omnivore	1	4

Supplementary Literature Cited

S1. S. LaDochy, R. Medina, W. Patzert, *Climate Research* **33**, 159 (2007).

S2. C. I. Millar, R. D. Westfall, D. L. Delany, J. C. King, L. J. Graumlich, *Arctic Antarctic and Alpine Research* **36**, 181 (2004).

S3. J. Parra, W. Monahan, *Global Change Biology* **14**, 2115 (2008).

S4. J. Grinnell, T. Storer, *Animal Life in the Yosemite*. (University California Press, Berkeley, California, 1924), pp. 752

S5. K. P. Burnham, D. R. Anderson, *Model selection and inference: a practical theoretic approach*. (Springer-Verlag., New York, 2002).

S6. D. I. MacKenzie *et al.*, *Inferring patterns and dynamics of species occurrence*. (Elsevier, San Diego, 2006).

S7. G. C. White, K. P. Burnham, *Bird Study* **46**, 120 (1999).

S8. R. K. Colwell, C. X. Mao, J. Chang, *Ecology* **85**, 2717 (2004).

S9. A. Chao, in *Encyclopedia of Statistical Sciences,* N. Balakrishnan, C. B. Read, B. Vidakovic, Eds. (Wiley, New York, 2005).

S10. A. Chao, R. L. Chazdon, R. K. Colwell, T.-J. Shen, *Ecology Letters* **8**, 148 (2005).

S11. R. J. Wilson, D. Gutierrez, J. Gutierrez, V. J. Monserrat, *Global Change Biology* **13**, 1873 (2007).