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Weasel (*Mustela nivalis*) decline in NE Spain: prey or land use change?

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Abstract
In this note, we reported the decline of weasel populations in NE Spain between the end of the last century and present. Our results suggested a delayed numerical response of weasels to wood mice abundance during the first study period (1995–1998), but no response at all in the second and longer period (2008–2015). Small mammals' outbreaks triggered weasel' populations in the first period, but they did not in the second period. Other factors may be invoked to explain the recent lack of numerical responses of weasels to mice. Population declines of small mammals have been noted in the study area in recent years, whereas an increase of casual predation records of weasels by generalist raptors has been documented. Both trends seemed to be related to the effects of the process of natural afforestation experienced by Mediterranean areas due to land abandonment. Top-down increased predation may add to bottom-up decreasing prey availability to explain current weasel declines.

The distribution and abundance of wild organisms are changing due to anthropogenic global change drivers (Sala et al. 2000; Vitousek 1994). Monitoring such changes is needed to evaluate the performance of conservation policies (EEA 2012; Díaz and Concepción 2016) and to determine the mechanistic causes of change as well as their likely impacts on ecosystem function and structure (Gilman et al. 2010). Such a monitoring program is being currently developed for small mammals in Spain (Torre et al. 2018), where incidental captures of small mammal predators may occur (Flowerdew et al. 2004; Torre et

al. 2016). This was the case for weasels (*Mustela nivalis*), small carnivores whose populations are considered stable throughout its distribution range (McDonald et al. 2016) in spite of population declines associated to declines in its staple prey were reported for northern Europe (Hellstedt et al. 2006) and Portugal (Gisbert and Santos-Reis 2007).

We report a case of strong decline in a Mediterranean weasel population and test whether the decline was associated to declines in the monitored small mammal populations. Voles, the staple prey of weasels in northern Europe (Sundell and Ylönen 2008), are scarce in forests and shrublands of the Mediterranean region (Torre et al. 2013), so that a change in staple prey to the dominant wood mice (*Apodemus* spp.) or other murid rodents (*Mus* spp.) is to be expected. Alternatively, Mediterranean weasel population declines might be related to top-down factors linked to changes in land uses or populations of their top predators.

Field work was carried out within six Natural Parks (Montseny, Montnegre-Corredor, Sant Llorenç del Munt i l'Obac, Serralada de Marina, Collserola, and Garraf) of Barcelona province (Catalonia, NE Spain), located on the eastern side of the Iberian Peninsula (Supp. Fig. 1).

Sampling was performed in two different periods, with a gap of 10 years. In the first period, sampling design was mostly aimed at the inventory of small mammal communities, but the initial steps in creating a monitoring program for small mammals were set during this period. From February 1995

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to November 1998, we established 23 altogether live-trapping stations in four Natural Parks. In Montseny, we established nine live-trapping grids of 49 Sherman traps (Sherman folding small animal trap, 23 × 7.5 × 9 cm, Sherman Co., USA) arranged in a 7 × 7 design, spaced 15 m, and set for three consecutive nights. From February 1995 to July 1997, we performed ten trapping sessions distributed seasonally (every season, from winter to fall). From spring 1997 to fall 1998, we established 14 live-trapping grids of 25 Sherman traps (Sherman folding small animal trap, 23 × 7.5 × 9 cm, Sherman Co., USA) arranged in a 5 × 5 design, spaced 15 m, and set for three consecutive nights. Three Natural Parks were sampled during this period trying to cover the most representative habitats of every area. In Montnegre-Corredor, we sampled six habitats, five in Sant Llorenç del Munt i l'Obac, and three in Collserola. The plots were sampled during a year on a seasonal basis (spring–summer–fall). The plots sampled during this period were situated along an elevation gradient from 160 to 1520 m a.s.l., covering the most representative habitats of every vegetation domain (Torre and Arrizabalaga 2008).

During the second period, the live-trapping design was aimed at monitoring the small mammals' populations, so a different scheme was proposed according to our experience. This design showed intermediate sampling effort (36 traps in 6 × 6 or 9 × 4 grids for riverbeds) and two different trapping devices (18 Sherman and 18 Longworth traps—14 × 6.5 × 8.5 cm nest chamber plus a 13-cm long tunnel) intercalated in position, but showed the same between trap distance and number of days of trapping per session. This scheme was named SEMICE (acronym of the Spanish monitoring program for common small mammal species), and our goal was obtaining confident data on species' populations presenting higher detectability with the sampling methods used. Despite using two different trap models, our results highlighted that both performed similar in small sized and poor species communities (i.e. Mediterranean, Torre et al. 2018), but showed some, but subtle, biases in rich small mammals' communities (Torre et al. 2016). Sampling was performed from spring 2008 to fall 2015 by surveying 22 plots during 16 trapping sessions (two sessions per year, spring and fall). The sampling scheme incorporated two new natural Parks (Garraf and Serralada de Marina), and the distribution of sampling stations was more evenly distributed at the spatial scale, but with a lower sampling effort per park than in the first period (5.75 ± 2.5 n = 4, vs. 3.33 ± 1.03 n = 6, plots per park for the first and second period, respectively). The plots sampled during this period were situated along an elevation gradient from 95 to 1520 m. Only four plots in two Natural Parks (Montseny: fir forest, Juniperus shrubland; Collserola: dense holm-oak/pine mixed woodland, cleared holm-oak/pine mixed woodland) were trapped in both periods.

The small mammals captured were identified to species, sexed, marked (rodents and shrews with toe clips in the first period, and rodents with ear tags—National Band Co., USA—and shrews with fur clips, in the second period, Sikes et al. 2011), and released at the point of capture (Gurnell and Flowerdew 2006). Wood mice (Apodemus sylvaticus/flavicollis) were considered as a single species (Apodemus spp.) due to difficulties in field identification (Torre et al. 2018). Weasels (Mustela nivalis) were released without manipulation at the point of capture. Research on live animals followed the American Society of Mammalogists guidelines (Sikes et al. 2011).

We used counts (i.e. the number of different individuals trapped within the 3 days, Morris 1996) as an index of population size in each study plot and session. We assumed that the unseen proportion of the population was constant, and that counts and estimates yielded comparable results (Slade and Blair 2000).

We applied Occupancy Estimation models to account for differences in detectability (Mackenzie et al. 2002), because live-trapping schemes were different within and between sampling periods (sampling effort, sampling devices, see above). When sampling schemes affect detectability of the target species, and detectability is below 0.3, its true occupancy can be underestimated (Mackenzie et al. 2002). We considered weasels as a non-target species of our scheme (their ranges outperform the size of live-trapping grids, Camps and Llimona 2000), so the use of occupancy models was suitable to account for low detectability of that species with live-trapping methods (Graham 2002). We used two presence/absence matrices for the first period (one for every sampling grid scheme), and one matrix for the second period. Wood mice showed high (and similar) detectability with Longworth and Sherman traps (Torre et al. 2016, 2018), and detectability did not affect occupancy estimates in the study area (Torre et al. 2018). Since wood mice naïve occupancy was always 100% for all the plots sampled in both periods, we used occupancy models only for comparative purposes (i.e. using the same variables in the analyses for both weasels and mice).

Presence software (Mackenzie 2012) was used to determine whether estimated occupancy (Ψ) and detection probabilities (p) changed between sampling schemes and sampling periods. We fitted the same model for weasels and wood mice: occupancy was left invariable between sampling periods, but with variable probability of detection (Watkins et al. 2010; Otto and Roloff 2011). Relationships among weasel and small mammal abundance and their changes among study periods were tested by means of GLMs on square-root transformed data ($X' = \sqrt{(X+0.5)}$). Since most common small mammal species showed population synchrony in the study area (i.e. captures obtained in different plots were positively associated among sampling periods: Díaz et al. 2010, Torre et al. 2018),

all captures obtained in every period were aggregated. Counts (i.e. captures) were relativized correcting for sampling effort (captures per 100 traps × night) in different periods. Delayed effects of small mammal abundance on weasel abundance were tested by relating weasel abundance in autumn with rodent abundance in spring of the same year, and weasel abundance in spring with rodent abundance in the fall of the previous year, thus discarding summer and winter data for the period 1995–1998, since these seasons were not sampled between 2008 and 2015. Changes in rodent abundance among periods also considered seasonality in rodent abundance by incorporating season as a fixed factor in GLMs, using data for spring and autumn seasons only.

We trapped 15 weasels and 2584 small mammals with a sampling effort of 17,331 trap-nights during the first period, and one weasel and 2659 small mammals with a sampling effort of 20,304 trap-nights during the second. Weasels were trapped in almost half of the plots sampled (47.8%) and along the whole elevation gradient (160–1502 m.a.s.l) during the first period. Either one or no weasel was caught during each trapping period, and the location and timing of captures excluded recaptures of the same individuals. Overall, average weasel-estimated occupancy was seven times higher in the first than in the second period (0.57 vs. 0.083; Suppl Fig. 2). Wood mice (*Apodemus* spp.) represented the bulk of captures in both periods (69.0 and 62.5%, respectively).

Weasel and small mammal abundances fluctuated widely in both sampling periods (Fig. 1). Weasel abundance was larger in the first period with no seasonal fluctuations, whereas mean small mammal abundances did not differ among periods and were usually larger in spring than in autumn (Suppl. Table

1). Weasel abundance was not directly related to small mammal abundance ($F_{1, 26}$ = 1.83, 2.92, and 3.11, p = 0.188, 0.100, and 0.089, for *Apodemus*, murids, and all small mammals, respectively; period and period × abundance interactions were not significant either), but it was for the first (but not for the second) period when considering delayed effects (Table 1, Fig. 2). Delayed effects were found for *Apodemus* and murid abundance but not for total small mammal abundance, and the model including *Apodemus* spp. only was more parsimonious than the model including all murids (AICc$_{Apodemus}$ = − 52.49, AICc$_{murids}$ = − 54.57; ΔAICc = 2.08). Thirteen out of 15 weasels were captured between spring 1996 and spring 1998, a period in which small mammal abundance was sustained well above the average for seven consecutive sampling sessions (22.5 ± 5.9 ind./100 trap- nights, n = 7; mean abundance 14.5 ± 8.9 ind./100 trap- nights, n = 14). However, during the second period, we did not observe rodent populations to be above the average during two consecutive sampling sessions (i.e. a spring high was always followed by a fall decline). Mean weasel abundance in the second period would have been 0.40 individuals/100 trap-nights (range 0.04–2.19, backtransformed estimates) if it would have depended on *Apodemus* spp. abundance as in the first period (Fig. 1). Alternative methods fitting generalised mixed linear models to grid data using Natural Parks as a random factor to account for potential spatial dependence of captures rendered the same general results (not shown), but would have not allowed to estimate expected weasel abundance as a function of prey abundance in the second period.

We have documented the decline of weasel populations in the Western Mediterranean between the end of the last century

Fig. 1 Abundance (No. individuals/100 traps-night) of weasels (right y-axis) and small mammals (left y-axis) during both study periods. Asterisks: weasels, open bars: *Apodemus* spp., grey bars: other murids (*Mus* spp.), closed bars: other small mammals. WI winter, SP spring, SU summer, FA autumn. Numbers indicate years from 1995 to 2015
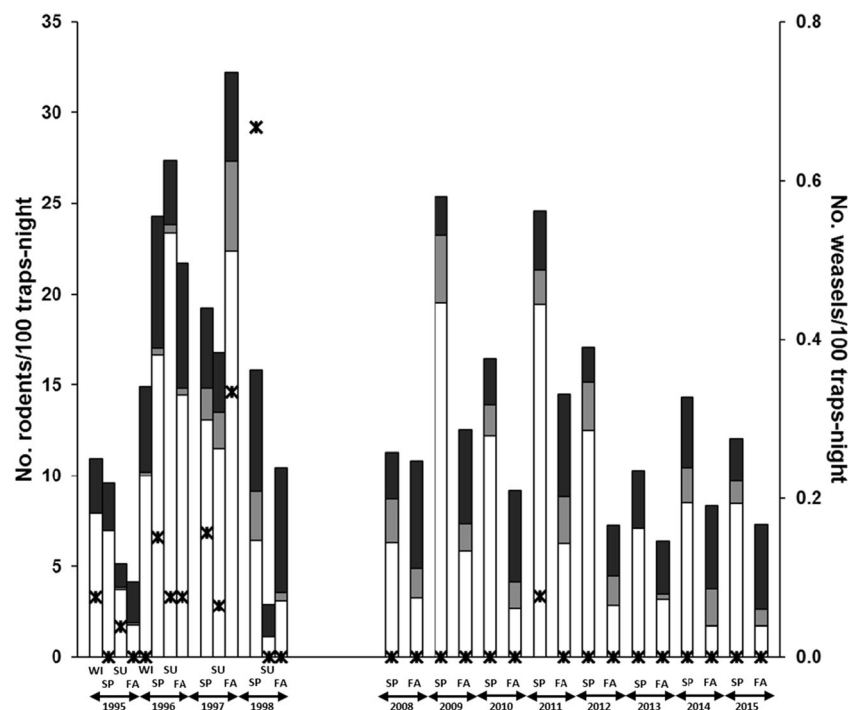
Table 1 Results of GLMs testing for the delayed relationships among weasel and small mammal abundances. Dependent variables are abundances in spring or autumn and independent variables abundances in the previous autumn or spring, respectively

	df	F
Period	1	1.71
Apodemus spp. abundance	1	6.12*
Period × *Apodemus* spp.	1	6.25*
Error	18	
Period	1	2.21
Murid rodent abundance	1	7.47*
Period × murid rodents	1	7.37*
Error	18	
Period	1	1.16
Abundance of all small mammals	1	4.00
Period × all small mammals	1	3.59
Error	18	

* $p < 0.05$; otherwise, non-significant

and present. Weasel populations seem to show stable trends throughout its distribution range (McDonald et al. 2016), although population declines associated to vole declines have been recognised in northern Europe (Hellstedt et al. 2006), whereas climatic factors were also invoked for the Mediterranean (Gisbert and Santos-Reis 2007; Araújo et al. 2011). Our results suggested a delayed numerical response of weasels to wood mice abundance during the first study period (1995–1998), but no response in the second and longer period (2008–2015).

Some authors advised tracking field signs to be more suitable than live-trapping for estimating weasel relative abundance (see however Graham 2002 and Sundell et al. 2013, for criticism); nonetheless, weasels can be normally captured with commercial live traps (i.e. Longworth: Flowerdew et al. 2004), and live-trapping was recommended as the most
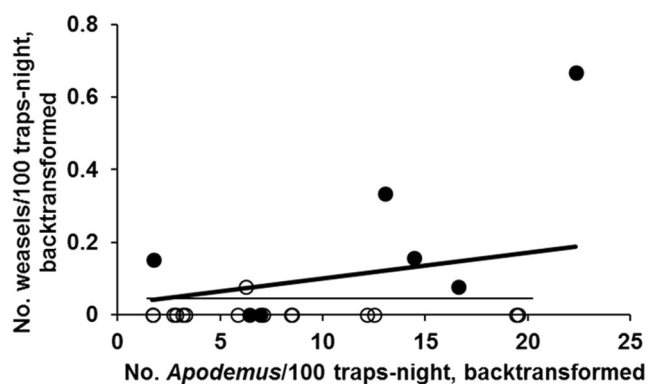

Fig. 2 Abundance of weasels in autumn or spring as related to *Apodemus* spp. abundance during the previous spring or autumn. Filled circles, thick line: 1995–1998; open circles, thin line: 2008–2015. Lines are backtransformed linear regressions

efficient sampling method in Mediterranean environments (Díaz-Ruiz et al. 2017). Our results suggested a decline of weasel populations once controlling for differences in species' detectability and occupancy due to differences in sampling schemes between periods (Mackenzie et al. 2002). This decline was not mainly related to bottom-up changes in prey abundance, as normally happens in northern populations (Hellstedt et al. 2006). However, we must be aware that our argument is correlative, and careful methodology is needed to properly document delayed responses (Jedrzejewski et al. 1995). We cannot completely rule out the effects of a different sampling protocol in the lack of weasel captures in the second period. Nonetheless, this possibility seems unlikely since the only weasel captured during the second period, as well as four others of *Mustela* spp. (either *M. nivalis* or *M. erminea*) within SEMICE-like grids in NE Iberia, were obtained in Longworth traps (authors unpub.).

We hypothesised that weasel's response in the first period may have been caused by small mammals outbreaks following an abnormally wet year, which boosted wood mice population growth rates (Díaz et al. 2010). During this period, small mammals sustained abundance higher than the average for a long time, thus allowing weasel response. However, if small mammals' outbreaks triggered weasel' populations in the first period, they did not in the second. Other factors may be invoked to explain the recent lack of numerical responses of weasels to mice. Population declines of some small mammals have been noted in the study area in recent years (Torre et al. 2018), whereas an increase of casual predation records of weasels by generalist raptors has been documented (Palazón et al. 2016); however, most of these records were obtained within the recent generalisation of the use of remote cameras for monitoring raptors' nests in the study area. On the other hand, both trends seemed to be related to the effects of the process of natural afforestation experienced by Mediterranean areas due to land abandonment (Doblas-Miranda et al. 2015). Woodland and shrubland recovery may have positive effects on populations of forest small mammal predators (either specialists or generalists), increasing predation risk for both small mammal prey and their predators (Torre and Díaz 2004). Top-down increased predation may add to bottom-up decreasing prey availability to explain current weasel declines. This argument can be relevant according to open habitat preference of weasels and the undergoing process of encroachment by woody vegetation experienced by open fields (McDonald et al. 2016). In addition, afforestation and encroachment may increase the use of road verges by weasels thus increasing road casualties (Grilo et al. 2009), and climate change may also increase habitat unfavourability for weasels in Mediterranean areas due to indirect effects on prey (Gisbert and Santos-Reis 2007; Araújo et al. 2011). The combination of the SEMICE protocol with other monitoring schemes may provide the data needed to test these hypotheses.

References

Araújo MB, Guilhaumon F, Rodrigues-Neto D, Pozo-Ortego I, Gómez Calmaestra R (2011). Impactos, vulnerabilidad y adaptación al cambio climático de la biodiversidad española. 2. Fauna de vertebrados. Dirección general de medio Natural y Política Forestal. Ministerio de Medio Ambiente, y Medio Rural y Marino. 640 pp. Madrid, España

Camps D, Llimona F (2000) Primeres dades sobre l'estudi de la mostela (*Mustela nivalis*) al Parc de Collserola. In: F Llimona, JM Espelta, JC Guix, E Mateos, JD Rodríguez-Teijeiro (ed) *I Jornades sobre Recerca en els sistemes naturals de Collserola: aplicacions a la gestió del Parc*, 111–114

Diaz M, Torre I, Arrizabalaga A (2010) Relative roles of density and rainfall on the short-term regulation of Mediterranean wood mouse *Apodemus sylvaticus* populations. Acta Theriol 55:251–260

Díaz M, Concepción ED (2016) Enhancing the effectiveness of CAP greening as a conservation tool: a plea for regional targeting considering landscape constraints. Curr Landsc Ecol Rep 1:168–177

Díaz-Ruiz F, Jareño D, de Diego N, Ferreras P, García JT, Olea PP, Viñuela J, Oñate JJ, Herranz J, Acebes P, Santamaría AE, Domínguez JC (2017) Comparación de métodos para el seguimiento de las poblaciones de comadreja *Mustela nivalis* en ambientes agrícolas. XIII Congreso Sociedad Española para la Conservación y Estudio de los Mamíferos (SECEM), Guadalajara 6–9 Dec 2017

Doblas-Miranda E, Martínez-Vilalta J, Álvarez A, Ávila A, Bonet FJ, Brotons L, Castro J, Curiel Yuste J, Díaz M, Ferrandis P, García-Hurtado E, Iriondo JM, Keenan T, Latron J, Lloret F, Llusià J, Loepfe L, Mayol M, Moré G, Moya D, Peñuelas J, Pons X, Poyatos R, Sardas J, Sus O, Vallejo R, Vayreda J, Retana J (2015) Reassessing global change research priorities in the Mediterranean Basin: how far have we come and where do we go from here? Glob Ecol Biogeogr 24:25–43

European Environment Agency (EEA) (2012) Streamlining European biodiversity indicators 2020: Building a future on lessons learnt from the SEBI 2010 process. EEA, Copenhagen 50 pp

Flowerdew JR, Shore RF, Poulton SMC, Sparks TH (2004) Live trapping to monitor small mammals in Britain. Mammal Rev 34:31–50

Gisbert J, Santos-Reis M (2007). *Mustela nivalis* Linnaeus, 1766. Pp 283–286. In: L.J. Palomo, J. Gisbert y J.C. Blanco (eds.), Atlas y Libro Rojo de los Mamíferos Terrestres de España. Dirección General de Conservación de la Naturaleza-SECEM-SECEMU, Madrid, 586 pp.

Gilman SE, Urban MC, Tewksbury J, Gilchrist GW, Holt RD (2010) A framework for community interactions under climate change. Trends Ecol Evol 25:325–331

Graham IM (2002) Estimating weasel *Mustela nivalis* abundance from tunnel tracking indices at fluctuating field vole *Microtus agrestis* density. Wildl Biol 8:279–287

Grilo C, Bissonette JA, Santos-Reis M (2009) Spatial–temporal patterns in Mediterranean carnivore road casualties: consequences for mitigation. Biol Conserv 142:301–313. https://doi.org/10.1016/J.BIOCON.2008.10.026

Gurnell J, Flowerdew JR (2006) Live trapping small mammals: a practical guide. The Mammal Society, London, p 47

Hellstedt P, Sundell J, Helle P, Henttonen H (2006) Large-scale spatial and temporal patterns in population dynamics of the stoat, *Mustela erminea*, and the least weasel, *M. nivalis*, in Finland. Oikos 115: 286–298

Jedrzejewski W, Jedrzejewska B, Szymura L (1995) Weasel population response, home range, and predation on rodents in a deciduous forest in Poland. Ecology 76:179–195

Mackenzie DI (2012) PRESENCE User Manual; p 83

Mackenzie DI, Nichols JD, Lachman GB, Droege S, Royle JA, Langtimm CA (2002) Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248–2255

McDonald RM, Abramov AM, Stubbe M, Herrero J, Maran T, Tikhonov A et al. (2016) Mustela nivalis. The IUCN red list of threatened species

Morris DW (1996) Coexistence of specialist and generalist rodents via habitat selec- tion. Ecology 77:2352–2364

Otto CRV, Roloff GJ (2011) Using multiple methods to assess detection probabilities of forest-floor wildlife. J Wildl Manag 75:423–431

Palazón S, Camps D, Carbonell F, Grajera J (2016) Predation of the weasel (*Mustela nivalis*) by diurnal raptors. Galemys 28: 66–67

Sala OE, Stuart Chapin IIIF, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH (2000) Global biodiversity scenarios for the year 2100. Science 287:1770–1774

Sikes RS, Gannon WL, Animal Care and use Committee of the American Society of Mammalogists (2011) Guidelines of the American Society of Mammalogists for the use of wild mammals in research. J Mammal 92:235–253

Slade NA, Blair SM (2000) An empirical test of using counts of individuals captured as indices of population size. J Mammal 81:1035–1045

Sundell J, O'Hara RB, Helle P, Hellstedt P, Henttonen H, Pietiäinen H (2013) Numerical response of small mustelids to vole abundance: delayed or not? Oikos 122:1112–1120

Sundell J, Ylönen H (2008) Specialist predator in a multi-species prey community: boreal voles and weasels. Integr Zool 3:51–63

Torre I, Raspall A, Arrizabalaga A, Díaz M (2018) SEMICE: an unbiased and powerful monitoring protocol for small mammals in the Mediterranean region. Mamm Biol 88:161–167

Torre I, Freixas L, Arrizabalaga A, Díaz M (2016) The efficiency of two widely used commercial live-traps to develop monitoring protocols for small mammal biodiversity. Ecol Indic 66:481–487. https://doi.org/10.1016/j.ecolind.2016.02.017

Torre I, Arrizabalaga A, Freixas L, Ribas A, Flaquer C, Díaz M (2013) Using scats of a generalist carnivore as a tool to monitor small mammal communities in Mediterranean habitats. Basic Appl Ecol 14:155–164

Torre I, Arrizabalaga A (2008) Habitat preferences of the bank vole Myodes glareolus in a Mediterranean mountain range. Acta Theriol 53:241–250

Torre I, Díaz M (2004) Small mammal abundance in Mediterranean post-fire habitats: a role for predators? Acta Oecol 25:137–142

Vitousek PM (1994) Beyond global warming: ecology and global change. Ecology 75(7):1861–1876

Watkins AF, McWhirter JL, King CM (2010) Variable detectability in long-term population surveys of small mammals. Eur J Wildl Res 56:261–274