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Eco-geographical variation in the diet of the Barn Owl *(Tyto alba)* in mountainous areas of France

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Abstract Because of the worldwide distribution of the Barn Owl *(Tyto alba)* and the easily way to find its pellets, it is often used to diet studies. To investigate the eco-geographical impact of mountainous areas on its diet, we conducted studies in the Jura, Alpes, Central and Pyrénées mountains and we also did pellet analysis from 8 sites in the Jura mountains. Analysis of the tooth and skull content of pellets allowed us to draw up two types of change in the diet of *Tyto alba* in correlation with mountain elevation. The first one concerns the Jura, Alpes and Central mountains, where the diversity of the diet declines with the increase in elevation. The second one concerns the Pyrénées mountains, where there is no change in the diversity of the diet, perhaps because of the higher diversity of small mammals caused by mediterranean influence. Thus, it seems that elevation causes a decrease in diet diversity of *Tyto alba* in continental mountains (Jura, Alpes and Central mountains) probably because of more homogeneous landscapes dedicated to grass production. However, in Mediterranean mountains (Pyrénées), a more diversified small mammal guild provides a constant level of diet diversity.

Keywords: Barn Owl, small mammals, mountain, mediterranean influence, continental influence

Összefoglalás A gyöngybagoly *(Tyto alba)* egész világon való elterjedése, és köpeteinek könnyű fellelhetősége miatt gyakori alanya táplálkozási vizsgálatoknak. E dolgozatban a hegyvidéki környezet gyöngybagoly táplálkozására kifejtett öko-geográfiai hatásait teszteltük a Jura, az Alpok, a Francia-középhegység és a Pireneusok területén gyűjtött minták alapján, és köpet-analízist végeztünk a Jura-hegységből származó, 8 különböző területről gyűjtött mintából. A köpetekben talált fog- és koponyamaradványok analízise alapján két csoportot lehetett elkülöníteni: a Jura, az Alpok és a Francia-középhegység területén a táplálék-diverzitása csökkent a tengerszint feletti magasság növekedésével, míg a Pireneusok területén ilyen változást nem tapasztaltunk. A különbség abból adódhat, hogy a kontinentális hegységekben (Jura, Alpok, Francia-középhegység) a tengerszintfeletti magasság növekedésével a homogénebb élőhelyek kedveznek a fűfélék növekedésének, így a kisemlős diverzitás is csökken, míg a mediterrán hegységek (Pireneusok) területén egy sokkal változatosabb kisemlős közösség biztosítja a táplálék-diverzitás állandóságát.

Kulcsszavak: gyöngybagoly, kisemlősök, hegység, mediterrán hatás, kontinentális hatás

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Introduction

Because of its worldwide distribution and the easiness to find its pellets, the Barn Owl *(Tyto alba)* is one of the most studied raptor species in the world (Michelat & Giraudoux 1993, Begall 2005, Rasoma & Goodman 2007). This species is able to adapt its diet to variables of its environment, such as small mammal abundance, landscape structure, landscape composition, season etc. (Taylor 2004). Its diet is particularly composed of small mammals in Europe (Bosè & Guidali 2001, Bontzorlos *et al.* 2005, Bernard *et al.* 2010), including the Mediterranean (Leonardi & Dell'arte 2006), and in North America (Colvin & McLean 1986). The Barn Owl is also able to specialize on bats (Boireau 2009, Sommer *et al.* 2009, Roulin & Christe 2013), insects, birds, reptiles or primates (Vargas *et al.* 2002, Tores & Yom-Tov 2003, Shehab *et al.* 2004, Escarlate-Tavares & Pessôa 2005, Alivizatos *et al.* 2006, Platt *et al.* 2009, Souza *et al.* 2009). Thus, it appears that the diet of the Barn Owl in spatial dimension (at world scale) is incredibly varied. There also exist some examples of temporal diet variation linked with temporal variation in prey abundance, making the Barn Owl an opportunistic predator. For example, Bernard *et al.* (2010) showed that during multiannual variation of grassland vole abundance (*Microtus arvalis* or *Arvicola terrestris*), the Barn Owl could adapt its diet to those food resources variation.

Although knowledge about the diet of the Barn Owl at spatial scales is good, there is less information about the variation of diet linked with variation of elevation in mountainous areas. Actually, according to Schneider (1964), we are not able to find information on Barn Owl diet above 700 meters of elevation. However, we and other authors (Libois *et al.* 1983) found pellets up until 1000 meters.

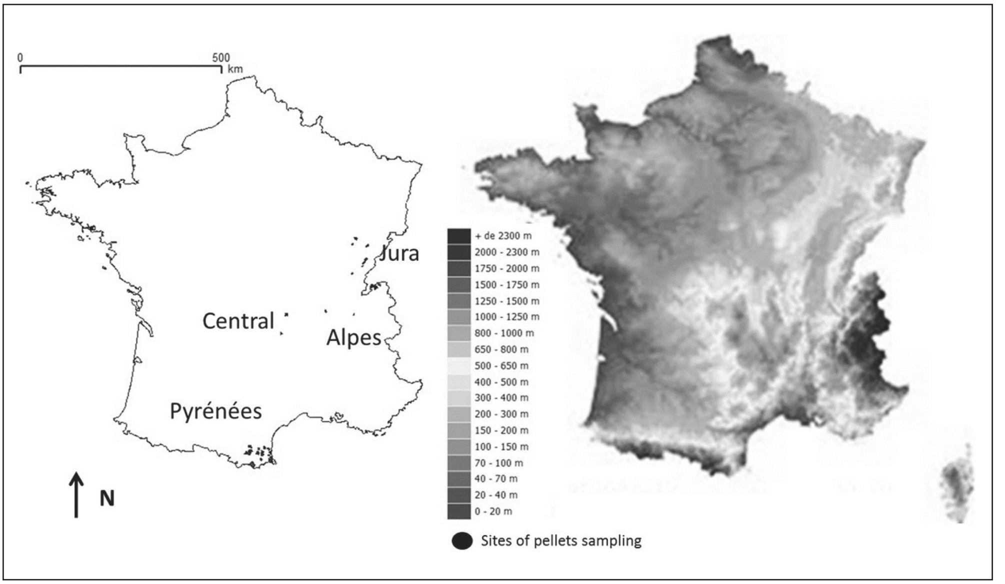

Figure 1. Localisation of the study sites in black (map on the left) and elevation in France (map on the right)

1. ábra A vizsgálati területek elhelyezkedése (bal oldali térkép) és tengerszint feletti magassága Franciaországban (jobb oldali térkép)

We analysed pellet contents from eight sites in the Jura mountains and used data from others studies carried out in the Jura, Alpes, Central and Pyrénées mountains to study the correlation between diet diversity and elevation both in continental and Mediterranean areas.

Material and methods

Study area

The study took place in 44 municipalities of France (8 in Jura, 14 in Alpes, 2 in Central and 19 in Pyrénées) *(Figure 1)*. The climate is continental in the Jura, Central and Alpes mountains, whereas there is a Mediterranean influence in the Pyrénées (Libois *et al.* 1983). The altitude ranged about 9 to 1000 meters. The distance between the sites was at least 2 kilometers, which was lower than the maximal potential distance of predation (Taberlet 1983).

Pellet collection

We collected pellets between 2010 and 2013 in several places in the Jura mountains *(Table 1)*. We identified the small mammal species in the collected pellets by tooth and skull analysis, skull analysis, using informations from Corbet (1964), Restoin and Restoin (1972), Erome and Aulagnier (1982), Lange *et al.* (1986), Michelat and Giraudoux (1989) and Barčiovå and Macholån (2009) in this study. We also considered the number of individuals found in pellets in studies by Michelat and Giraudoux (1993) in the Jura mountains, Aulagnier (1982) and Rigaux and Riols (2008) in the Central mountains and Libois *et al.* (1983) in the Pyrénées, or the proportion of small mammal species from the study by Taberlet (1986) in the Alpes *(Table 1)*. In this study we were not able to individualized Barn Owls to know if several individuals could use the same site.

Elevation value

The elevation of each site was obtained by using IGN French maps.

Diet diversity computing

To compute the diversity of the diet at each site, we decided to calculate a simple Shannon Diversity Index (SDI) as follows (Chao & Shen 2003): assume that there are *S* species in a community and they are labelled from 1 to *S*. Denote the probabilities of species discovery (or relative abundance) by $(\pi_1,\pi_2,\ldots,\pi_S)$ where $\sum_{i=1}^{S}\pi_i = 1$

$$SDI = -\sum_{i=1}^{S}\pi_i \log(\pi_i)$$

Statistical analysis

To study the variation of the SDI in the Barn Owl's diet, we analysed the data from the continental mountains (Jura, Alpes and Central) separately from the Mediterranean Pyrénées mountains because of the potential difference in the small mammals species present (22 and 27, respectively). We fitted a simple linear model, and checked the normal distribution of residuals and the homocedasticity of the variance. The null hypothesis is that the SDI of the Barn Owl's diet does not depend on the elevation in meters.

site	elevation	*Microtus arvalis*	*Microtus agrestis*	*Microtus subterraneus*	*Microtus nivalis*	*Arvicola terrestris*	*Arvicola sapidus*	*Clethrionomys glareolus*	*Microtus duodecimcostatus*	*Pitymys pyrenalicus*
Saint-Maurice	293	137	6	0	0	4	0	4	0	0
Ferme de Courbey	289	16	7	0	0	2	0	14	0	0
Chapelle d'huin	782	18	0	0	0	2	0	0	0	0
Chenevrey-et-morogne	200	41	1	0	0	1	0	0	0	0
Courvières	820	18	0	0	0	0	0	0	0	0
Cuvier	827	178	2	0	0	0	0	0	0	0
Blye	470	79	1	0	0	0	0	0	0	0
Mièges	749	338	23	0	0	0	0	0	0	0
Bouclans	430	362	12	0	0	15	0	4	0	0
Courpière	310	2350	647	3	0	106	3	115	0	0
Canet	9	0	34	0	0	0	10	0	35	0
Claira	10	0	5	0	0	0	4	0	16	0
Corneilla del vercol	11	0	31	0	0	0	1	0	79	0
Argelès-sur-mer	16	0	21	0	0	0	0	0	2	0
Espira de l'agly	28	0	3	0	0	0	0	0	5	0
Pezilla-la-rivière	67	0	89	0	0	0	2	0	31	0
Sorède des albères	80	0	6	0	0	0	1	0	1	0
Thuir	91	0	63	0	0	0	2	0	0	0
Saint-féliu d'avall	97	0	255	0	0	0	29	0	43	0
Latour de France	101	0	12	0	10	0	6	0	0	0
Ille-sur-tête	149	0	0	0	0	0	0	0	0	0
Caudiès de fen	309	0	19	0	0	0	0	0	0	0
Oms	515	0	23	0	0	0	2	0	0	0
Sournia	515	0	30	0	0	0	0	10	0	1
Montbolo	576	0	70	0	0	0	0	0	0	0
Mosset	600	19	198	0	2	0	0	17	6	0
Prats de mollo	735	9	783	0	1	0	0	2	0	1
Rabouillet	900	28	73	0	0	0	1	27	0	8
Col d'aussières	1000	21	22	0	0	0	0	3	0	5
Brens	570	36.92	6.27	0	0	11.46	0	0.88	0	0
Brenthonne	550	28.39	8.81	0	0	5.84	0	1.02	0	0
Chens sur léman	410	30.12	3.39	0	0	2.58	0	0.70	0	0
Douvaine	430	46.56	5.31	0	0	3.35	0	0.69	0	0
Draillant	630	28.90	10.02	0	0	2.79	0	0.49	0	0
Fessy	580	34.53	10.54	0	0	3.36	0	1.79	0	0
Féternes	780	20.92	8.04	0	0	5.76	0	0.45	0	0
Le lyaud	650	34.85	6.17	0	0	2.66	0	0.28	0	0
Marclaz	430	36.43	11.92	0	0	10.37	0	0.68	0	0
Messery 1	420	32.78	9.42	0	0	3.83	0	1.18	0	0
Messery 2	420	39.17	4.46	0	0	3.14	0	1.82	0	0
Nernier	400	37.57	7.84	0	0	1.43	0	1.24	0	0
Perrignier	560	27.53	11.63	0	0	4.97	0	0.60	0	0
Saint-Didier	550	24.74	6.25	0	0	11.72	0	0.78	0	0
Sciez	410	37.69	7.75	0	0	2.81	0	0.78	0	0
Cohade	450	293	53	0	0	3	1	9	0	0

Table 1. Numbers of individuals found in pellets from our analysis and the studies of Michelat and Giraudoux (1993) in the Jura, Aulagnier (1982) and Rigaux and Riols (2008) in the Central, Libois *et al.* (1983) in the Pyrénées or proportion of each species of small mammal from the study of Taberlet (1986) in the Alpes

1. táblázat A bagolyköpetekben talált egyedek száma a különböző gyűjtőhelyeken

Computing environment

Data management were performed with R 2.12.0. software (R-Core Team 2012), using the following packages: pgirmess (Giraudoux 2012) and vegan (Oksanen *et al.* 2014).

Results

Jura mountains diet composition

Saint-Maurice is the most diverse site in terms of prey species, 12 species dominating the diet (in decreasing order of abundance: *Microtus arvalis*, *Crocidura russula* and *Sorex coronatus/araneus*). The same order of abundance was found for Courvières, Cuvier, Blye, Mièges and Bouclans. Ferme de Courbey provided only 9 species dominated by *Sorex coronatus/araneus*, *Microtus arvalis* and *Clethrionomys glareolus*. Chapelle d'Huin was dominated by *Microtus arvalis, Sorex coronatus/araneus* and *Arvicola terrestris,* while Chenevrey-et-Morogne was dominated by *Microtus arvalis, Crocidura russula* and *Apodemus* spp.

Alpes diet composition

The Alpes diet composition was mainly dominated by *Microtus arvalis*, *Crocidura russula* and *Sorex coronatus/araneus,* and occasionally by species like *Arvicola terrestris* or *Apodemus* spp.

Central mountains diet composition

Both site in the Central mountains were dominated in terms of number of individuals by *Microtus arvalis*, *Crocidura russula* and *Sorex coronatus/araneus*.

Pyrénées diet composition

For the diet of the Barn Owl in the Pyrénées mountains, there is a lowland site with strong Mediterranean influence, where the Barn Owl feeds mainly on *Mus spretus.* At middle altitudes, the Barn Owl feeds on *Sorex* spp., *Microtus arvalis*, *Clethrionomys glareolus* and *Pitymys pyrenaicus*. The middle altitudes are characterized by the presence of *Microtus agrestis*, *Apodemus* spp., *Crocidura* spp.

Elevation effect on the SDI of the Barn Owl's diet

For the continental mountains (Jura, Alpes and Central), we found a significant negative relationship between elevation (in meters) and the SDI value *(Figure 2a),* following this equation: SDI value=-0.40* elevation value + 1.59 (ANOVA, P-value=0.04, R^2=0.12). However, for the Mediterranean mountain (Pyrénées), we did not find relationship between the elevation (in meters) and the SDI value (ANOVA, P-value=0.27) *(Figure 2b)*.

Discussion

Continental mountain diet composition

Our first results indicate that the prey species at continental mountain sites are dominated by *Microtus arvalis*, *Crocidura russula* and *Sorex coronatus/araneus*. This may be explained by the environmental context of those sites, i.e., they are surrounded by human-inhabited areas and open fields with crops and grass, which are their most favourable habitats (Quéré & Le Louarn 2011). This seems to be the same

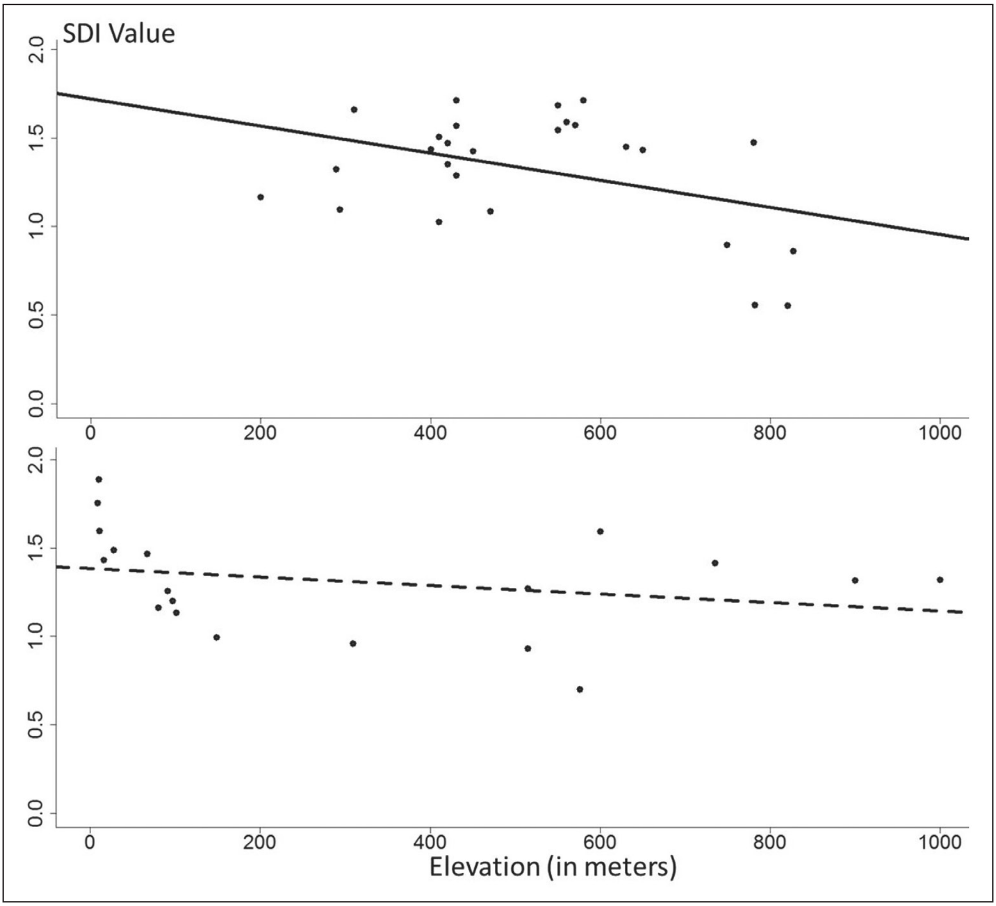

Figure 2. SDI value of the Barn Owl's diet variation regarding on elevation in continental mountains (a) and Mediterranean mountains (b)

2. ábra A gyöngybagoly táplálkozási változatosságának SDI értéke a tengerszint feletti magasság függvényében a kontinentális (a), illetve a mediterrán hegységekben (b)

for *Crocidura russula,* as Michelat and Giraudoux (1993) found that this species was only trapped in open fields and grove areas. Taberlet (1986) considered *C. russula* to be associated with open landscapes and with human-created habitats in the northern part of its distribution. *Sorex coronatus/araneus,* the third most abundant species in the present study, was trapped particularly in grove and hedgerows by Michelat and Giraudoux (1993). The occurrence of *Mus musculus* and *Neomys fodiens* as part of the Barn Owl's diet could be explained by the vicinity of a village, as well as a little river, respectively.

Conversely, the site of Ferme de Courbey is different from the other sites, because it is dominated by *Sorex coronatus*, *Microtus arvalis* and *Clethrionomys glareolus*. The immediate vicinity of abandoned land and forests may explain the strong prevalence of *Sorex coronatus* and *Clethrionomys glareolus,* which are hedgerow- and forest specific species (Michelat & Giraudoux 1993, Quéré & Le Louarn 2011) as for the strong presence of a forested specific species: *Apodemus* spp. The strong prevalence of *Microtus arvalis* could be explained by the presence of crops and grass fields in the valley.

Moreover, as expected, we found strong prevalence of *Microtus arvalis* and *Sorex coronatus*/*araneus* in the pellets, as these species comprise the basic diet of the Barn Owl in Europe (Michelat & Giraudoux 1993, Bosè & Guidali 2001, Askew *et al.* 2007, Bernard *et al.* 2010).

Mediterranean mountain diet composition

Considering the diversity of the landscapes, the Pyrénées-orientales area is one of the most varied in France. Vegetation maps show habitats ranging from coastline to medium-high mountains. The eumediterranean status of the area is indicated by the presence of *Mus spretus* and the absence of *Microtus arvalis* or *Sorex* spp. There also exist submediterranean areas with simultaneous presence of *Mus spretus* and *Sorex* spp. *Microtus duodecimeostatus*, *Suncus etruscus* and *Crocidura suaveolens* presence claimed for Mediterranean areas. *Microtus duodecimeostatus* characterized the presence of crop fields. The abundance of the three species of *Crocidurinae,* especially *Crocidura russula,* characterized some micro-habitats, like dykes (Fons 1975, Genoud & Hausser 1979).

Elevation effect on the SDI value of the Barn Owl's diet indicates two ecogeographical trajectories: continental and Mediterranean mountains

Our results show that it is possible to differentiate between French continental and Mediterranean mountain areas using SDI values of prey diversity in the Barn Owl's pellets and relate these to elevation: the SDI decreases with increasing elevation in continental mountains and does not change in Mediterranean areas. As for continental mountains, two variables could explain the decrease of diet diversity when elevation increases: i) landscape composition, creating outbreaks of certain prey species, and ii) limited number of species. Indeed, in mountainous areas of France, land use policy led to an agricultural specialization towards grass production and towards larger parcel sizes (López-i-Gelats *et al.* 2011). This promoted the emergence of multiannual vole (*Arvicola terrestris* and *Microtus arvalis*) population fluctuations at large spatial and temporal scales (Delattre *et al.* 1992, Giraudoux *et al.* 1997, Delattre *et al.* 2006, Foltête *et al.* 2008, Berthier *et al.* 2013). Delattre *et al.* (1992) showed that damages due to multiannual fluctuation patterns of the Common Vole increases with the Ratio of Permanent Grassland to Farmland (RPGF). For *Arvicola terrestris,* Saucy (1994), in Switzerland, found cyclic changes in population abundance with statistically significant periods ranging between 5 and 7 years. In Franche-Comté, France, Giraudoux *et al.* (1997) found a 5-6 year cycle that was established since the early '70s after the expansion of permanent grassland in farmland at a regional scale. This specialization toward grass production could lead to a very important population increase of *Arvicola terrestris* and *Microtus arvalis*. Also, Bernard *et al.* (2010) showed that during multiannual variation of grassland vole abundance, rodent frequency in the diet of *Tyto alba* ranged from 54% to 61%, with *Arvicola terrestris* and *Microtus arvalis* as dominant preys, and that the proportion of *Sorex* spp. could reach 34%.

This means that in the continental sites of the present study, above 700 meters, three species could represent almost 100% of the diet of the Barn Owl because of landscape homogeneity (grassland). Thus, the agricultural specialization creating landscape homogeneity and vole outbreaks in grassland areas could be an explanation of the decrease of SDI value in continental mountains. Another possibility is that the number of potential prey species is 22. Indeed, as our continental sites reach only 820 meters at the maximum of elevation the diet of the Barn Owl could not account the presence of new species as *Microtus nivalis*, *Sorex alpinus*, *Sorex antinorii*, *Apodemus alpicola*. In the Mediterranean Pyrénées mountains, we observed that the SDI value remained stable in lowland, as well as in mountainous areas. The first explanation for that can be that this area is not concerned by outbreaks of Water Vole or Common Vole, keeping the diet of the Barn Owl relatively diversified. Moreover, while some species are present in coastline areas *(Microtus duodecimeostatus, Mycromis minutus, Mus spretus, Sorex coronatus/araneus)* (Libois *et al.* 1983), they are absent in the mountains and are replaced by mountain species *(Microtus arvalis, Microtus nivalis, Clethrionomys glareolus, Pitymys pyrenaicus, Sorex minutus, Neomys fodiens)* (Quéré & Le Louarn 2011).

Conclusion

To study the eco-geographical impact of mountainous areas on the Barn Owl's diet, we used the results of some studies from the Jura, Alpes, Central and Pyrénées mountains and we also carried out pellet analysis at 8 sites in the Jura mountains. Our results indicate that there are two dietary types of *Tyto alba* in correlation with elevation. The first one is typical of the Jura, Alpes and Central mountains, were the diversity of the diet declines with the increase in elevation. The second is typical of the Pyrénées mountains, where the diversity of the diet remains stable perhaps because of the higher diversity of small mammals as a result of Mediterranean influence. Finally, we propose that elevation makes diet diversity of *Tyto alba* decrease in continental mountains probably because of more homogeneous landscapes due to specialization towards grass production. In Mediterranean mountain areas, the influence of a more diverse small mammal guild contributes to a constant level of diet diversity.

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