ISSN 1067-4136, Russian Journal of Ecology, 2018, Vol. 49, No. 6, pp. 526–530. © Pleiades Publishing, Ltd., 2018.
Original Russian Text © A.V. Bobretsov, L.E. Lukyanova, K.V. Maklakov, 2018, published in Ekologiya, 2018, No. 6, pp. 458–463.

Effects of Landscape Heterogeneity on Common Shrew (*Sorex araneus*) Population Dynamics

A. V. Bobretsov[a, b, *], **L. E. Lukyanova**[c, **], **and K. V. Maklakov**[c]

[a]*Pechora-Ilych State Nature Biosphere Reserve, Yaksha, Troitsko-Pechorskii district, Komi Republic, 169436, Russia*
[b]*Institute of Biology of Komi Scientific Center, Ural Branch, Russian Academy of Sciences, Syktyvkar, Komi Republic, 167982 Russia*
[c]*Institute of Plant and Animal Ecology, Ural Branch, Russian Academy of Sciences, Yekaterinburg, 620144 Russia*
**e-mail: avbobr@mail.ru*
***e-mail: lukyanova@ipae.uran.ru*

Received December 15, 2017

Abstract—The effects of landscape heterogeneity on changes in the common shrew population were researched. Multiyear (1987–2017) time series data on species abundance in the plain and piedmont areas of the Pechora-Ilych State Nature Biosphere Reserve have been analyzed using the Fourier spectral analysis method. A cyclic component of three years and another one of lower value at five years were identified in the common shrew population dynamics in the piedmont area. In the plain area, changes in the animal population are more chaotic and periodic components are poorly manifested in the time series. The influence of landscape heterogeneity on the species population and its amplitude of fluctuation were also identified; these parameters are significant in the piedmont area and negligible on the plain.

Keywords: landscape heterogeneity, common shrew, population dynamics, population cycles, fluctuation amplitude

DOI: 10.1134/S1067413618060048

The common shrew (*Sorex araneus* Linnaeus, 1758) is one of the most widespread and abundant Palearctic shrew species. Its population varies widely everywhere on an annual basis. It is believed to be most variable on the periphery of its habitat area and most sustainable in the central area of its habitat (1, 2). The nature of species abundance fluctuations is variable. In some regions, populations of this species are acyclic or just demonstrate a trend towards regular three- to four-year-long cycles (2–5). Alongside this, the cyclic population are also present (1, 6–10). These occur not only in the central part of the species habitat area but on its periphery (11). In some areas, cyclic fluctuations in the common shrew population dynamics have transformed into chaotic (12–14). There are no geographic patterns in the distribution of the population dynamics featured by this species. It is not uncommon that populations with different population dynamics coexist in a relatively small area. For instance, in Finland, cyclic populations (8, 11) were registered alongside acyclic (3).

The landscape heterogeneity of the area significantly affects the small mammalian population dynamics formation and amplitude of fluctuation (15, 16). According to J. Loman (17), any differences in the small mammalian population dynamics must be linked, either directly or indirectly, to the landscape structure. In this context, the most important landscape parameter is “landscape picture”: the composition and ratio of various habitat types, their size, and configuration (18).

The correlation between the population dynamics and various landscapes has been demonstrated mostly through the example of voles. This is researched very poorly in shrews; therefore, we have used multiyear data on common shrew abundance in various landscape sections of the Pechora-Ilych Biosphere Reserve. The purpose of this study was to assess the effects of landscape heterogeneity on the *Sorex araneus* population dynamics, including periodicity, amplitude of fluctuation, and synchronism of changes. It was assumed that the species population dynamic should be different in various landscapes that feature different structures and quality of habitats.

MATERIAL AND METHODS

Annual small mammal counts data for the plain and piedmont areas of the Pechora-Ilych Biosphere Reserve collected from 1987 to 2017 were used. The shrew population was assessed using trap trenches. The trench length was 50 m, and five cones were embedded in its bottom. The counts were performed in late summer (end of July and August). The most abundant biotope types in each area were covered by the census. The number of individuals caught by a trap trench within 10 days of its operation (individuals per 10 trench–days) was used as a relative abundance parameter. In total, the traps had operated for 3203 trench–days, and 6600 animals were caught. Census stations are located 86 km from each other.

Trap trenches were chosen because shrews are reluctant to enter break-back traps with bread baits. The share of common shrews in the total small mammalian population of the piedmont taiga in the Biosphere Reserve was 26.6% based on the trap trench census, while, based on the break-back trap census, it was only 7.4%. Trap trenches caught small numbers of shrews even in depression years, while there were often no animals in break-back traps during this phase. The catching efficiency of trap trenches reflects not only the species population but the animals' mobility (19). Still, the abundance parameters using the two methods had reliably correlated with each other: Spearman's rank correlation coefficient was +0.73 ($t(31) = 5.83$; $p < 0.001$).

An important requirement for time series data to be processed using statistical analysis methods is their duration. For this reason, using a series consisting of less than 25–30 consecutive values is not recommended (20). Our data meet this requirement. The Fourier spectral analysis method was used to identify and assess the cyclicity in the time series. The data were preliminary converted into logarithmic form because the distribution of the annual abundance parameters had deviated from the normal probability distribution (the correlation was established using the Kolmogorov–Smirnov test). The purpose of this method is to resolve a time series into components (harmonics) having different amplitudes and frequencies. The most powerful ones, having clearly manifested peaks at certain sections of the periodogram, were the cyclic components. Statistica 6.0 for Windows and PAST v. 3.17 were used for calculations and diagram construction.

According to physical and geographical zoning, the plain and piedmont sections of the Pechora-Ilych Biosphere Reserve belong to different physiographic provinces and countries as independent landscape districts (21). The plain area is located on the eastern periphery of the East European Plain and features a homogenous relief. The vegetation is pretty monotonous in that area. Pine forests of various types predominate there (86%), and almost half of those are lichen pine forests (43%). Another mandatory element of this landscape are swamps. The alternation of pine forests and swamps is a typical feature of the plain area. Spruce forests occupy only 11% of the forested area; these are mostly associated with river valleys and are highly fragmented.

The piedmont area is located within the Ural Mountain Country (North Urals); this is a steeplysloping elevated plain crossed by several ranges in the longitudinal direction. Polydominant dark coniferous taiga occupies the majority of the area (76%). The wood stands consist of spruce with large participation of fir, Siberian pine, birch, and, to a lesser degree, pine. The forests are mostly overmature and feature a thick moss layer. Green moss, polytric, and sphagnum spruce forests predominate in depressions between the ranges. Range slopes are covered by spruce–fir forests with a significant participation of large ferns in the ground layer. Forests with grass layers occupy large areas on flooded plains.

Therefore, the studied landscape areas differ significantly from each other by environmental conditions. The piedmont landscape provides favorable conditions for the common shrew, while unfavorable for shrews are dry pine forests and swamps predominate in the plain area.

RESULTS

The common shrew population parameters had varied in the plain area for years from 3.8 to 46.2 individuals, with an average value of 13.5 ± 1.9 individuals per 10 trench–days; in the North Urals piedmont, the population had parameters varying from 3.1 to 114.5 individuals, with an average value of 33.5 ± 5.4 individuals per 10 trench–days (Fig. 1). In the former, shrew abundance changed 12 times; in the latter case, 37 times. The standard deviation of abundance parameters for the plain population was 10.2, while, for the piedmont population, it was 30. The changes in shrew populations inhabiting various landscape sections of the Biosphere Reserve were pretty synchronous. Spearman's rank correlation coefficient r_S between the abundance of animals in the plain and piedmont areas was +0.71 ($t(31) = 5.50$, $p < 0.001$). The maximum animal abundance peaks on the plain (1992, 2001, 2008, and 2013) coincided with population explosions of the species in the piedmont area. Only in some years was asynchrony in the population fluctuations observed.

The spectral analysis has identified only one powerful periodic component at three years and another one of lower value at five years in common shrew population dynamics in the piedmont area (Fig. 2). Out of the nine cycles registered there, six had a frequency at a period of three years and three had a frequency at a period of five years. The time series of shrew abundance data in the plain area lacked significant periodic components. Relatively low harmonics were present there at frequencies with periods of 2.3, 5, and 7.7 years; this indicates weak periodic components in the species population dynamics in the plain section of the Biosphere Reserve and its chaotic nature.

The abundance change trajectory depends on the population the previous year. The correlation between these two parameters is statistically significant: Spearman's rank correlation coefficient was –0.78 ($t(31) =$

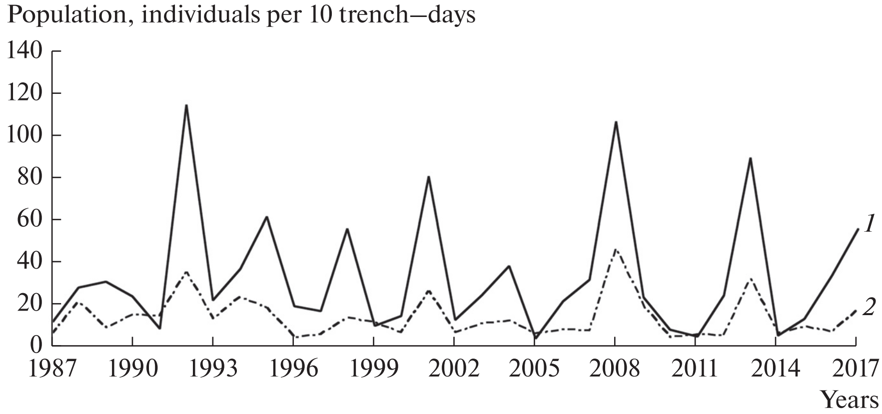

Fig. 1. Common shrew population dynamics in the piedmont (*1*) and plain (*2*) sections of the Pechora-Ilych Biosphere Reserve.

5.30, $p < 0.001$) for shrews inhabiting the plain area and – 0.54 ($t(31) = 3.37$, $p < 0.01$) for shrews of the piedmont area. This makes it possible to forecast their population in the next year. If the abundance is less than nine individuals per 10 trench–days, the common shrew population on the plain will always increase; if it is more than 15 individuals per 10 trench–days, the common shrew population will decrease. If the abundance is nine to 15 individuals per 10 trench–days, the further population dynamics trajectory is uncertain: it may either increase or decrease. In the piedmont area, the parameters are growing if the abundance is less than 20 individuals per 10 trench–days and decreasing if the abundance is more than 38 individuals per 10 trench–days. The uncertainty zone for the population dynamics trajectory in this landscape type is higher (20–38 individuals per 10 trench–days).

DISCUSSION

Certain differences have been identified between the common shrew population dynamics patterns observed in various landscape areas. The most significant cyclic fluctuations in shrew abundance were discovered only in the North Urals piedmont area (Fig. 2): the cycle duration is three years there. Similar cyclic population fluctuations of this species are not uncommon and were registered both on the periphery of its habitat area and in its central habitat area. For instance, three-year-long cycles were noted for common shrews in the western part of Finland (8), while three- to four-year-long cycles were registered in the southern part of Karelia (10). The above examples show that shrews feature population dynamics cycles in relatively unfavorable conditions on the periphery of their habitat area. In the central part of the habitat area, the cycle duration for cyclic common shrew populations is also three to five years: three years in Białowieża Forest, Poland (9), and three to five years in the temperate zone of Russia (1). A similar periodicity in population fluctuations of this species was noted in the eastern part of its habitat area: four years in Central Siberia (6) and three to four years in the southern part of West Siberia (22).

It is necessary to note that a periodic component at five years is present in the time series data on shrew abundance in the piedmont area. However, it is relatively weak and constitutes only one-third of the total number of identified cycles. The presence of several cycles having a different duration in a time series is a pretty common phenomenon in animal population dynamics (23). It is generally believed that this increases adaptive capability of the population to environmental changes (24).

Periodic components are poorly manifested in the common shrew population dynamics in the plain area. Several peaks were noted at certain frequencies; however, these periodic components turned out to be statistically insignificant. Shrew abundance on the plain is pretty low in comparison with the piedmont area:

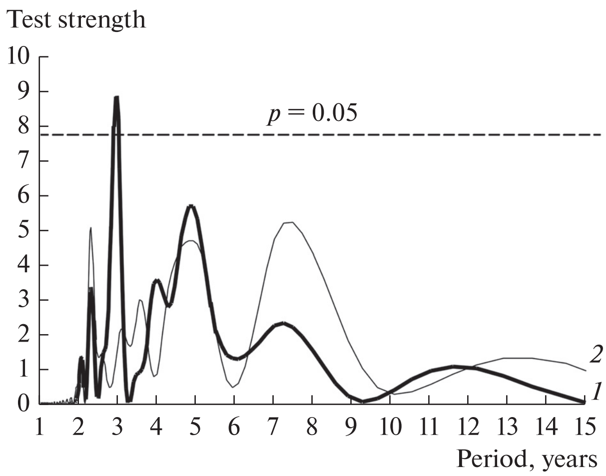

Fig. 2. Periodogram of the common shrew population fluctuations in the piedmont (*1*) and plain (*2*) sections of the Pechora-Ilych Biosphere Reserve.

the maximum populations parameters are 2.5 times lower there.

Shrew population and distribution throughout biotopes is primarily determined by the potential food deposits and their availability (25). Spruce forests with grass layers, meadows, and green moss spruce forests, being optimum habitats for this species, are the most rich in this respect. On the plain, the earthworm population (one of the shrew's main foods) in these biotopes is 13.5 to 30.8 individuals/m^2, while, in poorer (pessimum) pine forests, it is 0.2 to 1.8 individuals/m^2 (26). In spruce forests with grass layers in the piedmont area, the earthworm population increases to 80 individuals/m^2 (27). The average shrew population in the biotopes is changing respectively. On the plain, it is 22.4 individuals per 10 trench–days in high-grass spruce forests, 7.7 individuals per 10 trench–days in green moss pine forests, and 3.2 individuals per 10 trench–days in lichen pine forests.

Changes in the ratio of optimum and pessimum habitats within a landscape affect the total animal population level (18, 28). Not only changes in the habitat structure, but habitat areas are of importance (29). An increase in the number and area of optimum habitats results in small mammalian population growth. In the plain area, with predomination of nutritionally poor pine forest, the average common shrew population level is 13.5 individuals per 10 trench–days. In the piedmont area, where the above habitats are lacking while dark coniferous forests with a high share of grassy and green moss habitats are predominant, the average common shrew population level is as much as 33.5 individuals per 10 trench–days. Similar biotopes located in different areas featured different animal abundance levels as a result of landscape effects. The shrew population was much higher in piedmont habitats in comparison with their analogues on the plain. For instance, the average animal abundance index value in a spruce forest with a grass layer located in the piedmont area was 36.9 individuals per 10 trench–days, while, in a similar biotope on the plain, it was 22.4 individuals per 10 trench–days.

Therefore, the common shrew population dynamics may differ depending on the landscape composition (ratio of various habitat types) and species abundance level. In South Karelia, where the small mammalian population level is also low, periodical components are manifested pretty poorly in the species dynamics series (30), similarly with the plain section of the Biosphere Reserve. In addition, the plain area can be considered a highly fragmented landscape for common shrew where optimum habitats are small and isolated from each other: in fact, these are interspersed between large areas occupied by unfavorable biotopes (lichen pine forests and swamps). It is known that the landscape fragmentation adversely affects the animal population dynamics: the small mammalian population goes down (31) and its amplitude decreases (32).

CONCLUSIONS

The common shrew population dynamics are different in plain and piedmont landscapes of the Pechora-Ilych State Nature Biosphere Reserve by their periodicity and amplitudes of fluctuation. Periodic fluctuations of species abundance are clearly manifested only in the North Urals piedmont area. Cycles at three years were registered there. A periodical component of lower value at five years was also noted: out of the nine registered cycles, it constituted only two. The population dynamics in the plain area is more chaotic. The number and amplitude of population fluctuations featured by shrews inhabiting the North Urals piedmont area were 2.5 times higher in comparison with animals living on the plain. These values are largely determined by the landscape structure: in this particular case, by changes in the ratio of areas of optimum and pessimum habitats. In the piedmont area, common shrew optimum habitats occupy large areas. On the plain, their area is insignificant and the sites are isolated from each other. Therefore, the plain area is a naturally fragmented landscape for the common shrew; this adversely affects the species population parameters and the amplitude of its fluctuations.

ACKNOWLEDGMENTS

The study was performed in the framework of the State Assignment of the Institute of Biology of Komi Scientific Center, Ural Branch, Russian Academy of Sciences "Distribution, systematics, and spatial organization of the fauna and animal life of taiga and tundra landscapes and ecosystems of the northeastern part of European Russia" (registration № AAAA-A17-117112850235-2) and Institute of Plant and Animal Ecology, Ural Branch, Russian Academy of Sciences "Ecological mechanisms of stability, variability, and adaptive changes of animal populations and communities (№ 01201356803).

REFERENCES

1. Khodasheva, K.S. and Eliseeva, V.I., *Zemleroiki v ekosistemakh Tsentral'noi lesostepi Russkoi ravniny* (Shrews in Ecosystems of the Central Forest–Steppe of the Russian Plain), Moscow: Nauka, 1992.
2. Balakirev, A.E., Okulova, N.M., and Ivanter, E.V., On analysis of factors affecting the long-term population dynamics of the common shrew in the north and south of the species range, *Povolzh. Ekol. Zh.,* 2004, no. 2, pp. 111–122.
3. Henttonen, H., Haukisalmi, V., Kaikusalo, A., et al., Long-term population dynamics of the common shrew *Sorex araneus* in Finland, *Ann. Zool. Fenn.,* 1989, vol. 26, no. 4, pp. 349–355.
4. Popov, I.Y., Structure and dynamics of shrews on permanent plots in the European southern taiga, in *Advances in the Biology of Shrews II,* Special Publication of the International Society of Shrew Biologists, New York, 2005, vol. 1, pp. 291–301.

5. Tomášková, L., Bejček, V., Sedlaček, F., et al., Population biology of shrews (*Sorex araneus* and *S. minutus*) from a polluted area in central Europe, in *Advances in the Biology of Shrews II,* Special Publication of the International Society of Shrew Biologists, New York, 2005, vol. 1, pp. 189–197.
6. Sheftel, B.I., Long-term and seasonal dynamics of shrews in Central Siberia, *Ann. Zool. Fenn.,* 1989, vol. 26, no. 4, pp. 357–369.
7. Sergeev, V.E., Il'yashenko, V.B., Onishchenko, S.S., and Kolegova, I.A., Long-term dynamics of the shrew taxocene in dark taiga forests of southern Western Siberia, *Sib. Ekol. Zh.,* 2001, no. 6, pp. 785–790.
8. Korpimäki, E., Norrdahl, K., Huitu, O., and Klemola, T., Predator-induced synchrony in population oscillations of coexisting small mammal species, *Proc. R. Soc. B: Biol. Sci.,* 2005, vol. 272, no. 1559, pp. 193–202.
9. Zub, K., Jedrzejewska, B., Jedrzejewski, W., and Barton, K.A., Voles and shrews and non-cyclic mice in a marginal grassland within European temperate forest, *Acta Theriol.,* 2012, vol. 57, no. 3, pp. 205–216.
10. Guseva, T.L., Korosov, A.V., Bespyatova, L.A., and Anikanova, V.S., Long-term dynamics of the biotopic distribution of common shrews (*Sorex araneus* Linnaeus, 1758) in mosaic landscapes of Karelia, *Uch. Zap. Petrozavodsk. Gos. Univ.,* 2014, vol. 2, no. 2, pp. 13–20.
11. Tast, J., Kaikusalo, A., and Jarvinen, A., Population fluctuations of *Sorex araneus* at Kilpisjarvi, Finnish Lapland, as compared with rodent cycles in *Advances in the Biology of Shrews II,* Special Publication of the International Society of Shrew Biologists, New York, 2005, vol. 1, pp. 215–228.
12. Didorchuk, M.V., Population dynamics and community structure of small mammals in the Ryazan Meshchera lowland, *Zool. Zh.,* 2009, vol. 88, no. 1, pp. 78–91.
13. Sheftel', B.I., Cyclic dynamics of small mammal populations and global climate change, in *Mlekopitayushchie Severnoi Evrazii: Zhizn' v severnykh shirotakh* (Mammals of Northern Eurasia: Life at High Latitudes), Surgut: Surgut. Gos. Univ., 2014, p. 19.
14. Kataev, G.D., The common shrew *Sorex araneus*: Long-term observations of population abundance on the Kola Peninsula (1962–2015), in *Teriofauna Rossii i sopredel'nykh territorii: Mat-ly mezhdun. soveshch. (X s"ezd teriologich. obshch-va pri RAN)* (Theriofauna of Russia and Neighboring Countries: Proc. Int. Conf and X Congress of Theriologica Society, Russian Academy of Sciences), Moscow: KMK, 2016, p. 163.
15. Huitu, O., Norrdahl, K., and Korpimaki, E., Landscape effects on temporal and spatial properties of vole population fluctuations, *Oecologia,* 2003, vol. 135, no. 2, pp. 209–220.
16. Pearson, S.M., Landscape ecology and population dynamics, in *Encyclopedia of Biodiversity,* Waltham, MA: Academic, 2013, vol. 4, pp. 488–502.
17. Loman, J., Small rodent population synchrony in western Sweden: Effects of landscape structure, *Web Ecol.,* 2008, vol. 8, no. 1, pp. 14–21.
18. Nabe-Nielsen, J., Sibly, R.M., Forchhammer, M.C., et al., The effects of landscape modifications on the long-term persistence of animal populations, *PLoS One,* 2010; vol. 5, no. 1, e8932.
19. Shchipanov, N.A., Kuptsov, A.V., Kalinin, A.A., and Oleinichenko, V.Yu., Cone traps and live traps catch different shrews (Insectivora, Soricidae), *Zool. Zh.,* 2003, vol. 82, no. 10, pp. 1258–1265.
20. Boonstra, R. and Krebs, C.J., Population dynamics of red-backed voles (*Myodes*) in North America, *Oecologia,* 2012, vol. 168, no. 3, pp. 601–620.
21. Shakirov, A.V., *Fiziko-geograficheskoe raionirovanie Urala* (Physiographic Zoning of the Urals), Yekaterinburg: Ural Otd. Ross. Akad. Nauk, 2011.
22. Vinogradov, V.V., Long-term dynamics and structure of shrews association (Soricidiae) in the mountain taiga of the Eastern Sayan, *Contemp. Probl. Ecol.,* 2012, vol. 5, no. 1, pp. 97–103.
23. Erdakov, L.N. and Moroldoev, I.V., Variation of long-term cyclicity in the population dynamics of northern red-backed vole, *Myodes rutilus* Pallas, 1779, *Printsipy Ekol.,* 2017, no. 4, pp. 26–36.
24. Koltunov, E.V. and Erdakov, L.N., Specific features of cyclicity in the long-tern dynamics of reproduction outbreaks in different geographic populations of the Siberian silk moth (*Dendrolimus superans sibiricus* Tschetv.) vin Siberia, *Sovrem. Probl. Nauki Obraz.,* 2013, no. 6. http://www.science-education.ru/ru/article/view?id=11003.
25. Ivanter, E.V. and Makarov, A.M., *Territorial'naya ekologiya zemleroek-burozubok (Insectivora, Sorex)* (Territorial Ecology of Shrews (Insectivora, *Sorex*)), Petrozavodsk: Petrozavodsk. Gos. Univ., 2001.
26. Krylova, L.P., Akulova, L.I., and Dolgin, M.M., *Dozhdevye chervi (Oligochaeta, Lumbricidae) taezhnoi zony Respubliki Komi* (Earthworms (Oligochaeta, Lumbricidae) in the Taiga Zone of the Komi Republic), Syktyvkar: Komi Ped. Inst., 2011.
27. Smirnova, O.V., Bobrovskii, M.V., Khanina, L.G., and Smirnov, V.E., Biodiversity and successional status of dark conifer forests in the Shezhimopechorskii and Bol'sheporozhnyi regions of the Pechora–Ilych Nature Reserve, Tr. Pechoro-Ilych. Gos. Zap., Syktyvkar, 2007, no. 15, pp. 28–47.
28. Lidicker, W.Z., The landscape concept: Something old, something new, in *Landscape Approaches in Mammalian Ecology and Conservation,* Lidicker, W.Z., Ed., Minneapolis: Univ. of Minnesota Press, 1995, pp. 3–19.
29. Hanski, I., *Metapopulation Ecology,* Oxford: Oxford Univ. Press, 1999.
30. Ivanter, E.V., Korosov, A.V., and Yakimova, A.E., Ecological and statistical analysis of long-term changes in the abundance of small mammals at the northern limit of the range (northeastern Ladoga region), *Russ. J. Ecol.,* 2015, vol. 46, no. 1, pp. 89–95.
31. Hörnfeldt, B., Long-term decline in numbers of cyclic voles in boreal Sweden: Analysis and presentation of hypotheses, *Oikos,* 2004, vol. 107, no. 2, pp. 376–392.
32. Dalkvist, T., Sibly, R.M., and Topping, C.J., How predation and landscape fragmentation affect vole population dynamics, *PLoS One,* 2011, vol. 6, no. 7, e22834.

Translated by L. Emeliyanov

SPELL: 1. OK