International Journal of Environmental Protection and Policy
2019; 7(1): 32-38
http://www.sciencepublishinggroup.com/j/ijepp
doi: 10.11648/j.ijepp.20190701.15
ISSN: 2330-7528 (Print); ISSN: 2330-7536 (Online)

Methodology of Species Diversity Indicators and Terrestrial Vertebrate Numbers Assessment from the Example of the Zone Affected by the Planned Nizhnezeisk Water Reservoir

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To cite this article:
Sergey Podolsky, Vyacheslav Kastrikin, Mikhail Parilov, Klara Pavlova, Lilia Levik. Methodology of Species Diversity Indicators and Terrestrial Vertebrate Numbers Assessment from the Example of the Zone Affected by the Planned Nizhnezeisk Water Reservoir. *International Journal of Environmental Protection and Policy.* Vol. 7, No. 1, 2019, pp. 32-38. doi: 10.11648/j.ijepp.20190701.15

Received: October 17, 2018; **Accepted**: November 27, 2018; **Published**: April 2, 2019

Abstract: Comparative assessment of the importance of nature conservation in different shoreline areas has become a relevant task as the strategy of sparing management of natural resources is developed for areas impacted by existing and planned water reservoirs. Integral biodiversity indices that characterize species diversity along with abundance parameters for every animal species sighted were developed for the area that would be influenced by the Lower Zeya Hydropower System (currently at the planning stage). The present article includes lists of mammals, reptiles, and amphibians seen in the area, grading scales for the abundance of species and ecological groups of terrestrial vertebrates, a list of the main biotopes, zoning principles for the areas influenced by the reservoir, formulas for calculating the integral parameters of species diversity and ani-mal abundance, and schematic maps of the spatial distribution of the values of integral indices of richness and nature protection significance of the animal populations. Specific recommendations for strengthening the network of Special Protected Natural Areas are given. This study allows for the conclusion that construction of the Lower Zeya hydropower plant will be associated with a high risk of negative consequences for biodiversity and ecological stability on both the local and regional levels.

Keywords: Species Diversity, Animal Population, Nature Protection Significance, Special Protected Natural Areas, Lower Zeya Hydropower Plant

1. Introduction

Comparative assessment of the importance of nature conservation in different shoreline areas has become a relevant task as the strategy of sparing management of natural resources is developed for areas impacted by existing and planned water reservoirs. Integral biodiversity indices that characterize species diversity along with abundance parameters for every animal species sighted were developed for the area that would be influenced by the Lower Zeya Hydropower System (currently at the planning stage). The present article includes lists of mammals, reptiles, and amphibians seen in the area, grading scales for the abundance of species and ecological groups of terrestrial vertebrates, a list of the main biotopes, zoning principles for the areas influenced by the reservoir, formulas for calculating the integral parameters of species diversity and animal abundance, and schematic maps of the spatial distribution of the values of integral indices of richness and nature protection significance of the animal populations. Specific recommendations for strengthening the network of Special Protected Natural Areas are given. This study allows for the conclusion that construction of the Lower Zeya hydropower plant will be associated with a high risk of negative consequences for biodiversity and ecological stability on both the local and regional levels.

Hydropower production has become one of the leading factors of anthropogenic impact on the fauna of the Amur region, as the Zeya and Bureya hydroelectric power stations (HPS) operate in the area, the Lower Bureya HPS will soon start operating, and the Lower Zeya HPS is being designed. Comparative assessment of the significance of various shore areas for nature protection often becomes a relevant task during the development of a strategy for sparing use of natural resources in areas affected by existing and planned large water reservoirs. Integral indices that characterize the species diversity along with abundance parameters for every animal species in the area can serve as objective criteria. Such indices were developed for the zone that will be affected by the Lower Zeya hydropower system.

The authors are grateful to Sergey Yu. Ignatenko, Director of the Zeya Nature Reserve, and to the staff of the Zeya Nature Reserve for their invaluable assistance in organizing and conducting fieldwork. Financial support for the present study was received from the UNDP/GEF-MNR RF Project called "Organization and Implementation of Monitoring (Including Preproject Monitoring) of the State of Biodiversity in the Areas Affected by Planned, Constructed, and Operating Hydropower Facilities in the Amur Region" (contract no. 01/K/2015), and within the framework of the research topic "Development of Evaluation Indicators and Criteria for the Transformation of Terrestrial ecosystems by Changes in the Water Regime of the Territory Influenced by Natural and Anthropogenic Factors" of the Institute of Water Problems, Russian Academy of Sciences.

2. Method

Most of the area under consideration belongs to the basin of the Zeya River (middle reaches) within the Amur–Zeya Plain, and the southern part of the area belongs to the lower Zeya basin and borders on the Zeya–Bureya Plain. Information on the species composition, abundance, and spatial and biotope-associated distribution of mammals, amphibians, and rep-tiles in every season was obtained and analyzed in 2014–2016 [9]. Most of the methods used were conventional, such as winter route censuses (WRCs) [6], multiple-day monitoring at selected sites [12], census of the Red deer vocalizations [10], and small mammal censuses on snap trap lines [7]. Four multiple-day monitoring sites (total area of 55 km^2), 755 km of WRC routes, 12 sites for red deer vocalization censuses (total area of 118 km^2, 35 vocalizing males were registered), 48 trap lines, and 1710 trap-days for the registration of small mammals included in the study (140 small mammals of nine species were caught by the traps).

Data from long-term observations in areas affected by the Zeya and Bureya water reservoirs [3, 11] were used at the work planning stage and during analysis of the results.

3. Result

Fifty-seven mammalian species, six reptile species, and six amphibian species were identified in the terrestrial vertebrate fauna of the planned Lower Zeya hydropower system basin. The number of animal species exceeded those for the adjacent Zeya and Khingan nature reserves (54 and 55 species, respectively) [1, 3]. Eight animal species were identified in the zone of immediate influence of the planned hydropower system. These species were the Eurasian water shrew *Neomys fodiens* Pennant, 1771; the Ussuri white-toothed shrew *Crocidura lasiura* Dobson, 1890; the Amur hedgehog *Erinaceus amurensis* Schrenk, 1859; the Parti-coloured bat *Vespertilio murinus* Linnaeus, 1758; the Amur tiger *Pantera tigris* (Temminck, 1844); the Amur leopard cat *Felis bengalensis* ssp. Kerr, 1792; the Mountain weasel *Mustela altaica raddei* Ognev, 1930; the Steppe polecat *Mustela eversmanii amurensis* Ognev, 1930; and two reptile species included in the Red Book of the Amur region [4]: the Sakhalin viper *Vipera (Pelias) sachalinensis* Tsarevsky, 1917 and the Manchurian black water snake *Elaphe schrenckii* Strauch, 1873. The presence of the Amur lemming *Lemmus amurensis* Vinogradov, 1924 and the Slender shrew *Sorex gracillimus* Thomas, 1907 in the area is very likely. Very high species diversity and the significance of terrestrial vertebrate fauna for nature protection are due to the borderline zoogeographical location [2] and biotope diversity.

Isolation and spatial differentiation of the zone affected by the hydropower plant is a necessary condition for comparative assessment of the biodiversity parameters. The complex approach used involved the analysis of relief features, expected and observed phenomena, formation of "water–land" ecotones, and anthropogenic factors and the intensity of their impact [9].

Let us consider the criteria for subzone identification, the main features of the subzones, and expected phenomena.

I The flooding subzone includes the water surface of the planned water reservoir at the normal water level (NWL) and the drainage zone affected by water level regulation. The upper boundary of the subzone corresponds to the highest water level (HWL). Characteristic phenomena include massive death of small terrestrial animals during filling of the reservoir with water, degradation of the water head ecosystems and their conversion into lacustrine ecosystems, severance of connections between water ecosystems located upstream and downstream of the dam and between groups of terrestrial animals from opposite shores of the water reservoir, and massive death of Siberian roe deer (*Capreolus pygargus* Pallas, 1771) during seasonal migrations.

II The subzone of a significant effect on water reservoir shores (SSE) includes shore slopes facing the reservoir, adjacent watersheds, and small river valleys located at a distance of 1.5 to 5 km from the NWL line. The outer boundary of this subzone is drawn along the tops and ridges of the hills and hill chains closest to the reservoir. Characteristic features of this subzone include the presence of a coastal flooding area with fundamentally altered phytocenosises, intensification of erosion processes (landslides, avalanches, and mudslides), microclimatic influence of the water reservoir (increased air humidity and lower temperatures in spring and summer), intensive poaching, and a higher predator pressure. A considerable decrease in population sizes is expected for many species and ecological groups (mouse-like rodents, insectivores, weasels, ungulates, and small passerine birds) that inhabit the slopes near the water reservoir.

III The subzone of a moderate effect on water reservoir shores (SME) includes territories located within the catchment area of the water reservoir, but outside the SSE borders. It is recommended to draw the outer boundary of the subzone along the borders of the catchment area of the water reservoir, but the distance between this boundary and the NWL line should not exceed 20–30 km. This subzone is characterized by a certain increase in disturbance factor and poaching, increased frequency of forest fires caused by human activity, a temporary increase in the number of animals leaving the flood zone, and changes in the "predator–prey" systems.

IV The subzone of near-estuarine fragments of streams conventionally termed "living" valleys (SAV) includes floodplains and adjoining parts of the slopes in the near-estuarine parts of the valleys of large and medium-sized tributaries of the water reservoir. Eco-tone communities formed in the area are characterized by higher numbers and elevated migratory activity of many species of animals, including ungulates, predators, mouse-like rodents and rheophilic fish. Our observations in areas influenced by the Zeya and Bureya water reservoirs showed that the "living" valley segments were approximately 3 km long in the case of medium-sized tributaries and 10–20 km long in the case of large tributaries.

V The subzone influenced by nonfreezing ice clearing includes the riverbed, the valley, and the adjacent slopes in the area where the nonfreezing ice clearing is at its greatest. An increase in fog frequency, especially in the winter season, is characteristic of the area, along with death of terrestrial animals during attempts to cross the ice clearing or walk on thin ice along the clearing edges, and accumulation of many fish species during spawning and feeding migrations. The ecosystems of this subzone are exposed to the entirety of run-off regulation effects (common to the downstream area of the hydropower plant).

VI The subzone influenced by runoff regulation includes the riverbed and the river valley significantly affected by runoff regulation downstream of the non-freezing ice clearing boundary. This area is characterized by a decrease in flow during floods; changes in the area, duration, calendar time, and depth of flood-plain flooding; a decrease in the average groundwater level and the amplitude of its fluctuations; drainage of a part of floodplain lands; silting of floodplain lakes; decrease in fish capacity of floodplain water bodies, and a decrease in nesting success of birds that feed their young with small fish (cranes, storks, and others). The subzone configuration is refined during the monitoring process based on data on the decrease in flood frequency, duration, and height.

The main habitats were identified within each sub-zone in order to characterize the features of spatial and biotopic distribution of wild animals. Ecologically close habitats were grouped into 17 biotopes: (1) river beds and banks without a continuous vegetation cover or with pioneer near-water vegetation; (2) water areas and lake shores without a continuous vegetation cover or with pioneer near-water vegetation; (3) «urema» forests of poplar, alder, and bird cherry and riverside willow thickets; (4) multi-species valley forests with broad-leaved herbs; (5) waterlogged hummocky meadows with groups of willow trees and scattered dwarf birch thicket; (6) moist reed-sedge and sedge-reed meadows with mixed herbs; (7) upland meadows with graminoid plants and mixed herbs; (8) pine forests with scattered larch and small-leaved tree species; (9) light coniferous forests of larch and pine with scattered birch groves; (10) small-leaved forests with meadows and large-leaf herbs, sometimes with larch groves; (11) mixed nemoral forests with some contribution from black birch, Mongolian oak, and other deciduous species; (12) dry light forests on steep slopes with oak, black birch, white birch, and pine trees, xerophytes, and mixed herbs; (13) felling and forest fire sites undergoing regeneration; (14) fields and sown meadows; (15) wormwood fallows, sometimes with mixed herbs, and ruderal communities; (16) rural and urban inhabited areas; and (17) wastelands at quarry sites and gold mining ranges.

Information on the species composition of terrestrial vertebrates and the population size for each species was collected for each biotope (1)–(17) studied and each subzone (I–VI). Abundance scores were used to compare the biodiversity, because data on the abundance of various species and groups of terrestrial animals were essentially heterogeneous. A five-point scale "associated" with the quantitative results of censuses and differentiated for different taxonomic and ecological groups of terrestrial vertebrates of the study area was developed with both our data and published information taken into account (Tables 1, 2).

Table 1. *Graded abundance indices for the major ecological and taxonomic groups of mammals in the zone of influence of the projected Lower Zeya reservoir asinferred from abundance scores.*

Species and ecological groups	Animal number indices	Species abundance scores				
		1 point	2 points	3 points	4 points	5 points
		very rare species	rare species	common species	numerous species	mass species
Shrews	Individuals per 100 cone days (c–d)	<1	1–5	6–10	11–20	>20
	Individuals per 100 trap-days (t–d)	<0.5	0.6–2.0	2.1–6.0	6.1–10.0	>10.0
Bats	Sightings per 1 km	<1	1–5	6–10	11–15	>15
Wolf	Individuals per 100 km^2	<0.1	0.2–0.3	0.4–0.5	0.5–0.7	>0.7
Red fox	Individuals per 10 km^2	<0.1	0.2–0.5	0.6–1.0	1.1–2.0	>2.0
Raccoon dog	Presence	<0.1	0.2–0.5	0.6–1.0	1.1–2.0	>2.0
Badger	Presence	<0.1	0.2–0.5	0.6–1.0	1.1–2.0	>2.0
Wolverine	Individuals per 100 km^2	<0.05	0.05–0.1	0.2–0.3	0.4–0.5	>0.5
Sable	Individuals per 10 km^2	<0.5	0.6–1.5	1.6–3.0	3.1–6.0	>6.0
Siberian weasel	Individuals per 10 km^2	<0.5	0.6–1.5	1.6–3.0	3.1–6.0	>6.0
American mink	Individuals per 10 km shoreline	<0.5	0.5–1.5	1.6–3.0	3.1–6.0	>6.0
Greater weasel	Individuals per 10 km^2	<1.0	1.0–1.5	1.5–3.0	3.0–4.0	>4.0
Least weasel	Individuals per 10 km^2	<1.0	1.0–1.5	1.5–3.0	3.0–4.0	>4.0
Otter	Presence	+	–	–	–	–
Brown bear	Individuals per 100 km^2	<0.4	0.4–0.8	0.8–1.6	1.7–2.0	>2.0
Lynx	Individuals per 100 km^2	<0.05	0.05–0.1	0.2–0.3	0.4–0.5	>0.5
Amur tiger	Presence	+	–	–	–	–
Mouselike rodents	Individuals per 100 trap days	<1.0	1.1–2.0	2.1–7.0	7.1–15.0	>15.0
Musk beaver	Individuals per ha	<0.5	0.6–1.0	1.1–3.0	3.1–6.0	>6.0
Arctic ground squirrel	Presence	+	–	–	–	–
Chipmunk	Individuals per 100 trap days	<0.1	0.1–0.3	0.4–1.0	2.0–3.0	>3.0
Squirrel	Individuals per 10 km^2	<2.0	2.1–5.0	5.1–10.0	10.1–15.0	>15.0
Siberian flying squirrel	Individuals per 10 km^2	<0.5	0.6–1.0	1.1–4.0	4.0–6.0	>6.0
Arctic hare	Individuals per 10 km^2	<1.0	1.0–2.0	3.0–6.0	7.0–10.0	>10.0
Northern pika	Individuals per 100 trap days	<0.05	0.06–0.1	0.2–0.5	0.6–1.0	>1.0
Elk	Individuals per 10 km^2	<0.2	0.2–0.5	0.6–1.0	1.1–3.0	>3.0
Far Eastern red deer	Individuals per 10 km^2	<0.5	0.5–1.0	1.1–2.0	2.1–5.0	>5.0
Roe deer	Individuals per 10 km^2	<0.5	0.5–3.0	3.1–6.0	6.1–12.0	>12.0
Musk deer	Individuals per 10 km^2	<0.5	0.5–2.0	2.1–4.0	4.1–8.0	>8.0
Wild boar	Individuals per 10 km^2	<0.5	0.5–3.0	3.1–6.0	6.1–12.0	>12.0

Table 2. *Graded indices of amphibian and reptile population sizes derived from abundance scores.*

Species and ecological groups	Animal number indices	Species abundance scores				
		1 point	2 points	3 points	4 points	5 points
		very rare species	rare species	common species	numerous species	mass species
Siberian newt	Species per 1 hectare	<2.0	2.0–6.0	6.1–11.0	11.1–20.0	>20.0
North China and Siberian wood frogs	Species per 1 hectare	<5.0	5.0–10.0	10.1–20.0	20.1–50.0	>50.0
Japanese tree toad	Species per 1 hectare	<2.0	2.0–5.0	5.1–10.0	10.1–20.0	>20.0
Viviparous lizard	Species per 1 hectare	<1.0	1.0–2.0	2.1–5.0	5.1–10.0	>10.0
Central Asian viper	Species per 1 hectare	<0.1	0.1–0.5	0.6–1.0	1.1–2.0	>2.0
Sakhalin viper	Species per 1 hectare	<0.1	0.1–0.5	0.6–1.0	1.1–2.0	>2.0
Dione snake	Species per 1 hectare	<0.1	0.1–0.5	0.6–1.0	1.1–2.0	>2.0
Manchurian black water snake	Presence	+	–	–	–	–

The “index of animal population richness”:

$$I_r = NP_{max} + \Sigma P_i,$$

where N is the number of species detected within the biotope; P_{max} is the maximal score on the abundance scale (5 in the present study); and ΣP_i is the sum of score points for all species detected within the biotope, which was developed for the assessment of the generalized parameters of species diversity and animal complex abundance in various biotopes.

This index provides a balanced characteristic of species diversity and the abundance of each terrestrial vertebrate species for every biotope within a specific subzone affected by the water reservoir. More-over, the index can be used to compare animal populations of different territories within one region or several neighboring regions.

A gradation scale for animal population “richness” was developed for the index (I_r) values calculated. The points were assigned according to the following rule: *1* point for less than 80, *2* for 80–99, *3* for 100–119, *4* for 120–139, *5* for 140–159, *6* for 160–179, *7* for 180–199, *8* for 200–219, *9* for 220–239, *10* for 240–259, *11* for 260–279, *12* for 280–299, *13* for 300–319, *14* for 320–339, *15* for 340– 359, and *16* for 360 or more.

The I_r values expressed using the scale described above were mapped onto the contours of habitats (1)– (17). Thus, an analytical map of terrestrial vertebrate community “richness” was created (Figure 1).

The index of "relative richness of the animal population" I_{rr} can be used for a more precise identification of the most significant and vulnerable areas within the area affected by a specific hydropower system. The index is calculated as follows:

$$I_{rr} = (NP_{max} + \Sigma P_i)/(N_v P_{max} + \Sigma P_{iaa}) \times 100\%$$

where N_v is the number of species detected in the area affected by the hydro-power system; P_{max} is the maximal score on the abundance scale; and ΣP_{iaa} is the sum of averaged scores for the abundance of all species detected in the area affected by the hydropower system. The P_{aa} value for each species is calculated by dividing the sum of average abundance values in all subzones (I–VI) by the number of subzones (6 in the present study). The average abundance of the species in each subzone (P_a) is defined as the sum of the scores for all biotopes divided by the number of biotopes in which this species was found. The richness index for the animal community in a specific biotope (I_r) is the numerator, and the richness index for the animal community of the entire zone affected by the hydropower system (I_z) is in the denominator. Thus, the index of "relative richness of the animal population" (I_{rr}) represents the share (percentage) of the "richness" of a particular biotope in the overall "richness" of the animal population in the zone affected by the hydropower system.

4. Discussion

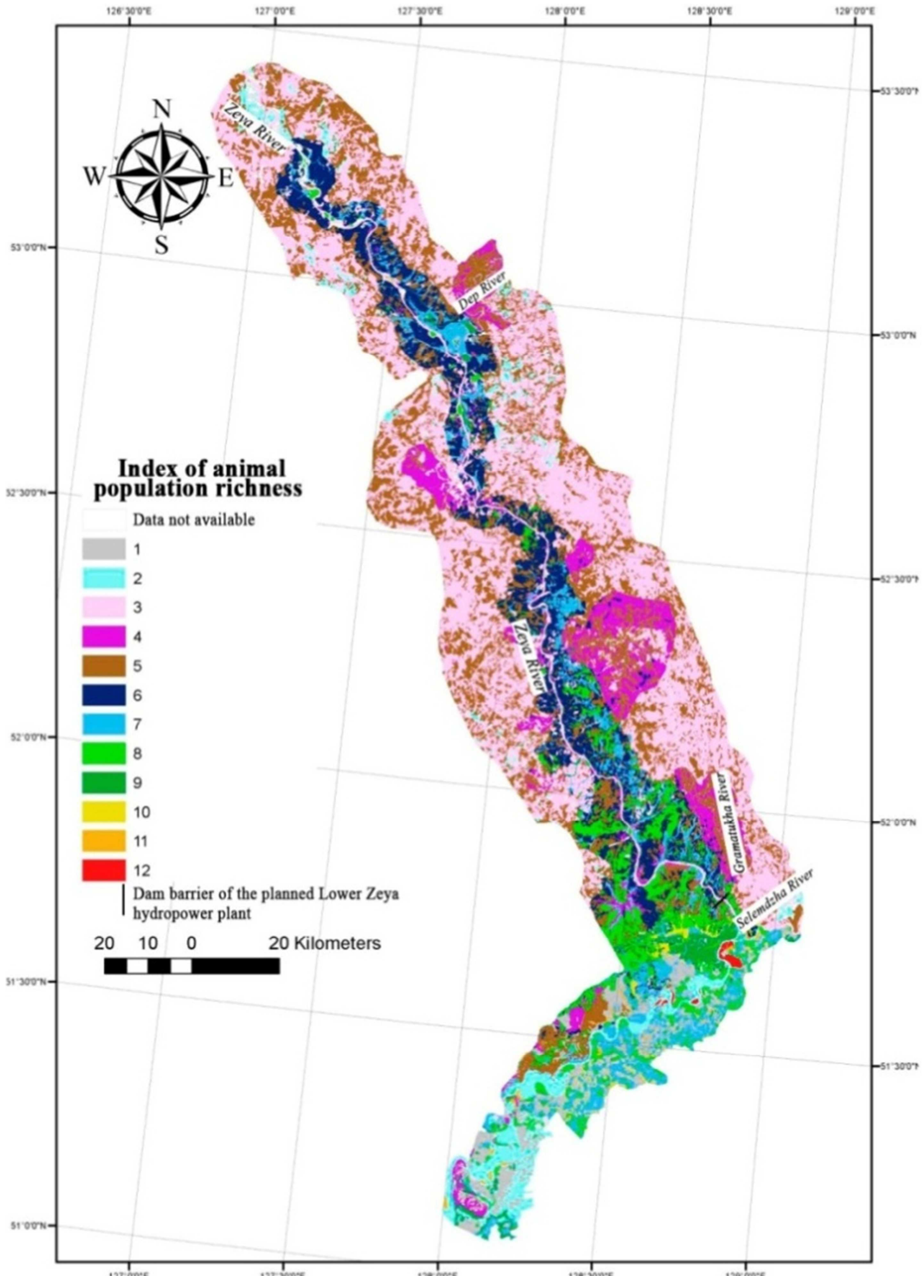

Figure 1. *Map of animal population "richness" in the zone influenced by the planned Lower Zeya hydrosystem.*

Analysis of the animal population "richness" map (Figure 1) revealed the major regularities of the spatial distribution of the integral biodiversity parameters: (1) biodiversity parameters increase gradually from north to south; (2) the Zeya River valley (including the estimated flooding area) is characterized by maximal "richness" of the animal community over the entire zone influenced by the hydropower system; (3) increased "richness" is most conspicuous in the Zeya River floodplain, Zeya valley slopes, and wetland areas near the estuaries of large (the Dep River) and medium-sized (the Tygda and Gramatukha rivers) tributaries of the Zeya; (4) biodiversity parameters in the zone affected by the headwater of the planned water reservoir decrease gradually upon an increase in the distance to the Zeya valley; (5) areas with maximal values of the indices are intermingled with strongly "depleted" areas transformed by human activity (farmland, wasteland, inhabited areas, and others) in the zone influenced by the planned tail pond of the hydropower system.

The use of the indices proposed in the present study enables visualization of highly generalized data from field studies of fauna and terrestrial vertebrate populations. The creation of such maps is of practical importance, as analysis of these maps enables unbiased identification of areas most valuable for nature protection and economy. This enables optimal planning of Special Protected Natural Area systems and the organization of sparing management of natural resources during hydrosystem construction. For instance, creation of the "Nizhnezeiskii" cluster national park in the area of the planned Lower Zeya hydrosystem was proposed. Areas with the highest val-ues of animal community "richness" (I_r), the estuarine zone of the Dep River and the area bordering on Gramatukha River valley and the Selemdzha River estuary, would be the major parts of the planned nature park.

5. Conclusion

The map of animal population "richness" showed that disturbances in the Zeya ecological corridor pose an extreme danger for the stability of natural complexes in the area. The floodplains and valleys of large rivers of the Amur basin form a system of major ecological corridors for interregional species exchange. A complex combination of intra- and extrazonal biotopes in the Zeya valley enables long-distance north-west migration of Manchurian species (the Japanese tree toad *Hyla japonica* Gunther, 1859;the North China wood frog *Rana dybowskii* Guenther, 1876;the Dione snake *Elaphe dione* Pallas, 1773;the Amur hedgehog *Erinaceus amurensis* Schrenk, 1859; the Ussuri shrew *Crocidura lasiura* Dobson, 1890;the Reed vole *Microtus fortis* Bucchner, 1889; the Korean field mouse *Apodemus peninsulae* Thomas, 1906; the Asian badger *Meles meles leucurus* Hodgson, 1847, the Raccoon dog *Nictereutes procyonoides* Gray, 1834; the Leopard cat *Felis bengalensis* ssp. Kerr, 1792; the Wild boar *Sus scrofa* Linnaeus, 1758, and others). Daurian–Mongolian species, such as the Mongolian toad *Bufo raddei* Strauch, 1876, the Maximowicz's vole *Microtus maximowiczii* Schrenk, 1858, the Striped dwarf hamster *Cricetulus barabensis* Pallas, 1773, the Arctic ground squirrel *Citellus undulatus* Pallas, 1778, the Mountain weasel *Mustela altaica raddei* Ognev, 1930, and the Steppe polecat *Mustela eversmanni amurensis* Ognev, 1930, use this corridor for migrations to the northwest from the major living ranges. The length of the Zeya ecological corridor was significantly reduced after construction of Zeya hydroelectric dam in 1974. The northward migration of most "southern" species became restricted to the southern foothills of Tukuringra and Soktakhan ridges after this. If the lower Zeya HPS is constructed, the ecological corridor under consideration will become almost 300 km shorter and end near the mouth of the Gramatukha River. Many terrestrial species (the Japanese tree toad, the North China wood frog, the Dione snake, the Arctic ground squirrel, the Mountain weasel, and the Steppe polecat) can then disappear from the fauna of the Lower Zeya water reservoir shores. Moreover, the Zeya River bed plays an important role in seasonal migrations of ungulates, waterfowl, and some fish species. Thousands of roe deer cross the Zeya in snowy winters. According to different estimates, water reservoir construction along the migration route would cause the death of 3000 to 10000 individuals at a time. The mass death of the Roe deer could be repeated many times. Spring migration of waterfowl will be disturbed due to a delay in ice melting at the artificial water body. Fish migrations through the dam barrier will stop.

Degradation of floodplain meadows and forests [5] and bayou lakes will occur in the tail pond due to runoff regulation and changes in the fluctuation pattern of the groundwater level. This will lead to a decrease in the population sizes for many species and groups of terrestrial animals. The threat to the nesting groups of the Oriental stork (*Ciconia boyciana* Swinhoe, 1873) and the Japanese (*Grus japonensis* Muller, 1776) and the White-naped (*Grus vipio* Pallas, 1811) cranes appears the most significant [8]. The map (Figure 1) shows that disruption of small sites with "rich" biota in the tail pond of the planned hydropower complex will be sufficient to initiate a sharp regional decline in biodiversity.

A complex of compensatory and protective measures can be used for a significant reduction of the intensity of some factors related to anthropogenic impact (poaching, fires caused by human activity, and others). However, effective compensation for the disruption of the trans-regional Zeya ecological corridor is impossible, and the same is true for disturbances in the seasonal migrations of roe deer and spawning migrations of fish and for degradation of floodplain ecosystems in the tail pond. Thus, the construction of the Lower Zeya hydropower plant is associated with a significant threat to biodiversity and environmental sustainability at the regional level.

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