



RESEARCH REPORT

on

Status and Development of Biodiversity and Landscapes in the Chernobyl Exclusion

Zone

2016

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Summary

This Research Report includes 50 pages, 5 tables.

The objects of research include biogeocenoses of the Chernobyl Exclusion Zone (ChEZ).

The research objective was to assess biodiversity in ChEZ.

Available literature data on the current state of natural ecosystems in ChEZ were analyzed. Data on the diversity of the flora and fauna species (natural zone and structure of vegetation, diversity of animal species, their special characteristics, including rare/endangered species) were summarized. Trends in the status changes of the basic biodiversity components were identified. Main adverse impact factors for key components of biodiversity were analyzed and their main causes were assessed: natural factors, anthropogenic factors, etc. Main trends in the development of ChEZ natural complexes were described, including the ones caused by chronic exposure effects in biota objects, forecasts for further evolution of the ecosystems under the conditions of radiation exposure was made.

Key words: Chernobyl Exclusion Zone, biodiversity, flora, fauna.

Реферат

Звіт про науково-дослідну роботу включає: 50 сторін., 5 таблиць.

Об'єкт дослідження - біогеоценози Чорнобильської зони відчуження (ЧЗВ).

Мета дослідження - оцінка біорізноманіття ЧЗВ.

Проведено аналіз наявних літературних даних щодо поточного стану природних екосистем ЧЗВ. Наведено дані щодо різноманіття видів флори і фауни (природна зона і структура рослинності, видове різноманіття тварин, в тому числі рідкісні / зникаючі види). Визначено тенденції зміни стану основних компонентів біорізноманіття. Проаналізовано основні фактори негативного впливу для найбільш важливих компонентів біорізноманіття. Відзначено основні тенденції розвитку природних комплексів ЧЗВ, включаючи ті, що обумовлені дією хронічного опромінення на об'єкти біоти, надано прогноз щодо подальшої еволюції екосистем ЧЗВ.

Ключові слова: Чорнобильська зона відчуження, біорізноманіття, флора, фауна.

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List of abbreviations

ChEZ	Chornobyl Exclusion Zone and Zone of Absolute (Obligatory) Resettlement
SSRI ChC	“Chornobyl Centre for Nuclear Safety, Radioactive waste and Radioecology”
PSRER	Paliessie State Radioecological Reserve
NRFU	Nature Reserve Fund of Ukraine
RBU	Red Book of Ukraine

Introduction

The accident at Chernobyl NPP, which happened in April 1986, was the most severe man-caused disaster in the history of mankind. The radioactivity discarded from the reactor has widely spread around the whole world, but the areas located 30-50 km around the plant were the most affected. The ecological systems, which have already experienced hundreds of years of anthropogenic transformation, were deprived of support and faced processes of natural disasters. Approximately 6,000 km² of Ukrainian, Belarusian and Russian lands have been depopulated within several weeks. In 1988, Paliessie State Radioecological Reserve (PSRER) was established on the territory of Belarus Republic adjacent to the ChNPP. PSRER area was 2,150 km², it was assigned the corresponding set of tasks and types of activities. The Exclusion Zone of Chernobyl NPP, also known as the Chernobyl Exclusion Zone (ChEZ), was established in Ukraine. Its total area is 2,600 km² (as of today).

Termination of economic activities and evacuation of people have started the process of reserve-genetic succession in former agrocenoses, reforestation of open landscapes, transformation of forest cultures, increase in a number and diversity of plant and animal species, changes in species composition of biocenoses. Today, some natural landscapes within ChEZ are of high natural value in terms of evolved ecosystems and animal & plant species living there; many species have high conservation status.

However, while fauna and flora in PSRER have been studied systematically and comprehensively, the studies within ChEZ were actively conducted only in the first years after the accident. It should be noted that despite of close attention of biologists to ChEZ, the vast majority of research dealt with the effects of radiation exposure and radiation contamination of biota, and only a few ones assessed its biodiversity and development features that were not related to radiation.

Despite a lack of targeted studies and of ChEZ natural complexes conservation, scientific experts admit their undoubted value in terms of biodiversity support and enrichment on a continental scale; and this value is steadily increasing over time. Its flora and fauna have reached the variety and abundance, which was absent there for centuries. Before the accident, 13 sites of natural reserve fund were established there, but they covered maximum 1% of the total area and had a low conservation status (wildlife refuges and nature sanctuaries). In 2007, a new zoological reserve of national level named "Chernobyl Special" was added by the Presidential Decree and the total area of protected areas was increased up to 20%. However, this site also has a status of a wildlife refuge

and a specific environmental organization has not been established. Nevertheless, both former national efforts and this new one demonstrate general understanding of value of this region as a wildlife reserve.

Moreover, natural systems within ChEZ were recognized to be the most appropriate, efficient and safe barrier to the spread of radioactivity. Supporting their stable condition ensures safety of the surrounding areas. Consequently, accumulation of data and conduction of comprehensive studies for the ChEZ biodiversity assessment are necessary and urgent.

1 Total natural geographic characteristics of ChEZ

According to natural and areal zoning, ChEZ is a part of the Kyiv subprovince of Ukrainian Polissia, mainly in the interstream area of the Rivers Pripyat and Uzh [1]. The total area of ChEZ is about 2,600 km². Local relief is characterized by general eastward steepness of the terrain; presence of morainic-frontal, morainic-hilly and frontal plains; prevailing altitudes of 115-140 meters above sea level and maximum elevations of up to 160 m in the north-western and central parts of the zone.

According to classification, the territory of ChEZ belongs to a zone of moderate continental climate with positive water balance [2]. Higher temperatures and relatively low relative humidity in summer and low temperatures, high humidity and presence of snow cover in winter are typical of this climate type. Therewith, the climate is forming as affected by both marine and continental airstreams. The summer usually settles in mid-May. July is the warmest month of the year, but one-third of cases include records of highest temperatures in June and August. Abundant rains and temperature drops are characteristic of the summer period and this is due to the passage of western cyclones.

The Pripyat River is one of the largest water bodies within the Chernobyl Exclusion Zone. This river crosses the Exclusion Zone from north to south-west and flows into the Kiev Reservoir on the border of 30-kilometer zone [3]. This river is flat, swampiness of its shores does not exceed 15%. Floodplain downstreams of the Pripyat and Uzh Rivers are wide, up to 5-7 km. The area is characterized by the presence of small rivers (Sakhan, Braginka, Iliia, Hrezlia, Veresnia, etc.) and borders on the Kyiv Reservoir in the south-east. The Chernobyl NPP cooling pond, a large artificial lake, is located in the very centre of ChEZ. Total area of its water surface is approximately 22 km². There is also a significant number of other, smaller lakes of glacial origin and several lakes of artificial origin within ChEZ. Dense population of the river basins has positive impact on their hydrological conditions.

In terms of parent rock materials, hydrology characteristics, soil and vegetation cover, geographers & landscapers distinguish seven landscapes within the territory of ChEZ: Chystogalivskiyi (168 km²), Korogodskiyi-Vilchanskyyi (546 km²), Radynskiyi (66 km²), Hdenskiyi (673 km²), Shepelychskiyi (247 km²), Uzhskiyi (342 km²), and Nyzhnopripyatskiyi (499 km²). [4, 5]. Approximately 40% (over 100,000 ha) of ChEZ territory are occupied by fallow lands that have formed on the abandoned areas: 39,000 ha of the fallow lands are located on the sites affected by reclamation systems and 62,000 ha are under the conditions of natural moistening [6].

Sod-podzolic soils, which occupy 36.4% of the ChEZ area, dominate in its soil cover [7]. Their formation is contributed by carbonate-free parent rocks, specific characteristics of climate, and predominance of forests in the vegetation. Sod-to-low podzolic and sod-to-medium podzolic soils are the most common among the sod-podzolic soils. The first ones are well developed mainly on river terraces, though are also found in outwash plains. The forming rocks of low podzolic soils include alluvial and fluvio-glacial deposits of sand and combined sand mechanical composition. Their high permeable characteristics cause quick transmission of precipitation that washes away nutrients; the soils are characterized by low fertility and are mostly occupied by pine forests.

The sod-to-medium podzolic soils cover approximately 12.7% of ChEZ territory, including mostly watersheds composed of loamy-glacial and water-glacial deposits. These soils are semi-structured, do not form solid massifs, have better water & physical properties and are more fertile than the low podzolic ones.

The sod-to-podzolic loamy soils are located in the ChEZ areas, where ground water level is close to the surface. They are mostly occupied by meadows; peaty horizon accumulates in some places of these soils and contributes to the formation of marshes (approximately 10%).

Marshy soils occupy 9.6% of ChEZ. They are mostly located in modern and relic river valleys, basins and also in watershed lowering areas [8].

Vegetation cover in ChEZ is formed of forests, meadows, marshes and fallow lands in the places of former farmlands and small population centres. [9]. Pine forests and mixed forests of pine and broadleaved trees dominate among the forests. The meadows are divided into uplands, lowlands and bottomlands. Lowlands dominate among marshes (grass, grass-moss, shrubs, and forest ones), but there are also transition (sphagnous) ones. According to the estimates [10], landscape areals with marshy organogenic soils occupy up to 22.5% of ChEZ territory. ChEZ territory is generally characterized by a significant variety of wetland types, which differ in terms of their location, relief, types of soil and primary vegetational cover.

Presence of abandoned population centres (up to 70) is a characteristic feature of ChEZ. Nowadays, limited population is present in only about 15 of them, including the town of Chernobyl and several villages in the south and west of ChEZ. Actually, all centres of population (villages, towns) are now

natural & territorial systems that are running wild, overgrowing with vegetation and giving housing for animals.

ChEZ is a specific limited-access area. One of its tasks is to prevent radioactivity removal beyond its boundaries. Therefore, not all natural systems are fully abandoned by people. They maintain operating conditions of some drainage canals (especially on the left bank of the Pripyat River), regulate groundwater level; flood control dams were built along the main channel of the Pripyat River. Firebreaks are being established along roads and forests. Foresters are working there. Some of population centres were subject to changes. In addition, some industrial enterprises continue their operational activities (ChNPP, storage facilities, burial grounds, etc.).

However, conservative conditions contributing to the recovery of local rich natural complexes have established in the most of ChEZ territory due to limited economic activity and almost complete absence of people.

2 The fauna of the Chernobyl Zone

The fauna of ChEZ is characterized by a significant variety and increased number of species. And this is primarily the result of practically conservative conditions that have established during all the post-accident years and under the absence of human impact.

According to the results of our research and based on literature data, approximately 411 species of vertebrates can be present within ChEZ; including 1 cyclostomes species, 66 fish species, 11 amphibian species, 7 reptile species, 253 bird species and 73 mammal species. Permanent or seasonal stay of 338 species has been already confirmed. Data in the book [11] were used to describe the ChEZ fauna and some additions were made basing on the research results over the last 10 years.

2.1 Class cyclostomes - *Cyclostomat*

The Ukrainian lamprey (*Lampetra mariae*) is the only species representing this class within ChEZ. One of the first its findings by researchers was in the Teterev River [12]. In 1959-1961 it was caught in the nearby rivers of Belarus [13], and in 1984 it was caught in the Uzh River near the village of Cherevach (16 units are now in the collection of the National Scientific and Natural History Museum of NAS of Ukraine, cat. No. 2360 [14]. After the Chernobyl accident, the Ukrainian lamprey was caught for the first time only in 1997 in the Teterev River (Orane village). And a year later its larva was caught in the Chernobyl cooling pond [15]. The author of this paper is reporting an overall local decline in the number of lamprey and is attributing this fact to hyper-radiosensitivity of the species.

2.2 Class bony fish - *Osteichthyes*

In terms of their group structure, bony fishes are among the largest groups of vertebrates common within ChEZ. According to the information available, this class may be represented by 59 fish species. Presence of 51 fish species in the circulating and enclosed water bodies of ChEZ has been confirmed.

Theoretically, all species living in the water bodies of the Dnieper River basin and in the northern part of the Kyiv Reservoir should be also present in ChEZ water bodies [15-18]. In addition, appearance of additional species that used to live only in the lower Dnieper should not be excluded (and particularly small species of Gobiidae family) [14].

Unfortunately, during the post-accident years an increased focus was on the problems of radioecology and radiobiology of some model species of ichthyofauna [19-25]. Therefore, there is a lack of data on small, limited or rare species. Also, there is practically no information on the fauna of closed natural water bodies and drainage canals, though there are large quantities of them and they may have their individual ichthyosystem.

The ChNPP cooling pond (CP) is a unique water body within ChEZ. Most of fish species came to the CP from the Pripyat River and its floodplain system during the construction of the water body, and some were brought into CP for aquaculture in 1983-1985 [26]. In the post-accident years, especially after the final shutdown of ChNPP, the hydrological, thermal and radiological parameters of the cooling pond, and its hydrobiological characteristics as well, have undergone significant changes. As a result of the effects caused by a set of factors (mostly temperature and chemical contamination), fish kill phenomena were repeatedly observed in the cooling pond, and they were accompanied by mass mortality of pike-perch, silver carp, channel catfish and other fish species. After the ChNPP shutdown, a process of reciprocal changes in the cooling pond's species and numerical structure has started.

The analysis of species composition in fish population based on the data of [15], occurrence of dominant species in the recent period, assessment of production characteristics of basic food objects, application of the research data from similar water bodies allowed to determine that current total fish biomass in the CP may range between 220 and 750 kg/ha. Thus, the assumed total CP fish stock is from 500 to 1,700 t [27]. Currently, the work towards the ChNPP cooling pond decommissioning and reduction of its water level shall result in a change of the most important biotic and abiotic factors of the water environment that provide necessary conditions for the existence of aquatic organisms, formation and functioning of their populations, communities, biocenoses and entire ecosystems.

The status of fish fauna in the Pripyat River, which is the largest river within ChEZ, much depends on status of ichthyocomplexes in the Kyiv Reservoir, where fishing has not been recently stopped and was not properly controlled. Possibly, a decline in the number and diversity of commercial fish species in the lower reaches of the Pripyat River and in the northern part of the Kyiv Reservoir is a result of uncontrolled fishing.

According to our research results and literature data [15], small rivers in ChEZ are still the hotbeds of rare (protected) species and demonstrate higher diversity of fish fauna due to a reduced anthropogenic pressure. Moreover, the upper reaches of the Kyiv Reservoir are traditionally rich in spawning and nursery grounds. Consequently, many water bodies in ChEZ have great value in terms of preservation and enrichment of their fauna and fish stocks, and therefore are potentially productive for the establishment of ichthyological reserves.

2.3 Red Book representatives of the local fish fauna

10 species can be included into this category from among the two classes described above. One species of cyclostomes class, i.e. the Ukrainian lamprey (endangered, Red Book of Ukraine 2009). And also nine species of the bony fish class.

Table 1. The fauna of "Red Book" fishes within ChEZ

Scientific name	RBU 2009 (conservation status)
<i>Acipenser ruthenus</i> L.	Endangered
<i>Leuciscus leuciscus</i> (L.)	Sensitive
<i>Eupallasella percnurus</i> (Pallas, 1814)	Endangered
<i>Barbus barbus borysthenticus</i> Dybowski	Endangered
<i>Alburnoides rossicus</i> (Berg)	Endangered
<i>Carassius carassius</i> (L.)	Sensitive
<i>Lota lota</i> (L.)	Sensitive
<i>Gymnocephalus acerinus</i> (Guld.)	Endangered
<i>Gymnocephalus baloni</i> Holcik&Hensel	Unvalued

2.4 The class Amphibians – Amphibia

Unfortunately, detailed studies of faunal structure, quantity and distributional pattern of this group in ChEZ were not carried out during the post-accident years. According to the data available, the amphibian fauna in ChEZ is represented by 12 species, some of them are abundant and common to this area. And there is practically no information on some species status. Our sampled observations and catching results gave contradicting results and should be supplemented [11].

The research results from the adjacent PSRER territory [28] revealed that the range of amphibians statial location noticeably expanded and sometimes their total number increased due to a significant

reduction of anthropogenic pressure and changes in biotopes that have occurred in the former cultural landscape. The green frogs, red-bellied toads and tinker frogs dominate among amphibians. The fauna of amphibians in ChEZ and in Paliessie Reserve are generally identical.

However, for instance, the composition of the green frogs population within ChEZ is completely unknown. The reason is that the edible frog *Rana esculenta* is not a common species, but is a polyhybrid complex of the pool frog *R. lessonae* and the lake frog *R. ridibunda*, which is characterized by its semiclinal propagation ability [29]. In numerous cases, they exist sympatrically and with various degrees of hybridization. Identification of the two species and of the hybrid has certain difficulties and is only possible with the use of the methods of genetic analysis or the less reliable method of complex morphometry [30]. However, studies of the adjacent territories (the Dnieper region) indicate that all the three forms may occur within ChEZ [29].

2.5 Class Reptiles – Reptilia

Reptiles in ChEZ are represented by 7 species [31].

The sand lizard (*Lacerta agilis*) is probably a dominant species among the reptiles, since it occurs on open areas almost everywhere. The two other common species, including the pond turtle (*Emys orbicularis*) and the grass snake (*Natrix natrix*), live near water bodies. The slow worm (*Anguis fragilis*) is not numerous and was found in different parts of ChEZ. The viviparous lizard (*Lacerta vivipara*) is probably common on moist deciduous forest sites. Population density of the viviparous lizard in PSRER amounts up to 5.1 animals/ha [28]. The common adder (*Vipera berus*) is not an abundant species in ChEZ. Our few findings of the adder were only in swamp forest stations and in floodplains of the Uzh and Pripyat Rivers. The smooth snake (*Coronella austriaca*) was found only in the floodplain of Uzh River and near an abandoned farm of Yakovetske Forestry.

The territory of adjacent PSRER is inhabited by the same reptile species as the ChEZ area. [28]. A characteristic feature of changes occurring in the populations of amphibians within PSRER is their territorial redistribution. For example, it is pointed out that the sand lizard started appearing in the habitats that are atypical for this species, i.e. humid regions, as a result of successive transformations and anthropogenic pressure reduction. The overgrowing of the sites suitable for eggs incubation led to territorial redistribution of the pond turtles [32]. Apparently, the same changes patterns in the abundance and territorial distribution of reptiles should be expected in ChEZ.

2.6 Red Book representatives of the local herpetofauna

From among the full list of species included into the RBU, only the smooth snake (sensitive category) lives in the Exclusion Zone. It was found twice in the Uzh River floodplain and once near an abandoned farm of Yakovetske Forestry.

2.7 Class Birds – Aves

Birds form the most numerous group of vertebrates in ChEZ. In theory, up to 254 species belonging to 18 orders can be observed there during nesting and seasonal migrations periods. To date, 201 species have been registered, including registration of 178 species during nesting season and 23 more in the period of seasonal migrations and wintering.

The current state of knowledge on ChEZ avifauna is quite low. Since 1986, the data on composition, presence and territorial distribution features of bird species in ChEZ have been presented in 20 scientific papers only [33-53]. A half of these papers has only mentioned ChEZ or its surroundings. Presence of some species has not been confirmed or was established without a sufficient confidence. Particularly this refers to the birds of wetlands and semi-aquatic systems [33, 54]. Furthermore, there are only rough ideas about the structure of birds fauna in old forest lands in the west of the zone [55]. Dominance of a large number of old and hollow trees among the forest stands should attract many rare species of the birds of prey and owls.

It is worth mentioning that this large area with a low level of disturbance enables a gradual spread of rare bird species within ChEZ, including the grouse, black stork, oystercatcher, white-tailed eagle, gray crane, etc. ChEZ can also refuge not only large and well-known birds, but also small ones though still interesting and rare. For example, the green woodpecker (*Picus viridis*), white-backed woodpecker (*Dendrocopos leucotos*) and penduline tit (*Remiz pendulinus*) have been disappearing throughout Ukraine in recent decades; population of the aquatic warbler (*Acrocephalus paludicola*) is also reducing [56-59]. ChEZ has all necessary conditions to support existence of these species.

The fauna of migratory and wintering birds has not been accounted yet. Only the most numerous of them are in the list of known species. Plus, many species are notable for their cautious and covert behaviour not only in the breeding season, but also in other seasons thus making it difficult to

account them. It should be noted that the local ornithocomplexes are still subject to gradual changes due to the successional transformations of habitats and long-term development of intraspecific processes and intraspecific interactions.

2.8 Red Book representatives of the local avifauna

Among the local vertebrate species, this is the most numerous group of species listed in RBU (2009). To date, 32 species belonging to 11 orders, 15 families and 26 genera have been observed in the territory of ChEZ. However, there is every reason to expect new findings, because a large part of the area is still almost unstudied. The local avifauna is valuable, because more than a half of its members are subject to protection according to the Berne Convention of 1979 [60]. In addition, over 210 bird species (including rare ones) cross ChEZ during their seasonal flights and nomadic migrations, since ChEZ is located at the crossroad of major migration routes along the Dnieper and Pripyat Rivers. All of them and their migration routes are subject to protection under the Bonn Convention of 1970 [61].

Table 2. Composition of the fauna of “Red Book” bird species in ChEZ

SPECIES	RBU 2009	Migrating
<i>Ciconia nigra L.</i>	4	MN
<i>Anser erythropus</i>	2	M
<i>Anas strepera L.</i>	3	MN
<i>Bucephala clangula (L.)</i>	3	MNW
<i>Pandion haliaetus (L.)</i>	1	M
<i>Milvus korschun (Gm.)</i>	2	M
<i>Circus cyaneus (L.)</i>	3	MN
<i>Circus macrourus (Gm.)</i>	1	M
<i>Circus pygargus (L.)</i>	2	MN
<i>Circaetus ferox (Gm.)</i>	3	MN
<i>Aquila clanga Pall.</i>	3	MN
<i>Aquila pomarina Ch.L.Brehm</i>	3	MN
<i>Aquila chrysaetos (L.)</i>	2	MNW
<i>Haliaeetus albicilla (L.)</i>	3	MNW
<i>Falco peregrinus Tunst.</i>	3	MNO
<i>Falco cherrug I.E.Gray</i>	2	MN

<i>Tetrastes bonasia (L.)</i>	2	NS
<i>Lyrurus tetrrix (L.)</i>	1	NS
<i>Grus grus (L.)</i>	3	MN
<i>Burchinus oediconemus (L.)</i>	4	MN
<i>Haematopus ostralegus L.</i>	2	MN
<i>Sterna albifrons Pall.</i>	3	MN
<i>Columba oenas L.</i>	2	MN
<i>Asio flammeus (Pontopp.)</i>	3	MN
<i>Bubo bubo (L.)</i>	3	NS
<i>Glaucidium passerinum L.</i>	2	NS
<i>Aegolius funereus (Linneus, 1758)</i>	3	NS
<i>Strix nebulosa Forst.</i>	3	MNS
<i>Coracias garrulus L.</i>	1	MN
<i>Dendrocopos leucotos (Bechst.)</i>	3	NS
<i>Lanius excubitor L.</i>	3	MN
<i>Aquila heliaca Savigny, 1809</i>	3	MO

* - RBU categories (2009): 1 – endangered, 2 – sensitive, 3 – rare, 4 – was not assessed. Attendance status: N – nesting, S – sedentary, M – appear in migration seasons, W – wintering, O – occasional.

2.9 Class of mammals - Mammalia

The mammalian fauna in ChEZ may be represented by 73 species. 59 of them have already been observed within ChEZ. The existence of 59 species has been proved to date. They belong to 7 orders, 19 families and 43 genera. They include 3 common species: the muskrat, the American mink and the racoon dog. They are adventitious and were introduced in different periods of the 20th century. 2 more species, including bison and Przewalski's horse, were brought there in the 1990s. And if the bison lived in this area in ancient times, the Przewalski's horse is considered to be a geographical vicariate and ecological analogue of the tarpan wild horse, which lived in the European forest area in ancient times [62, 63].

During the whole post-accident period, studies of mammals within ChEZ were extremely scarce. Only a few publications on small mammals are available among reputed papers on zoology [64, 65]; general papers on fauna [66-68]; and some hunting and rare animals [69-74]. Some information is available in research data on PSRER, which territory is neighbouring to ChEZ [28, 75-78] and in

the reports of the Institute of Zoology under the National Academy of Sciences of Ukraine [79] and of SSE "Ecocenter".

The past decade has added works on the assessment of mice species diversity [80, 81], a series of works on the assessment of species composition and spatial distribution of the chiropterans fauna [82-85], on application of new technologies for mammal biodiversity assessments [86]; the carnivores were also subject to studies [74, 87], as well as the ungulates [88-91].

Other publications, as a rule, were focused on radioecology or radiobiology issues of the most common mammal species.

A new strategy for ChEZ long-term management appeared in late 1990s. It was environmental rehabilitation built on versatile use of biological resources including conservation of valuable natural objects, obtaining products of forest and hunting ranges, intensification of radionuclides fixation processes in the landscape biological component. Accordingly, some studies were started to assess suitability of the area for game management and establish new objects of natural reserve fund there. "The program for the recovery of initial faunal assemblage and biodiversity of Ukrainian Polissia in the Exclusion Zone and Zone Of Absolute (Obligatory) Resettlement" ("The Fauna Program") was proposed; and its performance was partially started [92]. Implementation of the Fauna Program envisaged practical activities that have directly effects for the abundance and species composition of ChEZ animals, including limitation and regulation of the number of wolves, introduction of large herbivorous mammals ("tarpan-like horses", bison and "recovered" aurochs). However, reasonability and efficiency aspects of those activities were repeatedly discussed by scientists [93, 94]. The two initiatives have been actually implemented, including introduction of the Przewalski's horses and bison and shooting of wolves. In late 2000s, the Fauna Program was stopped. Though, the issue of estimating the macrofauna species abundance remains open and it is still urgent.

According to the data available, the order of duplicidentates (lat. Leporiformes) is represented by the brown hare (*Lepus europaeus*), which is a common species in ChEZ [66], and the alpine hare, which was recently found on two ChEZ sites only (the areas of Tovstyi Lis and Paryshiv village).

The most numerous group of mammals includes representatives of the rodents order (*Rodentia*), 18 species were observed in ChEZ [95].

Representation of the bats fauna may be the second after rodents (up to 17-19 species) within ChEZ. The most intensive studies began since 2007 under the support of the Ukrainian Ministry of Emergencies, Ministry of Ecology and Natural Resources, the Rufford Small Grants Foundation (56.02.10) and the Centre for Ecology & Hydrology under the UK Natural Environment Research Council (Project 5/LA/0589). Presence of 14 chiropterans species has been confirmed [82, 84]. Moreover, the greater noctule bat (*Nyctalus lasiopterus*) was registered in ChEZ. It is a rare species and nothing was known about it in Ukraine for 60 years already [83].

The order of carnivora (*Carnivora*) is represented by 13 species of four families: lynx, racoon dog, wolf, common fox, brown bear, stone-marten, pine marten, ermine, weasel, American mink, polecat, badger and otter. The weasel family is the most numerous (*Mustelidae*) and includes 8 species. Data on the presence of some species and their abundance became available only due to automatic cameras ("camera traps"), which are widely used by SSRI ChC during the last 4 years. Therefore, we got an opportunity to confirm presence of the brown bear (*Ursus arctos*) in ChEZ territory. With due regard for the alarming status of its Ukrainian population in the Carpathians [96], the appearance of this species in ChEZ is quite important and ChEZ could become a its new reproduction centre.

The order of odd-toed hoofed quadrupeds (*Perissodactyla*) is presented by the Przewalski's horse (*Equus przewalskii*). As mentioned above, this species is not a natural inhabitant of Polissia region. In 1998-1999, more than 30 horses were brought into ChEZ from Askania Nova Reserve and Lozovskyi Stud Farm and placed into an open-air cage near Chernobyl, 8 of them have died for a number of reasons in the first 5 months [71, 72]. In 1999 the horses were set free (10 males, 17 females). And according to SE "Chornobylis" data, their number has increased up to 31-32 animals in the autumn of 2000. There were 60 horses in early 2004, and only 40 animals in October 2007 [89]. However, according to our data for October 2012, the livestock included 60 recorded horses in ChEZ territory plus about 17 animals have left for Belarusian territory [97]. By 2016 the total number of horses was about 100 animals, but their recording is extremely difficult due to large percentage of forest lands and lack of regular observations.

The artiodactyls (*Artiodactyla*). The most part of local ungulates, including the wild boar (*Sus scrofa*), elk (*Alces alces*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), are characterized by their increased abundance in the post-accident years (even under the conditions of increasing population of wolves and other predators). However, there are still no accurate data on their population, only approximate estimates are available. Apparently, deer is the most numerous

and widespread species, its livestock is up to 1,500 or more. Abundance of elk is only a bit lower, it tends to moist biotopes. The roe deer predominantly lives in the hearts of forest lands and in reforestation areas; its abundance apparently does not exceed 1000 units. Recently, the wild boar used to be the most abundant species among the hoofed animals, totalling up to 2500-3000 animals. However by 2016, after the epidemic of African swine fever, it is experiencing an abundance depression (several hundred of animals at most).

Another species, the bison (*Bison bonasus*), has appeared in ChEZ only recently, and mostly due to humans. It was a common species in Polissia in the distant past, but people exterminated it hundreds of years ago [98, 99]. In 1998, two animals were brought into ChEZ together with the Przewalski’s horses, but both have died in an open-air cage already (one animal died at the beginning and another died after a couple of years). At the same time, 16 units of bison were also introduced into the neighbouring Belarus Reserve in 1996 [100]. By 2007 their number increased up to 54 animals; and it was up to 116 units according to 2016 accounting data, [100]. Naturally, there were expectations of visits of these animals into the Ukrainian part of the exclusion zone. In the spring of 2012, footprints of a bison were found for the first time near the village of Tovstyi Lis, although it is possible that it stayed there before. Later, camera traps helped to found out that it was the only adult male. There is very little information about it, though the animal was regularly recorded on the same site in different seasons. Natural conditions of ChEZ fully meet its needs, and future appearance of new animal units is possible [101].

The fauna of ChEZ is unique. However, its investigations are of shallow and unsystematic character. Only composition of the vertebrate species (not completely) was actually established. However, development of any practical activities (scientific, environmental, etc.) should be based on clear and accurate data on species composition, population dynamics, biotopical distribution, population structure and other parameters.

2.10 Rare species of local mammals

This group of the “Red Book” vertebrates living in ChEZ goes the second after birds (22 species). And these are mostly chiropterans (13 species).

Table 3. Species composition of the fauna of “Red Book” mammals

Species, Latin	RBU 2009
<i>Lepus timidus Linnaeus</i>	3

<i>Sicista betulina</i> (Pallas, 1779)	3
<i>Myotis mystacinus</i> (Kuhl, 1817)	2
<i>Myotis brandtii</i> (Eversmann, 1845)	3
<i>Myotis</i> (s.str.) <i>dasycneme</i> (Boie, 1825)	1
<i>Myotis</i> (s.str.) <i>daubentonii</i> (Kuhl, 1817)	2
<i>Plecotus auritus</i> (Linnaeus, 1758)	2
<i>Barbastella barbastellus</i> (Schreber, 1774)	1
<i>Nyctalus leisleri</i> (Kuhl, 1817)	3
<i>Nyctalus noctula</i> (Schreber, 1774)	2
<i>Nyctalus lasiopterus</i> (Schreber, 1780)	1
<i>Pipistrellus pygmaeus</i> (Leach, 1825)	4
<i>Pipistrellus kuhlii</i> (Kuhl, 1817)	2
<i>Vespertilio murinus</i> Linnaeus, 1758	2
<i>Eptesicus serotinus</i> (Schreber, 1774)	2
<i>Lynx lynx</i> Linnaeus	3
<i>Ursus arctos</i> Linnaeus	1
<i>Mustela erminea</i> Linnaeus	4
<i>Mustela putorius</i> Linnaeus	4
<i>Lutra lutra</i> (Linnaeus)	4
<i>Equus przewalskii</i> Poll., 1881	0
<i>Bison bonasus</i> (Linnaeus)	0

* RBU categories (2009): 1 – endangered, 2 – sensitive, 3 – rare, 4 – was not assessed, 0 - extinct in nature.

Besides, 38 species of mammals are in the European list of animals subject to special protection according to the Berne Convention of 1979 [60]. Some mammals (bats), as well as birds, are migrating animals and therefore they and their migration paths are subject to protection under the Bonn Convention of 1970 [61].

The data above may be an evidence of the uniqueness of ChEZ natural ecosystems. Nature in this area should be subject to continuous detailed investigations.

3 Plant biocenoses of the Chernobyl Zone

The scientific observations that are being conducted within ChEZ indicate the development of phytocenoses as the major factor that is changing the local profile and one of the most important factors that stabilize the radiation conditions. The composition and structure of phytocenoses has changed significantly in the course of the successions, which have followed the evacuation of people and cessation of agricultural and forestry activities. Plants play a key role in ecosystems while characterizing and defining the status and development prospects for the exclusion zone on the whole and its components. Plant communities are among the most important objects of research.

From the very beginning, the initiated processes of reserve-genetic succession used to be in the centre of scientific attention. Numerous forecasts regarding the further development of vegetative ground cover and natural territorial complex within the zone were developed in the first years after the accident [4, 102-105]. They have provided a huge amount of useful information that allowed development of treatment strategy for the exclusion zone. Over the last 30 years, many changes occurred both in radiation and in general ecological conditions, state approaches to the zone were also changed. The situation requires new assessments and development of yet other forecasts regarding the development of phytocenoses and natural territorial complex as a whole. However, in the last 15 years studies to this end has almost died.

3.1 Geobotanical description

According to the geobotanical zoning, ChEZ is located in Polissia subprovince of European broad-leaved woodlands of the forest zone. Most of ChEZ is a part of the Kyiv Polissia geobotanical district of oak and pine forests, and its part on the left bank of the Pripyat River is in the Polissia & Dnieper geobotanical district of pine and oak-pine forests and hornbeam oak-woods, eutrophic bogs and flood plains [106].

Major types of natural vegetation growing within ChEZ include forest, meadow-marshy vegetation and fallow soils vegetation on the sites of former farmlands and small villages.

Literature indicates [107] that natural flora of the South Polissia district in Polissia Subprovince is very poor in endemics. For the vast territory, authors recognize presence of approximately 20 endemic and sub-endemic species. The following among them could grow within ChEZ: *Dianthus pineticola*, *Silene lithuanica*, *Dianthus pseudosquarrosus*, *Jurinea pseudocyanoides*, *Tragopogon*

bjelorusicus, *Corispermum hyssopifolium* L. (*C. insulare* Klokov), *S. Marschallii* Stev. (*C. borysthenticum* Andrz.), *S. nitidum* Kit. (*C. hybridum* Bess. Ex Andrz.).

The territory of ChEZ includes the distribution borders of a number of species, mostly of the bog florocenocomplex (*Salix myrsinifolia*, *S. myrtilloides*, *Saxifraga hirculus*, *Betula humilis*, *Carex juncella* (Fr.) Th. Fr. (*C. wiluica* Meinsh.)), *Pedicularis sceptrum-carolinum*, and *Acer tataricum*, *Picea abies*).

During the post-accident period, the ChEZ flora was prevalently investigated by Balashov L.S., Bednaya S.M., Melankholin P.N., Petrov M.F. [55, 108-117]. All the papers listed above contain fragmentary floristic and geobotanical data of local studies dealing with the research of various aspects; i.e. some taxa, some flora fractions, vegetation types. However, inventory of floristic and geobotanical data has not been performed.

According to Petrov M.F., the flora of ChEZ currently includes 5 divisions, 128 families, 524 genera and 1228 species of vascular plants. And taxa of Angiosperms division (*Magnoliophyta*) absolutely dominate: 116 families (90.3%), 5053 genera (96.3%), 1197 species (97.5%) (Table 4) [6, 108, 114, 118]. The basic proportion of ChEZ flora corresponds to the proportions of most floras in the Holarctic midlatitudes.

Table 4. Taxonomic composition of ChEZ flora [6].

Division, class	Classis	Family	Genus	Species
<i>Lycopodiophyta</i>	1	2	4	5
<i>Equisetophyta</i>	1	1	1	6
<i>Polypodiophyta</i>	1	7	10	13
<i>Pinophyta</i>	1	2 (1)	4 (4)	7 (9)
<i>Magnoliophyta, в m.ч.:</i>	2	116 (10)	505 (76)	1197 (189)
<i>Liliopsida</i>	–	28 (2)	104 (16)	269 (36)
<i>Magnoliopsida</i>	–	88 (8)	401 (58)	928 (151)
Total	6	128 (11)	524 (80)	1228 (210)

The key families of ChEZ flora include *Asteraceae*, *Roaceae*, of *Rosaceae*, *Cureraceae*, the *Brassicaceae*, *Caryophyllaceae*, *Scrophulariaceae*, *Lamiaceae*, *Fabaceae*, *Ranunculaceae*. Generally, the range of flora families is represented as typical in forest zone (Table 5).

Table 5. The most abundant 11 families of ChEZ flora [6]

Familia	Genus	Species	Genus		Species	
			Quan-ty	%	Quan-ty	%
<i>Asteraceae Dumort</i>	60 (10)	153 (20)	60	11.1	153	12.6
<i>Poaceae Barnhart</i>	44 (5)	93 (10)	44	8.4	93	7.6
<i>Rosaceae Lindl</i>	23 (3)	71 (17)	23	4.5	71	6.0
<i>Cyperaceae Juss</i>	10 (1)	65 (1)	10	2.0	65	5.4
<i>Fabaceae Lindl</i>	16 (4)	56 (6)	16	3.1	56	4.6
<i>Caryophyllaceae Juss</i>	25 (2)	54 (4)	25	5.1	54	4.6
<i>Brassicaceae Burnett</i>	31 (2)	54 (7)	31	5.7	54	4.5
<i>Scrophulariaceae Juss</i>	14	49 (3)	14	2.7	49	4.1
<i>Lamiaceae Lindl</i>	23 (2)	44 (4)	23	4.6	44	3.6
<i>Apiaceae Lindl</i>	23 (2)	36 (2)	23	4.4	36	3.0
<i>Ranunculaceae Juss</i>	15 (3)	35 (5)	15	2.9	35	2.9
Total	285 (33)	710 (76)	285	54.4	710	58.4

Note: quantity of the taxa not covered by the statistical estimation is presented in brackets

Natural vegetation is dominated by forest areas, which are represented by typical vegetation in the region. The Scotch pine stands prevail among the structure of ChEZ forest species. Plantations of pine cover over 80% of the total forest area within ChEZ. Most of the pine stands are of artificial origin, these forest plantations were planted in 40-60s of the 20th century. The birch is a significant part of ChEZ forest structure. This species occupies over 23% of ChEZ forests. Oak plantations cover maximum 5%. The oak plantations are mostly the cultures of 50-60s of the 20th century. However, 100-150-year-old forests have survived on some sites, and in some places they are 200 years old; these include mostly oak, pine-oak or pine forests in the north-west, north and in some places of the southern and eastern parts of ChEZ. They were one of the reasons for establishing the sites of Ukrainian Nature Reserve Fund back in the pre-accident times [55]. Alder, aspen and hornbeam also grow within ChEZ.

This used to be entirely forest area (southern outskirts of Eurasian natural-geographic zone of forests). However, in the early 20th century total forest cover amounted to maximum 11-12% due to intensive deforestation [119]. In Soviet times, the forest area was increased up to 48 %. Resulting from the evacuation of people and stop of economic activity, changing processes in vegetation cover within the ChEZ territory were started due to cultivation of forest, natural forestation and

targeted afforestation activities in the areas, transformation of arable lands into fallows and meadow cenoses. To date, forests cover approximately 55% of ChEZ areas [120].

Pine forests develop on sod-to-low podzolic and medium-podzolic sandy and sandy-loam soils with varying degrees of moistening, as well as on peat-podzolic and peat soils. Their herb stratum is represented by the following association groups: lichenaceous (in some places), green moss (the largest areas), bilberry and green moss (commonly), sphagnum (rarely), brake fern (rarely in the southern part). The area is mainly occupied by pine cultures (*Pinus sylvestris*). Usually they do not have dense grass or are dominated by gramineous plants (bushgrass - *Calamagrostis epigeios* (L.) Roth). Pine-oak-hornbeam forests (sudubravas) develop on more fertile soils with grass-shrub layer that is typical of broad-leaved forests. Oak-hornbeam forests grow on sod-podzolic clayed soils or on gray podzolics and have well-developed undergrowth. Alder stands develop in damp and wet lowland areas with sod-podzolic-gley soils.

ChEZ meadows are divided into uplands, lowlands and floodplain meadows [121]. During the post-accident period, transformation of species composition in the ChEZ phytocenoses took place under the edaphic growing conditions and thus resulted in the formation of grassy groups with various plant species, which botanical composition is determined by their relation to soil trophicity and moisture. 240 species of plants belonging to 30 botanical families have been identified during the observations of fallow and meadow communities. Basic types of plant communities in the meadows and fallows include rough, mixed herbs & wheatgrass, wheatgrass, wet herbs & wheatgrass, sedge & wet herbs communities.

Floodplain meadows are extremely diverse in terms of composition of their plant species. This primarily depends on the topographic and environmental conditions of floodplains, which formation is related to natural conditions of river basins and directions of human activities. The herb stratum is represented by the formations of meadow fescue (*Festuca pratensis* Huds.), black bent (*Agrostis gigantea* Roth), browntop (*Agrostis tenuis* Sibth.), smooth meadow-grass (*Poa pratensis* L.), etc.

Upland (real, steppified and rough) meadows are formed on sod loamy and clayey-sandy soils with varying degrees of podsolization and are quite poor in minerals. They belong to the formations of meadow fescue (*Festuca pratensis* Huds.), couch grass (*Elitrigia repens* L.), yarrow (*Achillea millefolium* L.), browntop (*Agrostis tenuis* Sibth.). There are groupings of fowl bluegrass (*Poa palustris* L.) in lowland meadows (marshy and peaty ones), complemented by the plants of tufted hairgrass (*Deschampsia caespitosa* (L.) Beauv.), lesser pond-sedge (*Carex acutiformis* Ehrh.),

purple loosestrife (*Lythrum salicaria* L.), purple marshlocks (*Comarum palustre* L.), loosestrife *Lusimachia*, soft rush (*Juncus effusus* L.), bittersweet (*Solanum duclamara* L.).

After the termination of economic activities, large areas in ChEZ, former agricultural lands (their vegetation) have undergone significant changes. In the first years after the accident, the agricultural lands were overgrown with annual weeds. Over the next two-three years, annual weeds were displaced by rootstock weeds (two-year and perennial ones). Starting from 1994-1995, floristic composition of meadows and fallows has stabilized. The unforested lands in ChEZ are now covered with vegetation, which is dominated by couch grass, bush grass, etc. Over the past decade, the intensive processes of ChEZ meadows and fallows overgrowing with forest timber species are observed (forestation). They mostly includes natural seeding of birch and pine. Scientists believe that over 40% of the meadows are already covered with forest timber species due to the natural forestation processes. An extremely dense grass stand (90-100% coverage) has formed in the areas completely covered with couch grass. Their dense litter layer prevents rooting and growth of other plants, especially woody ones. Under such conditions, the forestation processes are extremely slow in the areas with predominating wheatgrass.

The change of marsh vegetation cover in the areas, where water conditions have remained constant, was governed by the natural development of wetland phytocenoses [122]. At the same time, regeneration of marshy vegetation was observed on the sites with secondary swamping, particularly overgrowth with grey willow (*Salix cinerea*) and moor birch (*Betula pubescens*). Species composition of marshes depended on their type and structure. ChEZ marshes are dominated by lowland ones (otherwise: eutrophic), approximately 80% (grassy, grassy-moss, shrub and forest). These marshes are found in topographic lows, in floodplains and on lakeshores; the inflow is mainly from groundwater, which is relatively rich in nutrients. The most developed formations include grassy, grassy-moss, forest swamps. The marshes have a highly diverse composition of plant species, and this is caused by their formation in forest zone (sedge and sedge-hypnum groups) and proximity to forest-steppe (wild grasses). Each type of marshes has its own set of associated tree species and lower-level plants.

The black alder (*Alnus glutinosa*) and moor birch (*Betula pubescens*) are common in ChEZ lowland marshes. The bushed layer is formed of willows, and the grey willow *Salix cinerea* is the most common dominant among them; *S. triandra* and *S. pentandra* are also found often. *Betula humilis* is a rare species of the marsh flora, though sometimes it can form thickets.

The herbaceous cover of eutrophic marshes is dominated by sedges. *Carex omskiana* and *C. appropinquata* are mostly characteristic dominants in marshes. The common dominants also include some rhizomatous sedges, including *Carex acuta*, *C. acutiformis* and *C. vesicaria*. While *C. diandra*, *S. pseudocyperus*, *C. riparia*, *C. nigra* are met rarer. The common reed (*Phragmites australis*) prevails among gramineals in low-land marshes, especially in the floodplain ones. The dominants among gramineals include *Glyceria maxima* and *G. fluitans*, *Calamagrostis canescens* and *C. stricta*. Common are *Eriophorum polystachyon* and *E. latifolium*, as well as horsetails (*Equisetum fluviatile* and *E. palustre*). The following species are numerous in low-land marshes: *Menyanthes trifoliata*, *Potentilla palustris*, *Calla palustris*, *Caltha palustris*, plus fenny tallgrass species: *Ranunculus lingua*, *Filipendula denudata*, *Iris pseudacorus*, *Peucedanum palustre*.

Transient (sphagnum) swamps are also found in ChEZ. The sphagnum swamps are formed in wet lowlands and are covered with a thick moss cover of Sphagnum genus (*Sphagnum*). The following trees dominate in mesotrophic marshes: *Betula pubescens* and *Betula pubescens*, *Pinus sylvestris*; small willows are among shrubs: *Salix rosmarinifolia*, (*S. lapponum* and *S. myrtilloides*) and dwarf birch. Suffrutescent species are abundant in forest marshes: *Vaccinium uliginosum* and *Ledum palustre*. And sparse trees are in the open marshes: *Oxycoccus palustris* and *Andromeda polipholia*. The typical dominants of grassy species in these marshes usually include *Carex lasiocarpa*, *Carex limosa*. The moss cover of mesotrophic marshes is formed of *Sphagnum fallax*, *S. centrale*, *S. palustre*, *S. obtusum*, and on oligo-mesotrophic sites it is formed of *Sphagnum flexuosum*, *S. angustifolium*.

Forestation of almost entire ChEZ territory, which is not covered by forest, may be forecasted for the next period.

3.2 Red Book species

60 species of higher vascular plants, which are listed in RBU 2009, were recorded in ChEZ territory. And 11 more vascular plant species were found in the adjacent areas and can grow in similar ecotopes of ChEZ. [6]. Also the following are subject to protection: 2 moss species; 2 observed species and 3 areally possible species of water grass; 2 observed species and 1 areally possible species of lichen; 1 observed species and 8 areally possible species of fungus.

54 more species, which are not included into the RBU and international agreements on species protection, are rare in ChEZ and, to some extent, in Kyiv and Ukrainian Polissia [6, 116, 123, 124].

Acer pseudoplatanus L., Acer tataricum L., Alnus incana (L.) Moench, Arctostaphylos uva-ursi (L.) Spreng., Calla palustris L., Carex hartmanii Cajand, Carex juncella (Fr.) Th.Fr., Carex lepidocarpa Tausch., Carex limosa L., Carex paniculata L., Carex pilulifera L., Centaurea stoebe L., Centaurea sumensis Kalen., Cerasus fruticosa (Pall.) Woronow, Chamaecytisus lindemannii (V. Krecz.) Klaskova, Circaea alpina L., Cystopteris fragilis (L.) Bernh., Dianthus pseudosquarrosus (Novak) Klokov, Drosera rotundifolia L., Eriophorum angustifolium Honck., Eriophorum vaginatum L., Fragaria viridis Duchesne, Galatella linosyris (L.) Rchb. f., Gymnocarpium dryopteris (L.) Newman, Hierochloë australis (Schrad.) Roem. & Schult., Hierochloë repens (Host) P.Beauv., Juncus filiformis L., Juniperus communis L., Koeleria grandis Besser ex Gorski, Lemna gibba L., Myriophyllum alterniflorum DC., Ophioglossum vulgatum L., Oxycoccus palustris Pers., Paris quadrifolia L., Parnassia palustris L., Peucedanum lubimenkoanum Kotov, Phleum phleoides (L.) H. Karst., Phlomis tuberosa L., Phyteuma spicatum L., Picea abies H.Karst., Potentilla heptaphylla L., Ptarmica vulgaris Blackw. ex DC., Pyrola chlorantha Sw., Ribes spicatum Robson, Salix myrsinifolia Salisb., Scolochloa festucacea (Willd.) Link, Senecio erucifolius L., Senecio paludosus L., Sparganium minimum Wallr., Teucrium scordium L., Tilia platyphyllos Scop., Triglochin palustre L., Viola riviniana Rchb., Viola stagnina Kit. (=V. persicifolia Schreb. [125]).

Similarly to the ChEZ fauna, further detailed investigations in different sites of the zone are required to prove the presence of rare flora species.

4 ChEZ sites with the highest biodiversity index

Extensive forestry and agricultural activities have been performed in this area for centuries. In 1986, the lands were left not in their best condition and therefore they sometimes failed to meet the needs of many species. Both species composition and abundance is the richest in the places of abandoned population centres, in wet lowland meadows, on the lands adjacent to water bodies, and in middle-aged and old mixed and deciduous forests, on open woodlands and edges.

A significant amount of data on biological diversity and conservation value of ChEZ resulted in raising an issue of establishing a reserve, as a promising option for the future management of the excluded territories. The present knowledge, for instance on the fauna of ChEZ, are limited to the data on the diversity of its species. At the same time, we do not know statuses of certain species populations, their habitats, and factors predetermining their sustainable existence. Accordingly, it is difficult to identify activities (their scope) that should be implemented in the biosphere reserve, support conservation of biodiversity in the natural systems and reduce their vulnerability. Therefore, relevant knowledge on the conditions of local natural complexes is required to take managerial (reforming) decisions for these areas.

Due to a large area of ChEZ, conduction of research on its entire territory is quite difficult. Therefore, the priorities should be identified for the research areas. Although such selection would be not entirely correct, because preferences of certain representatives of ChEZ fauna may differ from our opinion, and the entire territory of ChEZ is unique. Nevertheless, the first detailed investigations should be conducted on the sites with a high index of biodiversity to further define their land-use conditions and conservation category.

The sites that have a high index of biodiversity and need introduction of reserve status should territorially include the entire northwest region of ChEZ. For example, the following areas are of great interest.

"Tovstyi Lis", 7,900 ha (was surveyed by SSRI ChC in 2012). This site has a large percentage of forests, which are located on damp and wet soils. Moreover, relatively more forests are growing on relatively rich or fertile soils of the "Tovstyi Lis" site. Forested areas of this site are characterized by a high percentage of old trees if compared to ChEZ on the whole (oak, hornbeam, pine, aspen) and they serve as a refuge for hollow-nesting birds and bats. Such a high percentage of older stands is of great environmental value, because it indicates that the area was not significantly affected by

forestry operations and retained features of the former ecosystems. Plus, old trees are carriers of the gene bank resistant to pests, tree infecting agents and man-caused environmental pollutants, and that is why they should be preserved. This site also includes wetlands, meadows and fallows (17% of the area). Marshlands of the Tovstyi Lis site have some rare species of marsh phytocomplex: *Salix myrsinifolia* and *S. myrtilloides*, *Saxifraga hirculus*, *Betula humilis*, *Carex juncella*, etc. The route recordings of birds on the site provided counting of 58 species. 4 species are rarely found in other ChEZ areas. 31 mammal species were found, including 7 chiropteran species. In addition to bats, the rare species include wolf, lynx, bear and Przewalski's horse. 8 habitats of plant species that have a conservation category under RBU were found during the studies on the "Tovstyi Lis" site. The discovered "Red Book" species of animals are represented by 9 bird species and 11 mammal species.

"Horodyshe", 5,115 ha (2013). The research results showed that the "Horodyshe" site is a typical natural and territorial complex of Kyiv Polissia, but at the same time it is rich in rare or unique landscapes, composition of flora and fauna. Generally, it is characterized by a several times larger (compared to ChEZ as a whole) area of forest lands, which are located on relatively rich and fertile soils with significant moistening level: its sudubravas and oak forests occupy approximately 38.5% of the territory (18% in the zone). Among valuable features of the "Horodyshe" site is also a high percentage of lands with high or normal water supply: they cover 20.8% of the total area of forest lands (8.5% in the zone). There is a large quantity of wetlands there (11.3% of the territory), particularly lowland sedge and reed ones. Jointly with wet or marshy forests, they have a salutary effect on preservation and dissemination of rare plants. 5 "Red Book" species of plants (club moss, floating watermoss, lesser butterfly orchid, broad-leaved helleborine, Siberian iris) were observed there; and findings of 10-15 more are quite probable. The old oak and hornbeam stands help to maintain a high faunal diversity of both the species that feed on wood and leaves of these species (insects, ungulates), and the species that inhabit hollows and crevices (birds, bats, weasels). A significant area of young forests of vegetative origin (birch, alder, hornbeam forests) form an important forage for ungulates thus also attracting rare wild animals (lynx). Inhabitation of 34 mammal species was observed on the "Horodyshe" site (and 10 more very probable). Relatively high abundance of the "Red Book" lynx and presence of such "Red Book" species as the otter, forest polecat, European barbastelle should be emphasized. The areas including many old hollow trees (oak, hornbeam, aspen) have the greatest value in terms of environmental protection, they are essential for supporting biological needs of the chiropterans (all "Red Book" species). Totally, 14 "Red Book" species of mammals were registered on the "Horodyshe" site. Its bird fauna is also of a high conservation value. During the nesting season of 2013, 90 species were registered on the

"Horodyshche" site, including 9 "Red Book" species (black stork, white-tailed eagle, lesser spotted eagle, Montagu's harrier, black grouse, hazel grouse, gray crane, white-backed woodpecker, northern grey shrike).

"Buda-Rechytsa" meadows, 5,870 ha (2014). The landscape is generally dominated by edaphotopes of fresh and moist subors. Currently, they are mostly covered by fallows on the places of plowed areas of the pre-accident period. Here are the southern boundaries of the distribution of some locally rare species, mostly of marsh phytocomplex: *Salix myrsinifolia* and *S. myrtilloides*, *Saxifraga hirculus*, *Betula humilis*, etc. The "Red Book" species of *Dactylorhiza incarnata* and *Iris sibirica* L. grow in the wet meadows. The vertebrate fauna is typical of Polissia. To date, 30 mammal species inhabiting the site were recorded (and 10 more are very probable). 12 "Red Book" species of mammals were found on this site (lynx, otter, bear, Przewalski's horse and 8 chiropteran species). In the nesting season of 2014, 77 bird species, including 9 "Red Book" ones, were registered on the site of "Buda-Rechytsa" meadows.

"Novoselki" site is of great value, 7,900 ha (2012), it is in the south of the exclusion zone, a characteristic feature of this site is high percentage of forests located on relatively rich and fertile soils. They cover 43% of the site total area. There is a high percentage of black alder *Alnus glutinosa*, ash common *Fraxinus excelsior* and green *F. lanceolata*, as well as hornbeam *Carpinus betulus* L. There are many old trees. There are 33 marshes on this site; their total area is 368 hectares. 92 bird species, 8 chiropteran species and 22 more species of mammals (a total of 30) have been found there. Habitats of 5 plant species, which have a protection category under RBU, have been found during the "Novoselki" site survey. "Red Book" birds, which were registered during their nesting period on the "Novoselki" site, are represented by 10 species. "Red Book" mammals are represented by 12 species, mostly chiropterans, as well as the Przewalski's horse, otter and forest polecat.

"Medyn Lis" stow, which is in the north of the zone, is also of great value (2011).

The comprehensive assessment of conservation value of these sites was carried out by SSRI ChC in 2011-2015 and continues today.

The south-eastern areas of ChEZ should also be highlighted, since they are locating a wildlife sanctuary of national level named "Chernobyl Special". And this territory has not been surveyed thus far. Attention also should be paid to a wildlife sanctuary of national importance named

"Ilinetskyi" and located to the east of Vilcha. During local researches of bats in 2007-2013, many other rare animals and plants have been found on its territory (orchids, smooth snakes, spotted eagles, eagle owl, gray crane, black stork, lynx, etc.).

The following should be done and complied for each site:

- 1) General description of radioecological conditions,
- 2) General description of landscape and soil conditions,
- 3) Description of plant systems,
- 4) Description of vertebrate fauna,
- 5) Search for "Red Book" species of plants and animals, other valuable natural objects, assess role of test areas in their lives,
- 6) Assessment of biological diversity indicators on test areas,
- 7) Assessment of the relative level of anthropogenic transformation of local systems and the level of current human impact,
- 8) Summary assessment of the need in establishing a conservation category on test areas and identification of relevant territorial boundaries.

Along with general radioecological description and cartographic layouts, these data shall constitute a passport of a certain site. And in case appropriate decisions are in place, the passport shall be used for the implementation of environmental protection activities.

To maintain favourable trends in preservation and development of plant and animal populations, the economic activities existing within ChEZ should be improved and ChEZ conservation status should be upgraded, i.e. it should be allocated for an absolute reserve of national importance.

5 General trends of biocenoses development in the post-accident period

5.1 Assessment of main adverse impact factors for key components of biodiversity

ChEZ natural ecosystems are impacted by a number of adverse factors of both natural and anthropogenic origin. This causes transformation of natural systems and changes in species composition and of animal & plant community structure.

Naturally occurring factors

The state of natural ecosystems in ChEZ is mainly affected by seasonal variations in temperature and humidity. Dry years, very cold winters, increased rainfall cause fluctuations of abundance in animal and plant populations, reductions in the productivity of vegetation, changes in forage reserve for animals. The amount of literature data on the impact of weather conditions on plant ontogenesis, arrested development on certain ontogenetic stages or transition to a latent state is currently increasing. [126, 127]. There are quite a number of examples of disappearance of certain plant species due to weather patterns, and later recovery of them in favourable years. [128].

Factors of anthropogenic origin

The most significant adverse changes in the biological diversity have occurred and are still occurring in ChEZ due to anthropogenic impact, both the indirect one related to liquidation or changing of habitats, and direct effects dealing with its operation and elimination.

In the post-accident period, such factors include measures dealing with the accident consequences elimination, which resulted in chemical contamination of the environment with non-radioactive substances used for decontamination. Disturbance of natural environment was noted during the burial, coverage of highly contaminated large areas with sand. Abandoned buildings, utility lines and machinery have been left in the territory of ChEZ. There are man-made landfill sites, which remained after the accident and are still being formed. These factors also cause deterioration in natural state of the environment and its pollution by chemicals. Since one of the ChEZ tasks is to prevent export of radioactivity, not all natural objects and natural-territorial complexes stay unaffected by humans. Operating condition of some main drainage canals is being maintained; groundwater level in the central areas of ChEZ is being adjusted; large protection flood-control dams were built along the Pripyat River main channel. Disturbance of hydrological conditions in natural areas is taking place due to hydro-amelioratory and flood protection activities. Amelioratory

fire protection strips are being regularly arranged along the roads and forest edges. Ploughing of lands reduces the amount of natural habitats for many plant and animal species, which inhabit open natural spaces; and this finally results in a reduction in their abundance, spread zones and fragmentation of habitats. In addition, some industrial enterprises are still in operation (ChNPP, storage facilities, burial grounds, etc.) and some facilities are under construction.

A significant threat to biodiversity is caused by fires. Forest fires, which are mainly caused by human careless handling of fire, result in drastic changes of habitats and loss of many biodiversity elements due to the direct destruction of plants and animals [129]. Remnants of forest floor decompose quickly and thus result in formation of an unstable soil horizon consisting of burned plant remnants, dead residues of trees. For example, from 2 to 10 fires (fire outbreaks) in forests and from 30 to 100 fires in fallows were observed within ChEZ in 90s of the last century [130]. Under the conditions of groundwater level lowering, burnoff of peat upper layers in marshes causes not only fundamental changes of vegetation, sharp deterioration in living conditions for many animal species, including rare ones, but also significant emissions of greenhouse gases into the atmosphere. Furthermore, fires in forests and fallow lands of ChEZ constitute a significant radioecological danger. Burnout of the major radioactivity accumulator, i.e. forest floor, causes transport of radioactive aerosols, soot and black over long distances.

Current deforestation of ChEZ and presence of forest pests provide an adverse impact on its forest ecosystems [120]. Legacy of past human activities, i.e. establishment of tree monoculture, is among the reasons of pests appearance and forest diseases. Depletion of gene pool of forest-forming species, simplification of their plant and animal species composition and reduction of its resistance to diseases & pests are observed in monodominant forest plantations, and the aftermath is observed forest mortality.

Among the factors of severe impact on ChEZ fauna is poaching (hunting and fishing). Illegal tourism within ChEZ also provides adverse effects. Uncontrolled streams of people cause destruction of natural habitats and produce negative impact on the populations of sensitive animal species because of trampling and on animals because of the effects of disturbance factor.

Introduction of invasive species is among the adverse impact factors in ChEZ biocenoses. In some cases, the impact of competitive relationship between invasive (alien) and native species poses a very tough natural burden on the biodiversity. Human intervention and appearance of invasive or introduced species violates the evolutionary-formed separation between ecological niches of native

species, as well as population control mechanisms, which can result in a decreased number of some species.

5.2 Chronic exposure effects in biota objects, forecast of future evolution of ecosystems under the conditions of a radiation factor impact

After the Chernobyl accident, the radioactive effects in biota were changing over time and they can be conventionally divided into two stages. The first one includes acute exposure, which followed radioactivity release from the destroyed reactor. It has caused numerous acute radiobiological effects in biota in the areas of the highest-level exposure (i.e. up to a distance of several dozens of kilometres from the point of release). No acute radiation-induced effects in biota outside ChEZ were reported. The environmental response to the Chernobyl accident included a complex interaction of such factors as absorbed dose, dose rate and its time and spatial variations, as well as radiosensitivity of different taxa. In plants and animals both individual and group effects were observed. The following were observed then: a) increased dying of coniferous plants, invertebrates and mammals living in soil [131] b) reproductive losses in plants and animals [132] c) chronic radiation syndrome in animals (mammals, birds, etc.) [133]. These effects were of temporary nature and were recorded within a limited area, and then normal status of biota started its gradual recovery, as radiation contamination decreased.

The second period of radiation impact included long-term radiation effects in organisms under the conditions of stabilizing radiation situation, reducing exposure level, immobilization of radioactivity by ecosystem components, and development of biological adaptation mechanisms. Correspondingly, biological effects after these impacts were different. [134, 135]. By the beginning of the next vegetative season following the accident, population viability of plants and animals has recovered to a great extent due to the combined effect of their reproduction and migration. Several years have passed prior to the extinction of major radiation-induced adverse effects in the plants and animals. Genetic radiation effects in both somatic and germ cells were observed in the plants and animals of ChEZ during the first few years after the accident [136, 137]. But adverse effects of radiation are opposed by powerful system of recovery processes, reliability system in certain organisms and entire biocenoses, which has ensured stability of a biocenosis.

Currently, ChEZ provides a unique opportunity for investigating long-term and short-term effects of radiation contamination of the environment and evolution of the contamination onto all biota samples existing within ChEZ.

Status of ChEZ biocenoses was significantly impacted by secondary ecological effects, i.e. termination of economic activities and resettlement of people from population centres. Commercial management of forests and recreational pressures on natural lands were stopped. Exceptionally favourable conditions for ruderal-wild plants and wild animals have formed after the elimination of their main competitor, i.e. humans with their cultivated plants and domestic animals. The situation can be described as a decompression of ecological niches: many niches became vacant. And according to the principle of their "inescapable filling", they were filled with wild forms. According to Yemelianov I.G. [138], this qualitative and quantitative reduction of anthropogenic pressure should naturally cause an increase in species diversity. This follows the principle of "alternative diversity": its decrease in certain ecosystem units results in increase in the other ones. In our case, there was a reduction of diversity in anthropogenic unit, and the increase in wildlife biodiversity has come to replace it.

Along with the biodiversity increase, a sharp decrease in the number of so-called synanthropic animal species and gradual disappearance of synanthropic flora plants were occurring. However, an increase in biological diversity was observed due to amplification of those species, which normal development was previously interfered with human activities, hunting and disturbance.

Recovery of natural vegetation through corresponding change phases in vegetation types started on the former arable lands. This led to a gradual recovery of the forest formation. And basing on these changes in the vegetation, which forms forage for the herbivores, a new composition of fauna species is being formed.

Quick and sizeable increase in a number of wild animals was due to some favourable circumstances. Firstly, availability of food resources (abandoned grain stores, fields, orchards, forest plantations) under the conditions of a lack of predators and absence of people. Another reason for the rapid increase in a number of animals was their naturally high reproductive potential. And finally, ChEZ is located near the long-standing reserves of wildlife, i.e. forest and marsh areas of Pripjat Polissia including Belarusian and Ukrainian natural reserves plus Dnieper-Teterev hunting reserve in the south. A certain migration of animals from these regions into the attractive lands of ChEZ could have occurred. The Dnieper system of large water reservoirs has a similar role in the ChEZ fauna enrichment. Over the past three decades, this system "delivers" a lot of fish and bird species to the lower reaches of Pripjat. In addition, some species of migratory birds and bats could also opt for the attractive conditions of ChEZ during their regular seasonal migrations.

Development characteristics of zoocenoses in ChEZ were determined by the presence of ecotypes, which are not normally associated with natural ecosystems; namely the ecotypes, which emerged in the places of abandoned centres of population (both of rural and urban type) and agricultural landscape. Over the whole post-accident period, gradual destruction of buildings, structures, communications has been occurring in the natural territorial complexes (NTC). And it was accompanied by intensive transformation of soil-plant systems in the former gardens, flower beds, orchards and parks. Those changes of NTC become very attractive to animals [45, 139]. There were rich food resources and safe conditions, places for nests and lairs. Nowadays, practically all vertebrate species live or often stay in the population centres (and especially in those, where people are absent completely), and there are appropriate conditions for them.

The current state of ChEZ biocenoses, including presence of large sites with monoculture young pine plantations, continued reforestation processes on many open areas, succession of burned areas and forests underflooding sites, long-term degradation processes of former industrial and intended-for-building NTC, etc., suggests further gradual development of its natural systems. In future, territorial redistribution of animals and changes in species abundance ratio on some sites shall be characteristic of ChEZ fauna. Most likely that no significant changes in the composition of species shall occur in the territory of ChEZ. The fauna associations came up to the stage of long-term natural fluctuations. And if humans do not interfere in the course of natural processes, their development (particularly, quantity and territorial division) shall depend on a current state of food supply and on inter-species relationships, i.e. on the capacity of ecological niches. Rare cases of truly new species appearance shall be possible due to natural expansion of certain fish and bird species. *Tetrao urogallus* and *Lepus timidus*, which live in the neighbouring territory of Belarus, may return to ChEZ soon. Also, an increase in the quantity of *Bison bonasus* is possible. Although we believe that most of probable "new" species could probably have been continuously or periodically living within ChEZ before and only has not been fixed yet. Disappearance of certain species is also possible. However, its causes will be formed of common problems of species or populations, not associated with conditions in ChEZ; for example, detriment of reproductive potential under the conditions of small quantity and impressive fragmentation of a population. Degradation of synanthropes system of animal and plant species has stopped at the moment. And these species have found their niches in certain areas within ChEZ.

Further changes shall be observed in the natural systems of the cooling pond caused by its drainage. Death of introduced fish species shall be observed. Certain changes shall take place in its onshore

semi-aquatic complexes. The already-started processes of succession on its drained bottom surface, changes in hydrological and microclimate conditions stimulate extensive redistribution of land animals and disappearance of some plant and animal species in the semi-aquatic complexes.

Changes of ChEZ fauna are closely connected to the processes occurring in its floristic complexes. Shoots of trees and shrubs is appearing on all the fallows within ChEZ, though with different intensities. At the same time, annually growing layer of dead vestige prevents natural forestation. In the areas with constant watering conditions, changes in vegetation cover of marshes are determined by natural development of wetland phytocenoses [140]. Recovery of marsh vegetation and overgrowing with *Salix cinerea*, *Betula pubescens* is observed on the sites of secondary swamping.

Further forestation of open areas in ChEZ can be forecasted for the following years. However, experience of the first decades demonstrated that this is a rather long-term process. Directions, rate and frequency of appearance of seedlings in new biotopes is determined by the bio-ecological characteristics of plants, weather conditions, microclimatic characteristics of a biotope and habitat-forming activity of animals. Into uninhabited ecotopes, plants penetrate gradually and consistently; "step-by-step", each time they occupy an effective habitation range per a generation; they also need the full range of necessary biotic and abiotic conditions. Currently, there are only the first "steps" towards formation of pioneer tree thickets within ChEZ [128]. Future formation of plant biocenoses determined by ChEZ soil conditions shall be most probable. At the same time, the mosaic structure of vegetation cover shall ensure high stability of new ecosystems and their self-regeneration ability.

Natural complexes in ChEZ have not yet reached their complete stability. Consequences of long-term uses of lands and resources cannot be corrected at once. Industrial forest management has caused formation of significant areas of monoculture pine plantations, which are sensitive to diseases, fire-hazardous and poor in natural components. In addition, many of introduced tree species aggressively fill the area and displace autochthonous species. Drainage of wetlands and the developed system of drainage canals have drastically changed the local pattern, depleted its biodiversity and diminished role of local lands in maintaining heat & gas balance in the atmosphere and purification of surface water. Long-term agricultural use of naturally depleted lands resulted in their pollution with chemicals, contamination and disturbance of soil layers.

SUMMING-UP

Together with Paliessie Radioecological Reserve in Belarus and Drevlianskyi Nature Reserve (30,873 hectares) in the Zhytomyr region of Ukraine, which was recently established (in 2008),

ChEZ forms an integrated natural & geographical system of protected areas and covers approximately 5,000 km². The spacing and diversity of its natural systems ensure recovery of stable links and flows in the biogeocenoses, which are not possible on protected areas of traditionally small sizes. It constitutes preconditions for the recovery and self-sustaining development of not only small species being sensitive to human disturbance, but also big ones requiring large individual areas. It is noteworthy that such a development of ecosystems does not in any way contradict the main purposes of ChEZ establishment. It was recognized that stable and balanced natural ecosystems constitute the most relevant, safe and efficient barrier to the spread of radioactive substances. Support of their safe condition contributes to radiation safety maintenance on adjacent areas as well.

Since general radio-ecological conditions within ChEZ have been considerably improved over the 30 years, further ways of the abandoned lands management become a subject of discussions. An idea of establishing protected areas with a high conservation category is the most acceptable. The Biosphere Reserve Project seems attractive, since managerial and environmental protection conditions in biosphere reserves are flexible and functional. The project envisages maintenance of traditional farming in certain areas, and on the other hand it facilitates nature conservation, scientific research, monitoring, educational projects, support of public awareness and interface between various organizations in the area. Therefore, proper zoning of future reserve is crucial for conservation of biodiversity; account must be taken of natural lands value and different levels of radiation contamination. Therefore, these works require giant efforts and involvement of large expert groups, heavy financial resources needed to use modern means during expedition to ChEZ.

This report corresponds to output 1.2 of the Comprehensive assessment of state and trends of natural ecosystems in ChEZ of the implementation plan and output 2.1. The ChEZ is upgraded to the status of Protected Area network to enhance the conservation and management of carbon stocks, including development and implementation of a fire prevention and management plan, and secure the long-term basis for appropriate management, monitoring and research for large areas of forests, wetlands and other habitat types . According to the set objectives, the available literature data on the current state of natural ecosystems within ChEZ were analyzed. Data on the diversity of flora and fauna species (natural zone and vegetation structure, diversity of animal species, special characteristics including rare/endangered species) were summarized. Trends in the changing status of main biodiversity components were defined. Main adverse impact factors for key components of biodiversity were analyzed. Basic trends in the development of ChEZ natural complexes were described.

The following are required to further address the tasks defined by the project: performance of comprehensive scientific research and observations of the state of natural environment within ChEZ; identification and comprehensive characterization of sites in ChEZ that are the most important for the existence of local "Red Book" species and also the sites with a high index of biodiversity; determine appropriateness and conservation categories of the sites; study biotopical distribution of species; develop concept for the development of environmental protection activities within ChEZ; recover and/or develop activities of comprehensive (radio-hydrogeological, radio-biological, botanical) research stations and test grounds within ChEZ; study the processes of ChEZ lands and forests evolution under the conditions of radiation exposure in order to prevent their degradation and to promote recovery processes in sustainable and harmonious autochthonous systems; conduct research and include re-afforestation activities within ChEZ into a system of pan-European measures for the reduction of greenhouse effect; develop concept for the local peat moors recovery and for their management as a component of global network of anti-greenhouse effect.

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