

PRZEWALSKI'S HORSE (*EQUUS FERUS PRZEWALSKII*) IN THE CHORNOBYL EXCLUSION ZONE AFTER 20 YEARS OF INTRODUCTION

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Przewalski's horse (*Equus ferus przewalskii*) in the Chornobyl Exclusion Zone after 20 years of introduction. — S. Gashchak, S. Paskevich. — Camera traps (CT) were used in 2018 to assess the current state of the Przewalski's horse (PH) population. Przewalski's horses were introduced into the Ukrainian Chornobyl Exclusion Zone (CEZ) in 1998. Up to 720 km² (of the 2 600 km² total CEZ area) were investigated between February and November 2018, however the assessment reported here was made between May–July when PH are more settled with regards to the territory used. Totally 137 PH were recorded in the Ukrainian part of the CEZ: 47 stallions, 66 mares (adult & fillies) and 24 foals (10 males, 4 females and 10 of unidentified gender). At least four more PH (stallion, 2 mares, 1 foal) are noted at a remote site in the Belarus CEZ (V. Dombrovsky, or. rep.). All foals were born April–July 2018. There were 13 harem herds with foals (3–16 individuals in total in each), four small non-breeding groups (2–3 individuals), ca. 6 stallion groups (2–6 individuals), and at least one solitary stallion. Harem and non-breeding herds generally kept to ca. 18 sites, stallion groups normally roamed. Two–three groups lived on territories which including both Ukrainian and Belorussian parts of the CEZ. During 2007–2010 PH crossed the river Prypiat and finally founded a local reproducing sub-population. Almost all PH are from the 2nd and higher generations, only two mares had a brand mark which identified the original introduced population. One herd (Ilinty) includes a domesticated breed mare (in autumn she moved to a neighbouring group, in Stechanka, where in 2019 gave birth to a hybrid foal sired by the Ilinty stallion). At least, two males (solitary stallion and colt) had signs of hybridization (i.e. PH and domesticated horse). Underestimation of the total PH population in our study is likely as not all appropriate sites were investigated. The total herd, as identified here, of PH grew seven-fold between 1998 and 2018. However, the rate of population increase between 2009–2018 was in 1.5 times less than that 1998–2008 previously reported. This reduced population growth rate was likely due to the changing age structure of the herd, the initial herd contained only older (more productive) mature mares, over time numbers of younger (less productive) mares increased. The present demographic indices and reproductive potential do not indicate any negative tendencies in the population development, and evidence the further fitness to the local conditions. PH are native to open steppe landscapes and our study confirms their preference to meadows in the CEZ. However, we observed that PH do not avoid forests. Reforestation of meadows and predominance of woodlands in the CEZ are obstacles for comprehensive monitoring of PH, and may contribute to an underestimation of the population size as direct visual observations do not work well in the woodlands. CT studies offer a solution to this problem.

Key words: Przewalski's horse, Chornobyl Exclusion Zone, adventive species, camera trap, population structure, spatial distribution, long-term dynamics.

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Introduction

Przewalski's horses were artificially introduced into ecosystems of the Chornobyl Exclusion Zone (CEZ) in 1998–1999 (Zarkikh et al., 2002). Only 23 of 31 individuals survived after the acclimatisation, and only 2 stallions and 15 mares founded the current population (Zharkikh, Yasinetska, 2009). All of them were from the Askania-Nova Biosphere Reserve (Ukraine). Native to open landscapes (steppe, semi-desert, etc.) PH horses introduced into the Polesie habitats of the CEZ which are predominantly woodland and wetland. The introduced Przewalski's horses therefore had to occupy niche of ancient and extinct forest horse (*Equus ferus ferus*) which inhabited the region in the distant past (Sokur, 1961). The introduction of a new large ungulate into the CEZ had implications for the local ecosystems. The Przewalski's horse is a protected species, and included in both the in-

ternational, where it is classified as 'endangered'¹, and national Red List of Ukraine (The Red Data Book of Ukraine, 2009). Therefore a new free-range population potentially has large conservation value and is worthy of comprehensive study. During the first 10 years after the introduction of PH to the CEZ, scientific monitoring was regularly carried out by zoologists from the biosphere reserve 'Askania Nova' and Schmalhausen Institute of Zoology (e.g., Zarkikh et al., 2002, Zvegintsova et al., 2008, Zharkikh, Yasinetska, 2009, Slivinska 2005, 2006). These former studies documented the adaptation of PH to the CEZ, changes in population demographics, their spatial distribution, health and interactions with people and wolves were described. As early as the mid-2000's researchers differed in estimations of total herd size and noted difficulties for the conducting complete census (Zharkikh, Yasinetska, 2009, Yasinetska, Zvegintsova, 2013) as a consequence of the spread of animals over a large, and mainly forested, area. Some individuals were reported to have migrated tens of kilometres from their point of release (Zharkikh, Yasinetska, 2009, Yasinetska, Zvegintsova, 2013). The census methodology used in these earlier studies could have influenced the results. The census lasted only approximately a week, 1–2 times per year, normally, though not always, in the October–March period (Zharkikh, Yasinetska, 2009). Such approach was acceptable in the beginning when the total herd was relatively small, had only 3–4 groups and was spread over a relatively small area (200–300 km²) (Zharkikh, Yasinetska, 2009). Later when their population grew to three-times its initial size, they split into 5–7 groups, with some solitary individuals, and spread over 400–500 km² (Zharkikh, Yasinetska, 2009), the risk of underestimation using this methodology increased. Expansion of wooded area (reforestation of former agricultural land) gave additional problems. As the area of land reforested increase further using direct visual observations as a census methodology became year-by-year harder. In 2006 ca. 38.5% of the CEZ areas (870 of 2260 km²) were former meadows (Development Project, 2006), but ca. 10% of former meadows (i.e. c. 90 km²) had been reforested for 5–20 years. It is not surprising that studies carried out between 2009 and 2017 did not provide clear estimates of how many horses there were (Slivinska, Zharkikh, 2012, Yasinetska, Zvegintsova, 2013). Young wood thicket has a good potential to hide even a large herd of PH. An additional complexity arose as horses migrated in 2007–2010 to the Belorussian part of the CEZ (referred to as the Polessky State Radiation and Ecological Reserve, PSRER) where they founded a semi-settled sub-population (Deriabina, 2013). The PH in Belarus dropped out census conducted in the Ukrainian CEZ, however, they are part of total population arising from the initial animals introduced in 1998. We had previously observed that from time-to-time Belorussian animals cross into the Ukrainian CEZ. Thus, the situation in the CEZ in general and around the PH specifically had changed, and needed new study techniques.

In 2001 we began to use camera traps in radioecological and environmental studies in the CEZ; camera trap offer a reliable approach with minimal disturbance to study animals and are increasingly being used in ecological studies (Burton et al. 2015, Gaschak 2008, Gashchak et al. 2016, 2017, Schlichting et al., 2019). The idea of this study was to apply camera traps to assess the current status of the Chernobyl PH population.

Methodology

Study sites. The first camera traps (CT) were set up 12–13/01/18, with most being installed in February; the remaining cameras were set-up over the year as new locations with PH were found. Using this approach we were able to investigate nearly 720 km² of the total CEZ area including approximately half (400 km² of 870 km² (Development Project, 2006)) of the meadow land in CEZ. The area we were able to cover does not mean a two-fold (or greater) underestimation of the PH populations since apart the CT footage we also took into account direct field observations, including footprints, landmarks, and oral reports of other researchers in the CEZ. The role of forests in the life of PH is unstudied. There are opinions that PH simply cross woodlands migrating to new meadows (Zharkikh, Yasinetska, 2009, Yasinetska, Zvegintsova, 2013). However, information collected over 20 years suggest a more important role of the woodlands than simply transition habitats.

¹ <https://www.iucnredlist.org/species/7961/97205530>

Totally, CT were deployed in 32 points (Table 1). One CT was stolen in the very beginning (no footage obtained), however subsequent direct observation of a PH herd at the site and other evidence (e.g. presence of faecal droppings) allowed us to include the site in our census.

The choice of CT location was defined by evidence of PH activity and considering the probable importance of the site to PH. Distance between the CT spots varied. In five cases it was 100–800 m, with multiple CT being located in the home range of a herd (Table 1: points P04/05, 08/09, 10/11, 17/18, 25/26). In 12 cases (P02/03, 03/04, 03/05, 03/06, 04/06, 05/06, 15/16, 16/17, 15/17, 21/22, 27/28, 30/31) the distance between cameras was 1–3 km. In 21 cases the distance ranged 3 to 5 km; in most of cases (453 of 496) the distance between individual camera exceeded 5 km.

Five CT were located inside abandoned farmed buildings and 12 were sited near to farm buildings (including four located near permanent saltlicks remained after the farm activity in the past). Four CT were located near so-named ‘tyrlo’ (areas of bare earth resulting from frequent PH occupancy and use for dust baths, and well marked by dung piles). Three CTs were mounted near trails or bridges. In this study, potential watering places were not used as CT spots.

Although it was initially envisaged that the CT would run continually until November 2018, some CTs stopped working before this (memory cards full, discharge of the batteries, breakage). In 16 of the 27 camera sites, the CT worked for more than 6 months and at 6 sites they operated for 2–5 months. At the remaining five sites the operational period was too short to be useful (Table 1).

Equipment. Several models of CT were used in the study: Ltl Acorn 6210MC/MG — 27 (14/13) sites, CCBetter — 6 sites, Browning BTC-7 — 2 sites, Bushwhacker Big Eye — 1 site, ScoutGuard 882MK — 1 site. This list includes CTs that were used to replace broken units. Different technical features did not allow us to apply the same settings on all cameras. If the CT allowed it, we set: normal sensitivity, three photos per burst, minimal possible interval (0–5 sec) between triggering. Two CT (Browning BTC-7, Bushwhacker Big Eye) worked in video mode (20 sec) with smart option of continuing shooting if animals continued to trigger the sensor.

Table 1. Locations where the CT were set-up and length of operational period (in 2018)

Таблиця 1. Ділянки, де фотопастки були встановлені, і терміни їх роботи у 2018 р.

Locality/ Point	Coordinates (WGS84)	Site description	Operational days	Operational period (DD.MM)
L01/P01	N51.413, E30.020	Novoshepelychi village, dairy farm, inside an open-sided shed with a pile of salt	256	23.02–8.05; 10.05–8.11
L02/P02	N51.415, E29.996	Bridge over Sakhan river, between meadows, edge of forest	54	26.02–21.04
L03/P03	N51.415, E29.953	Sary Shepelychi village, inside wood poultry farm buildings	184	24.02–8.05; 3.06–20.06; 27.06–6.07; 16.08–8.11
L04/P04	N51.429, E29.952	Sary Shepelychi village, at entrance into dairy farm building (concrete)	253	16.02–22.05; 3.06–8.11
L04/P05	N51.429, E29.954	Sary Shepelychi village, near apple tree, 100 m from L04/P04	47	25.07–28.08; 25.07–6.08; 12.09–14.09
L05/P06	N51.422, E29.932	Bridge over channel - meadow, birch reforestation	300	13.01–8.11
L06/P07	N51.483, E29.937	Pass between flood plain gully and lake between forest and River Prypiat	365	12.01–8.11
L07/P08	N51.422, E29.856	Rechytsia village, bridge over river, asphalt road	52	24.02–17.04
L07/P09	N51.427, E29.851	Rechytsia village, inside dairy farm building (concrete)	243	15.03–13.11
L08/P10	N51.386, E29.788	Tovsty Lis village, inside dairy farm building (concrete)	105	16.02–1.03; 21.04–5.05; 3.06–6.06; 3.08–15.09; 11.10–13.11

Locality/ Point	Coordinates (WGS84)	Site description	Operational days	Operational period (DD.MM)
L08/P11	N51.385, E29.789	Tovsty Lis village, inside dairy farm building (bricks)	7	16.02–24.02
L09/P12	N51.378, E29.910	Buriakivka village, at entrance into wooden barn	267	17.02–30.08; 1.09–13.11
L10/P13	N51.345, E29.844	Stara Krasnytsia village, ruins of farm, asphalt ground nearby saltlick spot	233	15.03–20.04; 30.04–13.11
L11/P14	N51.301, E29.861	Ilinty village, inside granary building (bricks)	233	16.02–22.05; 3.06–21.06; 6.07–23.08; 3.09–13.11
L12/P15	N51.305, E29.920	Stechanka village dairy farm, on junction of paved roads	235	21.02–21.05; 30.05–15.06; 6.07–13.11
L13/P16	N51.314, E29.958	Meadow 'tyrlo' of PH, meadow with birch/pine tree reforestation	90	10.05–18.05; 15.06–5.09
L14/P17	N51.279, E29.910	Rozjeezhe village, at entrance into dairy farm building (concrete)	146	24.02–30.04; 15.06–3.09
L14/P18	N51.277, E29.918	Rozjeezhe village, nearby ruins of wooden barn, meadow with birch/pine tree reforestation	38	8.05–15.06
L15/P19	N51.240, E29.907	Glinka village, near barn with saltlicks	196	15.02–3.04; 19.04–28.06; 6.07–20.08; 1.09–4.10; 10.10–12.10
L16/P20	N51.264, E30.003	Korogod village, at entrance into dairy farm building (bricks)	220	16.03–14.08; 3.09–8.10; 10.10–13.11
L17/P21	N51.217, E30.056	Novosilky village, dairy farm, 40 m from building, on a trail to watering place	214	17.02–11.05; 5.07–13.11
L18/P22	N51.217, E30.041	Bridge over channel, wet meadow, birch reforestation, near to Novosilky village	21	5.07–26.07
L19/P23	N51.214, E30.134	Cherevach village, at entrance into dairy farm building	6	27.06–27.06; 9.08–15.08
L20/P24	N51.255, E30.125	Zapillia village, near barn with saltlicks, trail crossing the village between meadows	0	16.03–(stolen)
L21/P25	N51.288, E30.165	Meadow with birch/pine tree reforestation, trail cross, old meadow 'tyrlo' of PH	110	27.06–15.10
L21/P26	N51.290, E30.155	Meadow with birch/pine tree reforestation, crossing of trail and fire break	48	27.06–4.07; 5.07–14.08; 10.09–12.09
L22/P27	N51.340, E30.121	Field station (machine shed, brick building), asphalt ground, inside heavily reforested meadow	191	23.02–13.04; 19.04–18.07; 10.09–28.09; 10.10–13.11
L23/P28	N51.357, E30.118	Kopachi village, 200 m from dairy farm building with large salt pile, trail from forest to the farm	74	17.02–15.03; 20.04–7.06
L24/P29	N51.358, E30.062	Stow Stupnikove, 'tyrlo' of PH, meadow between pine forests, trail to Kopachi village	245	23.02–26.10
L25/P30	N51.320, E30.056	'tyrlo' of PH, meadow with birch/pine reforestation, between pine plantations, near to Chernobyl-2 settlement	121	20.04–20.05; 3.06–5.06; 16.06–14.07; 2.08–7.08; 1.09–26.10
L26/P31	N51.332, E30.062	'tyrlo' of PH, edge of pine forest, further meadow with birch/pine reforestation	110	20.04–23.05; 3.06–17.06; 2.08–4.10
L27/P32	N51.472, E30.018	Near to a dam with a road in the middle of meadow with birch reforestation	43	28.08–10.10

CT mounting. Normally the CT were deployed 4–10 m from the where PH were anticipated. Cameras were mounted on parts of buildings or trees. Height and angle varied depending on particular features of the set up. In most cases, a high risk of the CT being seen by people was supposed and therefore CT were masked.

Based on our own prior observations, PH are drawn to farm buildings, and take the opportunity to visit saltlicks and piles of fertilizers in the abandoned buildings. They often gnaw or lick brick walls. Therefore in order to keep the animals in front of the CT we put out saltlicks (April–May). However later we stopped this as it also attracted deer casing memory cards to be filled and discharging batteries.

Footage processing. In total 411 000 still photos and 1 120 videos were obtained, including about 20% showing PH. Quality varied depending on CT model, features of the particular CT, light, angle and behavior of the animals. PH were identified on gender features, relative size and proportions, leg stripes, spots on the body, color of fur and particular parts of body, scars. Only two PH of all recorded in 2018 had a band mark (mares, No. 17 and 45) received before introduction into CEZ.

After processing of all of photographs/footage we came to decision to estimate number and demographic structure of PH from photographs collected between May and July. This decision was taken because, during this period:

- 1) Moulting has finished and individual features become more obvious regardless of aspect angle and light;
- 2) Gender, age and rank differences are clearer;
- 3) Most PH are relatively settled and do not normally range far;
- 4) Daylight is the longest.

To distinguish individuals we made a photo-catalogue for every animal with shots from as many angles as possible obtained in a particular day. This helped us to recognize most individuals over periods of 2–3 weeks, sometimes — up to month. However, markers changed over time or disappeared and therefore the catalogue was updated periodically. Nevertheless, some individuals did not have specific markers to enable their identification. The presence of such individuals was recorded if all or majority of the identifiable herd members had been recorded. Night or transition (i.e. dawn and dusk) footage normally did not allow identification of most PH (the most used CT, Ltl Acorn 6210, has poor infrared illumination and matrix with relatively low resolution and sensitivity). In such cases we analyse consecutive footage for longer period and took into account records for diurnal period and features of PH behaviour.

The following gender-age categories were defined to assess demographic structure of the population: 1) dominant stallion in the herd (alfa-stallion), 2) mature mares, 3) immature 2–3 years old mares, 4) immature 2–3 years old stallions (in harem herds), 5) 1-year old stallions, 6) 1-year old mares, and 7) foals (males and females, separately if possible). Stallions (solitary or in stallion groups) were identified as mature or immature depending on size and proportions of the body. Since solitary stallions often appeared at night, and (by definition) rarely in groups their identification challenging. In the absence of clear individual characteristics, a PH was attributed as ‘unknown individual’.

As a whole PH were recorded if they are recognized and attributed to that group which more or less constantly kept to the given general locality (site) during May–July 2018. If well-recognized PH appeared outside of their usual locality, they were not recorded in the population of that site. Unidentified PH were not recorded if there was the possibility of repeated recording of an unrecognized local individual.

Results

From our analyses of the CT photographs/video footage up to 114 PH were recorded in the CEZ in period May–July 2018. Additionally a harem herd of 10 individuals was recorded by direct visual observations. PH were recorded at all studied sites, actually within that total area they occupied over

the first 10 years (Zharkikh, Yasinetska, 2009) (Fig. 1). Apart from this PH were found in a new area where they had been not recorded previously (see: Fig. 1). A short description for every locality and PH group is presented below. A few sites (L02, L20) where the CT did not work in May-July are not presented here.

Locality L01. A large salt pile under the brick shed on a former dairy farm in village Novoshepelychi. A pair of males (immature stallion and colt likely born 2017) visited the site several times in May 2018. Both had overgrown hoofs. After May they were not observed again. However, earlier (March-April) they were recorded at the Kopachi site (L022) and westward L01 (L02), so perhaps they spent time in that region in May-July. Apart from these two individuals, an alpha-stallion from the L03 herd (Stari Shepelychi) visited L01 three times in May and June; an alpha-stallion from the L04 herd (Stari Shepelychi) visited the site once in July.

Locality L03. The biggest herd (16 individuals) recorded in 2018 identified by a CT located inside a wooden poultry farm building in village Stari Shepelychi (Fig. 2, 3). The herd consisted of an alpha-stallion, eight mature mares, three one-year olds (2 females and 1 male), and four male-foals (1st was born in 3rd decade of April, two — in the beginning of May, and 4th — in 3rd decade of May). During the periods when the CT was operating, PH came into the building almost every day, often many times per day, generally resting for up to 0.5 hour (in May up to 2–3 hours). Often only alpha-stallion and a dominant mare came into the building.

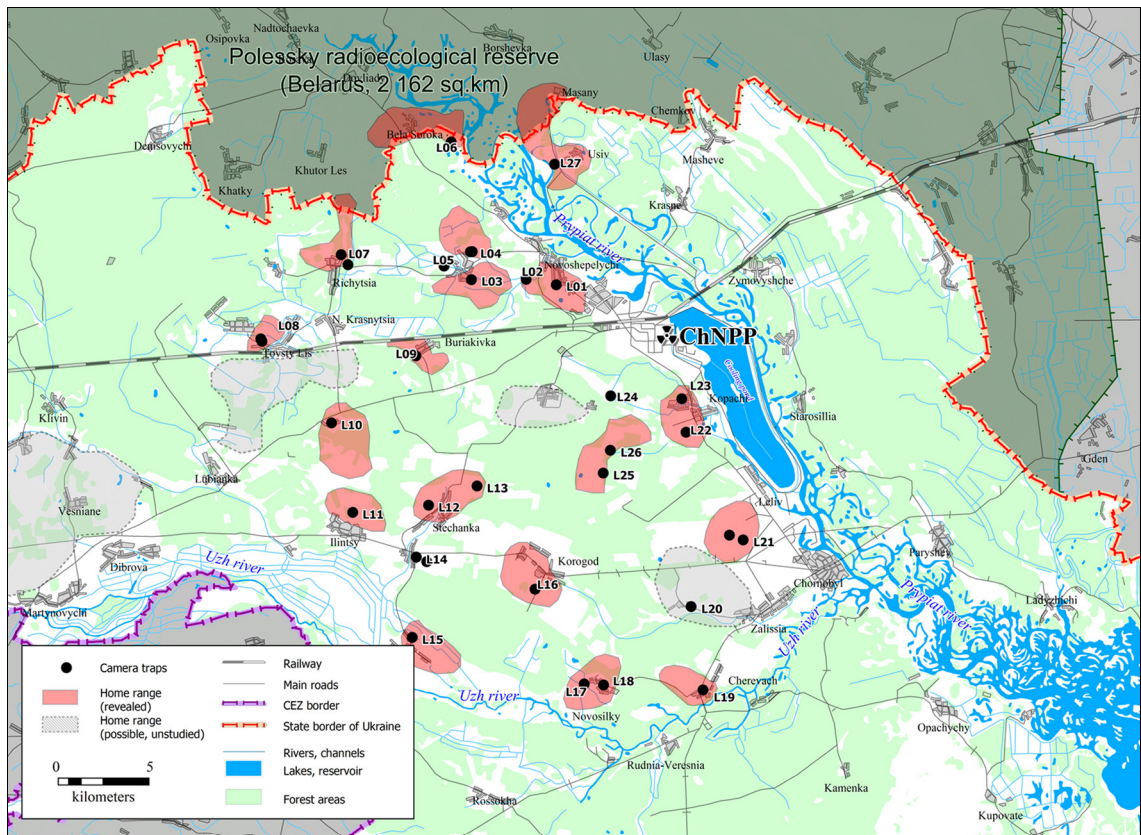


Fig. 1. PH home ranges of separate herds revealed or assumed in the CEZ, on study results of 2018. Hereafter shape and size of the home ranges represented on the maps are approximate, defined using visual observations (of PH and/or faecal droppings) and assuming that the PHs keep with about 3 km and preferred meadow habitats.

Рис. 1. Розташування індивідуальних ділянок окремих табунів коней Пржевальського в межах ЧЗВ, виявлених або можливих, за даними 2018 р. Тут і далі форма і розміри ділянок, представлені на картах, є умовними, визначені на основі візуальних спостережень коней, їх стежок і кучок гною, а також з припущенням, що коні тримаються ділянок радіусом до 3 км і віддають перевагу лучним місцям мешкання.



Fig. 2. PH from herd L03 resting inside the former poultry farm building.

Рис. 2. КП з табуна L03, що відпочивають всередині колишньої птахоферми.

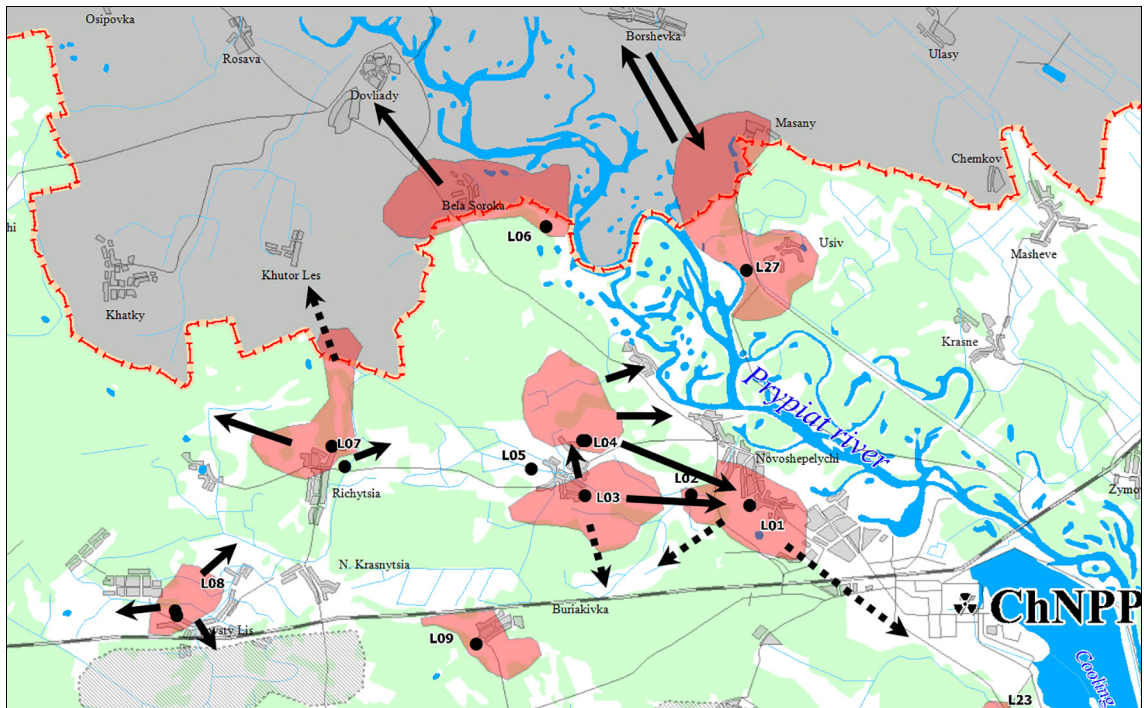


Fig. 3. Home ranges of PH herd in the northern part of CEZ, and real or possible migration routes.

Рис. 3. Території окремих табунів у північній частині ЧЗВ та реальні або можливі шляхи кочівель.

Tension in the herd was evident (compared to most other herds observed), mares often fought or chased each other. The potential lure effect of the saltlick placed in front of the camera cannot be excluded; until the saltlick ran out the PH spent a lot of time inside and competed for the salt. Apart from this herd no others were recorded inside or (by visual observation) near to the farm. During May–July 2018 the L03 herd was not recorded in any other localities, although the alpha-stallion visited a salt pile at L01 on a number of occasions (Fig. 3).

Locality L04. One CT was mounted in front of the side entrance into a farm building of a former dairy farm in Stari Shepelychi village. A second CT was located near to some apple trees approximately 100 m from the first CT. The local harem herd consisted of alpha-stallion, three mature mares, a colt (with white 'star' on forehead) and a female-foal (born approximately 09/07/18). This building was likely often visited by PH, however the animals normally did not stop at the CT. The second CT showed the animals to be at the location when not observed by the first camera. In July–August there were several times when over a long period the animals were shot near one camera and never near the other. Investigation of the territory around revealed a meadow 'tyrlo' (N51.435°, E29.956°) which likely belong this herd. In June an alpha-stallion from the neighbouring herd (L03) was observed at L04. Fresh scars on the neck of the local stallion and a change in behaviour (more rapid movement) indicated the likely confrontation with this visiting stallion. The L04 stallion sometimes disappeared, once in July he was recorded near the salt pile in Novoshepelychi (L01).

Locality L05. Though the CT (sited on a bridge over a system of drainage channels) was just 1.6 km from L04, the only horses recorded here in May–July (on 10/06/2018) were a vagrant pair of stallions (mature and colt). Later, in August, the same pair was recorded at L09.

Locality L06. This locality was 2.5 km SE-ward from Belorussian village Bela Soroka. We knew that some PH live nearby the village, however we did not anticipate to record them at the camera site. The local habitat was deciduous forests coming down to the reforested flood plain of Prypiat river. The CT was sited on a passage between a gully and lake towards the Prypiat River. The nearest meadows are northward, beyond a large lake (Kolodne) which connects with the Prypiat River and which cuts-off access to the meadows. No meadows are located close by southward, only wetlands and forest. On 15/06/18 a harem herd (stallion, four mares and two foals) ran into the camera trap view area from the direction of the river. Later (17/07/18) a herd of seven adults and three foals ran in the opposite direction. In both cases the quality of the pictures did not allow us to identify the animals. V. Dombrovsky (PSRER, Belarus) reported to us orally that his CT in Bela Soroka recorded in June–July from five adults and one foal to nine adults and three foals. Evidently, these animals live mainly on Belarus territory where they roam between the villages of Bela Soroka and Dovliady.

Locality 07. CT was mounted inside the last building of dairy farm, by the forest, in the village of Rechytsia. There were a number signs of PH at the site and a saltlick was placed there. However, until the beginning of May no PH were recorded. Almost all recordings at this site were made in May. The positioning of the CT was not optimal and prevented recognition of individual animals all of which were stallions. In 19 of 24 cases only 1–2 individuals (mature and younger) were recorded. On three occasion, three PH were observed and on single occasions groups of four and five. We cannot say if the observed animals were from one group, or represented different groups. The quality of the pictures did not allow us to compare them with other stallions herds recorded in other localities. Whilst the surrounding habitats near Rechytsia (meadows) correspond to the preference of PH, it is possible that animals observed at this site roam between Ukraine and Belarus.

Locality L08. The CT was located inside the last building of a dairy farm, in Tovsty Lis village; the surrounding area was meadow with birch reforestation. Fresh dunghills and regular observation of the local herd indicated the building was in their home range. The PH spent a lot time in front of the CT, the memory cards were filled rapidly, consequently the time period over which the CT operated in May–July was limited. However, the footage obtained and in situ observations allow us to concluded that the herd was always in the area and did not migrate far (until the end of August). The herd consists of a stallion, two mares, a filly, one female-foal (born in mid-late May) and 1 male-foal (born in early-mid June). No conflicts within the herd were recorded. No other PH were recorded at this site during May–July.

Locality L09. The CT was located in a wooden barn with stalls, on the edge of village Buriakivka. The immediate habitat was pine forest or reforested land, the nearest meadows were 500 m away. In May–July an old stallion was almost constantly at the site; the animals had scars on the head. In the period 11–27 May 2018 a mare with an approximately 2-week foal (male) joined him. Until 27/05/18 they appeared to be a small harem group. On 27th May something happened, the PH

appeared agitated and the mare with foal disappeared. After 7/06/18, the mare and foal were recorded at site L12 and subsequently within the L10 herd. Apart from the mare, on 12/05/18 a herd of six stallions was there in the night; as it was dark the animals could not be identified. During the night of 24/06/18, a new solitary young stallion was recorded in the company of the local older stallion, but then disappeared. In July two stallion groups visited the site (Fig. 4). One herd of five individuals visited up to 12 times between 9/07/18 and 30/07/18. They also were recorded on the 8/07/18 in L10. Sometimes they were together with the local old stallion. A second herd of six stallions visited on 24/07/18 just after the first one, and it looked like a chasing the first group. The second herd was well-recognized and recorded many times in different localities (see below) during 2018.

Locality L10. The CT was located in the ruins of a farm burnt in 2015. Surrounding habitats were also burn over a large area, though some birch trees survived. PH as well as other ungulates are attracted by a small brick construction where in the past some fertilizers (or possibly food supplements) were stored. The animals also licked the brick walls. We had to mount the CT on an abandoned machine which was on an area of asphalt about 15 m from the brick construction. It was too far for the CT, and affected our ability to recognize individuals at dusk/dawn and during the night. The CT also likely missed some animals. A herd of five PH visited the site throughout May during the night, and the animals were for short time periods only. Based upon the frequency of photographs, it is likely that this site was not in the centre of the group's home range. The herd consisted of a stallion, two mares, and fillies (born 2016–2017). On one occasion (22/05/18) an old mare with brand mark '17' joined the herd, soon after no PH were recorded by the CT for two weeks. When the animals were recorded again (8/06/18) a new mare with a foal (born early May) joined them. Previously this mare and foal were recorded at L09 (11/05–27/05) and L12 (7/06). In June the herd were recorded only a few times; the old mare '17' was no longer with the herd and was recorded at the site L12. In July the local harem herd were almost constantly recorded at L10. Additionally on 13/06/18 a group of three stallions was recorded, nocturnal pictures did not allow us to identify them. A group of five stallions came to the site on 8/07/18 (these animals were later (11/07/18) recorded at L09).

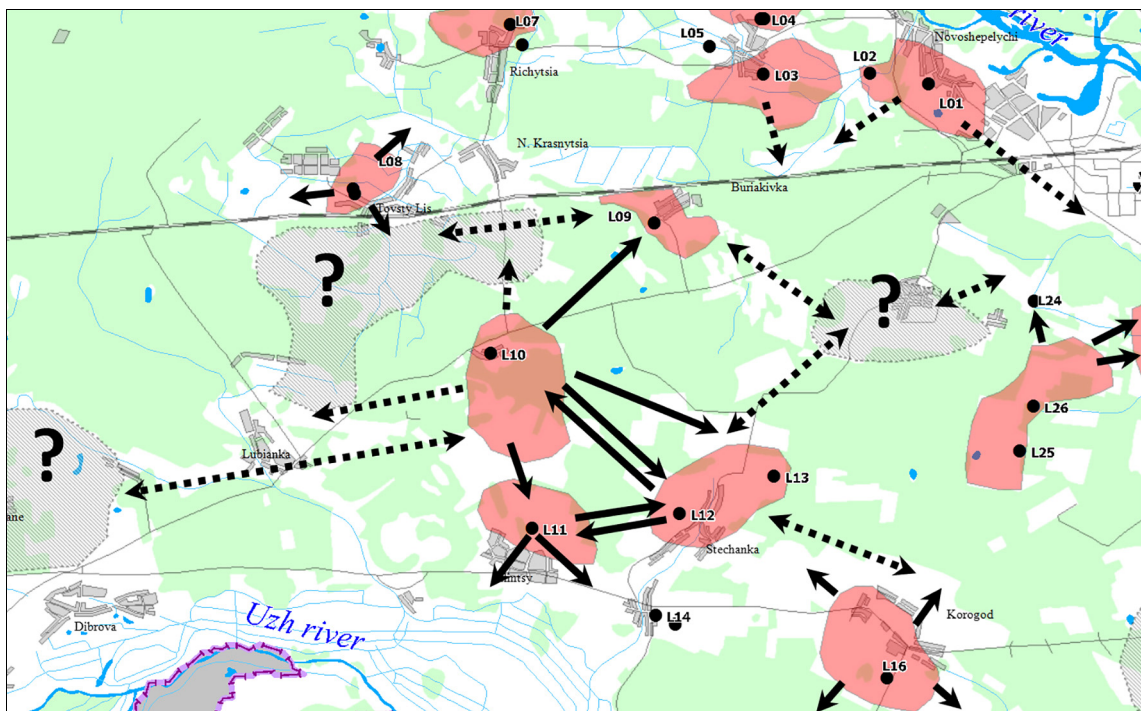


Fig. 4. Home ranges of PH herd in the western (studied) part of CEZ, and real or possible migration routes.

Рис. 4. Території окремих табунів у західній (дослідженій) частині ЧЗВ і реальні або можливі шляхи кочівель.



Fig. 5. Mixed harem nearby to Ilinty dairy farm (L11).

Рис. 5. Змішаний гаремний табун біля МТФ у с. Іллінці (L11).

Locality L11. The CT was mounted inside a former granary building, the last construction of the dairy farm in the village of Ilinty. Beyond the farm buildings the habitat was meadows with some birch reforestation. A high risk of this site being visited by people was anticipated and therefore CT was carefully masked. PHs kept nearby the farm throughout the study period. Initially they were represented only by a stallion with a mare. During 7/05–21/05 the mare was absent, and after came back with a female foal (born in mid-May). At the same a domestic mare (black colour) joined the PH (10/05/18). The stallion covered the domestic mare over several days (10/05, 11/05, 14/05, 15/05, 17/05). The domestic mare initially dominated the PH mare, and drove her away, but over time the animals became more tolerant of each other (Fig. 5). The herds were rarely observed during the night, but during the daytime the animals stayed inside the granary almost every day for long periods. During May–July this herd was recorded nowhere else, and no other PH were recorded at L11. The only exception was when the stallion visited L12 on 31/07/2018.

In autumn the domestic mare moved to a neighbouring group, in Stechanka village, where in 2019 gave birth to a hybrid foal sired by the Ilinty stallion.

Locality L12. This site was in the territory of a dairy farm in the village of Stechanka. Dung piles and PH footprints were everywhere at the site with no obvious preferred spots identified. The CT was mounted on a tree at the crossing of concrete passages between farm buildings. This was perhaps not the best place but evidence of people visiting the site limited the choice of CT mounting points. In order to attract and retain PH we put a saltlick in front of the CT. In the first half of May a solitary hybrid stallion (with a white 'star' on its forehead) was recorded (it was also recorded during April). This stallion was also observed (7/04–11/04/2018) in the stallion group at site L10 (Stara Krasnytsia). An old mare with the brand mark '17' was observed on 13/05/2018. During the second half of May and first week of June the CT either did not work or the quality of nocturnal pictures did not allow us to identify individual PH. During this time one or two PH were occasionally recorded. On 7/06/2018 some PH from the L10 herd (Stara Krasnytsia) visited L12.

The L10 animals comprised the alpha-stallion, a mare and foal (also recorded 11/05–27/05 at L09), and two unrecognized individuals. The animals stayed for only one day. From 8/06/2018 until August an old stallion together with old mare '17' kept to L12. It is possible that these PH were the animals recorded in May which could not be recognized. The farm territory was only a part of the animals' home range, from time-to-time they appeared in the neighbouring site L13 (Fig. 4). At the end of July (31/07) the alpha-stallion from Ilinty's farm (L11) visited L12 resulting in some confrontation with the local group. At the end of September the domestic mare from L11 joined the L12 herd and was subsequently observed to remain at the site for at least a year.

Locality L13. This site is a large meadow 'tyrlo' within a relatively dry fallow area of reforested by pine and birch trees to the north of Stechanka village. PH rarely visited the site, most often seen were the stallion and mare '17' from L12. On 13/05 and 16/05 a group of 2–3 stallions joined them, including the hybrid with a 'star' recorded previously at L12 and L10. Later (25/06) one unknown solitary stallion visited the site.

Locality L14. This site was a dairy farm in the village of Rozjeczhe (burnt in 1992). The CT was installed in front of the entrance into the surviving building. Dunghills, trails and having observed PH at the site in the previous winter gave us hope that we would initially observe animals here during the study period. However, the big harem herd (up to 15 individuals, including three foals) observed at the site only stayed until June; most recordings were via direct observation (21/04, 8/05, 30/05) rather than by CT. The animals rarely came to the actual CT spot (in spite of a saltlick nearby). During 8/05–15/05 the CT was moved 600 m eastward, to the ruins of a wooden barn where the herd was often observed. However, no results were obtained from this new location. After June the herd was recorded in the village of Glinka (L15) more 4 km southward of L14. No other PH were recorded at L14 during May–July.

Locality L15. This site was almost at the centre of the village of Glinka. The CT was deployed near a barn with remains of some fertilizers or saltlicks which attracted ungulates including PH. Grassy meadows of the Uzh River flood plain surround the abandoned village with numerous patches of reforestation. The potential risk of theft and local features forced us to put the CT too close to where animals passed. This resulted in partial photographs of individuals and groups, and the potential exclusion of some animals. In May 2018, PH were recorded only once (2/05): 2–3 adults including a stallion. The quality of photographs meant that the animals could not be identified. After 6/06/18 the harem herd previously recorded at L14 were observed at this site. The herd consisted of an alpha-stallion, seven mares (perhaps some fillies), male and female 1 year olds, and three male-foals (two were born in the second half of April, one at the beginning of May). The herd was not at the site constantly visiting the barn only five times in June and three times in July. The animals always entered the CTs field of view from the neighbouring meadow to the east. Very few dunghills were found in other parts of the village, and none in neighbouring village of Zamoshnia where in the past we knew that PH had stayed regularly. No other horses were noted in L15 in June–July, but new scars on the stallion indicated that in June he fought with another animal. Our previous observations in 2015–2016 showed that PH often cross through the pine tree woodland between this meadow and lands around the villages of Rozjeczhe and Korogod (2–3 km) (Fig. 6); such periodical movements are not excluded in May–July 2018. Lands to the southeast of Glinka also had appropriate habitats, but the absence of roads prevented comprehensive investigation.

Locality L16. The CT was mounted in front of the side entrance into a farm building on the large dairy farm in the village of Korogod. A number dunghills were found inside the building and was evidence that animals regularly licked the brick walls. The farm is surrounded by dry grassy meadow with some birch/pine reforestation. During May–July an old solitary stallion kept to the site constantly. On the night of 23/05/18 two stallions were recorded but not identified. Over a month, 21/06 and 24/06–28/06, two–three stallions were noted during the night. During daylight apart from the resident old stallion, one younger stallion (perhaps a colt) was identified. This younger animal was observed at the site in July, on a two occasions it was observed together with the old stallion. On 10/07–12/07 a nomadic herd of five stallions came to the site; this was a herd recorded in several

other localities (L22 — 10/05, 4/06; L25 — 12/05, 17/06, 8/07, L09 — 24/07; L21 — 20–21/09). On a few occasions the local stallions were observed with the bachelor herd; no conflicts were noted.

Locality L17. This site was a former dairy farm in Novosilky village. There was evidence of PH were both inside the farm buildings and outside. As evidence of people was also common the CT was installed on a trail to a watering place at the edge of forest (pine plantations). This set up was not successful, animals could pass the behind the CT. Based on CT images, in early May it is likely that five–six PH were at the site: a stallion, three adult mares and 1–2 not identified. On 11/05/2018 we found two dead PH (one stallion) in a building in the central part of the village. It appeared that the animals were trapped by the door. After 6/07/2018 a herd of five PH kept to the area of the site: a stallion, three mares and a colt (born 2017).

Locality L18. In theory, this locality could be combined with L17, the CT was deployed on a trail going down from the village (Novosilky) to the flood-plain meadow 400 m further away was a watering place which the L17 herd likely used (Fig. 6). The distance between L17 and L18 was a little more than 1 km. The CT was run for only 3 weeks (5/07–26/07). Surrounding habitats were represented by grassy wet meadows with a system of drain channels, and numerous patches of birch and willow reforestation. Over the operational period the CT recorded: one stallion (unrecognized) twice and once a herd of five individuals which looked like the one from the L17. Animals observed at this site always appeared watchful.

Locality L19. This site was a dairy farm in the village of Cherevach. There were abundant evidences of PH found both inside and outside the farm buildings. Moreover, PH were commonly observed near to the village in January–April 2018. Unfortunately the CT worked not very well and the data obtained from this site in May–July were poor. In January–February 2018 we saw a large herd of up to 16–17 individuals, including four colts/fillies. In March–April, two smaller harems: 1) a stallion, two mares and a colt (16/03/18 nearby Cherevach); and 2) nine animals in total comprising, a stallion, 5–6 mares, 2–3 colts (21/04/18, 1.5 km north of the village). We cannot rule out that these two smaller herds were combined in the beginning of 2018, and later divided on two groups. The CT was not sited until 27/06/18 in front of the entrance into a building on the dairy farm.

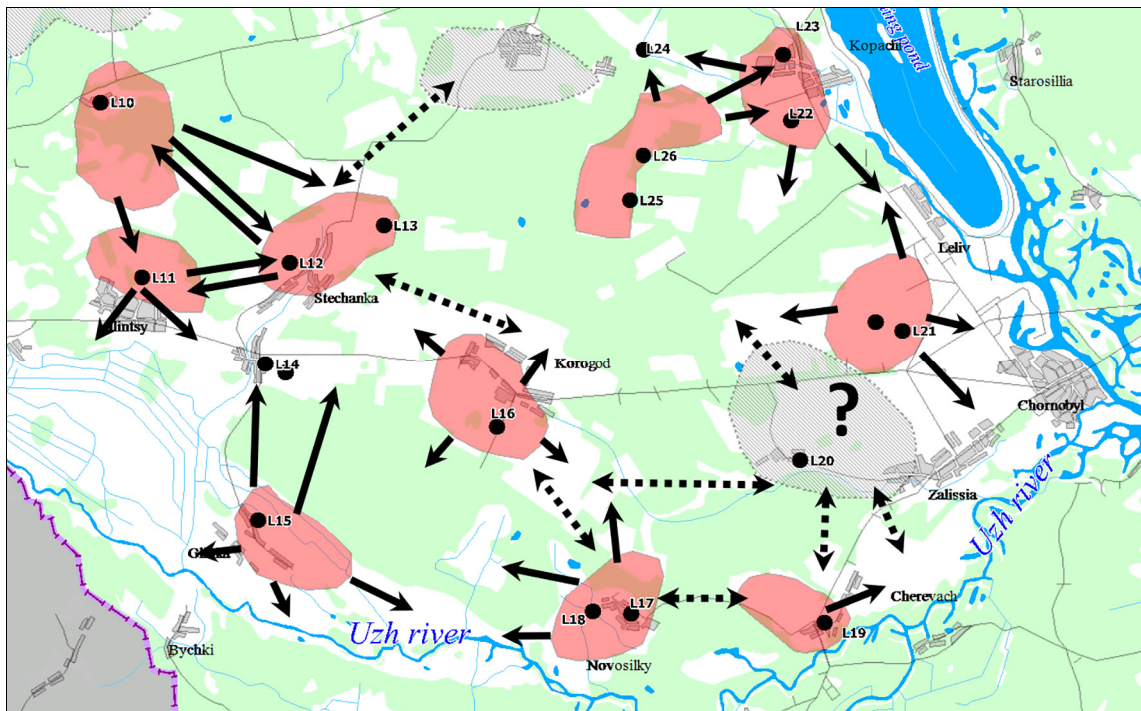


Fig. 6. Home ranges of PH herd in the southern (studied) part of CEZ, and real or possible migration routes.

Рис. 6. Території окремих табунів у південній частині ЧЗВ та реальні або можливі шляхи кочівель.

Unfortunately, the camera malfunctioned and we did not get any pictures of the PH in June–July. In August (11/08, 12/08, 14/08) a harem herd passed the CT: a stallion, two mares, a colt (born 2017) and a foal; picture quality was poor. The large herd we had observed near to Cherevach in March–April was not seen again and we have no information on where it went during the summer. However, the camera at L20 (near to the village of Zapillia) to the north of L19 was not studied as the CT was stolen. Dunghills were common at L20 and on 1/09/18 we observed a large unknown harem herd (see below), it is possible that these animals were initially from Cherevach (L19).

Locality L21. This site was a relatively dry fallow meadow with active reforestation (birch, aspen, pine). Two CT were deployed here (Fig. 7). One was mounted on a fence pole (marking the so called ‘10km zone’) where animals (including PH) went through a gap in the fence, the trail going through the fence crossed a fire break close to the CT. The second CT was at an intersection of trails app. 800 m away from the first CT. Both CT were installed comparatively late (27/06/18). The CT recorded only a small herd (a stallion and two mares) which roamed around, we also observed these animals near to Chernobyl town. On 29/07/18 a new unknown stallion was recorded by the CT.

Locality L22. This locality included two agricultural brick constructions within a dry grassy habitat heavy reforested by pine trees and birch over the last 20 years. One construction was a shed for agricultural machines, the area between the two buildings was paved. The CT was mounted in this paved area. The site is remote from any roads and there was lots of evidence of animals. A small group comprising a stallion, a mare (possibly immature) and colt (likely born 2016) came to the site often to rest in the shed. The colt appeared on 26/06/2018 and subsequently stayed with the herd. Previously this colt had been observed with a harem herd living on meadow land between L23 and L24. The L22 herd roamed over the meadow near to Kopachi village (1.8 km northward of L22, see Fig. 7) and in May they were only PH recorded at the dairy farm in Kopachi. Thus, site L23 was within the home range of the animals observed at L22. Sometimes the animals migrated further, on 8/07/18 (and in August) the L22 herd was recorded at L24 (4.5 km to the NW). Apart from this herd, a vagrant and well-recognized stallion group (6 individuals) were observed at L22 (10/05/18 and 4/06/18).

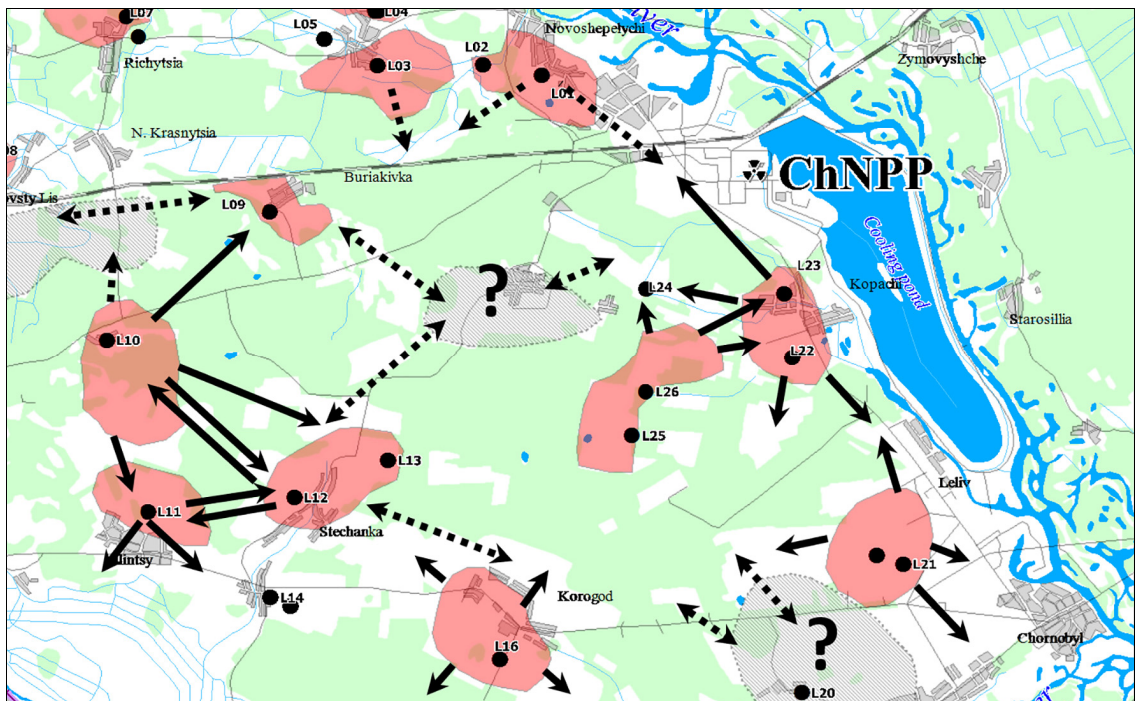


Fig. 7. Home ranges of PH herd in the central part of CEZ, and real or possible migration routes.

Рис. 7. Території окремих табунів у центральній частині ЧЗВ та реальні або можливі шляхи кочівель.

During the study period, these stallions were recorded at many sites of the region (L09, L16, L21, L22, L25; see below). A solitary unknown stallion was at site L22 13/05/18 and 15/05/18.

Locality L23. This site was a dairy farm in the village of Kopachi. A large salt pile in one farm building attracted ungulates and there was abundant evidence of PH. However, the farm is situated near the road between Chernobyl town and the Chernobyl nuclear power plant and consequently people often visit this site. Therefore, we had to mount CT on the tree a little far from the building (200 m), near a trail coming from the neighbouring forest. Until May a large harem herd stayed at the site before moving to L24, and soon afterwards to sites L25/L26. In May only the stallion and mare from site L22 were observed at L23. On 12/05/18 two PH ('older' and 'younger') were observed on the side of the Kopachi–Prypiat road, 2 km north of L23. These animals might have been from site L22/L23 or L01. The two L01 stallions were absent (from L01) on day 12/05/18, and in March–April we recorded that they had visited L22 too. No observations were made at L23 in June–July, because on 5/06/18 there was a large fire near the village and we had to remove the CT.

Locality L24. This site (stow 'Stupnikove') was a large meadow 'tyrlo' in the middle of meadow land with different habitats (dry, wet, thickets, reforestation, channels, etc.). The meadow stretched between pine forests until the village of Kopachi (L23). Apart from the 'tyrlo' (with large dunghills) a number PH's trails traversed the meadow suggesting that PH inhabited this area constantly. In February–April a large harem herd (7–9 individuals) was observed at the site. The herd included: a stallion, four mares and two colts (2016–2017). One more colt joined the group from occasionally. The animals migrated between L24 and L23. However, there appeared to be confrontation between mares in the herd; at the beginning of May the herd broke-up. Most of the animals went to L25/L26 site while one mare and two colts stayed at L24 until 4/05/18–7/05/18. It is possible that the colt joined the L22 group, while the other animals (mare and filly) joined the harem herd at sites L25/L26. Almost no PH were subsequently noted at site L24 until August; on a few occasions during the night, 1–2 horses were observed but could not be identified. Additionally the group from L22/L23 was recorded at L24 on 8/07/18; in August these animals visited L24 more often.

Locality L25. This site was a large former meadow with extensive birch/pine reforestation. The site was remote from any roads, and surrounded by pine tree plantations. It was on the plateau of the so called Chystohalovka upland (and for this reason was rather dry) about 1.7 km far from the abandoned settlement Chernobyl-2 (Fig. 7, 8). Our first exploration of the site (20/04/18) revealed abundant evidence of PH ('tyrlo', trails, dunghills). The CT was installed near to the largest 'tyrlo'. As it turned out, this was likely the centre of the home range of animals utilizing the site. PH spent up to 0.5–1.5 hours at the site almost every day. This resulted in rapid filling of the CT the memory card and discharge of the batteries and subsequently for periods in May, June and July the CT did not work. However, footage (as well as the field observations) allow to state that: the local herd kept to the site almost all of the time. It was the same herd, which we earlier recorded on the meadows between L23 and L24. The age and number of the dunghills and trails at L25 indicated that it was within their home range in the earlier period. By the end of June, this herd included nine PH: a stallion, three mares (one infertile), one filly and one colt (born 2016–2017), one male-foal (born 6/05–8/05) and one female-foal (born mid/late May). One old mare had a brand mark '45' (received before introduction into CEZ). She appeared to have fractious relationships with the dominant mare, and often left the herd together with the filly. Such behaviour has previously been noted in April at site L24. However after the birth of her own foal mare '45' joined the herd permanently. The infertile mare also sometimes disappeared. Apart from this herd, a group of the vagrant stallions (5–6 individuals) came to site L25 three times (12/05, 17/06 and 8/07). On 12/05 they were together with the local herd but without the local alpha-stallion. The group of vagrant stallions is the same one as recorded at many other sites over the year (see below). The alpha-stallion of local herd copulated the dominant mare 20/05/18, '45' mare — 4/06/18, 5/06/18, 27/06/18 (Fig. 9), and the 'infertile' mare on 12/07/18. This herd was not recorded in other localities (other than L26) during May–July. However, a lack of water and the direction of main trails suggests that they regularly went down to the meadows (L23/L24) which had a number drainage channels.



Fig. 8. PH herd L25 on the 'tyrlo' ('tyrlo' from the space, Google Planet Earth).

Рис. 8. Табун L25 на своєму тирлі (вигляд тирла з космосу, за: Google Planet Earth).



Fig. 9. Stallion copulating with mare '45'. In the background – smoke from a large fire (5/06/18).

Рис. 9. Жеребець криє кобилу «45». На задньому фоні – дим великої пожежі (5/06/18 р.)

Locality L26. This site is within the home range of the L25 herd being 1.3 km from the L25 CT. This site was a 'tyrlo' situated at the forest edge. The remains of some fertilizers were nearby the 'tyrlo'. PH trails crossed the spot and going northward to Kopachi (L23) and wet meadows (L24). The CT did not work at the end of May, of the end of June and the whole of July. However, the footage obtained confirmed observations at the L25 locality. The herd likely visited L26 less than L25; no other PH were recorded at L26.

Locality 27. This is the only locality on the opposite (eastern or left) bank of the Prypiat river (Fig. 3). For twenty years there were no evidences that PH had got over the river. Our finding (on 28/08/18) of numerous footprints and dunghills nearby the village of Usiv (in the north of left-bank of the CEZ) was unanticipated. Apart from the separate dunghills and trails, we found a 'tyrlo' on barren sand (N51.479°, E30.013°). Number and age of the dunghills indicated that PH were at the site in May–July also. The late operating period of the CT (28/08–10/10) and not very successful set up (the animals could bypass the CT) did not give good results. Only one horse was recorded (19/09, 23/09, both at night) with no evidence of a herd at the site. V. Dombrovsky (pers. comm.; PSRER, Belarus) reported that in the second half of 2018 he recorded one small herd (stallion, 1–2 mares and a foal) nearby the village of Borschiovka (8 km northward of L27) and big herd of 10 individuals (a stallion, seven mares/colts/fillies, two foals) near to the village of Masany (3.5 km northward of L27). In his opinion, the later herd time-to-time went to the territory of Ukraine (i.e. surroundings of Usiv village). The features of the given locality were: flood plain of the Prypiat river with rather dry meadows on upper sand ridges, and grassy and overgrown habitats in lower wet places, nearby lakes, marshes and channels; reforestation has taken place everywhere.

Vagrant non-territorial groups. Apart from the territorial groups or individuals with their own home range, there were several groups of stallions, which normally roamed over a large territory and which from time-to time visited different localities of the territorial groups.

One herd consisted of 5–6 stallions (adults & colts) and these covered a large territory over the study period. They were recorded in the following localities: L22 — 10/05, 4/06, L25 — 12/05, 17/06 and 8/07, L16 — 10/07–12/07, L09 — 24/07, L21 — 20/09–21/09. One young individual had a notable old wound (like a growth) on the left rear leg (metatarsus), which evidently did not trouble the animal. The second stallion group was not so established, and varied from three to six individuals, sometimes individual stallions were solitary. The animals roamed somewhere between villages of Stara Krasnytsia, Buriakivka, Stechanka, Ilinty, and perhaps, on meadows southward Buda, Tovsty Lis, Nova Krasnytsia. We recorded them in the following localities: L10 (several times in April, 13/06, 8/07), L09 (9/07–30/07), L13 (13/05, and several times in August). One stallion in this group showed signs of hybridization with domesticated horses (white 'star' on forehead, long mane, shape of head and body).

The potential third stallion group was difficult to characterize. In May 2018, two stallions were observed near to the dairy farm in village of Rechytsia, but sometimes, total the group number increased to 3–5 (see above). The low quality of the pictures does not allow to judge if they were from one not very tight group or not. Absence of fresh dunghills in the closest villages (Rudky, Nova Krasnytsia) and the disappearance of PH in June–July gave us reasons to think that they: (i) went either to Belarus (northward), and in this was the case, it was definitely a third group; or (ii) to meadows to the south of the railway ChNPP–Vilcha, and in this case, they could be representatives of the second stallion group. V. Dombrovsky (pers comm.; PSRER, Belarus), reported that in 2018 they did not find signs of PH on Belarussian territories adjoining to Rechytsia site (though in the past PH were common there).

We are not able to be definitive about the total number of solitary or grouped stallions, but this likely ranged from 15 to 30.

Unstudied territories. The size of the CEZ is large (2600 km²) and mainly woodland, only 870 km² are represented by open and semi-open landscape, the most appropriate for PH. To consider all of this area was too much for our one-year study, and in 2018, we investigated only a half of the open/semi-open land. Other researchers report the presence of PH in areas we were unable to cover.

I. Chyzhevsky (pers comm.; Enterprise ‘Ecocenter’, Chornobyl) reported that in March, June and November 2018 at least three mares were recorded in the western part of CEZ, near the village Vesniane. D. Vishnevsky (pers comm.; ChREBR, Chornobyl), reported a large herd (up to 15 individuals) noted southward of Nova Krasnytsia in summer 2018. This group could have been a new unknown harem herd, which lived on the meadows between Nova Krasnytsia, Tovsty Lis, Buda and Bovische (in 2015–2016 we worked in this area and recorded a harem herd many times). Alternatively, the group observed by D. Vishnevsky could be the result of groups we had observed relatively close by combining into a larger herd.

The area close to Chornobyl town (5 km around the town), were investigated in winter 2018, and the evidences of PH were almost everywhere. Although our CT in Zapillia (L20) was stolen, on 1/09/2018 we visually observed there a harem herd of 10 individuals, which had not been recorded anywhere else. The herd consisted of a stallion, five mares and four foals. Evidently, they kept close to Zapillia all summer. The territory between Zapillia (L20), Novosilky (L17) and Korogod (L16) has several large meadows presenting good habitat for PH and winter investigations revealed many trails there. However, absence of roads prevented the area being included in our CT in summer 2018.

Discussion

Up to 141 PH were recorded in the CEZ in May–July 2018, including ca. 48 stallions, 68 mares and 25 foals (Table 2). A domestic black horse was in one harem. Consequently, taking into account that over the first 10 years (1998–2008) the total herd reached up to 65 individuals (Yasinetska, Zvegintsova, 2013), it grew by 2–2.5 times over the next 10 years (2008–2018). A similar growth was noted for the herd/group number. In total 22 herds/groups were counted in 2018 (13 harem herds all with foals (except for one herd), four small (non-breeding) herds, and ca. six stallion groups of 2–6 individuals). In 2005–2006 it was estimated that there were about seven herds (5–6 harems, 1–2 stallion) (Yasinetska, Zvegintsova, 2013). However, instability and migrations of stallion groups do not allow to us to estimate the total number of males and their spatial behaviour. Apart from this, some areas of CEZ were not investigated. The situation on the neighbour territory of PSRER (Belarus) was also unclear (though PH are known to have migrated there). Therefore we can assume that the total number of PH was greater than that we determined.

As already discussed the reduction in population rate may, in part, be the consequence of a changing age structure of the population. Initially the herd had fully mature females, with time the number of young, initially less fertile, females increased. The published data do not have full details of the age-gender compositions. However, if we take values of the offspring size (Zharkikh, Yasinetska, 2009), and assume 1:1 gender ratio among the foals, as well as no mortality in the population, we can approximate how the age composition of females changed over the years (Table 3).

Notably, young but mature females (3–5 years old) would contribute almost a half of all fertile mares in the years 2003–2006 when the lowest rate of population increase was reported (Zharkikh, Yasinetska, 2009). It is likely the actual growth rate was lower because of mortality (in all age groups). Our estimate is that 3–5 years old mares comprised about 25 % of the fertile mares in 2018.

The total number estimated in 2018 indicates the definite growth of the population, though the long-term trend was ambiguous (Fig. 10). Following the previous studies (Zharkikh, Yasinetska, 2009; Yasinetska, Zvegintsova, 2013), the number of the PH in mid-2000s increased by 3–4 times².

However this was less than might have been as the relative increase rate dropped down from 20–30 % in 2000–2002 to 3–12 % (or even negative) in 2005–2007 (recalculated on: Zharkikh, Yasinetska, 2009; Yasinetska, Zvegintsova, 2013). The earlier researchers explained the decline in rate of growth in PH numbers as a consequence of poaching and the subsequent changes in the population structure (i.e. the loss of fertile individuals). It temporary undermined the reproductive potential, and postponed further growth. However, the total herd reached ca. 60–70 individuals by 2008.

² Results depend on calculation method (totally 28 PH were released in CEZ in 1998–1999, but only 17 of 20 survived founded the further herd), and how close the census 2005–2008 was to real situation.

Further attempts of PH census in 2010–2013 were not complete, and the researchers admitted an underestimation (Slivinska, Zharkikh, 2012, Yasinetska, Zvegintsova, 2013).

In order to assess where the latest (2018) estimate is in respect to the previous trends we have to compare with 'cumulative' results for the periods 1998–2008 and 2009–2018. So, if the initial herd amounted to 20–28 PH, and grew up to 60–70 in 2008 (Slivinska, Zharkikh, 2012, Yasinetska, Zvegintsova, 2013), there was a relative increase of 110–250 % over the 10-year period.

The next 10 years gave only a 100–140 % increase (comparison of our data with the earlier published data mentioned above). It is unlikely that this decrease can be explained by human activity as few facts with regard to poaching were recorded and confirmed in the period 2009–2018.

Table 2. Structure of PH herd on the sites of CEZ revealed in May–July 2018.

Таблиця 2. Структура поголів'я КП за ділянками ЧЗВ, визначена у травні-липні 2018 р.

Locality	Identified individuals associated with the locality								Unknown individuals			Total	Herd
	m alpha	m 2-3	m 1	m 0	f ad	f 2-3	f 1	f 0	ad m	ad f	imm 0		
L01	1		1									2	S
L03	1		1	4	8		2					16	H
L04	1		1		3			1				6	H
L05									(2)			0	
L06									1	8	3	12	H
L07	2	1							(5)			3	S
L08	1			1	2	1		1				6	H
L09	1 (11)			(1)	(1)							1	
L10	1 (5)			1	3 (1)	1	1					7	H
L11	1				1			1		(1д.)		3	H
L12	1 (2)			(1)	1 (1)							2	G
L13	(1)				(1)				(2)			0	
L14	(1)		(1)	(3)	(7)		(1)					0	
L15	1		1	3	7		1					13	H
L16	2 (6)											2	S
L17	1		1		3							5	H
L18	(1)		(1)		(3)							0	
L19	1		1		2						1	5	H
L20									1	5	4	10	H
L21	1				2							3	G
L22	1 (6)	1							(1)			3	G
L23	(1)						(1)					0	
L24	(2)	(1)	(1)		(3)	(2)						0	
L25	1 (6)	1	1	1	3	1		1				9	H
L26	(1)	(1)	(1)	(1)	(3)	(1)		(1)				0	
L27									1	7	2	10	H
L09/L16/L21/L22/L25	6											6	S
L09/L10/(Nova Krasnytsia?)	5											5	S
L07/ (Belarus?)									5			5	S
Vesniane/Vilshanka					3							3	H
Borschiovka (Belarus)									1	2	1	4	H
Totally	29	3	7	10	36	4	4	4	9	24	11	141	

Note. Age-gender groups: 'm alpha' — dominant stallion in herd, 'm 2-3' — 2-3 year old male in harem herd, 'm1' — 1 year old male, 'm0' — foal male, 'f ad' — mature mare, 'f 2-3' — 2-3 year old mare, 'f1' — 1 year old mare, 'f0' — foal female, 'ad m' — stallion 1 year and older, 'ad f' — mare 1 year and older, 'imm0' — foal. '(...)' — in brackets PH not included into census of the given locality. Herd: H — harem herd with foal (except L17/L18, where no foal), G — small group of 2–3 individuals of different gender, no foal, S — stallion group.

Table 3. Change in the age composition of the PH mare population in the Chernobyl herd in 1998–2008. Calculated on data of annual offspring size (Zharkikh, Yasinetska, 2009), and on an assumed 1:1 gender ratio in the offspring and no mortality in the population.

Таблиця 3. Зміна вікового складу кобил чорнобильського поголів'я у 1998–2008 роках. Розраховано за даними про щорічний розмір приплоду (Zharkikh, Yasinetska, 2009) та припущення, що статеве відношення у приплоді складає 1:1, і немає смертності у популяції.

Year of birth (total foals)	Year of the assessment										
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
	Age composition of females, year old										
	1	2	3	4	5	6	7	8	9	10	11
1998 (3)	1										
1999 (1)	1	1									
2000 (6)	3	1	1								
2001 (12)	6	3	1	1							
2002 (14)	7	6	3	1	1						
2003 (13)	6	7	6	3	1	1					
2004 (12)	6	6	7	6	3	1	1				
2005 (10)	5	6	6	7	6	3	1	1			
2006 (8)	4	5	6	6	7	6	3	1	1		
2007 (6)	3	4	5	6	6	7	6	3	1	1	
2008 (11)	6	3	4	5	6	6	7	6	3	1	1
Number of mares from founding population	15	15	15	15	15	15	15	15	15	15	15
Total number of mares (3 y and older)	15	15	16	17	20	26	33	39	45	50	54
Percentage of total mares who are 3–5 years old	0,0	0,0	6,3	11,8	25,0	38,5	48,5	48,7	42,2	34,0	27,8

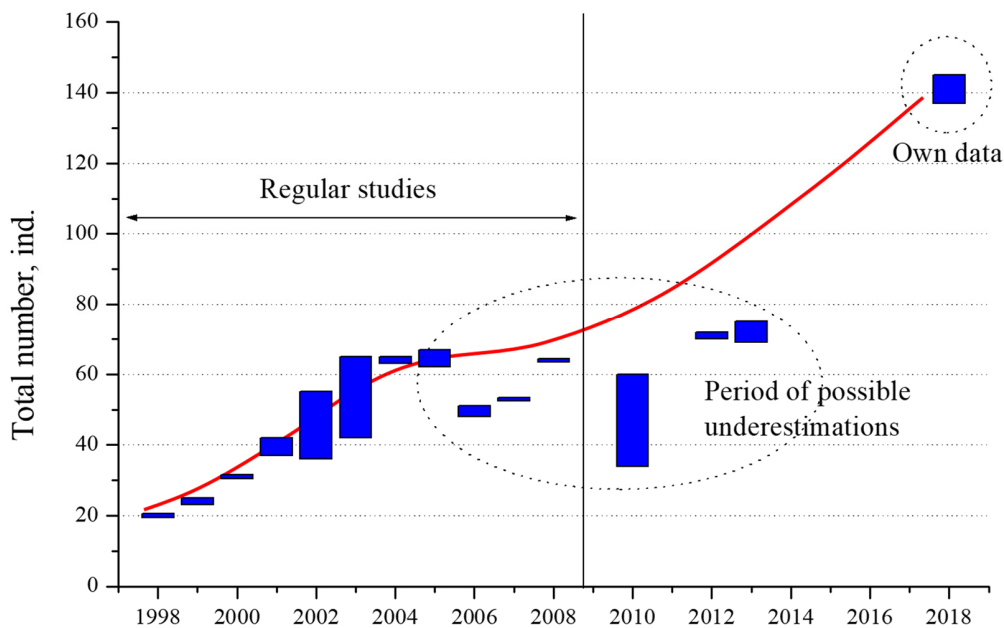


Fig. 10. Long-term dynamics of the Przewalski's horse population in CEZ based on published (Zharkikh, Yasinetska, 2009, Slivinska, Zharkikh, 2012, Yasinetska, Zvegintsova, 2013) and our own data.

Рис. 10. Багаторічна динаміка чисельності КП у ЧЗВ за літературними (Zharkikh, Yasinetska, 2009, Сливинская, Жарких, 2012, Ясинецкая, Звегинцова, 2013) і власними даними.

It appears to be probable that more natural reasons (inbreeding, age changes in the population structure) contributed to the slowed growth.

Contrary to the 'Askania-Nova' Biosphere Reserve no selective culling, removal of individuals or introduction of new animals has occurred in the CEZ. Stallions head the groups regardless own fertility, and perhaps absence of foals in 4 of 17 heterosexual groups is just on infertility of some males. There was evidence of hybridization with domestic horses. At least two males (stallion and colt) recorded in 2018 had clear signs of hybridization. Many other individuals to different extents deviated from PH 'standards'. A domestic horse joined a PH herd in village Ilinty in May 2018 and became pregnant soon afterwards following mating with a PH stallion. Although hybrids are known to sometimes be fertile this is not always the case (Steklenev, 1999), consequently, their participation in development of the population is constrained.

On our data, not all mature mares (> 3 y.o.) gave birth in 2018 (only 39 %). However, in 1999–2003, when only mature mares of the first generation from 'Askania-Nova' participated in the reproduction, it ranged ca. 4–40 % (20 % average) (Zharkikh, Yasinetska, 2009; Yasinetska, Zvegintsova, 2013). Thus, the reproductive potential in 2018 was similar as the highest rate observed in the past.

Gender ratio in the whole herd in 2018 was 1:1.2 for males and females, respectively. Unfortunately, the earlier published data (Zharkikh, Yasinetska, 2009; Yasinetska, Zvegintsova, 2013) do not give detailed information to compare. Gender ratio in the offspring in 1998–2008 was close to 1:1 (Zharkikh, Yasinetska, 2009), however in 2018 among those foals which were identified ($n = 14$) males predominated (1:0.25).

Data from 1998–2008 (Yasinetska, Zvegintsova, 2013) showed the size of PH groups gradually reduced from 6–25 to 3–16 individuals per herd (similar to our data from 2018). Groups of 2–5 adults were more consolidated and stable than bigger herds. All large harem herds (6–9 adults) exhibited internal tension, had sub-groups, and from time-to-time the herds divided.

Knowledge of how PH interact with the local environment (vegetation, soil, water objects, landscapes, predators, etc.) is preliminary and the species is mostly unstudied in the CEZ. The PH are settling to the conditions which are not native for them, but it is possible that some factors (e.g. availability of suitable habitat) which are constraining the populations.

The spatial distribution of PH had not changed much compared with 10-year old data (Zharkikh, Yasinetska, 2009). The only exception was the expansion northward, onto Belorussian territory and founding a sub-herd on the opposite bank of Prypiat river.

It is unclear how the PH crossed the river (100–200 m width at low water), both swimming and ice passage present challenges; there are no bridges in the area where PH have established on the opposite bank of the Prypiat.

Our knowledge of the spatial distribution is likely conservative, and correspond to the belief (based on native habitats for the species) that PH prefer open landscapes (meadows). However, undoubtedly the animals do not avoid woodlands. They escape into thickets at danger, or cross large wood stands to get to new meadows or water places. We recorded horses several kilometres into the forests distant from meadows. Forest as a feeding place is not excluded. Footage obtained during the study revealed that PH sometimes eat branches of trees and shrubs. The utilisation of forest by PH should be studied.

Although CT are not flawless, and are not able to totally replace the direct observations of researcher in some circumstances, they are a powerful tool considerably expanding capabilities for the PH (and other) studies, especially in the large forested territory of the CEZ. Studies in 2018 showed growth of the PH population, and the likely good status of the species, and suggests its fitness to the local conditions. However, the study revealed unclear or unknown aspects of the ecology and biology of the PH in the CEZ (e.g. territorial and forage behaviour, interaction between herds, formation and dividing of the herds, etc.).

Further work would answer these questions and help to understand the prospects of this species in the region.

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References

- Akimov, I. A. (ed.). 2009. *The Red Data Book of Ukraine. Animals*. Hlobkonsaltnyh, Kyiv, 1–600. (In Ukrainian)
- Burton, A.C., Neilson, E., Moreira, D., Ladle, A., Steenweg, R., Fisher, J.T., Bayne, E. and Boutin, S. 2015. Wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. *J. Appl. Ecol.*, **52**: 675–685. doi:10.1111/1365-2664.12432
- Deriabina, T. G. 2013. Przewalski’s horse (*Equus przewalskii* Poljakov): observation results of an invasive species // Ecosystems and radiation: aspects of being and development: Collection of articles. Ed. by Y. I. Bondar. Institute of Radiology, Minsk, 301–308. (In Russian)
- Development ... 2006. *Development Project for the Forestry of the State Specialized Integrated Enterprise "Chernobyl Puschcha*. Ukrainian state engineering forest management production association. Integrated expedition. Irpin. (In Ukrainian)
- Gaschak, S. P. 2008. About an experience of automatic photography of wild animals in Chernobyl zone. In: Zagorodniuk, I. (ed.). *Rare Theriofauna and Its Conservation*. Luhansk, 28–36. (Proceedings of the Theriological School. Vol. 9). (In Ukrainian)
- Gashchak, S. P., Y. O. Gulyaichenko, N. A. Beresford, M. D. Wood. 2016. Brown bear (*Ursus arctos* L.) in Chernobyl exclusion zone. *Proceedings of Theriological School*, **14** 71–84.
- Gashchak, S. P., Y. O. Gulyaichenko, N. A. Beresford, M. D. Wood. 2017. European bison (*Bison bonasus*) in the Chernobyl exclusion zone (Ukraine) and prospects for its revival. *Proceedings of Theriological School*, **15**: 58–66.
- Schlichting, P. E., C. N. Love, S. C. Webstera, J. C. Beasley. 2019. Efficiency and composition of vertebrate scavengers at the land-water interface in the Chernobyl Exclusion Zone. *Food Webs*. **18**: e00107.
- Slyvinska, K. A. 2005. Przewalski’s horse (*Equus przewalskii* Pljakov, 1881) in conditions of the Chernobyl exclusion zone. *Bulletin of Ecological State of the Exclusion Zone and Zone of Unconditional (Compulsory) Resettlement*, No. 1 (25): 37–41. (In Ukrainian)
- Slyvinska, K. A., L. S. Balashov. 2006. Phytocenotic composition of forage habitats of Przewalski’s horse (*Equus przewalskii* Poljakov, 1881) in conditions of Chernobyl exclusion zone. *Ukraine Botanical Journal*, **63** (1): 22–30. (In Ukrainian)
- Slyvinska, Y. A., T. L. Zharkikh. 2012. Census results of Przewalski’s horse population in the exclusion zone of Chernobyl NPP in 2011. *Topical Questions of Natural Sciences and Methods of Teaching* (to 70th anniversary of a researcher and teacher I. I. Kocherga). Publishing house of M. Gogol Nizhyn State University, Nizhyn, 114–115. (In Russian).
- Sokur, I. T. 1961. *Historical Changes and Use of Mammals Fauna in Ukraine*. Publ. House of AS Ukr. SSR, Kyiv, 1–84. (In Ukrainian).
- Steklenev, E. P. 1999. Reproductive characters of Przewalski horse and domestic horse hybrids. In: Akimov, I. (ed.). Przewalski’s horse (*Equus przewalskii* Poll., 1881). Problems of preservation and reintroducing in nature area: Proceedings of the VI International symposium of the preservation of the Przewalski horse, dedicated to centenary of the species breeding in ‘Ascania Nova’ reservation. *Vestnik of zoology*, Supp. 11: 202–203.
- Zharkikh, T. L., N. I. Yasynetska. 2009. Ten yeas of development of the Przewalski horse population in the Chernobyl Exclusive Zone. *Equus*, 139–156.
- Zharkikh, T. N., N. I. Yasynetska, A. N. Borovsky, N. S. Zvegintsova. 2002. Study of Przewalski’s horse population in the zone of the Chernobyl NPP. *Bulletin of Moscow Society of Nature Investigators. Division of Biology*, **107** (5): 9–16. (In Russian)
- Zvegintsova, N. S., T. L. Zharkikh, N. I. Yasynetska. 2008. Dynamics of infection with Strongylidae of the Przewalski horse (*Equus przewalskii*) population in the Chernobyl exclusion zone. *Vestnik of Zoology*, **42** (5): 455–460.
- Yasinetska, N. I. N. S. Zvegintsova. 2013. Structure and modern state of Przewalski’s horse population in the zone of ChNPP. *Visti of Biosphere Reserve Askania-Nova*, **5**: 203–211. (In Russian)