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DISTRIBUTION AND MINIMUM POPULATION SIZE OF EURASIAN LYNX (*Lynx lynx*) IN CROATIA IN THE PERIOD 2018–2020

RASPROSTRANJENOST I NAJMANJA VELIČINA POPULACIJE EUROAZIJSKOG RISA (*Lynx lynx*) U HRVATSKOJ U RAZDOBLJU 2018.–2020.

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SUMMARY

Scientific data on distribution and abundance of endangered species are the foundation for their effective conservation and management. In this paper, we present results of the first scientifically – based estimation of lynx population size in Croatia. The goal of the study was to determine the area of lynx distribution and to estimate the minimum size of lynx population in Croatia in the period 2018 - 2020. To determine lynx distribution, 902 signs of lynx presence were collected in the period from the beginning of May 2018 until the end of April 2020. Out of those, 92.8% of lynx observations were categorized as C1, 2.8% as C2 and 4.4% as C3. Permanent lynx presence was confirmed in Primorsko – Goranska and Ličko – Senjska county, in southern part of Karlovac county and north-eastern part of Zadar county on the total surface of 7200 km2. For the minimum population size estimation, 804 camera trap photographs led to identification of 89 – 108 adult lynxes. Among 108 identified individuals there were 29 females, 22 males, while for 7 animals the sex was not determined. During the two reproductive seasons, we photographed 44 cubs in 25 litters. Future important steps in lynx population monitoring are correcting the deficiencies identified in this study and implementation of methodology that will allow us to use spatial capture recapture models for estimation of lynx abundance in Croatia.

KEY WORDS: distribution, abundance, *Lynx lynx*, minimum population size, Croatia

INTRODUCTION
UVOD

Population monitoring implies repeated, standardized assessment of indicators that reveal ecologic processes, and is carried out within a defined area over a specified period of time (Thompson et al. 1998). The term itself is used in very different contexts - from collecting data for assessing population status to planning of interventions (e.g. highway construction or species reintroduction, hunting quotas). Population monitoring is an indispensable activity in the management of a certain population and has a key role in

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the management of protected wild species, where the goal of monitoring is to determine the efficacy of conservation actions (Breitenmoser et al. 2006). Monitoring objectives must be clearly defined to decide which indicators should be monitored and which methods should be used. Basic monitoring involves collecting data on the distribution, abundance and density of the population and their changes over time. This serves as a foundation for efficient population management (Thompson et al. 1998).

The Eurasian lynx (*Lynx lynx*) is protected in Croatia by the Ordinance on declaring protected and strictly protected wildlife species (Official Gazette No 144/13, 73/16) and it is listed as critically endangered (CR) on the IUCN Red List of Threatened Species. Habitats Directive (92/43/EEC) lists Eurasian lynx on Annexes II and IV, requiring strict protection and population monitoring. For the Habitat Directive reporting period 2013-2017, the conservation status of the lynx population in the Alpine region in Croatia was evaluated as unfavorable - bad (U2), while the situation in the Continental and Mediterranean region was assessed as unfavorable - inadequate (U1) (Anonymous 2019). The loss of genetic diversity is considered as the most important threat to lynx in Croatia, as the entire Dinaric population originated from six reintroduced animals (Sindičić et al. 2013). Decrease in population size was also invigorated by high human – induced mortality (Sindičić et al. 2016), while lack of appropriate management indirectly influenced the unfavorable status of lynx population in Croatia (Sindičić et al. 2019).

With the development of technology, photo traps became the most effective and cost-efficient methodology for monitoring lynx population (Rovero and Zimmerman 2016). In Croatia first lynx monitoring activities using automatic cameras (camera traps) were conducted in Gorski Kotar in the 2011 – 2014 period (Kusak 2012; Kusak and Modrić 2012; Kusak et al. 2013, Kusak et al. 2014),while wide – scale population monitoring with camera traps is in place since 2018 within the project LIFE16 NAT/SI/000634 "Preventing the Extinction of the Dinaric-SE Alpine Lynx Population through Reinforcement and Long-term Conservation" (acronym LIFE Lynx) (Sindičić et al. 2018).

In this paper, we present results of the lynx population monitoring in Croatia for the period 2018 - 2020. The goal of the monitoring was to determine the lynx distribution area and to estimate the minimum size of the lynx population in Croatia.

MATERIALS AND METHODS
MATERIJALI I METODE

Signs of lynx presence were collected for two years, from 1st of May 2018 until 30th of April 2020. This period overlaps with two "lynx years" defined as period from the beginning of May to end of April, since kittens are mostly born in May and leave the mother in April of the following year (Zimmerman et al. 2005). All available observations from all possible sources, including photos, mortality, sightings, lynx prey, footprints and samples collected for DNA analysis (feces, urine, hair) were archived in Faculty of Veterinary Medicine University of Zagreb database (Gomerčić 2017), which is publicly available on the internet address http://lynx.vef.hr. Each sign of lynx presence was registered with information about location and time, provider of the information and was categorized according to SCALP criteria (Breitenmoser et al. 2006):

Collected data was mapped using program QGIS (QGIS.org 2020). Lynx distribution was determined on a 10 x 10 km Pan-European grid (European Environmental Agency 2017), with permanent presence confirmed for quadrants in which lynx was recorded based on at least one C1 observation or two C2 observations. Quadrants with only one C2 observation were defined as areas of sporadic presence, while quadrants with only C3 observations were defined as areas of possible presence but without solid evidence (Kusak et al. 2016). Total surface of permanent, occasional and areas of possible lynx presence in Croatia were calculated by summing the surface of quadrants with predefined observations.

For the estimation of minimum population size a network of camera traps was set in Gorski kotar, Lika and northern Dalmatia - areas previously defined as lynx distribution area in Croatia (Sindičić et al. 2010). Three additional camera traps were placed on Pelješac, as we wanted to check several undocumented reports of lynx sightings on the peninsula. For optimal camera trap placement, we used 10 x 10 km grid cells and a lynx sensitivity (presence probability) map produced by Kusak et al. (2016). At least one non-baited camera trap was placed within each 10 x 10 km grid cell, while cells that were categorized by Kusak et al. (2016) as unsuitable or low suitably for lynx were excluded from the research. To maximize lynx detectability camera traps were set at optimal locations within cells, where landscape and terrain features were likely to channel lynx movements, like lynx marking sites, forest roads and game paths. Those locations were identified based on previously archived observations of lynx presence and with the help of local hunters and rangers. Different brands and models of camera traps with active infrared sensor and infrared flash were used, set to capture one photo and 30 seconds of video or three photos without the video. During the period May 2018 - April 2020, camera traps were set at 182 locations. Although camera traps were intended to stay at each location all year round, due to malfunctions, theft and snow coverage some of them were not active during the entire research period on the selected location. We checked camera traps at least

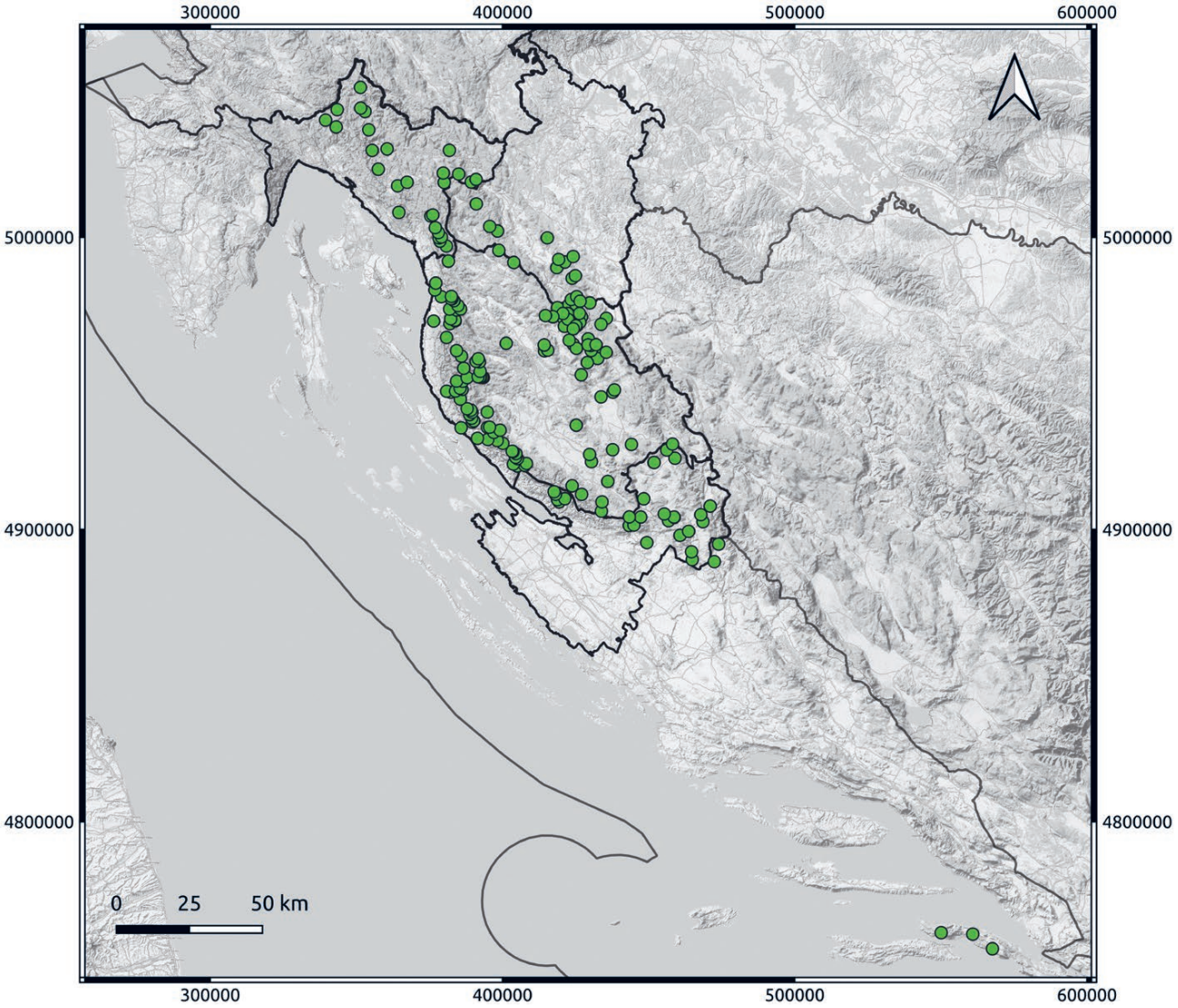

Figure 1. Locations of camera traps used for lynx monitoring in Croatia in the period 1st of May – 30th of April.
Slika 1. Lokacije fotozamki korištene za monitoring risa u Hrvatskoj u razdoblju 01. svibnja 2018. – 30. travnja 2020.

every two months to change memory cards and batteries. Images were processed in program Camelot (Hendry and Mann 2017) and for each event, the species, number of animals, age category (juvenile or adult) and sex was defined, while empty photos were erased. An event is defined as one visit of animals lasting 10 minutes during which several photos and videos could be taken. Lynx photos were additionally archived in http://lynx.vef.hr database.

Opportunistically collected photos of lynx from other sources (i.e. from hunters, institutions for management of protected areas, private persons, as well as from company Geonatura Ltd. comprising results of preconstruction monitoring for windfarm "Lički medvjed" financed by Green Trust Energy Ltd., Split) were also included in the analysis.

Lynx from the Dinaric population have coats with rosettes, large and small spots, while coats without spots are not present (Topličanec et al. in press). Unique coat pattern of lynx in Dinaric population enabled the identification of individuals by visual comparation. Each newly photographed individual was compared with reference photographs of individuals belonging to the same coat pattern type until all photographs of the individuals within the database have been checked. When both flanks of the same individual are known lynx gets a unique identifier (Rovero and Zimmerman 2016). If for a new animal we have photos of one flank only then we cannot connect which right and left flank belong to the same individual. For example, if we have five lynxes with left flank photos only and five lynxes with right photos only, this could be the same five animals or ten different animals. That is why our estimation of the minimum population size has a span. Animals' gender was determined from photographs in cases when the genital area was captured or female was recorded with cubs. For some animals, gender and age were determined when they were captured during the radiotelemetry re-

Table 1. Observations of Eurasian lynx presence in Croatia in the period 1st of May 2018 - 30th of April 2020.
Tablica 1. Pregled znakova prisutnosti Euroazijskog risa u Hrvatskoj u razdoblju 1. svibnja 2018. – 30. travnja 2020.

Type of observation *Vrsta znaka prisutnosti*	Season (May 1 – April 30) Sezona (01.05. – 30.04.)		Total	SCALP category *SCALP kategorija*		
	2018-2019	2019-2020		1	2	3
Photography – *Fotografija*	345	459	804	802		2
Captured animal – *Uhvaćena životinja*	1	5	6	6		
Mortality – *Smrtnost*	2	2	4	4		
Footprint – *Otisak šape*	12	9	21		20	1
Hair – *Dlaka*	11	14	25	14		11
Prey – *Plijen*	1	5	6		5	1
Scat – *Izmet*	5	10	15	10		5
Urine – *Urin*	4	1	5			5
Sighting – *Viđenje*	10	6	16			16
Total – *Ukupno*	391	511	902	836	25	41

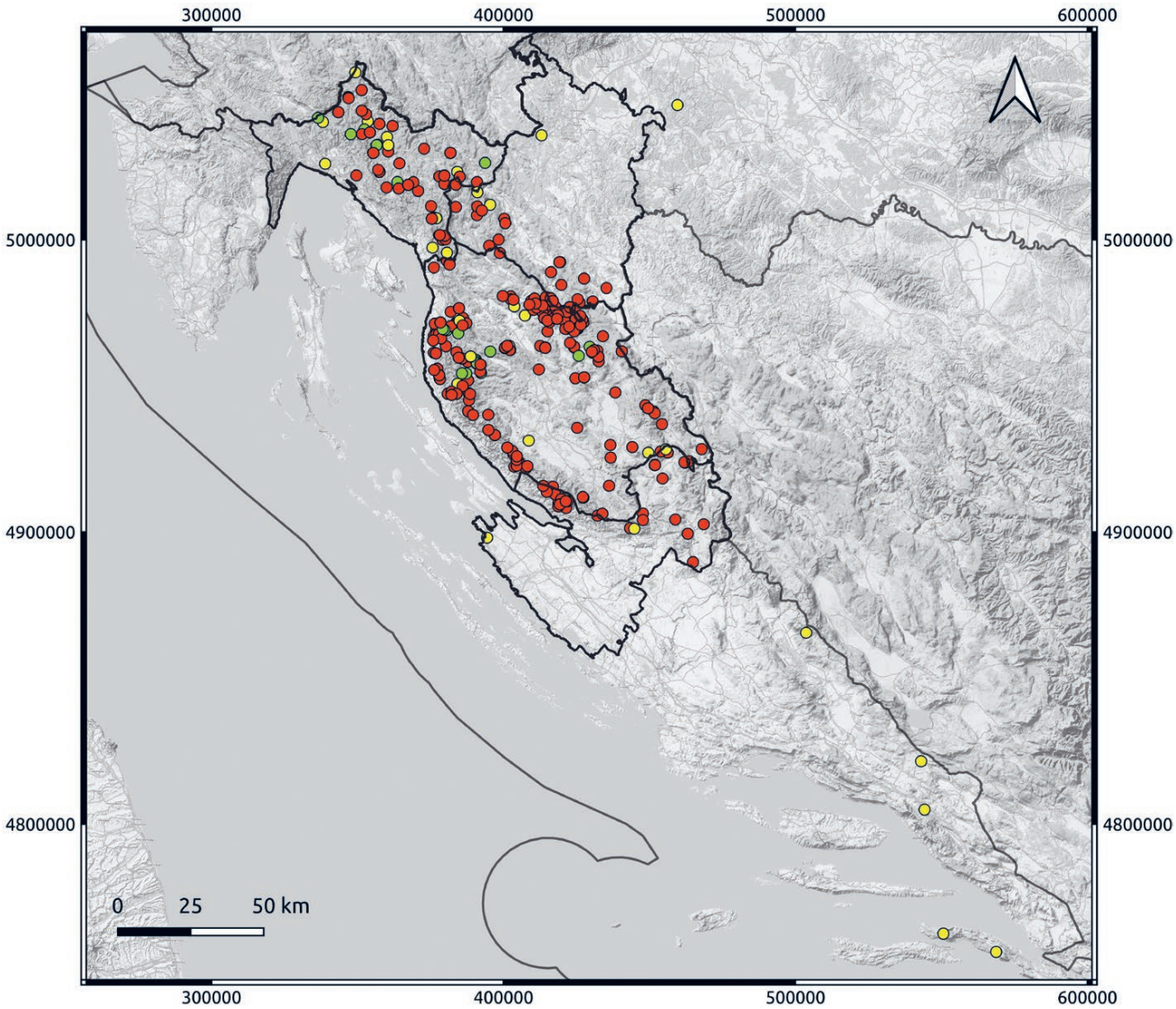

Figure 2. Signs of lynx presence in Croatia collected in the period 1st of May – 30th of April. C1 observations are presented with red dots, C2 – green dots, C3 observations – yellow dots. Black lines define borders of Croatian counties – Primorsko - Goranska, Ličko – Senjska, Karlovačka and Zadar county.
Slika 2. Znakovi prisutnosti risa u Hrvatskoj prikupljeni u razdoblju 1. svibnja 2018. – 30. travnja 2020. C1 prisutnost je predstavljena crvenim točkama, C2 – zelene točke, C3 – žute točke. Crne linije obilježavaju granice hrvatskih županija – Primorsko-goranska, Ličko-senjska, Karlovačka i Zadarska županija

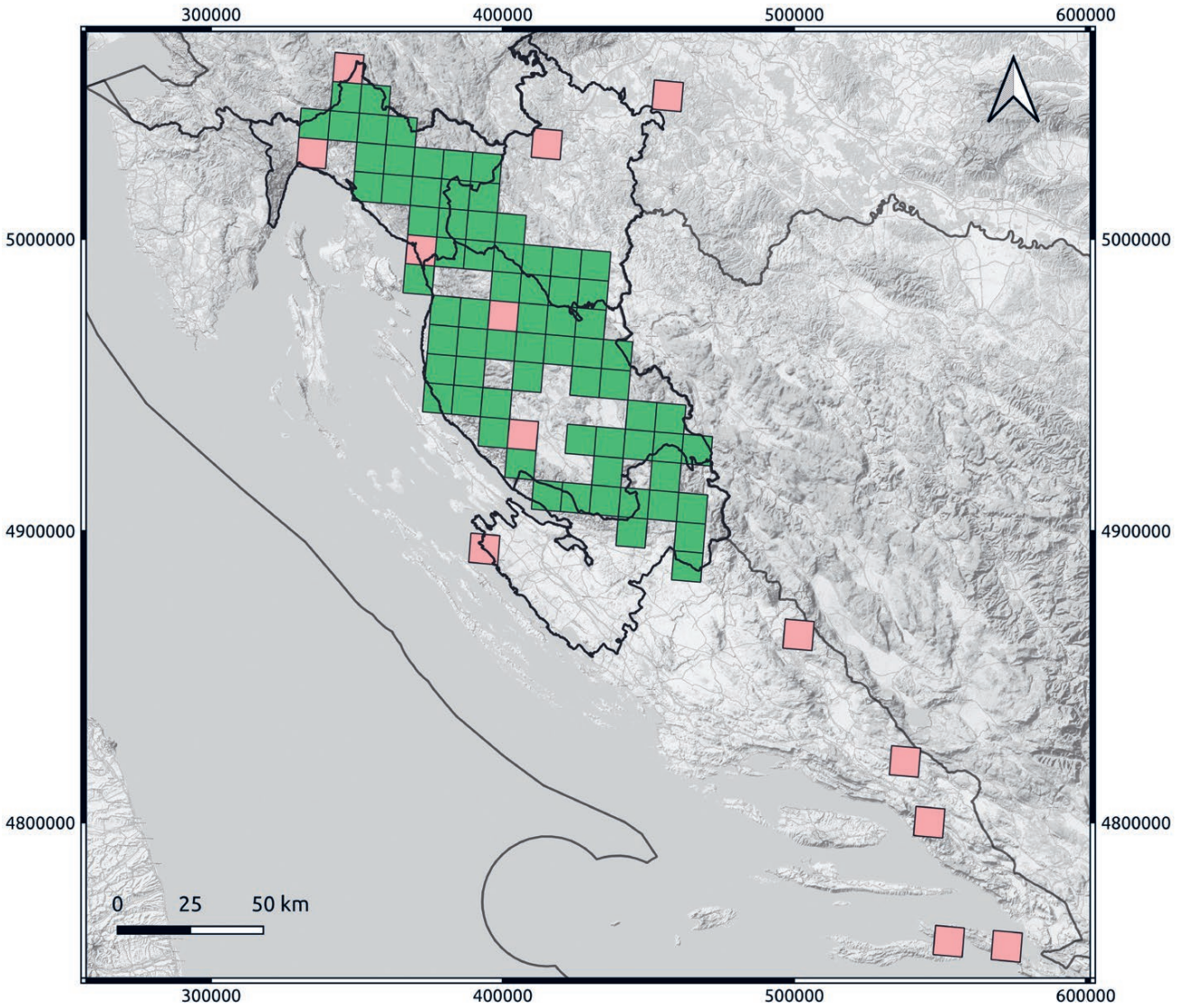

Figure 3. Lynx distribution in Croatia for the period 1st of May – 30th of April. Squares marked in green represent the area of permanent distribution, while squares colored in red represent the area of possible, unconfirmed distribution. Black lines define borders of Croatian counties – Primorsko - Goranska, Ličko – Senjska, Karlovačka and Zadar county.

Slika 3. Rasprostranjenost risa u Hrvatskoj u razdoblju 1. svibnja 2018. to 30. travnja 2020. Kvadrati označeni zeleno predstavljaju područje stalne prisutnosti, dok crveni kvadrati predstavljaju područja moguće, nepotvrđene rasprostranjenosti. Crne linije obilježavaju granice hrvatskih županija – Primorsko-goranska, Ličko-senjska, Karlovačka i Zadarska županija

search, or when found dead. Individuals were categorized as adults or kittens, when photographed with an adult (mother).

This estimation of minimum population size does not include lynxes that were released in Croatia within LIFE Lynx project. Out of seven lynxes released in Croatia and Slovenia in 2019 and 2020, two males – Alojzije and Boris, established their territories in Croatia.

RESULTS
REZULTATI

A total of 902 records of lynx presence were collected in Croatia in the period from 1st of May 2018 until 30th of April 2020 (Table 1). Out of those, 92.7% of observations were categorized as C1, 2.8% as C2 and 4.5% as C3.

Permanent lynx presence was confirmed in Primorsko – Goranska and Ličko – Senjska county, in south part of Karlovac county and north-eastern part of Zadar county on the total surface of 7100 km^2. Areas of occasional presence were not registered according to the used methodology, while on the surface of 1300 km^2 lynx signs of presence were recorded as C3 observations, i.e. those which could not be verified. Those include Pelješac peninsula, then mountains Biokovo and Dinara, which are apart from the core of the permanent distribution range in Croatia but are bordering to lynx distribution area in Bosnia and Herzegovina (Anonymous 2018).

Table 2. Number, sex and age of lynxes identified in Croatia in the period 1st of May 2018 – 30th of April 2020
Tablica 2. Broj, spol i starost risova identificiranih u Hrvatskoj u razdoblju 1. svibnja 2018. – 30. travnja 2020.

Number of identified lynx *Broj identificiranih risova*		Season *Sezona*	
		2018-2019	2019-2020
Adults *Odrasli*		52-62	69-82
Kittens *Mladunčad*		21	23
Sex (adults) *Spol (odrasli)*	Male *Mužjak*	14	19
	Female *Ženka*	21	24
	Unknown *Nepoznato*	27	39
	Both *Obije*	39	50
Photographed body side *Fotografirana strana tijela*	Left *Lijeva*	10	13
	Right *Desna*	13	19

The total effort of lynx recording by camera traps at 182 locations was 31710 camera-trap days or on average, camera traps were active at each location for 163.13 days. Those camera traps recorded 687 lynx events, while 117 records were obtained from other sources.

During the 2018 - 2019 season we identified 39 adult lynxes based on both sides of the body, while additional ten individuals were identified based only on the left body side and 13 based only on the right body side. We identified 21 females and 14 males, while sex could not be identified for 27 animals. If we assume that none of the animals photographed only from the right side matches the one photographed from the left side, then the maximum number of adult animals identified in the season 2018 – 2019 was 62. However, if all 13 lynxes photographed only from the right side match the animals photographed only from the left side, then the minimal number of identified lynxes was 52.

During the 2019 – 2020 season, we identified a minimum of 69 and a maximum of 82 adult animals; 50 lynxes were identified based on both sides, while additional 19 individuals were identified based only on the right and 13 more based only on the left body size. We could identify 24 females and 19 males, while for 39 individuals sex could not be determined. Out of 82 individuals identified in 2019-2020 season, 36 (43.9%, 35 adults and one kitten) of them were already known for the season 2018-2019.

We identified a total of 89 – 108 different adult animals during both seasons. Out of those, 61 were identified from both sides, 28 from the right and 19 only from the left flank. Among 108 adult individuals there were 29 females, 22 males and 57 animals of unknown sex. A total of 30 animals (27.8% out of 108) were observed only once, while three lynxes with the highest number of observations were observed 46, 21 and 20 times.

We compared the identified animals with data from Slovenia (Fležar et al. 2019), and found that seven animals were recorded both in Croatia and Slovenia.

During the two seasons, we photographed 44 kittens belonging to 25 different litters. There were two cases of females with three kittens, 15 cases of females with two, and we recorded a single kitten in eight cases. Seven offspring from the 2018-2019 season could be identified based on their coat pattern (five based on both sides, two by the right side only). Only one kitten from the first study season was recorded in the second season as an adult individual.

DISCUSSION
RASPRAVA

Scientific data on distribution and abundance are the foundation for effective population management (Breitenmoser et al. 2006). Since the reintroduction of lynx to Slovenia in 1973 lynx monitoring in Croatia was mainly limited to the mortality records (Frković 2001). Only in the early 2000s research and monitoring of various aspects of lynx biology and ecology started (Gomerčić et al. 2009; Gomerčić et al. 2010, Kusak 2012). Even though, one of the goals of Croatian lynx management plan for the period 2010 – 2015 was to establish a national monitoring system (Sindičić et al. 2010), this was achieved only in 2018 as combined effort of LIFE Lynx project implementation (Sindičić et al. 2018), lynx monitoring in protected areas (especially National park Plitvice lakes and Nature park Velebit), cooperation with numerous hunting grounds and wildlife monitoring contracts of company Geonatura Ltd. Since at the beginning of this study almost 10,000 km^2 was considered as potential lynx distribution area in Croatia (Sindičić et al. 2010), the first challenge of our research was to establish monitoring of an elusive species over such a large area. Weingarth et al. (2015) advise that when establishing monitoring in a new area, a survey should be carried out for as long as possible and then optimize the methodology for future monitoring based on the collected data. Therefore, we established our monitoring system over the entire assumed area of lynx distribution in Croatia with photo traps active throughout the year, to record as many different individuals as possible and get a basic insight into the population demography. Afterwards, based on this data, we can plan the optimal methodology for future lynx monitoring and perform more accurate estimate of population size (e.g. using the spatial capture-recapture model).

To determine the number of lynxes in Central European populations, it is recommended to use a 2.7 x 2.7 km cell grid (Zimmermann et al. 2013), while in the Slovenian part of the Dinaric population, a 3 x 3 km grid was used (Fležar et al. 2019). In this study, it was not possible to cover the entire study area with recommended density of camera traps, due to the financial limitations. Moreover, areas of Kapela and Velebit mountains were partly not accessible due to the danger of mine fields. Therefore, our results present the minimum and not the actual number of lynx individuals present in Croatia in the studied period. Until now, results of population census using camera traps were published for several Eurasian lynx populations. The largest dataset comes from Switzerland, where monitoring with camera traps started already in 1999 (Pesenti and Zimmermann 2013). Weingarth et al. (2012) used camera traps for the estimation of lynx population size in German National park Bavarian forest, Blanc et al. (2013) we considered 4 scenarios comparing low versus high detection probability and small versus large populations and contrasted abundance estimates obtained from both approaches. Standard CR and SECR models both provided minimally biased abundance estimates, but precision was improved when using SECR models. The associated confidence intervals also provided better coverage than their non-spatial counterpart. We concluded SECR models exhibit better statistical performance than standard closed CR models and allow for sound management strategies based on density maps of activity centers. To illustrate the comparison, we considered the Eurasian lynx (Lynx lynx) implemented their research on French Jura Mountains, while Gimenez et al. (2019) estimated lynx population size in French part of Jura and Voges in the period from 2011 until 2016. In these studies, camera traps were active between two and four months per year, mostly during the winter months (January – April), but area of survey were much smaller than the area covered in this study. One of the challenges of population monitoring on such a large area arises from the different terrain configuration and the differences in previously available data for certain areas. For instance, we noticed differences in the quality of results between the two geographical areas - Gorski kotar (i.e. Primorsko - Goranska county) and Lika (i.e. Ličko-Senjska county). In Gorski kotar, a significant number of marking sites were known from previous research period (Kusak 2012; Kusak and Modrić 2012; Kusak et al. 2013; Kusak et al. 2014), while in Lika (except northern Velebit and Plitvice Lakes National Park) photo-traps have never been used before to monitor lynx. As a result, in Gorski kotar (where most of camera traps are placed on marking sites) we have a higher percentage of animals identified based on both flanks, and a lower proportion of animals of unknown sex and those recorded only once. To reach this level of data reliability in Lika, it is necessary to enhance our camera trap network, what was not been possible in all locations within this study.

During the two seasons, we identified a total of 89 - 108 adult lynxes. During the second season (2019-2020) we determined that a minimum of 69 - 82 adult lynxes were present in Croatia. The fact that we conducted monitoring throughout the year and had a high percentage of animals recorded only once (27.8%), indicate that we recorded a certain number of individuals in dispersion. Probably those individuals did not establish a territory in Croatia but were recorded in their search for territory or during the mating season. Another explanation for the low rate of repeated records could be insufficient detectability of lynxes caused by low density of camera traps in some areas, then also partly by eventually high turnover of lynx individuals in Dinaric population. Although 43.5% of individuals identified in 2018 - 2019 were not photographed during the 2019 - 2020 season, we cannot claim that all of those individuals perished from the population but probably some of them were not captured due to the low density of camera traps. Also, results of long-term monitoring in certain areas (Gorski kotar, northern Velebit) suggest that some animals are re-recorded (recaptured) after more than a year of absence from photo-traps (unpublished data).

The actual lynx number is more likely to be closer to older estimation of 130 lynxes (Firšt et. al. 2005), then to later estimation of 40 – 60 individuals (Sindičić et al. 2010). This wide variation in estimates illustrates the importance of properly designed and performed monitoring system. This research presents the first published scientifically – based estimation of lynx population size in Croatia. Thus, we cannot state that there was an increase in lynx population size in Croatia when we compare this study with past results. Future important steps in lynx population monitoring are correcting the deficiencies identified in this study and implementation of methodology that will allow us to use spatial capture recapture models.

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SAŽETAK

Znanstveni podaci o rasprostranjenosti i brojnosti temelj su za učinkovito upravljanje i zaštitu ugroženih populacija. U ovom radu predstavljamo rezultate prve znanstveno utemeljene procjene veličine populacije risa u Hrvatskoj. Cilj praćenja bio je utvrditi područje rasprostranjenosti risa i procijeniti najmanju veličinu populacije risa u Hrvatskoj u razdoblju 2018. - 2020. godine. U svrhu utvrđivanja rasprostranjenosti populacije, prikupljena su 902 znaka prisutnosti risa u razdoblju od 1. svibnja 2018. do 30. travnja 2020. Od toga je 92,8% podataka kategorizirano kao C1, 2,8% kao C2 i 4,4% C3. Trajna prisutnost risa potvrđena je u Primorsko-goranskoj i Ličko-senjskoj županiji, u južnom dijelu Karlovačke županije i sjeveroistočnom dijelu Zadarske županije, na ukupnoj površini od 7200 km^2. Za procjenu minimalne veličine populacije, prikupljene su 804 fotografije s fotozamki tijekom obje sezone te je identificirano 89 do 108 odraslih životinja. Među 108 identificiranih jedinki, bilo je 29 ženki, 22 mužjaka i 57 životinja nepoznatog spola. Tijekom dvije sezone fotografirali smo 44 mladunca u 25 legla. Budući važni koraci u praćenju populacije risa su ispravljanje nedostataka utvrđenih u ovoj studiji, kako bi se omogućila procjena brojnosti korištenjem modela prostornog hvatanja i ponovnog hvatanja jedinki.

KLJUČNE RIJEČI: rasprostranjenost, *Lynx lynx*, najmanja veličina populacije, Hrvatska