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Monitoring of Eurasian lynx (*Lynx lynx*) population in Croatia during the season 2022/2023

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ABSTRACT

The Eurasian lynx (*Lynx lynx*) is the third largest European carnivore, after the brown bear (*Ursus arctors*) and the grey wolf (*Canis lupus*), and the largest felid of the European continent. Towards the late 19th and early-20th century, lynx distribution has been significantly reduced in most European countries primarily due to direct persecution, environmental changes, and decrease in the population of wild ungulate prey. During the 1970s, the Eurasian lynx was reintroduced in several European states, including Slovenia in 1973. In the early 2000s, action plans for the conservation of European large carnivores were published and emphasized that more focused conservation in Western and Central Europe was necessary. Also, European experts agreed that standardized assessments of lynx population status in Europe were missing. In 2017, the EU LIFE Lynx project (LIFE16 NAT/SI/000634) was launched to prevent another extinction of the Eurasian lynx in the Dinaric mountains, and it focused on several aspects of lynx conservation, primarily translocations of individuals from Carpathian Mountains to Croatia and Slovenia.

The goal of this thesis was to monitor the Eurasian lynx population in Croatia during the season 2022/2023, as a part of implementation of the LIFE Lynx project. Since lynx is an elusive species and individuals are photo identifiable by the coat pattern, camera trapping was the main monitoring method used in this work. A total of 203 camera traps were placed in the study area in the period from 1st of May 2022 until 30th of April 2023. I visited LIFE Lynx camera traps at least every two months to replace memory cards and batteries and to check the settings.

To determine the main lynx population parameters, a total of 220 opportunistic data about signs of lynx presence, from various external sources, and 589 systematic data, from camera traps, were collected.

No lynx mortality was recorded in this season. Lynx presence was confirmed in the same core area as in the previous seasons, namely in Primorsko-Goranska and Ličko-Senjska County, north-eastern part of Zadar County, in the south of Karlovačka County, and, outside the core area, in the northern part out of Karlovačka County and on Dinara Mountain, on the total surface of 7300 km^2. The minimum population size was estimated to 79-91 adult lynxes, of which 27 identified individuals were females, 21 males, while for 43 animals the sex was not determined. A total of 26 kittens were identified, belonging to 18 different litters. Both minimum population size estimation and reproduction appeared higher than the previous seasons, but probably this was the consequence of increased monitoring effort. Moreover, the graphical representation of the life history of individual lynxes identified in the study period allowed to evaluate the monitoring success

of single animals, both adults and juveniles, through the years. Future recommendations are to continue monitoring activities with increased efforts, and to encourage the cooperation between wildlife research groups, local hunters, and public.

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INTRODUCTION

1.1 Eurasian lynx taxonomy and morphology

Genus *Lynx* is a monophyletic group comprising four species distributed along the northern hemisphere: the bobcat (*Lynx rufus*), the Canadian lynx (*Lynx canadensis*), the Iberian lynx (*Lynx pardinus*), and the Eurasian lynx (*Lynx lynx*) (Kitchener et al., 2017). Genetic research confirmed monophyletic ancestry of the four species of genus *Lynx*, as well as their taxonomic position as separate species (Johnson et al., 2006). Ancestor of the modern lynx evolved in North America and the progenitors of the Eurasian and Iberian lynx migrated across the Bering Peninsula to Eurasia about 1.6-1.2 million years ago (Schmidt et al., 2011).

Eurasian and Iberian lynx are the ones present in Europe (Kitchener et al., 2017). Eurasian lynx is widespread and occurs throughout Europe and large parts of Asia (Nagl et al., 2022) and three subspecies of *Lynx lynx* were described in Europe (Kitchener et al. 2017): the Northern lynx *L. l. lynx* (Linnaeus, 1758), the Carpathian lynx *L. l. carpathicus* (Heptner, 1972), and the Balkan lynx *L. l. balcanicus* (Bureš, 1941), even if the phylogenetic subdivision of the species is still under discussion (Bonn Lynx Expert Group, 2021).

The Eurasian lynx is grouped into 11 populations, based on a range of criteria, such as distribution and other geographical, ecological, political, and social factors (Boitani et al., 2015). Out of those, five populations are autochthonous (Scandinavian, Karelian, Baltic, Carpathian, and Balkan populations), whereas the other populations, based in central and western Europe, origin from reintroductions in the 1970s and 1980s (Dinaric, Alpine, Jura, Vosges-Palatinian, and Bohemian-Bavarian populations) (Boitani et al., 2015).

(a) (b)

Figure 1.1: Eurasian lynx. (a) Side view. (b) Front view (© Matej Vranič, LIFE Lynx).

Eurasian lynx (Fig. 1.1) is the largest felid of the European continent, twice the weight of the Iberian lynx. Body mass of adults ranges 12-35 kg, with males bigger than females (Breitenmoser et al., 2006). Total body length is 70-130 cm, with shoulder height about 65 cm and its characteristic short black tail, round head with ear tufts and flared facial hair, long legs, and large feet (Breitenmoser et al., 2000, 2006).

Front feet have five fingers, of which the fifth one does not touch the ground, while the back feet have only four fingers (Breitenmoser et al., 2000, 2006). The claws are retractile, sharp, and strong, especially the claws of the forepaws, which are used for holding the prey (Breitenmoser et al., 2000, 2006; Viranta et al., 2016). An adult lynx pawprint (Fig. 1.2a) is round, with a diameter between 7-9 cm, forepaws are larger than back paws and their tracks generally follow a straight line (Fig. 1.2b) (Skrbinšek, 2017).

(a) (b)

Figure 1.2: Lynx pawprints. (a) An adult lynx pawprint in the snow (© Fridolin Zimmermann). (b) Lynx tracks following a straight line (© Miha Krofel).

In general, mammals coat color patterns have three different evolutionary functions: camouflage, intra- and inter-specific communication, and physiological adaptations (Darul et al., 2022). Complex patterns such as various types of spots are typical of felid species living in closed environments (e.g., forest), but polymorphism of coat color patterns is also present within several species of felids, such as the Eurasian lynx (Darul et al. 2022). Lynx color coat consists of a combination of a general coloration and spotting, with some exceptions. The coat is greyish with different shades as rusty, yellowish, or reddish at the back and flanks, with a whitish belly (Breitenmoser et al., 2000, 2006). Based on a study using 195 photographs of Eurasian lynx individuals from Croatia (Topličanec et al., 2022), four lynx coat pattern types have been recognized in the Croatian population (Fig. 1.3): no spots, small spots, big spots, and rosettes. The particularity is that each individual has unique coat pattern, and this feature allows researchers to identify individual lynx, for example from camera-trap recordings for population estimates (Breitenmoser et al., 2006; Hočevar et al., 2020).

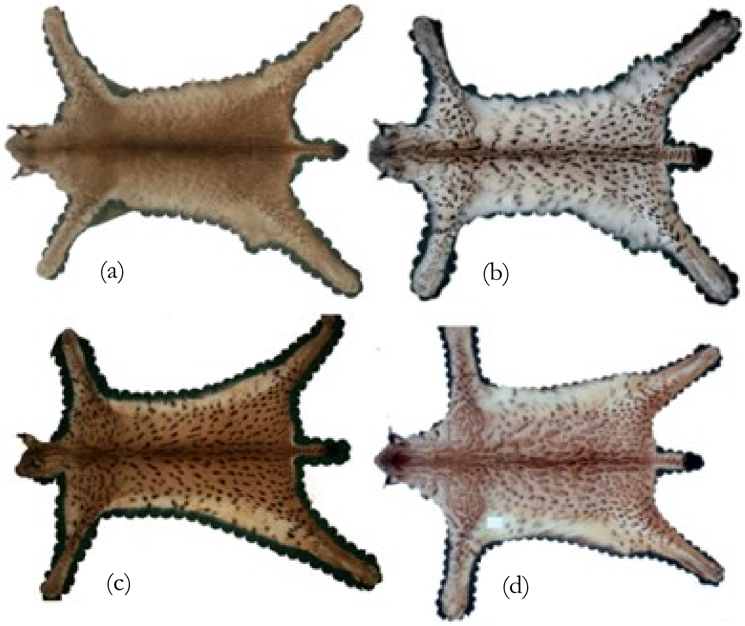

Figure 1.3: Lynx coat pattern types, shown in representative photographs of trophy pelts. (a) No spots. (b) Small spots. (c) Big spots. (d) Rosettes (adapted from Topličanec et al., 2022).

1.2 Eurasian lynx biology and ecology

The Eurasian lynx is a medium-sized carnivorous and is the third largest predator in Europe, after the brown bear (*Ursus arctors*) and the grey wolf (*Canis lupus*). Generally, lynx's consumption rate averages 1-2.5 kg of meat per day, but it could be much more after some days of fasting (Breitenmoser et al., 2006). The prey of this species ranges in size from mice to lagomorphs to small ungulates, which are its main prey throughout large parts of Europe. They include roe deer (*Capreolus capreolus*) (Fig. 1.4a), chamois (*Rupicapra rupicapra*) or musk deer (*Moschus moschiferus*) (Breitenmoser et al., 2006; Nagl et al., 2022). Lynx can also prey large ungulates, such as red deer (*Cervus elaphus*) or wild boar (*Sus scrofa*), but in these cases it selects the youngest individuals (Breitenmoser et al., 2006; Nagl et al., 2022). Eurasian lynx uses two techniques of hunting: ambush and stalking (Hočevar et al., 2020). It applies the killing bite to the throat, crushing the windpipe, or with a bite on the back of the neck, severing the spinal cord while holding its prey with its strong forepaws and then starts to eat at a hindquarter (Fig. 1.4b) (Breitenmoser et al., 2006, Krofel et al., 2009). Since felids are mostly solitary hunters, each bite must be made with precision to kill the prey as soon as possible to avoid being hurt during the struggle (Krofel et al., 2009).

(a) (b)

Figure 1.4: Lynx hunting technique. (a) Camera trap picture of a lynx with one of its typical preys, a roe deer (© KORA). (b) Picture of a killed roe deer which shows that lynx starts to eat at a hindquarter (© U. Breitenmoser, KORA).

Lynx has no natural enemies, apart from some sporadic cases of adult/juvenile individuals killed by wolves, but it also can happen that a large prey animal can fatally injure a lynx during the fight (Breitenmoser et al., 2000). Mortality among juvenile lynx is high and about 50% of young individuals do not reach the adult age (Breitenmoser et al., 2000; Boutros et al., 2007). However, the main causes of death are humans, such as overhunting, poaching and traffic accidents (Breitenmoser et al., 2000, Sindičić et al., 2016). In nature, lynxes can live up to 17 years, while in captivity up to 25 years (Breitenmoser et al., 2000).

Female lynxes are sexually mature at the age of 2 years, whereas males are mature at 3 years old (Breitenmoser et al., 2006). Lynx is a seasonal breeder and mating takes place from February to March or April. During the mating season, individuals are more vocal, and males follow the females to check their reproductive status. Female estrus lasts about three days and the male, which accompanies the female all that time, copulates often. Gestation period lasts from 67 to 74 days, so births take place usually in late May or beginning of June. Eurasian lynx females have 2-3 kittens, which weigh about 300 g each (Breitenmoser et al., 2006; Hočevar et al., 2020). Kittens usually follow their mother until the next mating season (Fig. 1.5), when they are about 10 months old and then start becoming independent. Initially, young individuals stay in their mother's territory, but then they disperse and must find an unoccupied territory with sufficient prey density (Breitenmoser et al., 2006; Hočevar et al., 2020).

(a) (b)

Figure 1.5: (a) Camera trap picture of lynx L13 with her kitten in Lika region, Croatia (© LIFE Lynx). (b) Two lynx kittens, approximately one month old, in a den and completely dependent on their mother (Bernese Oberland, 2011 © Fridolin Zimmermann).

Eurasian lynx's geographical range includes area from central Eastern Europe to Eastern Asia, comprising a quiet large variety of environments, with different ecological and climatic conditions (Schmidt et al., 2011). The Eurasian lynx population in Europe consists of a core population in the European part of Russia, which extends to the northern and eastern Europe comprising Scandinavian and Baltic states and along mountain ranges in southeastern and central Europe, meaning Carpathian, Balkans, Dinarics, Alps, Jura, and Vosges (Schmidt et al., 2011; Kaczensky et al., 2013). Three "lynx regions" are distinguished in continental Europe (Fig. 1.6) (Bonn Lynx Expert Group, 2021): (1) the Balkan lynx region in the south-east, including the southern part of the Dinaric Range, (2) the Carpathian lynx region between the central Dinaric Range and the southern rim of the Carpathians north to the Harz Mountains, and (3) the Baltic lowland lynx region in the northern part of the continent.

In Europe, the lynx inhabits all types of forest such as large deciduous, mixed, and coniferous forests, but it can also survive in more open landscapes (Breitenmoser et al. 2000; Hočevar et al., 2020). Lynx habitat selection is mainly influenced by human presence and prey availability, in fact Filla et al. (2017) have shown that Eurasian lynx use more open habitats and areas with high human disturbance during the night time, when they are more active (Breitenmoser et al., 2000), whereas they prefer dens habitat in undisturbed areas (e.g., forest) for resting during the day, because they have to balance prey hunting with the risk of encounters with humans.

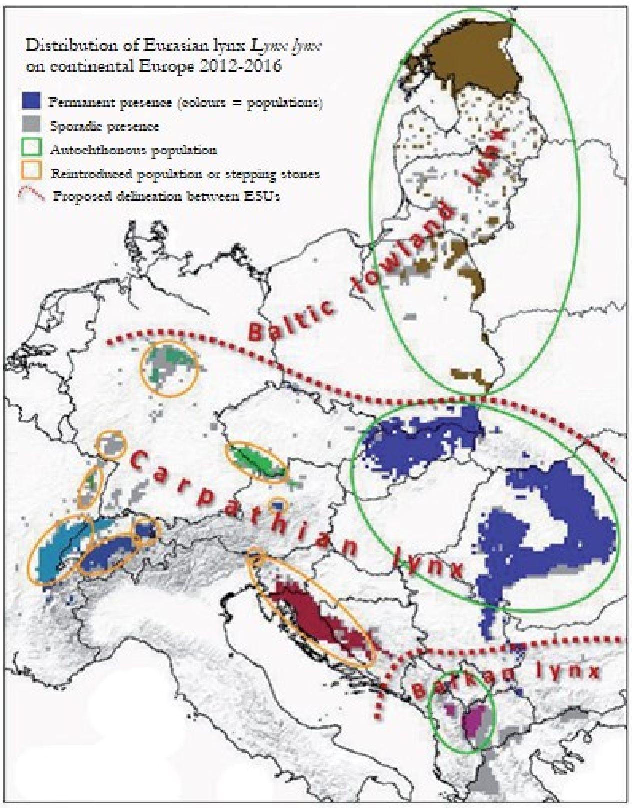

Figure 1.6: Distribution of Eurasian lynx on continental Europe (2012-2016). The autochthonous populations (green circles) represent three different phylogenetic lines. The dashed red lines represent the proposed delineation of the ESU's distribution range for recovery and reintroduction projects, respectively (adapted from Bonn Lynx Expert Group, 2021).

Lynx is territorial and solitary living species, except for females with kittens before their independence. Both males and females occupy individual home ranges, which they mark (Fig. 1.7) with gland secretions, urine, and faeces, but they exhibit territorial behavior only towards conspecifics of the same sex. Male home ranges are larger than those of females, therefore there is usually large overlap between male and female territories. Females choose their smaller home ranges to nurse kittens according to resources, such as prey and habitat, while the males choose the territory to grant access to females. An adult male monopolizes one or two, and rarely more, females. Thanks to several studies based on telemetry, size of the home ranges of lynx has been estimated in Europe: 180-2780 km^2 for males and 98-759 km^2 for females (Breitenmoser et al., 2000, 2006; Hočevar et al., 2020). Distance traveled by lynx within its home range per night depends on several factors, e.g., age, sex, presence of kittens, social status, and prey density, but in general they ranged from 1-45 km and in presence of a fresh kill a lynx can stay in its proximity for several days (Breitenmoser et al., 2000).

Figure 1.7: Camera trap picture of lynx Vida marking her territory in Ričičko Bilo, Croatia (© LIFE Lynx).

1.3 Eurasian lynx in Europe

The Eurasian lynx originated in Asia and started to spread out throughout Europe around the early Late Pleistocene (Lucena-Perez et al., 2022). The early to mid-Holocene distribution of this predator covered all of Europe, with exception of Iberian Peninsula, previously inhabited by both *L. lynx* and *L. pardinus* during the Late Glacial (Sommer and Benecke, 2006). By the end of the 19th century and mid-20th century, lynx distribution had been greatly reduced, mainly due to direct persecution, environmental changes such as deforestation and decline of wild ungulate prey (Breitenmoser, 1998). In fact, the most relevant threats to Eurasian lynx in Europe are largely due to conflicts with human activities, such as hunting, persecution (e.g., illegal killings), accidental mortality, and habitat loss due to infrastructure development and their inadequate management (Boitani et al., 2015).

Because of human activities, in the beginning of the 20th century lynx disappeared from most of its European range, first in the south, and later in the north and reached its minimum number around 1950, when even the Nordic population was significantly reduced (Breitenmoser et al., 2000). Only four populations survived: Nordic, Baltic, Carpathian, and Balkan populations (von Arx et al., 2004).

The first assessment of the Eurasian lynx across Europe was initiated by the IUCN (International Union for Conservation of Nature) and WWF (World Wildlife Fund) in 1962 (Bonn Lynx Expert Group, 2021) and, few years later, three meetings were organized to discuss the reintroduction of this species in some West European countries (Breitenmoser et al., 2000). In fact, in the 1970s lynx was reintroduced into several countries, e.g., into Switzerland, Slovenia, Italy and Austria thanks to several projects, some of which were neither coordinated nor accompanied by any research program, while some releases were even clandestine and illegal (Molinari-Jobin et al., 2003). Moreover, the increasing population spread into neighboring countries, e.g., into France from the Swiss Jura Mountains, mainly during the 1980s (Breitenmoser-Würsten et al., 2007).

In 1990, the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) of the Council of Europe, required a review of the status and the conservation needs of lynx in Europe (Bonn Lynx Expert Group, 2021) and ten years later, the Council of Europe published several action plans for the conservation of all European large carnivore species, including lynx, compiled under the guidance of the Large Carnivore Initiative for Europe (LCIE) (von Arx et al., 2004).

Despite the lynx situation has improved, conservation plans have revealed that more focused conservation actions in all autochthonous and reintroduced populations in Western and Central Europe are required. These actions include the need to conserve all autochthonous and reintroduced populations, to promote further reintroductions, to foster natural or assisted connectivity between populations in order to secure the long-term maintenance of large viable metapopulations[1], to develop and implement management measures about interactions concerning lynx in the cultural multi-purpose landscapes of Europe, to obtain information through monitoring and research, and to reduce human induced lynx mortality (Bonn Lynx Expert Group, 2021). Therefore, since populations can expand across international borders, an international and cooperative approach in practical management is required (von Arx et al., 2004). Activities such as translocations and reintroductions or genetic remedy (reinforcement) require standards and common protocols, because activities in one population in one country will affect those of neighboring countries (Bonn Lynx Expert Group, 2021).

[1] A metapopulation is a set of populations which occasionally exchange individuals/genes (Marinko and Velkavrh, 2020).

To the present day, Eurasian lynx is classified as "Least Concern" by the IUCN Red List (IUCN Red List of Threatened Species), but all reintroduced populations are classified as "Endangered" (Alpine, Dinaric, and Jura population) or "Critically Endangered" (Bohemian-Bavarian and Vosges-Palatinian population), together with the autochthonous Balkan population also classified as "Critically Endangered" (Kaczensky et al., 2012).
The Eurasian lynx is protected by the Bern Convention (Appendix III – "Protected fauna species", except for the Balkan lynx *L. l. balcanicus*, which is listed under Appendix II – "Strictly protected fauna species") and the EU Habitats Directive (Annex II – "Animal and plant species of community interest whose conservation requires the designation of special areas of conservation" and Annex IV – "Animal and plant species of community interest in need of strict protection", except for Estonia, Finland, and Latvia, where it has an exception from Annex II) (Bonn Lynx Expert Group, 2021). The Eurasian lynx is also protected by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Appendix II – "All species which although not necessarily now threatened with extinction may become so unless trade in specimens of such species is subject to strict regulation").

1.4 Lynx monitoring techniques

To obtain knowledges about the status of a rare species, repeated and long-term field censuses are required (Breitenmoser et al., 2006). According to Hellawell (1991), monitoring, being a process and not a result, cannot be defined independently from the entire conservation plan, but it is necessary to include two other definitions:

1. *Survey*: obtaining of a set of qualitative or quantitative observations by means of a standardized procedure in a restricted period, without any preconception of what the results ought to be.
2. *Surveillance*: an extended program of surveys to assess the variability and/or range of states or values, without any preconceptions of what the findings might be.
3. *Monitoring*: a regular and defined surveillance to assess the compliance of a measure with an expected norm or a specific goal to reach.

According to this definition, monitoring is repeated observations of a population of which the results are continuously compared with a specific and desired goal.

Monitoring the conservation status of a species includes obtaining information on distribution, population size, population dynamics (demography), health, genetic status, threats, and conflicts, such as monitoring of conflicts with human activities (hunting, livestock breeding) (Bonn Lynx Expert Group, 2021). As reported by the Bonn lynx Expert Group (2021) the parameters which can be studied are:

- *Distribution*: in the European context, distribution is presented by using the 10 × 10 km EEA (European Environment Agency) reference grid. According to Kaczensky (2018), in every grid cell carnivore presence and frequency can be (1) *Permanent*, when presence is confirmed in ≥ 3 years in the last 5 years or in > 50% of the time or reproduction confirmed within the last 3 years, (2) *Sporadic* (highly fluctuating presence), when presence is confirmed in < 3 years in the last 5 years or in < 50% of the time, (3) *Confirmed presence*, when there is no doubt about the species presence in that area (presence confirmed with hard facts such as photographs and DNA analysis, or based on lynx prey or footprints examined by an expert), or (4) *Unconfirmed presence*, when carnivore presence evidence is not confirmed with solid data (for instance animal observations without hard evidence like photographs).
- *Population size and trend*: study of population size includes obtaining parameters such as minimum population size estimation, mainly based on camera trapping. The minimum total number includes number of individuals identified by their both sides and the number of individuals identified by one side only. Moreover, as reported by Gomerčić et al. (2021), the estimation of the minimum population size has a span, because if for a new animal we have one flank photos only, we cannot associate 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 (Gomerčić et al., 2021). So, the maximum number of adult animals identified is the sum of number of individuals identified by their both sides, with number of individuals identified by the left side and the ones identified by the right side.

  Study of population trend describes the temporal change of parameters, e.g., distribution and abundance.
- *Demographic data*: study of demographic data includes obtaining data about natality, mortality, age structure, and sex ratio.
- *Health and genetic monitoring*: study of health and genetic is important especially for small, reintroduced, isolated, and fragmented populations which are all the European lynx populations, since health issues can be linked genetic status. These populations should be

genetically managed to minimize loss of genetic diversity (heterozygosity) and to avoid inbreeding.

Population monitoring is an indispensable activity in the management of protected wild species. Also, rigorous monitoring is necessary during repopulation and reintroduction projects to obtain feedback on the success of conservation measures (Juergens, 2006). The most common and useful method for lynx monitoring is camera trapping, which allows to monitor wildlife in a non-invasively way. Camera trapping is particularly useful for monitoring elusive and individually recognizable wild animals, such as lynx (Stergar and Slijepčević, 2017) and, since the lynx individuals are identifiable by the coat pattern, camera trap monitoring allows to estimate the minimum number of animals and the population density, to monitor the evolution of the populations through regularly repeated sessions (KORA Foundation, 2022).

1.5 Eurasian lynx in Croatia

Eurasian lynx population present in Croatia belongs to the Dinaric population (Breitenmoser et al., 2000), which also includes all lynx in Slovenia, as well as lynx in Bosnia and Herzegovina (Sindičić et al., 2009, 2013). In the beginning of the 20th century the autochthonous Eurasian lynx disappeared from Croatia mainly due to human persecution and overhunting, but also because of habitat loss and depletion of its prey (Čop and Frković, 1998; Sindičić et al., 2009). Lynx was successfully reintroduced thanks to the translocation of six individuals, three males and three females, from Slovakia into Kočevje forests of Slovenia, organized by Slovenian hunters in 1973. The population rapidly expanded for the presence of a favorable habitat rich in prey species, and in 1974 the lynx appeared again in Croatia. This is considered as one of the most successful reintroductions of a large predator, even though the population remained isolated and there was no natural migration of individuals from the neighboring Alpine or Balkan populations (Sindičić et al., 2013). At that time lynx was still a game species, until 1982, when its legal status changed, and the lynx became a protected species in Croatia. This initial population growth and range expansions lasted for the next 15 years, followed by a period of stabilization until the early 90s, when the population began to decline (Sindičić et al., 2009, 2013, 2016). The loss of genetic diversity is considered the most significant threat to lynx in Croatia, with several factors, such as habitat fragmentation, prey species depletion, poaching and traffic accidents, enhancing this process (Sindičić et al., 2016; Gomerčić et al., 2021). In fact, as reported by Mueller et al. (2022), once a small and isolated population has been established, the risk of inbreeding and reduction of genetic diversity, as well as accumulation of deleterious mutations through genetic drift, is increased. Inbreeding is usually observed in reintroductions with few founding individuals, such as the Dinaric population which originated from six reintroduced animals (Gomerčić et al., 2021; Mueller et al., 2022). In the long term these processes erode the genetic variability necessary for adaptive evolution and the fact that the recessive deleterious alleles become exposed phenotypically, because of increasingly homozygous individuals, can lead to reduction of the biological fitness (Sindičić et al., 2013).

This species is protected in Croatia by the Ordinance on declaring protected and strictly protected wildlife species (Gomerčić et al., 2021).

1.5.1 Current lynx conservation and research projects in Croatia

1.5.1.1 LIFE Lynx project

To prevent another extinction of the Eurasian lynx in the Dinaric mountains, an EU LIFE program funded project was launched in 2017, named "Preventing the Extinction of the Dinaric-SE Alpine Lynx Population Through Reinforcement and Long-term Conservation" (LIFE16 NAT/SI/000634) (LIFE Lynx). The aim was to translocate lynxes from Carpathian to the Dinaric Mountains and southeastern Alps and to create a connection between the Dinaric and SE-Alpine lynx populations with regular gene flow (Fležar et al., 2021, 2022). The project is implemented in 5 countries (Italy, Slovenia, Croatia, Slovakia, and Romania) (Fig. 1.8) by 11 partner institutions. Faculty of Veterinary Medicine University of Zagreb is one of the three partners from Croatia, under the coordination of Associate Professor Magda Sindičić.

Camera trapping, non-invasive genetic sampling, GPS telemetry, health monitoring and collecting opportunistic data, subsequently categorized into SCALP categories (Molinari-Jobin et al., 2021), are used to monitor the success of the translocations (Fležar et al., 2022).

In the period 2019-2023 a total of 18 lynxes were translocated from Carpathian Mountains to Dinaric mountains of Croatia and Slovenia, and Alpine region of Slovenia.

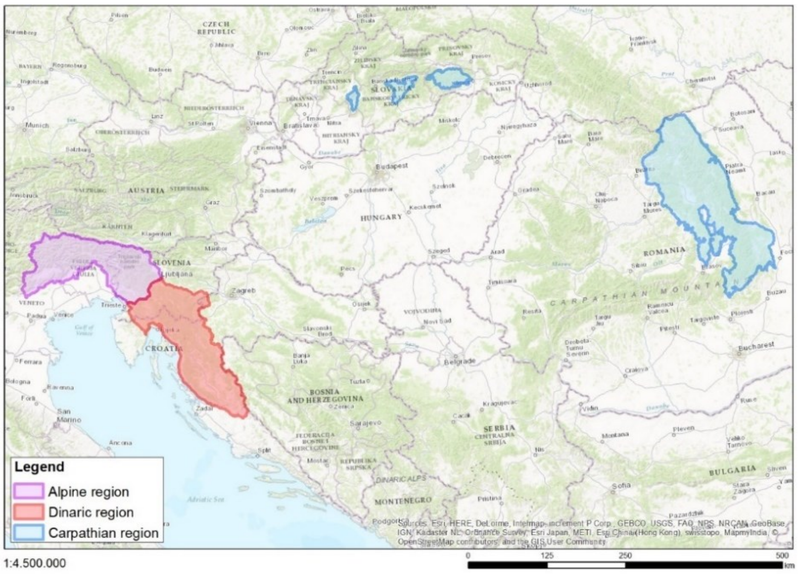

Figure 1.8: Map showing areas involved in the LIFE Lynx project (© LIFE Lynx).

1.5.1.2 Development of lynx monitoring program

In the period January 2022-September 2023 project entitled "Development of system for monitoring the status of species and habitat types. Group 6: Development of monitoring program for large carnivores with capacity building of participants (KK.06.5.1.03.0001)" was implemented by the Faculty of Veterinary Medicine University of Zagreb and partners, under the coordination by the Ministry of economy and sustainable development of Republic of Croatia and financed by the EU Operational program competitiveness and cohesion.

The main goal of the project was to satisfy the nature conservation standards required by the Birds Directive and the Habitats Directive as the main EU nature protection legislation. Lynx monitoring program for Croatia was developed and tested, under the coordination of Professor Tomislav Gomerčić.

1.5.1.3 Lynx monitoring in National Park Plitvice Lakes

Project entitled "Spatial ecology of lynxes in National Park Plitvice lakes", led by Professor Josip Kusak from Veterinary Medicine University of Zagreb was implemented in the period 2019-2023, financed by the public institution National Park Plitvice Lakes. The aim of this project was to monitor the lynx using camera traps and radio telemetry.

1.5.2 Current lynx distribution and population size in Croatia

Since 2018, systematic monitoring of lynx population in Croatia is implemented within the LIFE Lynx project (Slijepčević et al., 2019; Gomerčić et al. 2021; Krofel et al., 2021; Fležar et al. 2022, 2023). In the study period from the beginning of May 2018 until the end of April 2020 (2 lynx seasons), Gomerčić et al. (2021) determined the lynx distribution area and estimated the minimum lynx population size in Croatia, presenting the first scientifically based estimation of lynx population size in this country. A total of 902 records of lynx presence were collected, both opportunistic and systematic data. Permanent lynx presence (Fig. 1.9) was confirmed in Primorsko-Goranska and Ličko-Senjska County, in southern part of Karlovačka County and north-eastern part of Zadar County, on the total surface of 7100 km^2. Surface of occasional presence was 1300 km^2 including Pelješac peninsula, 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.

The minimum population size has been estimated at 52-62 adult lynxes during 2018/2019 season, of which 21 were females, 14 males, and for 27 animals the sex was not determined. During the 2019/2020 season, the minimum population size has been estimated at 69-82, of which 24 were females, 19 males, and for 39 animals the sex was not determined. A total of 89-108 different adult lynxes have been identified during both seasons. Among 108 identified individuals, 29 were females, 22 males, while for 57 animals the sex was not determined. During these two reproductive seasons, 44 cubs in 25 litters were photographed, eight cases of females with one kitten, 15 cases of females with two, and two cases of females with three kittens.

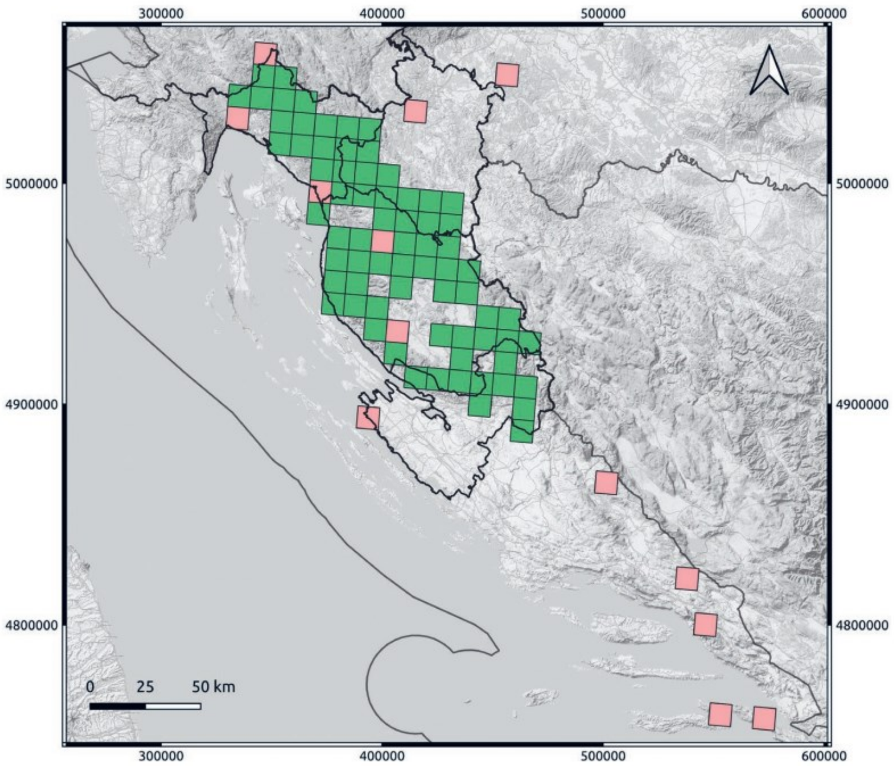

Figure 1.9: Lynx distribution in Croatia during the period 1st of May 2018-30th of April 2020. Green squares represent the area of permanent distribution, while red squares represent the area of unconfirmed distribution. Black lines define borders of Croatian counties – Primorsko-Goranska, Ličko-Senjska, Karlovačka and Zadar County (Gomerčić et al., 2021).

Systematic monitoring of lynx population in Croatia and Slovenia, implemented within the LIFE Lynx project, is based on several complementary methods, i.e., camera trapping, non-invasive genetic sampling, GPS telemetry and collecting opportunistic records. The surveillance results are presented in reports focused on "lynx-monitoring year" (i.e., 1st May 2021 until 30th April 2022), which is in accordance with the SCALP methodology as an international standard for assessing and reporting the lynx status (Molinari-Jobin et al., 2021). Reports provide information about the basic demographic parameters (e.g., lynx distribution, minimum number of adult individuals, and minimum number of reproductions) and the key parameters describing the genetic status (e.g., inbreeding coefficient) of the lynx population during reinforcement process, as well as detailed information about the history and current status of all the translocated animals after their release (Slijepčević et al. 2019; Krofel et al. 2021; Fležar et al. 2022, 2023).

Fležar et al. (2022) reported that the minimum number of adult lynxes identified in 2020/2021 season in Croatia was 74, while the minimum number of adult females was 22, the minimum number of adult males was 30, and the minimum number of adult lynxes of unknown sex was 22

(Table 1.1). The minimum number of kittens was 22 and the minimum number of reproductive events was 14.

	Slovenia	Croatia	Italy	Dinaric-SE Alpine area
Total no. of systematic camera trapping sites (funded by LIFE Lynx)	159 (113)	102 (102)	45 (45)	307 (238)
Area monitored (km2)	4000	4900	1900	9800
Density of camera trapping sites per 100 km2	4.0	2.1	2.4	3.1
Min. no. of adult lynx	24*	74	0	95**
Min. no. of females	11*	22	0	33
Min. no. of males	11*	30	0	38*
Min. no. of adult lynx of unknown sex	2	22	0	24
Min. no. of kittens	8	22	0	30
Min. no. of reproductions	5	14	0	19

*Does not include 5 lynxes (2 males, 3 females) translocated to the Alps at the end of April 2021
**Includes three transboundary lynx (Bojan, Bunker2 and Damir) and 5 translocated lynxes (Katalin, Boris, Goru, Emil and Alojzije)

Table 1.1: Summary of data obtained per country in the season 2020/2021. The minimum number of adult lynxes in the Dinaric-SE Alpine region considers the fact that two animals were detected both in Slovenia and Croatia. Sex of some of the animals could not be determined for all the animals, but these individuals are included in the min. no. of adult lynx, but not included in the min. number of males or females (Fležar et al., 2022).

The minimum number of adult lynxes identified in 2021/2022 season in Croatia was 66, while the minimum number of adult females was 17, the minimum number of adult males was 32, and the minimum number of adult lynxes of unknown sex was 30. Because of this, the minimum population size has been estimated as 66 adult lynxes, while the minimum number of kittens was 20 and the minimum number of reproductive events was 10 (Fležar et al. 2023) (Table 1.2). In Croatia, opportunistic data contributed five supplemental reproduction records, in addition to the 10 records obtained through systematic camera trapping.

	Slovenia	Croatia	Italy	Dinaric-SE Alpine area
Total no. of systematic camera trapping sites (funded by LIFE Lynx)	173 (123)	221 (221)	45 (45)	439 (389)
Area monitored (km2)	4400	7200	2000	13600
Density of camera trapping sites per 100 km2	4.0	3.1	2.25	3.2
Min. no. of adult lynx	29	66	0	93*
Min. no. of adult females	12	17	0	29
Min. no. of adult males	11	32	0	41*
Min. no. of adult lynx of unknown sex	6	30	0	36
Min. no. of kittens	15	20	0	35
Min. no. of reproductions	5	10	0	15

*Includes two lynxes (Klif, Damir) which were recorded in Slovenia and Croatia and 10 translocated lynxes (Katalin, Goru, Julija, Lenka, Tris, Aida, Zois, Emil, Boris and Alojzije).

Table 1.2: Summary of the data obtained per country in 2021/2022 lynx-monitoring year. The minimum number of adult lynxes in the Dinaric-SE Alpine region considers the fact that two animals were detected both in Slovenia and Croatia. Sex of some of the animals could not be determined for all the animals, but these individuals are included in the min. no. of adult lynx, but not included in the min. number of males or females (Fležar et al., 2023).

AIMS

The aim of this research was to assess and monitor the status of the Eurasian lynx population in Croatia during the 2022/2023 season, using opportunistic signs of lynx presence and systematic camera trap data. Data was collected by Faculty of the Veterinary Medicine University of Zagreb during the implementation of projects:

1. Preventing the extinction of the Dinaric-SE Alpine lynx population trough reinforcement and long-term conservation (LIFE16 NAT/SI/000634).
2. Development of system for monitoring the status of species and habitat types. Group 6: Development of monitoring program for large carnivores with capacity building of participants (KK.06.5.1.03.0001).
3. Spatial ecology of lynxes in National Park Plitvice lakes.

In detail, specific goals of the monitoring project, analyzing both opportunistic and systematic collected data, are to:

1. Prepare a lynx distribution map, distinguishing between confirmed and unconfirmed presence areas of the species.
2. Obtain the minimum population size, considering only adult individuals.
3. Report demographic data, including reproduction information by providing number of litters and kittens, as well as sex ratio of the population.
4. Obtain a graphic visualization about the life history of individual lynxes identified during the study period, starting from the first time they were photo-captured or capture for telemetry research projects.

The achievement of these objectives enables the evaluation of population trend and size by comparing the lynx distribution areas and the minimum population size between the current and previous seasons. Moreover, these results allow the analysis of demographic data through the comparison of the reproduction activity and other demographic parameters with those of the previous years.

MATERIALS AND METHODS

3.1 Data collection

3.1.1 Study area

The study area included entire lynx distribution in Croatia, including Gorski Kotar, Lika, and northern Dalmatia region, administratively belonging to Primorsko-Goranska, Ličko-Senjska, Zadar, and Karlovačka County, with a total surface area of 6,354 km^2 (Fig. 3.1).

The study area is part of the Dinaric Mountains. The Dinaric karst region habitat is composed of rugged karst terrains, and the forest, gradually composed by pubescent oak, hornbeam, flowering ash, beech, fir, and pine forests, is present on higher parts of the plateaus and mountains (Zupan Hajna, 2019). Along the Adriatic Sea coast Mediterranean climate prevails with dry and hot summers and wet and fresh winters, with 800 mm per year precipitation, in intermountain basins there is a moderate continental climate, while in the inner parts and on higher elevations a mountainous climate is prevalent (Zupan Hajna, 2019).

Figure 3.1: Study area map. The map shows the Croatian Counties involved in the study, from the north to the south: Karlovačka County, Primorsko-Goranska County containing Gorski Kotar region, Ličko-Senjska County containing Lika region, and Zadar County containing northern Dalmatia region.

3.1.2 Opportunistic data collection

Opportunistic data, also referred to as "chance records", are not collected using a systematic method, such as camera trapping placed according to a specified system within the 10 x 10 km grid (Breitenmoser et al., 2006), but are collected from different sources, e. g., hunters, institutions for management of protected areas or private persons (Gomerčić et al., 2021). These records include lynx photos and sightings, dead lynx, hearing of lynx calls, footprints, faeces, urine, and lynx prey (Hočevar et al., 2020).

Opportunistic data were collected by Faculty of Veterinary Medicine University of Zagreb staff as a part of their regular lynx research activities and were archived in a database available on-line (http://www.lynx.vef.hr). Additionally, National Park Plitvice lakes provided data from their large carnivore monitoring system (project "Spatial ecology of lynxes in National Park Plitvice lakes", led by Professor Josip Kusak and financed by the public institution National Park Plitvice lakes).

3.1.3 Systematic data collection

Systematic data collection is the monitoring in the strict sense of the word, which includes collection of data in a targeted and systematic way, to assure the collection of homogenous and unbiased sample (Hočevar et al., 2020). The main monitoring method is camera trapping, so for example, a lynx photo from a grid of camera traps set up specifically to monitor lynx population is considered a systematic record (Hočevar et al., 2020). Camera trapping is a suitable tool for detection of many elusive large mammal species because it allows obtaining reliable and robust data. In fact, it is currently recognized as the most effective method for monitoring lynx abundance and distribution in Europe (Soyumert, 2020; Hočevar et al., 2020). This is a non-invasive method based on using remotely triggered cameras that automatically take images and videos of animals and other subjects passing in front of them (Rovero and Zimmermann, 2016).

Camera trap systematic data in this research were provided by two projects:

- LIFE Lynx project ("Preventing the Extinction of the Dinaric-SE Alpine Lynx Population Through Reinforcement and Long-term Conservation"; LIFE16 NAT/SI/000634).
- Development of system for monitoring the status of species and habitat types. Group 6: Development of monitoring program for large carnivores with capacity building of participants (KK.06.5.1.03.0001).

Passive infrared digital cameras activated by an infrared sensor perceiving a change in heat and motion between the moving subject and the background temperature were used. The captured pictures were color images when shot during the day and black-and-white images when shot at night. Camera traps were placed on locations with the highest chance of lynx observations (e.g., wildlife trails, forest roads, lynx marking locations), identified based on previously archived observations of lynx presence and thanks to the help of local hunters and rangers. Camera traps were placed at about 40-50 cm above ground level, as recommended by Rovero and Zimmermann (2016), usually fixed on trees, abandoned houses, wooden or other suitable objects, protected by metal boxes and without using any attractants (e.g., sight, sound, scent).

For the LIFE Lynx project, mostly Cuddeback model 1224 and Acorn LTL 6511 were used, with the following technical settings: activation speed 0.25 s, camera resolution 5 and 12 MP, flash with infrared light (wavelength IR, 850 nm), wide range. Camera traps were set to record one photo and 30 seconds of video or three photos without the video. 10 × 10 km grid cells were used for optimal camera trap placement on the study area, with at least 1 camera trap for each quadrant and the minimum distance between two camera trap locations was at least 1 km.
A network of 85 camera traps (Fig. 3.2) was set in the study area, they were active a total of 7872 days during the period 01.05.2022-31.04.2023. I visited camera traps at least every two months to replace memory cards and batteries and to check the settings.

For the Development of lynx monitoring program two different models of camera traps were used: Browning BTC-5PXD (IR) and Cuddeback Ambush H1453. All the camera traps were used with the following technical settings: activation speed 0.25 s, camera resolution 20 MP, flash with infrared light (wavelength IR, 850 nm), wide range. Camera traps were placed on six reference areas for a total of 31 quadrants (10 × 10 km): Donji Lapac (6 quadrants), Lika Sredogorje (5 quadrants), Northern Velebit (5 quadrants), Southern Velebit (5 quadrants), Gorski Kotar (5 quadrants), and Platak (5 quadrants). Four camera traps were placed within a 10 × 10 quadrant.
118 camera traps (Fig. 3.2) were active during the period 14.9.-14.12.2022 in areas Donji Lapac, Lika sredogorje and Northern Velebit, then in the period 16.1.-16.4.2023 in Platak, Gorski Kotar and Southern Velebit. Cameras were active a total of 10.346 days (5340 in the period 14.9.-14.12.2022, 5006 in the period 16.1.-16.4.2023).

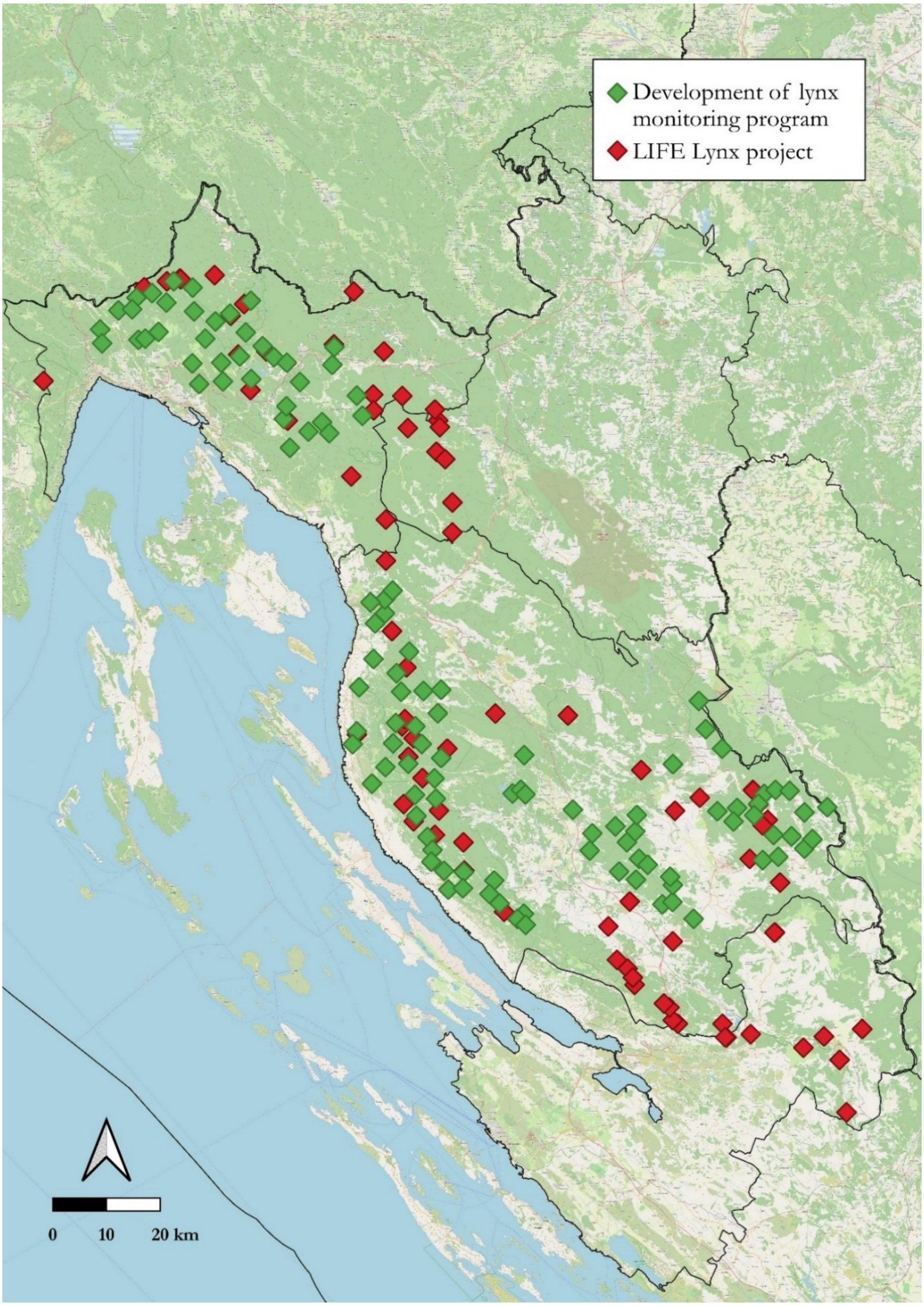

Figure 3.2: Camera traps distribution in the study area during the period 1st of May 2022-30th of April 2023. Green marks represent camera traps provided by the project Development of lynx monitoring program, while red marks represent camera traps provided by the LIFE Lynx project.

3.2 Data analysis

3.2.1 SCALP categories

Lynx presence data was categorized based on their verifiability according to SCALP ("Status and Conservation of the Alpine Lynx Population") criteria (Molinari-Jobin et al., 2012), which recognizes three categories of opportunistic data reliability:

- Category 1 (C1): "Hard facts", verified and unchallenged observations, such as (1) dead lynx, (2) captured lynx, (3) good quality and georeferenced lynx photos, and (4) samples as excrements or hair, attributed to lynx by means of a scientifically reliable analysis (analysis of the DNA).
- Category 2 (C2): Observations controlled and confirmed by a lynx expert, such as (1) livestock or (2) wild prey killed by a lynx and (3) lynx tracks or other signs of presence.
- Category 3 (C3): Unconfirmed category 2 observations and all observations such as (1) sightings and calls which, if not additionally documented, by their nature cannot be verified, (2) kills, tracks, and other field signs traceable to a lynx too old or badly documented (Molinari-Jobin et al., 2012, 2021).

3.2.2 Camera trap data

Processing systematic data from camera traps started with processing memory cards collected from the field. First step was to erase empty photos and select the best representable image(s) for each event. An event is defined as the same animal captured within 10 minutes, to avoid inflated counts caused by repeated detections of the same individual (Rovero and Zimmerman, 2016; Gomerčić et al., 2021).

After empty photographs were erased, the remaining ones were first processed using the camera trap software Camelot (Hendry and Mann, 2018). Camelot is an open-source software that provides versatile outputs that can be processed by programs. This software furnished a specialized image identification interface called "library" (Fig. 3.3), where images could be single- or multi selected and details of the sighted species identified (Hendry and Mann, 2018). In fact, on each photograph, we identified the species, the number of animals, age category (juvenile or adult) and, if possible, the sex. Furthermore, we also identified humans and vehicles pictures in Camelot.

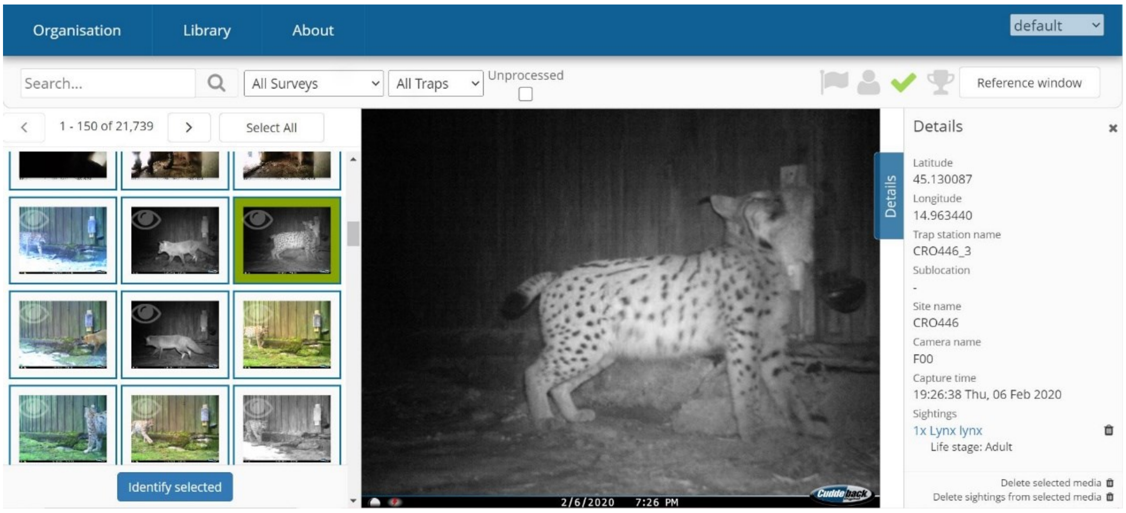

Figure 3.3: Camelot library output, showing an example of lynx picture. On the right the details column is visible, including details of coordinates of the camera trap location, trap station name, site name, camera name, capture time and date, and sightings with life stage.

3.2.2.1 Lynx-web GIS database

Each event of all photographed lynxes was inserted in the Faculty of Veterinary Medicine of Zagreb lynx database (Gomerčić, 2017) (Fig. 3.4). This is an online database, available to public (http://lynx.vef.hr), containing lynx both opportunistic and systematic presence data in Croatia. As the first step, we geocoordinated all the images before inserting them into the database, using XnView software, which allows to edit metadata GPS of a picture. Subsequently, geocoordinated lynx photographs were stored with precise date, time, and location through the "Admin page" of the database. Every lynx's photo was categorized as adults or kittens.

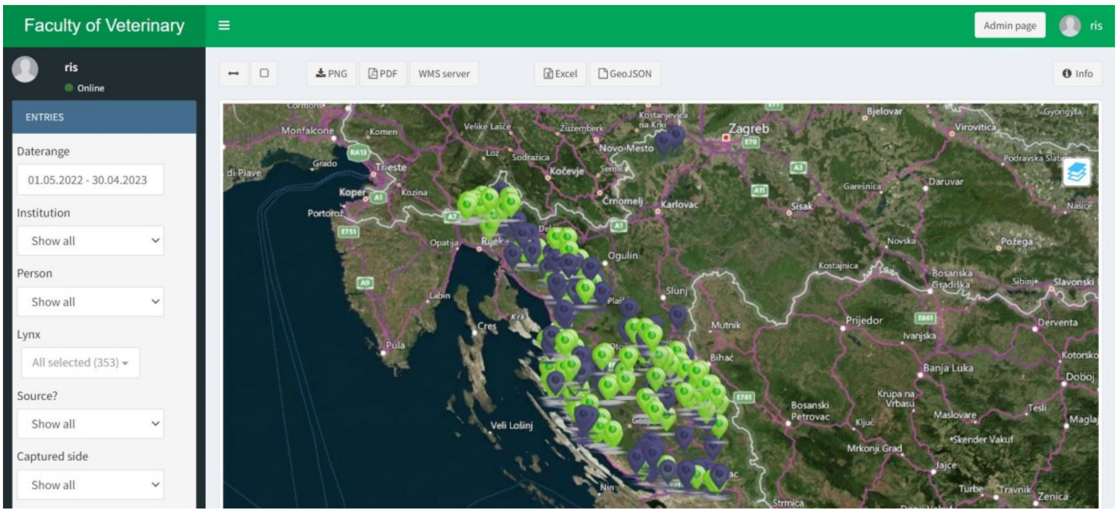

Figure 3.4: Lynx-web GIS database main page output, showing lynx presence entries in the period 1st of May 2022-30th April 2023.

3.2.2.2 Lynx photo-identification

Eurasian lynx individuals have specific and unique coat pattern which makes them uniquely identifiable. Identification is done by visually comparing patterns of the same side of the body.
Lynx photographs collected from camera traps were compared to lynxes already identified during previous years, stored in a database. Individuals' sex was determined from images when the genitals were exposed, or female was photographed with cubs. For this reason, videos were considered as additional help for the identification process.
The photo-identification process was to select a specific pattern (red circles), usually located on the animal's flank, and gradually compare other near patterns (green circles) to confirm it was the same individual (Fig. 3.5).
Camera trapping and individual identification allowed to obtain a robust estimation of the minimum population size in the study area (Fležar et al., 2023).

(a) (b)

Figure 3.5: Lynx photo-identification process example with camera trap photographs of right side (a) and left side (b) of lynx Fulir.

3.2.2.3 QGIS

Geographic Information Systems (GIS) is a system with which it is possible to manage, analyze, and map data. It allows to better understand and visualize the spatial distribution of a population, creating a distribution map by adding "layers" of spatially referenced data (Berke, 2010). In this research, we used both opportunistic and systematic data obtained from the Lynx database to map the distribution of the Croatian lynx population and the reproductive sites in the season 2022/2023, using program QGIS (QGIS. org 2020).

Lynx distribution was determined on a 10 × 10 km Pan-European grid (European Environmental Agency, 2017). Total surface of confirmed and unconfirmed presence was calculated by summing respectively the surface of quadrants with presence of C1 and C2 observations and quadrants with presence of C3 observations.

3.2.2.4 ggplot2 package in R

ggplot2 is an open-source R package, based on grammatical theory of graphics, which allows to create visualizations to better understand data as a part of the data analysis process (Wickham, 2011). In this research, ggplot2 was used to obtain a plot that shows the life history of individual lynxes photographed and identified in the season 2022/2023, using data obtained from the Lynx database.

RESULTS

4.1 Lynx distribution

A total of 220 opportunistic records of Eurasian lynx presence were collected in Croatia in the period from 1st of May 2022 to 30th of April 2023 (Table 4.1), of which 143 observations were categorized as C1, 33 as C2 and 44 as C3. The most abundant type of data were photographs (135 records). Captured animal was a juvenile orphan lynx, found in Gorski Kotar area. No lynx mortality was collected in this season.

Type of data	Number of data	SCALP category		
		1	**2**	**3**
Photograph	135	135		
Captured animal	1	1		
Footprint	18		18	
Hair	21	7		14
Prey	15		15	
Scat	12			12
Urine	1			1
Sighting	16			16
Vocalization	1			1
Total	220	143	33	44

Table 4.1: Opportunistic data of Eurasian lynx presence in Croatia collected in the period 1st May 2022-30th April 2023.

A total of 589 systematic data (camera trap photos) of Eurasian lynx presence were collected in Croatia in the study period. Out of those, 289 data were provided by the LIFE Lynx project and 300 were provided by the project Development of lynx monitoring program.

A total of 809 signs of lynx presence, both opportunistic and systematic data, were collected in Croatia during the study period (Fig. 4.1).

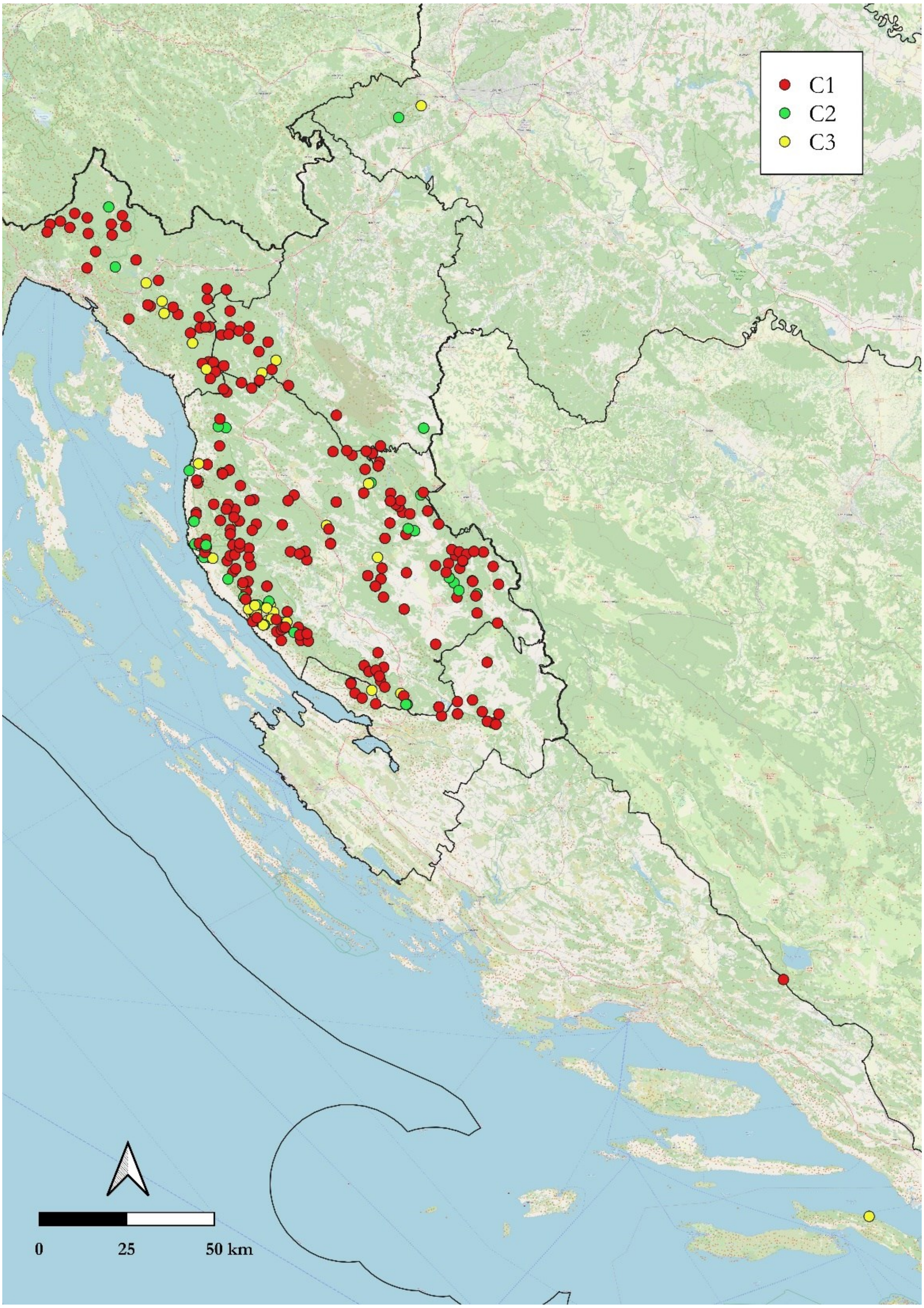

Figure 4.1: Signs of lynx presence in Croatia collected in the period 1st of May 2022-30th of April 2023, classified as C1 (red dots), C2 (green dots), and C3 observations (yellow dots), based on SCALP category.

Based on the collected C1 and C2 data, lynx presence in the monitoring year 2022/23 was confirmed in Primorsko-Goranska and Ličko-Senjska County, north-eastern part of Zadar County, and in the south of Karlovačka County. Outside this core area, one C2 and one C3 sign were recorded in the northern part out of Karlovačka County (Žumberak Mountain), one C1 sign on Dinara Mountain (Split-Dalmatia County, on the border with Bosnia and Herzegovina). Also, one C3 observation was recorded on the Pelješac peninsula. According to that total surface of lynx confirmed presence in Croatia in the season 2022/2023 was 7300 km^2, with additional 300 km^2 of unconfirmed presence (Fig. 4.2).

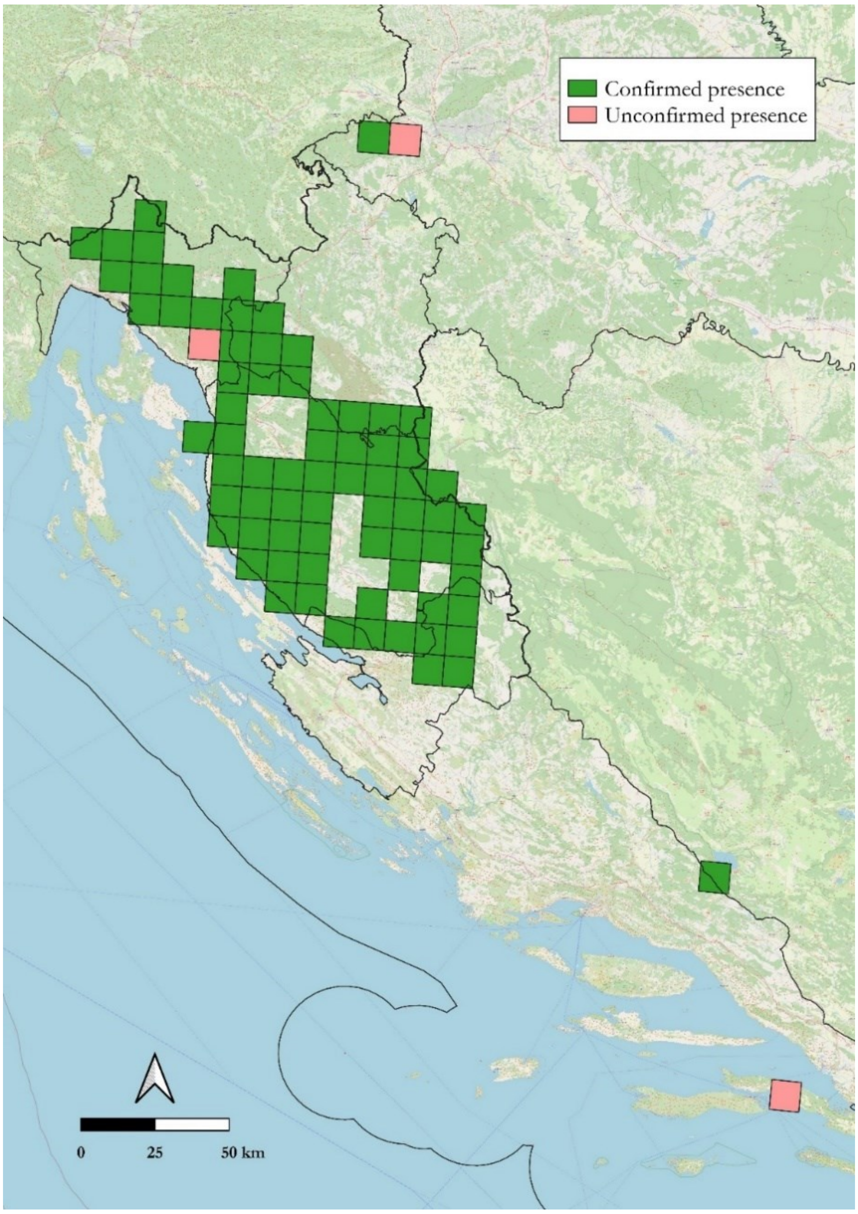

Figure 4.2: Lynx distribution in Croatia during the period 1st of May 2022-30th of April 2023. Green squares represent the areas with confirmed lynx presence, while squares marked in pink represent the areas with unconfirmed presence of the species.

4.2 Minimum population size

During the 2022/2023 season 65 adult individuals were identified based on both flanks, 14 based only on the left body side, and 12 based only on the right body side. The minimum population size estimation of identified adult lynxes was 79. In the case there were not matches between the individuals photographed only from the right side and those photographed from the left side, number of adult individuals identified was 91. Because of this, the estimation of the minimum population size was 79-91. A total of 27 females and 21 males were identified, whereas sex could not be determined for 43 individuals (Table 4.2).

		Number of identified lynxes
Adults		79-91
Photographed body flank	Both	65
	Left	14
	Right	12
Sex (adults)	Females	27
	Males	21
	Unknown	43

Table 4.2: Number, body flank and sex of adult lynxes identified in Croatia during the 2022/2023 season.

4.3 Reproduction

A total of 26 kittens were identified during the 2022/2023 season, belonging to 18 different litters. Twenty kittens could be identified based on their coat pattern. There were 11 cases of females with one kitten, 6 cases of females with two kittens, and one female with three kittens (Table 4.3, Fig. 4.3). Additionally, on 12 events a mother with cubs was photographed but nor mother or cubs could not be identified (Fig. 4.4), so we cannot confirm if they are the same animals as some from the 18 identified litters.

One juvenile male lynx was found orphan, called Karlo. He was found in Gorski Kotar region, then he was transported first to the Zagreb Zoo and then to the specialized recovery center for lynxes at the Zoo Bojnice in Slovakia. Lastly, he was released in the southeastern Italian Alps, as a part of the UlyCA 2 project, to connect the Dinaric population with the Alpine one.

Mother ID	Number of kittens	Kitten ID
Eva	2	Unidentified
Golo trlo 6	1	Golo trlo6 mladunac 2023
Golotrlo6 Mladunac 2020	1	Unidentified
Ibsen	2	Ibsen mladunac2 2022, Ibsen mladunac1 2022
Irena	2	Irena mladunac1 2022, Irena mladunac2 2022
Unknown	1	Karlo
Megi	1	Unidentified
Miley	2	Miley mladunac1 2022, Miley mladunac2 2022
Unknown	1	Mladunac Loznica 2022
Unknown	1	Mladunac Rizvanusa 2022
Pangea	1	Unidentified
Rosa	2	Rosa mladunac1 2022, Rosa mladunac2 2022
Shiny	2	Shiny mladunac1 2022, Shiny mladunac2 2022
Spot	1	Spot mladunac 2022
Suzi	3	Suzi mladunac1 2022, Suzi mladunac2 2022, Suzi mladunac3 2022
Tara	1	Tara mladunac 2022
Torun	1	Unidentified
Unjka	1	Unjka mladunac1 2022
Total	26	

Table 4.3: Females with their respective kittens identified in Croatia during the 2022/2023 season.

Figure 4.3: Reproductive sites distribution showing identified litters in Croatia during the period 1st of May 2022-30th of April 2023. Red dots represent reproductive sites with one kitten only (lynxes Golotrlo6 mladunac 2020 and Golo trlo 6 were recorded on the same location), yellow dots represent reproductive sites with two kittens, while green dots represent reproductive sites with three kittens.

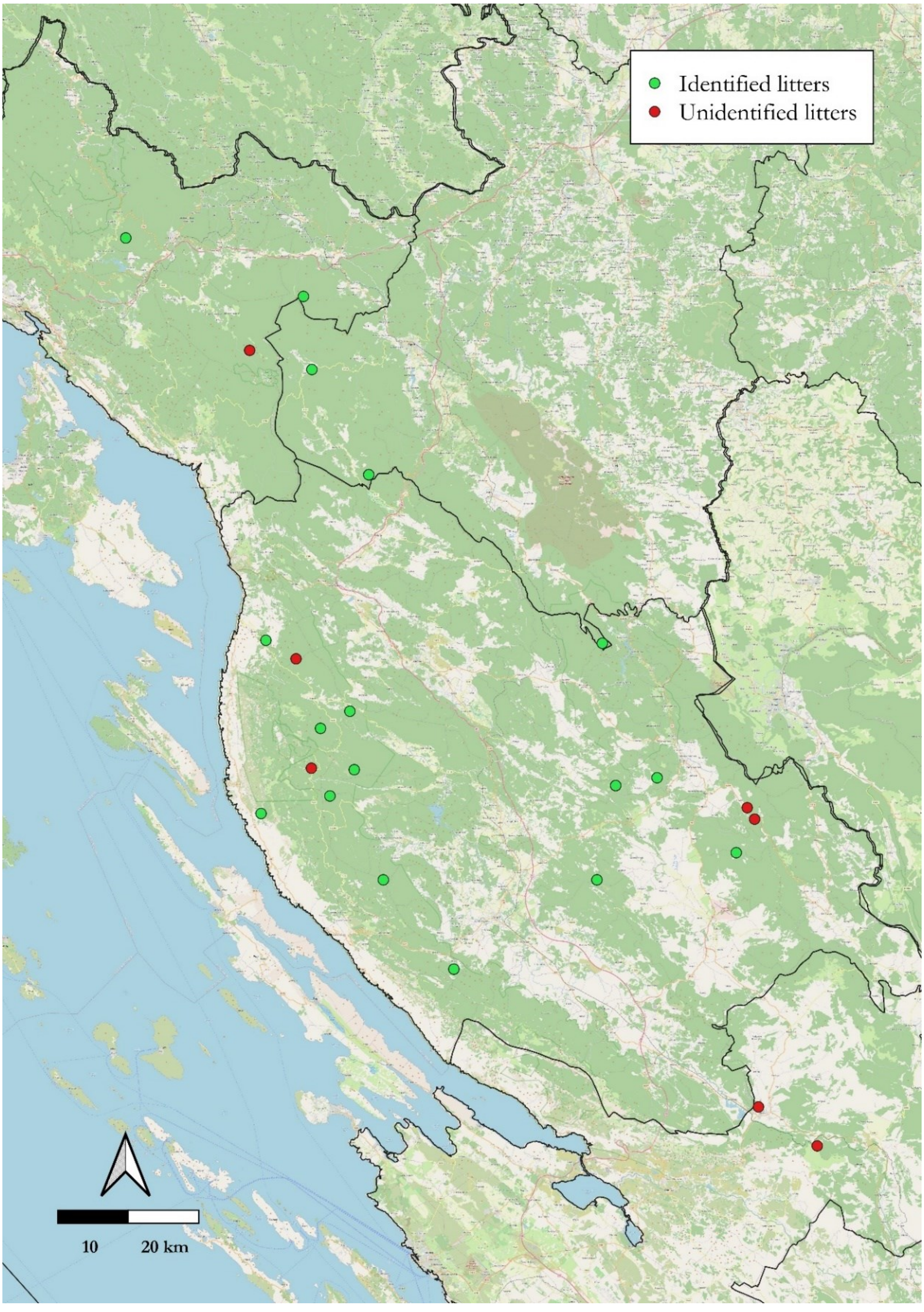

Figure 4.4: Reproductive sites distribution showing identified and unidentified litters in Croatia during the period 1st of May 2022-30th of April 2023. Red dots represent identified litters, while green dots represent unidentified litters. Number of both red and green dots are smaller than the real number of the respective litters because some events were recorded on the same location.

4.4 Life history of individual lynxes

A total of 111 individuals were identified during the season 2022/2023, including adults and juveniles. Fig. 4.5 shows life history of 51 lynxes that were detected for the first time before 2022, while the second plot (Fig. 4.6) represents 60 individuals detected for the first time in 2022.

Among these individuals, animal that was monitored for the longest period is female named Spot, photographed for the first time in 2014. Lynx monitored for the shortest period was female Danielle, photographed for the first time in May 2023. The most photographed lynx was male Šiljo, detected in 146 events from June 2020 to October 2022, while Mila mladunac 2021 was the juvenile that has been photographed the most, in fact it was detected in 20 events from August 2021 to December 2022.

This graphical representation enabled to observe that some individuals, since their initial identification, may experience extended periods without being photo-captured. For example, lynx Arabella (Fig. 4.5) was identified for the first time in October 2021 with her mother called Buna when she was a juvenile, and after more than a year she was photographed as an adult individual in January 2023.

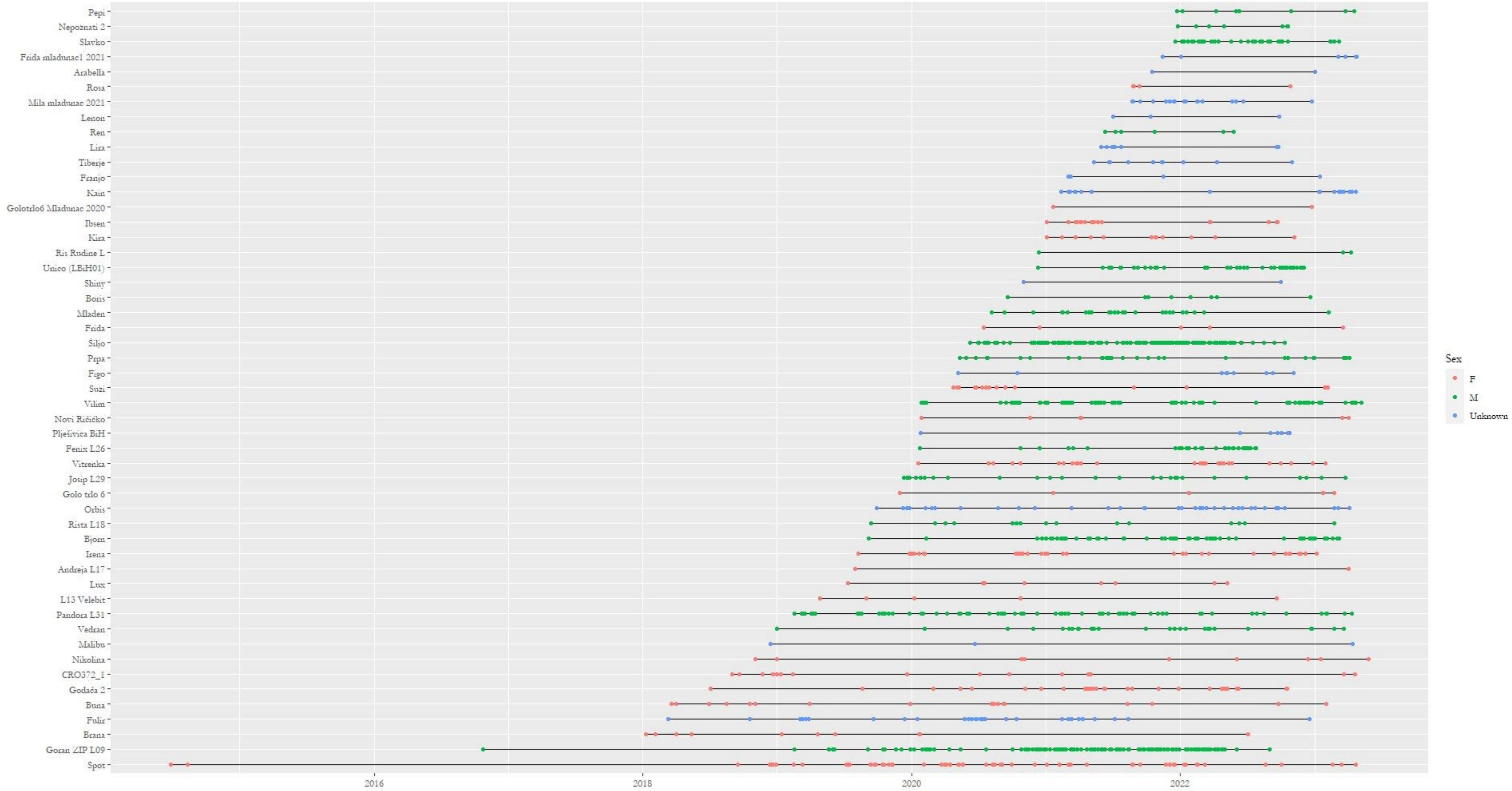

Figure 4.5: Life history and detection of 51 lynxes identified for the first time before 2022. Red dots represent lynxes identified as females, green dots represent males, and blue dots represent lynxes whose sex is unknown.

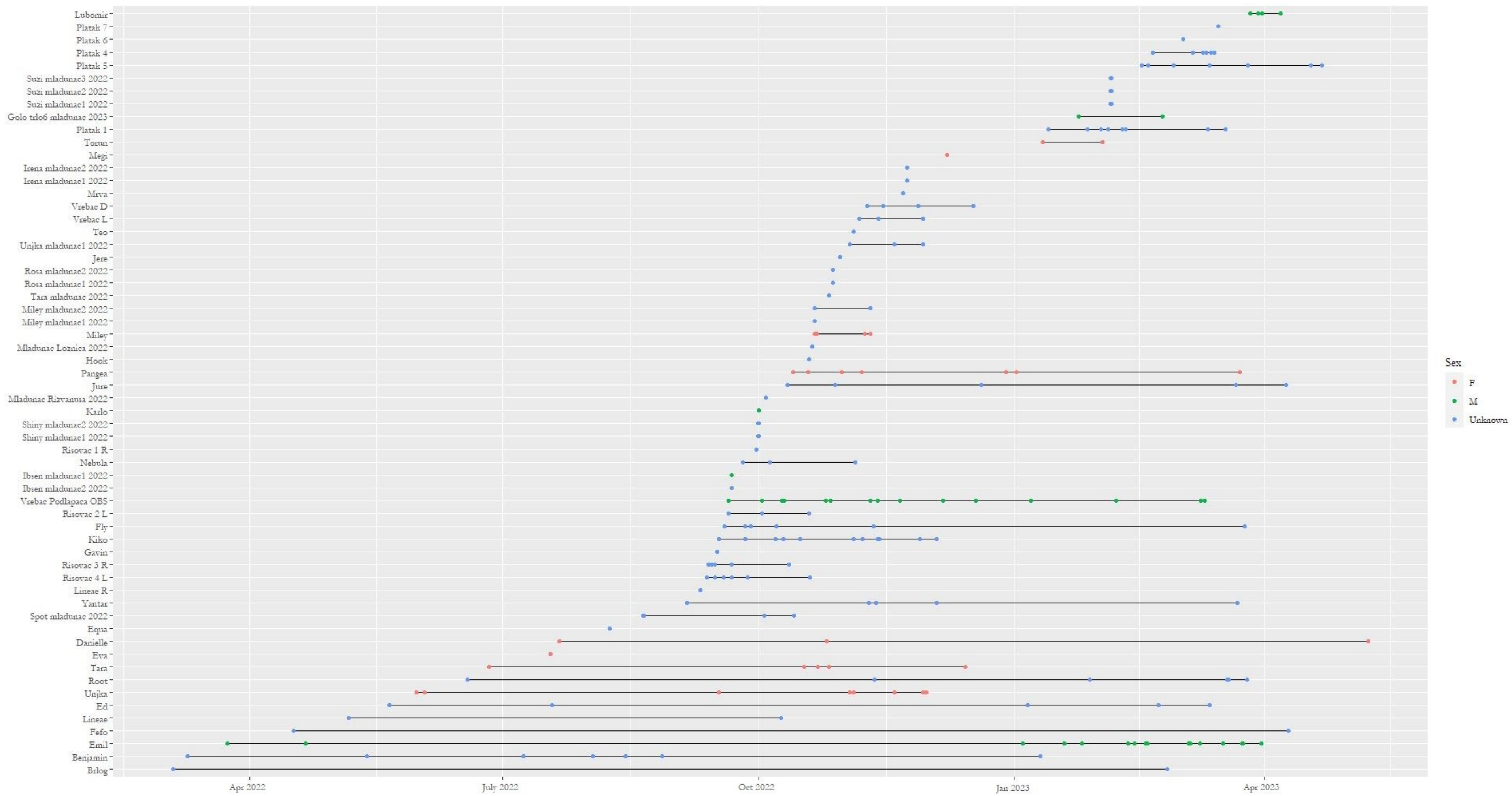

Figure 4.6: Life history and detection of 60 lynxes identified for the first time from 2022. Red dots represent lynxes identified as females, green dots represent males, and blue dots represent lynxes whose sex is unknown.

DISCUSSION

The results from this monitoring study allowed an assessment of the status of the Eurasian lynx population in Croatia in the 2022/2023 season.

To reach the goals of the study, collection and analyzes of both opportunistic and systematic data was essential. The implementation of the project Development of lynx monitoring program during the study period has allowed collection of a significantly greater amount of systematic data than in previous years (Fležar et al., 2022, 2023), resulting in a better insight into the population status.

Systematic and opportunistic data confirmed lynx distribution remained the same as recorded in the previous seasons, including the main part of Primorsko-Goranska and Ličko-Senjska County, north-eastern part of Zadar County, and southern part of Karlovačka County. But additionally, lynx presence was confirmed in two locations outside the core area, namely north of the core distribution in Žumberak Mountain and the further south along the border with Bosnia Herzegovina, specifically on Dinara Mountain. Unconfirmed lynx presence has been recorded outside the core area, on Pelješac peninsula, the same as it was reported by Gomerčić et al. (2021) during two lynx-monitoring years from 2018 to 2020. It is possible to assume that individual lynxes occasionally disperse to Pelješac from Bosnia and Herzegovina but, as reported by Fležar et al. (2022), poaching might be a barrier to permanent residence.

Minimum population size was estimated to 79-91 adult lynxes, and additionally 26 kittens were recorded. Although these numbers are higher than in the previous seasons, this increase is most probably the result of more intensive camera trapping effort, primarily due to the implementation of the Development of lynx monitoring program.

Mortality monitoring is a very important part of the management of endangered populations, especially during the reintroduction projects. Monitoring of mortality in the Dinaric lynx population in the past seasons showed that the most frequent cause of mortality relates to human activity, including car accidents and poaching cases, while infectious diseases are not a significant threat (Sindičić et al., 2023). During this lynx-monitoring year, no lynx mortality was recorded and for this reason it was not possible to include this parameter in the study.

The graphical representation of the life history of individual lynxes identified during the study period showed long periods between two recording of some individuals. For instance, few individuals who had not been camera-trapped for three years, have been photographed again in this season. Similar was already observed by Gomerčić et al. (2021), who concluded that some animals reappear in photo-traps after an absence of over a year.

In conclusion, according to available data, the status of Eurasian lynx population in Croatia in 2022/2023 season is stable and similar to the previous years. Increase in the estimation of minimum population size and increase in recorded reproduction is probably the result of significantly improved network of systematically placed camera traps. It is necessary to implement the same methods and efforts for a several seasons to be able to compare the results. However, results of this study clearly show how an increase in monitoring effort results in better quality knowledge about population status. Considering the high risks Croatian lynx population is facing due to the inbreeding and ongoing reinforcement project, it is recommended to continue those increased camera trapping monitoring efforts. Additionally, it proved that non-systematic observations are a very important method for monitoring outside core population areas, so it is recommended to keep investing into informing and educating the public, especially hunters, about signs of lynx presence and how important it is to report about them.

CONCLUSION

This thesis presents monitoring of the Eurasian lynx population in Croatia, during the 2022/2023 season, underlining the significance of ongoing conservation attempts to ensure the species' future. The main population parameters obtained in the study period, compared to the ones of the previous seasons, allowed to observe that:

1. Confirmed lynx presence distribution remained the same, with signs of presence recorded in two new locations outside the core area.
2. Estimated minimum lynx population size (79-91) and reproduction activity were higher than recorded in the previous seasons, mainly as a consequence of increased systematic monitoring effort.
3. It is recommended to continue monitoring activities with increased efforts, also involving the public.

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