ELECTROCUTION HOTSPOT ANALYSIS REPORT

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Background

The Eurasian Griffon Vulture (*Gyps fulvus*) is a large, long-lived scavenger that plays a crucial role in ecosystems by consuming vertebrate carcasses. This scavenging behavior not only recycles nutrients but also helps limit the spread of disease.

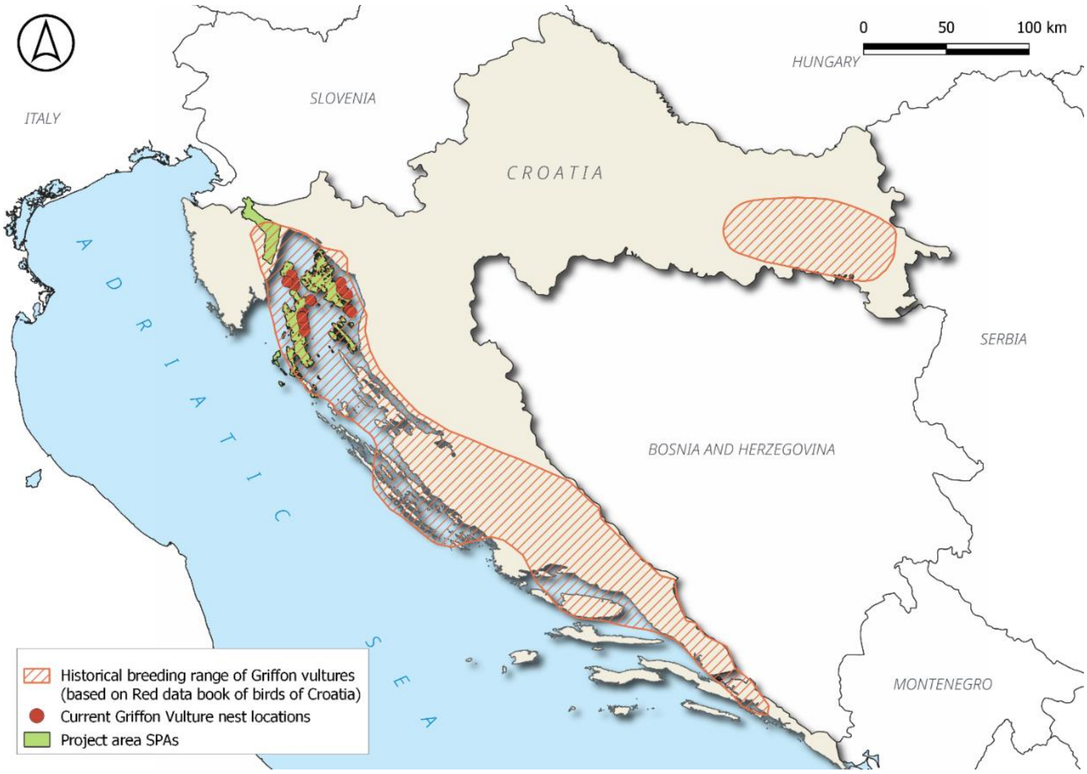


Figure 1 Vulture historical breeding range with project area overview

Despite its broad distribution and population size, which have led to its classification as "Least Concern" on the IUCN Red List (2021), the species is facing local population declines. In the Balkans, a notable decline was followed by a slow population recovery over the last 40 years, yet the vulture's range has decreased by half.

Currently, more than 120 vulture pairs nest primarily in the Kvarner region, encompassing the islands of Cres, Krk, Prvić, and Plavnik, with a new nesting site on the eastern side of Učka Mountain.

Some of the causes contributing to these population trends are illegal poisoning, reduced food availability, interaction with energy infrastructure and nest disturbance.

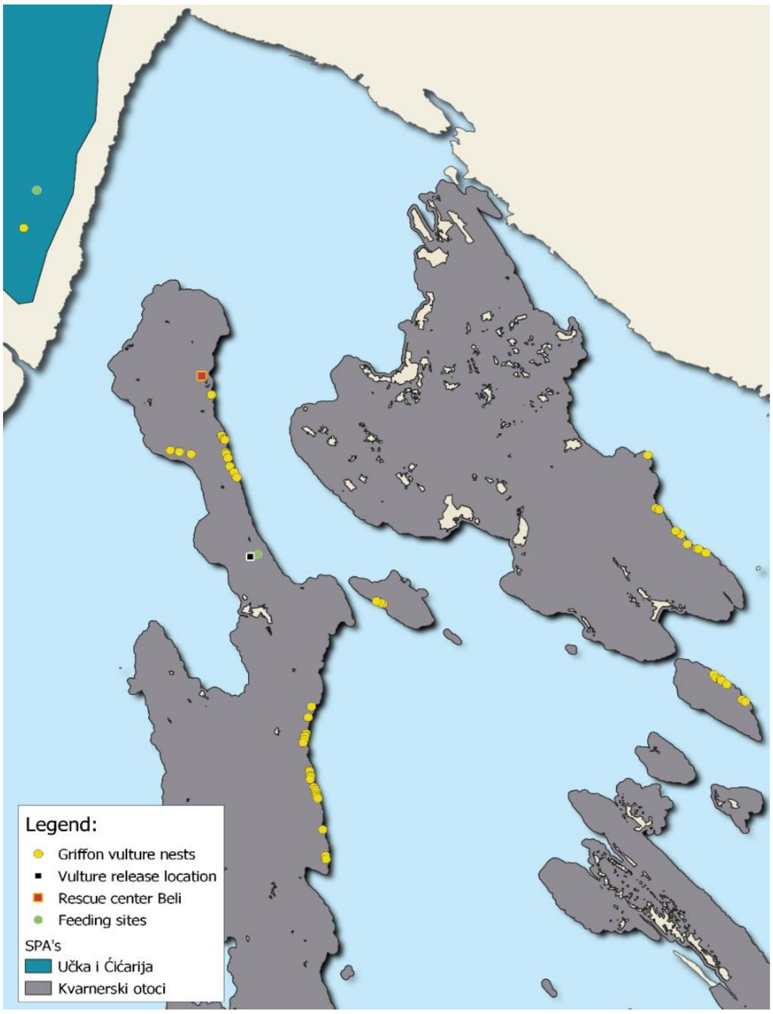


Figure 2 Overview of vulture nest locations, release areas and feeding sites on Kvarner islands

This study focuses on identifying areas with a high risk of vulture electrocution to prioritize which power poles should be retrofitted for safety. By analyzing telemetry data from GPS transmitters and conducting carcass searches, the study maps vulture home ranges in relation to the power line network within the project area.

Identified pylons will be targeted for retrofitting as part of the LIFE SUPport project.

Electric grid infrastructure

Power lines are widespread across vulture habitats and pose significant risks to vultures and other raptor species. The primary risks include:

- **Electrocution:** Can occur when birds perch on electric pylons as, depending on the pylon's typology, a bird can bridge the gap between two energized components, or between an energized and a grounded component, causing a short circuit that often results in the bird's death and can lead to power outages.
- **Collision:** Can occur when birds in flight collide with power line cables they fail to see ahead, often leading to fatal injuries from the impact with the cable or the impact with the ground.

The only effective way to mitigate these risks is through proper safety measures, such as undergrounding power lines or retrofitting above-ground structures.

In Croatia, power lines are categorized by voltage levels into three main categories:

- **High Voltage** (>110 kV): Transmission lines carrying electricity from production centers to substations.
- **Medium Voltage** (10/20 and 35 kV): Distribution lines that deliver electricity to businesses and residential consumers; these are the subject of this study.
- **Low Voltage** (>0,4 kV): Lines delivering electricity directly to consumption points, posing minimal collision risk.

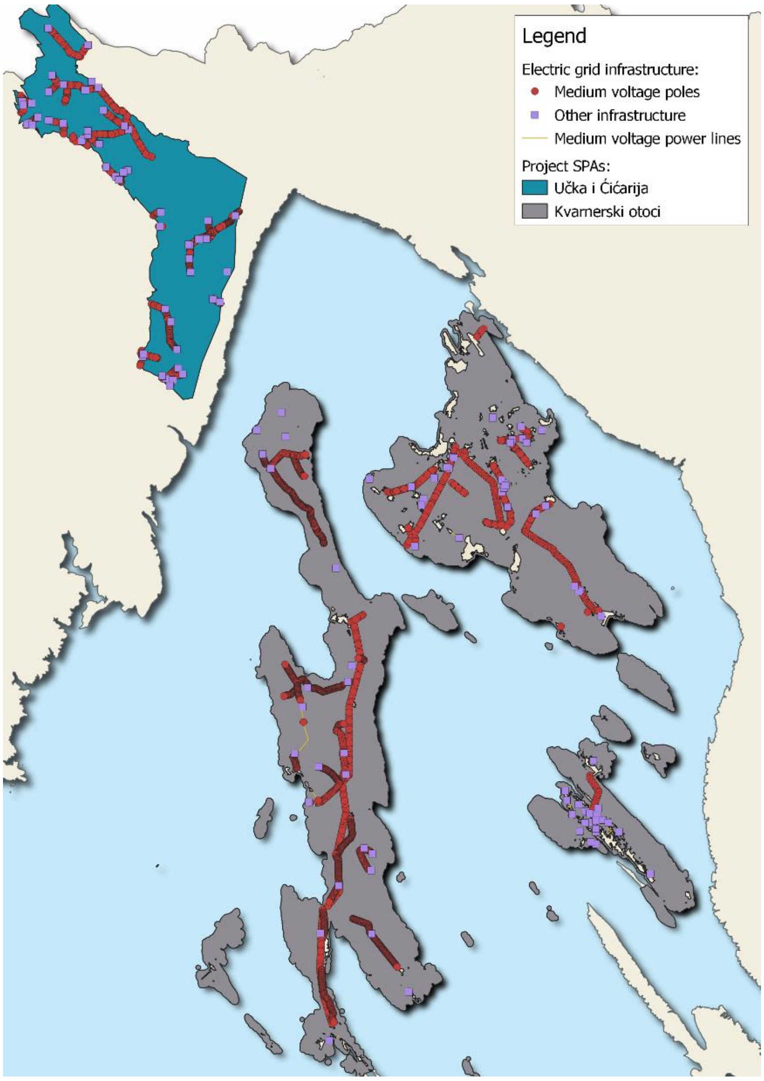


Figure 3 Electric grid infrastructure in the project area

While voltage levels are important, the proximity of power lines to bird habitats or migration routes is a more critical factor in predicting interactions. Therefore, it is essential to be aware of where existing structures overlap with areas that are sensitive to vultures. However, if power lines are built or mitigated in a way that is safe for birds, electrocution can be prevented regardless of the area's importance to bird populations.

In Croatia, the electric grid is divided both by the type of power lines and geographically. The transmission grid, consisting of high voltage power lines, is managed by HOPS - Croatian Transmission System Operator Ltd who are not partners on this project. Meanwhile, the distribution grid, which includes low and medium voltage power lines, is managed by HEP - Distribution System Operator Ltd.

(HEP DSO). This grid is further divided into 21 distribution areas, with the project area specifically managed by Elektroprimorje Rijeka.

Methods and Results

Standardisation of movement data

The study analyzed movement data from 35 Griffon Vultures, all rehabilitated at the Rescue Center for Griffon Vultures on the island of Cres. Unlike other European vulture populations that nest in mountainous areas, the Kvarner vultures nest on cliffs facing the sea. Consequently, many of the birds admitted to the rescue center are young and inexperienced, often falling into the sea during their first flights. After rehabilitation, these birds are ringed, and some are equipped with GPS transmitters before being released.

In total, data from 35 Griffon Vultures were available for analysis. Of these, only one was an adult at the time of release, and its gender (male) was the only one confirmed. As it is common in young non-breeding Griffon vultures, rather than being tied to specific areas around the colony, these young birds performed large exploratory movements throught the year, reaching as far as France, Turkey, and Poland (see Figure 5). For this reason, we focused the analysis on the entire the annual cycle.

All tracks used had to go through a filtering proccess to ensure they were comparable. Since some tags were reused on multiple birds, the initial step was to filter the data using a deployment table provided by the Rescue Center. The resulting data set comprised 959,613 points, with an average of 27,418 locations recorded per individual and a median of 10,645. The mean was skewed due to a wide range of data points, with one bird having only 11 locations and the most numerous having 135,010 locations.

The results were visually inspected to ensure proper deployment times were collected. However, some fixes were either collected before the bird's release or showed human movement, requiring fine-tuning of the cleaning process to remove non-bird movement. Additionally, duplicate fixes were removed, and positions with a low HDOP value (< 10) were excluded to ensure positional accuracy. All fixes recorded after the death of a bird were also removed where it was possible.

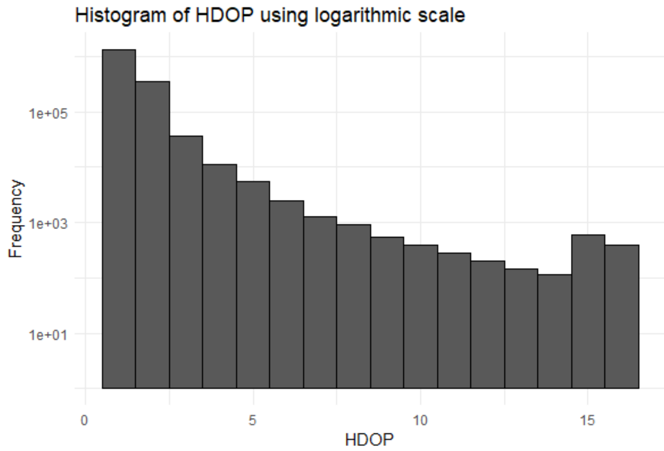


Figure 4 Distribution of HDOP values in the dataset before filtering

The cleanup process removed 16,582 points. Upon inspection, two vultures were found to have fewer than 200 fixes each (representing less than a day of movement) and were consequently removed from the dataset. This resulted in a total of 943,031 fixes (≈ 98 % of the original count).

To ensure consistent and accurate analysis, it was crucial to examine how the transmitters sampled data. The data revealed seven different sampling intervals (see Table 1), with the most common interval being 10 minutes. These irregular intervals were often caused by factors like signal loss or environmental conditions, making downsampling an essential step in standardizing the data. This standardization facilitates easier analysis and comparison by distributing the points evenly throughout the study period, thereby avoiding bias.

Resampling also improves computational efficiency. By resampling to a coarser time scale, the volume of data is reduced, speeding up the analysis without significantly compromising the results.

Freq	Hour	Min	Sec
1	1	0	0
5	0	2	0
3	0	5	0
17	0	10	0
5	0	15	0
1	0	20	0
1	0	0	1

Table 1 Sampling rate frequencies (median)

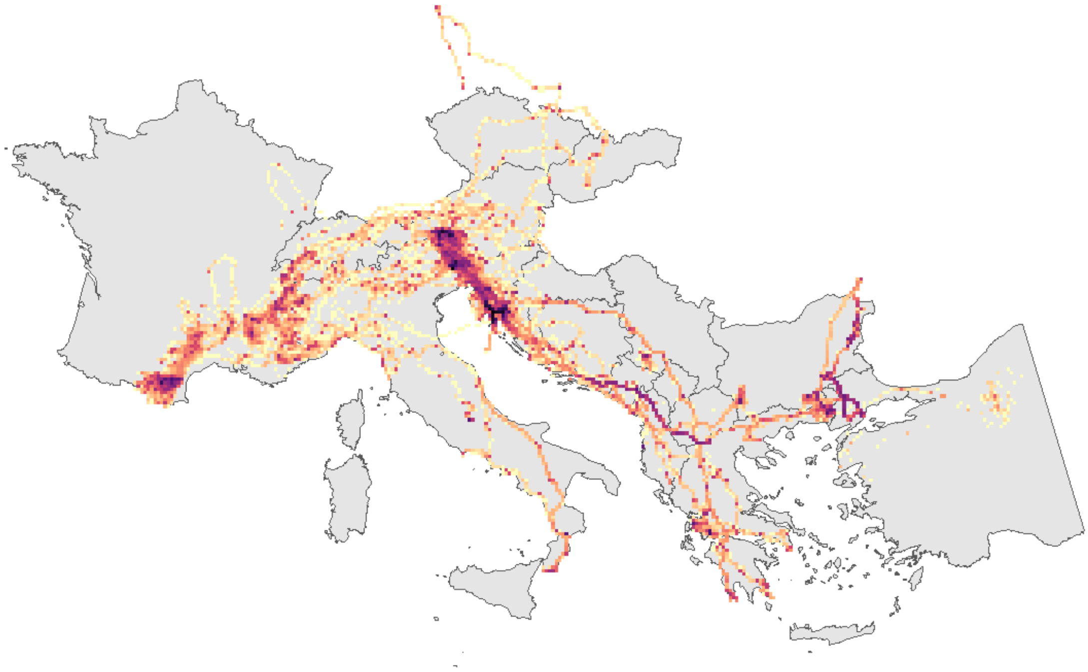


Figure 5 Heatmap of GPS fixes prior to resampling

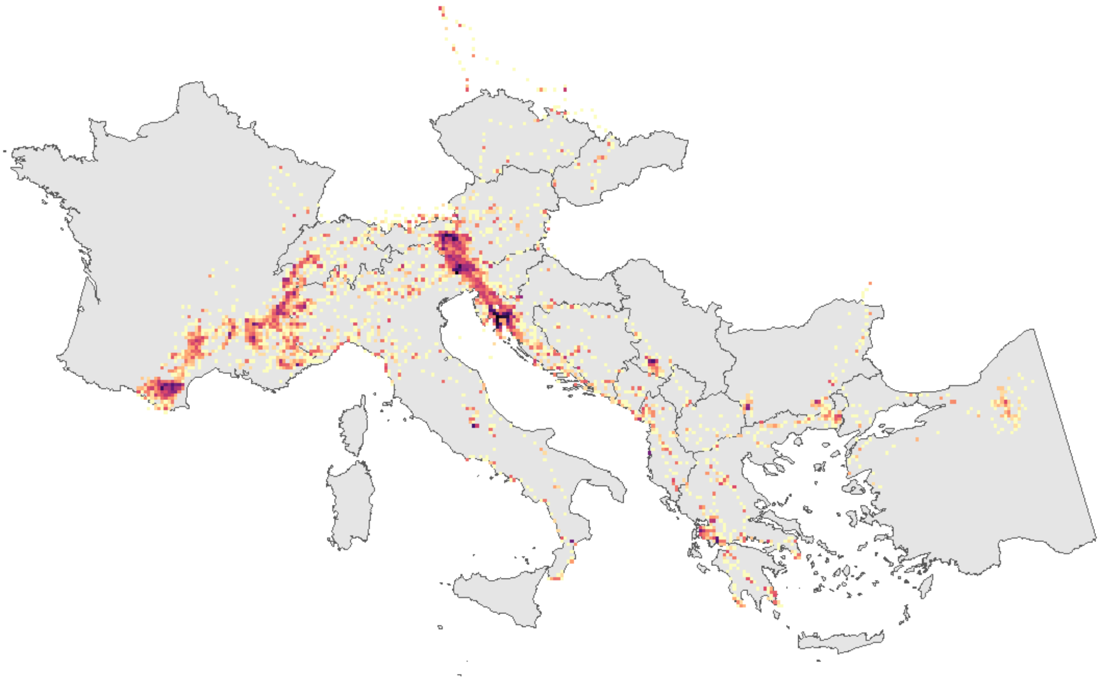


Figure 6 Heatmap of GPS fixes after resampling

Since vultures aren't nocturnal animals we checked the distribution of day/night locations and kept the day locations leaving out around 19 % of data.

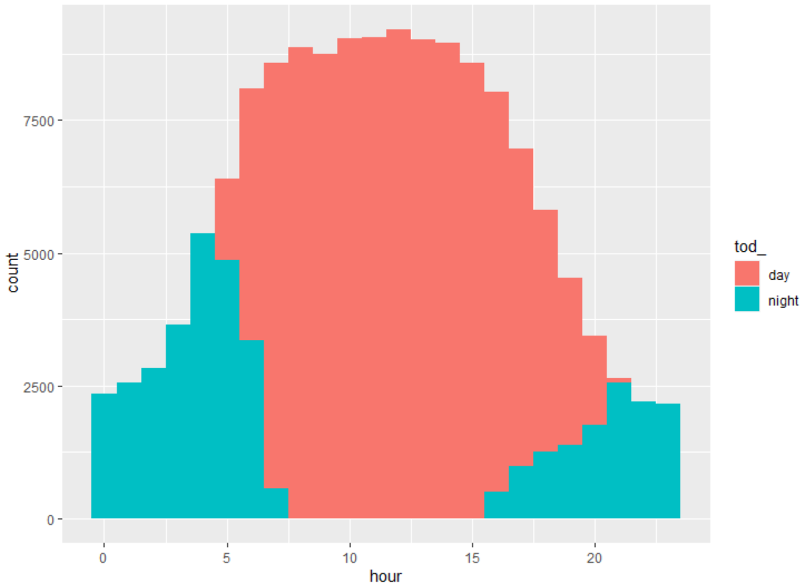


Figure 7 Distribution of day/night locations

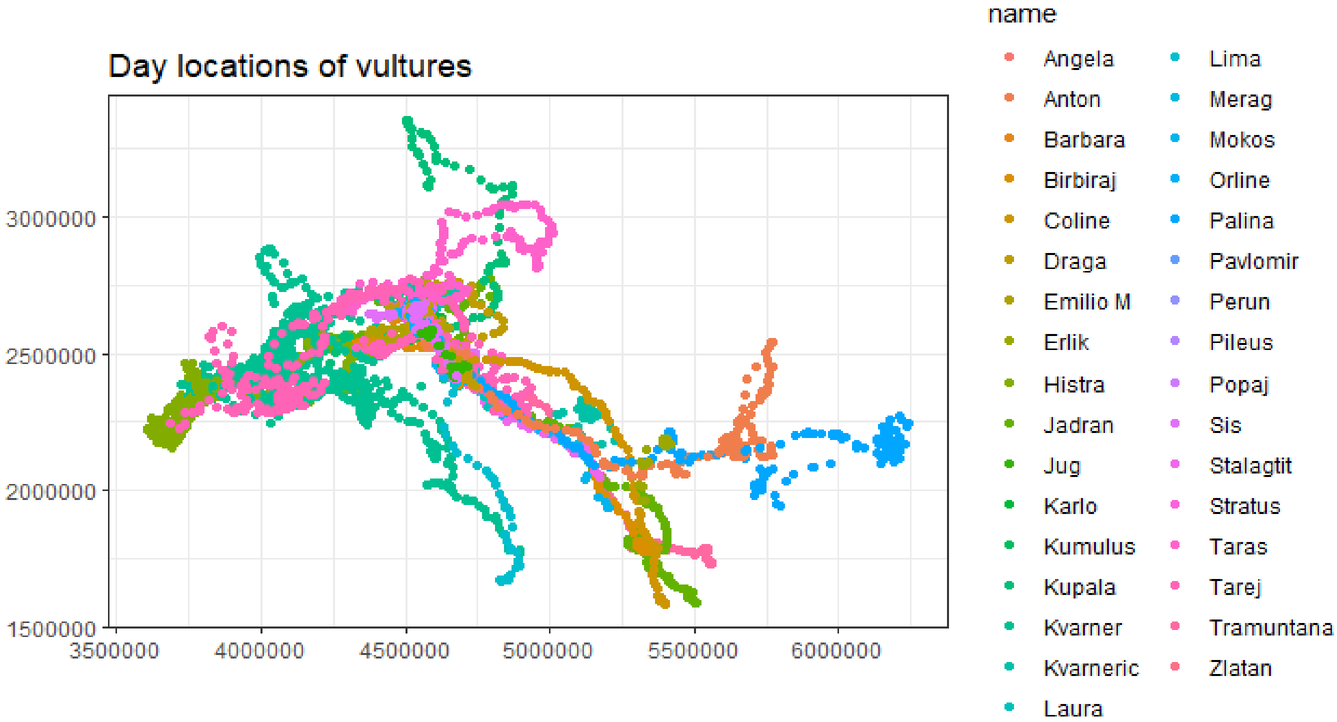


Figure 8 Spatial distribution of day locations of the 33 vultures to be used in the home range estimation

Due to the high concentration of points outside Croatian borders, particularly in parts of Slovenia, eastern Italy, and southern Austria, which indicates the significance of these areas, we decided to extend our area of interest to include these regions as well.

Home range estimation

To identify areas posing significant risks to vultures, we focused on understanding their home ranges - essentially the geographical area where an animal regularly lives and moves.

A home range is shaped by the animal's ecological needs, mainly driven by the availability of food resources. Due to their foraging behavior, vultures tend to have larger home ranges compared to some other species. Additionally, various factors, such as the bird's age, season (e.g., breeding vs. non-breeding), weather, and human impacts, can influence these ranges. For example, Griffon vultures in the Kvarner Islands often cross the sea, traveling between islands and mainland Europe.

Within an animal's home range, specific areas can be identified where it spends most of its time—these are known as core areas. These areas typically contain essential resources like food, water, and nesting sites, while the rest of the home range is used less frequently for activities such as exploration or occasional foraging.

Mapping these areas where vultures are most likely to be found helps us identify power lines that pose the highest risk to them. This, in turn, allows us to focus on mitigating these risks to protect the vulture population.

Calculating Vulture Home Ranges

To calculate home ranges, we applied *kernel density estimation (KDE)* to the movement data. KDE creates a probability density surface based on locations where the vultures have been, highlighting where they spend most of their time.

We started with the original dataset, which was cropped to fit the project area, retaining approximately 78% of the resampled daytime locations. To ensure the data was representative of the Kvarner Griffons' annual movements, we refined it further, including only vultures that were tracked for more than three months.

The data was then organized into annual cycles of 365 days, allowing us to analyze movement patterns over time. Consequently, the number of vultures in the analysis was narrowed down from 33 to 16, covering the period from May 2018 to May 2024. For further analysis, all data was projected using the ETRS89-extended / LAEA Europe projection (EPSG: 3035).

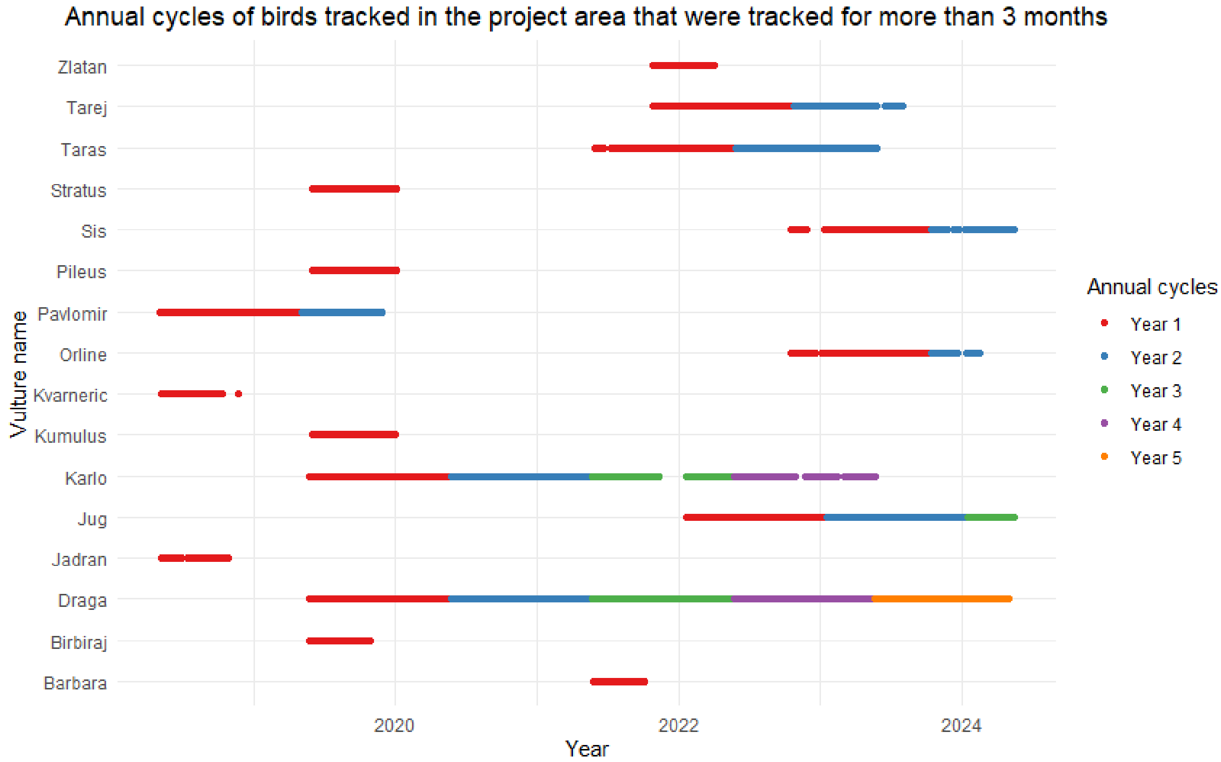


Figure 9 Annual cycles of vultures tracked for more than three months in the project area

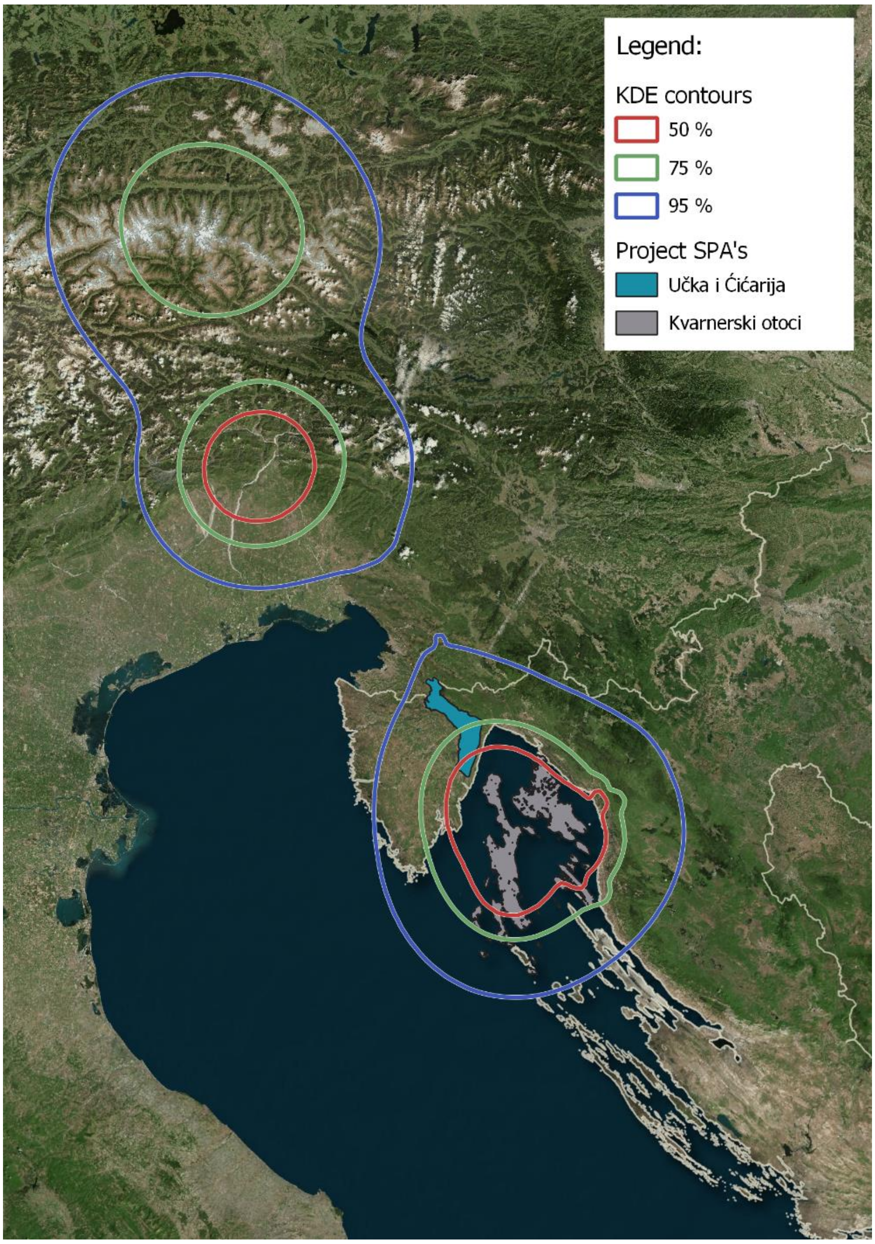
For each bird, we calculated a maximum 50 %, 75 % and 95 % utilization distributions (UD, generating corresponding isopleths or home range contours These individual contours were then combined to produce a comprehensive map of the overall vulture home ranges.

Prioritizing Areas for Risk Mitigation

We prioritized the mid-range areas (75% KDE) for retrofitting efforts, as these areas offer a balanced focus between the core habitat (50%) and the broader vulture range (95%). This choice was guided by the unique geography of our study area—an archipelago where vultures regularly cross between islands and mainland Europe. By focusing on the mid-range, we gain a clearer understanding of the critical areas needing pylon retrofitting.

To ensure accuracy, we also calculated a weighted utilization distribution, taking into account the varying number of GPS points recorded per bird each year. This method prevents months with higher data density from disproportionately influencing the results. We then aggregated the individual home ranges to visualize the population's overall range more effectively.

Bandwidth Selection in KDE and Its Impact



When calculating KDEs, the choice of bandwidth is crucial as it determines the smoothness of the resulting density estimate. Among the bandwidth options, the reference and plug-in methods are notable. The reference bandwidth is computationally efficient and provides a good initial look at the data, but it tends to underperform for multimodal distributions (common in biological data), often overestimating the utilization distribution and creating larger home ranges than are accurate.

As shown on the map (see Figure 10), the home range estimated using the reference bandwidth extends from near Rosenheim (Germany) in the north to Biograd na Moru (Croatia) in the south, and from Treviso (Italy) in the west to Zrinska Gora (Croatia) in the east. The core ranges are located in the Kvarner islands and the southern parts of Učka, as well as the area north of Udine, with the 75% range extending further to National Park Hohe Tauern and the wider Kvarner region. However, this vast range, which overlaps a large area including extensive stretches of sea, is not very informative for prioritizing retrofitting efforts on electrical pylons.

In contrast, the plug-in bandwidth is considered an improvement over the reference bandwidth because it better adapts to the underlying data structure making it more accurate, despite being more computationally intensive.

The resulting home ranges are generally smaller (see Figure 11), with core range KDEs better reflecting key areas for the vultures, such as roosting and feeding locations in the Kvarner region, southern Učka, as well as around Lago di Cornino Nature Reserve (Italy), and in central Hohe Tauern National Park.

To ensure robust results, we tested multiple bandwidth selection methods for KDE, including the reference and plug-in bandwidths, as well as fixed bandwidths of 1,000, 3,000, and 5,000 meters.

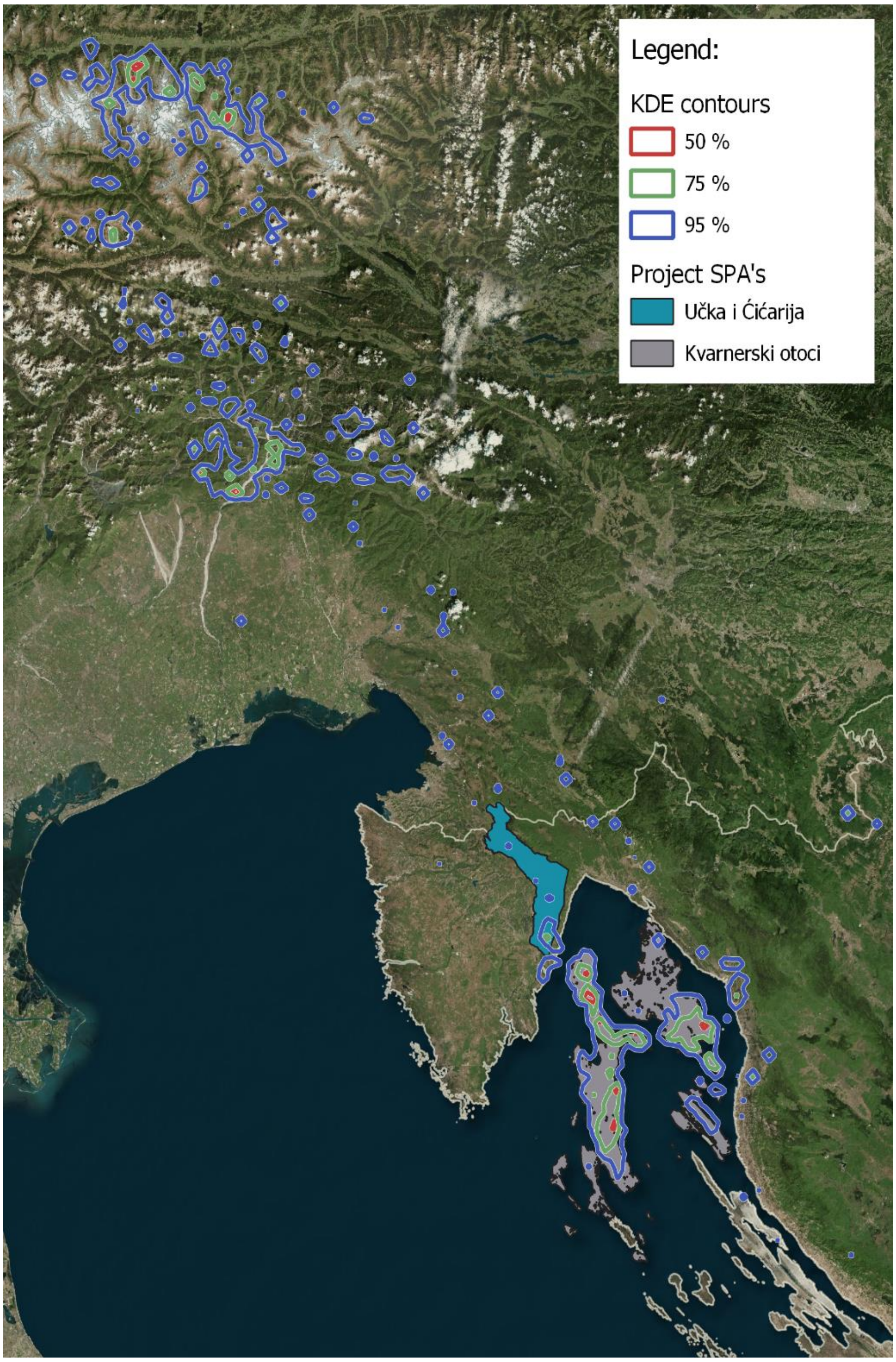


Figure 11 Home range calculated using the plug-in bandwidth

These provided a range of options between the reference and plug-in bandwidths. After careful evaluation and expert judgment, we determined that the 3,000-meter bandwidth (Figure 12) was the most suitable for addressing our research question, balancing computational efficiency with the accuracy needed to identify critical areas for retrofitting pylons.

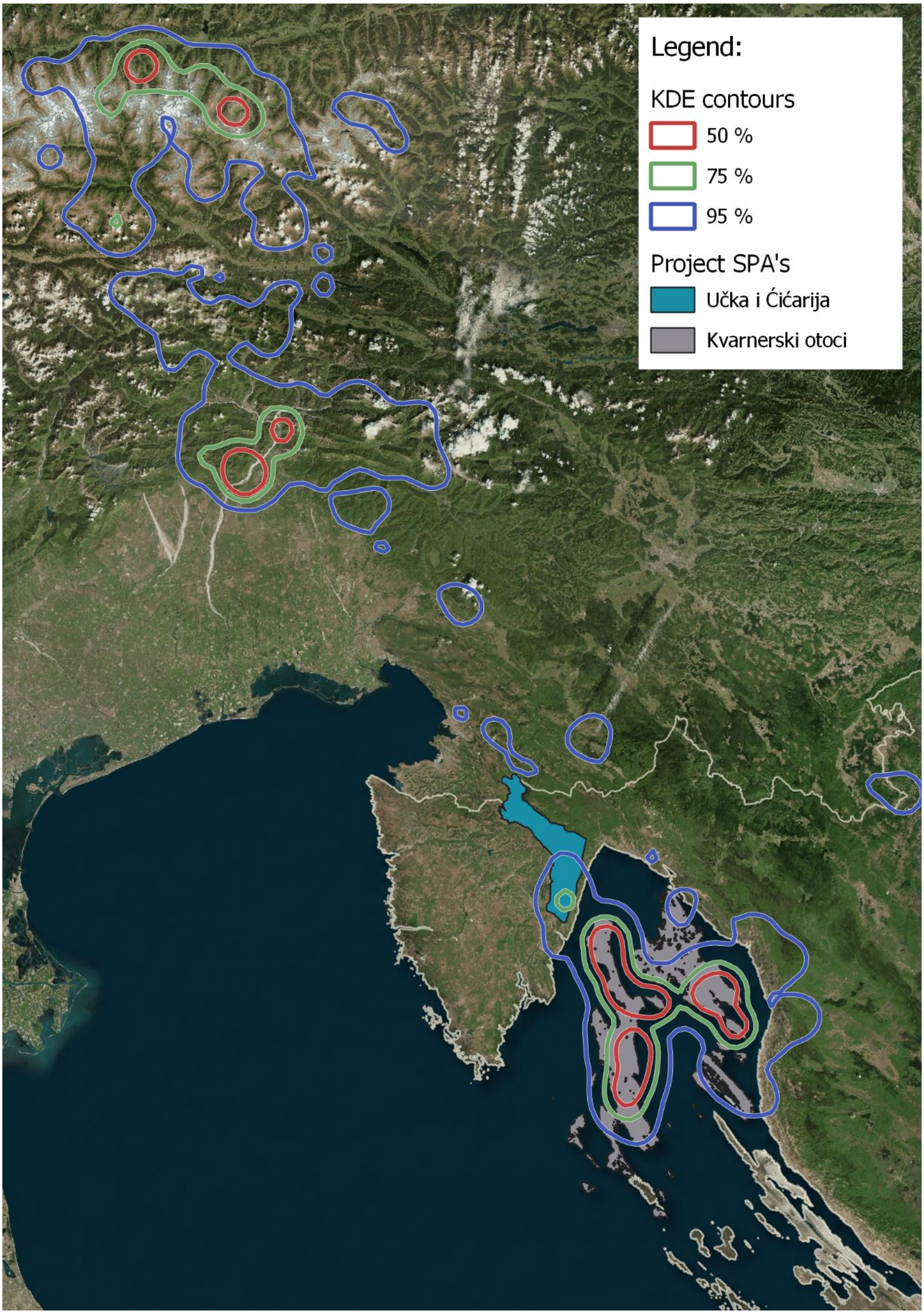


Figure 12 Home range calculated using the 3000 m bandwith

Carcass search

An essential component of risk analysis is conducting field searches for birds killed by electrocution in the project area. In 2023, Association Biom organized two workshops on the island of Cres to train participants for independent volunteer fieldwork focused on discovering dead birds.

The workshops included presentations on the project, previous work on electrocution, and the theoretical knowledge required for fieldwork. The following day focused on the practical application of this knowledge in the field. Trained volunteers, guided by input from the volunteer coordinator, were dispatched to pre-selected poles identified as potentially dangerous.

All fieldwork was conducted from February to June, subject to volunteer availability and appropriate weather conditions.

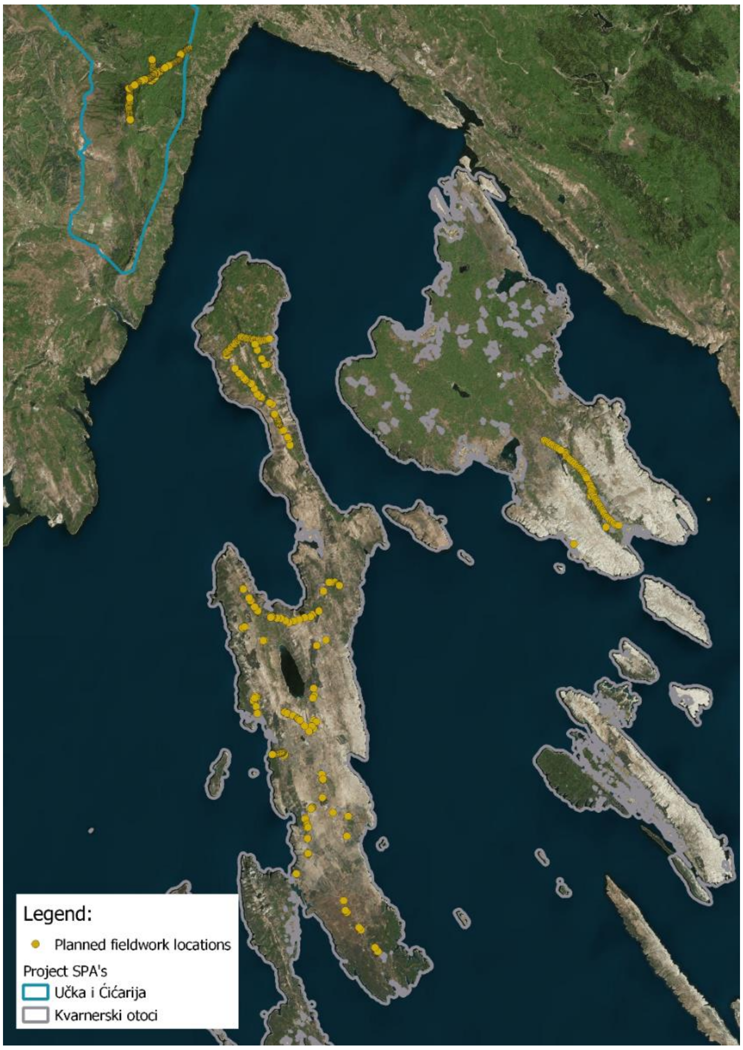


Figure 13 Locations where carcass search fieldwork was done

In the field, volunteers meticulously examined the designated areas (Figure 13), paying special attention to the structures of the poles and their consoles to assess their condition. If any construction elements appeared damaged, volunteers were instructed to photograph the pole, its markings, and its location. They also conducted detailed inspections within a 5-meter radius of the poles, searching for bird remains. Upon finding remains, volunteers were to identify the species and photograph the scene. If the deceased bird was a raptor or vulture, it was collected in a sample bag, or a sample was taken if the bird was in an advanced state of decay, and delivered to the Public Institution Priroda for further analysis.

Other bird species were moved away from the poles to prevent repeated recordings in future monitoring. Each pole was also photographed and documented as dangerous.

Mortality data was collected in a field form (Figure 14) that included information on the date and time, found species with the collection code (specimen) and carcass photo, any mitigation measures present on the pole (insulating covers, raised perch, diverters), any visible damage to the mitigation measures visible and general description of the pole (its number, material, head shape, presence of a disconnector or transformer, and a photo).

Column names			Carcass			Mitigation measures				Pole description					
	Date	Time	Species	Collection code	Carcass photo	Insulation / Insulating covers	Raised perch	Diverters / Spikes	Visible damage on mitigation measures	Pole no.	Pole head photo	Pole material	Pole head shape	Disconnector	Transformer
	Datum	Vrijeme	Vrsta	Šifra uzorka	Fotografija lešine	Izolacija / Izolacijske kape	Prečka za sjedenje	Šiljci za odvraćanje	Vidljivo oštećenje na mjerama za ublažavanje	Broj stupa	Fotografija glave stupa	Materijal stupa	Oblik konzole	Rastavljač	Trafo
PRIMJER	2021-07-14	17:57				Yes	Yes	No	No	362/276		Čelični	Gama	Yes	No
PRIMJER	2021-07-14	18:05				Yes	Yes	No	No	364/277		Betonski	Gama	No	No
PRIMJER	2021-07-14	18:09	Largus sp.	CRES_AK_1	CRES_AK_1.jpeg (4 photos)	No	No	No	No	278		Čelični	Delta	Yes	Yes
PRIMJER	2021-07-14	18:21				Yes	Yes	No	No	279		Čelični	Gama	No	No

Figure 14 Example of the field form for the carass search

After returning from the field, volunteers submitted their data, including photographs, completed field forms, and a brief narrative report, to the coordinator.

Unfortunately, not all designated areas could be visited by volunteers. The most common issues included terrain inaccessibility due to high and dense vegetation making approach to poles impossible, fenced-off areas for cattle or sheep breeding, and routes only accessible through private properties.

Method validation

To validate the mid-range calculated using the 3000 meters bandwidth, we tested it against carcass search data from 2017 to 2024 within the project area. This data was sourced from previous BIOM projects conducted on Cres Island, carcass searches from 2024 specific to this project, and data collected by the Ministry of Economy and Sustainable Development.

This dataset included 156 cases of bird deaths due to electrocution, of which 51 were vultures (Table 2).

Species	Count
Gyps fulvus	51
Aves sp.	29
Corvus corax	24
Strix aluco	14
Bubo bubo	10
Larus michahellis	9

Buteo buteo	5
Corvus cornix	4
Corvus sp.	4
Falco tinnunculus	3
Garrulus glandarius	2
Aquila chrysaetos	1

Table 2 Distribution of bird species in carcass search dataset

By overlaying the carcass search data onto the home range map created in QGIS, we evaluated the distribution of deaths within each range. The middle range captured approximately 79 % of all bird deaths and about 92 % of all vulture deaths, demonstrating its accuracy and effectiveness (see Table 3 and Figure 15). This made it the most suitable method for identifying electrocution hotspots and prioritizing poles for mitigation measures.

KDE level	All birds (count)	Vultures (count)
50 %	82	42
75 %	124	47
95 %	156	51

Table 3 Mortality distribution in vulture home range

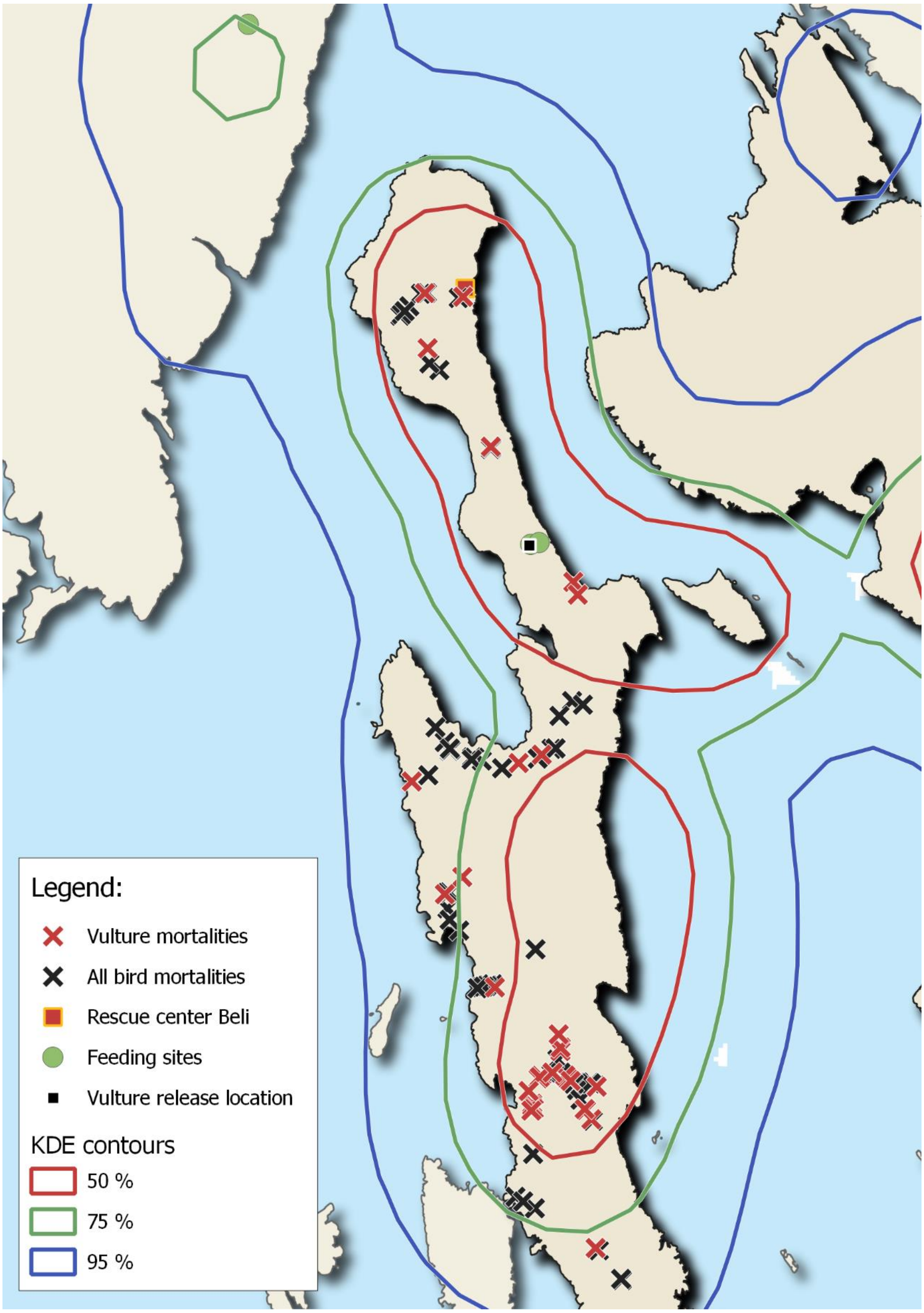


Figure 15 Vulture home range in relation to historical carcass search

Discussion

Our findings, influenced by the age of the studied vultures, provide preliminary insights into potential home ranges. For a more comprehensive understanding, analyzing adult vultures in the project area will be necessary, which will be possible once a planned soft-release aviary is operational. Nevertheless, the current data are sufficient for the purposes of this report.

We overlaid Kernel Density Estimates (KDEs) calculated with a 3,000-meter bandwidth onto the clipped power lines provided by HEP DSO within the project area.

This overlay enabled us to pinpoint which power lines intersect with each KDE region, offering a detailed spatial analysis of potential risk areas. The project area includes a total of 3,164 medium-voltage poles and disconnectors (24 kV and 38 kV).

Among these, 2,060 poles were found to be within the vultures' home range (95% KDE), as detailed in Table 4.

KDE region	Number of poles
50 %	755
75 %	1,042
95 %	2,060

Table 4 Number of poles in KDE regions

KDE regions can be understood as risk zones, with the core range representing the highest risk and the outer areas indicating progressively lower risk.

Specifically, in the KDE results, there are 755 poles within the 0-50% KDE range (core area), 287 poles in the 50-75% range, and 1,018 poles in the 75-95% range.

Thus, poles within the 50% KDE range are classified as Risk Category 1, those in the 50-75% range as Risk Category 2, and those in the 75-95% range as Risk Category 3.

To achieve the project's goal of mitigating approximately 200 poles, we developed two scenarios in response to HEP DSO's separate initiative to address some poles under the 'NPOO-Modernizacija mreže u Natura 2000 područjima' project. The first scenario considers all poles, including those planned for mitigation under the NPOO project, while the second excludes these poles from our risk assessment to prevent duplication and optimize mitigation effectiveness (see Table 5 and Figure 16). This approach allows us to plan mitigation measures independently of the NPOO project's progress.

KDE region	Number of poles
50 %	308
75 %	429
95 %	1,215

Table 5 Number of poles in KDE regions after accounting for HEP DSO project

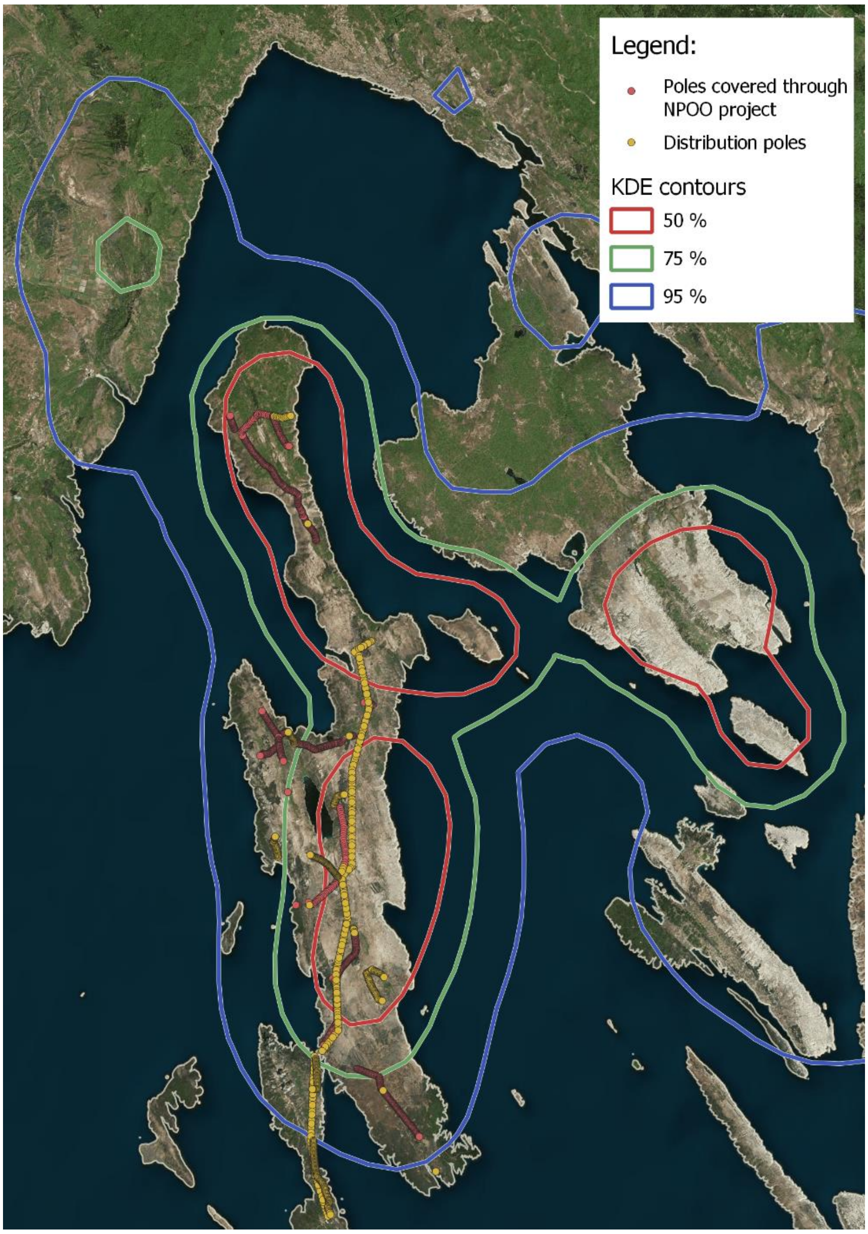


Figure 16 Locations of distribution poles on Cres island

Considering the geographical spread of the poles across the islands of Cres and Krk, which would escalate the cost of mitigation, and noting that all recorded bird mortalities occurred on Cres island, we have decided to concentrate our mitigation efforts there. Additionally, the most at-risk poles on Krk island are situated in lower elevation areas less frequented by vultures.

As a result, we created a table (Table 6) showing the difference in poles for mitigation on Cres island, divided into the three risk categories, depending on the realization of the NPOO project.

KDE region	Number of poles (NPOO project incl.)	Number of poles (NPOO project excl.)
50 %	254	701
75 %	323	936
95 %	437	1282

Table 6 Number of poles in KDE regions of Cres island (NPOO project included)

We recommend prioritizing mitigation efforts on poles classified as Risk Category 1, while leaving the precise selection of locations to HEP DSO's experts. If the cost-benefit analysis of retrofitting some Risk Category 1 poles is unfavorable, we suggest addressing poles in Risk Category 2 to maximize coverage within these two categories.

Recommendations

1. **Supplying the categorized poles:** As part of the report, HEP DSO will be provided with the categorized poles with a column labeld “KAT_RIZIKA” indicating their risk category from 1 to 3. Poles without a category are considered low-risk. Data will be in a format compatible with GIS programs, allowing the data to be easily viewed and further actions planned.

2. **Prioritize High-Risk Poles:** HEP DSO should focus their mitigation efforts on poles classified as Risk Category 1, which pose the highest risk of vulture electrocution. This prioritization should take into account the cost-benefit analysis of each location.

3. **Sequential Mitigation Approach:** Once all high-risk poles (Risk Category 1) are mitigated, proceed to mitigate poles in the Risk Category 2 list. If further mitigation is required to meet the project goals, then address the poles in Risk Category 3.

By following this structured approach, we can ensure that mitigation efforts are strategically targeted, thereby enhancing the protection of vultures within their home range while fulfilling the project's mitigation requirements effectively.

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