Drone-Assisted Aerial Surveys of Large Animals in Siberian Winter Forests

Victor Atuchin (atuchin@isp.nsc.ru)
Institute of Semiconductor Physics https://orcid.org/0000-0002-7424-5604
Alexander Prosekov
Kemerovskij gosudarstvennyj universitet
Anna Vesnina
Kemerovskij gosudarstvennyj universitet
Alexander Kuznetsov
Kemerovskij gosudarstvennyj universitet

Research

Keywords: European elk, digital technologies, unmanned aerial vehicle, drone plane, thermal imager, aerial imagery, Siberia

Posted Date: August 11th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-55278/v1

Abstract

There are two main reasons for monitoring the population of forest animals. First of all, regular surveys reveal the real state of biodiversity. Second, they guarantee a prompt response to any negative environmental factor that affects the animal population and make it possible to eliminate the threat before any permanent damage has been done. The research objective was to study the potential of drone planes equipped with t*hermal* infrared *imaging* cameras. Drone planes proved effective in covering large areas, while thermal infrared cameras provided accurate statistics in the harsh winter conditions of Siberia. The research featured the population of the European elk (*Alces alces*), which is gradually deteriorating due to poaching and deforestation. The surveyed territory included the Salair State Nature Reserve in the Kemerovo Region, or Kuzbass (Russia). The authors developed an effective methodology for processing the data obtained from drone-mounted thermal infrared cameras. The research provided reliable results concerning the changes in the elk population on the territory in question. The use of drone planes proved an effective means of ungulate animal survey on large areas of Siberian winter forests.

Background

Overpopulation increases the chance of human contacts with nature, which inevitably reduces or changes the natural habitat of wild fauna [1]. Mining and industrial use of pristine lands, as well as urban and rural development, produce a human-induced impact on the environment, thus causing the transformation and degradation of natural biocenoses and reducing biodiversity [2]. In the conditions of limited natural resources, the effectiveness of environmental management decisions depends on an accurate and timely analysis of environmental data. Therefore, improved methods of information collecting and processing can lower the environmental impact of managerial actions in the sphere of rational exploitation of natural resources and natural balance. A consistent approach to environmental management requires new systems of effective environmental monitoring. Surveys of large mammal population and distribution remain an urgent task. Large animals occupy the top of food chains, which makes them a sensitive integral indicator of the environmental state [3].

Animal surveys contribute to the rational conservation of biodiversity. A proper analysis of statistics on migration, fertility, and mortality can reveal cases of poaching and assess its real scale. A competent approach provides basic data for informed managerial decisions on the matters of animal population as an integral part of national wealth [4-8]. Animal survey is an important control factor that helps to balance socio-economic and natural interests. Unfortunately, the existing methods are based on direct counting or indirect evidence, e.g. footprints, feces, etc. Their results often prove unreliable [9]. Based on old databases, these methods are expensive and time-consuming. Moreover, most traditional methods require direct participation of humans, which cannot but affects the life of animals. Aerial survey method is an exception as it presupposes direct observation of animals from an aircraft.

Digital technologies are the most promising way to improve traditional survey methods of land and air accounting. They can reduce the shortcomings of manual methods and simplify their implementation.

This approach is especially promising for monitoring the environment in the vast and sparsely populated forests of Siberia. For example, the use of a GPS system makes it easier to determine the length of the daily tracks left in snow by a wild mammal. Winter track count is a typical animal survey method in Russia [10]. GPS collars make it possible to monitor the life of endangered animals, e.g. Amur tigers, cougars, brown bears, etc. [11, 12, 13, 14, 15, 16.17]. Trail cameras are another positive example of digital technology in this sphere [18,19].

Nowadays, aerial accounting often requires the use of drone planes and copters equipped with various sensors and cameras [20-31]. Unmanned aerial vehicles (UAV) equipped with radio receivers can track the routes of animals with GPS collars, i.e. as a biotelemetry method [32], for sampling [33], for collecting data from a particular habitat [34], and in anti-poaching operations [20]. The use of UAV eliminates any possible threat to the operator and the researcher team. In addition, UAVs produce less noise pollution, thus increasing the reliability of the survey. They can cover large remote areas in a short time. However, the use of UAVs for animal surveys requires reliable algorithms that would allow naturalists to obtain the necessary information with minimal impact on animal behavior [22,35,36].

In dense forests, camera-based visual counting is almost impossible. Modern thermal imaging systems can solve this problem. It provides high noise immunity even in complex environments [24.25.37.38]. However, UAVs require modern software to process the bulk of high-resolution real time video they record during each flight [39]. The research objective was to develop and test effective methods for monitoring the population of large warm-blooded animals in the winter conditions of Siberian forests. The areas in question are large and sparsely populated, which makes it difficult to control the current state of the environment using traditional methods. Siberian winter lasts 4-6 months, depending on the latitude. The snow cover is total while the temperature drops below –55 °C. To survive in the harsh conditions of low temperatures and limited food resources, forest species seek salvation in long hibernation. European elks (*Alces alces*), grey wolves (*Canis lupus*), and Siberian roe deer (*Capreolus pygargus*) are almost the only large warm-blooded forests of Siberia that do not hibernate. The present research featured the European elk as a test object for animal survey. With its weight reaching ~600 kg, it is the largest deer species on the planet (Figure 1S). The experimental survey covered the uninhabited territory of the Salair Nature Reserve, located in the northern part of the Salair Ridge (Kemerovo region) near the Tanai ski resort (54°42'46"N, 85°3'42"E).

Methods

In 2019 and 2020, rangers measured the elk population in the park using the traditional daily track count method from January 1 to February 28-29. Parallel to the track count, they used drone-mounted thermal infrared cameras: on February 26, 2019 and February 29, 2020. The drone planes were Supercam S250 (Unmanned Systems LLC, Izhevsk, Russia). Table 1 demonstrates the characteristics of this model. Its take-off weight is 7.5–9.5 kg, which allows for 1.5 kg of payload, e.g. a camera and a thermal imager. The drone plane can operate at wind velocity of up to 15 m/s and air temperature from –50°C to +45 °C. In addition, it can withstand moderate rain or snowfall. These advantageous characteristics make it possible to monitor the territory in almost any weather conditions. The drone plane carries a receiver of the global satellite navigation system (GNSS) for precise coordinate control and positioning of photography points. It has the capabilities of bungee launch and parachute recovery.

Tables 2 and 3 show the main characteristics of the camera and the thermal imager, which is important for understanding the capabilities and limitations of this study. Sony RX1R II is a full-frame camera with no crop factor, which makes it possible to cover a wide area without additional maneuvering. The camera is compact: in fact, it is one of the smallest full-size cameras and weighs less than 500 g. The lens does not have to be changed. In addition, it is one of the cheapest cameras in its class. The high resolution allows for visual identification of various animal species in the photos and video.

We chose a compact, light, and low power ATOM500 (weight 32 g) thermal imaging camera. Its allowable range of working conditions is quite impressive: this camera can be used in extreme temperature and humidity conditions. As assumed, the sensitivity level allows it to identify thermal signatures of animals against the underlying surface even at temperatures below–10°C, i.e. for much of the year. In winter, the European elk (*Alces alces*) is covered by thick fur and, respectively, the fur surface temperature is drastically lower the temperature of the body (35.8 – 37°C). On this reason, the temperature difference between fur and snow surfaces is unclear, and the detection of thermal anomaly of the European elk on the snow background is not a trivial task.

The research covered the territory of the Salair Nature Reserve (Kemerovo region, Russia). The reserve is an environmentally sensitive territory of regional significance. Figure 1 specifies its geographical location. The Salair national park is mostly black taiga of firs and aspens with patches of birch and aspen undergrowth. The elk is one of the main protected species in the park. Therefore, its population survey is an important tool of its protection and reproduction [40, 41]. The Salair taiga borders on agricultural steppe areas in the east, north, and west. In the south, it joins the taiga massif of Gornaya Shoriya and Altai.

The drone planes delivered a large volume of photo and thermal imaging. We processed the obtained data using the Thermal Infrared Object Finder software (TIOF) developed at Kemerovo State University. The application was designed in Python and can be installed on any PC. It is capable of processing a large amount of infrared image data to identify specific animals. The analysis fixes the so-called thermal anomalies, which are warmer than the ambient temperature and indicate the presence of an animal [42]. To determine the effectiveness of the developed algorithm, we compared the UAV survey results with those obtained by the traditional daily track count in 2019-2020.

Results And Discussion

Thermal imaging is able to detect animals by their thermal signature according to the contrast between the body temperature and the environment, which might reach 30–40 °C. Therefore, winter surveys are more efficient. Unfortunately, the method cannot tell the difference between species of similar mass and shape, e.g. a wolf and a wild boar. Visual analysis of conventional photo and video made it possible to identify animals with the same thermal signature. The simultaneous use of photo and thermal imaging improves the accuracy and reliability of aerial surveys. Figure 2S provides an example of such an analysis. The left image shows three types of objects: the white of the snow background, the numerous translucent round crowns of naked trees and shrubs, and the dark round crowns of coniferous trees. Under this resolution, the patchy background of winter taiga makes it hard to detect heat signatures in the photo image: the silhouettes of trees and shrubs obscure the contours of the animals. However, the thermal image on the right clearly shows the signatures of two elks as their body temperature differs significantly from the fairly uniform temperature background of the winter taiga.

In 2019, it took two flights to survey the territory. Figure 3S (a) shows the flight routes. The dots indicate the centers where RGB images were taken. In 2020, we launched one flight, its route shown in Figure 3S (b). To facilitate the comparison, we placed a fan-shape of glades into the bottom left corner of both Figure 3S (a) and Figure 3S (b). The glades are the system of ski slopes of the Tanay ski resort. Table 4 demonstrates the basic technical information on the flights.

We developed the following algorithm to process the images obtained from the drone planes:

1) We sequenced the infrared video with an interval of ~ 0.6 s.

2) After that, the infrared images were processed using software according to the degree of color intensity and pixel clusters. As a result, we obtained numerous infrared images with thermal extremes, which indicated an object with a higher temperature than that of the snow, e.g. an animal, a human, or a car.

3) We uploaded the RGB photos and telemetry into the Agisoft Metashape Professional software for alignment.

4) The infrared images underwent a visual inspection for the initial screening of “junk” data.

5) The coordinates of the infrared images with extremes were compared in-camera with the aligned RGB photographs, and the presence of large game was determined visually.

6) Finally, we compared the research results at different stages.

Figure 2 illustrates an example of comparing images in the visible and IR spectra. The low-resolution infrared image (Figure 2a, right) shows two thermal signatures. However, the photo image with a similar resolution (Figure 2a, right) provides no reliable identification of the signatures. When the resolution was increased, the body contours of two elks became visible – see the red frame in the photo image (Figure 2b, left).

The analysis employed software developed by the Kemerovo State University which allows *jpeg* and *png* image processing. The processing time depended on the number of images: it took the program 25-50 s to process materials of one standard UAV flight that lasted 100-150 min. The software allows for a thermal sensitivity that exceeds the capabilities of a human observer. Taking into consideration the limited flight time, this made it possible to detect even weak thermal anomalies. Figure 4S gives a comparative analysis of the processed results for infrared images taken from a height of 200 m and 400 m. Figure 4S shows a thermal signature that is clearly visible to the human eye. The shot was made from a height of 200 m. When the same area was shot from 400 m, the same thermal signature was almost indistinguishable to the human eye, while the software application was able to detect it.

The survey of 2019 detected 34 objects (numbers 1-34). Figure 3 shows their spatial distribution. Out of 34 objects, numbers 1-25 are elks. Table 1S shows the coordinates of the animals detected by the drone planes in 2019. The detected objects (34) also included untargeted objects not related to wild animals, e.g. a human person and a group of animals contained in the rehabilitation center of the Tanay ski resort.

The Tanai resort caused too many “false positives”. As a result, the contour of the scanning section had to be changed in 2020 to exclude the Tanai resort premises. Figure 4 demonstrates the ratio of the scanned areas in 2019 and 2020. The survey of 2020 revealed 63 objects, of which 55 were elks. Figure 5 shows their spatial distribution. Table 2S specifies the coordinates of the animals detected by the UAV survey in 2020. We failed to calculate the coordinates of numbers 20, 21, and 22 on the RGB images as these objects were too close to the frame. The remaining objects (8) were people. Figure 5S demonstrates a test snapshot of untargeted search objects – some random fishermen that happened to be in the area.

The map of elk distribution (Figure 5) shows two clusters, the largest one being Group 2, which included 15 elks. Figure 6 demonstrates the maximum number of animals recorded in one RGB image – 11 elks. The maximum number of animals fixed in one infrared image was 5 elks (Figure 7). This difference resulted from the different technical characteristics of the thermal infrared camera and the visible spectrum equipment. The bandwidth of the infrared image was 1/3 in the center of the width of the visible spectrum. In Figure 6, the outline of the infrared image is blue. Thus, the shooting area of the infrared image was approximately nine times smaller than the shooting area of the RGB image. All the routes were planned specifically to achieve a transverse overlap of 10%-15% for infrared imaging, in which case the overlap of RGB images was 70%. Figure 7 compares RGB and infrared images of the same surface areas in Group 2. It becomes clear that the distance between the elks was about 50 m

A comparative analysis of the data obtained in 2019 and 2020 revealed that 25 and 55 elks were identified in 2019 and 2020, respectively, where the two studied areas overlapped (15.9 km^2). Therefore, the number of animals within the same habitat almost doubled. Figure 8 shows their spatial distribution. The survey of 2020 revealed two clusters of elks. Such uneven distribution could be explained by some behavioral characteristics of the animals. We detected two wolves during the visual analysis of the images obtained in 2020 and the corresponding infrared images with thermal anomalies over an area of 7 km^2 (Figure 6S). It was the first time wolves had been detected in the Salair Nature Reserve. No traditional track counts had ever revealed wolves on this territory, and naturalists had always considered the park a wolf-free zone. According to daily track counts, the wolf population had almost disappeared in the Kemerovo region by 2015-2017 as a result of man-induced factors: rangers reported only accidental visits from the neighboring regions [41,42]. Thus, the developed method of digital survey provided a more complete identification of large animals in the given habitat. Accuracy is especially important for monitoring the population of such large predators as wolves. Mistakes can have an extremely negative effect on the managing populations of herbivores.

During the aerial surveys of 2019-2020, the population, distribution, and habitat of the European elk proved to correspond to the data obtained by the traditional method of winter track counts submitted by the Department of Animal Object Protection of the Kemerovo Region. We registered a significant increase in the elk population in the forests of the Salair Ridge. In addition, we detected wolves in the surveyed area. The research justified the combined use of various digital technologies for game animal survey, i.e. photo and thermal imaging. The equipment performance was good even in the harsh winter conditions, which means great prospects for research on larger areas.

Conclusions

The current state of Siberian forestry requires new methods of poaching control and competent resource management. Therefore, traditional methods for animal survey have to be perfected. Digital technologies proved to be the most promising method that can improve the shortcomings of traditional accounting methods. These technologies eliminate the problem of inaccessibility of research sites and reduce error probability caused by the human factor. According to the new methodology, survey is done automatically using drone-mounted thermal infrared cameras, and the data processing is performed by specialized software.

This research featured the population of the European elk (*Alces alces*) on the territory of the Salair Nature Reserve using drone planes with two types of payload. The obtained data on the elk population confirmed the data obtained by the traditional winter track counts. This indicates that:

1) Aerial surveys are a promising practical method for determining the population of large ungulate animals, e.g. elks, roe deer, wild boars, deer, as well as wolves.

2) Drone-mounted thermal infrared cameras provide accurate data on the animal presence in the winter period. The combined use of video and thermal imaging cameras allows for reliable identification of the thermal signature of the detected object.

3) The method can be used to check the data obtained by traditional survey methods, i.e. as a part of a complex survey.

4) Unmanned aerial vehicles make it possible to monitor vast forest areas in a short period of time. This advantage allows scientists to observe animal behavior in winter.

Declarations

- Ethics approval and consent to participate

Not applicable.

- Consent for publication

Not applicable

- Availability of data and material

All data generated or analyzed in this study are included in this published article and its supplementary information file.

- Competing interests

There are no competing interests

- Funding

There are no funding for this study.

- Authors' contributions

AP designed this study and wrote the paper. AV studied scientific sources, processed the information and compiled the manuscript. VA provided the conceptualization and wrote the paper. AK carried out the measurements and analysis of the results. All authors read and approved the final manuscript.

- Authors' information (optional)

Alexander Prosekov was born in Topki (Russia) in May 1976. In 1998, he received a diploma from the Kemerovo Technological Institute of food industry. In 1999 he received the degree of candidate of technical sciences, in 2004, he was awarded the degree of doctor of technical sciences. In 2005, by the decision of the Higher School of Economics, he was awarded the academic title of Professor. Since 2008, he has been the vice-rector for research and innovation, and since 2012, the rector of the Kemerovo Institute of Food Industry. Since 2017, he has been the rector of Kemerovo State University. Since 2019, the range of main scientific interests has been supplemented by the topic of conservation of bioresources. He is the author and coauthor of over 450 publications, corresponding member of RAS, winner of RF Government prize in science and technology.

Anna Vesnina was born in Berezovsky, Russia in September 1996. In 2018, she received her diploma, and, in 2020, she completed her master's degree in biotechnology at Kemerovo State University. Research interests include research in the field of proper nutrition, nutrigenetics, conservation of biological resources (biodiversity) and rational nature management.

Victor Atuchin was born in Prokopievsk, Russia in August, 1957. He received the diploma degree in radiophysics from the Tomsk State University, Tomsk, Russia in 1979 and the Ph.D. degree in solid state physics from the Institute of Semiconductor Physics of SB of RAS, Novosibirsk, Russia, in 1993. In 1980, he joined the Institute of Semiconductor Physics as an Engineer of Electronics, and as a Head of Laboratory of Optical Materials and Structures in July 2002. Since 1980, his principal research interests include materials science, nonlinear optics and sensors. He is the author or coauthor of 342 publications in refereed journals.

Alexander Kuznetsov **(author information is not available at the moment of paper submission).**

References

1. Venter O, Sanderson EW, Magrach A, Allan JR, Beher J, Jones KR, Possingham HP, Laurance WF, Wood P, Fekete BM, Levy MA, Watson JE (2016) Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nature commun 7. https://doi.org/10.1038/ncomms12558.
2. Newbold T, Hudson LN, Hill SL, Contu S, Lysenko I, Senior RA, Börger L, Bennett DJ, Choimes A, Collen B, Day J, De Palma A, Díaz S, Echeverria-Londoño S, Edgar MJ, Feldman A, Garon M, Harrison ML, Alhusseini T, Ingram DJ, Itescu Y, Kattge J, Kemp V, Kirkpatrick L, Kleyer M, Correia DL, Martin CD, Meiri S, Novosolov M, Pan Y, Phillips HR, Purves DW, Robinson A, Simpson J, Tuck SL, Weiher E, White HJ, Ewers RM, Mace GM, Scharlemann JP, Purvis A (2015) Global effects of land use on local terrestrial biodiversity. Nature 520 (7545):45-50. doi: 10.1038/nature14324.
3. Valentea AM, Binantel H, Villanua D, Acevedo P (2018) Evaluation of methods to monitor wild mammals on Mediterranean farmland. Mammalian Biology. 91:23-29. https://doi.org/10.1016/j.mambio.2018.03.010.
4. Federal Law «On Hunting and the Preservation of Hunting Resources and on Amending Certain Legislative Acts of the Russian Federation» № 209-FZ. **http://www.consultant.ru/document/cons_doc_LAW_89923/.** Accessed 20 February 2020.
5. Sukhomirov GI (2018) On the issue of environmental impact assessment of draft limits and quotas for game animals. Paper presented at the VII international scientific and practical conference on the climate, ecology, agriculture of Eurasia, Irkutsk University, Irkutsk, 23-27 May 2018.
6. Kozorez AI, Gurinovich AV (2019) Insurmountable contradictions of winter route accounting. Transactions of Belgorod State Technological University 2 (222):149–155.
7. Kolesnikov VV, Piminov VN, Economov AV, Shevnina MS, Makarova DS, Strelnikov DP, Sinitsyn AA, Skumatov DV, Tuzharov ES, Mashkin VI, Pankratov AP, Kozlovsky IS (2016) Long-term changes and distribution of resources of the large game animals in Russia. Agricultural Sci. Euro-North-East 6 (55):56–61.
8. Kuzyakin VA (2017) Population survey of game animals. Moscow.
9. Glushkov VM (2017) The hunting industry of the Russian Federation needs professional monitoring. Humanitarian Aspects of Hunting and Game Management 3(6):152-159.
10. Kondratenkov IA (2018) Some aspects of the theory of winter route accounting of game animals. Volga Ecol. J 1: 26-48. doi: 10.18500/1684-7318-2018-1-26-48.

11. Melin M, Packalen P, Matala J, Mehtätalo L, Pusenius J (2013) As-sessing and modeling moose (Alces alces) habitats with airborne laser scanning data. Int. J. Appl. Earth Observ. Geoinform 23:389–396. doi:10.1016/j.jag.2012.11.004
12. Blecha KA, Alldredge MW (2015) Improvements on GPS location cluster analysis for the prediction of large carnivore feeding activities: Ground-truth detection probability and inclusion of activity sensor measures. PloS One 10(9):e0138915. https://doi.org/10.1371/journal.pone.0138915.
13. Deacy WW, Leacock WB, Ward EJ, Armstrong JB (2019) Aerial surveys cause large but ephemeral decreases in bear presence at salmon streams in Kodiak, Alaska. PloS One,14 (9):e0222085. https://doi.org/10.1371/journal.pone.0222085.
14. Petrunenko YK, Seredkin IV, Mikell DG (2014) The use GPS collars to study the ecology of the Amur tiger. Paper presented at the international scientific and practical conference, Almaty, 11-12 March 2014.
15. Panchenko DV, Danilov PI, Paasivaara A, Krasovsky YA (2018) Forest reindeer in the Kostomuksha reserve. Bull. Hunting Sci (4):284–288.
16. Eriksen A, Wabakken P, Zimmermann B, Andreassen HP, Arnemo JM, Gundersen H, Liberg O, Linnell J, Milner MJ, Pedersen HC, Sand H, Solberg EJ, Storaas T (2011) Activity patterns of predator and prey: a simultaneous study of GPS-collared wolves and moose. Animal Behaviour 81:423-431. doi: 10.1016/j.anbehav.2010.11.011.
17. Boughton RK, Allen BL. Tillman E.A, Wisely SM, Engeman RM (2019) Road hogs: Implications from GPS collared feral swine in pastureland habitat on the general utility of road-based observation techniques for assessing abundance. Ecol. Indicators 99:171-177. doi: 10.1016/j.ecolind.2018.12.022.
18. Relative accounting methods for game animals. https://www.activestudy.info/metody-otnositelnogo-ucheta-oxotnichix-zhivotnyx/. Accessed 20 February 2020.
19. Domashov IA, Kostubh S, Kubanychbek Z (2015) Trail-cameras and their use for snow leopard survey (*Panthera uncia*) in Kyrgyzstan. Sc. New Technol. Innov. Kyrgyzstan (10):8-9.
20. Mulero-Pázmány M, Stolper R, van Essen LD, Negro JJ, Sassen T (2014) Remotely piloted aircraft systems as a rhinoceros anti-poaching tool in Africa. PloS One 9 (1):e83873. https://doi.org/10.1371/journal.pone.0083873.
21. Vermeulen C, Lejeune P, Lisein J, Sawadogo P, Bouché P (2013) Unmanned aerial survey of elephants/ PloS One 8 (2):e54700. https://doi.org/10.1371/journal.pone.0054700.
22. Ditmer MA, Werden LK, Tanner JC, Vincent JB, Callahan P, Iaizzo PA, Laske TG, Garshelis DL (2019) Bears habituate to the repeated exposure of a novel stimulus, unmanned aircraft systems Conserv. Physiology 7 (1):coy067. https://doi.org/10.1093/conphys/coy067.
23. Ditmer MA, Vincent JB, Werden LK, Tanner JC, Laske TG, Iaizzo PA, Garshelis DL, Fieberg JR (2015) Bears show a physiological but limited behavioral response to unmanned aerial vehicles. Curr. Biol. 25 (17):2278-2283. doi: 10.1016/j.cub.2015.07.024.

24. Corcoran E, Denman S, Hanger J, Wilson B, Hamilton G (2019) Automated detection of koalas using low-level aerial surveillance and machine learning. Sci. Rep. 9 (1):3208. https://doi.org/10.1038/s41598-019-39917-5.
25. Spaan D, Burke C, McAree O, Aureli F, Rangel-Rivera CE, Hutschenreiter A, Longmore SN, McWhirter PR, Wich SA (2019) Thermal infrared imaging from drones offers a major advance for spider monkey surveys. Drones 3:34. https://doi.org/10.3390/drones3020034.
26. Bevan E, Wibbels T, Najera BMZ, Martinez MAC, Martinez LAS, Martinez FI, Cuevas JM, Anderson T, Bonka A, Hernandez MH, Pena LJ, Burchfield PM (2015) Unmanned aerial vehicles (UAVs) for monitoring sea turtles in near-shore waters. Mar. Turt. Newsl. 145: 19–22.
27. Hodgson A, Kelly N, Peel D (2012) Unmanned aerial vehicles (UAVs) for surveying marine fauna: a dugong case study. PloS One 8(11):e79556. https://doi.org/10.1371/journal.pone.0079556.
28. Seymour AC, Dale J, Hammill M, Halpin PN, Johnston DW (2017) Automated detection and enumeration of marine wildlife using unmanned aircraft systems (UAS) and thermal imagery. Sci. Reports 7:45127. https://doi.org/10.1038/srep45127.
29. Burnett JD, Lemos L, Barlow D, Wing MG, Chandler T, Torres LG (2018) Estimating morphometric attributes of baleen whales with photogrammetry from small UASs: A case study with blue and gray whales. Marine Mammal Sci. 35 (1):108-135. https://doi.org/10.1111/mms.12527
30. Rodríguez A, Negro JJ, Mulero M, Rodríguez C, Hernández-Pliego J, Bustamante J, The eye in the sky: combined use of unmanned aerial systems and GPS data loggers for ecological research and conservation of small birds. PloS One 7 (12):e50336. https://doi.org/10.1371/journal.pone.0050336.
31. Lee WY, Park M, Hyun CU (2019) Detection of two arctic birds in Greenland and an endangered bird in Korea using RGB and thermal cameras with an unmanned aerial vehicle (UAV). PloS One 14 (9):e0222088. https://doi.org/10.1371/journal.pone.0222088.
32. Dos Santos GAM, Barnes Z, Lo E, Ritoper B, Nishizaki L, Tejeda X, Ke A, Han L, Schurgers C, Lin A, Ryan Kastner (2014) Small unmanned aerial vehicle system for wildlife radio collar tracking. Paper presented at the Conference: 2014 IEEE 11th International Conference on Mobile Ad Hoc and Sensor Systems (MASS), Philadelphia, PA, USA. 28–30 October 2014.
33. Wolinsky H (2017) Biology goes in the air: Unmanned aerial vehicles offer biologists an efficient tool for observation and sampling from a safe distance. EMBO Rep. 18 (8):1284–1289. https://doi.org/10.15252/embr.201744740.
34. Bennitt E, Bartlam-Brooks H, Hubel TY, Wilson AM (2019) Terrestrial mammalian wildlife responses to unmanned aerial systems approaches. Sci. Reports 9 (1):2142. https://doi.org/10.1038/s41598-019-38610-x.
35. Schroeder NM, Panebianco A, Musso RG, Carmanchahi P (2020) An experimental approach to evaluate the potential of drones in terrestrial mammal research: a gregarious ungulate as a study model. Royal Soc. Open Sci. 7 (1):191482. https://doi.org/10.1098/rsos.191482.
36. Mulero-Pázmány M, Jenni-Eiermann S, Strebel N, Sattler T, Negro JJ, Tablado Z, Unmanned aircraft systems as a new source of disturbance for wildlife: A systematic review. PloS One 12 (6):e0178448.

https://doi.org/10.1371/journal.pone.0178448.

37. Christiansen P, Steen KA, Jørgensen RN, Karstoft H (2014) Automated detection and recognition of wildlife using thermal cameras. Sensors 14 (8):13778–13793. https://doi.org/10.3390/s140813778.
38. Gade R, Moeslund TB (2014) Thermal cameras and applications: a survey. Machine Vision Appl. 25:245–262. https://doi.org/10.1007/s00138-013-0570-5.
39. Longmore SN, Collins RP, Pfeifer S, Fox SE, Mulero-Pazmany M, Bezombes F, Goodwin A, Ovelar MD, Knapen JH, Wich SA (2017) Adapting astronomical source detection software to help detect animals in thermal images obtained by unmanned aerial systems. Int. J. Remote Sensing 38 (8-10):2623-2638. doi: 10.1080/01431161.2017.1280639.
40. Report on the environmental state and protection in the Kemerovo region in 2018. http://kuzbasseco.ru/wp-content/uploads/2019/02/Doclad_2018.pdf. Accessed 26 March 2020.
41. Report on the environmental state and protection in the Kemerovo region in 2019. http://ecokem.ru/wp-content/uploads/2020/02/doclad_2019.pdf. 26 March 2020.
42. Prosekov AY, Rada AO, Kuznetsov AD, Shumelov DI, Prokopyev GO, Teptyuk AD (2019) The program for processing thermal images and video materials to determine the exact coordinates of the extremes of the intensity of infrared radiation. RU Patent №2019614354, 26 April 2019.
43. Hodgson JC, Mott R, Baylis SM, Pham TT, Wotherspoon S, Kilpatrick AD, Segaran RR, Reid I, Terauds A, Koh LP (2018) Drones count wildlife more accurately and precisely than humans. Meth. Ecol. Evol. 9(5):1160-1167. https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12974
44. Population of boars and bears increased, unlike that of polecat, foxes, and ermines. http://kuzbass85.ru/2017/04/20/v-kuzbasse-stalo-bolshe-kabanov-i-medvedey-no-snizilas-chislennost-horya-ryisi-i-gornostaya/. Accessed 26 December 2019.
45. Are there wolves in Kuznetsk Alatau? URL: http://ecokem.ru/zhivut-li-volki-v-kuzneckom-alatau/. Accessed 26 December 2019.

Tables

Table 1: Specifications of UAV Supercam S250

Characteristic	Description
Wingspread	2.5 m
Flight time	3 h
Flying range	≤180 km
Engine	Electric
Radio line range of action	50–70 km
Lift flight	50-500 m
Velocity	65-120 km/h
Working flight altitude	150- 5000 m

Table 2: Specifications of Sony RX1R II camera

Characteristic	**Description**
Matrix	Full-frame Exmor R® CMOS sensor
Resolution / Pixel size	35.9 x 24.0 mm / 35 mm full frame
Screen format	3:2
Resolution	About 42.5 MP
ISO	100-25600 (1/3 EV steps)

Table 3: Specifications of thermal imaging module ATOM M500

Characteristic	Description
Type of infrared receiver	uncooled microbolometric amorphous silicon matrix
Resolution / Pixel Size	640×480 / 17 μm
Sensitivity	≤60 μm at 300 K with a F#1.0 lens
Frames per second	50 hz
Spectral range	8 ~ 14 μm

Table 4: Data on UAV flights

Data	2019	2020
Flight time	4 h 9 min	2 h 13 min
Area surveyed	26.0 km^2	19.2 km^2
Total thermal video duration:	3 h 44 m, storage capacity 8.74 GB	2 h 29 min, storage capacity 5.43 GB
Number of infrared shots after sequencing	28,407, storage capacity 3.31 GB.	12,986, storage capacity 1.43 ГБ
Total RGB shots	4,827 shots, storage capacity 72.9 GB	3,310 shots, storage capacity 45.8 GB

Figures

Figure 1

The red contour is the territory of the Salair State Nature Reserve.

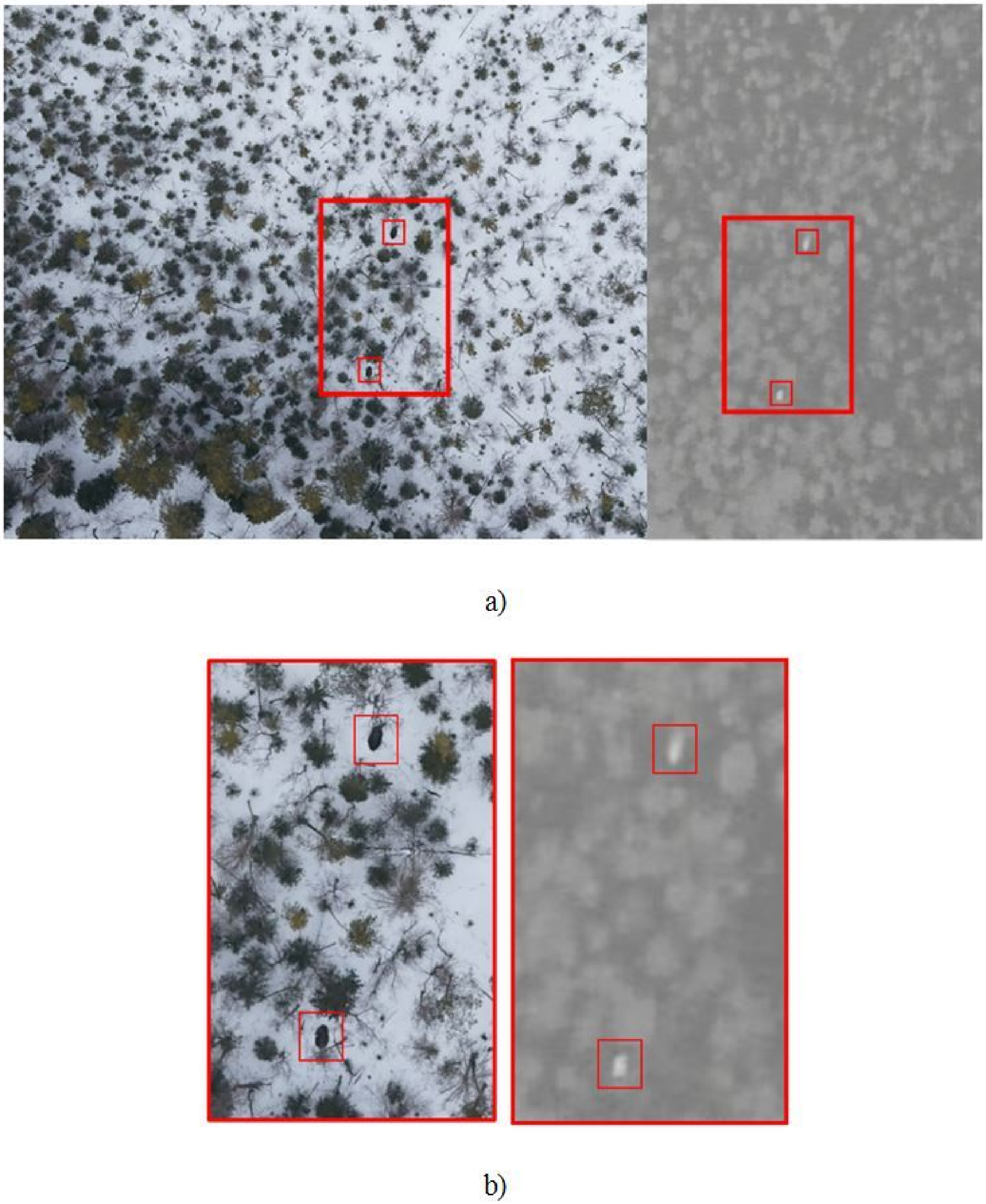

Figure 2

RGB vs. infrared images.

Figure 3

Map of the elk population in the area surveyed in 2019. A cluster of animals was detected on the territory of the Tanai resort.

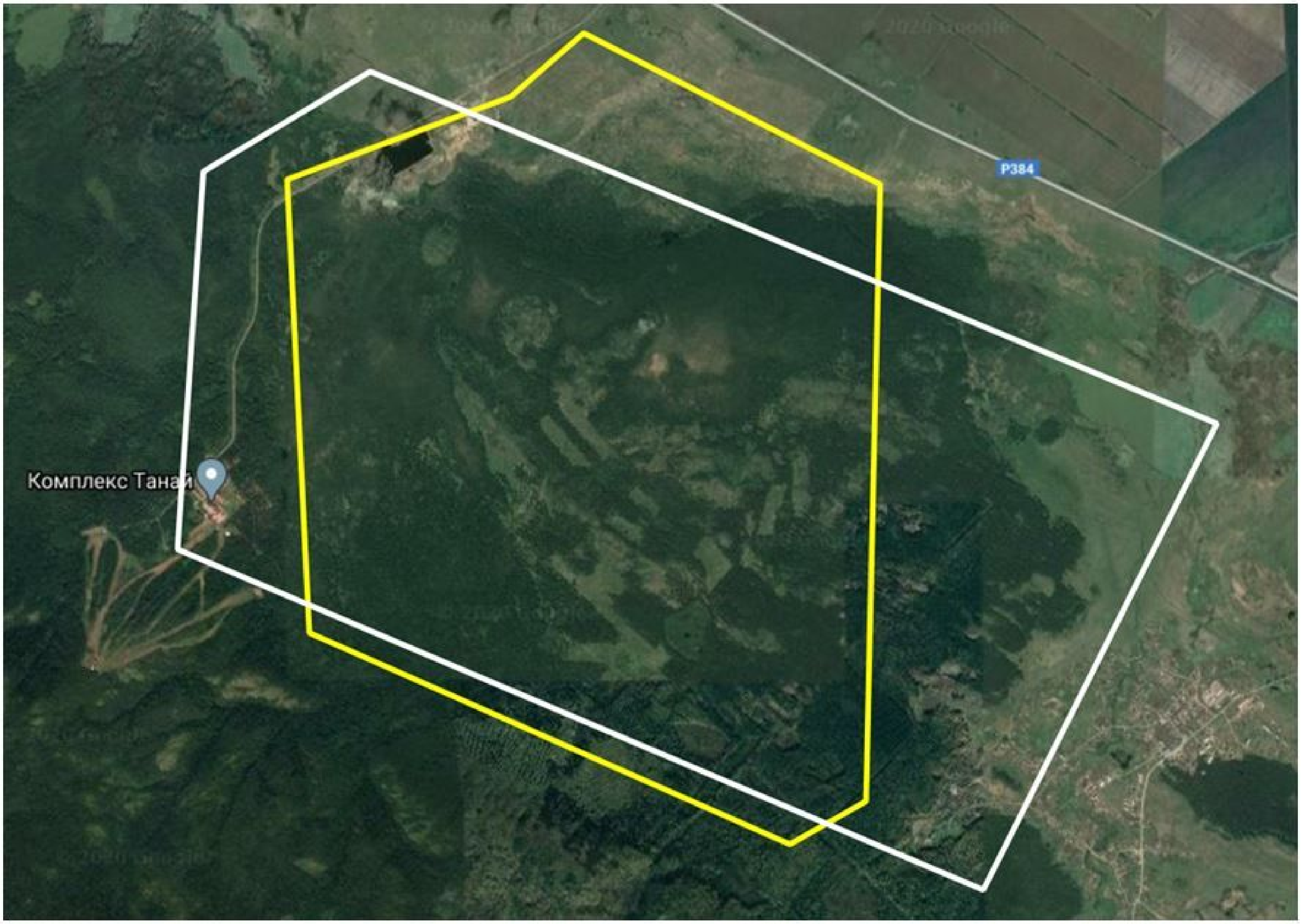

Figure 4

The boundaries of the territories surveyed in 2019 and 2020.

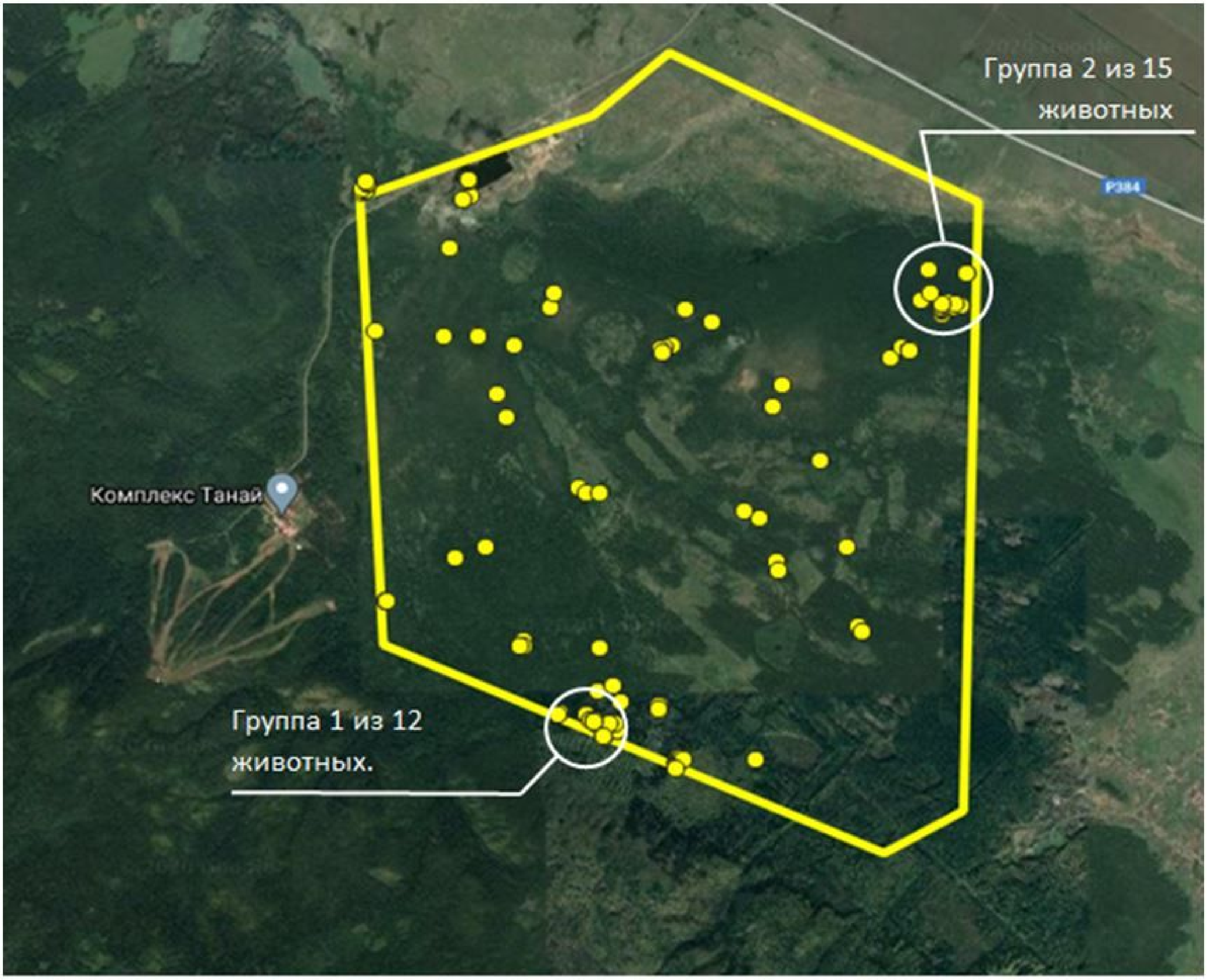

Figure 5

Map of the elk population in the area surveyed in 2020. Two animal clusters were identified outside the Tanai resort.

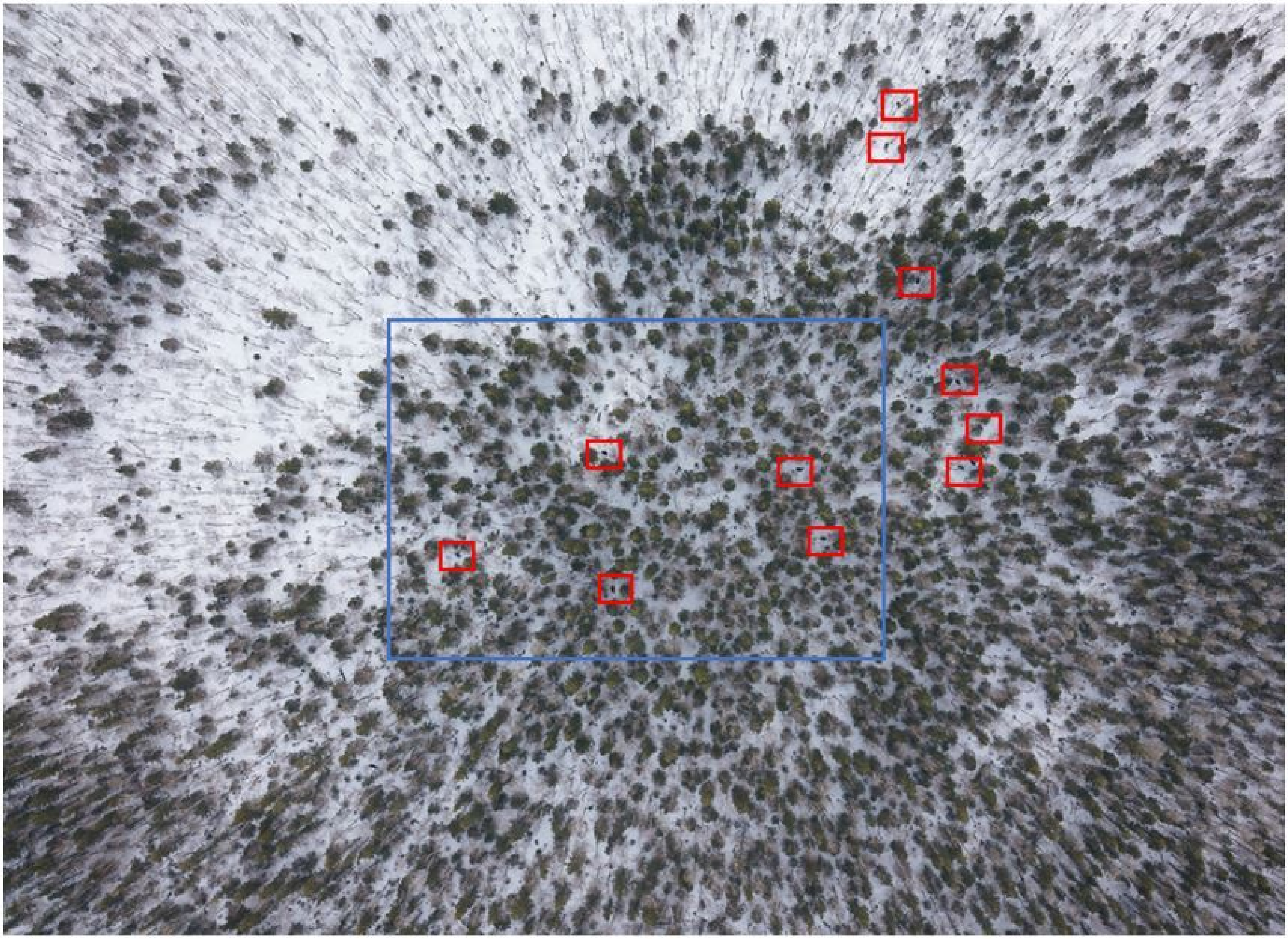

Figure 6

RGB-image of Group 2.

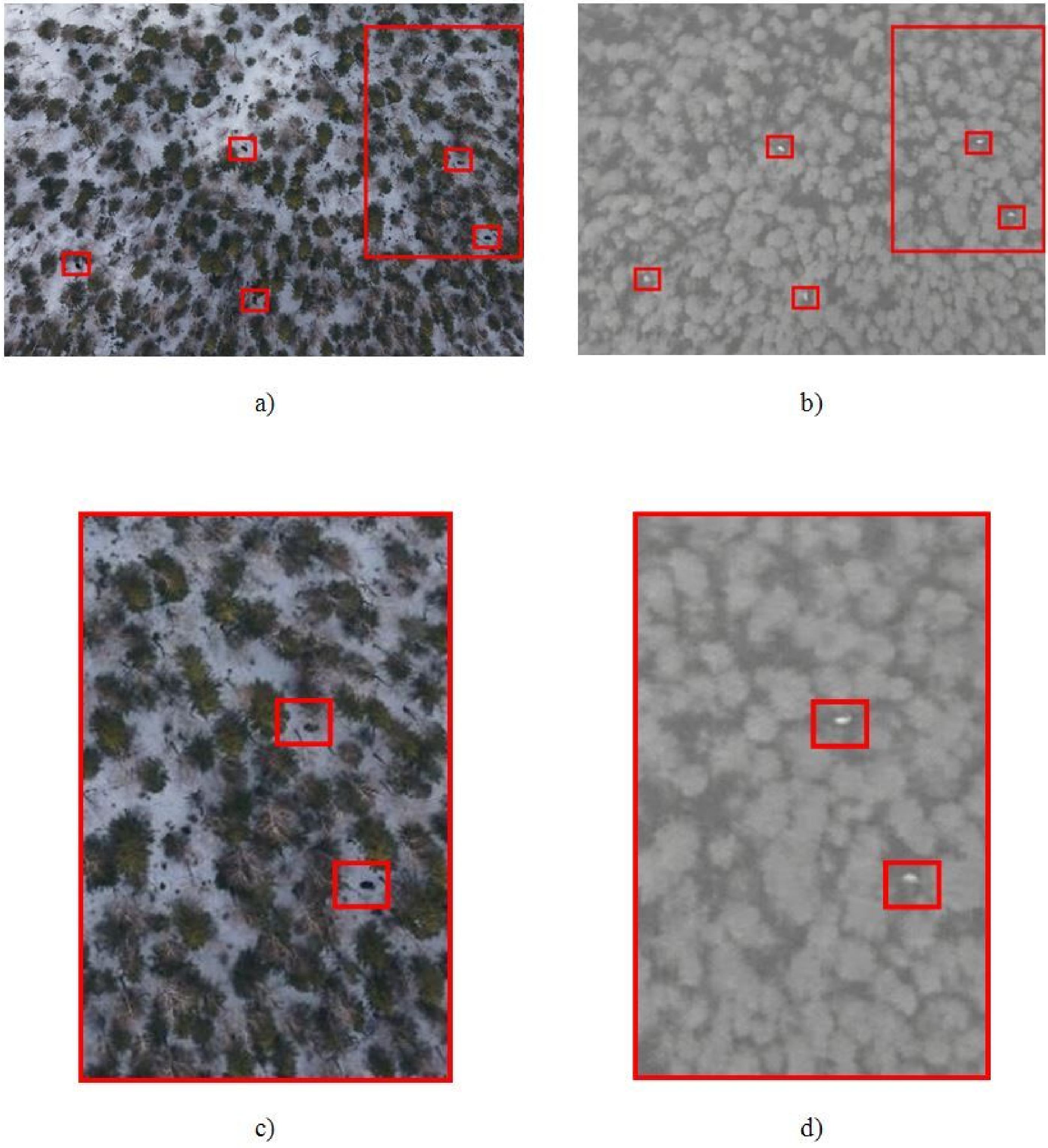

Figure 7

Comparison of RGB and infrared images of Group 2: a) part of the RGB image corresponding to the capture of the infrared image; b) the infrared image corresponding to image a; c and d are zoom-in images of a and b, respectively.

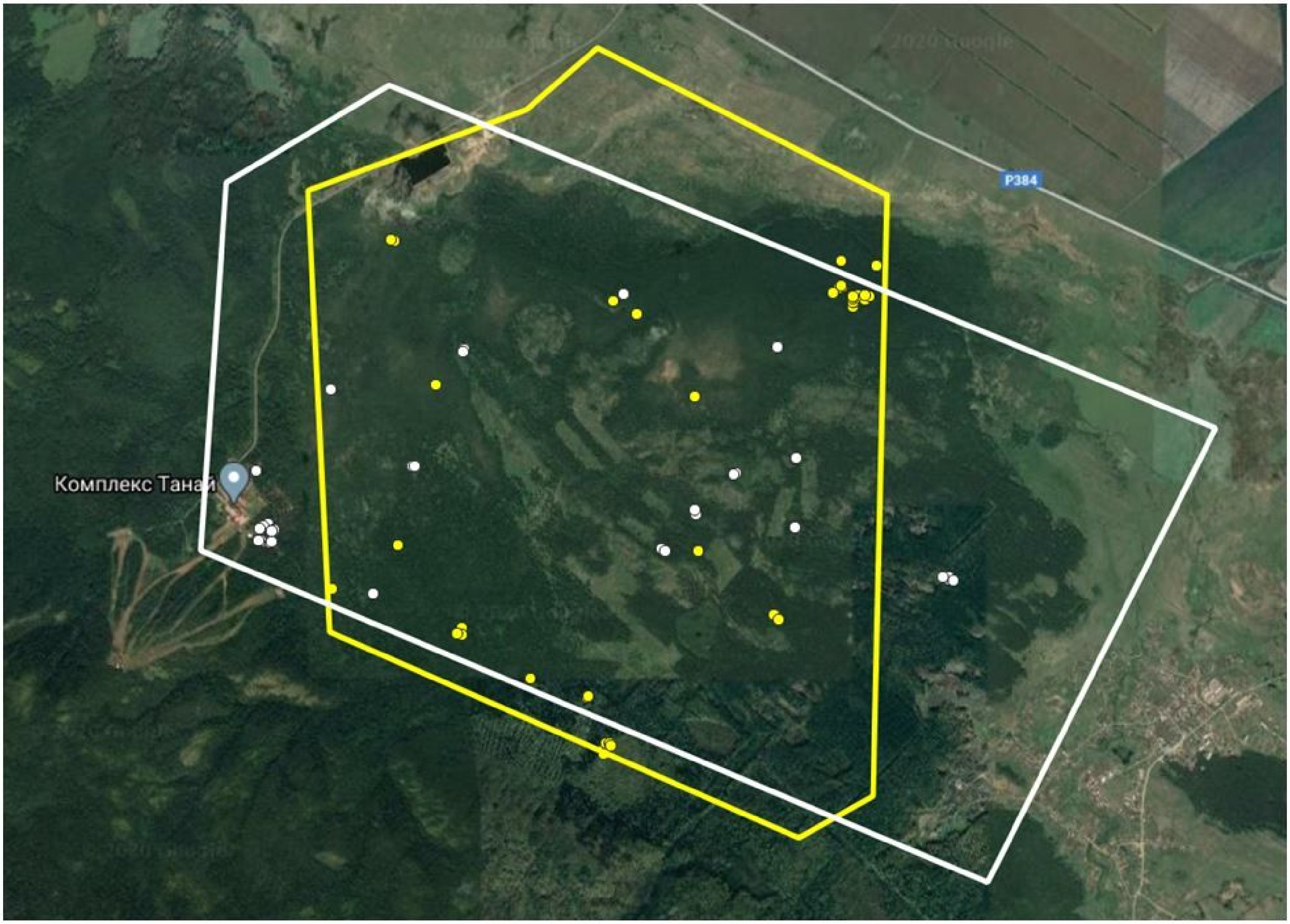

Figure 8

The area under survey and the distribution of elks in 2019 (white) 2020 (yellow)