

Review

# Methods for Monitoring Large Terrestrial Animals in the Wild

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**Abstract:** Reliable information about wildlife is absolutely important for making informed management decisions. The issues with the effectiveness of the control and monitoring of both large and small wild animals are relevant to assess and protect the world's biodiversity. Monitoring becomes part of the methods in wildlife ecology for observation, assessment, and forecasting of the human environment. World practice reveals the potential of the joint application of both proven traditional and modern technologies using specialized equipment to organize environmental control and management processes. Monitoring large terrestrial animals require an individual approach due to their low density and larger habitat. Elk/moose are such animals. This work aims to evaluate the methods for monitoring large wild animals, suitable for controlling the number of elk/moose in the framework of nature conservation activities. Using different models allows determining the population size without affecting the animals and without significant financial costs. Although, the accuracy of each model is determined by its postulates implementation and initial conditions that need statistical data. Depending on the geographical, climatic, and economic conditions in each territory, it is possible to use different tools and equipment (e.g., cameras, GPS sensors, and unmanned aerial vehicles), a flexible variation of which will allow reaching the golden mean between the desires and capabilities of researchers.

**Keywords:** monitoring methods; large wild animals; elk; moose; hunting; unmanned aerial vehicles

## 1. Introduction

It is difficult to overestimate the importance of monitoring animals in the wild as it is part of the environmental control system. It includes monitoring, evaluating, and predicting the state of the human environment. The problems of the control and monitoring effectiveness of both large and small wild animals are relevant all over the world [1]. Today, modern monitoring methods are being implemented. This is supported by the use of new monitoring technologies [2,3].

Wild animals are at risk during their co-existence with humans due to capture, extermination, and anthropological impact on their habitat areas. Understanding the need to regulate the population of different animals, including commercial species, partly solves the problem of preserving the fauna diversity on our planet. Environmental monitoring issues concern the general public (ecologists, biologists, hunters, statesmen, top managers, researchers, and ordinary citizens). Animal control

takes into account various natural and man-made factors that affect the state of the environment. Monitoring helps identify patterns of such changes and ensure proper environmental management. In addition, it makes it possible to establish a correlation and find connections between biology, ecology, and economics, e.g., hunting and eco-tourism.

Ideally, it is desirable to get an absolute estimate of wildlife populations [4–6]. However, in reality, it is difficult to get data close to absolute. This problem is most acute for animals that live in hardly accessible areas and vast territories, such as impenetrable taiga, jungles, and tropical forests.

Monitoring biodiversity on a large scale and with adequate representation requires significant effort and resources, and presents a logistical challenge for researchers [7]. Monitoring schemes for butterflies and birds [8,9] can be classified as successful projects of civil science, with the presentation of a large amount of data on the occurrence of species as well as in terms of the number and distribution of species. For animals, there are no such monitoring schemes; an attempt was made to initially accumulate data for 21 candidates (genetic composition, species population, species characteristics, community composition, ecosystem functioning, and ecosystem structure, [www.geobon.org/ebvs](http://www.geobon.org/ebvs)) [7].

Traditional wildlife counting methods (Table 1) are widely used throughout the world [10,11]. In the scientific context, different counting methods have been proposed for decades, and there is a constant debate about their effectiveness.

**Table 1.** Traditional wildlife monitoring methods.

Method	Animals	Sources
Survey and questionnaire	Large and medium-sized animals	[12–15]
Counting by traces of vital activity (counting indirect signs—the number of burrows, claw marks, the number of feces, etc.)	Large and medium-sized mammals	[16–21]
Sampling and marking	All animal species	[22–27]
Winter route tracking	Large, medium, and small animals, birds	[28,29]
The use of traps, pens, and nets	Large and medium-sized mammals	[11,30–33]
Remote tracking using specialized equipment (camera traps, sensor nets, acoustic sensors, and GPS sensors)	All animal, bird, and insect species	[16,34–48]
Aerial survey (counting, photo, and video shooting from aerial devices and systems)	Large animals	[1,49–52]

Researchers face an acute problem of choosing a method of control and observation for all animal species, both small and large. Among other things, it depends on the habitat. Individual monitoring methods have been developed for marine animals [53,54], insects [55–58], and terrestrial animals [59,60]. The size of the studied animals is also important for choosing the monitoring method. This review is limited to considering only large terrestrial animals. Large animals are usually those with the highest quantitative parameters of ontogenesis (weight, length, height, etc.) in their classes. Large forest animals include elephant, rhinoceros, hippo, giraffe, bear, crocodile, tiger, etc.

The habitat of large terrestrial animals is assumed to be land. Russia occupies the first place in terms of the area among the countries (almost half of its territory consists of forests with a rich variety of flora and fauna). Bear (brown and polar), elk, and bison are considered to be the large animals of Russian forests [61].

Elk are widely distributed throughout the world, including the Scandinavian Peninsula, Alaska, the European part of Russia, and Western Siberia (including Kemerovo oblast—Kuzbass) [62]. An important commercial animal, elk is an object of sport hunting, wildlife watching, and a protected species.

Elks inhabit forests, willows on the shores of steppe lakes, and river floodplains in forest-steppe; they also love cool coniferous forests, where there is swampy soil. Elks do not usually actively use their entire territory, but only a part of it, mainly where there are sufficient stocks of the main seasonal feed and good protective conditions throughout the year. Elks correspond to a high degree of settledness; some individuals can adhere to a small area of the territory for a long time. They look for a new place of residence when the amount of food decreases, for example, in the winter with a significant height of snow cover; however, in the spring they return to their original place. A group of elk is quite grouped—in winter they try not to scatter far from each other, but in spring they show more independence. These animals adapt well to changing environmental conditions.

Some methods make it possible to estimate the population size based on relative counts, one of which is distance sampling [63]. However, they do not apply to large animals for various reasons. Populations of rare or elusive large mammals are difficult to control because they are usually secretive, lone, occur at low densities, and have large domestic ranges, which poses significant methodological problems for population estimation [64,65]. The elk population is rather small, so it is important to assess the effectiveness of monitoring in the field of hunting as an environmental protection measure for biological diversity support and endangered species preservation.

The purpose of this work is to assess methods for monitoring large wild animals that are suitable for controlling elk within the Kuzbass nature protection measures. The need for this review is based on the diversity of methods, the disparity of information about them, and the lack of a comprehensive methodology for counting large wild animals and the prospect of combining different survey methods, including the use of unmanned aerial systems in order to obtain the most reliable information.

## 2. Methods

Undertaken in November 2019 and updated in July 2020, the literature search considered the articles published from 1 January 2015 until the present. Article databases from Scopus, Web of Sciences, and Google Scholar were used for cross-checking. We used a search strategy based on multiple queries. The final ones were selected after several search passes by qualitative evaluation of the number of results obtained and their relevance.

Table 2 lists the queries used and the number of articles identified by each query. The entire bibliography of the included studies was manually checked for compliance with the search subject by title and abstract. Articles whose titles and/or abstracts contained “moose/elk monitoring methods” were passed to the full-text selection stage by default. To narrow the scope of the “Animal monitoring methods” search, both the Scopus and Web of Science databases excluded publications from the fields unrelated to the search topic (such as Medicine, Pharmacology, Immunology and Microbiology, Neuroscience, Engineering, Chemistry, Computer Science, Physics and Astronomy, Social Science, etc.). Due to the number of publications of the query in Google Scholar, sources from the year 2019 were put under review. After excluding intersections across all search databases, 1205 sources remained under review.

**Table 2.** Strategies for searching the literature sources for the review.

Database	Search Query	Number of Articles	Matching Search Results*
Scopus	Moose monitoring methods [title/abstract/keywords]	19	8
	Elk monitoring methods [title/abstract/keywords]	20	2
	Animal monitoring methods [title/abstract/keywords]	1976	827
WoS	Moose monitoring methods	17	8
	Elk monitoring methods	19	5
	Animal monitoring methods	499	322
Google Scholar	Moose monitoring methods	11,800	468
	Elk monitoring methods	16,300	231

\* Even indirect matching was taken into account

### 3. Results and Discussion

The global experience of wildlife monitoring is represented by the use of various traditional counting methods. These include observation, trapping, experiments, collection, analysis of demographic data, and surveys of reserve employees [12–14,17,25,66].

#### 3.1. Active Observation Methods

The method of trapping using box traps, trap pens, drip nets, independently or in combination with indirect indicators, allows assessing the impact of traps on the population of wild animals to determine their density and identify the risk of disease. This method is a traditional one, and using several methods together can improve its accuracy. However, the quality of its application is directly dependent on the number of qualified professionals engaged; any attempt to save finances leads to errors in monitoring and external negative impact on the studied animal population with all the resulting negative consequences [59]. It is possible to improve the monitoring accuracy by identifying individual species, but in this case, it is necessary to physically impact the animals, which can be invasive, expensive, and difficult from the point of view of logistics [67].

#### 3.2. Passive Observation Methods

The authors of [15] used surveys of hunters in the Northeastern and upper Midwestern regions of the United States (approximately 11,000 hunters annually between 2012 and 2014) to monitor the number of elk (*Alces alces*) and collect information. The study [68] presents the results of testing a smartphone application for interviewing hunters (Alberta, Canada, during 2012–2014) for reporting the number of elk (*Alces alces*). The potential of the developed application Loose Survey and its cost-effectiveness in comparison with more expensive methods of the aerial survey are underlined. However, the human factor should be taken into account as it can significantly reduce the accuracy of this approach.

Observation of winter routes [69,70] from ungulate tracks is one of the oldest large animal monitoring methods, which are used to track changes in an animal's moving path, habitat, winter shelters, breeding grounds, and to determine the population size. The main advantages of this method are long-term usage possibility, low financial costs, and feasibility. While, the list of disadvantages includes the occurrence of errors and unreliability of the data obtained, whose value is not stable, as well as the presence of a human factor. Obermoller et al. used the method of observing the movement dynamics of female species to estimate the number of elk calves, and the data obtained were extended to the population size by applying modeling [71]. Migration appears to be an effective behavioral strategy for extending access to seasonal resources and can be a sustainable strategy of industrial

centers or settlements for ungulates experiencing climate change [72]. If the snow cover is not high enough, it is either not possible to collect data on the number of animals or they have significant distortions [73].

The method of monitoring ungulates based on counting the number of fecal pellets is among the traditional ones [74]. It is used both as the main and complementary methods [75–77]. Blåhed et al. optimized the SNP (single nucleotide polymorphism) genotyping of fecal samples from elk (*Alces alces*) for identification of a species and its gender (489 fecal samples) [78]. Together with other traditional methods, genetic methods allow specifying the number of animals and complete information about the sex ratio, settlement, reproduction, and genetic variability. Pfeffer et al. compared the results of the obtained numbers of elk (*Alces alces*) and roe deer (*Capreolus capreolus*) in Northern Sweden after using fecal count and camera traps together with the random encounter model (REM), which can estimate the density without having to recognize individual species [79]. The authors found that, compared to density estimates from camera traps, fecal counts appear to underestimate the population density for roe deer. For elk, the data obtained from the two methods were comparable. In comparison with other methods, the method of counting groups of pellets has the main advantage—cost effectiveness—and can be used in areas that are not impenetrable forests.

### 3.3. Remote Monitoring

Remote monitoring involves the use of specialized equipment (photo and video equipment, acoustic devices, and sensors), usually providing not only data collection, but also almost real-time data transmission. The most reliable data can be obtained by organizing constant automatic monitoring—continuous automatic tracking of animals in real-time [80]. There are enough advantages of this control method, although it is difficult to implement it in remote wild areas (lack of a steady connection, inability to ensure uninterrupted operation of batteries, maintenance of equipment, and sensors used). Therefore, the scope of application is limited to small hunting farms or reserves located not too far away from industrial centers.

Tracking methods using a wireless sensor network (WSN) can achieve similar goals. Zhang and team [35] used simulation modeling based on the collected data to obtain a more reliable picture of the sika deer population.

There is a relatively new group of visual and acoustic wild animal monitoring methods using automatic recorders. Tracking technologies allow researchers to study the life of nature with huge spatial and temporal resolution. They have been developed relatively recently to assess biodiversity by measuring the acoustic heterogeneity created by animals in natural habitats [36].

Monitoring methods using camera traps and acoustic sensors are considered cost-effective [3]. The list of advantages includes the ability to simultaneously evaluate various indicators. The effectiveness and adequacy of these methods determine the potential for their use in the long term. With the development of technologies to produce widely available hardware and software, the methods will be extensively applied.

Night photography, telemetering, and camera traps in combination with the search and calculation of indirect indicators (traces of vital activities) were simultaneously used to determine the number of elk (*Cervus canadensis*) [81].

Visual observation methods using GPS location and digital visualization (3D) images are among the relatively new monitoring methods, that have already proven their effectiveness for environmental activities. Remote sensing methods (GPS or geolocation) present a comprehensive analysis of various data. Monitoring methods using 2D and 3D cameras create a “presence effect” in the process of detecting an animal. They provide an automated, non-contact, and cost-effective way to study animal behavior. Digital technologies and Big Data allow us to approach wildlife monitoring in a different way considering its versatility. The integrated use of aerial photography methods with the interpretation of indirect signs (the number of tracks) contributes to the overall effectiveness of the monitoring.

The significant cost of visual observation methods using digital technologies does not expand the possibilities of their application [34,35,38].

Smith et al. determined the migration routes and numbers of elk by observing and collecting data from global positioning system (GPS) collars [82]. The authors modeled the seasonal selection of habitat-related resources. Phillips et al. determined the number of elk using a probabilistic model combined with GPS collar detection data [83]. The reliability of the obtained population size estimates was recognized as an advantage. The risks include the use of this model in territories with different characteristics. It is important to consider the factors under which this model is valid. Bergman et al. jointly analyzed the data obtained from field route observations of elk and GPS collars and came to the conclusion about the economic efficiency and benefits of their joint use [84].

### 3.4. Methods of Aerial Survey

Many problems with the previously described methods can be avoided with the help of an aerial survey. Bristow et al. used several approaches to estimate the number of elk in Arizona: the efficiency of the hybrid model (double-counting and double-observer methods) was compared to the traditional tracking by tagging and recording individual animals during helicopter flights [85]. In terms of economy, the hybrid model is preferable, while in terms of precision, an aerial survey is better. The development of the hybrid model was more expensive than using traditional counting methods.

The development of unmanned aerial vehicles has opened up new opportunities for using them to solve civil tasks. Unmanned aerial vehicles (UAVs) and continuous shooting (photo, video, and IR) are a sustainable and effective group of modern methods of wildlife recording. Monitoring methods using UAVs can determine the number of animals in a given area. This method can be used for one or several types of species.

The authors [51,86–91] used unmanned aerial vehicles with consumer-level digital cameras to count the number of elk. Havens and Sharp used a modified drone “Predator” for this purpose [2]. Patterson et al. used small unmanned aerial systems (UAS) for aerial photography of caribou (reindeer of North America, Labrador, Canada) and recognized the advantages and capabilities of a small electric-powered fixed-wing UAS Brican TD100E [92].

Xu et al. [93] used aerial photography from a quadcopter to estimate the number of large horned animals, including elk, in combination with a system for processing RGB images. To detect and count large horned individuals, the RGB image obtained by the drone was processed with a modern machine learning algorithm.

The authors underlined the performance and efficiency of this model. Shao et al. [94] used the method of aerial photography using UAVs to count large horned animals, including elk. A system based on convolutional neural networks (CNNs) using aerial photographs was applied. Witczuk et al. [95] used drones with thermal infrared imaging to count ungulates. Dziki-Michalska et al. [96] analyzed data collected by volunteers, hunters, and foresters in combination with aerial photography. Data on the abundance of large animals, including moose, collected from various sources, were used to construct regression models. The authors note that the use of aerial photography increases the accuracy of the modeling, but significant financial costs do not allow its use on an ongoing basis.

UAV aerial photography is very promising with regard to the development of geospatial data collection methods. They are justified in cases where it is necessary to get accurate information about the area at a certain time. The main advantages of UAVs are the following: the ability to automatically detect almost all animals, both in semi-arid savannas and areas with significant vegetation; the accuracy of the results obtained; high-quality images; and fast data processing. Despite its effectiveness, the latter method is not often used as it is quite costly, even though they are cheaper to operate than helicopters and manned fixed-wing aerial vehicles. UAVs require special piloting skills, have limitations on their use over large spatial and temporal scales, including regulations, and depend on weather conditions [51,86–91].

#### 4. Conclusions

Effective monitoring issues are problematic within the framework of foreign and domestic science. In many territories (Alaska, Canada, Scandinavian countries, and Siberia), biologists, researchers, and hunting farm employees traditionally walk around the property and count the tracks of animals (elk, deer, roe, etc.), making an absolute (counting all individuals of the territory) or relative (counting a part of the animals and obtaining an idea of the entire population using the appropriate conversion factors) census [73,97,98]. The size of the territories, their inaccessibility, a lack of funding for hunting farms and natural territories, as well as adverse weather conditions impede the spread of modern wildlife control and monitoring methods. World practice confirms the need to modernize monitoring technologies and the readiness to use new methods, if they take into account most of the disadvantages of the traditional methods (full snow cover, low accuracy, and non-dependence on weather conditions and vegetation cover), if there is technical support or instructions, and in case they do not exceed the cost of existing methods.

It has already been proven effective to use several methods simultaneously with specialized equipment, such as photo traps, video-, or IR cameras. If the observation area is accessible and limited, and the number of animals is insignificant, to obtain reliable information about the population size, it is sufficient to mark them, as described in [99], with GPS collars [42]. If the terrain conditions allow, a stationary camera with a GPS sensor will allow getting almost complete information at a fairly low cost. However, there are areas with vegetation that does not allow free movement, while there is no other way to monitor elk or other large animals with UAVs. It is known that the effectiveness of animal detection by UAVs significantly increases with the use of infrared detectors in low-altitude flights [100]. The use of these technologies to detect and enumerate groups of wild animals in wildlife monitoring is superior to conventional remote sensing technologies [101], but improvements in detection and identification technology are needed to exceed the accuracy of traditional aerial photography of animals [102,103].

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