CHAPTER 7: DRONES AND CONSERVATION

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An acacia tree in the Kenyan savannah.

There are fewer different kinds of plants and animals in the world today than in the recent past,[1] in large part because of hunting[2] and land-cover change.[3] Hunting by people has been leading to species extinctions since prehistoric times.[4] The threat of extinctions is growing worse; at present it is estimated that one-fifth of the world's extant vertebrate species are threatened.[5] In tropical regions, vast areas of forest are being converted to agricultural purposes, decreasing biodiversity.[6]

Conservation workers are therefore in need of tools that allow them to frequently monitor wildlife populations to determine trends, to monitor land-cover change (as specialists refer to deforestation and similar phenomena), and to detect threats such as poachers.

Currently, wildlife monitoring is commonly conducted on foot, by car, by ship, and by manned plane.[7] Although these methods are well-developed and yield good data, they are expensive and time-consuming. This means they aren't done often, which makes proper statistical trend analyses difficult. For example, a recent survey of the range of the Sumatran orangutan (*Pongo abelii*) took three years to complete at a total cost of $250,000. The survey involved three ground teams that were often deployed to the field at the same time. Due to large mountainous or peat swamp areas that needed to be surveyed, teams sometimes had to walk for several days just to reach the survey location, which made data-gathering a slow and costly process. Conducting such surveys at sufficiently short intervals for trend analyses is not realistic.

The most common approach to classifying land-cover types, and detecting and monitoring changes in land cover, is to use satellite imagery and data.[8] Low- and medium-resolution satellite images are freely available—for example, Landsat (landsat.gsfc.nasa.gov) and MODIS (modis.gsfc.nasa.gov)—but the low resolution (greater than 900 square meters per pixel) makes it difficult to detect small-scale change or to differentiate between similar land-cover types (e.g., young versus mature oil palm plantations or low-impact logged forest versus primary forest).[9] High-resolution satellites, such as QuickBird (digitalglobe.com) and IKONOS (geoeye.com), are better. Pixels as small as a tenth of a square meter make it possible to detect some such changes. However, these images are expensive, at over $10 per square kilometer.[10] Tropical areas are often cloudy. This poses difficulty for frequent monitoring of land-cover change because satellite imagery cannot be obtained at regular intervals.[11]

Even in places where forests are not being cut down, hunting—unsustainable and illegal (hereafter referred to as poaching)—has led to declines in wildlife populations or even extinctions.[12] The poaching threat to wildlife is highlighted by declines in tigers, rhinoceros, and elephants across Africa and Asia.[13] Especially for rhinos in Africa, poaching has reached levels that are endangering populations.

For all three applications—wildlife monitoring, land-cover classification and monitoring, and anti-poaching efforts—drones can help. In the past 15 years, drones have become cheaper and more widely available; in the past few years in particular, many studies have used drones for conservation purposes.[14] This chapter reviews such studies and discusses the limits and future potential of drones for conservation.

Rhinoceros in Nepal and orangutan nests in Sumatra, Indonesia.

Serge Wich

WILDLIFE SURVEYS

In general, the aim of wildlife surveys using drones is to determine the distribution and density of species, which is important baseline information for conservation. Drones have been used to study a wide variety of terrestrial and aquatic species.

In relatively open African savannah-woodland areas, researchers have used drones to count large terrestrial animals such as the black rhinoceros (*Diceros bicornis*), the white rhinoceros (*Ceratotherium simum*),[15] and elephants (*Loxodonta africana*).[16] These studies indicate that rhinos and elephants can be counted well with standard RGB cameras, but that for elephants, drone survey costs might not be competitive with manned aircraft at present due to the limited flight times (around 45 minutes) of systems available for such surveys.[17]

Several bird species—Canada geese (*Branta canadensis)*, snow geese (*Chen caerulescens*), black-headed gull (*Chroicocephalus ridibundus)*, and white ibis (*Eudocimus albus)*[18]—have been studied with drones as well. Surveys that aim to count birds on the ground need to consider that the drone may disturb the birds, leading them to fly up from the ground and potentially creating a collision risk with the survey drone.[19]

In addition to directly detecting individual animals, researchers have used drones to see and count signs of animal life. These can range from small mounds made by gophers (*Thomomys talpoides*) and ground squirrels (*Ictidomys tridecemlineatus*)[20] to large nests made by Sumatran orangutans[21] and chimpanzees (*Pan troglodytes)*[22].

As all great apes do, orangutans make a new night nest almost every day. The number of nests in an area is often used to determine the animals' presence. This is often favored over direct sightings, because the low densities of orangutan populations mean that survey efforts would have to be very large to detect the orangutans themselves. Recent drone surveys have established that nests can be detected on photos taken from a camera on a drone. Such surveys are now being used to determine the presence of orangutans not only in rainforest areas, but also in areas that have been logged previously and are now being reforested. In such areas, the relative density of nests found during ground surveys correlates well with findings from aerial surveys, which means that using drones to determine the distribution and relative density of orangutans appears promising.

Drones have been used to study animals of different sizes in various aquatic habitats. Smaller fish like salmon have been studied during the annual salmon run in southern British Columbia.[23] The aim of the study was to obtain a high-resolution orthomosaic from drone images to identify individual salmon. The researchers managed to obtain images that gave them a new perspective on how salmon were distributed in the river and allowed them to identify spawning areas. Studies have also investigated the distribution of larger species such as the dugong,[24] the Florida manatee (*Trichechus manatus*), and the American alligator (*Alligator mississippiensis*).[25] Such studies now open up new opportunities to survey species over large areas from the air at potentially lower cost than traditional survey methods, with less disturbance to the studied species. Drones have even been used in cold and challenging environments to detect harp and hooded seals (*Pagophilus groenlandicus* and *Cystophora cristata*).[26] The aim of the seal studies was to assess the feasibility of drones for surveys of seal whelping areas that could potentially replace the costly manned aerial surveys of the West Ice area of the Greenland Sea. The results showed that both adult seals and pups could easily be identified on the images but that long-range drones that can land on ice are needed for these surveys.

DRONE PLATFORMS

Drone surveys for conservation have used both multi-rotor and fixed-wing systems. The choice usually depends on the size of the area to be covered, the detail to be obtained, and the availability of landing areas. For example, it is easier to fly a multi-rotor drone at low altitude compared to a fixed-wing craft, and the low speed of multi-rotors means that motion blur on images is not an issue. Also, the VTOL (vertical takeoff and landing) capability of multi-rotors makes them very suitable when only small areas are available for starting and ending flights.

A large variety of systems have been used, from low-cost do-it-yourself aircraft with limited flight time (60 to 90 minutes) and payload capability[27] to high-end systems able to fly for up to 24 hours and carry heavier payloads, such as the ScanEagle.[28] Fixed-wing drones range in cost from less than $1,000 for a DIY setup that can easily be operated by two people with a simple control system to hundreds of thousands or millions of dollars for high-end systems operated by a team of people with complex and large control arrangements. Multi-rotor systems also range from those with flight durations of about 10 minutes that are available for less than $1,000 and are ready to fly out of the box to systems that cost several tens of thousands of dollars and come with longer flight durations and the capability to carry heavier payloads.

The choice of system is often a trade-off between what is needed and what the costs are, given the available budget. Many conservationists would benefit from systems with a long (multiple-hour) flight duration, but at present the costs often exceed the available funding. Thus there seems to be a relatively large number of conservationists and scientists using systems that cost below $20,000.

COMPARING DRONE SURVEYS TO TRADITIONAL SURVEYS

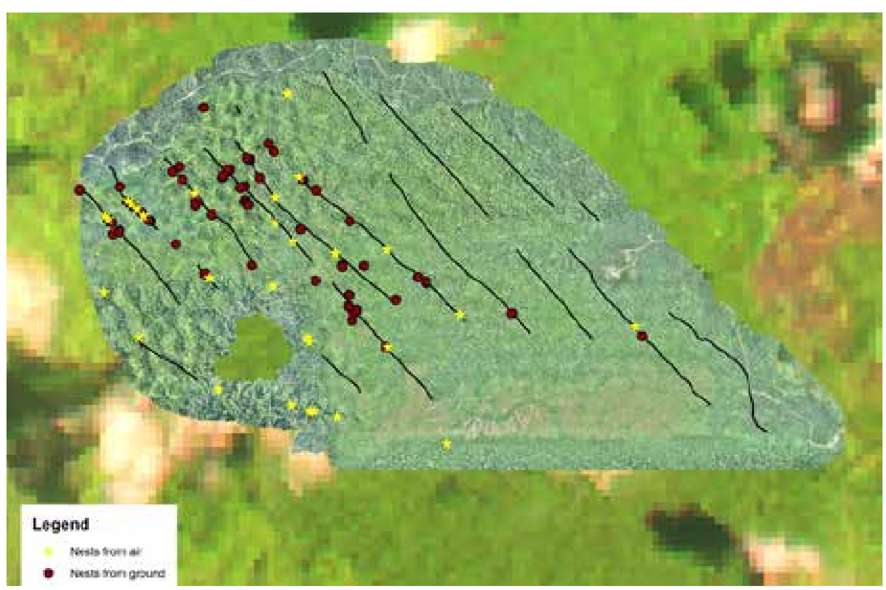
If drones are to ever replace traditional surveying methods, then wildlife counts obtained from drones must be validated against on-the-ground surveys and manned aircraft surveys. The comparison to manned aircraft is important, because during manned flights, data is typically collected by observers who look out the windows and count, rather than by digital cameras, although manned aircraft could in principle carry such cameras.

Ensuring that data are comparable is necessary to be able to determine distribution and density from drone-based data. A mixture of methods using both real and model* animals has been used to assess the detectability of animals from drones. These studies, in both the terrestrial and aquatic realms, have shown that counts based on photo or video data compare well with those achieved during traditional surveys in which humans make direct observations.

These studies also show that factors such as sea conditions[29] or the height of chimpanzee nests in trees, influence detectability.[30] There are limits to the applicability of aerial surveys. Most of the wildlife surveys so far have been conducted to determine where animals live. There has been less effort on deriving density—just how many animals there are—from this data. For animals that can be detected directly, obtaining density can be fairly straightforward if the detection probability is similar throughout the image or in a defined part of it. This can potentially lead to better estimates from aerial drone surveys than from a manned aircraft, where observers are biased toward seeing animals closer to the flight path. In those cases, a detection probability function needs to be fitted on the data that compensates for the decreasing probability of visual detection with distance.[31] For indirect signs, such as great ape nests, not everything observed from the ground is detected on aerial imagery. Although ecologists already have a track history of correction factors to be applied to manned aircraft data, more studies are needed to figure out what analogous correction factors are needed for data derived from drones.

SENSORS

Studies aimed at detecting wildlife have relied almost exclusively on standard RGB cameras. In some cases, thermal-imaging cameras mounted on drones or on telescopic boom lifts, which simulate drone heights, have been used to successfully detect animals.[32] Animal counts from drones are not restricted to wildlife. A drone-mounted thermal camera was used to count cattle at a concentrated feeding operation.[33] This study was aimed at testing how well thermal-imaging cameras could be used to detect large mammals, and the results showed that individual cows could be identified on images that were obtained from a multi-rotor system flying at 100 meters above ground level.



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Transects of drone flights can be seen in this image, as can the location of primate nests.

* For instance, kayaks instead of sea mammals.

COMPUTER VISION AND WILDLIFE SURVEYS

In most wildlife surveys, images from drone flights are processed manually for detecting and counting species.[34] This can, however, be time-consuming and costly with the large number of images and hours of video that are collected by drones. Researchers have therefore been exploring methods to use computer vision algorithms to automatically detect animals or their signs, such as orangutan nests.[35] A main task of such algorithms is to differentiate the object of interest (the animal or nest) from the background. An important consideration is whether object detection needs to occur on the drone itself or can be done on a computer once the data has been transferred from the drone. If the weight limit for an onboard computer is a key factor, successful algorithms that are computationally intensive such as convolutional neural networks are probably not suitable, and less computationally-intensive models such as support vector machines are more suitable.[36] This field will develop rapidly as more drone data is collected.

TRACKING ANIMALS WITH RADIO TRANSMITTERS AND DRONES

Aside from wildlife surveys, which count static averages of populations in specific areas, biologists sometimes want to track wildlife to establish patterns of behavior. An established technique has been to attach VHF radio transmitters to individual animals so scientists on foot or in airplanes can locate and track them. Researchers have recently started to investigate the use of drones to locate animals with a VHF collar. Such work is nascent, but it is a promising way to reduce the cost and effort that biologists currently incur while tracking wildlife.[37] In addition to VHF transmitters, researchers use GPS loggers that transmit their data to phone networks or satellites. In areas where phone networks are unavailable and satellite uploads are too costly, there might be opportunities to use drones as data relays or data mules. In such a setting, drones would fly over areas where animals with GPS loggers are present and such loggers would upload data to the drone once a connection has been established; the data would then be relayed or stored on the drone. Experiments with such systems are now being undertaken by several research groups.

LAND-COVER CLASSIFICATION AND CHANGE DETECTION

Monitoring changes in land cover is one of the key tasks for conservation. Such monitoring entails determining whether certain land covers such as pristine rainforest are being converted to other land covers such as oil palm plantations or are being degraded by logging. Most of this monitoring is currently conducted by analyzing satellite images. The resolution of satellite images continues to improve, as does the frequency with which satellite images are captured.

An example of animal detection with computer vision algorithms.

Jan van Gemert

The cost of satellite imagery is also coming down. However, drones can still compete with satellites in certain respects, while complementing satellite imagery in others.

The use of drones for such efforts is still in its infancy, but recent studies are promising. A key aspect of any land-cover classification study is to assess the accuracy of the resulting land-cover map against control points. Traditionally, many studies have used ground control points for the validation of land-cover classification based on satellite imagery. In such studies, the assessments of the land-cover classification from satellite image analysis are compared to the land-cover type determined from the control point during the ground surveys, and accuracy scores are calculated for how well the satellite image-based analysis compares to the ground control points.

Recently researchers have started to use drones as an alternative to traditional ground-based validation of satellite-based classifications.[38] The higher resolution of drone-based imagery can be used to calibrate satellite images by figuring out what features on the ground correspond to what features in satellite images. These studies have been conducted with standard RGB cameras. However, studies that use hyperspectral or multispectral images to classify land cover are becoming more common.[39] Hyperspectral cameras are used to measure the radio frequency spectrum of natural light reflected from vegetation and ground cover in great detail (multispectral cameras do this as well; hyperspectral cameras take in more detail than multispectral cameras, though there is not a clear dividing line), which can then be used to algorithmically determine which plants, trees, or minerals are present.

Although multispectral systems have shrunk in size and weight and can be used in small drone systems, hyperspectral cameras still tend to be relatively large and heavy (about 2 kilograms), which limits their use to larger drones.[40] The development of smaller and lighter Lidar (light detection and ranging) systems also promises to open a whole suite of interesting research applications that require high-resolution point clouds to derive forest metrics.[41] But even given these constraints, the applications[42] that have been used at a landscape scale range widely. They include mapping of moss beds in the Antarctic,[43] mapping of canopy cover and gap sizes,[44] using aerial images of canopy gaps to assess biodiversity of the understory in a forest,[45] land-cover mapping,[46] and assessing soil erosion.[47]

Researchers are also using drone imagery to assess habitat quality for wildlife. Such studies often determine land-cover classifications based on orthomosaics from drone-based images and link these to bird breeding density[48] or bird flight pathways.[49] Although land-cover change monitoring is one of the major applications of satellite-based monitoring, drones are ideal for this purpose because of the very high-resolution images they provide and the flexibility with which they can be deployed to capture images.[50] Small-scale changes can be readily detected and flights can be programmed to specifically monitor forest boundaries or certain key areas at high risk of human encroachment. This makes drones suitable as a monitoring tool for conservation workers, but also for local communities that would like to monitor the areas they manage.[51] Local communities could use drones to detect potential illegal incursions into their area, for instance, as well as to monitor REDD+ (Reducing Emissions from Deforestation and Forest Degradation) projects. Using drones also would potentially allow the communities to regularly obtain data on the above-ground carbon stock present in the forests they manage for carbon projects. This could reduce costs compared to present practices, in which specialist teams conduct such work.

COMPUTER VISION AND LAND COVER

As with detecting and counting wildlife, researchers are using computer algorithms to automatically detect landscape features in images. Studies have examined how to automatically detect trees with various methods, such as counting oil palm trees in plantations using the point cloud generated by photogrammetry software[52] and automatic tree crown segregation for tree detection based on RGB images.[53] Models to automatically detect tree species are also being developed.[54]

POACHING

Wildlife poaching is a major threat to many species and has sharply reduced the wild numbers of iconic species such as rhinos, tigers, and elephants. In South Africa alone, the total number of rhinos killed in 2014 was 1,215.[55] A persistent difficulty in curbing these crimes is detecting poachers before they reach the target species. Drones have been deployed to achieve early detection of poachers and their potential target species.[56] Operations using drones to prevent poaching have been started in Nepal[57] and several other locations around the world.[58] Although the effectiveness of such drone deployments remains unclear, thermal cameras have been used in South Africa to detect and intercept poachers at night.[59]

The most sophisticated and potentially most successful approach uses models that combine information—such as the locations of previous rhino kills, satellite data, and knowledge about infrastructure and rhino movements—to predict where rhinos will be at times when poaching is highly probable. Rangers and drones are then deployed in such areas to intercept the poachers before they reach their target.[60] This approach has been claimed to be very successful.[61] Although such methods can work in the relatively open savannah-woodland areas, current sensors do not allow for detection of humans or animals through the thick canopy of tropical rainforests. But video from drones might still be useful in detecting smoke plumes. Video footage acquired by the group Conservation Drones in Indonesia and Congo-Brazzaville allowed for the detection of smoke plumes, which can be the sign of fresh forest clearing or of bushmeat poachers drying animals on racks in the forest. Such information could facilitate more targeted deployment of local rangers to increase their success in intercepting bushmeat poachers or people clearing forests.

CONCLUSION

The use of drones for conservation has just started and is showing promising results for the detection of wildlife, classifying and monitoring land cover, and reducing poaching. The next few years will likely see very rapid

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Deforestation in Sumatra, Indonesia, can be seen in the bald patches in the right image.

developments on several fronts that will increase the use of drones for conservation. First, drone flight durations will continue to increase due to improvements in the systems that power drones, such as batteries and solar cells. Second, the rapid development of sensors will continue with increasingly smaller sensors that can be used in drones. Specifically, the development of small Lidar, hyperspectral, and thermal sensors will benefit conservation, as will advances in smaller and higher-resolution standard RGB cameras. Third, drones will become more user-friendly, which will lower barriers to entry. Fourth, data analyses for both wildlife detection and land-cover classification will become more sophisticated, which will aid the efforts of conservation workers. Fifth, onboard processing of images and video will allow for automatic detection of wildlife and humans. In combination with better transmission systems, this information then can be relayed in near real time to rangers on the ground so they can adapt fast to changing situations in the field. Sixth, the simultaneous, coordinated use of multiple drones (swarming) will allow for more effective mapping and monitoring of large areas. Seventh, further integration of the various technologies that conservation workers are using will be necessary to face the increasing challenges.[62] §

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