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Review on the Impact of Some Conservation Technologies on Biodiversity Conservation and Assessment

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Abstract

Technology has played an important role in efficiency of carrying out time-consuming tasks and can serve as a key means of strengthening conservation outcomes. This paper review examines the impact of conservation technologies on biodiversity conservation and assessments. It mainly consists of descriptions of Technologies with their potential benefits for the conservation of biodiversity and assessment. We surveyed previous writings and attempts to develop an understanding of the role of the technologies that could play in the biodiversity conservation and assessments. Successful implementation of these technologies, according to the authors, could help researchers who are interested in the protection of species and to innovate in a way that would achieve higher profits. Furthermore, integration of multiple technologies greatly increases the spatial and temporal scales over which ecological patterns and processes can be assessed, and threats to protected ecosystems can be identified and mitigated.

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Introduction

Reducing the loss of biodiversity is crucial for ensuring the future well-being of our planet and humanity (Hooper *et al.,* 2012). The parties to the Convention on Biological Diversity (CBD) proposed a plan to reduce the rate of biodiversity loss by 2020 (Decision X/2: Strategic Plan for Biodiversity 2011 2020). This plan outlines 20 targets to evaluate progress (the Aichi Biodiversity Targets).

Measuring progress towards these targets requires data and synthetic indicators (Butchart *et al.,* 2010) for an indicator analysis up to 2010). For example, to prevent the extinction of threatened species (Target 12) and ensure adequate protection of terrestrial, fresh water and marine areas (Target 11), countries need indicators that measure trends in abundance and distribution of species; protected area management effectiveness; and extinction risk of species (Ahumada *et al.*, 2013).

Ecologists and conservation practitioners have proven themselves adept at incorporating emerging technologies into field data collection efforts (Pimm *et al.,* 2015). The innovative use of technology is expanding the bounds of traditional ecological inference and conservation strategies (Snaddon *et al.*, 2013).

Using technology in the attempt to conserve biodiversity allows to collect and process more data, more effectively which can support decision-making and contribute to tracing any changes (Berger-Tal and Lahoz-Monfort, 2018). Continuing to expand efficient data collection in both time and space is crucial in the face of the enormous pressure that global changes are exerting on natural ecosystems (Rockström *et al.*, 2009). Rapid habitat and biodiversity losses (Pimm *et al.*, 2014), illegal wildlife harvest and trade (Milner-Gulland and Bennett, 2003), and climate change (IPCC, 2014) all affect ecosystems across the globe and increasingly require more than just field surveys to understand, monitor, and report on their effects.

Conservation biologists have endeavored to preserve biodiversity from the most extreme excesses of human environmental destruction. Most of these efforts to reverse halt, and even slow biodiversity decline have proven ineffective, with the downward trends in most biotic groups showing no signs of abating. Human pressure on remaining tracts of natural habitat has not eased and will likely intensify because of climate change.

Although the quest for ever-increasing standards of living by an ever-growing human population is the cause of the biodiversity crisis, it can also be the source of its mitigation by harnessing the technological innovation that is driving economic development to stem biodiversity loss. Such an effort will require much greater invasive mediation in biological processes, thereby further blurring the line between nature and humans that conservation biologists have long sought to preserve (O'Brien, 2015).

With the help of technological devices such as cameras, drones, satellite imagery, acoustic wave sensors and electronic tagging of animals (Speaker *et al.*, 2021) many issues associated with manual work such as slow pace and inaccuracy, can be solved (Kwok, 2019).

Hence, smart deployment and use of technologies can open up new ecological scales to investigate the assembly, competition, dispersal, and migration of organisms and their interactions with the surrounding environment.

Additionally, combating illegal activities such as poaching/hunting, logging, and encroachment require efficient monitoring and tangible evidence for investigating and prosecuting offenders. Preventing human–wildlife conflict, especially with large animals that can cause serious injury or death, often requires similar deployment of these technologies. Therefore, the objective of this paper is to review the impact of some conservation technologies in the assessment biodiversity resources and its conservation.

Remote sensing technology

Satellite

Satellite remote sensing platforms offer widespread geospatial coverage and, in many cases, long temporal records of Earth's biomes. However, most satellites (especially those satellite data providers offering free data access) lack the spatial resolution for organismic-level analysis, and often have limited spectral ranges, constraining their potential applications (Asner, 2015). While this is rapidly changing with the recent revolution in the way Earth-observing satellites are designed, built, and deployed, the traditional large-platform satellites still have many advantages.

Government-sponsored satellite sensors have the longest temporal data archive of earth-observing images and are often freely available to the public. NASA's Landsat program just passed its 44th year of continuous operation, providing an incredible opportunity to analyze ecological and land use dynamics over very large areas (Hansen *et al.*, 2013). There are many other optical multispectral and active sensors (e.g., radar, laser) that produce data at spatial resolutions ranging from 30m to 1 km, offering data products for understanding vegetation dynamics and biomass, climate and weather patterns, and biophysical variables like surface temperature, soil moisture, and CO_2 flux (Goetz *et al.*, 2009). Increased cooperation between the ecology and remote sensing communities could lead to improved biodiversity and ecosystem monitoring opportunities through publically funded satellites and sensors (Skidmore *et al.*, 2015).

Tropical forests for instance are the most biologically diverse and vulnerable ecosystem, undergoing rapid changes over the last two decades and resulting in the loss of irreplaceable biodiversity. Parks have been established in an attempt to slow biodiversity loss, but the effectiveness of this tool has been questioned, particularly in areas such as tropical Africa suffering from widespread conditions of poverty, rapid population growth and political instability where little or no formal management exists on the ground.

As few countries within Africa have stable monitoring systems to generate time-series data of forest cover change, remotely sensed satellite imagery offers a practical way to examine trends in forest cover change within and outside parks. Recent advances in remote sensing technology have allowed conservationists to investigate forest cover trends at increasingly large scales at high resolutions across whole biomes, offering an efficient, practical and affordable way to explore park effectiveness (Jenna, 2015).

Monitoring migratory bird populations over large geographic areas and extended periods can be a difficult and resource-demanding task. Because satellite technology offers a relatively cheap and verifiable means to gather environmental information at multiple spatial and temporal scales, it can become a very useful tool for the latter, provided that relevant relationships between populations and remote sensing data are found. The inter-annual variation in abundance and movements of long-distance migratory birds often depend on both local factors and those operating on a larger scale e.g. climate, food production in the oceans (Maria Paz Acuna RUZ., 2015).

Radar

It is among many optical multispectral and active sensors that produce data at spatial resolutions. The term "radar" stands for radio detection and ranging. Electromagnetic waves are emitted from an antenna in pulses that scatter when they hit a new medium with different dielectric properties (the ability of a material to store magnetic and electric energy). Some of the energy from these pulses is reflected back to the radar antenna, where it is received. It is then possible to calculate the distance to the target and its location by using the delay in receiving the echo, the speed of light, the beam width emitted by the antenna, and the position of the antenna. Pulse volumes can affect the resolution of the radar.

In general, a smaller pulse volume gives a higher resolution. A smaller pulse combined with a narrower beam allows for the best information regarding the target's position and reduces the odds that several targets will be included within a single echo. In most cases, it is fairly easy to distinguish migrating targets as they produce clear echoes; however, larger groups of birds or bats can take up several pulse volumes and show up as patches of echoes on the radar (Bruderer 1997).

The ability of radar to successfully detect targets and distinguish among them is also affected by the wavelength. A longer wavelength, which corresponds to a lower frequency, is typically less disturbed by environmental factors such as inclement weather. On the other hand, a shorter wavelength, or a higher frequency, is associated with higher noise levels, a greater chance of disturbance by smaller targets, and a smaller range. However, smaller wavelengths have the advantage of being able to be projected in sharper beams by smaller antennas and generally have higher precision (Bruderer, 1997).

Radar is a type of microwave that air traffic control and aircraft use for navigation, surveillance, communication, and detection of weather patterns and bird flocks. These sources of EMR may make airports areas with high levels of microwaves (Joseph *et al.*, 2012), and have the potential to affect habitat use by birds and/or cause negative consequences at the individual or population levels. However, little is known about how these MW might affect animals. Some studies indicate that even low doses of electromagnetic radiation can have significant effects on many aspects of an organism's ecology and behavior (Kelly and Allan, 2006).

Airborne

There is a veritable explosion underway of remote sensing platforms and sensors. From satellites, aircraft, and a plethora of in situ devices, remote sensing is providing information about changes in biodiversity at spatial scales from global to microbial. New airborne and satellite remote sensing instruments provide observations of key biological patterns ranging from the biome to the ecosystem to the organism, while also tracking environmental drivers of these patterns e.g., climate, land use, and sea surface state (Woody Turner, 2015).

Over the past several decades airborne platforms have begun to fill a critical gap between the provided in field studies and those by satellite-based sensors. At one extreme, field plots provide highly detailed measurements of the physiology, taxonomy, growth, and mortality of individual organisms (Gentry, 1988), while at the other extreme Earth observing satellites provide wall-to-wall coverage of ecosystem type, structure, and land-cover change (Friedl *et al.*, 2002). Advancements in sensor technology, image processing and analysis, and mission planning now allow measurement of ecosystem properties in plot-level detail at landscape-to-regional scales previously only possible with satellites, and at steadily decreasing cost.

Due to severe threatening of biodiversity, the monitoring and reporting on the state of nature has become more and more important in the last decades. Especially the spreading of invasive species requires up-to-date monitoring and reporting for conservation and management efforts. One of the most endangered ecosystems is alluvial forests, since their high stand dynamics opens many niches for invasive species. However, to monitor natural and close-to-natural stands can be difficult using only field measurements, mainly over extended areas. Especially, canopy gaps are difficult to survey from the ground, but LiDAR data are a powerful tool to acquire synoptic 3D data from the sites (Katalin Varga, 2015).

While airborne remote sensing has long been used in forestry and agriculture (Colwell, 1964); a shift from basic analogue and digital photography to high-fidelity hyperspectral, active radar and laser, and passive thermal instrumentation has changed the field dramatically. The proliferation of these modern sensors mounted on aircraft operated by government, commercial, and non-profit entities has revealed ecological processes in great detail across spatial scales that have long eluded ecologists. Some of these data or resulting products are made available to the public (e.g., earthexplorer.usgs.gov, cao.carnegiescience.edu).

Satellite and airborne radar provide other forms of data which can also be integrated into conservation assessments, for example LIDAR mapping of the topography of forest canopies, and associated estimates of vegetation density, and hence biomass, and therefore stocks of carbon relevant to carbon offsetting schemes (Simonson *et al.,* 2012). Thus, it is used to reveal forest canopy chemistry, biological diversity, carbon stocks, ecosystem structure, and even elephant and lion behavior (Féret and Asner, 2014). Other airborne platforms are also developed for temperate ecosystem monitoring (neonscience.org) and snow mapping (aso.jpl.nasa.gov).

Drones/Unmanned aircraft systems

Mapping land cover and determining species are two major tasks for conservation workers. Remote sensing technology is increasingly being used to assess changes in land cover. However, conventional satellite- and air-borne sensors can be prohibitively costly and inaccessible for researchers in developing countries. Species abundance is often determined by ground surveys or costly and risky surveys with small manned planes. In addition, ground surveys are often expensive, time consuming, and limited in their spatial coverage (Serge Wich, 2015).

In 2012, Lian Pin Koh co-founded the Conservation Drones.org initiative (http://ConservationDrones.org) to introduce drone technology in the conservation community for monitoring of land-cover change and species distribution and density. Conservation drones are inexpensive and autonomous unmanned aerial vehicles equipped with cameras to record high quality video and photographic images.

The use of unmanned aircraft systems (UAS, also known as drones) is gradually gaining popularity and acceptance the environmental community (Whitehead and Hugenholtz, 2014). The mainstreaming of this technology is partly driven by an increasingly challenging funding climate in the environmental sector: UAS present excellent cost-saving opportunities (compared with manual labor) in field-based applications such as the detection, monitoring and mapping of wildlife, their habitats and the wider landscape (Wich, 2015). These applications are relevant to species conservation, habitat protection and restoration, pest eradication, and watershed management. In addition, UAS can provide data at previously unavailable resolutions (e.g., ≤5 cm), allowing for increasingly fine-grained analyses of ecological questions (Anderson and Gaston, 2013).

Most UAS are fully autonomous aircrafts, with an on-board guidance system flying the UAS along pre-programmed waypoints over an area of interest. They can be equipped with different camera systems for taking still RGB photographs, RGB video footage, thermal images, multi-band images, and even hyperspectral and LiDAR (Watts *et al.*, 2012). UAS have monitored large mammals with UHF (Ultra High Frequency) or RFID (Radio Frequency Identification Technology) devices, substantially reducing costs compared to satellite and ground-based collaring and tracking operations.

UAS can be purchased off the shelf, or assembled from scratch as demonstrated by Koh and Wich (2012) for an array of conservation issues, allowing considerable flexibility in the choice of UAS. The latter approach is less-costly and allows malfunctioning or damaged parts to be replaced in the field, which is essential for remote areas. Some of the applications of conservation drones include mapping land use, surveying biodiversity, and monitoring illegal activities (Wich, 2015).

For example, the photographs captured by a UAS can be stitched together to produce a mosaic that provides detailed information on the type of land use, agriculture, and settlements in the landscape (Whitehead *et al.*, 2014). These images can also be processed to produce three-dimensional models of the landscape, such as terrain relief and forest canopy height (Dandois and Ellis, 2010) or they can be used to obtain data on species diversity and forest gap size (Getzin *et al.*, 2012).

Each photograph is automatically tagged with the UAS location coordinates when the picture was taken, allowing accurate (1–2 m) repositioning of the final imagery. The area mapped during one flight is a function of the ground resolution required and the flight duration of the UAS. Covering an area of ~500 ha in a one-hour flight is feasible with a ground resolution of ~5 cm per pixel. Several small UAS can now fly for approximately an hour, with increasing flight durations allowing mapping of progressively larger areas, with several flights per day to expand the total area mapped.

The use of drones could lead to significant savings in terms of time, manpower, and financial resources for conservation workers and researchers, but more assessments of the total costs of using UAS need to be made (Vermeulen *et al.*, 2013). Such analyses should include the costs of personnel, computer hard and software, and UAS maintenance. These potential cost savings would increase the efficiency of monitoring and surveying forests and wildlife in the developing tropics. UAS are a potential game-changer and could become a standard item in the toolbox of field biologists everywhere.

Ground deployed technology

Telemetry

Radio tracking is the system of determining information about an animal through the use of radio signals from or to a device carried by the animal. Radio-telemetry technology and tracking methods for studying the behavior and ecology of wild animals have advanced significantly since it was first used in the 1960s (Cochran *et al.*, 1963). Currently, wildlife researchers are using radio telemetry in both developed and developing countries. For instance, in Ethiopia radio telemetry has been used to study the behavioral ecology of Ethiopian wolves (*Canis simensis*) (Zelealem *et al.*, 2005) and Golden Jackal (*Canis aureus*) (Admasu *et al.*, 2004).

There are three types of radio tracking in use today: very high frequency (VHF) radio tracking, satellite tracking, Global positioning system (GPS) tracking. Three of them have strong and weak sides. However, animal freedom movement argues that it is ethically wrong to use animals in such a way that we cause them suffering, either by the deficiency of essential components of a happy existence, or by causing them pain (Singer, 1977).

Advantages of wildlife radio telemetry

Studding the behavior of wild animal has supplied important information to wildlife management and conservation (Sillero-Zubiri *et al.*, 2004). For many years, the only way researchers were using to track wildlife was to simply follow and observe the movement and habits of an animal.

Today, scientists have new tools to help them to determine the home range, how animals move and how they use their environment (Cochran *et al.*, 1963). A lot of valuable information about animal migration can be obtained from wildlife radio telemetry. By using data generated from wildlife radio telemetry, researchers can determine migratory routes, critical stopover sites, and anthropogenic barriers to the migration from remote areas.

The technology of Global Positioning System (GPS) allows scientists to obtain precise movement patterns of an animal through GPS telemetry where the animal location and its distance to survey sites can be quantified (Stewart *et al.*, 2018). Such technology has helped to identify, for example, the use of unpredicted habitats (Raymond *et al.*, 2015), to explore the social dynamics of reintroduced species (Fritts *et al.*,1997), and to reveal unfamiliar life history characteristics of threatened species (Davidson-Watts *et al.*, 2006).

Radio telemetry can be used for determining bird movements over areas ranging in size from the restricted breeding territories of resident bird species to the movement patterns of international migratory species. It has important applications in the investigation of infectious diseases of migratory species (Fuller *et al.*, 2005).

Animal tags are also being fitted with additional secondary sensors, allowing collection of physiological and environmental data. Accelerometers are being built into tags to measure fine-scale body movements, providing insight into energetics and behavior (Williams *et al.*, 2014), while other electronic devices can be attached to record physiological measurements such as heart rate and internal temperature (Signer *et al.*, 2010).
Animal movement and the ecological and evolutionary processes driving such behavior are fundamental characteristics of animal ecology and, when understood,

enable insight into many biological phenomena. Animals move in attempts to find resources or to avoid risks, concurrently providing ecosystem services such as seed and nutrient dispersal (Côrtes and Uriarte, 2012) and acting as vectors for diseases and parasites (Altizer *et al.*, 2011). Data on animal movement provides insight into the placement and maintenance of conservation corridors (Chetkiewicz *et al.*, 2006) and movement itself facilitates connectivity between patches of fragmented landscapes (Mueller *et al.*, 2014).

By making use of satellite or cell-phone communication networks, data from animal tags can be downloaded remotely in real time using mobile devices, circumnavigating difficulties around tag and data retrieval (and loss) and facilitating immediate responses to changes in animal locations (Kays *et al.*, 2015). This provides much needed assistance to conservation managers who can receive alerts when problem animals leave predefined areas or acquire real time locations on endangered species that frequently come into contact with people (Wall *et al.*, 2014).

As the quality and type of tracking data have improved, so has the ability to measure the environment through which animals move. Remote sensing techniques provide extensive and continually improving measurements of ecosystems, and when combined with high resolution telemetry data can be a powerful tool to understand animal movement and habitat preference (Davies and Asner, 2014).

Effect of radio-telemetry on wild animals

Regardless of which telemetry system is selected, potential effects on an animal's normal behavior must be considered whenever an animal is handled or instrumented. It is to the researcher's advantage to minimize these effects since the goal of radio-tracking is to obtain data most closely reflecting the animals' natural behaviors. Adverse effects from capturing and radio-tagging an animal can range from short to long-term and from apparently tolerable to severe or death (Birgham, 1989). Experiments designed to detect adverse effects from radio-tagging have focused mainly on birds and mammals.

There are a limited number of studies on the impact of radio tagging on a larger mammal. Although the majority of radio-tagged mammals are large predators or ungulates, most studies on the impacts of radio-tagging on mammals have concerned smaller mammals such as black-tailed jack rabbits, meadow voles, and lemmings. This might be because of the weight of radio telemetry which can affect the movement of small mammals more. Conversely, the studies involving the impacts of radio-tagging on white-tailed deer noted adverse effects (Nelson *et al.*, 1981). Instrumented small mammals have shown impaired movements, decreased digging ability, and decreased survival (White *et al.*, 1990).

Despite its positive impact, since most birds are relatively light and depend upon flying for survival, it is possible to expect that negative effects from the transmitter's weight and attachment packages would be easier to detect on a bird than on a large mammal Therefore, the effects of radio-tagging on birds have been primarily concerned with the transmitter-to-body weight ratio (Fuller *et al.*, 2005).

Further improvements to animal tracking technology can still be made, and some caution is required in the use of the technology (Hebblewhite and Haydon, 2010). Tag size is still too large for placement on many small birds and mammals (Kays *et al.*, 2015), and although some studies have tracked insects (Ovaskainen *et al.*, 2008), they are largely excluded from animal movement studies. There are also challenges around location accuracy, especially when attempting to match telemetry data with high resolution remote sensing.

Ethical and legal Considerations

The concept of rights for animals raises the disturbing, and controversial, issue of their legal status. It is often argued that our legal tradition classifies everything as either “human” or “non-human”, and animals are in the category “other” than human. One of the results of this classification for animals, it is pointed out, like inanimate, they are classified as “things”. Therefore, animals can be owned and are subject to the property rights of their owners with concern to a moral perspective on animal suffering; different positions have been occurred for human conduct towards animals (Birgham, 1989).

The paradox is that field research activities that use telemetry have generated valuable information which informs conservation efforts, yet there are also potential negative impacts on individuals (i.e. welfare) and populations. The ethical considerations of tagging endangered animals is a complex issue, as one of the assumptions of telemetry is that the tagging and presence of the device do not deleteriously affect the individual

(Wilson and McMahon, 2006). However, sample sizes are relatively low (relative to other methods) and animals can be studied in their natural environment.

Ethical considerations and potential behavioral adjustments induced by tagging need continual attention with concerted efforts to reduce adverse effects. However, the knowledge that has been gained through animal telemetry and the prospects for future discovery are enormous. Kays *et al.*, (2015) suggest that we are moving into a ‘golden age’ of animal tracking science and are beginning to use animals to inform us about crucial changes to the planet and to make predictions of future change, moving from simply studying animals, to using animals to study the planet.

Accurate detection of kill sites and events remains an important objective of predator-prey studies. However, obtaining this information is often constrained by the cost and labor of fieldwork. To resolve this issue, researchers have used telemetry and targeted visits to identify kill sites. However, locations were often investigated well after the kill event due to limited data retrieval options, thus decreasing potential for remaining kill site evidence (carcass consumption by predators’ scavengers) (Joseph, 2015).

Researchers planning a radio-telemetry study should strive to ensure that study animals are affected as little as possible by the transmitter, and are handled humanely and effectively during capture and transmitter attachment procedures. Capture techniques should be designed to minimize stress to the animal at all times, and their selection should be based upon an understanding of the behavioral and physical characteristics of the species to be restrained, the field conditions under which the procedure will occur, the knowledge and skill of the persons handling the animals, the goals of the investigation, and the availability of appropriate equipment and facilities (http://www.for.gov.bc.ca/ric).

Capture sessions should be timed to avoid disturbing animals during their most sensitive periods, such as when they are breeding or tending young. If chemical restraint is required, it should only be performed by trained personnel. In addition to administering an immobilizing drug, personnel involved in chemical immobilization should be capable of monitoring the anaesthetized animal and providing appropriate support measures should an anaesthesia emergency occur. As well, any animal which is subjected to general anaesthesia should not be released or left unattended until it has fully recovered (http://www.for.gov.bc.ca/ric).

Camera-trapping

One of the most pressing problems faced by animal ecologists is choosing the most appropriate method for surveying and monitoring populations (Breck, 2006). Camera traps are remote cameras that take photos when a sensor is triggered by the movement of an animal or person and, increasingly, send the image in real-time to the operator. They have helped researchers document the presence of elusive wildlife for decades, but innovative scientists have begun to apply this technology to new environments and species. The installation of camera traps in trees, for example, has successfully documented canopy use by arboreal mammals.

Modern digital camera-traps are remotely triggered by infrared sensors and are much less obtrusive, although sound and light produced by cameras vary by make and model (Meek *et al.*, 2014). Studying species in the dark requires its own technology. Researchers in the US adapted thermal imaging sensors—which detect the heat energy emitted by animals—to study hibernating bats in caves and their response to white-nose syndrome. Hummingbird researchers adapted this popular technique by separating the sensor from the camera to give cameras time to film the tiny, fast flying birds.

Traditional methods such as live trapping may increase the risk of injury to an animal and cause behavioral avoidance (or attraction) to the traps. Direct observations at points and along transect lines may also affect behavior due to the physical presence of the researcher, and are often difficult due to dense vegetation or clumped distributions of the target species. Terrain, remoteness, or weather conditions may preclude repeat visits by survey teams, making it difficult to replace baits or conduct replicate counts (Breck, 2006).

Camera-traps solve many of these issues by collecting animal movements in space and time through time-stamped photographs. Camera-traps do not require the researcher to be present and can be hidden or camouflaged to produce relatively unbiased samples. They can be established in any terrain or habitat and operate for as long as the power source allows. Camera trapping can be more efficient than other survey methods, especially for rapid assessment of biodiversity (Silveira *et al.*, 2003).

Camera traps can be set to take multiple photographs at desired time intervals, thus allowing multiple records of individual animals, and detection of family groups moving together.

They can rapidly record and store hundreds to thousands of digital images on a single SD card, thus facilitating rapid sharing of data. There is now a wide range of commercial camera-traps available to researchers, varying in detection angle and distance, field of view, trigger speed, recovery time, resolution, and price (Trolliet *et al.*, 2014).

The ecological applications of camera-trap data are diverse. Photos from single camera-traps can produce information on sex, age, breeding status and identity of individual animals, as well as other demographic parameters, and determine their activity patterns (Lynam *et al.*, 2013). Photos from arrays of camera-traps can be used to measure movement and home range, and where individuals have identifiable coat patterns, camera-traps can be used to estimate population size (Burton *et al.*, 2015).

Using species detection/non-detection records and an occupancy modeling approach, it may be possible to predict the occurrence of rare species in a conservation area (MacKenzie *et al.*, 2005). Camera-traps can help identify habitat preferences (Gray and Phan, 2011), although camera trap placement can bias results for different species (Harmsen *et al.*, 2009), for example, if animals respond to human scent left on a device. Camera-traps have also been used for the study of ecological processes such as nest predation and plant animal interactions (Pender *et al.*, 2013).

Conventional camera-traps have been used to help improve detection rates of illegal human activity (Hossain *et al.*, 2016). An adaptation of the camera-trap design can make it possible to transmit images or video in real time via SMS or MMS across local 3G telephone networks. Such wireless cellular camera-traps can detect individual animals such as problem elephants, or poachers, alerting park authorities who can then respond appropriately.

There are a number of considerations when choosing a particular camera-trap device (Glen *et al.*, 2013). For example, if the study objective is to generate a rapid inventory of species presence, a low-cost ($40–100) model that takes photographs sufficient to identify species should suffice, although a non-intrusive infrared flash camera is preferable. However, if the objective is to enumerate populations of marked individuals, a much more sophisticated device with a high-resolution infrared camera is required.

Wireless Sensor Networks

Wireless Sensor Networks (WSN) – composed of interconnected but spatially distributed autonomous monitoring devices – have great potential to aid in understanding ecological dynamics and protecting endangered species (Benson *et al.*, 2010). Specially designed sensor networks can detect motion, sound, smell, and external environmental variables (e.g., temperature, humidity, light, etc.) in a non-invasive manner and in remote regions. WSN technology is used not only to monitor remote locations but also to locate where events occur. This is crucial for gathering evidence for illegal activity or uncovering subtle ecological interactions.

Distributed computing in WSN enables information to be collected remotely while processing only relevant data at a specific location, reducing data storage overhead or allowing increased sampling frequency. WSN have already been successfully used in military, industry, commercial, civil, and healthcare applications (Arampatzis *et al.*, 2005). Recent research on sensor networks has focused on networking techniques and networked information processing suitable for highly dynamic environments and resource-constrained sensor nodes. Sensor nodes have decreased in size and are much cheaper, resulting in the emergence of many new civilian applications from environment monitoring to vehicular and body sensor networks.

Sensors are routinely deployed in very harsh conditions such as glaciers, on animals, or in very remote locations (e.g., Martinez *et al.*, 2005). Low-cost, off-the-shelf sensor parts can be integrated with microcontrollers (e.g., Arduino) and microSD cards to create standalone sensor nodes that can communicate (via radio transmitters) with each other and/or a network hub. Soil moisture, tree growth, photosynthetically active radiation, water flow, and animal activity are just a few variables that can be continuously monitored remotely (Collins *et al.*, 2006). WSN technology can be used for creating virtual fences, focal area monitoring, and/or behavior-specific surveillance. In a virtual fence set-up, a series of sensors are placed around the protected boundary of a target area and can identify an intrusion and its location, instantly communicating this to network monitors.

Fig.1 Image indicating radar

Fig.2 Lian Pin Koh & Serge Which prepare their drone for flight

Fig.3 Monitoring incoming data from the drone on a video screen

Fig.4 A drone captured this photo of an endangered Sumatran Elephant in Indonesia

Fig.5 From up high the drones capture images of orangutannests in the forest canopy

Fig.6 Telemetry transmitter attachment using a *attachment using a leg bandbackpack harness*

Credit: Nicolas Gaidet

Fig.7 Telemetry transmitter

CREDIT: USGS western ecological research center

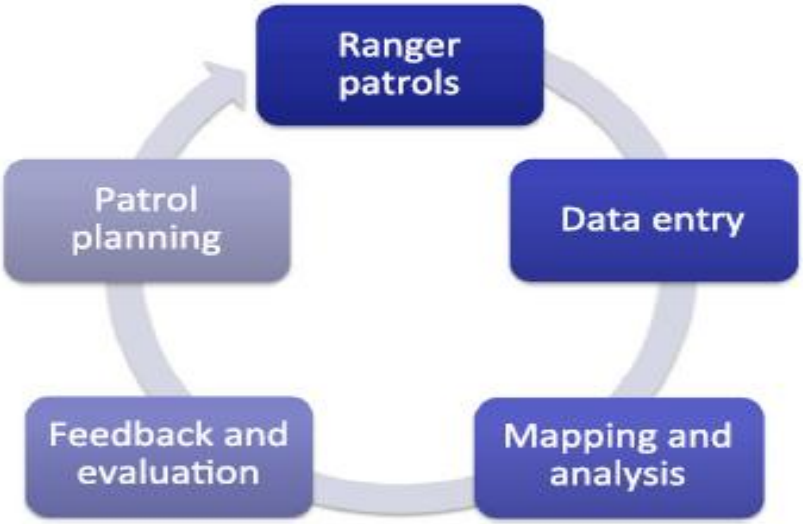
Fig.8 Platform terminal transmitters (PTT; three on the left); GPS transmitter (one on the right)

CREDIT: SCOTT NEWMAN

Fig.9 The hummingbird camera trap trigger system setup connects a high-speed video camera (covered, on the left) to two sensors, one on either side of the target Heliconia flower, to detect and begin filming the bird before it reaches the flower

Photo credit: Rico-Guevara and Mickley (2017)

Fig.10 The SMART approach for turning ranger-based data into information useful for park management and patrol planning. SMART creates flows of data in the form of point-based observations and tracklogs from ranger patrols. After initial processing (debriefing and data entry), mapping and analysis in the form of queries and data summaries, progress assessments, and reports can be produced. Reports are evaluated by the site manager and fed-back to ranger teams as patrol plans



A WSN exploits the capabilities of fiber optics, passive infrared, doppler radar, and other specialized sensor devices to create the virtual fence. Although the application of WSN in wildlife research and management is still in its infancy, they have become successful in the establishment of early warning systems and studying animal behavior. Alternatively, events such as gunfire (poaching), felling of trees, human or animal trespassing, and vehicle movement, among others, require monitoring of a focal area.

Integrated Technologies for Biodiversity Conservation

Protected area management

Protected areas are critical for long-term conservation of endangered species but their effectiveness depends on how well they are managed (Watson *et al.*, 2013). Many parks suffer from funding shortages and insufficient numbers of rangers and guards, leaving them unable to adequately manage encroachment, fire, hunting/poaching, and other unsustainable resource harvesting (Bruner, 2001). However, even parks with relatively large staff may not meet targets set for reducing threats and protecting populations of endangered species (Venter *et al.*, 2014). More must be done than simply putting extra boots on the ground.

The primary form of field-based monitoring in parks around the world is ranger/staff patrols. Ranger patrols have various mandates including research and monitoring, community engagement, and implementing law enforcement. In each role ranger teams collect data using combinations of notebooks, datasheets, mobile devices, GPS and digital cameras. Patrol based monitoring works by setting up a flow of data from the field useful for park management and patrol planning (Stokes, 2010).

A new technology that facilitates this process is the Spatial Monitoring and Reporting Tool (SMART), open-source software developed through collaboration among conservation agencies and organizations concerned with improving site based conservation area effectiveness. Patrol teams can collect field data via an Android or Windows Mobile-enabled smartphone, tablet or PDA, and upload and manage the data through the SMART software (David *et al.*, 2016).

Users can create spatial queries and summaries about patrol movements, human activities, wildlife, or significant habitat features, and create custom reports. For example, how many foot patrols by a particular team resulted in encounters with people involved in illegal timber cases? Where did law enforcement teams record illegally killed elephant carcasses? A planning module allows target setting for patrols, teams, stations, or the entire conservation area, and monitor their progress towards achieving targets in real-time. Observations of animal carcasses or other evidence of illegal activity derived from local informants, researchers, tourists or the public can be added to the database and linked to patrol plans (smartconservationtools.org).

Remote sensing tools can supplement SMART data, particularly where forest loss or conversion is a primary threat. Landsat satellites acquire the same scene every 16 days, allowing images to be mosaicked to obtain cloud-free scenes. Scene can then be directly compared with scenes from the same or earlier seasons. When areas of recent change are identified, the georeferenced image can be sent to law enforcement teams to enable field inspection and follow up actions. These approaches are useful for detecting deforestation on a range of scales from small (<10 ha) to very large (>10,000 ha), and for certain kinds of degradation. They are, however, not suitable for detecting low intensity forms of degradation such as firewood collection, highly selective logging, or the gradual effects of over-burning in deciduous forest. If the suspected areas are very remote, a fixed-wing UAS can be sent to capture high-resolution aerial photographs, helping authorities track down illegal loggers in national parks and provide evidence for their conviction (David *et al.*, 2016).

WSN can provide significant support for surveillance and monitoring of protected areas. They can be used to create virtual fences to detect intrusions by humans, which can be covertly detected and reported to rangers who can decide on the appropriate response. WSN can also provide an early warning system for detecting the movement of animals and allowing managers to potentially avoid human–animal conflicts. This can build trust between protected area managers and local people, who are often at odds with various management practices. Road networks in protected areas can disrupt animal movement and lead to animal mortality from vehicle collisions. WSN can be used as an early warning system to traveling vehicles, avoiding or minimizing collisions (David *et al.*, 2016).

Finally, WSN can profile forest health and potentially be used for population estimation if combined with other technologies. Combining patrol and remote sensing monitoring tools, along with intelligence derived from local informants is a model for protected area management that is replicable and scalable across conservation sites (David *et al.*, 2016).

Wildlife is under threat from various kinds of human activities, such as habitat destruction, illegal wildlife trade, spread of invasive species and diseases, and from the human impact on the Earth’s climate, which is changing the nature of wild habitats. Advances in technology give conservationists, scientists, and the general public the advantage to better understand the animals, their habitats, and the threats they can face.

The use of technology in conservation should be seen as force that can transform the work of researchers from across all fields interested in the protection of species. A range of established and emerging technologies that can be used by ecologists and conservation practitioners to increase the spatial and temporal scales at which they work are discussed. The spatial links between the data at each scale allows researchers to increase the dimensionality of their datasets and perform spatially explicit analyses and predictions.

The continued pursuit of higher standards of living and the material benefits of technological innovation by all societies will ensure a constant, if not increasing, pressure on the Earth’s habitats and biodiversity. Moreover, with most national economic policies founded on the notion of continuous economic growth it will take a remarkable change in economic ideology and social organization for the current trend in resource exploitation to be arrested. Indeed, the willing and even aggressive adoption by conservation biologists of novel tools to tackle the multiple threats faced by habitats and the biota they harbor will be crucial to counteract widespread species extinction and ecosystem collapse. Generally, integration of multiple technologies greatly increases the spatial and temporal scales over which ecological patterns and processes can be assessed, and threats to protected ecosystems can be identified and mitigated. A range of technology options relevant to ecologists and conservation practitioners, including ways they can be linked to increase the dimensionality of data collection efforts are described. Remote sensing and ground-based, technologies are broadly discussed in the context of ecological research and conservation efforts. Examples of technology integration across all of these domains are provided for large-scale protected area management and investigation of ecological dynamics.

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