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Current technologies and interdisciplinary research on biodiversity conservation

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Abstract

Biodiversity conservation is highly important in the current environmental protection. Besides the science and politics analysis, the scientists also invent the novel technologies to support the biodiversity conservation. This paper examines the important technologies in the biodiversity conservation, including big data, citizen science, CRISPR, geographic information system, automatic data capture system, and light detection and ranging.

Keywords

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Introduction

In contemporary environmental protection, biodiversity conservation is an important task. For biodiversity conservation, scientists and policymakers have made many efforts, including performing important scientific research, making laws and policies, applying efficient governance models, and conducting high-quality protection education. This paper focuses on an indispensable aspect: the contemporary biodiversity technologies.

Biodiversity technologies can enhance biodiversity conservation and require support from interdisciplinary research. Scientists in different disciplines need to cooperate with each other to jointly develop novel technologies. This paper introduces the most important biodiversity technologies of this century, including big data, citizen science, CRISPR, geographic information system (GIS), automatic data capture system (ADCS), and light detection and ranging (LiDAR) ([Table 1](#)).

***Table 1.** Brief summary of biodiversity technologies in this paper*

Technologies	Main applications	Year	Reference
Big data	Information management; Biodiversity research integration	1991 to now	(Menon 2014, Arts, van der Wal et al. 2015, Franklin, Serra-Diaz et al. 2017)
Modern citizen science	Species distribution; species monitoring	1995 to now	(Devictor, Whittaker et al. 2010, Brereton, Cruickshanks et al. 2011)
CRISPR	Genetic modification; Possibility of de-extinction	2014 to now	(Doudna and Charpentier 2014, Zhang, Wen et al. 2014)
Geographic information system (GIS)	Measurement; Statistical analysis; Global Positioning System	1986 to now	(Maliene, Grigonis et al. 2011)
Automatic data capture system (ADCS)	Industry (e.g., fisheries) management	2000 to now	(Bradley, Merrifield et al. 2019)

Light detection and ranging (LiDAR)	Forest management; Marine management	1995 to now	(Campbell and Wynne 2011, Shan and Toth 2018)
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Big data

Big data is an information asset with massive amounts of data, high growth rates, and complex structures (Sagiroglu and Sinanc 2013). Big data, with its new processing methodologies, has strong decision-making power, insightful discovery ability, and process optimization capabilities. Big data has the characteristics of **4V**: **V**olume, **V**elocity, **V**ariety, and **V**eracity (Zikopoulos and Eaton 2011). Big data cannot be captured, managed, and processed with traditional software tools within a short time frame. Big data has been widely used in achieving sustainable development, such as sustainable cities and communities, responsible consumption and production, climate action, and life quality improvement.

There will be **several opportunities and challenges** for the application of big data in biodiversity conservation (Koureas, Hardisty et al. 2016):

Opportunity 1: Integrating biodiversity research

There are increasing numbers of scientists using big data to **enhance biodiversity conservation** (Menon 2014, Arts, van der Wal et al. 2015, Franklin, Serra-Diaz et al. 2017). Biodiversity conservation requires a novel methodology that integrates (1) genes, genomes, phylogeny, (2) biodiversity conservation science, (3) taxonomy and systematics, (4) agro-biodiversity, (5) evolutionary biology, and (6) population and community ecology. After mobilizing and integrating different data, the big data system can contribute to experiments, observations, models, and processes that will further support biodiversity conservation (see [Figure 1](#)). For example, big data was used for bioinformatics (from big data) to forecast biodiversity conservation and ecology (Menon 2014). Based on big data, scientists used deep learning to achieve

large-scale biodiversity monitoring (Klein, McKown et al. 2015).

Figure 1 Schematic illustration showing big data integrating the different aspects of information (left) and contributing to experiments, observations, models, and processes (right) that further support biodiversity conservation.

Franklin and Serra-Diaz used big data to examine the impact of global change on plant communities (Franklin, Serra-Diaz et al. 2017). In this study, the authors collected data from environmental maps, species occurrence records, community compositions, and species traits. After collecting the data, the authors set up a spatially explicit model and predicted the impact of global change on plant communities. This paper successfully provided more meaningful insights into global plant distribution.

A research group mobilized and integrated big data in studies of spatial and phylogenetic patterns of biodiversity (Soltis and Soltis 2016). The authors discussed integrating biodiversity science, systematics, ecology, and evolution. This paper emphasized the importance of an integrative method. With support from the integrative method, people can now make biodiversity projections to provide important data for scientists, the public, and policymakers.

Opportunity 2. Data is everywhere and is produced at an increasing rate.

Data is everywhere and is produced at an increasing global internet traffic rate. That

means there are more data and faster data transfers that can support big data and its contribution to biodiversity conservation.

Opportunity 3. Databases can be organized for better usage

Big data can now be organized in a better way. For example, there are many organized novel public databases (e.g., the National Center for Biotechnology Information database, the Genbank). The databases provide much information and support research all over the world. Scientists can share their data via publication and easily download the data they want for their studies. As a result, the novel databases support big data and its aid to biodiversity conservation.

Opportunity 4. Dark data is important, due to its volume

Of the available data, 80% is dark data, or data that has not been published, and 20% is published and discoverable data in scientific research (Cisco 2017). With the technology from big data, scientists might have better access to information from the dark data. In this case, scientists would have more available data and perform better research in biodiversity conservation.

Challenge 1. Mobilizing data at all scales

It is difficult to mobilize biological data at all scales quickly, efficiently, and cost-effectively. There are vast quantities of data. For instance, there are 3 billion specimens in collections worldwide. In the biodiversity literature, there are more than 3,000 million pages.

Challenge 2. Linking and aggregating data at different scales

There is different data at different scales: 50 thousand community data files (e.g., scratchpads), 5 million national data files (e.g., Natural History Museum's Data Portal), and 500 million global data files (e.g., Global Biodiversity Information Facility Data

Portal). The data is in different sizes and different formats. There is a lot of work to be done in linking and aggregating different data.

Challenge 3. Synthesizing data (e.g., modelling human pressures on biodiversity)

There are large, linked biodiversity datasets. These are part of a clear, singular, long-term vision that biodiversity data can contribute to. Based on the synthesized data, big data has potential applications in identifying trends, explaining patterns, and making predictions. Furthermore, big data can contribute to real-time alerts, the creation of a suitable policy tool, and modelling the biosphere.

Big data example: using Wikipedia to quantify cultural interest in species

Based on big data, scientists used Wikipedia to **quantify cultural interest in species** (Mittermeier, Grenyer et al. 2018). Considering that people use Wikipedia to study popular science and knowledge, the authors studied around 60,000 vertebrates via nearly 300 language editions of Wikipedia. Based on the paper, the authors found that public interest (a large proportion of all pageviews) may follow species distribution (people pay more attention to the animals around them), body size (people pay more attention to large animals), and diet (people pay more attention to animals with a certain diet). As a result, only a small number of species (e.g., lion, wolf, tiger, panda, whale, polar bear, and shark) receive a large proportion of public interest. In another paper, the same group used Wikipedia to explore the cultural importance of global reptiles (Roll, Mittermeier et al. 2016). The authors used data of the page views to understand the global-scale patterns of human interest. The most popular species (in the top 5% of page views) were attractive animals, those which were brightly coloured, or those which were morphologically close to us. Some other species that do not have these characteristics are highly important in the ecosystem or are classified as endangered on the International Union for Conservation of Nature (IUCN) Red List, and they do not receive enough public attention and protection. This trend might be very dangerous to the ecosystem and to biodiversity conservation work.

Modern citizen science

Citizen science refers to a large number of amateur scientific enthusiasts who have not received official professional training. They participate in scientific research through network organizations. Based on internet development in recent years, citizen science has made more information available from amateur scientific enthusiasts and has played an increasingly important role. Citizen science brings happiness and fun to science enthusiasts. It is also able to support professional science work, especially in biodiversity conservation.

eBird

A previous paper examined citizen science supporting biodiversity conservation (Devictor, Whittaker et al. 2010). In this paper, the authors examined famous citizen science projects (e.g., eBird, UK Butterfly Monitoring Scheme, French Garden Butterfly Monitoring, Appalachian Mountain Watch, and Big Garden Bird Watch). The **eBird** was constructed by the Cornell Lab with the purpose of bird observation and conservation (Sullivan, Wood et al. 2009). The eBird founders constructed a platform (<http://www.ebird.org/content/ebird>) and asked amateur scientific enthusiasts to share their information: (1) 'Find more birds': Based on the latest bird watching reports, amateurs might explore birds and bird-watching hotspots; (2) 'Share your observation': Every observation is important. Users can contribute the observation to the eBird platform. (3) 'Track your list': The eBird platform will help users save information and images. Based on the information shared by different users, scientists and the platform can better understand birds' distribution and design a more accurate conservation plan.

United Kingdom Butterfly Monitoring Scheme (UKBMS)

United Kingdom Butterfly Monitoring Scheme (UKBMS) is another application of citizen science (Brereton, Cruickshanks et al. 2011). The UKBMS set up a platform

(<https://www.ukbms.org/involved>) and encouraged amateur scientific enthusiasts to share their information on the platform. Amateur scientific enthusiasts can easily get involved and contribute. They can (1) set up a new transect, (2) record a countryside butterfly, or (3) attend a UKBMS meeting or workshop. It is a very convenient platform for amateur scientific enthusiasts to share their information, learn from each other, and enjoy an interesting experience.

French Garden Butterfly Monitoring

French Garden Butterfly Monitoring was a system based on citizen participation (Henry, Manil et al. 2005), in collaboration with a major national gardening firm (Jardinerie Gamm Vert). On the website (<http://noeconservation.org>), amateur scientific enthusiasts record butterflies that they observe every month. The website can collect information from amateur scientific enthusiasts and support scientific research based on the information. The amateur scientific enthusiasts can also share information among each other and have interesting communications.

CRISPR

CRISPR-Cas9 is a novel genome engineering technique (Doudna and Charpentier 2014, Zhang, Wen et al. 2014). Briefly, CRISPR is a special gene originating in bacteria that contains fragments from viruses that have attacked the bacteria. Bacteria use CRISPR fragments to detect and resist attacks from the same virus and destroy its DNA. The CRISPR-associated protein Cas9 is an endonuclease that introduces a site-specific double-strand break in the DNA. Through support from the CRISPR-Cas9 genome engineering technique, scientists are able to accurately and efficiently make and manipulate DNA.

CRISPR/Cas 9 on de-extinction work

Although de-extinction work is still in its infancy, CRISPR/Cas9 might be crucial to any realistic de-extinction. In recent years, de-extinction has started to move from science

imagination to a real laboratory work of discussion, research, and planning (Sherkow and Greely 2013).

In previous years, researchers normally applied back-breeding or cloning in attempts at de-extinction work (Sherkow and Greely 2013). CRISPR/Cas9 might offer more possibilities. This paper uses the mammoth as an example to illustrate the possible steps for de-extinction efforts (Brand 2014, Shapiro 2015). First, scientists might obtain ancient DNA and sequence the ancient DNA to obtain its genetic information. Second, based on the genetic information, the scientists can manually create the genome of the extinct animal (e.g., mammoth) via CRISPR/Cas9 genome editing. Third, the scientists can apply the cloning technique to put the genome into a cell and activate the cell. Although de-extinction is a very difficult and long-term process, scientists believe it will be possible to realize de-extinction through CRISPR/Cas9 in the future.

Geographic Information System (GIS)

GIS is a specific and indispensable spatial information system in current biodiversity conservation. GIS is a technical system that collects, stores, manages, calculates, analyses, displays, and describes the geographical data in the earth's surface. GIS can analyse and process spatial information. GIS technology integrates the unique visual effects and geographic analysis functions of maps with general database operations (Maliene, Grigonis et al. 2011).

GIS has various applications, such as real estate, public health, crime maps, national defence, natural resources, landscape architecture, archaeology, community planning, transportation, and logistics. The GIS system also supports the Global Positioning System (GPS) service. For example, it enables people to use GPS to find nearby restaurants, gas stations, and schools. In biodiversity conservation, GIS can support the scientists find and protect the habitats of endangered species.

In applications, there is a well-known software- ArcGIS. ArcGIS provides users with a

scalable, comprehensive GIS platform. ArcGIS includes many components: from fine-grained objects (such as individual geometric objects) to coarse-grained objects (such as map objects interacting with ArcMap documents). ArcGIS is extremely extensive and it integrates comprehensive GIS functions (e.g., geostatistical analysis, spatial statistical analysis, or visualization of species distribution) for users (Johnston, Ver Hoef et al. 2001, Wong and Lee 2005).

Automatic Data Capture System (ADCS)

The automatic data capture system (ADCS) has provided new opportunities for biodiversity conservation. Decades ago, scientists needed to obtain data through fieldwork. Now, scientists have ADCS, and they can more easily obtain data and perform analyses.

ADCS provides a larger amount of data, which means 'digital conservation'. Koen Arts et al. divided 'digital conservation' into five components: (1) data on nature, (2) data on people, (3) data integration and analysis, (4) communication and experience, and (5) participatory governance. Digital technology may be reconceptualised by conservationists to provide additional power for biodiversity conservation (Arts, van der Wal et al. 2015).

To describe the basic concepts and advantages of the ADCS, this paper gives a simple example: the ADCS can be used to examine the impact of industry on ecology and policy response performance (Bradley, Merrifield et al. 2019).

The traditional system was paper-based (see [Figure 2a](#)). First, the industry (e.g., fisheries) provided paper logs. Then, scientists aggregated all paper logs and organized them into files. The files were sent to a research institute for further analysis. Finally, the government decided upon and implemented a new policy. Due to the complicated communications between each unit, this traditional system was inefficient and time-consuming.

The ADCS is based on computers and the internet (see [Figure 2b](#)). The industry provides information via the internet. The information is then automatically collected and analysed. After that, the processed data is sent to the government and research institutes. With cloud-based integrated data sharing, the government and research institute examine the data and design a new policy together. Because the data is relatively unified (computerized and networked), the ADCS is much more efficient than the traditional system.

Figure 2 A simplified comparison between (a) the traditional system and (b) the ADCS in the process of acquiring data and making decisions. The idea and information were from a previous paper (Bradley, Merrifield et al. 2019), and the figure was replotted by the author of this paper.

LiDAR

Light Detection And Ranging (LiDAR) is a remote sensing approach that use the laser to measure ranges to the Earth (Campbell and Wynne 2011). LiDAR can measure the distance by illuminating the target with laser light and a sensor (see [Figure 3](#)). The differences in laser return times and wavelengths can be used to calculate the digital

three-dimensional representations of the target (Shan and Toth 2018).

Figure 3 is a simplified illustration showing how LiDAR works. Time 0 is the start point, the laser is well-prepared to scan the target. At Time 1 and Time 2, no target is found. At Time 3, the target is found by laser since the target obstructed the light path. Time 4 is the ending point. After the data treatment, scientists can get clear target signals and know where the target is.

Figure 3 Schematic illustration showing how LiDAR works. The red colour represents the laser. The green colour represents the signal obtained.

LiDAR has been widely used in many fields, including the terrestrial laser scanning (TLS) for the trees and forests (Jackson, Shenkin et al. 2019, Lau, Martius et al. 2019), fish biomass estimation in the marine protected areas (Wedding, Friedlander et al. 2008), airborne laser swath mapping (ALSM) (Kim, Arrowsmith et al. 2006), and autonomous vehicle (e.g., self-driving car) (Lim and Taeihagh 2019). This paper introduces several applications of LiDAR during biodiversity conservation.

LiDAR in the forest management

LiDAR is a novel technique which is used in forest management.

To better perform efficient biodiversity conservation, scientists need to know the current status of the forests. Traditionally, to understand the status, scientists had to

perform long-term fieldwork in the forest. The regular fieldwork included conducting trees' census, measuring diameter at breast height (DBH), monitoring trees' sap-flow, measuring stomatal resistance, measuring leaf-water potential and so on (Oliveras and Llorens 2001, Oliveras, Martínez-Vilalta et al. 2003). The fieldwork was quite heavy, and the scientists had to spend a lot of manpower and time on it.

Currently, LiDAR makes biodiversity conservation easier and saves a lot of manpower and time. Briefly, the scientists can use LiDAR to scan the trees in the forest and obtain the cloud points. Based on the cloud points, scientists can obtain a lot of information like the number of trees, the branch length, the architecture of trees, and the total biomass (Jackson, Shenkin et al. 2019, Lau, Martius et al. 2019). Furthermore, scientists can connect LiDAR scanning result (e.g., the cloud points) with the fieldwork and set up the model. Based on the model, scientists can directly use the LiDAR scanning to estimate the forest status. LiDAR scanning result can save time for scientists and support policymakers in the conservation decision.

Tree structure analysis via LiDAR

Previously, if the scientists would like to measure the tree size and understand why the tree grows so tall (e.g., decided by hydraulics or wind speed), the scientists had to spend a lot of time to perform the fieldwork and collect the data (e.g., DBH, height, weight, or biomass). Especially, it was very difficult for scientists to manually measure large trees. Furthermore, some trees cannot be measured directly because some areas were inaccessible (e.g., no roads). These points above were difficulties during the measurement.

Currently, with the development of LiDAR and computation technique, scientists are able to "turn trees into cloud points". Scientists can directly analyze the tree via the LiDAR point clouds, which improve the measurement accuracy and save a lot of time and manpower.

Alexander Shenkin et al. found the world's tallest tropical tree ("Menara" – height 100.8 m, trunk diameter 220 cm, weighing 81.5 t), after examining thousands of trees from the LiDAR point clouds in the tropical area (Shenkin, Chandler et al. 2019).

Toby Jackson et al. try to study why trees can grow so tall. The authors perform the Principal Components Analysis (PCA) based on the LiDAR point clouds from a lot of trees. Toby Jackson et al. concludes that the wind speed rather than hydraulics is the most important factor that determines the height of trees (Jackson, Shenkin et al. 2019).

Tanago Gonzalez et al. try to measure the above-ground biomass (AGB) of large-tropical trees. There are several options: (1) to directly sacrifice/cut the trees and weight them: this method requires a lot of manpower and it is unfriendly to the environment; (2) to infer from indirect measurements (e.g., DBH, height, crown size and shape): this method has many uncertainties and is not accurate; (3) to estimate AGB based on three-dimensional tree modelling of LiDAR point clouds: the model works very well (estimated AGB from LiDAR and reference tree AGB have a good linear relationship) and the systematic bias is around 15.2%-35.7%. Tanago Gonzalez et al. prove that it is possible to accurately estimate AGB via the LiDAR point clouds (Gonzalez de Tanago, Lau et al. 2018).

LiDAR in marine conservation

Marine biodiversity conservation is normally based on the spatial approach: (1) the spatial approach is a robust tool for implementing ecosystem-based management; (2) the spatial approach is efficient in addressing research questions at the broad scales relevant to informing management. In the spatial approach, scientists require innovative techniques (e.g., LiDAR) to scale-up ecological studies to support marine conservation and management.

To better perform the spatial analysis, scientists examine the coral reef ecosystems in

multi-scale seascapes. In this case, the scientists apply the LiDAR system (with the information of seascape ecology, predictive modelling, and coral reef remote sensing). The objectives are (1) to evaluate the use of LiDAR to measure coral reef habitat complexity and (2) to design marine protected area (Pittman, Costa et al. 2010, Pittman and Brown 2011, Wedding, Lepczyk et al. 2011).

For example, Simon Pittman et al. applied the LiDAR to examine the seascape of fish habitat and recommended sustainable fisheries (Pittman, Costa et al. 2010). Furthermore, Pittman and Brown used the LiDAR to examine the fish species distributions across coral reef seascape (Pittman and Brown 2011). Lisa Wedding et al. applied the LiDAR and successfully quantified the seascape structure (Wedding, Lepczyk et al. 2011). These studies above have enhanced scientists' understanding of marine seascape and provided policymakers with more accurate marine conservation information.

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