

# The algorithm of life: How AI is revolutionizing biodiversity and conservation

## Abstract

This article explores the ways in which artificial intelligence (AI) is changing the biodiversity and conservation landscape. Climate change, habitat loss, and human activity pose tremendous dangers to the planet's unique tapestry of life, calling for creative and scalable solutions. AI proves to be a potent ally, providing a range of cutting-edge instruments and techniques that are radically changing the way we tackle environmental issues. Fundamentally, AI transforms the gathering and analysis of data. Together with AI-powered image recognition and machine learning algorithms, high-resolution satellite imagery, drone footage, and remote sensors allow for automated and accurate species identification and tracking, deforestation monitoring, and the detection of illicit poaching activities across large and frequently inaccessible terrains. In terms of scale and accuracy, this real-time, thorough data collection greatly outperforms conventional manual techniques. AI is also quite good at predictive modeling. AI can detect important migration routes, predict the spread of invasive species, anticipate disease outbreaks among wildlife, and calculate the possible effects of climate change on particular ecosystems by evaluating intricate environmental datasets. This insight enables conservationists to create robust conservation plans, allocate resources more wisely, and take preventive actions. AI also makes it easier to allocate resources optimally; directing initiatives to restore habitats, reforest, and better manage protected areas. AI is being used in citizen science projects, which democratize conservation efforts by processing and validating vast amounts of user input. By identifying patterns in surveillance data, it also helps create more effective anti-poaching tactics. It even helps create more sustainable farming methods that have less of an adverse influence on the biodiversity of the area. This paradigm change represents a once-in-a-lifetime chance to tackle the growing biodiversity threat with more accuracy, effectiveness, and scope. AI-driven solutions have the potential to not only lessen current dangers but also promote a better comprehension of ecological systems, facilitating better decision-making and paving the way for creative, data-driven approaches to a genuinely sustainable future in which nature and mankind may coexist peacefully.

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## Introduction

The planet is experiencing a crisis in biodiversity that has never been seen before. Habitats are disappearing, species extinction rates are rising, and human activity and climate change are putting tremendous strain on ecosystems' fragile balance. This crisis is widely acknowledged by scientific bodies and has been extensively documented in reports such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services' Global Assessment Report on Biodiversity and Ecosystem Services<sup>1</sup> and the World Wildlife Fund's Living Planet Report.<sup>2</sup> Despite their importance, traditional conservation techniques are frequently constrained by their size, expense, and the sheer amount of data needed to make wise decisions. These limitations often hinder the scalability and efficiency of conservation efforts, as discussed in various conservation management literatures.<sup>3</sup> Here comes artificial intelligence (AI), a game-changing technology that is drastically altering our capacity to comprehend, observe, and safeguard the natural environment. AI is becoming a vital weapon in the worldwide struggle to protect biodiversity, from complex algorithms that recognize individual species to predictive models that foresee the effects of climate change. The increasing integration of AI in conservation is highlighted by organizations like Microsoft's "AI for Earth" initiative and Google Earth Engine, which showcase diverse applications (Microsoft AI for Earth; Google Earth Engine). The several ways artificial intelligence (AI) is being used in conservation will be covered in this article, along

with its significant effects, important applications, success stories, and a critical evaluation of the difficulties and prospects of this formidable technology.

## The urgency of action: Why biodiversity needs AI

The diversity of life on Earth, or biodiversity, is the cornerstone of robust ecosystems and vital to human welfare. It controls the climate and gives us clean water, food, medicine, and air. This foundational role of biodiversity in supporting ecosystem services essential for human well-being is widely recognized and elaborated upon in numerous scientific and policy documents, including the Millennium Ecosystem Assessment<sup>4</sup> and subsequent ecological research.<sup>5</sup> However, the rate at which species are going extinct is alarmingly high due to human development, pollution, climate change, and unsustainable resource extraction. This accelerated loss of biodiversity is a critical concern, with current extinction rates estimated to be tens to hundreds of times higher than the average over the past 10 million years.<sup>1</sup> The problem's scope is enormous and frequently beyond the capabilities of human-led initiatives, posing significant challenges to traditional conservation methods due to the vast scales and complexities involved in monitoring and managing diverse ecosystems.<sup>6</sup> AI can provide capabilities that surpass human limitations in this situation, offering unprecedented tools for data analysis, pattern recognition, and predictive modeling in conservation efforts.<sup>7</sup>

## Processing big data

Large volumes of data are produced by conservation, including DNA sequencing, camera trap images, satellite imaging, and auditory recordings. AI excels at processing and analyzing these “big data” sets, identifying patterns and insights that would be impossible for humans to discern. This capability of AI is particularly crucial in modern conservation, where the sheer scale and complexity of data generated from diverse monitoring technologies necessitate advanced analytical approaches.<sup>8</sup> For instance, deep learning algorithms can rapidly process thousands of camera trap images to identify and count species, a task that would be incredibly time-consuming and prone to human error.<sup>9</sup> Similarly, machine learning can analyze vast genomic datasets to understand population connectivity or detect illegal wildlife trade (e.g., specific applications in DNA forensics for conservation, as reviewed by **Ogden et al.**,<sup>10</sup> The integration of AI in handling such “big data” in conservation is revolutionizing our ability to monitor, understand, and respond to environmental changes at unprecedented scales.<sup>11</sup>

## Automation and efficiency

AI may automate time-consuming and labor-intensive conservation tasks, like species identification, habitat mapping, and threat detection, allowing for real-time monitoring and freeing up important human resources for more strategic actions. For instance, AI-powered camera traps can automatically identify and count animal species, significantly reducing the manual effort previously required for data collection and analysis.<sup>9</sup> Similarly, machine learning algorithms applied to satellite imagery enable rapid and large-scale habitat mapping and the detection of changes such as deforestation or land degradation in near real-time, tasks that would be prohibitively slow and expensive with traditional methods.<sup>8</sup> Furthermore, AI can enhance threat detection, such as identifying poaching hotspots or illegal fishing activities, by analyzing patterns in vast datasets, allowing conservationists to deploy resources more effectively, and proactively.<sup>11</sup> By automating these foundational data collection and analysis processes, AI empowers human conservationists to shift their focus from laborious, routine tasks to more strategic actions, such as designing effective interventions, engaging with local communities, and developing long-term conservation policies.

## Case study

In order to reduce disasters, it is crucial to conduct research in the area of automatic forest fire identification. Decision-makers can also prepare mitigation strategies and extinguishing techniques with the aid of early fire detection. This study uses AI-based computer vision approaches to investigate smoke and fire detection from photos. Though their training time can be prohibitive, Convolutional Neural Networks (CNN) is a type of Artificial Intelligence (AI) approach that has been demonstrated to beat state-of-the-art approaches in image categorization and other computer vision applications. Furthermore, if there is insufficient dataset available, a pretrained CNN may perform poorly. To address this issue, transfer learning is exercised on pre-trained models. However, the models may lose their classification abilities on the original datasets when transfer learning is applied. To solve this problem, we use learning without forgetting (LwF), which trains the network with a new task but keeps the network’s preexisting abilities intact.

## Predictive power

AI is capable of creating complex models that forecast future events, including disease outbreaks, species migration patterns, and

the effects of climate change on particular ecosystems. Because of this foresight, conservationists are able to employ proactive tactics as opposed to reactive ones. For instance, predictive models driven by AI can analyze environmental data to foresee how climate change will shift species distributions, allowing for the proactive establishment of protected areas or corridors.<sup>12</sup> Similarly, machine learning can be used to predict the spread of wildlife diseases by identifying environmental and behavioral factors that increase risk, enabling timely interventions to prevent epidemics.<sup>13</sup> By providing these advanced forecasting capabilities, AI empowers conservationists to move beyond simply reacting to existing problems and instead implement preventative measures and adaptive management strategies that anticipate future challenges, thereby maximizing the impact of limited resources.<sup>14</sup>

## Scalability and reach

From dense rainforests to deep oceans, AI-powered tools can function across vast and frequently inaccessible terrains, offering a global reach that is not possible with traditional methods. The sheer scale and remoteness of many critical biodiversity hotspots, such as the Amazon rainforest or the deep sea, present significant logistical and financial challenges for human-led monitoring and research.<sup>8</sup> However, AI-driven technologies like autonomous underwater vehicles (AUVs) equipped with AI for species identification and habitat mapping can explore and collect data from the ocean depths more efficiently and safely than human divers. Similarly, drones integrated with AI for image recognition can survey vast expanses of rainforests to detect deforestation, monitor wildlife, and identify poaching activities, even in areas inaccessible by foot. Acoustic monitoring, combined with AI to analyze animal vocalizations, offers a cost-effective way to track biodiversity recovery in remote forest areas.<sup>15</sup> These capabilities overcome the limitations of traditional methods, which are often constrained by manpower, cost, and the physical risks associated with operating in challenging environments, thereby expanding the scope and scale of conservation efforts globally.

## Key applications of AI in biodiversity and conservation

The applications of AI in conservation are numerous and constantly growing, touching upon practically every area of biodiversity protection. AI-driven technologies are being increasingly utilized to monitor wildlife populations, enhance habitat management, and combat poaching.<sup>16</sup> Many excellent AI-powered tools, software, and websites are commonly used by people to identify various species, including birds, butterflies, and bugs. Here are some of the most prominent ones.

### For birds

**Merlin Bird ID by Cornell Lab:** This is arguably one of the most popular and highly-regarded bird identification apps. It uses AI for both photo identification (upload a picture) and sound identification (record bird songs/calls). It’s constantly updated with new species packs for various regions worldwide and is powered by data from eBird.

### For butterflies, moths, and bugs (Insects):

**a) Butterfly identifier-AI scan:** Dedicated specifically to butterflies, this app uses AI to identify butterfly species from photos, providing detailed information about them.

**b) Lep’s by fieldguide:** This app specifically focuses on Lepidoptera (moths and butterflies) and serves as a community platform for

enthusiasts. It uses AI to identify species from photos and allows users to record observations.

- c) **Picture insect: bug identifier:** This app is widely used for identifying a broad range of insects, including butterflies, moths, spiders, and general bugs. You can snap a photo or upload one from your gallery, and its AI analyzes the image to provide identification and information. It also offers insights into insect bites and pest control.
- d) **Seek by iNaturalist:** While not solely focused on insects, Seek is an excellent all-around nature identification app that leverages AI to identify plants, animals, fungi, and insects from photos. It's connected to the larger iNaturalist community, which helps verify identifications. This is a fantastic platform (website and app) that allows users to upload observations of any living organism. It uses AI for initial identification suggestions, but the strength of iNaturalist lies in its community of naturalists who can confirm or correct identifications. It's a powerful tool for citizen science and biodiversity tracking.
- e) **Obsidentify:** Developed by a large nature platform in the Netherlands, Obsidentify covers all types of wild plants, animals, and fungi. It's known for being surprisingly good at identifying even smaller groups like flies and bugs.

#### Key features that make these AI tools popular:

- A. **Community and citizen science:** Many of these platforms leverage user contributions to improve their AI models and build comprehensive biodiversity data like plants, animals and birds.
- B. **Extensive databases:** These tools are typically backed by vast databases of species information, including images, descriptions, habitats, and behaviors of animals, birds and wildlife.
- C. **Image recognition:** Users can simply take a photo of the organism, and the AI analyzes it to suggest potential species.
- D. **Sound identification (especially for birds):** AI can analyze bird songs and calls to identify the species.
- E. **User-friendly interface:** They are designed to be easy to use for both amateur enthusiasts and experienced naturalists.
- F. When using these tools, it's always a good idea to cross-reference with other sources if possible, as AI identification can sometimes have limitations, especially with less common or difficult-to-distinguish species.

#### Enhanced monitoring and data collection

Effective conservation is based on timely and accurate data. The way we gather, analyze, and interpret data about animals and their environments is being revolutionized by artificial intelligence. AI's capacity to process and derive insights from "big data" including DNA sequencing, camera trap images, satellite imagery, and auditory recordings far surpasses human capabilities, enabling breakthroughs in monitoring and understanding biodiversity.<sup>8,11</sup> For example, AI-powered computer vision can automatically identify and count species from millions of camera trap images, a task that would be incredibly labor-intensive and slow for human analysts.<sup>9</sup> Similarly, machine learning algorithms applied to remote sensing data allow for rapid and large-scale mapping of habitats and the detection of environmental changes, like deforestation, in near real-time.<sup>8</sup> Acoustic monitoring, combined with AI for sound classification, provides a non-invasive and efficient way to track animal presence and behavior across vast

or inaccessible areas. This revolution in data collection and analysis allows conservationists to move from reactive responses to proactive strategies, enabling more timely interventions and a more precise understanding of ecological trends and threats.<sup>14</sup>

## Species identification and tracking

### Image and video analysis

AI-powered computer vision is revolutionizing camera trap monitoring. Algorithms can automatically identify individual animals, classify species, and even track their movements and behavior from vast datasets of images and videos. This significantly reduces the manual effort required and improves accuracy.<sup>9</sup> For example, systems can distinguish between different tiger stripes or elephant ear patterns, allowing for individual identification and population estimation. This ability to quickly and accurately process what would otherwise be overwhelming amounts of data frees up valuable human resources for more strategic conservation actions. Scientists and researchers in ecological fields are increasingly leveraging AI-powered tools for species identification and tracking, particularly through image and video analysis from sources like camera traps, drones, and satellites. These tools are transforming biodiversity monitoring and conservation efforts. Some of the commonly used and highly impactful AI-powered tools for image and video analysis are as under:

#### Platforms and frameworks for camera trap data analysis:

- 1) **Agouti:** An open-source web platform for managing and analyzing camera trap data. It offers an efficient workflow and is designed for processing large volumes of images, retaining important metadata, and includes GIS-based tools for spatial analysis.
- 2) **CTAP (Camera trap analysis package):** Developed by the Zoological Society of London, CTAP is designed for managing and analyzing large volumes of camera trap data and provides standardized outputs for monitoring wildlife.
- 3) **eMammal:** A data management system and archive for camera trap research projects, often used by both researchers and citizen scientists for classifying species. While it focuses primarily on mammals, it provides a standardized protocol for data collection.
- 4) **PyTorch-wildlife (by Microsoft):** This open-source AI framework enhances biodiversity monitoring by automating the analysis of camera trap data. It utilizes convolutional neural networks (CNNs) for animal detection and classification, offering a modular, scalable, and user-friendly solution. It includes a "model zoo" with pre-trained models for various ecosystems.
- 5) **TRAPPER:** Another open-source tool for managing and analyzing camera trap data, supporting bulk image imports and working with relational databases.
- 6) **Wildbook (by Wild Me):** This platform blends structured wildlife research with artificial intelligence, citizen science, and computer vision to accelerate population analysis. It's particularly known for individual animal identification based on unique patterns (e.g., stripes on zebras, spots on giraffes) and is used for species like giraffes (Giraffe Spotter), whales, and sharks.
- 7) **Wildlife insights:** This is a revolutionary platform developed in collaboration with conservation organizations and Google. It uses powerful AI and machine learning (specifically the **SpeciesNet** model) to automatically identify animals in camera trap images.

It's designed to process millions of images, reducing manual effort significantly. SpeciesNet is also being made open-source for wider use and improvement.

#### Tools for acoustic analysis (often with image/video integration):

- i. **Kaleidoscope pro (by Wildlife Acoustics):** While primarily an acoustic analysis software, it uses sophisticated pattern recognition algorithms to automatically scan wildlife audio recordings for bird songs, frog calls, bat echolocations, and other animal vocalizations. It can also integrate with visual data by providing context for what might be present. Its "Bat Automatic Identification" feature is particularly strong.

#### General computer vision and deep learning libraries/frameworks:

- a) **OpenCV (Open source computer vision library):** A comprehensive library for computer vision tasks, including image processing, object detection, and tracking. While not AI-specific, it's often used in conjunction with deep learning frameworks.
- b) **PyTorch:** Another popular open-source machine learning library, favored by many researchers for its flexibility and ease of use in building and training deep learning models.
- c) **TensorFlow/Keras:** Widely used open-source machine learning libraries from Google. Researchers can train custom deep learning models (like CNNs) for image classification, object detection (e.g., using YOLO or Faster R-CNN architectures), and object tracking in images and videos.

#### Applications and concepts:

- A. **Automated camera trap analysis:** This is one of the most common applications. AI models (trained on massive datasets) are used to detect, classify, and count animals in images and videos captured by motion-triggered cameras in the field. This significantly reduces the manual effort of reviewing millions of images.
- B. **Behavioral analysis:** AI can be trained to recognize and classify different animal behaviors (e.g., feeding, mating, predator-prey interactions) from video footage, offering insights into ecology and ethology.
- C. **Drone-based surveys:** Drones equipped with high-resolution cameras collect vast amounts of aerial imagery. AI processes these images to identify and count large animals, map habitat changes, and monitor landscapes.
- D. **eDNA (environmental DNA) analysis:** While not directly image/video analysis, AI is crucial in processing the large genomic datasets generated from eDNA samples to identify species present in an environment from traces of DNA.
- E. **Human-wildlife conflict mitigation:** AI can power early warning systems by detecting animals approaching human settlements or agricultural areas, alerting communities, and informing mitigation strategies.
- F. **Individual animal identification:** Using unique natural markings (e.g., spots, stripes, scars) to identify and track individual animals over time, providing data for population dynamics, movement patterns, and social structures.
- G. **Satellite imagery analysis:** For large-scale monitoring, AI analyzes satellite imagery to detect deforestation, track changes in vegetation cover, monitor the spread of invasive species, and assess the health of ecosystems.

#### Key challenges and considerations for researchers:

- a) **Computational resources:** Training and deploying advanced deep learning models can require significant computational power, especially for large datasets.
- b) **Data quality and quantity:** High-quality, diverse, and well-annotated datasets are crucial for training robust AI models. This often requires significant manual effort from experts.
- c) **Domain expertise:** While AI automates analysis, ecological expertise is still vital for interpreting results, designing studies, and understanding the biological implications.
- d) **Ethical considerations:** Researchers must consider the ethical implications of using AI for monitoring, including data privacy, potential for misuse, and minimizing disturbance to wildlife.
- e) **Model interpretability:** Understanding why an AI model makes a particular identification can be challenging, which is important for scientific rigor.

The field of AI in ecological research is rapidly advancing, and new tools and methodologies are constantly emerging, making it an exciting time for biodiversity monitoring and conservation.

#### Acoustic monitoring

A wealth of information on biodiversity can be found in the sounds of nature, such as bird calls, bat echolocation, whale music, and even insect buzz. Even in loud settings, machine learning algorithms may be trained to identify the distinctive vocalizations of many species. This makes it possible to track animal movements over large areas, detect poaching operations (such as gunshots or chainsaws), and passively and non-invasively monitor nocturnal or elusive animals. This field, known as bioacoustics, leverages AI and machine learning to analyze vast soundscapes (the collection of all sounds in a specific environment) for ecological insights. Algorithms can be trained using techniques like Convolutional Neural Networks (CNNs) and Mel-frequency Cepstral Coefficients (MFCC) to accurately classify animal sounds, even amidst significant background noise.<sup>17</sup> For instance, passive acoustic monitoring (PAM) with AI is revolutionizing the study of elusive or nocturnal species, such as bats, owls, or certain marine mammals, that are difficult to observe directly. By deploying networks of acoustic sensors, conservationists can continuously monitor the presence, abundance, and even behavior of these animals over extended periods without disturbance. Beyond species monitoring, acoustic AI systems are proving highly effective in detecting illegal activities. Organizations like Rainforest Connection use solar-powered sensors and AI to listen for the specific sounds of chainsaws indicating illegal logging, or gunshots signaling poaching, and send real-time alerts to rangers on the ground, enabling swift intervention.<sup>18</sup> This capability is crucial for protecting remote and vulnerable ecosystems from human threats.

#### Environmental DNA (eDNA) analysis

DNA is released into the air, water, and soil by organisms. Without direct observation, artificial intelligence (AI) is being used to analyze environmental DNA (eDNA) samples and quickly determine the presence of species, including invasive or rare ones. This extremely sensitive approach provides a potent tool for assessing biodiversity and identifying problems early. The analysis of eDNA has emerged as a groundbreaking method in biodiversity monitoring, capable of detecting species through trace amounts of genetic material shed into the environment.<sup>19</sup> When coupled with AI and machine learning, the power of eDNA analysis is significantly amplified. AI algorithms

can efficiently process the massive datasets generated from eDNA sequencing, identify complex genetic patterns, and accurately determine the presence or absence of target species from a mixed sample.<sup>16</sup> This overcomes the challenges of traditional methods that often require direct observation or capture, which can be labor-intensive, costly, and ineffective for elusive or rare species. For instance, AI-driven eDNA analysis is being employed to detect invasive species in aquatic environments before they become widespread, allowing for rapid intervention.<sup>20</sup> Similarly, it's used to confirm the presence of critically endangered or cryptic species in remote habitats, providing crucial data for conservation planning without disturbing the animals.<sup>21</sup> The high sensitivity and non-invasive nature of AI-enhanced eDNA monitoring make it an invaluable tool for early detection of biodiversity threats, rapid biodiversity assessments, and tracking the effectiveness of conservation interventions.

## Habitat mapping and ecosystem health monitoring

### Satellite imagery and remote sensing

The analysis of drone and satellite photography is changing as a result of artificial intelligence, especially deep learning. With previously unheard-of speed and accuracy, algorithms can map vital ecosystems, monitor water quality, identify illicit logging, detect changes in forest cover (deforestation, replanting), and evaluate land degradation. AI is used by platforms such as Global Forest Watch to deliver near-real-time deforestation notifications, facilitating prompt action.<sup>22</sup> Deep learning's capacity to process vast amounts of remote sensing data has revolutionized environmental monitoring.<sup>8</sup> For instance, AI algorithms are highly effective in analyzing satellite imagery to identify and quantify deforestation, even in remote and cloud-covered regions, providing timely and accurate information on forest changes.<sup>23</sup> Platforms like Global Forest Watch (GFW) leverage these advancements, integrating various satellite data and AI models to provide near-real-time deforestation alerts, which empower governments, NGOs, and local communities to respond rapidly to illegal activities.<sup>22</sup>

### IoT sensors and networks

Real-time data on environmental characteristics including temperature, humidity, water levels, and air quality is gathered via networks of networked sensors, often known as the Internet of Things, or IoT. Artificial intelligence (AI) algorithms examine this constant flow of data to track the health of ecosystems, identify irregularities, and forecast environmental shifts like the start of a drought or the spread of pollution.<sup>24</sup> The integration of AI with IoT sensors is a transformative force in environmental monitoring and conservation. IoT sensors, deployed across various environments, continuously collect massive amounts of data on critical parameters. AI algorithms are then employed to process this data in real-time, allowing for immediate insights, and proactive decision-making. By automating data collection and providing real-time analysis and predictive insights, AI-powered IoT systems significantly enhance the efficiency and effectiveness of environmental monitoring and conservation efforts.<sup>25</sup>

### Combating wildlife crime

One of the main causes of the decline in biodiversity is poaching and the illegal wildlife trade. AI is offering vital resources to counter these illegal operations. AI-powered technologies are revolutionizing anti-poaching efforts and the detection of illegal wildlife trade by enhancing surveillance, improving data analysis, and enabling

proactive interventions. For instance, AI-equipped camera traps, like RESOLVE's TrailGuard AI can automatically detect humans and vehicles in protected areas and send real-time alerts to rangers in as little as 30-42 seconds, significantly reducing response times and increasing the chances of apprehending poachers.<sup>9</sup> These systems are trained to differentiate between animals and humans, minimizing false alarms and allowing limited human resources to be deployed more strategically. Beyond ground-based surveillance, AI is also being used to combat illegal wildlife trade online. Organizations like the International Fund for Animal Welfare (IFAW) and WWF leverage AI to scan vast online marketplaces and social media platforms, identifying suspicious listings, images of illegal wildlife products (e.g., ivory, pangolin scales), and coded language used by traffickers. The "AI Guardian of Endangered Species" tool, developed by IFAW and Baidu, for example, has shown high accuracy in detecting images of illegally traded wildlife products online, leading to the removal of illicit posts and aiding law enforcement investigations. Furthermore, predictive analytics powered by AI can analyze historical poaching data, environmental factors, and even socio-economic indicators to identify high-risk areas and anticipate poacher movements, enabling patrols to be optimized and resources to be allocated more effectively. This proactive approach shifts the paradigm from reactive responses to preventative measures, leading to a more efficient and impactful fight against wildlife crime.

## Anti-poaching surveillance and prediction

### AI-powered drones and camera traps

Automated aerial patrols over vast protected areas can be carried out by drones outfitted with high-resolution cameras, infrared imaging, and artificial intelligence algorithms. These drones can identify the movements of people and animals, spot suspicious activity, and instantly notify rangers. By distinguishing between poachers and wildlife, smart video traps can lower false alarms and increase patrol effectiveness. The integration of AI into drone technology has significantly enhanced their utility in anti-poaching and wildlife monitoring efforts. Drones equipped with high-resolution visual and thermal cameras can cover extensive and often inaccessible terrain much faster and more safely than ground patrols.<sup>26</sup> Infrared and thermal imaging are particularly crucial for detecting heat signatures of humans and animals at night or through dense foliage, when most poaching occurs. The "smart" aspect comes from AI algorithms, often using deep learning techniques like Convolutional Neural Networks (CNNs) and object detection models (e.g., YOLO, MobileNet SSD). These algorithms are trained on massive datasets to accurately differentiate between wildlife and potential poachers or vehicles.<sup>9,27</sup> This capability is vital for reducing false alarms, which can otherwise strain limited ranger resources and lead to patrol fatigue.<sup>28</sup> When suspicious activity is detected, the AI-powered drones can send immediate, real-time alerts with precise GPS coordinates to rangers on the ground or at a command center, enabling rapid response and increased chances of interception.<sup>29</sup> Case studies and deployments in various conservation areas, such as Kruger National Park, have demonstrated the effectiveness of AI-powered drones in deterring poachers and increasing detections. The ability to autonomously monitor, classify, and alert in real-time makes AI drones an invaluable tool for modern anti-poaching strategies.

### Predictive analytics for poaching hotspots

In order to forecast regions and periods of high poaching danger, artificial intelligence (AI) models can use past poaching data, environmental elements (such as road networks, human population

density, and lunar cycles), and socioeconomic aspects. This increases the likelihood that poachers will be caught by enabling conservation organizations to deploy resources strategically and carry out preventive interventions.<sup>30</sup> Patrol data is analyzed via the SMART (Spatial Monitoring and Reporting Tool) project, which is frequently combined with AI to find patterns and boost efficiency. Predictive analytics, powered by AI, has emerged as a game-changer in anti-poaching strategies. By analyzing vast datasets, including historical poaching incidents, geographical information (like terrain, proximity to human settlements, and access points), and even behavioral patterns of both wildlife and poachers, AI algorithms can identify high-risk areas and times. This proactive approach shifts conservation efforts from reactive responses to anticipatory interventions, enabling rangers to be deployed where they are most needed, thereby increasing the likelihood of intercepting illegal activities before they occur. A prime example of this integration is the SMART (Spatial Monitoring and Reporting Tool) project. SMART is a widely used platform for collecting, storing, and analyzing patrol data from protected areas globally. While SMART itself provides robust analytical capabilities, its effectiveness is significantly enhanced when combined with AI and machine learning. AI models are integrated into SMART to process this rich patrol data, identify patterns, and generate predictions about future poaching hotspots. This integration allows conservation managers to optimize patrol routes, allocate limited resources more efficiently, and make evidence-based decisions.<sup>30</sup> Success stories abound, with projects like the Protection Assistant for Wildlife Security (PAWS) demonstrating the effectiveness of AI-driven predictive patrolling. PAWS, often integrated with SMART, uses AI to forecast poaching risk levels, leading to a significant reduction in illicit activities in pilot areas. In some regions, AI-boosted strategies have led to a marked reduction in poaching incidents, including achieving zero rhino poaching in parts of Kenya, showcasing the immense potential of this formidable technology.

### Illegal wildlife trade detection

One of the main causes of the decline in biodiversity is poaching and the illegal wildlife trade.<sup>31</sup> AI is offering vital resources to counter these illegal operations.<sup>28</sup> AI's ability to analyze vast amounts of digital data, particularly from social media and online marketplaces, is proving to be a powerful weapon against wildlife trafficking.<sup>32</sup> Criminal networks increasingly exploit these platforms to advertise and sell illegal animal products, often using coded language and disguised images to evade detection.<sup>33</sup> Through these sophisticated applications, AI is significantly enhancing the efficiency and reach of efforts to combat online wildlife trafficking, complementing traditional law enforcement methods and making it harder for criminals to operate in the digital realm.

### Strategic conservation planning and management

The capacity of AI to evaluate intricate data and generate forecasts is crucial for making well-informed conservation decisions. This statement underscores core strength of AI in the conservation domain: its ability to move beyond simple data aggregation to provide actionable insights and strategic foresight. AI excels at processing and synthesizing vast and complex datasets, often beyond human analytical capacity. This includes integrating disparate data sources such as satellite imagery, genetic information, acoustic recordings, climate models, and socio-economic data.<sup>8,11</sup> By applying machine learning algorithms to these datasets, AI can uncover hidden patterns, correlations, and anomalies that might otherwise go unnoticed. Furthermore, AI's predictive modeling capabilities are particularly valuable for conservation.<sup>14</sup> This foresight enables conservationists

to transition from reactive problem-solving to proactive, evidence-based strategies. Instead of merely responding to crises, they can anticipate challenges, allocate limited resources more effectively, and design interventions that are more likely to succeed in the long term.<sup>34,35</sup> Ultimately, AI's ability to transform complex data into clear, actionable predictions empowers conservation leaders to make more precise, impactful, and timely decisions for biodiversity protection.

## Predictive modeling for species and ecosystems

### Climate change impact assessment

The impacts of climate change on species distributions, migration paths, and ecosystem resilience can be replicated by AI models.<sup>36</sup> This aids in the identification of species and ecosystems that are at risk, which helps conservationists build adaptive management plans like creating protected areas that are climate resilient or enabling assisted migration.<sup>37</sup> AI's ability to process vast ecological and climate datasets allows for the creation of sophisticated predictive models that simulate how environmental changes, particularly those driven by climate change, will affect biodiversity.<sup>38</sup> These models can project.<sup>39</sup> In essence, AI equips conservationists with the knowledge to anticipate climate change impacts and implement forward-thinking solutions to protect biodiversity and build a more resilient future for species and ecosystems.

### Species distribution modeling

In order to help identify important conservation areas, plan reintroduction programs, and comprehend the possible spread of invasive species, artificial intelligence (AI) systems can forecast optimal habitats for species depending on environmental criteria. AI plays a crucial role in species distribution modeling (SDM), which predicts the geographic distribution of species based on their environmental requirements.<sup>40</sup> By analyzing vast datasets of species occurrence records, climate data (temperature, precipitation), topographic features (elevation, slope), land cover, and other environmental variables, AI and machine learning algorithms can identify complex relationships and predict areas most suitable for a given species.<sup>8,41</sup> By providing detailed insights into habitat suitability, AI empowers conservationists to make data-driven decisions that are more precise, efficient, and ultimately more effective in protecting biodiversity.

### Disease outbreak prediction

AI can forecast the possibility of disease outbreaks in wildlife populations by examining environmental data, animal migrations, and illness incidence. This enables early intervention and mitigation measures. The predictive power of AI in wildlife disease surveillance is revolutionizing how conservationists anticipate and respond to health threats in animal populations. By leveraging vast datasets, including climate patterns, ecological changes, host characteristics, viral genetics, and historical disease outbreaks, AI algorithms can identify subtle patterns and correlations that are imperceptible to human.<sup>42,43</sup> The output of these AI models can be critical predictions, such as: where and when an outbreak is likely to occur, sometimes weeks or months in advance,<sup>42</sup> the potential severity and spread of an outbreak, and which animal populations are at highest risk. This foresight enables early intervention and mitigation measures. Conservationists can implement targeted vaccination programs, establish biosecurity measures, manage wildlife populations, and even adjust human activities in critical areas to prevent or contain outbreaks, thereby safeguarding both wildlife and public health.<sup>42</sup>

## Optimizing resource allocation

Resources for conservation are frequently limited. By determining the most effective actions based on data-driven insights, AI can assist in optimizing the deployment of patrols, monitoring tools, and restoration initiatives. Conservation efforts often face significant constraints in terms of funding, personnel, and time.<sup>44</sup> AI offers a powerful solution by enabling strategic resource allocation and maximizing the impact of limited budgets and human capital. This optimization is achieved through various applications. By providing data-driven insights and predictive capabilities, AI enables conservation managers to make more informed decisions about where and how to invest their limited resources, ultimately leading to more effective and efficient conservation outcomes.<sup>34,35</sup>

## Invasive species management

Through the analysis of eDNA, satellite imaging, and environmental data, artificial intelligence (AI) can help with the early detection, monitoring, and prediction of the spread of invasive species. This stops additional ecological harm by enabling focused and effective eradication or control operations. Invasive alien species (IAS) pose a significant threat to global biodiversity, causing ecological and economic damage.<sup>34,35</sup> AI is becoming an indispensable tool in managing this challenge by enhancing our ability to detect, track, and predict their movements. By providing timely and accurate information on invasive species presence, distribution, and future spread, AI empowers conservation managers to implement focused and effective eradication or control operations. This minimizes ecological harm and protects native biodiversity from the devastating impacts of biological invasions.<sup>34,35</sup>

## Habitat restoration and ecosystem services

Restoring damaged habitats is essential to the regeneration of biodiversity. AI has the potential to improve these initiatives' efficacy. Habitat restoration is a critical but often complex and resource-intensive endeavor. AI can significantly enhance the effectiveness and efficiency of these initiatives by providing data-driven insights and automating various aspects of the restoration process. By leveraging AI, restoration efforts can become more precise, scalable, efficient, and ultimately more successful in reversing environmental degradation and fostering biodiversity regeneration.<sup>45</sup> AI is playing an increasingly vital role in habitat restoration and managing ecosystem services by enabling more precise, efficient, and data-driven interventions. Here's an example and a case study demonstrating its impact:

### Example: AI for optimal reforestation and carbon sequestration

**Species/ecosystem:** Forests, particularly in regions prone to deforestation or requiring extensive reforestation efforts.

**Case Study/application:** Using AI to Optimize Restoration Planning and Outcomes (e.g., in the Amazon or other large-scale reforestation initiatives).

## How AI is applied

### Data collection and analysis (Remote Sensing & GIS):

- 1) **Biodiversity data:** Information on existing species presence, historical distribution, and ecological requirements is fed into the models.
- 2) **Climate data integration:** AI models incorporate climate data (temperature, precipitation, historical weather patterns, climate change projections) to understand environmental suitability.

3) **Satellite imagery and drone data:** AI algorithms analyze vast amounts of satellite imagery and drone footage. These images provide detailed information on:

- i. **Deforestation patterns:** Identifying areas that have been recently cleared, where illegal logging occurs, or where natural disturbances (like wildfires) have taken place.
- ii. **Existing vegetation:** Identifying surviving tree species, canopy cover, and overall forest structure.
- iii. **Land degradation:** Assessing soil health, erosion, and the extent of degradation.
- iv. **Topography and hydrology:** Understanding the landscape features, water sources, and drainage patterns.

### Habitat suitability modeling and prioritization:

- 1) **Machine learning algorithms:** AI (often using techniques like machine learning and deep learning) processes these diverse datasets to identify and prioritize the most suitable locations for reforestation and habitat restoration.
- 2) **Multi-objective optimization:** Researchers are developing AI-powered tools (like the **CAPTAIN - conservation area prioritization through Artificial Intelligence** software) that can optimize restoration plans based on multiple objectives simultaneously. This means they can identify areas that will not only maximize carbon sequestration (e.g., by planting fast-growing, carbon-dense species) but also enhance biodiversity (by selecting native species that support local wildlife, creating ecological corridors) and minimize restoration costs.
- 3) **Predicting outcomes:** AI models can predict how different restoration strategies (e.g., planting specific tree species mixes, natural regeneration, assisted natural regeneration) will perform over time under various climate change scenarios.

### Species selection and planting strategies:

- a) Based on habitat suitability models, AI can recommend the most appropriate native tree species to plant in specific microclimates and soil conditions, maximizing their survival rates and ecological benefits.
- b) It can also help design planting patterns that promote biodiversity, create wildlife corridors, and enhance ecosystem resilience.

### Monitoring and adaptive management:

- 1) **Adaptive management:** The insights gained from AI-powered monitoring allow researchers and restoration practitioners to adapt their strategies in real-time, making adjustments to planting techniques, species selection, or management interventions to ensure the long-term success of the restoration project.
- 2) **Automated monitoring:** Post-restoration, drones and satellites continue to capture imagery. AI continuously analyzes this data to:
  - a) **Assess disturbances:** Detect new disturbances like illegal logging, fires, or pest outbreaks, allowing for rapid intervention.
  - b) **Detect invasive species:** Identify early signs of invasive species that could threaten the restored ecosystem.
  - c) **Evaluate biodiversity return:** In some cases, AI can even monitor the return of animal species to restored areas by analyzing camera trap data.

**d) Track reforestation progress:** Monitor tree growth, canopy cover, and overall vegetation health.

#### Evidence/Impact:

- a. Cost-effectiveness:** Optimizing resource allocation and reducing failures can lead to more cost-effective restoration projects.
- b. Enhanced ecosystem services:** Projects informed by AI are better able to achieve multiple ecosystem service benefits, such as:
  - i. Biodiversity conservation:** Creating or restoring habitats for a wider range of species.
  - ii. Carbon sequestration:** Maximizing the absorption of atmospheric carbon dioxide.
  - iii. Soil stability:** Reducing erosion and improving soil fertility.
  - iv. Water regulation:** Improving water quality and quantity through healthy forest ecosystems.
- c. Improved success rates:** By identifying optimal sites and strategies, AI helps improve the survival rates of planted trees and the overall ecological health of restored areas.
- d. Increased efficiency and scalability:** AI significantly reduces the manual effort and time required for large-scale ecological assessments and monitoring, allowing for restoration efforts to be implemented across much larger areas.
- e. Targeted interventions:** AI helps identify “hotspots” where intervention is most critical and will yield the greatest benefits.

In core, AI acts as a “smart assistant” for habitat restoration, enabling more informed decisions, efficient operations, and ultimately, more successful and impactful ecological recovery efforts.

#### Reforestation and land restoration

AI can determine the best sites for reforestation and restoration initiatives by analyzing soil composition, climate data, and historical land usage. It can also forecast the success rates of various restoration strategies and help choose suitable native species. AI-enabled drones can even plant seeds on their own and track the growth of saplings across wide regions. The application of AI in ecological restoration is transforming efforts to regenerate damaged ecosystems, moving beyond traditional, less efficient methods.<sup>45,46</sup> By integrating these sophisticated capabilities, AI transforms habitat restoration from a labor-intensive and often uncertain endeavor into a precise, scalable, and highly effective conservation strategy.<sup>45</sup>

#### Ecosystem service valuation

Through the analysis of enormous databases on environmental conditions and human activity, artificial intelligence (AI) can assist in quantifying the ecological and economic value of ecosystem services (such as carbon sequestration, pollination, and water purification). This strengthens the economic case for conservation and helps guide policy choices. The economic valuation of ecosystem services (ES) is crucial for integrating natural capital into policy and decision-making, ensuring that the benefits provided by nature are recognized and accounted. AI is transforming this field by enabling more accurate, rapid, and comprehensive assessments of these complex values. In essence, AI translates complex ecological functions into quantifiable economic terms, making the value of nature more tangible and thus better integrated into economic and policy frameworks.

#### Citizen science and public engagement

AI is significantly encouraging increased public participation in conservation and democratizing the collection of biodiversity data. This is primarily achieved through citizen science initiatives, where AI acts as a powerful enabler and facilitator. While challenges remain, such as ensuring data privacy and mitigating risks of misuse, AI's role in citizen science is fundamentally changing how biodiversity data is collected and how the public engages with conservation, fostering a more collaborative and informed approach to protecting our natural world.<sup>47</sup>

#### AI-powered mobile applications

AI-driven image and sound identification is a cornerstone of popular citizen science applications like iNaturalist and eBird,<sup>48,49</sup> making biodiversity data collection highly accessible and significantly broadening its scope beyond expert researchers.<sup>50,24</sup> In essence, AI-driven identification tools are fostering a global network of biodiversity observers, providing critical data that informs research, conservation planning, and our understanding of the natural world.

#### Gamification and education

AI may be used to create engaging teaching resources and games that motivate people to take action by increasing awareness of biodiversity and conservation issues. This application of AI is vital for fostering environmental literacy and inspiring a new generation of conservationists. By making learning about conservation more interactive, personalized, and accessible, AI tools can effectively increase public awareness, cultivate a sense of responsibility, and ultimately motivate individuals and communities to take meaningful action for biodiversity protection.<sup>34,35</sup>

#### Success stories: AI in action

The concrete advantages of AI in conservation are being demonstrated by a number of projects throughout the globe, showcasing its transformative impact across various facets of biodiversity protection. These initiatives highlight AI's capacity to enhance monitoring, combat illegal activities, and inform critical conservation decisions.<sup>51,52,53</sup>

#### Project SMART (Spatial Monitoring and Reporting Tool)

The Spatial Monitoring and Reporting Tool (SMART) is a powerful and widely adopted conservation software platform that integrates technology and data to enhance the effectiveness of protected area management, particularly in combating poaching. While it is not solely an AI-driven system, SMART has increasingly incorporated AI and machine learning to optimize its capabilities. SMART's core functionality involves collecting, storing, and analyzing patrol data, wildlife sightings, and illegal activities. In regions where SMART, augmented by AI, has been successfully implemented, there has been a notable and often significant decrease in poaching incidents. This is a direct result of conservation managers being able to make data-driven decisions that lead to more effective deployment of resources. By analyzing patterns in poaching activities and patrol efficacy, the combination of SMART's robust data management framework with AI and machine learning capabilities provides conservation managers with critical insights, transforming reactive responses into proactive interventions, and demonstrating concrete success in the fight against wildlife crime globally.<sup>54</sup>

## Wildbook

This description perfectly aligns with the capabilities of Wildbook, an open-source software platform that leverages AI and computer vision for individual animal identification.<sup>55</sup> Wildbook is a collaborative, web-based platform that blends structured wildlife research with artificial intelligence, citizen science, and computer vision to speed up population analysis and gain new insights for fighting extinction. Other notable open-source AI tools for camera trap image analysis, while often focused on species detection and classification rather than individual identification across a broad range of species.<sup>56</sup> Wildbook exemplifies how open-source AI software can empower researchers and citizen scientists to collect and analyze individual animal data at an unprecedented scale, providing crucial information for understanding and conserving wildlife populations.<sup>57</sup>

## Global Forest Watch (GFW)

Global Forest Watch (GFW), a dynamic online platform, significantly leverages satellite photography and artificial intelligence to provide near-real-time alerts concerning deforestation incidents worldwide. This crucial technology empowers governments, non-governmental organizations (NGOs), and local communities to react swiftly to illegal logging and forest fires, thereby safeguarding vital forest ecosystems. The impact of GFW's AI-driven alerts is evident in various regions. For instance, studies have shown an 18% decrease in the probability of deforestation in areas across Africa where users subscribe to GFW's near-real-time alerts.<sup>58</sup> This demonstrates the platform's effectiveness in turning satellite data into actionable insights for global forest protection.

## Conservation X Labs' sentinel system

The AI-powered acoustic monitoring system described is most notably embodied by Rainforest Connection (RFCx), through their Guardian System and associated Arbimon platform.<sup>59</sup> This technology is a prime example of how AI can provide crucial, real-time alerts in remote and isolated conservation areas. Projects utilizing Rainforest Connection's technology have demonstrated success in various regions, including the Amazon, parts of Africa, and Southeast Asia, effectively aiding local partners and indigenous communities in protecting their forests and wildlife from illegal exploitation.

## The AI for good summit

Numerous cutting-edge AI solutions are frequently showcased for environmental problems, encompassing a large number of biodiversity-focused projects.<sup>60-63</sup> Case studies frequently highlight applications of AI in marine conservation (e.g., recognizing whale species from acoustic data to prevent ship strikes), coral reef monitoring (evaluating coral health by analyzing underwater imagery), and precision agriculture to lessen habitat encroachment.<sup>64-67</sup> These global case studies underscore AI's pivotal role in addressing some of the most pressing environmental challenges, demonstrating its capacity to bring precision, efficiency, and scalability to conservation efforts.<sup>68,69</sup>

## Challenges and ethical considerations

Notwithstanding its enormous potential, there are a number of obstacles to the broad use of AI in conservation, as well as significant ethical issues. These challenges need to be carefully addressed to ensure that AI's deployment genuinely benefits biodiversity and local communities. Addressing these challenges requires a concerted effort involving interdisciplinary collaboration, robust ethical guidelines, sustainable funding models, and a commitment to ensuring that

AI serves as a truly beneficial tool for conservation, rather than inadvertently creating new problems.<sup>70</sup>

## Data scarcity and quality

Large, diversified, and high-quality datasets are necessary for training AI models. Such data can be limited, inconsistent, or biased in many conservation scenarios, especially for elusive or rare species. The practical challenges of data curation and annotation are also substantial. This point highlights a fundamental practical obstacle to the widespread and effective adoption of AI in conservation. The performance of any AI model is directly tied to the quality and quantity of the data it's trained on ("garbage in, garbage out"). Addressing these data challenges is crucial for unlocking AI's full potential in conservation. Strategies include promoting data sharing and standardization, investing in open-source data platforms, developing semi-automated annotation tools, and fostering collaboration between AI experts and conservation scientists to ensure data quality and relevance.<sup>71</sup>

## Technological infrastructure and expertise

Strong technical infrastructure, including dependable internet access and power, is necessary for the deployment and upkeep of AI systems, particularly in distant places. To properly create, apply, and understand these technologies, qualified staff with knowledge of both ecological and artificial intelligence is also required. These are significant practical hurdles to the widespread adoption of AI in conservation. The effective implementation and long-term sustainability of AI in conservation depend heavily on human capital with a unique blend of skills. Without adequate infrastructure and skilled personnel, even the most promising AI solutions risk remaining proof-of-concept projects rather than scalable, impactful conservation tools.<sup>72</sup>

## "Black Box" problem and interpretability

The complexity of certain sophisticated AI models, particularly deep learning networks, presents a significant challenge known as the "black box" problem. This difficulty in understanding the internal reasoning behind an AI's specific classification or prediction is a major obstacle to building confidence and guaranteeing accountability in conservation decisions. The field of Explainable AI (XAI) is actively working to address this challenge by developing methods and techniques that make AI models more transparent and interpretable. XAI aims to provide insights into how models make decisions, allowing conservationists to understand the reasoning behind a prediction or classification. By increasing the interpretability of AI, conservationists can gain greater confidence in the technology, ensure accountability, and ultimately make more informed and effective decisions for biodiversity protection.

## Cost and accessibility

Even though AI has the potential to save money in the long run, underfunded conservation organizations may not be able to afford the upfront hardware, software, and training costs. For many underfunded conservation organizations, securing the initial capital to overcome these barriers is a major challenge, even if the long-term benefits in terms of efficiency, reduced poaching, or more effective monitoring could eventually lead to cost savings or greater impact. This underscores the need for funding initiatives, partnerships with technology companies, and the development of more affordable and accessible AI solutions tailored for conservation contexts.<sup>72</sup>

## Bias and equity

AI algorithms can reinforce or even magnify preexisting prejudices if they are trained on biased data, producing unfair or ineffectual conservation results.<sup>62,73,74</sup> In order to benefit all parties involved, including local communities, it is imperative that AI solutions be created and implemented.<sup>75–77</sup> By prioritizing fairness, inclusivity, and transparency, AI can become a powerful and just tool for global biodiversity conservation.<sup>78</sup>

## Privacy and surveillance

Privacy issues are raised by the use of AI-powered surveillance technology, including drones and facial recognition for wildlife, especially if these tools could unintentionally be used to monitor human populations or violate local rights. By proactively addressing these privacy concerns, AI can be integrated into conservation efforts in a way that respects human rights and fosters trust with local communities, ensuring that technology serves as an enabler for equitable and effective conservation.<sup>79</sup>

## Misuse and security risks

AI has the potential to be abused for negative ends, including supporting poachers or enabling the illegal wildlife trade, just like any other potent technology.<sup>33</sup> Strong security protocols and moral standards are crucial.<sup>77</sup> By proactively addressing these security and ethical challenges, the conservation community can maximize AI's potential as a powerful ally against wildlife crime and environmental degradation, while minimizing the risks of its malicious exploitation.<sup>78</sup>

## The “Technological Fix” mentality

AI is a useful tool, but it's not a panacea. It can be harmful to rely too much on technology without addressing the underlying factors that contribute to biodiversity loss, such as habitat degradation, unsustainable consumption, and policy failures.<sup>74</sup> AI should support basic conservation initiatives and community involvement, not take their place. AI excels at identifying patterns, making predictions, and automating tasks related to the symptoms of biodiversity loss (e.g., detecting deforestation, identifying poaching activity). AI alone cannot solve these systemic issues. Without addressing the underlying drivers, AI might only provide temporary fixes or shift problems to other areas.<sup>80</sup> AI is a powerful amplifier for conservation efforts, capable of providing unprecedented insights and efficiencies. However, its true value is realized when it is integrated thoughtfully into a broader strategy that prioritizes addressing the root causes of biodiversity loss, builds on human expertise, and meaningfully engages local communities.<sup>70</sup>

## Interdisciplinary collaboration

Strong cooperation between AI researchers, ecologists, conservation practitioners, policymakers, and local communities is necessary for the effective application of AI in conservation.<sup>74</sup> Developing pertinent and significant answers requires bridging these disciplinary gaps.<sup>77</sup> In essence, AI in conservation thrives not in isolation, but within a collaborative ecosystem where diverse knowledge sets and perspectives converge to tackle complex environmental challenges.<sup>78</sup>

## The future of AI in conservation

Although AI's application to biodiversity and conservation is still in its infancy, it has enormous potential. Future developments indicate that AI solutions will become more complex and networked.<sup>81</sup> While the obstacles and ethical considerations remain significant,

the rapid advancements in AI capabilities, coupled with increasing interdisciplinary collaboration, suggest a future where AI becomes an indispensable, highly integrated, and increasingly intelligent partner in the global fight to conserve biodiversity.<sup>82</sup>

## Hyper-realistic digital twins

The development of “digital twins” of ecosystems, which are virtual representations that mimic intricate environmental interactions, has the potential to completely change conservation planning. Without endangering actual ecosystems, these AI-powered models may evaluate various conservation scenarios, forecast results, and optimize actions. This concept represents a significant leap forward in strategic conservation.<sup>83</sup> The development of ecosystem digital twins represents a paradigm shift from reactive conservation to proactive, predictive, and optimized management. By allowing “what-if” scenarios to be explored in a risk-free virtual environment, AI-powered digital twins hold immense promise for accelerating conservation progress and making more impactful decisions.<sup>84</sup>

## Autonomous robotic systems

Artificial intelligence (AI) and robotics advancements may result in the deployment of autonomous robots for jobs like invasive species removal, habitat restoration (e.g., precision planting), or even monitoring in extremely difficult conditions (e.g., deep-sea research, isolated terrestrial locations).<sup>85–87</sup> While the ethical considerations (e.g., job displacement, potential for ecological damage, algorithmic bias) and upfront costs are real challenges, the advancements in AI and robotics are poised to make these tools indispensable for tackling some of the most intractable conservation problems.<sup>88–90</sup>

## Genomic AI and conservation genetics

In order to comprehend genetic variety, identify populations at risk, and direct breeding programs for endangered species—including the possibility of de-extinction efforts—AI will become even more important in the analysis of complicated genomic data.<sup>91</sup> The integration of AI into conservation genomics is still evolving, but its capacity to handle enormous, complex datasets and identify subtle patterns makes it an indispensable tool for understanding the genetic underpinnings of biodiversity and guiding future conservation strategies.<sup>92,93</sup>

## Personalized conservation and gamified engagement

By creating a stronger bond with nature and providing citizen scientists with specialized resources and challenges, AI has the potential to personalize conservation messages and actions for each individual. Gamified experiences have the potential to encourage pro-conservation actions and data collecting.<sup>24</sup> By combining personalization and gamification, AI has the potential to transform passive environmental awareness into active participation, creating a more engaged, and empowered community of conservation advocates and citizen scientists.<sup>94</sup>

## Global AI-powered data platforms

AI-powered global data platforms that are more connected and interoperable will make it possible to share and analyze biodiversity data in real time across continents, enabling quick responses to new threats and international conservation efforts.<sup>76,45</sup> While significant challenges remain, including ensuring data governance, addressing ethical concerns around surveillance, overcoming energy consumption challenges, and fostering trust among diverse stakeholders,<sup>95,96</sup> the move towards AI-powered, interconnected global data platforms is

a vital step in scaling up conservation efforts to meet the immense challenge of the biodiversity crisis.

### Explainable AI (XAI)

By making AI models more accessible and intelligible to conservationists, explainable AI research can help solve the “black box” issue, build trust, and facilitate improved decision-making. In essence, XAI is not just about making AI comprehensible; it’s about making AI more responsible, reliable, and ultimately, more effective as a partner in the urgent work of biodiversity conservation.<sup>77</sup>

### AI for policy and governance

AI is capable of analyzing enormous volumes of scientific literature, policy documents, and economic data to help create international accords and conservation strategies that are more successful and supported by statistics. By analyzing vast and diverse datasets, AI can indeed help create international accords and conservation strategies that are more successful and statistically supported.<sup>76</sup> This capacity is crucial for informed, evidence-based decision-making at national and global levels. The integration of AI into policy and economic analysis for conservation represents a powerful shift towards more informed, efficient, and impactful global environmental governance.<sup>97–99</sup>

### Conclusion

An increasingly potent ally in the pressing struggle to preserve the biodiversity of our world is artificial intelligence. AI is giving us previously unthinkable skills that were unthinkable only a few decades ago, such as improving our capacity to monitor species and habitats, fight wildlife crime, plan conservation initiatives, and repair ecosystems. AI is giving conservation a new degree of accuracy, effectiveness, and scalability in everything from the silent monitoring of camera traps in the rainforest to the painstaking examination of satellite data in the cloud. But in order to fully realize AI’s transformational potential, its difficulties and moral ramifications must be carefully examined. Responsible use of AI requires addressing concerns of bias and accessibility, ensuring data quality, developing a strong infrastructure, and encouraging interdisciplinary collaboration. While AI is a sophisticated technology that, when used responsibly and ethically, may greatly enhance human efforts, it is not a solution to the biodiversity catastrophe. We can get closer to a future in which humans and the natural world cohabit sustainably while preserving the complex web of life that supports us all by wisely and cooperatively integrating AI. A significant new chapter in the continuous history of conservation is provided by the algorithm of life, magnified by artificial intelligence.

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