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Article

Enhancing Conservation Strategies with GIS: Advances, Collaborations, and Future Directions

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Highlights

- The application of Geographical Information Systems (GIS) for conservation, also known as Conservation GIS, has revolutionized conservation efforts by providing spatially explicit data to inform conservation decision-making.
- Conservation GIS has been used in a variety of applications, including biodiversity conservation and monitoring, habitat mapping and restoration, climate change mitigation and adaptation, wildlife tracking and management, and protected area management.
- The success of Conservation GIS in conservation efforts depends on data quality and availability, technical limitations, and policy and governance issues.
- Advancements in technology and data collection, integration with other fields such as machine learning and artificial intelligence, and collaborative approaches to Conservation GIS are important directions for the future of Conservation GIS.
- Conservation GIS provides a powerful tool to address the challenges of biodiversity loss, habitat degradation, and climate change, and it is essential to invest in its research and implementation to ensure its continued success in the future.

Tweetable Summary: Conservation GIS is revolutionizing conservation efforts by providing spatial data for informed decision-making. Advances in technology, collaboration, and integration with other fields such as machine learning and AI, can enhance its impact on biodiversity conservation and ecosystem management. #ConservationGIS #Biodiversity

Abstract: The use of Geographical Information Systems (GIS) for biodiversity monitoring and conservation, shortened to Conservation GIS, is an influential tool that has revolutionized conservation efforts by providing spatially explicit data to inform conservation decision-making. However, Conservation GIS also faces challenges related to data quality and availability, technical limitations, as well as policy and governance issues. The diverse and rising uses of GIS for conservation has resulted in a need for continued research and development of Conservation GIS, including advancements in technology and data collection, integration with other fields such as machine learning and artificial intelligence, and collaborative approaches to Conservation GIS. Conservation GIS has the potential to make a significant impact on conservation efforts, and this article emphasizes the importance of its implementation to achieve the broader goal of biodiversity conservation for planetary health. In this review, we discuss the various applications of Conservation GIS, including biodiversity conservation and monitoring, habitat mapping and restoration, climate change mitigation and adaptation, wildlife tracking and management, and protected area management. We highlight some of the key knowledge gaps or research questions that need to be addressed in the future to further advance the field of Conservation GIS. By addressing these challenges and knowledge gaps, Conservation GIS can become a powerful tool for addressing the challenges facing biodiversity and ecosystems worldwide, and for promoting sustainable land-use practices.

Keywords: Conservation GIS; spatial data; biodiversity conservation; habitat mapping; protected area management; machine learning; artificial intelligence; remote sensing; data collection; collaborative approaches

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Introduction

Conservation efforts have become increasingly important in recent years due to the ongoing threats to biodiversity and ecosystems. Human activities have resulted in habitat destruction, climate change, and pollution leading to declines in many species and the disruption of vital ecological processes (Dirzo et al. 2014; Díaz et al. 2019; IPBES 2019; Ripple et al. 2020). As a result, there is a growing need for conservation interventions to prevent further losses and promote the recovery of endangered species and ecosystems (Chapin et al. 2000, Pimm et al. 2014, IPBES 2019).

Conservation GIS, the integration of Geographic Information Systems (GIS) and conservation biology, is a rapidly growing interdisciplinary field that has revolutionized conservation efforts worldwide. GIS technology provides an effective tool for conservation planning and management because it helps utilize spatially explicit data on ecological patterns and processes for analyses (Possingham et al. 2000, Elith & Leathwick 2009). Therefore, it enables conservation practitioners to identify important habitats, prioritize areas for protection, and evaluate the effectiveness of conservation actions (Beger et al. 2010). By combining spatial data on species distributions, threats, and management actions, Conservation GIS can help optimize conservation efforts and ensure that they are targeted, efficient, and cost-effective (Pressey et al. 2007, Ferraro & Pressey 2015, Fink et al. 2018).

As such, the use of Conservation GIS has become increasingly widespread in the conservation community and has been applied to a wide range of taxa and ecosystems worldwide (Joppa & Pfaff 2010, Runge et al. 2014, Watson et al. 2014). One of the earliest examples of GIS being applied to conservation was the identification of critical habitat for the critically endangered California condor (Wilcove et al. 1986). GIS-based monitoring of African elephant populations has helped identify key areas for elephant conservation and management (Vanthomme et al. 2013). GIS-based habitat modeling has also been used to predict habitat suitability for the endangered snow leopard in China (Li et al. 2016). Additionally, GIS has been used to monitor the impact of land-use change on biodiversity, such as the impact of agriculture on bird populations in Costa Rica (Montero et al. 2021).

Despite its many successes, there are still many challenges facing the field of Conservation GIS. One major challenge is the integration of multiple data sources, including ecological, social, and economic data, to develop comprehensive conservation plans (Egoh et al. 2007, Metzger et al. 2005). Another challenge is the need to develop and use robust spatial models that can accurately predict species distributions and habitat suitability in dynamic landscapes (Guisan and Zimmermann 2000, Carroll et al. 2010).

In this article, we will review the current state of Conservation GIS, its applications in conservation biology, the challenges facing the field, as well as future directions. We will also explore the potential of emerging technologies, such as remote sensing, machine learning, and citizen science, to enhance the capabilities of Conservation GIS. Through this review, we hope to provide insights into the use of Conservation GIS as an effective tool for conservation planning and management in the face of global environmental change.

Overview of Conservation GIS

Conservation GIS, also known as Conservation Geographic Information Systems, refers to the use of GIS technology in conservation planning, management, and analysis of biodiversity and ecosystems. It involves the integration of spatial data and analytical tools to support decision-making processes and identify areas of high conservation value, prioritize conservation efforts, and monitor biodiversity changes over time. Conservation GIS can be used for a variety of purposes, including species distribution modeling, habitat suitability analysis, landscape connectivity analysis, and

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conservation zoning. It has been applied successfully in a range of conservation contexts, such as protected area management, wildlife conservation, and ecosystem restoration (Margules & Pressey, 2000; Rodrigues et al., 2004). Conservation GIS has become increasingly important in the face of global environmental challenges, such as habitat loss, fragmentation, and climate change, as it provides a powerful tool for guiding conservation efforts and promoting sustainable management of natural resources (Runting et al., 2019; Fa et al., 2020).

Conservation GIS has a relatively short but rapidly evolving history. The origins of GIS can be traced back to the 1960s and 1970s when researchers began to explore the potential of computer-based mapping and spatial analysis techniques. However, it wasn't until the late 1980s that GIS technology started to be widely used for conservation purposes (Gardner et al., 2003). At that time, researchers began to recognize the value of GIS in helping to identify areas of high conservation priority, assessing the impacts of land use change, and developing management plans for protected areas (Margules and Pressey, 2000; Beier et al., 2011).

In the 1990s, the use of GIS in conservation continued to expand, with a growing number of studies focused on mapping and modeling biodiversity and ecological processes (Turner et al., 1995; Daily et al., 2000; Pimm et al., 1998). The Society for Conservation GIS (SCGIS) was created in the USA in 1997. During this time, Conservation GIS also began to incorporate remote sensing data, such as satellite imagery, which allowed for the analysis of landscape-level patterns and changes in land use over time (Foody, 1996; Pontius et al., 2004).

In the 2000s, the field of Conservation GIS continued to advance with the development of new tools and approaches. This included the use of species distribution models to predict the potential distribution of species under different scenarios of climate change and habitat loss (Elith et al., 2006; Araújo and Peterson, 2012). More recently, there has been a growing focus on the use of participatory GIS to involve local communities in conservation planning and decision-making (McCall and Dunn, 2012; King et al., 2020). Overall, the history of Conservation GIS reflects the ongoing development and application of spatial analysis techniques to help address the complex challenges of biodiversity conservation and natural resource management.

Conservation GIS has been used in numerous conservation efforts around the world. One example is the use of GIS in monitoring wildlife populations and their habitats. In the Serengeti National Park, GIS was used to monitor the movements of wildebeests and their habitats, which helped in designing effective conservation strategies (Sinclair et al., 2002). Another example is the use of GIS in identifying critical habitats and migratory corridors for endangered species. For instance, in the case of the Siberian tiger, GIS was used to identify and map their habitats, which helped in designing effective conservation strategies (Carter et al., 2020). In addition, GIS has been used in the identification and mapping of areas that are important for biodiversity conservation which helped in prioritization and in guiding the allocation of resources for conservation. Overall, GIS has proven to be an important tool in conservation efforts, aiding in the development of effective conservation strategies and the allocation of resources.

Techniques and Tools in Conservation GIS

Mapping and spatial analysis techniques are essential tools for Conservation GIS, providing valuable insights into the distribution and abundance of species and habitats, and informing conservation planning and management decisions. Spatial data collection and analysis tools have played a crucial role in the success of Conservation GIS. With the advent of technologies like GPS units and mobile devices, it is now possible to collect spatial data in the field with high accuracy and precision. These tools have become essential in tracking wildlife movements, identifying habitats, and mapping land use and land cover changes. In addition, they have made it easier to monitor and manage conservation efforts in real-time, making decision-making more effective and efficient.

One commonly used technique is habitat modeling, which involves the creation of predictive models based on species occurrence data and environmental variables, such as climate, topography, and land use/cover. Habitat modeling has been used in numerous conservation applications, including the identification of critical habitat for endangered species, the development of conservation plans, and the evaluation of the effectiveness of conservation actions (Bakker et al., 2002; Elith et al., 2006). Another important technique is connectivity analysis, which involves the mapping and analysis of corridors and barriers between habitats, allowing conservation practitioners to identify and prioritize areas for habitat restoration, establishment, or protection. Connectivity analysis has been used in a variety of conservation contexts, such as landscape-scale conservation planning, species reintroduction, and management of invasive species (Beier et al., 2011; Ricketts et al., 2001; Sarkar et al., 2005). Spatial analysis techniques, such as hotspot analysis, clustering, and network analysis, can also provide important insights into patterns of biodiversity and threats to biodiversity. For example, hotspot analysis has been used to identify areas of high species richness, while network analysis has been used to evaluate the connectivity of protected areas (Joppa et al., 2008; Myers et al., 2000). Spatial statistics have been employed for analyzing patterns of species distribution, habitat connectivity, and landscape metrics (Legendre & Legendre, 2012; McGarigal et al., 2012; Fortin et al., 2002). Overall, mapping and spatial analysis techniques are critical components of Conservation GIS, enabling conservation practitioners to make informed decisions based on spatially-explicit data and models.

Remote sensing technologies have been playing a crucial role in the development and implementation of Conservation GIS. These technologies allow for the capture of high-quality data on the Earth's surface and provide valuable insights into the distribution and extent of various habitats, ecosystems, and species. Remote sensing techniques such as satellite and aerial imagery, LiDAR, and RADAR have been used extensively in conservation efforts to monitor deforestation, land use changes, wildlife populations, and other ecological phenomena. Satellite imagery has been used to monitor and map vegetation cover and land use changes over large areas, providing crucial information for conservation planning and management (Lillesand et al., 2015; Suzzi-Simmons 2023). LiDAR technology has been used to map the structure and height of forests and other vegetation, providing detailed information on habitat structure and potential wildlife corridors (Asner et al., 2012). RADAR has been used to detect changes in forest structure and biomass, providing information on forest degradation and fragmentation (Saatchi et al., 2001). Remote sensing technologies have also been used in combination with other data sources such as GPS and field surveys to develop predictive models of species distribution and habitat suitability (Petersen et al., 2018). These models have been used to identify areas of high conservation value and prioritize conservation efforts. In addition, remote sensing technologies have been used in disaster management and response, providing timely and accurate information on the extent of damage and the location of affected areas (Kemper & Kemper, 2020). Overall, remote sensing technologies have proven to be valuable tools in Conservation GIS, providing critical information on ecological processes and supporting the development of effective conservation strategies.

With the increasing use of these tools in conservation efforts, there has been a growing need for more advanced spatial analysis techniques to help extract meaningful information from the data collected. For example, statistical analysis tools like R and Python have been used to develop models that can help predict species distribution patterns, evaluate the effectiveness of conservation policies, and identify areas of high conservation value. The integration of these spatial data collection and analysis tools within Conservation GIS has greatly enhanced the field of conservation biology and paved the way for more effective conservation strategies.

Applications of Conservation GIS

Conservation GIS has been used extensively in biodiversity conservation and monitoring efforts, such as in the identification of priority conservation areas and the monitoring of threatened species populations. For example, in the Galapagos Islands, Conservation GIS was used to identify critical habitat areas for the Galapagos penguin, which was essential for designing effective conservation strategies for this endangered species (Lammers et al., 2015). By using GIS data on ocean currents, sea surface temperature, and habitat preferences of the Galapagos penguin, the study was able to identify important foraging and breeding areas. This information was used to prioritize conservation efforts and implement management strategies to protect these critical habitats. Overall, the study

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demonstrated the valuable role of Conservation GIS in identifying and managing important habitat areas for endangered species conservation.

Similarly, in the Cape Floristic Region of South Africa, Conservation GIS was used to identify priority areas for conservation efforts based on biodiversity values (Rebelo et al., 2010). The study used a comprehensive set of biodiversity data and analytical tools to identify areas with high biodiversity value and high threat levels. The study found that many of the highest priority areas for conservation were located outside of the existing protected area network, highlighting the importance of using GIS in identifying areas that require protection. The outcomes of this study have important implications for conservation planning and management in the region.

Conservation GIS is also valuable in habitat mapping and restoration efforts. For instance, Petus et al. (2014) used a combination of remote sensing and ground-truthing to map seagrass habitats in the Great Barrier Reef, an important ecosystem that supports a diverse range of marine life. The authors found that seagrass habitats were widely distributed throughout the reef and that they were particularly important for supporting populations of dugongs and green sea turtles. The study also highlighted the importance of ongoing monitoring and management of seagrass habitats to ensure their long-term conservation and restoration. The use of Conservation GIS in this study allowed for a detailed understanding of the spatial distribution and importance of seagrass habitats, which can inform restoration efforts and management decisions for the Great Barrier Reef ecosystem.

In another study, Ripple et al. (1997) found that forest fragmentation had a significant impact on habitat connectivity for the Northern spotted owl in the Pacific Northwest. Using Conservation GIS, they were able to identify areas where forest fragmentation was most severe and assess the degree of connectivity between owl habitat patches. The study also provided recommendations for future conservation efforts to enhance connectivity and preserve critical habitat for the endangered species. The findings of this study highlight the important role of Conservation GIS in assessing the impacts of human activities on wildlife habitat and informing conservation strategies.

Conservation GIS plays a crucial role in climate change mitigation and adaptation efforts as well. For example, Asner et al. (2009) aimed to map carbon stocks across the Brazilian Amazon and identify the drivers of carbon density patterns. The authors used a combination of field measurements, remote sensing data, and GIS to model carbon stocks in different forest types. The results showed that carbon stocks varied widely across different forest types, with areas of high carbon density concentrated in the western Amazon. The study also identified the main drivers of carbon density patterns, which included topography, climate, and forest structure. The findings of this study were used to inform forest management strategies for carbon sequestration, highlighting the importance of Conservation GIS in climate change mitigation efforts.

An excellent example of the application of remote sensing and GIS in conservation efforts is the Carnegie Airborne Observatory project which uses lidar technology to detect illegal gold mining in the Peruvian Amazon. In this study, the research team used lidar data to create detailed 3D maps of the forest canopy and identified areas of forest disturbance that were indicative of illegal gold mining. They found that gold mining caused extensive damage to the forest canopy and increased mercury contamination in the surrounding waterways. The study highlights the potential of lidar technology as a powerful tool in conservation efforts, allowing researchers to detect illegal activities that would be difficult to identify through traditional ground-based methods.

In Karki et al.'s (2019) study, Conservation GIS was used to assess the vulnerability of different ecosystems in the Himalayas to climate change. The authors used a range of climate models and ecological data to identify ecosystems that are most at risk of climate change impacts, including changes in temperature and precipitation. They also identified potential adaptation strategies, such as promoting community-based conservation and improving water management practices. The study highlights the important role that Conservation GIS can play in identifying and addressing the impacts of climate change on vulnerable ecosystems.

Conservation GIS is an important tool for wildlife tracking and management. For instance, the study conducted by Fryxell et al. (2010) aimed to use GPS and GIS technology to monitor and understand the movements and habitat preferences of wildebeest and zebras in the Serengeti ecosystem. The researchers found that the movements of these two species were influenced by both local vegetation and regional climate patterns, with wildebeest and zebras relying on different vegetation types at different times of the year. This information helped inform the development of wildlife management plans that aimed to maintain the ecological balance of the ecosystem and ensure the continued survival of these iconic species. In the United States, Mattson et al. (2013) used Conservation GIS to track the movements of grizzly bears in the Greater Yellowstone Ecosystem to understand their habitat use patterns and inform their management and conservation. The study found that grizzly bears tended to avoid human-dominated landscapes and preferred areas with high plant productivity and low levels of human disturbance. The results of the study were used to develop management strategies that sought to minimize human-bear conflicts and protect important grizzly bear habitats.

Several recent studies illustrate the latest advancements in the field which can inform conservation efforts. One recent study used Conservation GIS to map and analyze the distribution of critical habitat for the endangered Florida panther *(Puma concolor coryi)* (Frakes et al., 2021). The study identified several areas that were critical for the survival of the panther and recommended measures to conserve those areas. Another study used Conservation GIS to identify the habitat preferences of a threatened species of freshwater turtle, the *Emys orbicularis* (Nekrasova et al., 2021). The study found that the turtles preferred habitats with specific characteristics, such as slow-moving water and dense vegetation cover. A third study used Conservation GIS to map the spatial patterns of biodiversity in the Atlantic Forest biome in Brazil (Colli-Silva et al., 2020). The study found that the highest concentrations of species richness were in areas with high levels of forest cover and low levels of human disturbance. Another recent study used Conservation GIS to develop a framework for identifying key marine biodiversity areas in the Mediterranean Sea (Fanelli et al., 2021). The study used a combination of ecological and social criteria to identify areas that were both ecologically important and socially feasible to protect.

Finally, Conservation GIS is widely used in protected area management efforts. For example, The study by Driver et al. (2005) aimed to create a comprehensive spatial database of Kruger National Park's biodiversity, including information on species distribution, habitat types, and ecosystem processes. The researchers used Conservation GIS to collect and integrate spatial data from various sources, such as satellite imagery and field surveys, to create a detailed map of the park's biodiversity. This information was used to identify priority areas for conservation and management actions, such as the protection of key habitats and the control of invasive species. The study demonstrated the importance of Conservation GIS in providing a comprehensive understanding of biodiversity patterns and supporting evidence-based conservation and management decisions. Hansen et al. (2015) used Conservation GIS to analyze the effectiveness of protected areas in conserving biodiversity in the United States. They found that protected areas were generally successful in preserving biodiversity, but also highlighted the importance of considering factors such as habitat connectivity and climate change when designing protected area networks. The study also emphasized the need for ongoing monitoring and adaptive management to ensure the continued success of protected areas in conserving biodiversity. Overall, the study demonstrated the value of Conservation GIS in evaluating the effectiveness of conservation strategies and informing future management decisions.

In conclusion, these studies illustrate the power of Conservation GIS as a tool for informing conservation efforts. By combining spatial analysis techniques with conservation biology, Conservation GIS can provide valuable insights into the distribution of species and the factors that influence their survival. The studies discussed in this review highlight the importance of using Conservation GIS to identify critical habitats, prioritize conservation efforts, and develop strategies for adapting to future environmental changes. As such, Conservation GIS has the potential to be a key tool in the ongoing effort to conserve biodiversity and protect our natural world.

Challenges and Limitations of Conservation GIS

Conservation GIS has emerged as an indispensable tool for addressing conservation challenges, but it also faces several challenges and limitations. One of the primary challenges of Conservation GIS is the quality and availability of data. Despite the wealth of data available, data quality remains a significant issue, and there is often a lack of spatially explicit data for certain areas. This challenge is particularly acute for remote and under-studied areas, where data collection is more difficult and expensive.

In addition to data quality, technical limitations also present a significant challenge for Conservation GIS. The increasing complexity and size of datasets require advanced computing infrastructure, which may be a barrier for organizations with limited resources. Moreover, integrating data from different sources can be difficult, and the creation of standardized protocols for data management and analysis is needed (Breunig et al., 2020).

Policy and governance challenges also limit the effectiveness of Conservation GIS. Conservation actions often require cross-jurisdictional cooperation, and the lack of data sharing agreements and data privacy concerns can hinder collaboration. Moreover, there is a need for standardized policies and guidelines for data collection, analysis, and dissemination. In addition, the use of Conservation GIS can lead to unintended consequences, such as the potential for increased surveillance and infringement on human rights (McCarthy et al., 2012).

Furthermore, Conservation GIS can be limited by the lack of interdisciplinary approaches and integration with other fields such as ecology, social sciences, and economics (Coppolillo et al., 2000). Integration with machine learning and artificial intelligence also presents an opportunity to advance the capabilities of Conservation GIS (Kellenberger et al., 2018).

Addressing these challenges and limitations is crucial to ensure that Conservation GIS remains an effective and efficient tool for conservation management. This requires collaborative efforts between researchers, conservation practitioners, and policymakers to develop and implement standardized protocols for data management and analysis, as well as policies and guidelines for data sharing and privacy. The integration of interdisciplinary approaches and emerging technologies such as machine learning can also enhance the capabilities of Conservation GIS and increase its impact on conservation efforts. Ultimately, overcoming the challenges and limitations of Conservation GIS is essential to achieving conservation goals and preserving the planet's biodiversity for future generations.

Future Directions of Conservation GIS

The future of Conservation GIS holds immense potential for innovative approaches that can enhance conservation and management strategies. One key direction for the future of Conservation GIS is advancements in technology and data collection. This includes the development of new technologies for remote sensing, such as satellite-based sensors, drones, and LiDAR, which have the potential to provide more detailed and accurate data on species distribution, habitat suitability, and land-use changes. Additionally, there is a growing emphasis on citizen science and community-based monitoring, which can help increase the amount and quality of data available for Conservation GIS analysis (Chandler et al., 2017).

Another key direction for the future of Conservation GIS is integration with other fields, such as machine learning and artificial intelligence. The application of machine learning and artificial intelligence in Conservation GIS can improve predictive modeling, enhance the accuracy of species distribution models, and aid in the identification of potential conservation hotspots (Shivaprakash et al., 2022). These techniques can also be used to develop early warning systems for species at risk due to habitat loss or climate change, allowing for timely conservation interventions.

Finally, collaborative approaches to Conservation GIS are essential for achieving effective conservation outcomes. This includes the need for increased collaboration between conservation practitioners and GIS specialists, as well as the incorporation of local and Indigenous knowledge into GIS analysis. For example, The Wildlife Conservation Society (WCS) Spatial Planning Team developed a collaborative approach with local communities and governments to integrate local knowledge and prioritize conservation areas in the savannas of South America which resulted in the

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identification of critical areas for biodiversity conservation and improved the management of natural resources (Álvarez-Romero et al., 2017). The development of the Global Forest Watch (GFW) platform is an example of an interdisciplinary effort that integrates satellite imagery, crowdsourcing, and machine learning to monitor and report on deforestation around the world which has been successful in increasing transparency, promoting accountability, and supporting conservation efforts (Hansen et al., 2013). The use of participatory mapping in Madagascar, where local communities worked with researchers to map their own forest resources, provided a basis for community-based management plans and led to the establishment of community-managed protected areas which resulted in improved conservation outcomes and increased community involvement in natural resource management (Razafindratsima et al., 2016). These examples demonstrate the potential benefits of interdisciplinary and collaborative approaches in Conservation GIS. By incorporating different types of knowledge and expertise, conservation efforts can be more effective and lead to better outcomes for both biodiversity and local communities. Furthermore, Conservation GIS needs to be integrated with other sectors, such as agriculture and forestry, to address the drivers of biodiversity loss and promote sustainable land-use practices.

In conclusion, the future of Conservation GIS holds great promise for innovative approaches that can enhance conservation and management strategies. Advancements in technology and data collection, integration with other fields such as machine learning and artificial intelligence, and collaborative approaches are all important directions for the future of Conservation GIS. With continued research and development, Conservation GIS has the potential to become a powerful tool for addressing the challenges facing biodiversity and ecosystems worldwide.

Conclusion

In conclusion, Conservation GIS is a powerful tool that has revolutionized conservation efforts and has the potential to make a significant impact on conservation and management strategies. Through the integration of spatial data with conservation decision-making, Conservation GIS has helped to identify conservation priorities, develop management strategies, and monitor progress towards conservation goals (Beger et al., 2010; Hess et al., 2015; Devarajan 2021; VanDerWal et al., 2009).

The use of Conservation GIS has led to the identification of important biodiversity hotspots, such as the Amazon rainforest, and has aided in the development of effective management strategies to conserve these areas (Sloan et al., 2018; Ocampo-Peñuela et al., 2018). Additionally, Conservation GIS has been used to monitor and manage threatened and endangered species, such as elephants (Loarie et al., 2011) and whales (Mate et al., 2007), and to identify and prioritize habitat restoration efforts (Ward et al., 2016).

The broader implications of Conservation GIS for society are significant. Biodiversity conservation has been linked to numerous benefits for planetary well-being, including the provision of ecosystem services such as clean air and water, pollination, and carbon sequestration (IPBES, 2019). Furthermore, biodiversity conservation can contribute to poverty reduction, food security, and human health (Butchart et al., 2012). The use of Conservation GIS can aid in the development of effective conservation strategies that can help to maintain these benefits for current and future generations (Geldmann et al., 2019).

Despite the many successes of Conservation GIS, there are still knowledge gaps and research questions that need to be addressed in order to further advance the field. For example, there is a need for more comprehensive and standardized protocols for data management and analysis (LaRue et al., 2011). Additionally, there is a need for increased collaboration between conservation practitioners and GIS specialists, as well as the incorporation of local and indigenous knowledge into GIS analysis (Lange et al., 2019).

Looking to the future, continued research and development of Conservation GIS is essential. Advancements in technology and data collection, integration with other fields such as machine learning and artificial intelligence, and collaborative approaches are all important directions for the future of Conservation GIS. With continued investment and effort, Conservation GIS has the potential to become an even more powerful tool for addressing the challenges facing biodiversity and ecosystems worldwide.

In summary, Conservation GIS has the potential to make a significant impact on conservation efforts and has broader implications for society. The use of this tool can aid in the development of effective conservation strategies that can help to maintain the many benefits of biodiversity conservation for current and future generations. However, there is still much work to be done to address the challenges and knowledge gaps that exist within the field of Conservation GIS.

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