International experience in applying artificial intelligence (AI) in marine biodiversity management and recommendations for Vietnam

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1. THE ROLE OF MARINE ARTIFICIAL INTELLIGENCE TECHNOLOGY

Resolution No. 57-NQ/TW dated December 22, 2024, issued by the Politburo on breakthrough development in science, technology, innovation, and national digital transformation, emphasized the urgent need for digital transformation in the management of seas and islands [1]. Besides, Resolution No. 36-NQ/TW dated October 22, 2018, on the "Strategy for Sustainable Development of Vietnam's Marine Economy to 2030, with a Vision to 2045," set forth goals associated with the conservation of marine biodiversity and increasing the area of marine protected zones to 6% by 2050 [2]. To effectively manage marine biodiversity in service of sustainable marine economic development, it is imperative to achieve breakthroughs in digital transformation, with the application of artificial intelligence (AI) as an urgent and critical need.

Globally, many studies and practical applications have used AI to explore the vast ecosystems of the oceans [3,4,5]. Essentially, marine AI integrates advanced algorithms with marine science to analyze large datasets collected from ocean environments. These analyses lead to crucial insights into marine biodiversity, conservation efforts, and the impacts of climate change. Marine AI gathers data through innovative tools such as underwater drones, satellite imagery, and acoustic sensors. These technologies provide extensive information on oceanic conditions and marine organisms, including temperature, salinity, and behavioral patterns of aquatic species. Advanced processing techniques enable the effective analysis of complex marine datasets, which helps identify patterns and predict changes with high accuracy. This technology not only supports scientists in making informed decisions to protect marine ecosystems but also empowers the public to participate through citizen science initiatives and volunteer monitoring programs.

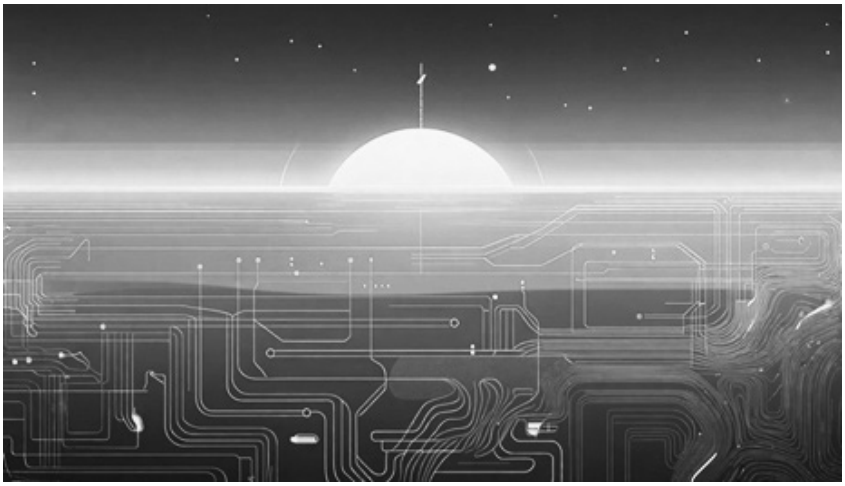

Figure 1. Diagram of marine artificial intelligence

2. BENEFITS OF AI TECHNOLOGY IN MARINE BIODIVERSITY MANAGEMENT

Marine AI technologies are being designed to support ocean conservation [3,5]. One innovative field in marine science is the development of AI-powered underwater drones. These devices can explore ocean depths that were previously inaccessible, capture detailed images, and collect critical data for mapping marine ecosystems. Using machine learning algorithms, these drones can identify and track species or detect signs of environmental degradation, which enables rapid response to conservation challenges.

Another innovation involves using AI to model the impacts of climate change on marine biodiversity. AI-assisted simulations can predict changes in habitats or the behavior of marine species due to climate change. This capability enhances the ability to implement proactive conservation strategies.

AI is also revolutionizing citizen science, as current platforms now allow volunteers to tag and classify marine wildlife through AI-guided applications, which can help enhance data collection for researchers.

The integration of these emerging technologies opens new avenues for engagement and continues to inspire collective action in protecting our oceans.

In the coming decade, marine artificial intelligence will be a beacon of hope for global conservation. Imagine AI-powered systems that can predict and mitigate the impacts of climate change on coral reefs, monitor illegal fishing activities, and model the migration patterns of endangered species. These advancements will enhance our understanding and protection of marine ecosystems. Marine AI technologies will empower scientists and conservationists with real-time data, promoting initiatives that are both proactive and preventative. Community participation becomes essential, as citizen scientists play a major role in data collection and verification. This collaborative approach will foster innovative solutions and drive governments to implement more effective conservation strategies.

3. SUCCESSFUL APPLICATIONS OF AI IN MARINE BIODIVERSITY CONSERVATION

In the field of marine conservation, AI has contributed to the successful protection of whales in the Gulf of St. Lawrence, Canada [3]. In 2017, North Atlantic right whales followed warming waters into the Gulf of St. Lawrence, hundreds of miles north of their usual habitat off the coast of Maine. The whales were pursuing their preferred prey (small crustaceans called copepods). As climate change warmed the northern waters, copepods shifted their range, and the whales followed. However, the Gulf is one of the busiest shipping corridors in the world, leading to a sharp increase in ship-whale collisions. Dozens of whales died from blunt force trauma or propeller strikes. A record number were also entangled in fishing gear, sometimes fatally. With only around 400 individuals remaining, the species, which already pushed to the brink of extinction by industrial whaling, faced a grave threat. Even the loss of a few dozen individuals posed a serious danger to such a small population.

Conventional conservation strategies struggled to keep up. Aerial surveys were costly and often hindered by poor weather, while whale sighting data used to alert ships was frequently outdated. In response, local biologists implemented a dynamic marine protected area strategy based on bioacoustics. They used underwater gliders equipped with hydrophones to monitor whale sounds over several years. This passive acoustic monitoring (PAM) allowed for continuous, more cost-effective, and accurate surveillance. These autonomous gliders (essentially the oceanic version of aerial drones) moved in pre-programmed paths, diving and surfacing every few hours to transmit data to onshore receivers (similar to mobile networks), which then relayed it to university laboratories. There, machine learning algorithms automatically analyzed the data to detect and identify the distinct calls of different whale species. Any detections were mapped and immediately sent to fisheries officials and ship captains. These AI-trained algorithms could accurately distinguish between whale species based on their vocalizations. Thanks to this AI application, no North Atlantic right whale deaths from ship strikes were recorded in 2020.

Another noteworthy initiative involves the use of AI-powered drones to combat illegal fishing [4]. In the Galápagos Islands of Ecuador, the government faces the daunting task of monitoring vast ocean territories to curb poaching and overfishing. Autonomous underwater vehicles (AUVs) equipped with AI technology are capable of covering long distances and detecting unauthorized vessels, providing a sustainable solution. These AI-driven AUVs have significantly reduced illegal activities, helping conserve marine ecosystems and supporting local fishing communities.

4. CHALLENGES OF AI IN MARINE BIODIVERSITY RESEARCH

Despite its many benefits, applying AI in marine biodiversity protection also presents significant challenges and raises ethical considerations. Using AI requires substantial resources and data, which may not be accessible in all regions, particularly those with limited scientific funding. Moreover, relying on automated systems raises concerns about privacy and data security, especially when it involves sensitive information related to marine territories and local communities.

From the ethical standpoint, AI deployment in marine environments must adhere to principles that prioritize ecological balance and respect the rights of indigenous and local populations. It is crucial that stakeholders work in partnership with local communities, incorporate their traditional knowledge, and ensure their voices are included in conservation dialogues. By addressing these challenges, we can harness the power of AI to promote sustainable interactions with the ocean and inspire collective action toward a healthier marine environment for future generations.

5. RECOMMENDATIONS FOR APPLYING MARINE AI IN VIETNAM

Building a "Smart Ocean" by integrating artificial intelligence into marine management in generaland

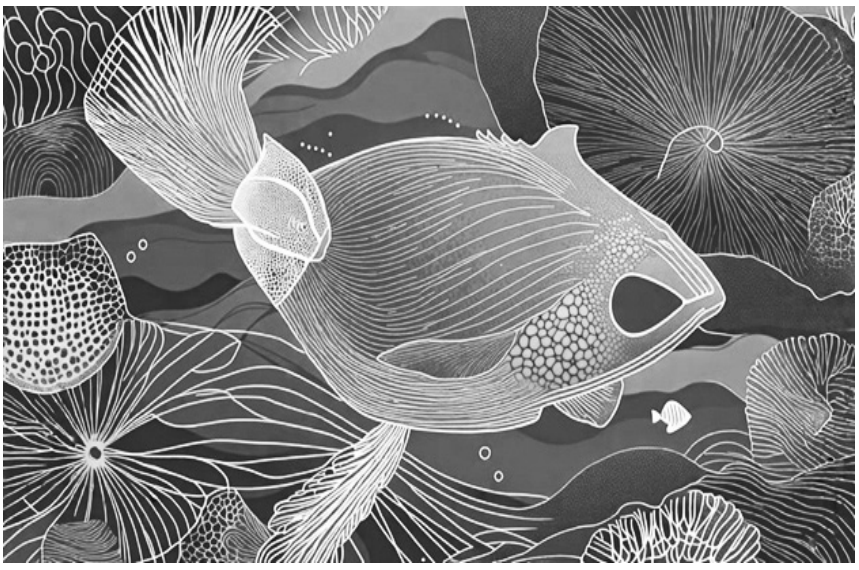

Figure 2. Using AI to identify fish behavior [4]

marine biodiversity conservation in particularwill enable Vietnam to sustainably harness its marine and ocean resources. By processing massive datasets with unprecedented speed and accuracy, marine AI provides essential insights for biodiversity conservation and ecosystem management. The combination of AI with traditional conservation approaches enhances the capacity to monitor marine life and address environmental challenges with more informed strategies. This innovative approach not only supports the work of scientists and conservationists but also creates opportunities for broader community engagement. Initiatives that apply AI to protect marine biodiversity offer a hopeful path for the future health of our oceans. Through collective action and ongoing innovation, we can ensure that Vietnam's marine ecosystems and protected areas are preserved for generations to come.

To strengthen marine biodiversity management and support the sustainable development of Vietnam's marine economy, the following recommendations are proposed:

Evaluate global experiences in applying AI to marine and biodiversity management, and use these insights to shape national AI-related policies and legal frameworks for marine governance.

Establish a national "Smart Ocean" program for Vietnam, focused on integrating AI into ocean and coastal management systems.

Review and revise existing national and ministerial science and technology programs on ocean governance, adding new tasks specifically related to marine AI.

Develop new research projects and programs that integrate AI with the management of marine protected areas (MPAs) and unique marine ecosystems such as coral reefs, seagrass beds, mangrove forests, and rare or endangered marine species.

Conduct scientific research to develop a foundation for applying AI in marine and ocean governance, marine economy sector management, and biodiversity conservation.

Establish specialized research teams, centers, and institutes dedicated to marine AI, along with smart devices for marine and seafloor monitoring.

Design a roadmap for AI application in marine and biodiversity management, outlining short-, medium-, and long-term implementation plans.

Provide training for marine professionals to equip them with AI knowledge and foster interdisciplinary collaboration with sectors like autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), remote sensing, and satellite technology.

Strengthen international cooperation in AI and marine biodiversity management to share expertise, tools, and best practices globally.

Mobilize financial resources to build the necessary infrastructure, equipment, and big data platforms for sustainable ocean governance■

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