The impact of artificial intelligence and big data systems in enhancing marine health to promote sustainable tourism

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Abstract

The marine ecosystem's health is paramount in maintaining biodiversity, livelihoods, and sustainable tourism. Yet, marine ecosystems are increasingly at risk due to human activities and climate change. Artificial Intelligence (AI) and Big Data systems provide cutting-edge solutions for tracking, analyzing, and maintaining marine health. AI provides real-time alerts for environmental change detection, whereas Big Data enables holistic insights for decision-making. Combined, they allow stakeholders to adopt proactive conservation measures. Recent technology has proven effective in monitoring coral reefs, tracking pollution, and the management of marine biodiversity. Applying these technologies to tourism management increases the resilience of coastal tourism destinations. Models of sustainable tourism grounded on data help to lower environmental damage and improve long-term ecosystem stability. Still, problems with data usage ethics and technological accessibility have to be taken care of. This work reviews modern applications, case studies, and theoretical models supporting technology-based marine preservation. It highlights the transforming potential of Big Data and artificial intelligence in supporting environmentally friendly sea travel.

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Introduction

Maintaining global biodiversity, economic benefits, and the cultural values underlying coasts depends on the health of marine ecosystems (Rußwurm, Venkatesa and Tuia, (2023). Major ecological services provided by seascapes and marine biomes include food production, temperature control, and amenity provision. But the stresses from pollution, overfishing, habitat loss, and climate change have seriously harmed oceans and seas globally (Hartigan, 2024; Wu and Margarita, 2024). Aimed at balancing the use of natural resources with their preservation, sustainable tourism has evolved into a necessary method to prevent negative effects. Snorkeling, diving, and animal viewing in sea-based tourism depend much on the condition of aquatic environments. Therefore, healthy marine habitats are necessary for coastal businesses, tourists, and livelihoods (Hermansyah, 2023; Nakamura and O'Donnell, 2025).

Technological developments have presented fresh chances for improved monitoring, management, and preservation of maritime habitats during the last several years. Implementing AI and Big Data infrastructure has dramatically changed environmental governance, offering real-time monitoring, predictive analytics, and decision support tools. Using satellite photos, sensor data, and underwater drone video, artificial intelligence systems can more precisely and quickly track changes in marine health than more conventional methods (Elsäßer *et al.*, 2024). Combining many data sources utilizing big data helps one better visualize natural and artificial events. These technologies help those involved in tourism create scientifically based actions to lessen negative effects and preserve the environment (Narayanan and Rajan, 2024). Big data and artificial intelligence working in concert help simplify maritime protection and decrease tourism's harmful environmental effects (Ning *et al.*, 2024).

Literature Review

Current Trends in AI and Big Data for Environmental Monitoring

Using artificial intelligence in concert with big data technology has transformed monitoring systems in the marine industry. These technologies promote enhanced environmental protection planning using data collecting and analysis, predictive modeling, and automation systems (Ditria *et al.*, 2022).

Emphasizing its capacity to handle vast satellite images and in-situ sensor data to identify particular abnormalities and environmental trends, Nieves, Ruescas, and Sauzède, (2023) underlined the part artificial intelligence plays in monitoring ocean and climate change (Roy, 2024; Shetty and Nair, 2024). In conducted a comprehensive literature analysis and discovered that 57% of AI usage in marine pollution relates to monitoring, thus highlighting the great prevalence of technology in environmental working evaluation (Kerfouf *et al.*, 2023).

Ditria *et al.*, (2022) report on the economic considerations and functional adequacy of autonomous systems for monitoring purposes driven by AI, stating these systems incur 1% of the cost previously incurred while processing data 200 times faster than traditional methods (Khan *et al.,* 2024). These innovations extend the precision of data and the spatial and temporal dimensions of monitoring the environment, improving marine protection decision-making (Sumiati, Hendriyati *et al.,* 2024).

Case Studies of Technology-Driven Marine Conservation

Multiple practical applications in Artificial Intelligence and Big Data for marine ecosystem preservation have been documented in case studies. Elsäßer *et al.,* (2024) developed the Deep Learning Algorithm Seagrass Finder that fully automates eelgrass identification and coverage estimations using underwater video footage. With best AUROC scores exceeding 0.95, the model performed exceptionally well and holds promise for large-scale seagrass monitoring deployment (Gladkova and Gladkov, 2021). The critically endangered flapper skate has greatly gained from the AI-powered database Skatespotter, which was discovered in Scotland. This specific technology has skippers and fishermen submit hundreds of photographs that feature unique species, and it has been able to identify approximately 2,500 unique species, significantly increasing catch rates within marine protected areas (Samara, Magnisalis, and Peristeras, 2020; The Guardian, 2025).

Additionally, Rußwurm, Venkatesa and Tuia, (2023) Marine Litter used the Sentinel 2 satellite imagery to identify coastal litter and employed deep learning for segmentation. At this stage, actively supervising plastic waste is an unprecedented resource for determining information about policy and cleanup operations (Rao and Chatterjee, 2024). These studies exemplify the combined work of SeagrassFinder and Skatespotter, which serve as examples of big data and AI in advanced marine conservation and biodiversity preservation.

Theoretical Framework

In travel, sustainability predominantly evolves from concepts integrating social, environmental, and financial motives. One of the most robust models available is the Triple Bottom Line (TBL) approach, which focuses on people, the planet, and profit. This approach advocates in marine tourism the need to protect ocean ecosystems while ensuring profits for seaside towns and improving tourist satisfaction (Onyango, 2025). The Carrying Capacity Theory is equally significant, emphasizing limits on recreational visitation and activities to mitigate ecological impacts. Stakeholder Theory posits that efficient maritime tourism also depends on the collaboration of numerous stakeholders like local governments, adjacent businesses, tourists, and environmental NGOs. These concepts ensure that increasing tourism does not damage the quality of marine environments, thus fostering healthy ecosystems and resilient economies.

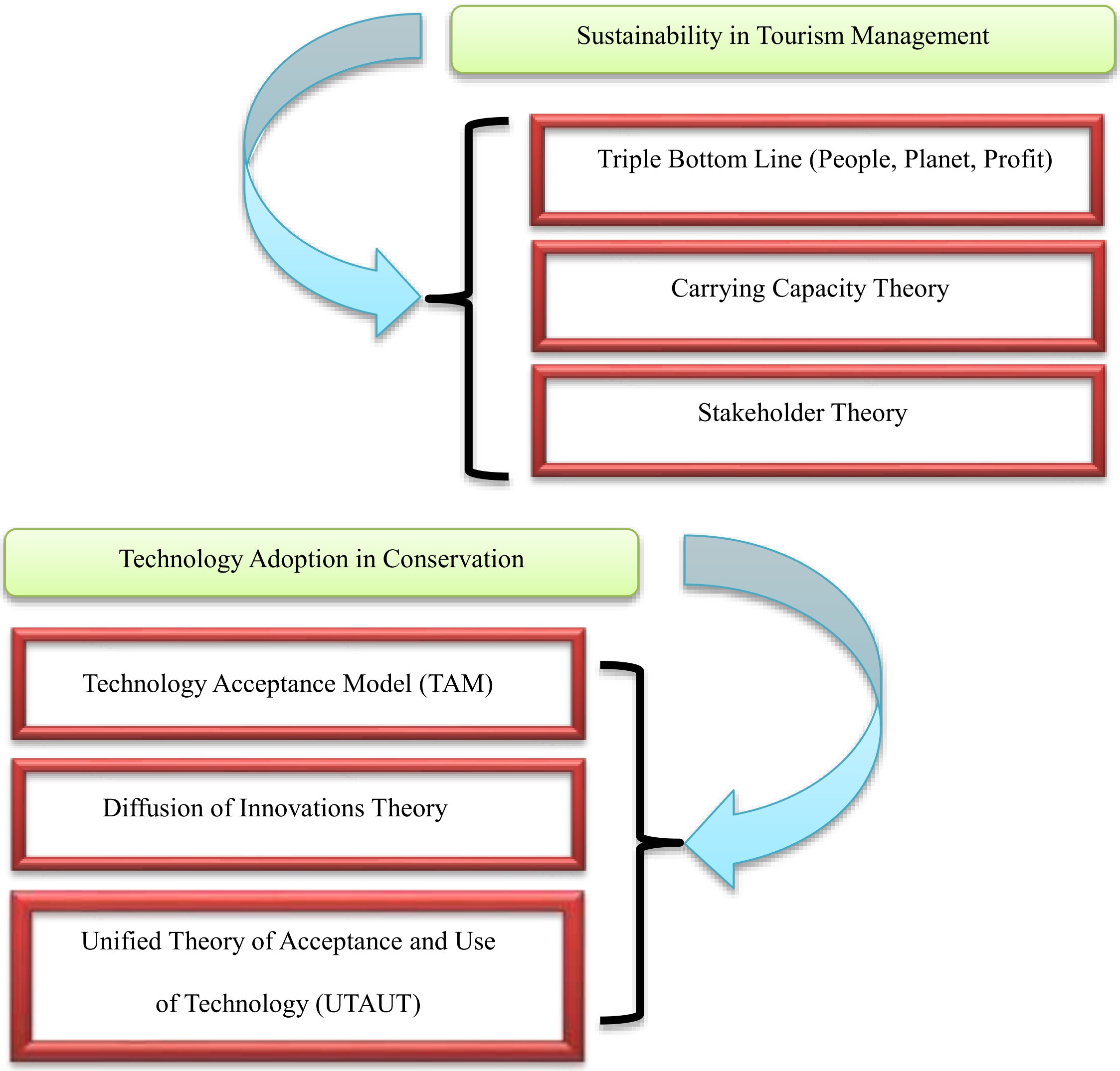

Figure 1: Technologies Acceptance Model (TAM).

Artificial intelligence systems and big data used in marine conservation are placed within particular technological adoption frameworks. For instance, in the technologies Acceptance Model (TAM) shown in Figure 1, it is noted that managers of tourism and conservation practitioners are driven towards new technologies by perceived usefulness and ease of use. Furthermore, the diffusion of innovations theory assists in clarifying the entry of Big Data and Artificial Intelligence technologies into environmental sectors: early adopters and innovators experiment with predictive analytics or autonomous monitoring drones and, in turn, motivate wider acceptance across institutions (Mehta and Reddy, 2024). The emerging acceptability of conservation technologies has been recently examined through the Unified Theory of Adoption and Use of Technology (UTAUT) as performance expectation, social influence, and context enable acceptance. Applying innovative technologies in eco-friendly maritime operations allows stakeholders to predict problems and initiatives better.

The Role of Artificial Intelligence in Marine Health Monitoring

Marine health monitoring systems incorporating environmental sensor data, satellite data, and data from autonomous vehicles depend on artificial intelligence. AI algorithms can facilitate preemptive action and informed decision-making through sustainable tourism and conservation endeavors by enabling early intervention through real-time analysis, oceanic trend prediction, and comprehensive oceanic health checks.

AI-Driven Predictive Models for Marine Ecosystem Changes

Large data sets, including satellite images, oceanic sensor data, and environmental factors, allow AI-based prediction models for marine ecosystem transitions to forecast changes in marine health. Using data sets, machine learning algorithms find patterns and linkages, allowing early predictions of changes like habitat loss, fish population dynamics, and coral bleaching. These models evaluate how pollutants, human activity, and climate change impact maritime environments. Timely, precise forecasts from artificial intelligence provide lawmakers, environmentalists, and tourism operators with the vision to implement preemptive projects, ensuring sustainable use of maritime resources and promoting environmentally friendly travel regulations.

Use of Machine Learning in Marine Species Tracking and Protection

Real-time analysis of vast amounts of environmental and biological data made possible by machine learning is transforming marine species monitoring and conservation. ML techniques examine data from GPS tags, seaflower sensors, and satellite images to track species movement, migration, and habitat usage. Using trend and anomaly detection, ML helps biologists project species behavior and possible hazards, including habitat degradation or fishing pressure (Nieves, Ruescas and Sauzède, 2023). This promotes focused protection of threatened species through policies and conservation initiatives. Furthermore, ML's assistance in detecting illicit fishing activities and habitat devastation helps make marine species preservation more successful.

Big Data Systems for Oceanic and Coastal Management

Big data systems in coastal and oceanic management aggregate massive satellite, sensor, and weather station information to monitor environmental changes. The systems provide vital information for smart decision-making, sustainable resource planning, and marine ecosystem protection, examining ocean temperature, pollutants, and trends in coastal erosion.

Data Collection Techniques: Satellites, Sensors, and IoT

Data collecting in coastal and marine management relies on a synergy of satellites, sensors, and the Internet of Things (IoT) to gather vast environmental data. Picking up data on sea surface temperature, chlorophyll concentrations, and meteorological conditions, satellites provide big-scale, real-time photos and remote sensing data. On buoys, boats, and underwater platforms, sensors monitor such factors as salinity, pH, and oxygen concentrations. IoT technologies like smart sensors and drones provide constant, localized data collecting, making dynamic monitoring of maritime environments possible (Ranganathan, 2019). These technologies together enable gathering varied, high-quality data to track environmental changes, wildlife behavior, and human activity and provide better decision-making for projects, including sustainable management and preservation.

Real-Time Analytics for Marine Biodiversity and Water Quality

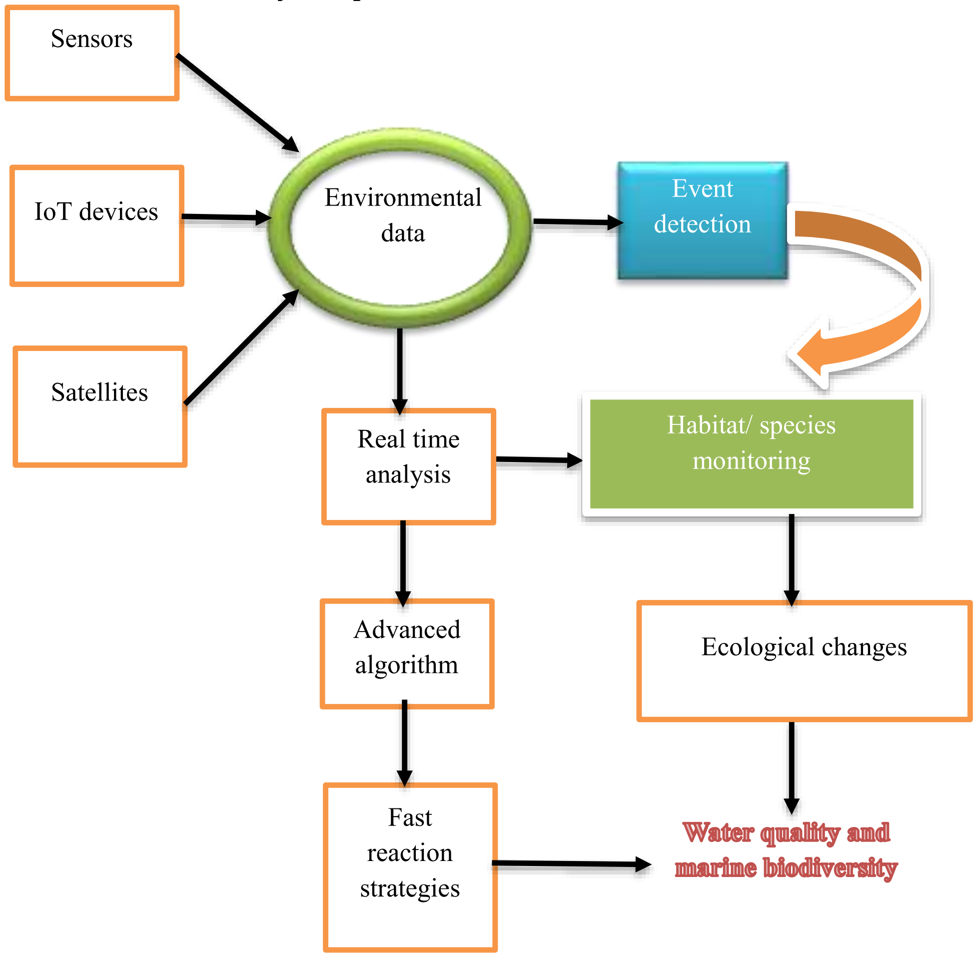

Figure 2: Marine biodiversity and water quality.

Water quality and marine biodiversity real-time analysis combines continuous environmental data processing and monitoring from all sources—including sensors, Internet of Things devices, and satellites, as explained in Figure 2. Using advanced algorithms, these systems can handle inputs like pH levels, polluting presence, dissolved oxygen, water temperature, and salinity. Real-time computation of this data helps to detect events such as algal blooms, pollutant level swings, or changes in biodiversity. This helps to implement fast reaction strategies meant to protect maritime environments. Real-time analysis also helps identify habitat deterioration, tracks species numbers, and notes ecological changes, providing useful information for policy-makers, researchers, and conservationists to ensure sustainable marine health and management.

Future Prospects and Innovations

Modern artificial intelligence, machine learning, and sophisticated sensor technologies will all help shape future ocean ecosystem management. More exact, real-time solutions supported by technologies such as autonomous underwater vehicles, deep learning algorithms for biodiversity monitoring, and predictive analytics for climate consequences would help sustainable development and tourist practices by underlining.

Emerging Technologies in Marine Conservation

Developing technologies in ocean preservation are transforming control and observation of marine surroundings. While current sensors and IoT devices allow continuous monitoring of water quality, temperature, and biodiversity, technologies, including autonomous underwater vehicles (AUVs) and drones, offer us immediate feedback on the condition of oceans. Using artificial intelligence and machine learning methods to analyze enormous volumes of data is now enabling predictions of changes in ecosystems and diminishing risks such as illegal fishing or coral bleaching. Additionally, blockchain technology is under study for traceability and sustainable fisheries management. By allowing proactive interventions, such technologies support sustainability and assist in preserving marine biodiversity using more precise, timely knowledge.

Strategic Recommendations for Sustainable Tourism Development

Strategic recommendations for expanding sustainable tourism include community support, renewable energy use, and environmentally friendly measures like lowering carbon emissions. Promoting conscientious travel through education and the media helps to lower the environmental impact. Big data and artificial intelligence, among other technologies, help maximize resource use and predict travel patterns, guaranteeing the least effect on ecosystems. Encouragement of coalitions among governments, businesses, and environmental groups also fosters group efforts to preserve natural and cultural legacy. Monitoring and implementing sustainable tourism policies in laws and rules and encouraging eco-tourism events would help strike a balance between environmental protection and economic growth and benefit of the society.

Conclusion

Adopting emerging technologies like IoT, big data, and artificial intelligence is crucial for supporting marine health, monitoring biodiversity, and enabling sustainable tourism. The technologies enable predictive modeling, real-time analysis, efficient resource management, and effective technology management to protect marine ecosystems. Using cooperation and implementing sustainable practices, this paper may balance economic development and preservation, thereby fostering a harmonic interaction between tourism, marine life, and nearby towns for the next generations.

Synopsis of Principal Results

The ground-breaking impact of artificial intelligence, big data, and the Internet of Things on sustainable tourism and marine conservation is highlighted in the main findings. They provide efficient resource management, predictive modeling, and real-time monitoring. Using proactive interventions, maximum tourist practices, and assistance in biodiversity conservation, they help preserve the marine environment and improve sustainability.

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