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Diving Deeper with AI Assistance in Marine System: A Compendium

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Abstract:
The vast expanse of marine ecosystems includes incredibly diverse habitats with varying chemical and physical conditions - such as temperature, salinity, light availability, and toxicity levels. Likewise, human zeal to study and explore this marine field is also broad. Marine biotechnology is one sub-field that utilizes marine resources and tools to create valuable biological compounds supporting living organisms. It's interesting to note that marine biotechnology has a lot of potential when it comes to commercial initiatives that can be applied to various sectors, such as pharmaceuticals, biomedical, cosmetics, nutraceuticals, food, feed, agriculture, and more. There are a lot of opportunities to be explored in this field, and it's exciting to see what the future holds. By 2030, many ocean-based industries will surpass global economic growth, creating around 40 million full-time equivalent jobs. Moreover, the world of technology and artificial intelligence (AI) is also making incredible strides and helping us to expand our knowledge of the marine field. The present review aims to summarize various applications of marine biotechnology that make it an essential contributor to the bio-economy. The paper also highlights how the world of AI helps better explore the field by monitoring marine biodiversity, modelling deep-sea resources, protecting ocean environments, etc.

Keywords — **Artificial Intelligence, Bio-economy, Marine Biotechnology, Marine Ecosystems, Ocean Environment**

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I. INTRODUCTION
Artificial intelligence has become a game-changing technology in today's world. Its vast and diverse applications impact various fields such as healthcare, finance, education, and more. It can improve efficiency, accuracy, and decision-making processes, benefitting society significantly. AI represents the ability of machines or software to exhibit human-like intelligence and perform a wide range of tasks, including learning, problem-solving, and decision-making. (Davenport T, Kalakota R, 2019) The advent of AI has brought about a substantial transformation across numerous industries, marine biotechnology being no exception. The use of algorithms and computational models has enabled the processing of vast amounts of data, identification of patterns, and learning from experience. This development has led to a significant revolution in the field of marine biotechnology. Integrating AI with other digital technologies, such as sensors and robots, has enabled the automation of various tasks and has revolutionized the way marine data is collected and analyzed. (Tao Song et al. 2023) The advanced capabilities of AI have made it possible to collect and analyze data with greater accuracy and efficiency, leading to significant breakthroughs in marine biotechnology. It would have far-reaching implications for public health, environmental safety, and other critical areas. With its potential for future applications, AI is rapidly reshaping the landscape of marine biotechnology research. The technology promises to unlock new avenues for exploration and discovery in the field, paving the way for ground-breaking innovations that can positively impact our

planet. Overall, AI is a transformative technology poised to revolutionize marine biotechnology and drive progress towards a sustainable future.

II. Ocean and Marine Biotechnology

An The oceans that cover around 70% of the Earth's surface harbour over a million visible organisms, including algae, corals, molluscs, fish, and mammals, as well as one billion microscopic species, like viruses, bacteria, microalgae, fungi, and archaea. The chemical and physical conditions of oceanic regions, like temperature, salinity, light availability, and toxicity, can vary considerably, resulting in unique features among marine organisms adapted to their surroundings. (Danovaro et al. 2011) The vastness of the oceans and the diversity of the species they harbour have yielded a wealth of natural products with structural versatility, thus incentivizing research into novel bioactive substances with exceptional potential for industrial applications.

Algae, in particular, including macroalgae, microalgae, and cyanobacteria, are highly promising, given their ability to produce a substantial number of bioactive molecules. Microorganisms, characterized by unique properties such as resistance to high temperatures or salinity, have also proven to be an invaluable source of enzymes and compounds, thanks to their adaptability to extreme conditions. (Dalmaso et al. 2015) Despite the vast potential of marine organisms, the oceans remain largely uncharted. Scientists have only identified approximately 9% of all marine species, leaving a staggering 91% yet to be classified. Fortunately, technological advancements continue to enhance our understanding of the marine environment and reveal the vast possibilities waiting to be discovered. Marine biotechnology, also known as "blue biotechnology," is a research field that utilizes marine products and tools to support living organisms. The field of marine bio-resources is a promising area of research, offering the potential for both high-value product development and advancements in exploratory technologies for studying the marine environment. By focusing on this discipline, we can tap into the vast potential offered by our oceans and develop innovative solutions that benefit both society and the planet. (Daniotti S, Re I, 2021)

The discovery of innovative applications in various marine systems is anticipated through the exploration and utilization of marine materials. Several marine-based products have been successfully developed, such as industrial enzymes, marine-based pharmaceuticals, biosensors, food ingredients, drug delivery systems, and chemical compounds. The enterprise sector and policymakers consider marine biotechnology a promising opportunity to create new products to fill market gaps. The field of marine biotechnology is rapidly evolving and gaining more attention as experts explore its potential to unlock sustainable utilization of marine biological resources. As our comprehension of this field continues to advance, we can anticipate a multitude of constructive effects on both the economy and the quality of life of individuals worldwide. (Dheior M, 2023) By harnessing the potential of marine biotechnology, we can look forward to a more sustainable, innovative, and prosperous future. Despite the progress made so far, the full potential of marine biotechnology is yet to be realized. Continued research and development in this field will be crucial in unlocking its maximum benefits and opening up new pathways for discovery and innovation.

III. Commercial Importance of Marine Biotechnology

Marine biotechnology is a fascinating field that offers tremendous potential for commercial ventures across multiple industries, including pharmaceuticals, biomedicine, cosmetics, nutraceuticals, food, feed, agriculture, and related fields. The marine environment is home to diverse organisms that have evolved unique traits to survive in this ecosystem.

Marine organisms have several characteristics, among which is the ability to produce different biomolecules, such as secondary metabolites, biopolymers, and enzymes, which are of great interest to biotechnology. These biomolecules are essential in chemical communication, defence mechanisms against environmental stressors, protection against predators and pathogens, and

support life-sustaining processes. (Romano G et al. 2022) They have evolved to exhibit biological activity even at low concentrations to counteract the effects of dilution and dispersion in seawater, making them highly desirable for biotechnology.

The intricate structures of marine metabolites offer exciting commercial possibilities. For example, researchers have discovered that some marine metabolites have potent antibacterial, antifungal, and antiviral properties, making them potential candidates for drug development. Other metabolites have shown promise in preventing or treating cancer, inflammation, and other diseases. (Srinivasan R et al. 2021) Furthermore, the use of marine biotechnology in the production of nutraceuticals, cosmetics, and functional foods is gaining attention, as these products can offer several health benefits. The potential benefits of marine biotechnology are immense, and its exploration is crucial for the continued progress of various industries. However, the marine environment is complex, and the discovery of new compounds and their characterization is a challenging task. Therefore, researchers must employ advanced techniques and technologies to identify and isolate new biomolecules. These techniques include high-throughput screening, genomics, transcriptomics, proteomics, and metabolomics. Using these methods, researchers can accelerate the discovery of new biomolecules and facilitate their commercialization. (Ambrosino L et al. 2019)

Newman and Cragg (2020) found that over 50% of the current medicines have their origins in natural compounds. This figure is even greater for agents used to treat cancer and microbial infections. The study emphasizes the vital importance of natural compounds in creating drugs that save lives. Various industries are interested in the properties and functions of marine organisms that go beyond biomolecules. These organisms can potentially remove and degrade individual chemical compounds or organic matter and develop intricate biochemical processes. However, marine resources still need to be explored and undervalued. Since the mid-20th century, collaborative efforts between field and experimental biologists and chemists, supported by recent advancements in ocean access techniques, have significantly increased our knowledge of marine resources. As a result, marine natural products chemistry has emerged as a mature and fully established subfield of chemistry, which focuses on the isolation and structure elucidation of secondary metabolites (Gerwick et al., 2012).

Marine biotechnology has been researching seaweed-derived polysaccharides, like carrageenans, and other marine organisms and their secondary metabolites since the 1970s (Rotter et al., 2020a). Various bioactive metabolites found in sessile macroorganisms, such as sponges, cnidarians, bryozoans, and tunicates, have been showcased in initial studies (de la Calle, 2017). All habitats' multicellular organisms host complex microbiota, contributing to the production of various secondary metabolites and impacting their hosts' fitness, making up the Holobiont concept. (Bordenstein SR, et al. 2015) Sponge and cnidarians symbiotic microbial communities play a significant role in producing bioactive molecules, making them prolific sources of such molecules. Microorganisms make up nearly 90% of the living biomass in the oceans and play a pivotal role in sustaining the equilibrium and vitality of marine ecosystems (Alvarez-Yela et al., 2019). Microorganisms generate a broad range of secondary metabolites, which are easier to research and scale up and entail fewer ethical and environmental concerns, making them increasingly prominent in sustainable marine biotechnology, with almost 60% of new marine natural products derived from them (Carroll et al., 2019). Nevertheless, microorganisms still provide a rich source of innovative metabolites and continue to be an active area of research.

IV. Marine biotechnology: An important contributor to Bio-economy

Marine biotechnology has been identified as a crucial economic growth sector on a global scale, with concentrations mainly in the European Union, North America, and the Asia-Pacific region (Selnes T et al. 2021). China, Japan, the United States, and Australia are home to some of the world's most prestigious marine biotechnology centres. Among them are the Institutes of Oceanology and the institutes of the Chinese Academy of Sciences in China, the Shimoda Marine Research Center in

Japan, the Scripps Institute of Oceanography in the United States, and the Australian Institute of Marine Science in Australia. These institutions are known for their cutting-edge research and innovative contributions to marine biotechnology. While marine biotechnology is an emerging field in some countries, such as South America, the Middle East, and Africa, its successful implementation is limited by factors such as the need for more significant investment, appropriate infrastructure, and skilled human resources (Thompson et al., 2017). Further, to promote the development of the marine economy, partnerships are being established between national and global research laboratories, including European participation.

Marine biotechnology is an exciting and growing field that is part of the blue bio-economy, defined by the European Commission (EU). This innovative field involves using aquatic biomass to create new and diverse products such as food, feed, energy, and packaging. The revised EU Bioeconomy Strategy recognizes the potential of marine biotechnology and thus sets several priorities, including developing alternatives to plastics and other fossil-based materials that are bio-based, marine-biodegradable, and recyclable. (Daniotti S, Re I, 2021) The blue economy, which encompasses all sectors related to the ocean, generated a remarkable turnover of €750 billion and provided nearly five million jobs in the European Union in 2018 (M. Senaratne et al. 2019) Marine biotechnology, a specialized sector within the ocean-based industries, is predicted to surpass the global economy's growth by offering almost 40 million full-time equivalent positions by 2030. This significant growth can create new job opportunities and provide additional income streams for fishermen and aquaculture specialists. Marine biotechnology holds immense potential, but it has its share of hurdles. Therefore, it is crucial that research efforts in the marine domain focus on refining methodologies for the large-scale production and processing of marine biomass. (Rotter A, 2020) Recognizing this necessity, the European Commission emphasizes the importance of developing these techniques to ensure sustainable growth in the industry. (Rosen MA et al. 2012). The following are some of the significant challenges to be looked forth for better advances in marine biotechnology:

i. There is a requirement for the harmonization of processes, protocols, and definitions followed by standardization in order to ensure consistency and efficiency.
ii. The fair and equitable distribution and utilization of biological resources necessitate the creation of ethical guidelines that national administrative authorities would endorse and comply with.
iii. There is a need to improve the collaboration and communication between the science industry and policymakers. It requires some changes in the way things are done. For instance, networking activities such as brokerage events and participatory workshops should be used to exchange expertise and opinions and explore the potential co-creation of strategic documents.
iv. It is paramount to have open-access repositories that showcase experts in various fields along with their contact information. It will provide a platform for individuals to demonstrate their skills and abilities and help others connect with them for networking and collaboration opportunities. By adopting this strategy, individuals can significantly enhance their visibility and establish themselves as influential leaders in their respective fields.
v. It is essential to continue investing in ocean observations that can demonstrate regulatory compliance and aid in assessing the value of natural assets and ecosystem services, as stated by Rayner et al. in 2019. Open science, full access to research publications and access to data are critical for ensuring fair access to public knowledge.

V. MARINE BIOTECHNOLOGY: AN IMPORTANT CONTRIBUTOR TO BIO-ECONOMY

Marine biotechnology has many applications in various industries, some of them may include the following:

i. **Biomedical Application:** Due to safety concerns, Jellyfish collagen is increasingly considered a viable alternative to mammalian-

derived collagen in various industries. In biomedical research, jellyfish collagen is a promising matrix for cell cultures that mimic human diseases. Recent studies indicate that jellyfish collagen is comparable to, and sometimes even superior to, rat tail collagen in cultivating human iPSC-derived microglia. (Mearns-Spragg A, et al. 2020)

ii. **Pharmaceutical applications:** Studies conducted in the Yucatan peninsula demonstrated that marine organisms such as sponges, ascidians, and gorgonians have antiviral properties against human adenovirus in 17% of the extracts and antitumor properties against one or more tumour cell lines in 37% of the extracts. (Pech-Puch D et al. 2020). Tiralongo and others reviewed the potential of marine fish skin mucus for antibacterial and antifungal activities. Furtado et al. showed that the proteasome inhibitor and potent cytotoxicity in glioma cell lines had anticancer activity by Streptomyces isolated from the Brasilian endemic ascidian Euherdmania sp. (Fuochi V et al. 2017)Controlling harmful algal blooms is crucial to preserve fishery resources, marine ecosystems, and human health. Ouyang et al. 2021 conducted repeated batch fermentation of immobilized Vibrio brasiliensis, an algicidal bacterium, to enhance the effectiveness of algicidal compounds. The process was intended to improve the productivity of the algicidal compounds, thereby contributing to the control of harmful algal blooms in aquatic ecosystems. The use of immobilized bacteria in repeated batch fermentation offers a promising approach for the large-scale production of algicidal compounds, with potential applications in various industries, including aquaculture, pharmaceuticals, and environmental remediation. Researchers have also demonstrated the analgesic potential of novel conopeptides from the carnivorous cone snail Conus quercinus. (Chao Peng et al. 2021)

iii. **Wellbeing applications:** Naturally occurring in algae, phenolic compounds possess high antioxidant properties that are highly sought after in the cosmetic industry. A recent study that focused on the Wadden Sea, which aimed to determine the amount of antioxidant potential in dissolved organic matter found in both the porewaters and water columns of the sea. The study's results demonstrated that the dissolved organic matter in the Wadden Sea possesses a higher antioxidant potential than the microalgae and macroalgae found in the same area. The findings suggest that the Wadden Sea could be a potent source of phenolic compounds, thereby having a significant value in the cosmetic industry. (Catalá TS et al. 2020) This discovery highlights the potential for developing new cosmetic products that leverage the antioxidant potential of phenolic compounds derived from the Wadden Sea. Such products could potentially revolutionize the cosmetic industry and lead to advancements in the global market.

iv. **Pigment production:** Marine organisms offer a rich source of pigments that can be utilized in various industries, including food, cosmetics, pharmaceuticals, and others. The extraction and isolation of two such pigments, astaxanthin and fucoxanthin, have been optimized through different methods. One such method is co-culturing involves the cultivation of two or more microorganisms together to enhance the production of the desired pigment. (Galasso C et al. 2017).

v. **Agriculture applications:** Researchers have made some notable discoveries in the field of agricultural science. According to Huang et al. 2020, Aspergillus sp., a fungus derived from seaweed, has been found to contain eleven new compounds that exhibit anti-phytopathogenic bacterial activity. This finding holds significant promise for improving global food safety. Additionally, Borchert et al. 2021 have studied the feasibility of using jellyfish as a biofertilizer.

The researchers have concluded that jellyfish could be a valuable resource for improving soil health, considering the low impact on greenhouse emissions and the relatively low cost of material pre-processing.

vi. **Alternative energy sources:** Bioethanol is emerging as an essential renewable energy source, providing an alternative to fossil fuels. Seaweed biomass is a promising resource for bioethanol production, but alginate, a key component of seaweed, needs to be efficiently degraded into alginate monosaccharide by alginate lyases. A recent study by Chu et al. 2020 has identified a new oligo-alginate lyase from the marine bacterium Stenotrophomonas maltophilia that has been shown to depolymerize alginate into monomers completely. A recent study has unveiled a novel oligo-alginate lyase enzyme derived from the marine bacterium Stenotrophomonas maltophilia. This enzyme has been demonstrated to break down alginate into its constituent monomers entirely, presenting an opportunity for significant improvement in bioethanol production from seaweed biomass. (Chu et al. 2020) The discovery of this enzyme offers a promising pathway for the efficient and sustainable production of biofuels, which could significantly impact the energy sector's future. This discovery has the potential to improve the efficiency of bioethanol production from seaweed biomass significantly.

vii. **Plastics and bioplastics:** Marine pollution due to plastic waste is a pressing concern that has recently gained significant attention. This issue poses a great challenge to the environment, society, and technology and requires urgent action to mitigate its impact. To address this challenge, a comprehensive research topic was undertaken, which included an overview of marine Actinobacteria and marine fungi that have the potential to biodegrade (micro)plastics. The research also explored methods for detecting and analyzing biodegradation and the potential for bioplastic production. Additionally, the most critical methods for plastic degradation and recycling valorization were reviewed by Oliveira et al. 2022. The study also highlighted the potential of jellyfish mucus to sequester microplastics, thus providing a novel bioremediation potential for this material.

The integration of AI and traditional data models has revolutionized marine research, allowing researchers to address an extensive range of global challenges related to the ocean's resources. The integration of AI has enabled researchers to improve marine safety, predict tides, sea ice, and climate, monitor marine biodiversity, investigate deep-sea resources, and solve water pollution problems. This recent advancement in marine research empowers researchers to overcome knowledge gaps and enter a new era of intelligence, where innovative solutions to complex ocean-related problems are now possible.

VI. MARINE A BRIEF INTRODUCTION TO AI

AI, or Artificial Intelligence, is a rapid and intriguing field that combines computer science, mathematics, and cognitive science. This interdisciplinary field comprises several approaches and techniques that allow machines to execute tasks which usually involve the need for human intelligence, such as learning from experience, reasoning, and problem-solving. Artificial Intelligence has emerged as a crucial technology across several industries, including healthcare, finance, transportation, and more, owing to its unparalleled ability to make predictions, analyze vast data sets, and identify patterns. (Sarker, I.H. 2022)

AI-driven systems have transformed the way we work and live, making complex problem-solving possible and simplifying our lives. The impact of AI on various sectors has been significant, and its continued development holds the potential to revolutionize several aspects of human life. With its ability to process vast amounts of data and improve performance through learning, AI has the potential to revolutionize the way we live and work. The

ultimate goal of AI is to assist humans in various intellectual functions with high performance. One significant advantage of AI systems over humans is their high throughput and consistent and accurate data processing ability. Some typical AI applications include face recognition, object detection, natural language processing, machine translation, speech recognition, content generation, video game development (e.g., procedural content generation), medical diagnosis, and more. (Bohr A, Memarzadeh K. 2020).

Although the idea of machine-aided analysis had been suggested earlier, AI was first proposed as a scientific idea at a workshop held at Dartmouth College (New Hampshire, USA) in 1956, which was the groundbreaking landmark of this field. (McCarthy et al. 2006). Since then, AI has had its share of ups and downs in development, following advances in hardware and algorithms and mismatches between expectation and reality. In recent times, Artificial Intelligence (AI) has found its way into multiple industries, including marine biotechnology. In oceanography, AI techniques have proven immense value in remote sensing, data collection and management, maritime transportation, ocean monitoring, and predicting various oceanic phenomena. Machine Learning (ML) is one of the most notable offshoots of AI techniques that enables computers to identify patterns and relationships in data without explicit programming. This category of algorithms is used to make accurate predictions or decisions based on the data presented to them.

Yet another more advanced form of machine learning is called deep learning (DL), which draws inspiration from the functionalities of neurons. By utilizing Artificial Neural Networks (ANNs) to process and interpret complex data, DL can recognize intricate patterns and make predictions similar to human brain functions. The use of AI and its subsets is empowering oceanographers to effectively monitor and predict the ocean's behaviour, which is crucial in understanding and mitigating the challenges faced by marine biotechnology. (Taye MM, 2023).

VII. Artificial Intelligence Uses in Marine Biotechnology

A. *Monitoring Marine Biodiversity*

Artificial intelligence (AI) has revolutionized marine ecosystem monitoring by analyzing many multi-parameter data points. This capability helps to build a robust and widely distributed monitoring network for marine environments. Monitoring marine ecology accurately requires more advanced data solutions than traditional methods can provide. AI-powered monitoring tools can help by automatically identifying, classifying and predicting data events. These tools can help us better understand marine environments and ensure their protection. A research team, for instance, used a neural network trained on more than 187,000 hours of acoustic data collected over 14 years to identify humpback whale songs. (Ditrai EM, 2022) Thus, using AI-powered monitoring tools could help overcome the challenges associated with monitoring complex marine ecosystems.

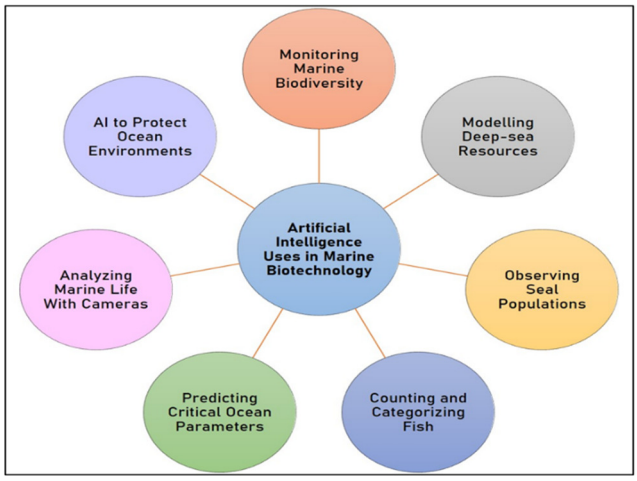

Fig 1: Some Major Uses of AI in Marine Biotechnology

B. *Modelling Deep-sea Resources*

Marine researchers have been working diligently to model seabed resources and have recently made significant progress by introducing a novel 3D modelling approach that utilizes a combination of advanced AI algorithms. This approach has been developed to enhance the re-transportation of sediments in the water, as well as the reconstruction of the seabed. By utilizing sensor data from an autonomous underwater vehicle (AUV) and a light-profile mapping system, researchers have achieved a remarkable feat through the creation of an AI-powered mathematical model. By analyzing this data, the researchers have generated a remarkable

3D colour reconstruction of the seafloor, allowing them to estimate the distribution of cobalt-rich manganese crusts with greater precision. This breakthrough has exciting implications for the scientific community and may lead to discoveries that will help to advance our understanding of the world's oceans. (Pourzangbar A et al. 2023).

C. Observing Seal Populations:

Ecologists have been monitoring seal populations globally for several years. However, the process of counting the number of seals in each photograph has been time-consuming, requiring hours of manual labour to identify each animal in the image. Fortunately, scientists are now employing deep-learning models for counting seal numbers based on the archived photos taken in the past. The AI-powered models can sort through 100 pictures in less than one minute, significantly faster than the hour it would take a human to perform the same task manually. Furthermore, this new model eliminates the need for individual seals to be labelled and counted in each picture beforehand, making the process more efficient. These technological advances provide critical new insights into the evolution of seal populations over time. (Wood SA et al. 2021).

D. Counting and Categorizing Fish

AI-powered technologies are revolutionizing how marine biologists monitor and study plankton and fish stocks. AI algorithms have enabled the automation of the formerly manual task of counting fish, monitoring their size, and distinguishing one type of fish from another. This process was time-consuming, requiring individuals to sort through hours of film footage to gather the necessary information. However, with AI, researchers can now immediately obtain information on different fish species and sizes. AI algorithms can also distinguish different species of fish and even individual fish. This capability provides researchers with deeper insights into the life of a fish over several years. AI in marine biology has significantly improved data collection and analysis accuracy and precision, providing a powerful tool for monitoring and studying marine ecosystems. (Jiang M and Zhu Z 2022).

E. Predicting Critical Ocean Parameters

The correlation between several vital factors, like sea surface temperature, tide level, and sea ice, has a crucial impact on climate and marine ecosystems. However, older methods have proven unreliable in accurately understanding the changes in temperature over time and across vast areas. A team of scientists developed an innovative deep-learning model to address this challenge. This model has outperformed older methods in analyzing data from the East China Sea, leading to more precise and reliable daily predictions of sea surface temperatures. (Xie B et al. 2024).

F. Analyzing Marine Life with Cameras

Autonomous underwater vehicles (AUVs) equipped with cameras can record large volumes of oceanic data. However, the processing and analysis of this data still rely on human intervention, leading to a significant bottleneck in the workflow. Researchers have recently employed AI-driven computer vision systems to overcome this limitation. These systems have demonstrated an accuracy of 80% in identifying different animal species on the seabed and up to 93% accuracy for particular species, provided sufficient data is available to train the algorithm. Researchers can use this technology to study marine organisms and vegetation, thereby increasing data availability for conservation research and biodiversity management. (Salhaoui M et al. 2020).

G. AI to Protect Ocean Environments

Artificial Intelligence (AI) have a noteworthy role in safeguarding ocean resources (Tao Song et al. 2023). There are two critical domains in which AI is making a substantial impact on ocean ecology:

i. Reducing Plastic Pollution: The problem of plastic pollution is an urgent and grave concern that poses a significant threat to the survival of marine life. Every year, an estimated one million birds and 100,000 marine animals perish due to the harmful effects of plastic waste discarded into the oceans. This causes immense suffering and loss of life and has far-reaching ecological consequences that threaten the delicate

balance of our planet's ecosystems. To combat this scourge, researchers have turned to AI to generate more informed tactics. By leveraging AI tools to extract plastics more efficiently, they hope to restore coastal environments.

ii. Saving Coral Reefs and Marine Life: Coral reefs are vital to marine life, providing habitat to over one-quarter of all marine species and supporting highly diverse ecosystems. (Hoegh-Guldberg O et al. 2017). To safeguard these reefs, experts are using AI to monitor, classify, and evaluate their health. They do this by analyzing data from underwater cameras equipped with video analytics systems. This method is proving to be an effective means of identifying and mitigating threats to coral reefs and marine life.

VIII. CONCLUSION

In recent times, the scientific community focusing on oceanography and marine sciences has shown a growing inclination towards using machine learning, deep learning, and computer vision. These cutting-edge technologies are being leveraged to enhance and accelerate research activities pertaining to marine conservation. Mobile underwater cameras, operated by divers or on underwater vehicles, have gained popularity for monitoring fisheries. Using deep learning algorithms, machine-assisted object detection and classification of fish species from Baited Remote Underwater Video Station (BRUVS) surveys presents an opportunity to optimize analysis time and rapidly report on marine ecosystem statuses. Enhancing underwater images is essential for better underwater vision. Significant progress has been made in underwater image enhancement, along with the development of deep learning. These technologies offer substantial advantages, including faster and more reliable results than manual monitoring. They can be applied to various tasks, such as fish detection and classification, coral classification, coastal morphological and morpho-dynamic modelling, sediment analysis, wind and wave modelling, weather prediction, ocean pollution, and resource management. (Marrable D et al. 2022)

However, machine learning models also face several challenges, such as environmental variability, limited data availability, and noise. These challenges can significantly impact the performance of the algorithms. Therefore, the success of any machine learning algorithm is determined based on its ability to perform well under such difficult conditions. Thus, it is essential to evaluate the performance of machine learning models under these challenges to ensure their effectiveness and reliability. Therefore, it is crucial to adopt modern computer intelligence techniques to process large amounts of data collected from various marine sites globally and monitor changes in the marine environment to help conservationists and government agencies take necessary actions. The efficiency and robustness of automated systems are paramount in handling environmental variations for various data types in marine sciences. These data types include imagery, videos, time sequences, and chemical and morphological features. The success of these systems will play a critical role in preserving marine ecosystems and the sustainability of marine resources for future generations.

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