AI-Powered Tracking for Sustainable Marine Ecosystem Resource Management Projects:

A Case of Oyster Detection With Machine Learning

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ABSTRACT

Ecosystems are our planet's life-support systems that facilitate sustainable development. Within the marine ecosystem, oysters serve as a keystone species. Numerous oyster restoration projects have been launched with a crucial element involving precise assessment of oyster population sizes within specific reef areas. However, the current methods of tracking oyster populations are approximate and lack precision. To address this research gap, the authors developed an AI-empowered project for oyster detection. Specifically, they created a dataset of wild oysters, utilized Roboflow for image annotation, and employed image augmentation techniques to augment the training data. Then, they fine-tuned a YOLOv8 computer vision object detection model using their dataset. The results demonstrated a mean average precision (mAP) of 85.2 percent and an accuracy of 87.7 percent for oyster detection. This approach improved upon previous attempts to detect wild oysters, offering a more effective solution for population assessment, which is a fundamental step toward sustainable oyster restoration project management.

KEYWORDS

AI, Ecosystem, Machine Learning, Oyster, Sustainable Development

INTRODUCTION

Sustainability and environmental awareness are of utmost importance in today's world (Alam & Islam, 2021; Severo et al., 2021). Climate change, habitat loss, pollution, and resource depletion are pressing issues that demand our attention. The health of our planet directly impacts our well-being, and we must strive to preserve and protect it for current and future generations. An increasing number of nations have been actively engaged in prioritizing sustainable development alongside economic growth (Cheng et

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al., 2022; He et al., 2022). Safeguarding the environment through sustainability encompasses targeted actions including the responsible stewardship of natural resources (Li et al., 2022; Sun et al., 2022), waste reduction (Sharma et al., 2020), mitigation of air pollution (Lin & Li, 2022; Yu et al., 2022), the preservation of biodiversity (Mittermeier et al., 2021), and the advancement of renewable energy utilization (Bui & Tseng, 2022; Zhu et al., 2022). These efforts collectively alleviate the negative impact of human activities on the environment, fostering an environmental self-regeneration and ensuring a sustainable future (Nunes et al., 2021; Uniyal et al., 2021; Zhou et al., 2022).

Ecosystems are the life-support systems of our planet, and they assume a fundamental role in achieving environmental sustainability (Arora & Mishra, 2019; Maes et al., 2019; Adla et al., 2022). These sophisticated networks, comprised of living organisms, their habitats, and the physical environments that they interact with, provide essential services supporting life on Earth (Cordier et al., 2021; Geary et al., 2020). Ecosystems control our climate, cleanse our air and water, pollinate the crops, and recycle vital nutrients (Fahad et al., 2022; Saha & Bauddh, 2020). They also offer essential territories for myriad species, boosting biodiversity (Davison et al., 2021; Swan et al., 2021). Furthermore, ecosystems offer essential resources, including provisions, pharmaceutical composites, and raw materials that contribute to human welfare and economic activities (Arroyo-Rodríguez et al., 2020; Pinho et al., 2021). Therefore, we must acknowledge the profound correlation between human activities and ecosystems to ensure sustainability. Safeguarding and revitalizing these natural ecosystems is not just a moral obligation, but it is also a vital requirement for our survival and the well-being of our planet (Dixson-Declève et al., 2022; Shrivastava & Zsolnai, 2022).

Within the living ecosystem of New York Harbor, oysters serve as a keystone species (Taillie et al., 2020). These remarkable filter feeders have the capacity to purify up to 50 gallons of water daily, significantly enhancing the water quality in the harbor (Everhart & Naundorf, 2021; Malik et al., 2023). Over the past decades, numerous oyster restoration projects have been launched, and they have been continually maintained and have managed to function to this day (Goelz et al., 2020; Pogoda et al., 2019; Ridlon et al., 2021; Wasson et al., 2020). The primary goal of these restoration projects is to rejuvenate the oyster populations in New York Harbor through the extensive creation and monitoring of oyster reefs. A crucial element of these restoration endeavors involves the precise assessment of oyster population sizes within specific reef areas (Hogan & Reidenbach, 2019; McClenachan et al., 2020). However, the current method of tracking oyster populations relies on estimates, and the counting techniques employed by existing oyster restoration projects lack precision (Zhu, 2023).

One of the key challenges in accurately counting oysters in a particular oyster reef is the limited availability of oyster detection models trained on wild oysters (Chand & Bollard, 2021). Most existing research papers in this field have primarily focused on training oyster detection models using computer-simulated oysters (Lin et al., 2022) or oysters from controlled farm environments (Sadrfaridpour et al., 2021). While these studies have provided valuable insights into oyster detection methodologies, the applicability of their findings to wild oyster populations in the New York Harbor remains uncertain.

In light of these limitations, there is an urgent demand for the creation of oyster detection models that are finely tuned to address the unique characteristics of wild oyster populations in the New York Harbor. Developing these models through the utilization of authentic data obtained from oyster reefs within the harbor promises to enhance the precision and dependability of oyster population evaluations. These advancements in oyster detection technology will yield benefits not only for the Billion Oyster Project (BOP) and similar oyster restoration initiatives but will also substantially contribute to our broader comprehension and preservation of oyster populations within estuarine ecosystems. To address this research gap, this paper develops and evaluates a novel oyster detection model using data collected from wild oyster reefs in the New York Harbor. By leveraging AI-empowered computer vision techniques and machine learning algorithms, we seek to enhance the accuracy of oyster population assessments and provide a more reliable method for monitoring oyster restoration efforts.

The paper is organized as follows. The next section reviews prior literature on the interconnections between sustainability and ecosystems and summarizes relevant research on oyster detection. The third section details the methodology by illustrating the dataset creation and model training processes. The fourth section presents the results of our experiments and discusses the practical applications of our findings. The last section concludes the paper by highlighting the contributions, limitations, and future research directions.

LITERATURE REVIEW

A comprehensive understanding of sustainability and its relationship with ecosystems is crucial in contemporary environmental discourse (Chapin et al., 1996; Kay et al., 1999; Lu et al., 2015; Roche & Campagne, 2017). Sustainability, often defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs, is intrinsically linked to ecosystems (Bennett et al., 2015; Filho et al., 2020; Schröter et al., 2017). Ecosystems, as the intricate web of living organisms and their physical environments, play a fundamental role in supporting sustainable practices (Custódio et al., 2019; Vannevel & Goethals, 2020; Zucchella & Previtali, 2018).

One key aspect of this relationship is the ecosystem services concept (Grunewald & Bastian, 2015; Peterson et al., 2010), highlighting the countless benefits humans derive from ecosystems. Ecosystem services encompass provisioning services (e.g., food and freshwater) (Deng et al., 2013; Shackleton, 2021), regulating services (e.g., climate regulation and disease control) (Balasubramanian, 2019; Kim et al., 2021), supporting services (e.g., nutrient cycling) (Abson & Termansen, 2011; Wrede et al., 2018), and cultural services (including spiritual and recreational benefits) (Daniel et al., 2012; Plieninger et al., 2013). Recognizing the significance and interrelationships of these services is essential for sustainable resource management and policy development (Bennett et al., 2009).

Biodiversity within ecosystems is another vital component of sustainability (Laurila-Pant et al., 2015). Diverse ecosystems are more resilient to environmental changes (Fischer et al., 2006), providing a buffer against disturbances and enhancing their capacity to deliver ecosystem services (Mori et al., 2016; Thom & Seidl, 2015). Moreover, biodiversity is critical for developing sustainable agriculture, medicine, and biotechnology (Mannion, 1995; Reid, 1995; Sen & Samanta, 2015). However, human activities, including deforestation, pollution, and habitat destruction, have led to ecosystem degradation and loss of biodiversity, which can have disastrous consequences for sustainability, disrupting the delicate balance of ecosystem services and threatening human well-being (Adla et al., 2022). Therefore, it is paramount to safeguard and restore ecosystems to achieve sustainability goals (Hobbs & Harris, 2001). This understanding underscores the importance of conservation efforts, sustainable resource management practices, and the incorporation of ecological principles into policymaking and decision-making processes.

Oysters play a crucial role in the vitality of living ecosystems, especially in aquatic environments like estuaries and coastal waters (Coen et al., 1998). As filter feeders, oysters are highly efficient in cleansing the surrounding water. Oysters can filter water to remove particles and impurities while enhancing water quality, which helps maintain the ecosystem's health and supports the survival of various species of marine life (Shih & Chang, 2015). Moreover, oysters contribute to forming complex reef structures that provide essential habitats and shelter for numerous aquatic organisms (Goodin et al., 2018). Oysters also serve as a food source for many creatures, creating a significant link in the food web. Their role in water purification, habitat creation, and nutrient cycling makes them a keystone species and exemplifies their importance for the balance and well-being of coastal ecosystems (Ruesink et al., 2005). From an ecological perspective, Protecting and restoring oyster populations is vital and crucial for ensuring the resilience and sustainability of our planet's coastal regions.

Oyster restoration projects play a vital role in revitalizing and preserving our delicate ecosystems (Grabowski & Peterson, 2007). As a keystone species, oysters contribute significantly to improving water quality and overall ecological balance. However, the success of these restoration initiatives is greatly hindered by the challenge of precisely counting oyster populations within our harbors (Hogan & Reidenbach, 2019; McClenachan et al., 2020). Accurate oyster population assessments are essential for monitoring progress, evaluating restoration success, and ensuring the long-term health of marine environments. The current methods for counting oysters in harbors are primarily based on estimations rather than precise measurements (Chand & Bollard, 2021). Oyster populations in these estuarine ecosystems are monitored using simplified sampling techniques, often involving visual observation, which may be highly subjective and prone to errors (Lin et al., 2022; Sadrfaridpour et al., 2021). Typically, these methods lack the necessary level of precision required for accurate population assessment. Oyster restoration projects rely on these approximate counts, making it challenging to evaluate the true impact of these initiatives on oyster populations and their ecosystems. The inaccuracies in counting methods hinder the effective management of oyster populations and compromise the success and objectives of oyster restoration projects, ultimately impeding the conservation efforts vital for this keystone species. Addressing this challenge is a fundamental step towards sustainable oyster restoration efforts and safeguarding the future of our harbors, which is the main focus of this study.

METHODOLOGY

By understanding the distribution and health of oyster populations, we can better manage and protect these essential aquatic ecosystems. Therefore, the collected data's transformation into a usable format was a critical step in our research. A key issue was the collection of data relevant to oyster populations in their natural habitats. To overcome this, we used a FIFISH V6 Underwater Drone (Fifishv6, 2023), a remotely operated vehicle (ROV) capable of capturing high-resolution underwater videos.

Dataset

To build the dataset, we deployed the ROV in different oyster reefs within the New York Harbor. The ROV captured video data of the oyster reefs, ensuring a diverse representation of oyster populations in their natural habitats. By systematically navigating the ROV in a grid-like pattern, we covered a wide range of oyster habitats and recorded videos for subsequent analysis. This video data served as the foundation for the subsequent steps in the research.

The next challenge was constructing a sufficiently large enough and diverse dataset to train a machine learning model. Our dataset relied on the data collected through our fieldwork but was also supplemented with additional data from Professor Miao Yu from the University of Maryland (Yu, 2023) and Dr. Anna Weiss from the Billion Oyster Project (Weiss, 2023). The result was a robust, representative dataset.

Model

Similar to the approach adopted by Lin et al. (2022) and Sadrfaridpour et al. (2021), we used a supervised learning approach to train our model. To annotate the oysters in the video frames, Roboflow was utilized (Roboflow, 2023). Roboflow provides efficient tools for object detection annotation, enabling accurate labeling of oysters in each video frame (Roboflow, 2023). This annotation process ensured that subsequent training of the object detection model would be based on accurately labeled data, improving the model's ability to detect oysters in real-world scenarios.

To prepare our dataset to be trained on the model, we employed image augmentation. By applying various transformations to the annotated frames, we increased the diversity and variability of the dataset. The augmentation techniques used included horizontal and vertical flips, 90° rotations in different directions (clockwise, counter-clockwise, and upside down), rotations within a range of -22° to +22°, horizontal and vertical shearing with a range of ±26° and ±28° respectively, brightness adjustment within a range of -25% to +25%, blur of up to 1.5 pixels, and the addition of noise up to 10% of the pixels. These augmentation techniques aimed to simulate different lighting conditions, angles, and disturbances typically encountered in underwater environments. These were performed to enhance our model's robustness and generalization capabilities (Zhang et al., 2023).

The final dataset consisted of 2000 annotated images, with 600 supplemented by outside sources, as mentioned earlier, each containing oyster instances labeled with bounding boxes. This dataset served as the foundation for training and evaluating the oyster detection model. To ensure an unbiased evaluation, the dataset was randomly split into train, validation, and test sets, following an 80:10:10 ratio. This split allowed for training the model on a large portion of the data while also providing independent sets for validation and testing.

Training With Pre-Trained Models

In training the oyster detection model, there are many viable computer vision object detection algorithms to train off of, such as YOLOv5 (Jocher, 2020) and YOLOX (Ge et al., 2022). However, we utilized the YOLOv8 (Jocher et al., 2023) computer vision object detection model, as it aligns with the latest advancements in the field. This algorithm has proven effective in detecting objects in complex scenes in real time and has been widely adopted in the field of computer vision (Terven & Cordova-Esparza, 2023). We used Google Colab, a cloud-based Jupyter Notebook environment (Google Colab, 2023), to finely tune a YOLOv8 model on our annotated oyster dataset, which granted us the computational resources required for training the model efficiently.

The training was performed using the annotated images from the training set, with the model being iteratively updated over 40 epochs. We then uploaded our model back to Roboflow to assess its performance with our validation and test sets using mAP and accuracy values (Roboflow, 2023). To ensure the robustness and reliability of the results, we conducted the evaluation by averaging the performance metrics over 10 independent runs of the oyster detection model. This approach helps mitigate any potential bias or variability introduced during the training and evaluation processes, providing a more comprehensive and unbiased assessment of the model's performance.

RESULTS

The developed oyster detection model was evaluated using various performance metrics to assess its accuracy and precision in detecting oysters within the New York Harbor. The results of the evaluation demonstrated promising capabilities for accurately identifying and localizing oysters in underwater video data.

Table 1 shows the mAP and accuracy values of the oyster detection model in the 10 individual runs. The mAP was found to be in the range of 84.4% to 85.9%, with an average of 85.2% and a standard

Table 1. mAP and accuracy values over ten runs

Run #	*mAP*	*Accuracy*
1	84.4%	91.8%
2	84.9%	89.5%
3	85.2%	87.6%
4	85.6%	85.9%
5	85.9%	84.5%
6	85.4%	86.7%
7	85.0%	88.2%
8	85.8%	85.1%
9	85.4%	87.0%
10	84.7%	90.3%
Average	85.2%	87.7%
Std. Dev.	0.5%	2.3%

deviation of 0.5%, indicating that the model correctly identified oyster instances in the video frames in most of the cases with very small variations. This mAP significantly improves the approximate counting methods commonly used in oyster population assessments (Zhu, 2023).

Moreover, the accuracy of the model was found to be in the range between 84.5% and 91.8%, with an average of 87.7% and a standard deviation of 2.3%. This also indicates that the model has the potential to greatly enhance the accuracy of oyster population detection.

It is important to note that these results represent a significant step forward in oyster detection technology, but further refinements and optimizations may be required to achieve even higher mAP and accuracy. Future research could focus on exploring additional image augmentation, fine-tuning model parameters, or incorporating more advanced object detection architectures to further improve the performance of the oyster detection model.

Upon completing the oyster detection model development and evaluation, a range of pivotal subjects come to the forefront, justifying comprehensive exploration. These encompass potential applications of the model and prospects for enhancement. One of the primary applications of the developed oyster detection model is real-time oyster counting and detection. The model's ability to accurately identify and localize oysters in underwater video data opens up possibilities for real-time monitoring of oyster populations in the New York Harbor. This capability can provide valuable insights for oyster restoration programs, enabling more efficient and targeted management strategies. Furthermore, real-time oyster detection can support environmental monitoring efforts by assessing the health and status of oyster populations in response to changing environmental conditions and aid in the design of more effective oyster restoration programs.

In addition to real-time oyster counting, the oyster detection model may have other potential applications. For instance, it can be used to analyze oyster behavior and interactions within the reef, providing insights into their ecological role and social dynamics. Furthermore, the model's ability to detect and localize other marine organisms or objects of interest in the video data opens up opportunities for broader ecological monitoring and research beyond oyster populations alone. This versatility enhances the value and applicability of the developed model in the context of broader marine ecosystem studies.

CONCLUSION

Sustainability and environmental awareness are of utmost importance worldwide. Ecosystems are our planet's life-support systems that facilitate sustainable development. Oysters play a crucial role in marine ecosystems, and their population assessment is integral to the success of restoration efforts. Numerous oyster restoration projects have been launched with a crucial element involving precise assessment of oyster population sizes within specific reef areas. However, the current methods of tracking oyster populations are approximate and lack precision. Our research aims to enhance these monitoring processes. We have demonstrated the use of an underwater remotely operated vehicle (ROV), the FIFISH V6, equipped with a high-resolution camera for capturing footage of the wild oyster reefs in the New York Harbor. Additionally, we curated and annotated a dataset composed of images extracted from this underwater footage, along with contributions from external sources.

To leverage this dataset, we employed the advanced YOLOv8 computer vision object detection model, utilizing Roboflow for training and evaluation. Our trained model can detect and count wild oysters with high mAP and accuracy – achieving an average mAP (mean Average Precision) of 85.2% and accuracy of 87.7% over 10 runs. Our model outperforms previous attempts and provides a more accurate tool for real-time oyster counting in the wild. The successful application of this model is the first step toward a comprehensive, efficient tool for ecosystem monitoring and oyster restoration projects.

While the developed oyster detection model has demonstrated promising results, there is room for improvement. One area of improvement lies in expanding and diversifying the dataset. The current model was trained on a dataset comprising 2,000 annotated images. However, the dataset size was limited due to the constraints imposed by the Roboflow platform, which restricts the number of images in a dataset. In most cases, increasing the dataset size by collecting and annotating more images from a wider range of oyster reefs would enhance the model's generalization capabilities and potentially improve its performance. Additionally, the model's performance may vary when applied to oyster populations in different geographical locations or with distinct ecological characteristics, underscoring the need for further evaluation and validation across diverse habitats.

For future work, expanding the dataset used for training the model can lead to more comprehensive and accurate results. Collecting additional video data from a wider range of oyster reefs in the New York Harbor, as well as other estuarine ecosystems, can improve the model's generalization capabilities and increase its applicability to diverse environments. Additionally, future work should focus on refining the model, addressing the current limitations, and exploring new data collection and analysis techniques with emerging technologies, such as big data analytics (Bag et al., 2022; Xie et al., 2022; Xing et al., 2022), blockchain (Buthelezi et al., 2022; Harshvardhan & Teoh, 2022; Qiu, 2022), edge computing (Liang et al., 2022; Huang et al., 2021), the Internet of Things (Almomani et al., 2021; Peng et al., 2021), and deep learning (Wu et al., 2022; Zhang & Song, 2022; Zhao, 2022). By continuously improving and expanding upon this research, we can contribute to the advancement of oyster restoration efforts, enhance ecological management practices, and further our understanding of oyster populations and their vital role in estuarine ecosystems.

CONFLICT OF INTEREST

Authors have no conflict of interest to declare.

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