Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 7, S. 477-488, 10, 2023

Araştırma Makalesi

IJANSER

https://alls-academy.com/index.php/ijanser
ISSN: 2980-0811

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 7, pp. 477-488, 10, 2023

Research Article

Innovations in Ocean Plastic Cleanup Technologies for Preserving Marine Resources

Sarker Mohammad Rezaul Karim[1*], Zulkefly Sulaiman[1], Nayeem Asif[2], Wahidul Alam[3] and Naina Islam[4]

[1]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
[2]Department of Architecture, Kullyah of Architecture and Environmental Design, International Islamic University Malaysia
[3]Department of Oceanography, Faculty of Marine Science and Fisheries, University of Chittagong, Chattagram 4331, Bangladesh
[4]Institute of Marine Sciences, Faculty of Marine Science and Fisheries, University of Chittagong, Chattagram 4331, Bangladesh

**Corresponding author's email: sarker.mohammad@upm.edu.my*

(Received: 20 November 2023, Accepted: 27 November 2023)

(4th International Conference on Engineering and Applied Natural Sciences ICEANS 2023, November 20-21, 2023)

ATIF/REFERENCE: Karim, S. M. R., Sulaiman, Z., Asif, N., Alam, W. & Islam, N. (2023). Innovations in Ocean Plastic Cleanup Technologies for Preserving Marine Resources. *International Journal of Advanced Natural Sciences and Engineering Researches*, 7(10), 477-488.

***Abstract* –** Plastic pollution in ocean is a burning issue globally and cleanup of the debris from the ocean is essential. The manuscript provides a thorough examination of diverse innovative ocean cleanup technologies, showcasing their unique strengths and contributions. Boyan Slat's Ocean Cleanup System excels in addressing large debris, while Seabin Technology effectively targets surface-level plastics in marinas. Mr. Trash Wheel demonstrates high efficiency in rivers, preventing plastics from entering oceans. Drones and Autonomous Vehicles offer versatility and coverage for large areas, while Community-Based Cleanup Initiatives foster engagement and address plastics at their source. The Bubble Barrier is effective in capturing floating plastics in rivers, and the Ocean Cleanup Interceptor efficiently tackles plastic pollution in river mouths. Bio-Inspired Cleanup explores biomimicry for precise plastic identification. The FRED (Floating Robot) is a mobile solution designed for high seas cleanup. Aquatic Drones with AI leverage artificial intelligence for precise plastic identification for collection, and Ocean Plastic Collector Arrays provide a passive, scalable design for surface-level plastics. This comprehensive review equips researchers and practitioners with valuable insights into the diverse and effective strategies available to combat ocean plastic pollution.

Keywords – Ocean Cleanup Technology, Bubble Barrier, Bio-Inspired Cleanup, Boyan Slat's Ocean Cleanup, Drones and Autonomous Vehicles, FRED, Mr. Trash Wheel, Seabin Technology

I. INTRODUCTION

Plastic pollution in the world's oceans has reached alarming proportions, presenting a pressing global environmental challenge. The accumulation of plastic waste in the ocean has significant consequences for marine life, human health, and the environment. According to a recent study, there are approximately 5.25 trillion pieces of plastic debris in the ocean, with an estimated 8 million metric tons added each year [1]. This has led to the development of various cleanup technologies to mitigate the impact of plastic pollution on the ocean, and there is an urgent need to study the effectiveness of different cleanup technologies for adoption to safeguard ocean resources. This review aims to provide an overview of the current landscape of ocean plastic cleanup technologies, their efficacy, challenges, and the critical role they play in preserving marine biodiversity and ecological balance.

Also highlighted by Jambeck et al. [2], an estimated 8 million metric tons of plastic enter the oceans each year, leading to profound ecological consequences. Plastic debris poses threats to marine life, disrupts food chains, and contributes to the formation of vast oceanic garbage patches. By synthesizing existing literature and research findings, this paper seeks to underscore the importance of implementing and advancing ocean plastic cleanup technologies as a pivotal strategy in mitigating the far-reaching consequences of plastic pollution. It will explore the various technologies currently deployed or under development, ranging from innovative autonomous systems to community-based cleanup initiatives. By drawing on studies like Lebreton et al. [3] and Wilcox et al. [4], which have assessed the distribution and impact of plastic debris, the review aims to evaluate the effectiveness of these technologies in reducing the abundance of plastic in oceans. Moreover, it will contribute valuable insights to the scientific community, policymakers, and environmental practitioners, guiding future research and interventions aimed at securing the longevity of ocean resources.

The importance of this paper lies in its potential to contribute to the ongoing efforts to safeguard the ocean resources. By providing a comprehensive overview of the current state of research on ocean plastic cleanup technologies, the paper can help to raise awareness of the issue and promote the development of more effective solutions.

II. CLEANUP TECHNOLOGIES

Plastic pollution in our oceans is a critical environmental challenge, necessitating innovative solutions for effective cleanup. A diverse array of cutting-edge technologies has been designed to tackle ocean plastic waste (Table 1). From autonomous robotic systems and community-driven initiatives to biomimicry-inspired solutions, each technology brings unique strengths and contributions to the global effort in combating the pervasive issue of plastic pollution. A short description of the technologies along with merits and demerits are narrated.

Boyan Slat's Ocean Cleanup System:

Boyan Slat's Ocean Cleanup System is a pioneering and passive ocean cleanup technology designed to address the issue of plastic pollution in the world's oceans. Developed by Boyan Slat, a Dutch inventor and entrepreneur, the system utilizes a passive drifting barrier, known as a "cleanup boom," to capture and concentrate plastic debris. The primary concept is to leverage ocean currents to passively guide plastic waste toward the cleanup boom, where it can then be efficiently collected and removed [5].

The system consists of long floating barriers with a skirt that hangs beneath the surface of the water. These barriers are strategically positioned in ocean gyres, where plastic tends to accumulate. The floating barriers are designed to passively catch and concentrate plastic debris as ocean currents move through the system. The skirt beneath the surface prevents plastic from escaping underneath. Once the plastic is concentrated, it is corralled towards collection platforms. These platforms act as vessels for the collected plastic and are periodically emptied by support vessels. The collected plastic is then transported to recycling facilities for processing. The goal is to recycle the retrieved plastic into usable materials, minimizing the environmental impact of plastic pollution. The Ocean Cleanup System is designed to target larger pieces of plastic debris, ranging from large fishing nets to smaller plastic fragments. By leveraging ocean currents, the system can cover vast areas of the ocean where plastic tends to accumulate, increasing its potential effectiveness. The system operates passively, driven by natural ocean currents, reducing the need for active energy inputs. The design allows for the potential cleanup of large areas affected by plastic pollution ([6], [7]

Fig. 1. Boyan's Slat Ocean Cleanup System [7]

The Ocean Cleanup System has undergone various iterations and testing phases, with a series of deployments to assess its efficiency and address design challenges. Continuous improvements are being made to enhance its effectiveness and minimize environmental impacts. The project represents a pioneering effort to combat ocean plastic pollution on a large scale, and ongoing developments aim to optimize its performance [8].

Seabin Technology:

Seabin Technology involves the deployment of floating garbage bins equipped with a pump system designed to capture and filter floating debris, microplastics, and oils from marinas, ports, and other water bodies. These innovative devices are strategically placed in the water, where they use a pump to create a flow, drawing in surrounding water and trapping floating debris inside a collection bag. The water is then filtered and pumped back into the marina. The collected debris is periodically removed, and the Seabin is capable of capturing various sizes of floating litter, including plastics and organic materials [9]. Seabin Technology has proven effective in capturing surface-level debris in marinas and enclosed water bodies. It addresses the issue of plastic pollution at its source by intercepting waste before it has the chance to disperse into the open ocean. Research by Gartry [10] and ITU [11] highlights the efficiency of Seabin-like technologies in removing floating debris from marinas and coastal areas, contributing to the reduction of plastic pollution in these environments. It is particularly effective in enclosed water bodies such as marinas and ports. Seabin is relatively easy to install and maintain, making them accessible for various locations. Capable of capturing microplastics along with larger debris. However, since it is primarily designed for use in marinas and ports, it has limitation to its application in open ocean environments. Regular maintenance is necessary to empty collected debris and ensure optimal performance.

Fig. 2. Seabin [11]

Mr. Trash Wheel:

The "Mr. Trash Wheel" is an innovative water-based cleanup technology designed to remove plastic and debris from rivers and water bodies, preventing it from reaching the oceans. One prominent example is the "Mr. Trash Wheel" in Baltimore, Maryland, which utilizes a solar-powered waterwheel to collect and remove floating debris from the city's Inner Harbor [12], [13]). The system consists of a floating platform with a large waterwheel at its center. Long booms with submerged skirts funnel waste into a central hub, where autonomous rakes scoop it on to a conveyor belt that deposits it on a barge for later disposal [14].

The waterwheel is powered by the energy generated through the flow of water, which is harnessed to turn the wheel.

The effectiveness of Mr. Trash Wheel lies in its ability to capture and remove surface-level debris from rivers before it enters the oceans. By strategically placing such devices in water bodies with significant plastic input, it acts as a barrier, preventing the further downstream transport of plastics and other pollutants. The system operates on solar power, making it environmentally friendly and sustainable [15]. Mr. Trash Wheel operates autonomously, requiring minimal human intervention for its day-to-day activities. Particularly effective in rivers and harbors, addressing plastic pollution at its source [16]. However, the application of Mr. Trash Wheel is primarily limited to rivers and water bodies with a consistent flow, and it may not be suitable for open ocean cleanup. While generally low-maintenance, these systems still require periodic checks and maintenance to ensure their continuous operation.

Fig. 3. Mr. Trash Wheel. Source: [17]

Drones and Autonomous Vehicles:

Drones and autonomous vehicles have emerged as innovative tools for addressing ocean plastic pollution by offering efficient and technologically advanced means of identification, monitoring, and cleanup. Unmanned aerial vehicles (UAVs) equipped with cameras and sensors can survey vast ocean expanses, identifying concentrations of plastic debris. Underwater drones are designed to navigate beneath the surface, capturing imagery and collecting data on underwater plastic waste. These technologies, when integrated with artificial intelligence (AI), enable automated plastic identification, streamlining cleanup efforts and optimizing resource allocation. The data collected by these vehicles provide valuable insights into the distribution and types of plastic pollution, aiding in the strategic deployment of cleanup resources.

Fig. 4. Drone and Automatic Vehicle [18]

The use of drones and autonomous vehicles enhances the effectiveness of ocean cleanup efforts by providing a bird's-eye view and underwater insights into plastic pollution. Research by Turton et al.[19] highlights the efficiency of drones in monitoring marine litter, allowing for rapid assessments of plastic debris in remote and inaccessible areas. Autonomous underwater vehicles, as demonstrated by Dowdeswell et al. [20], contribute to the understanding of sub-surface plastic distribution, aiding in targeted cleanup initiatives. Drones and autonomous vehicles can cover large areas, reaching remote or challenging locations [21]. Automation and AI enhance the speed and accuracy of plastic identification and data collection (Schmidt et al., 2017). The technology is scalable for both localized cleanup efforts and large-scale operations [22]. Some demerits are - Limited capacity for large debris collection compared to physical cleanup technologies [23]. Adverse weather conditions can impact the operation of aerial drones [24].

Community-Based Cleanup Initiatives:

Community-based cleanup initiatives involve engaging local communities in active participation to address plastic pollution in coastal areas. These initiatives leverage the power of community involvement, raising awareness, and fostering a sense of shared responsibility for environmental stewardship. By empowering local residents to take an active role in cleanup efforts, these initiatives not only contribute to immediate plastic waste reduction but also promote long-term sustainable practices. Community-based cleanup initiatives typically include organized cleanup events, educational programs, and the establishment of recycling and waste management systems at the community level. Local residents are encouraged to participate in beach cleanups, riverbank cleanups, or other activities targeting areas with high plastic pollution. These initiatives often collaborate with schools, NGOs, and local authorities to maximize outreach and impact. The goal is to instill a sense of ownership and responsibility among community members, encouraging behavioral changes that contribute to a cleaner environment.

Research has shown that involving local communities in cleanup activities can be highly effective in reducing plastic pollution. A study by Stojanovic et al. [25] demonstrated the positive impact of community engagement in cleanup initiatives, leading to a significant reduction in plastic waste along coastlines. The participatory nature of these initiatives ensures that cleanup efforts are sustained over time, as community members become advocates for environmental conservation. Local Empowerment: Empowers local communities to actively contribute to environmental conservation. Fosters the adoption of sustainable waste management practices at the community level. Encourages behavioral changes, leading to reduced plastic consumption and improved waste disposal habits. However, there are demerits of the technology as below - Organizing and maintaining community-based initiatives can be resource-intensive in terms of coordination, logistics, and ongoing community involvement. Limited in scope to specific community areas; may not address broader regional or open ocean plastic pollution.

Fig. 5. Community-based Cleanup

Bubble Barrier:

The Bubble Barrier [26] is an innovative ocean cleanup technology designed to capture and divert plastic waste from rivers and water bodies, preventing it from reaching the open sea. The system releases a curtain of bubbles from a perforated tube placed on the riverbed, creating a barrier that traps floating plastics and guides them to collection points along the riverbanks. The continuous release of bubbles generates an upward flow, creating a barrier that traps plastics and prevents their downstream movement. Typically installed across the width of a river, strategically placed in areas with high plastic concentration. The size and density of the bubbles are carefully controlled to effectively trap plastics while allowing water and marine life to pass through [14]. The Bubble Barrier has shown effectiveness in capturing a wide range of plastic debris, including both macroplastics and microplastics. Plastic Soup Foundation [15] and Hydro International [13] have demonstrated the system's ability to significantly reduce the transport of plastic waste in rivers, acting as a barrier that redirects the flow of plastics toward the riverbanks. The technology is non-intrusive to aquatic ecosystems and marine life, minimizing the risk of bycatch. Well-suited for river environments where plastic waste enters oceans, making it an effective solution at the source. Compared to some other cleanup technologies, the Bubble Barrier offers a relatively cost-effective and scalable solution [26]. The system has a few disadvantages - The Bubble Barrier is primarily designed for rivers and may not be as effective in open ocean environments. Effectiveness may depend on the depth and width of the river, requiring customized installations.

Fig. 6. Bubble Barrier [26]

Ocean Cleanup Interceptor:

The Ocean Cleanup Interceptor is an innovative and autonomous plastic collection system designed to tackle plastic pollution in rivers before it reaches the ocean. Developed by The Ocean Cleanup organization, founded by Boyan Slat, the Interceptor is a solar-powered vessel strategically positioned in river mouths to capture and remove plastic debris flowing downstream [27]. The system utilizes the natural flow of rivers, guiding plastic waste toward an opening where it is efficiently collected and prevented from entering the open sea. The Interceptor features a floating barrier that spans the width of the river, guiding plastic waste towards a conveyor belt. The conveyor belt then lifts the debris from the water and deposits it into onboard containers for later disposal. The modular design allows for scalability, enabling deployment in multiple river locations globally.

Fig. 7. Ocean Cleanup Array [27]

Bio-Inspired Cleanup:

Bio-inspired cleanup technologies draw inspiration from natural ecosystems and the behaviors of marine organisms to develop innovative strategies for plastic waste removal. These approaches leverage the efficiency and sustainability observed in nature to design solutions that minimize environmental impact while effectively capturing and managing ocean plastics.

Whale-Inspired Filtration: Taking inspiration from baleen whales' filtration mechanisms, researchers explore the development of vessels equipped with specialized filters [28]. These filters mimic the baleen structure, allowing for efficient plastic capture while minimizing bycatch. This bio-inspired approach aims to enhance filtration precision and reduce the ecological impact on marine life.

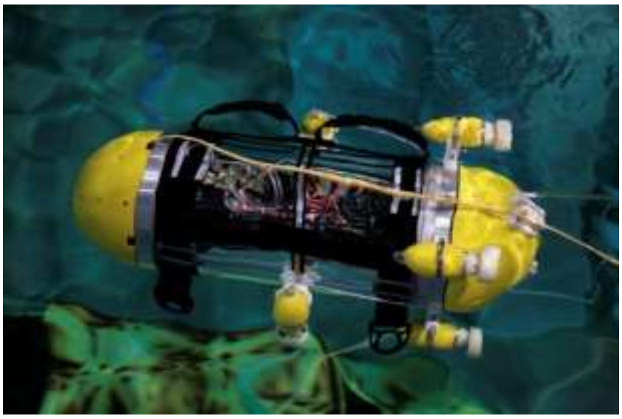

Fig. 8. Bio-Inspired Cleanup [28]

FRED (Floating Robot for Eliminating Debris):

FRED (Floating Robot for Eliminating Debris) is a solar-powered robotic garbage collector that is designed to clean up plastic debris from the ocean[12].It is a catamaran-based robot that is capable of picking up debris ranging in size from 3 centimeters to 2 feet[1]. FRED is offered in three sizes: a fully operational 16-foot prototype, two small-scale 6-foot prototypes, and smaller prototypes to serve as scouts for mapping out the region before the larger FREDs move in[1].

In addition to collecting debris, FRED is equipped with sensors that monitor water quality and create underwater geographic mapping [29]. The data collected by FRED can help predict the impacts of climate change or runoff pollution, and provide valuable data for understanding and managing waterways[1]. FRED is an innovative solution to the problem of ocean plastic pollution and has the potential to make a significant impact in safeguarding the ocean resources.

It is versatile and mobile; designed for high seas cleanup. However, the demerit is it is limited capacity for large debris; potential challenges in adverse weather.

Fig. 9. Floating Robot for Eliminating Debris [29]

Aquatic Drones with AI:

Aquatic drones equipped with artificial intelligence (AI) represent an innovative approach to identifying and collecting plastic waste in oceans. These unmanned vehicles leverage AI algorithms to autonomously detect and categorize plastic debris, allowing for efficient and targeted cleanup efforts. Aquatic drones with AI are designed to navigate oceanic environments, equipped with sensors and cameras for real-time data collection. The incorporation of AI algorithms enables these drones to distinguish between various materials in the water, with a specific focus on identifying and tracking plastic waste. Once detected, the AI system can instruct the drone to collect the plastic debris, either by using onboard collection mechanisms or by guiding other cleanup vessels to the location. The effectiveness of aquatic drones with AI lies in their ability to autonomously scan large areas of the ocean, identifying and targeting plastic waste with high precision. The use of AI enhances the accuracy of detection, reducing false positives and streamlining cleanup operations [30]. This technology is particularly effective in areas with dispersed plastic debris, where targeted identification is crucial for efficient cleanup. The AI algorithms enable precise identification of plastic waste, minimizing the chance of overlooking smaller or camouflaged debris. Aquatic drones can operate autonomously, reducing the need for constant human intervention and enabling extended surveillance periods. The technology can be adapted to various marine environments, making it suitable for both coastal and open ocean cleanup efforts.

The technology is subjected to the demerits as below - Developing and implementing AI-equipped aquatic drones involves significant initial costs for technology development and testing. Ongoing maintenance and software updates are necessary to ensure the continued effectiveness of the AI algorithms. Despite efforts to minimize environmental impact, the presence of drones in marine ecosystems may still pose challenges, particularly regarding potential disturbances to marine life.

Fig. 10. Aquatic Drone with AI [30]

Ocean Plastic Collector Arrays:

One of the most notable inventions of the NGO "Ocean Cleanup" is the Ocean Plastic Collector Array, which is a passive system designed to clean up plastic pollution from the world's oceans [31]. The system consists of a chain of floating barriers that are each two kilometers long and have no nets[2]. The barriers use the sea's currents to move the waste onto platforms so that the ocean may "clean itself"[2]. The Ocean Cleanup Array will be tested next year near Tsushima, an island located in the waters between Japan and South Korea, and will span over 2,000 meters[34]. The system will be operational for at least two years and will be almost entirely self-sufficient, running on energy harnessed from the sun and waves[4]. It requires low energy and is a scalable design. But it has limited effectiveness in high seas and may be challenged by weather conditions.

Table 1. Comparative description of different ocean cleanup innovative technologies.

Technology	Description	Effectiveness	Merits	Demerits	Reference
Boyan Slat's Ocean Cleanup System	A passive cleanup system using a floating barrier to concentrate plastic waste in ocean currents.	Effective for large debris; potential for significant reduction in surface-level plastics.	Passive and scalable design; targets surface-level plastics.	Challenges with capturing smaller plastics; potential environmental impact.	[5], [6], [7], [8]
Seabin Technology	Floating garbage bins with pumps to collect floating debris, microplastics, and oils in marinas.	Efficient in marinas; targets surface-level plastics.	Easy installation; targets plastics in localized areas.	Limited effectiveness in open ocean; requires maintenance.	[9], [10], [11]).
Mr. Trash Wheel	Solar-powered trash interceptor using a waterwheel to collect debris in rivers and water bodies.	Highly effective in rivers; prevents plastics in rivers.	Solar-powered and autonomous; prevents plastic from entering the ocean.	Limited to rivers and inland water bodies.	[12], [13], [14], [15], [16], [17]
Drones and Autonomous Vehicles	Unmanned aerial and underwater vehicles with cameras and collection devices for plastic cleanup.	Versatile for various environments; can cover large areas.	High-tech approach; minimizes human intervention.	Limited capacity for large debris collection; challenging in adverse weather.	[18], [19], [20], [21], [22], [23], [24]

Technology	Description	Effectiveness	Merits	Demerits	Reference
Community-Based Cleanup Initiatives	Engaging local communities in cleanup activities with technology support for waste collection.	Highly effective in coastal areas; involves local residents.	Fosters community engagement and awareness; addresses plastics at the source.	Resource-intensive in organization; ongoing community involvement needed.	[25]
Bubble Barrier	Releases a curtain of bubbles in rivers to trap and guide plastic waste to collection points.	Effective in capturing floating plastics in rivers.	Non-intrusive to marine life; applicable in river environments.	Limited to rivers; may not capture submerged plastics.	[13], [14], [15], [26]
Ocean Cleanup Interceptor	Solar-powered autonomous vessels stationed in river mouths to intercept and collect plastic waste.	Efficient in rivers; prevents plastics from reaching the ocean.	Solar-powered and autonomous; and need no manual operation.	Limited to river locations; may require maintenance.	[27]
Bio-Inspired Cleanup	Biomimicry-based technologies inspired by marine life for plastic capture and filtration.	Mimics natural processes for precise plastic identification.	Potential for biomimicry to optimize plastic capture; minimizes impact on marine life.	Complex engineering; may have scalability challenges.	[28]
FRED (Floating Robot for Eliminating Debris)	Autonomous robot designed to collect floating debris, such as plastics, from the ocean.	Targets surface-level plastics; can operate in open ocean environments.	Versatile and mobile; designed for high seas cleanup.	Limited capacity for large debris; potential challenges in adverse weather.	[29]

Technology	Description	Effectiveness	Merits	Demerits	Reference
Aquatic Drones with AI	Unmanned aerial and underwater vehicles equipped with AI for autonomous plastic identification.	Utilizes AI for precise identification of plastic waste.	High-tech approach; minimizes human intervention.	Initial technology development costs; ongoing maintenance.	[30]
Ocean Plastic Collector Arrays	Floating booms and platforms to concentrate and collect plastics through natural ocean currents.	Passive system targeting surface plastics; scalable design.	Low energy requirements; scalable design.	Limited effectiveness in high seas; may be challenged by weather conditions.	[31]

III. CONCLUSION

The ocean cleanup initiatives using innovative technologies is very important to protect our ocean from pollution which require collaborative works from different countries. The developing countries may have limitation to use expensive equipment but community engagement to clean the beaches and to stop debris emission from the sources should be implemented.

REFERENCES

[1] E. Watt, M. Picard, B. Maldonado, M. A. Abdelwahab, D. F. Mielewski, L. T. Drzal, … and A. K Mohanty. "Ocean plastics: environmental implications and potential routes for mitigation–a perspective". *RSC advances*, *11*(35), 21447-21462. 2021.

[2] J. R. Jambeck, G. Roland, C. Wilcox, T. R. Siegler, M. Perryman, A. Andrady, R. Narayan, and K. L. Law. "Plastic waste inputs from land into the ocean." *Science* 347, no. 6223 (2015): 768-771.

[3] C. M. Lebreton, Laurent Joost, Van Der Zwet, Jan-Willem Damsteeg, Boyan Slat, Anthony Andrady, and Julia Reisser. "River plastic emissions to the world's oceans." *Nature communications* 8, no. 1 (2017): 15611.

[4] C. Wilcox, E. Van Sebille, and B. D. Hardesty. "A global inventory of small floating plastic debris." Environmental research letters, 14(12), 124006. 2019.

[5] https://mymodernmet.com/boyan-slat-ocean-cleanup/).

[6] Boyan Slat. "The Ocean Cleanup: statement to the 2022 United Nations Ocean Conference". https://sdgs.un.org/sites/default/files/2022-06/BoyanSlat_Founder%26CEO___TheOceanCleanup.pdf

[7] https://theoceancleanup.com/about/.

[8] Daniel Boffey "Ocean cleanup device successfully collects plastic for first time". https://www.theguardian.com/environment/2019/oct/03/ocean-cleanup-device-successfully-collects-plastic-for-first-time

[9] Krishna Kulkarni, Anand, Veerbhadrappa Prabhushetty "Seabin: and floating bin for collecting pollutants floating on surface of water". *International Research Journal of Modernization in Engineering Technology and Science (IRJMETS*), 3(8), 120-124, 2021.

[10] Gartry, Laura. "Seabin designed by Australian surfers to clean up marinas, reduce ocean pollution". (2015). https://www.abc.net.au/news/2015-12-20/seabin-designed-by-australian-surfers-to-start-cleaning-up-ocean/7044174?utm_campaign=newsweb-article-new-share-null&utm_content=link&utm_medium=content_shared&utm_source=abc_news_web

[11] International Telecommunication Unit (ITU) "How Seabin is helping clean the oceans of plastic waste", (2020) https://www.itu.int/hub/2020/05/how-seabin-is-helping-clean-the-oceans-of-plastic-waste/

[12] Hydro International. "How Mr Trash Wheel Intercepts Plastic Before it Reaches the Ocean". 2019. https://www.hydro-international.com/content/news/how-mr-trash-wheel-intercepts-plastic-before-it-reaches-the-ocean.

[13] M. W. Viviano. "2014-2019 Mr Trash, Baltimore", 2019. https://www.oceansplasticleanup.com/Cleaning_Up_Operations/Mr_Trash_River_Barge_Litter_Cleaner_Baltimore_Autonomous_Solar_Waterwheel.

[14] Thomas Russell. "Meet Mr Trash Wheel – and the other new devices that eat river plastic", 2022. https://www.theguardian.com/environment/2022/jan/11/meet-mr-trash-wheel-and-the-other-ingenious-tools-that-eat-river-plastic

[15] Plastic Soup Foundation. "Bubble screen a technological breakthrough in battle against the plastic soup"**.** https://www.plasticsoupfoundation.org/en/2018/02/bubble-screen-a-technological-breakthrough-battle-against-the-plastic-soup/, 2018.

[16] Mrtrashwheel. "Using the power of nature to clean the oceans". 2023. https://www.mrtrashwheel.com/technology/

[17] https://www.oceansplasticleanup.com/Cleaning_Up_Operations/Mr_Trash_River_Barge_Litter_Cleaner_Baltimore_Autonomous_Solar_Waterwheel.

[18] https://www.spartnerships.com/amphibious-and-autonomous-drones-and-other-vehicles-making-waves-underwater/

[19] A. Borowicz, H. Le, G. Humphries, G. Nehls, C. Höschle, V. Kosarev, and H. J. Lynch. "Aerial-trained deep learning networks for surveying cetaceans from satellite imagery". *PloS one*, *14*(10), e0212532, 2019.

[20] J. A. Dowdeswell, J. Evans, R. Mugford, G. Griffiths, Steve McPhail, N. Millard, P. Stevenson et al. "Autonomous underwater vehicles (AUVs) and investigations of the ice–ocean interface in Antarctic and Arctic waters." *Journal of Glaciology* 54, no. 187 (2008): 661-672.

[21] Sharif Razavian, Ali, Hossein Azizpour, Josephine Sullivan, and Stefan Carlsson. "CNN features off-the-shelf: an astounding baseline for recognition." In *Proceedings of the IEEE conference on computer vision and pattern recognition workshops*, pp. 806-813. 2014.

[22] Pierella Karlusich, Juan José, Fabien Lombard, Jean-Olivier Irisson, Chris Bowler, and Rachel A. Foster. "Coupling Imaging and Omics in Plankton Surveys: State-of-the-Art, Challenges, and Future Directions". *Frontiers in Marine Science* 9 (2022): 878803.

[23] Merlino Silvia, Marco Paterni, Andrea Berton, and Luciano Massetti. "Unmanned aerial vehicles for debris survey in coastal areas: Long-term monitoring programme to study spatial and temporal accumulation of the dynamics of beached marine litter." *Remote Sensing* 12 (8), 1260, 2020.

[24] L. Talley, C. Gregory, Johnson, Sarah Purkey, Richard A. Feely, and Rik Wanninkhof. "Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP) provides key climate-relevant deep ocean observations." *US CLIVAR Variations* 15 (2017): 8-14.

[25] T. A. Stojanovic, D. D. Milinkovic, M. A. Đogo and V. R. Maksimovic, "Community-based marine litter reduction activities: A case study of a beach cleanup event in Montenegro." Marine Pollution Bulletin, 152, 110898. 2020. https://doi.org/10.1016/j.marpolbul.2019.110898

[26] https://thegreatbubblebarrier.com/

[27] The Ocean Cleanup. “Interceptor - The Ocean Cleanup”, 2020. https://theoceancleanup.com/technology/interceptor/

[28] https://www.ce.cit.tum.de/en/itr/research/bio-inspired-design/

[29] https://businessnorway.com/solutions/maritime-robotics-unmanned-surface-vehicles-for-autonomous-ocean-monitoring

[30] https://www.trendhunter.com/trends/smart-drone

[31] The Ocean Cleanup Array - The Index Project