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8. Conclusions

This chapter summarizes the main outcomes of the Maris Habitats project. It presents the main achievements, the limitations of the current prototype, and the future development steps required before the system can be considered for real marine deployment.

8.1 Achievements

The Maris Habitats project resulted in the development of a modular artificial reef concept combined with an environmental monitoring system. The final concept consists of Reef Blocks and optional Smart Modules for local environmental data collection. This allows the system to provide both physical habitat support and long-term observation of marine conditions.

One of the main achievements was the development of a modular Reef Block structure. The design uses repeated concrete-based Reef Blocks that can be arranged in different configurations depending on the site, project size, and monitoring needs. This supports scalability and makes the system adaptable to different marine environments.

Another achievement was the integration of the monitoring concept. The Smartlogger was designed as a removable unit so that battery replacement, sensor inspection, maintenance, and data retrieval can be carried out without removing the whole Reef Block from the seabed. This supports long-term use and reduces unnecessary disturbance to the marine environment.

The team also developed and tested a simplified prototype under controlled conditions. The prototype focused on basic sensing, data logging, and electronic integration. Although it does not represent the final marine-grade product, it helped validate the basic technical logic of the system.

In addition, the project included material research, structural design review, sustainability analysis, ethical analysis, market analysis, and packaging development. These activities helped define Maris Habitats as a modular reef infrastructure and environmental monitoring solution rather than only a physical artificial reef product.

8.2 Limitations

Although the project achieved its main concept and prototype goals, several limitations remain. The prototype was tested only under controlled conditions and was not deployed in a real marine environment. Therefore, the results cannot yet prove long-term underwater performance, ecological impact, or full durability in harsh marine conditions.

The prototype also uses a simplified sensor set due to budget and component availability. The final product is intended to include more advanced sensors, such as pH and conductivity sensors, but these were not fully integrated into the prototype. For this reason, the current testing only validates part of the intended monitoring function.

Another limitation is related to waterproofing and pressure resistance. The final system would need a certified marine-grade enclosure, reliable underwater connectors, and long-term leak testing before real deployment. The prototype housing is useful for basic validation, but it is not suitable for deep or long-term marine use.

One limitation of the Smartlogger is that the system does not transmit data in real time. Since the data is stored locally on the SD card, the user cannot monitor the Smartlogger during operation to confirm whether it is still functioning correctly. This means that possible failures, such as sensor errors, SD card issues, or power loss, may only be discovered after the Smartlogger has been retrieved and the stored data has been checked. For future development, real-time status monitoring or a simple diagnostic signal could be considered to improve reliability and make it easier to detect problems during operation.

The structural analysis was also based on simulations and simplified assumptions. Although the results support the feasibility of the design, real physical testing would still be required to evaluate stability, impact resistance, seabed interaction, and long-term material degradation. Marine structures can be affected by seawater exposure, chloride and sulfate attack, corrosion processes, and wave action over time **[1]**.

The ecological effect of the Reef Blocks has not yet been tested. The project can only claim that the structure may support habitat formation over time. Real ecological success would require long-term field observation, baseline comparison, and cooperation with marine experts. Artificial reef projects require careful site selection, suitable design, and long-term monitoring before their ecological performance can be evaluated **[2]**.

8.3 Personal Outcomes

The EPS@ISEP programme contributed to the development of key professional competencies, as evidenced by the students’ written testimonies. Participants reported improved ability to work in multicultural teams, enhancing communication skills and intercultural awareness. These accounts also indicate the development of project management and organisational skills, including task coordination, structured problem-solving, and adherence to deadlines. The application of practical methods, such as planning and continuous monitoring, supported effective teamwork throughout the project. In addition, the team perceived improvements in technical and presentation skills, including design capabilities and the ability to communicate and defend technical results. Overall, these outcomes highlight the acquisition of comp competencies relevant to international and multidisciplinary engineering practice.

8.4 Future Development

Future development should first focus on improving and validating the Smartlogger system. The electronic components should be integrated into a more robust marine-grade Smartlogger housing with reliable waterproofing, pressure resistance, and corrosion protection. The sensor system should also be expanded to include the final intended parameters, such as pH and conductivity.

Further testing is also needed for the power system. Battery life should be tested under realistic measurement cycles, and the energy consumption of the full system should be confirmed. This is important because the system is designed for long-term local data logging and scheduled maintenance.

The Reef Block structure should also be tested further. Future work should include physical stability tests, impact tests, and material durability tests in seawater. The connection between the Reef Block, Smartlogger attachment, and Smartlogger should be checked carefully to make sure that the system remains stable and safe during deployment.

Another important future step is field testing. A small pilot installation in a controlled marine environment would allow the team to collect real environmental data, observe biofouling, evaluate maintenance needs, and study how marine organisms interact with the Reef Blocks over time. Since marine sensors can be affected by biofouling, regular inspection, cleaning, and calibration should be considered during future testing **[3]**.

Future development should also include clearer data management procedures. The team should define how data is stored, documented, validated, and interpreted before it is used in reports or decision-making. For ocean data projects, data management planning is recommended to ensure that collected data is properly stored, preserved, and documented **[4]**.

Future work should involve stronger collaboration with public authorities, research institutions, environmental NGOs, and marine infrastructure partners. These stakeholders would be important for site selection, permits, environmental assessment, deployment, and long-term monitoring.

Maris Habitats provides a useful foundation for a modular reef infrastructure and environmental monitoring system. However, before real deployment, the concept must be further validated through marine-grade engineering, long-term testing, and ecological monitoring. These steps are necessary to help make the system safe, reliable, and useful for marine restoration and environmental observation.

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