Silion M., Beceanu C., Suciu Jr. G., Alexandru C., Alexandru L., Gheorghe O-C., Roșu M-L., Țăranu I., Pădeanu B-G. (2023), Real-time monitoring and predictive maintenance for sustainable aquaculture management, pp. 261-267. In Gastescu, P., Bretcan, P. (edit., 2023), Water resources and wetlands, 6th International Hybrid Conference Water resources and wetlands, 13-17 September 2023, Tulcea (Romania). pp. 287
Available online at http://www.limnology.ro/wrw2023/proceedings.html

6th International Hybrid Conference Water resources and wetlands, 13-17 September 2023, Tulcea (Romania)

REAL-TIME MONITORING AND PREDICTIVE MAINTENANCE FOR SUSTAINABLE AQUACULTURE MANAGEMENT

Mădălin SILION[1] , Cristian BECEANU [1], George SUCIU JR.[1], Cornelia ALEXANDRU[1], Lucian ALEXANDRU[1], Ovidiu-Claudiu GHEORGHE[2], Maria-Laura ROŞU [1], Ioana ŢĂRANU [1], Bogdan-Gabriel PĂDEANU[1]

[1]Beia Consult International, [2]Ovidius Aqua Line

[1] BEIA Consult International (BEIA): Peroni 16, Bucharest, 041386, Bucharest, Romania, +40744914798 E-mails: *madalin.silion@beia.ro*, *madalin.silion@beia.ro*, *george@beia.eu*, *cornelia.alexandru@beia.ro*, *lucian.alexandru@beia.ro*, *maria_laura.rosu@stud.etti.upb.ro*, *ioanataranu2001@gmail.com*, *padeanu.bogdangabriel123@gmail.com*,

[2] Ovidius Aqua Line: Str. Preot Popescu Gheoghe 1A, Borcea 917015, Calarasi, Romania, 0744.486.289 E-mail: *ovidiusaqualine@gmail.com*,

Abstract. Water quality monitoring is critical for the sustainable management of aquaculture farms and their surrounding ecosystems. The Blue-GreenWay and the iPREMAS projects have developed innovative solutions for real-time monitoring and predictive maintenance in aquaculture systems. The Blue-GreenWay project uses a combination of remote sensing and on-site monitoring to provide accurate and timely information on water quality, including temperature, dissolved oxygen, and chlorophyll-a concentration. The iPREMAS project introduces a novel platform for intelligent predictive maintenance, which measures critical parameters in real time and uses machine learning algorithms for time-series forecasting, anomaly detection, and fault classification. Combining the technologies developed in these two projects, we propose a comprehensive approach to water quality monitoring in aquaculture systems. The Blue-GreenWay sensors and remote sensing data provide baseline information on water quality, while the iPREMAS platform enables real-time monitoring of critical parameters and early detection of anomalies. Integrating these technologies will offer aquaculture farmers a powerful tool to manage their facilities, optimize production, and reduce environmental impact. Moreover, the real-time data from the combined system can be used to develop models to predict future water quality and assess the potential effects of climate change and other environmental stress factors. We present a case study of implementing the combined system in the Ovidius Aqua Line sturgeon farm. The system detected changes in water quality parameters and provided timely alerts to the farmers. The predictive maintenance platform enabled the farmers to schedule maintenance activities based on the forecasted status of the farm, reducing downtime and increasing efficiency. The combined system also allowed the farmers to optimize feed management and reduce the risk of disease outbreaks. Our results demonstrate the potential of combining the technologies developed in the Blue-GreenWay and iPREMAS projects for effective water quality monitoring in aquaculture systems, contributing to the sustainable management of water resources in aquatic resources.
Keywords: Water quality monitoring, Predictive maintenance, Sustainable management, Environmental impact, Aquaculture

1 INTRODUCTION

Marine Aquaculture (fish, mussel, oyster and seaweed) is among the emerging sectors of the blue economy (European Commission 2020). The interest in marine aquaculture production keeps increasing due to the wide potential on food security, derived compounds and their bioactivities (Garcia-Poza et al., 2020).

Due to the growing interest to move large scale aquaculture operations further out into the open ocean the need for new solutions to tackle the challenges of the harsh and exposed environment increases (Troell 2009). A novel approach is replacing monoculture systems by integrated multitrophic aquaculture (IMTA) to solve environmental issues such as eutrophication (Granada et al., 2016). Remote control, predictive maintenance as well as smart infrastructure are crucial for large scale commercialisation.

The iPREMAS and BLUE-GREENWAY projects are two research initiatives that aim to improve the environmental and economic aspects of aquaculture and coastal ecosystems. The iPREMAS project (Intelligent Predictive Maintenance for Aquaculture Systems) focuses on improving aquaculture farms' performance by introducing a new platform and a new service for intelligent predictive maintenance. The platform is based on innovative monitoring systems and intelligent infrastructure using Machine Learning (ML) and Artificial Intelligence (AI) techniques (Garcia-Poza et al., 2020). The platform measures vital parameters in real-time, introducing multi-sensor innovative indicators that power a chain of ML models for Time Series Forecasting (TSF), Anomaly Detection, Fault Classification, and Remaining Useful Life (RUL). These measurements provide the current state of the farm site, while the predictions offer insights into its future status. The prevision analyses allow us to identify whether preventive or corrective maintenance is needed (Voronov 2020). A cloud-based integration of various platform components improves connectivity and security while optimizing operational processes, enabling farmers to benefit from personalized software. The Software-as-a-Service (SaaS) approach benefits aquaculture farmers by providing a digital equivalent of the platform. Blockchain technology is being used to provide trust and traceability, such as securely managing sensor data information and the identity of stakeholders in the project outcomes. Security and confidentiality are ensured by implementing reliable and secure data transport. The new service offers farmers real-time access to the current state of the farm and facilitates planning activities and measures based on the predicted state.

The BLUE-GREENWAY project is the first project to apply new ecosystem restoration methodologies and identify shortcomings in wastewater management from urban & rural sources. The project aims to increase knowledge-sharing between Academia/PAs to improve the environmental status of ecosystems, manage freshwater and wastewater, strengthen farmers to enter this processing market, and build capacity for comprehensive sustainable water management (O'Connor et al., 2012). The project addresses the intertwined challenges of the land-sea chain by focusing on green procurement of products and services in wastewater management, treating water pollution problems resulting from land-based sources, and introducing innovative methodologies to restore ecosystems. A report will be developed describing step by step the Living Lab approach, to help PPs realise Living Labs. The labs will be used to integrate research and innovation processes, create a user-centred open innovation ecosystem based on systematic co-creation approach, promote and strengthen transnational cooperation and networking amongst existing clusters/networks. Living Labs will be organised in 3 countries, to transfer the knowledge of pilots to territorial stakeholders (SMEs, clusters, PAs, policy makers etc). The projects' added value lies in innovative, cost-efficient initiatives addressing the above challenges transnationally. It will support European entities in pooling efforts to implement new solutions to these challenges. This will contribute to a change in procurement policies and wastewater management, leading to positive socio-economic impacts.

Both projects aim to contribute to the European goals of enhancing environmental protection and fostering eco-innovation. The target of the iPREMAS project is to reduce Maintenance and Operation (M&O) costs for farmers and provides additional tools for mitigating adverse environmental effects in the event of calamities. Using machine learning and artificial intelligence techniques will optimize the operations and maintenance of aquaculture farms, reducing their environmental impact and increasing their efficiency. The BLUE-GREENWAY project intends to apply new ecosystem restoration methodologies and identify green products and services for wastewater management, improving the water quality and biodiversity of coastal ecosystems. Their aim is to train the participants in using the eGPP (Global Prime Partners) platform and raise awareness of topics of eutrophication and anoxia management. Together, both projects plan to involve knowledge-sharing and capacity-building among different stakeholders.

2 METHODS

2.1 iPREMAS

The pilot station in Romania was implemented at the Ovidius Aqua Line fish farm located on the banks of the Danube in Borcea, Calarasi county. It operates in an enclosure (yard) of 7 1500 sqm. This enclosure is a 600 sqm hall, thermally insulated, divided into rearing space, storage space, space for processing eggs and meat (DSV authorized), and offices. In this farm are reared for sale: sturgeon and trout species, both adults capable of reproduction and roe. The following steps were followed to define the technical solution:

1. Analysis of the recirculating aquaculture system (RAS) on the farm;
2. Identification of fish species;
3. Identification of stress factors;
4. Identification of assessment methodologies and processes;
5. Identification of methods for monitoring water quality parameters in the system;
6. Definition of sensor requirements for the pilot station.

The "iPREMAS" project ensures animal welfare
by monitoring in real-time the parameters such as temperature, pH, electroconductivity, dissolved oxygen, nitrates, nitrites, and pond water level. For the configuration of the monitoring system within the pilot station, the chosen solution was the Libelium Smart Water Extreme Station, together with the sensors for measuring the parameters already mentioned (https://shorturl.at/dpES7).

Data are acquired from the sensors every 15 minutes, transmitted live to the cloud platform, and can be visualized using Grafana. An alarm system has been developed to prevent water quality parameters from exceeding the optimal range. When a parameter goes out of range, a message with a brief description of the problem is sent to the Telegram app. The Libelium solution implemented in the iPREMAS project uses 4G technology for data transmission. It consists of the acquisition module (Waspmote) and the Meshlium device, which acts as an IoT- Gateway (Lucas and Southgate 2012). Once the data reaches Meshlium, it is stored in the InfluxDB - iPREMAS database. Subsequently, this acquired data is transmitted to the Grafana visualization platform using the MQTT Broker to display relevant information to users in tables or graphs (Salman and Jain 2017).

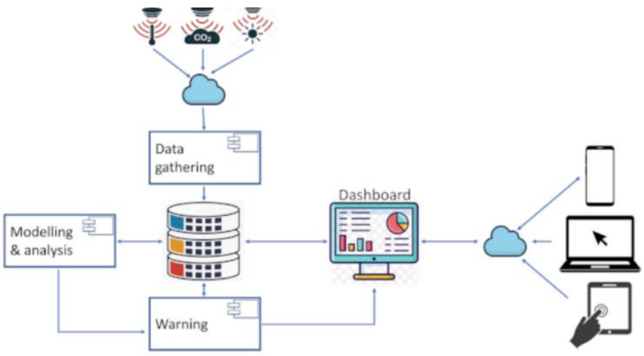

Figure 1. Possible Architecture of the Farmer Support Service Platform

2.2 Blue-Greenway

To address the everyday challenges of the land-sea chain, the "BLUE-GREENWAY" project follows a dual approach.

First, with short-term restoration measures in the sea part of the chain. The areas face pollution, freshwater & wastewater management problems. Human activities result in high loads of nutrients and organic matter in water bodies with poor circulation. In marine systems with limited water exchange and excessive anthropogenic input of nutrients/organic matter, water becomes eutrophic and permanently hypoxic/anoxic. The final result is the hydrogen sulfide production in the water column and massive fish mortality events (Lucas and Southgate 2012). The project will focus on designing mesoscale pilots, cost-efficient restoration methods, and transferable monitoring systems. Knowledge-sharing on using geoengineering materials will ensure the success of the remediation of ecosystems and the achievement of "BLUE" waters.

Figure 2. BLUE-GREEN WAY project implemented in BEIA's living laboratory

Figure 3. Testing and implementation of the monitoring system

Second, land measures focus on identifying & knowledge-sharing on the use of green products & services in wastewater management. This will be achieved via developing an integrated transnational, adaptable database with critical data on user profile types/needs; developing an eGPP tool for users to implement green criteria in tenders; establishing Experts' Board for setting the green criteria within the online tool; developing users' toolkit of educational material for knowledge-sharing via the online tool; supporting stakeholders/users network to ensure their deep engagement and sustainability of project outcomes; and developing guidelines to reduce nutrients loads from point and diffused pollution sources. This will achieve the "GREENWAY," its transferability after implementation, and its extension into take-up policies across European regions. Training material will be distributed to the participants and expert partners will be invited to train them. The outcomes of the Labs will be recorded in reports by the host partners, including evaluation of the Labs by the participants. The organisation of Living Labs by partners will enhance cooperation and improve mutual knowledge and understanding between the donor and beneficiary states.

2.3 Combined methods

Both iPREMAS and BLUE-GREENWAY are research projects that aim to improve the environmental and economic aspects of aquaculture and coastal ecosystems. Combining the technologies developed in these two projects, we propose a comprehensive approach to water quality monitoring in aquaculture using different systems for measuring key parameters in real time, such as water quality, oxygen level and nutrients concentration. Furthermore, we employ artificial intelligence techniques for analyzing the data collected by the monitoring systems and providing forecasts, warnings, and decision support (Cinar et al., 2020). Moreover, geoengineering materials for restoring the environmental status of eutrophic and anoxic coastal ecosystems are used in order to increase oxygen levels and reduce pollutants.

3 RESULTS AND DISCUSSION

In the iPREMAS project, users created an isolated organization in Grafana, with dashboards with multiple panels in the form of a graph or table (Rubio-Tamayo et al., 2018). Grafana also supports integration with official modules (such as maps) and applications that can be monitored (https://shorturl.at/sAZ13). Each dashboard is versatile and can be customized for a specific project.

Figure 4. Dissolved oxygen parameter visualized in Grafana

Figure 5. Different parameters visualized in Grafana

Sturgeons are cold-water fish and, like many other fish species, they require an adequate level of dissolved oxygen in their environment to thrive. The recommended quantity of dissolved oxygen for sturgeons is generally higher than for some other fish species. This type of fish typically prefers dissolved oxygen levels between 7-9 mg/L to maintain their health and well-being (https://shorturl.at/fqKQ2) Otherwise, the fish become stressed, stop consuming food, and are more susceptible to illnesses. A decrease in dissolved oxygen below 3 mg/L or prolonged exposure to concentrations below 5 mg/L can lead to fish suffocation. Also, the water PH needs to be 7,0 and the temperature between 18 – 22°C (https://shorturl.at/uvGOS).

Anoxic coastal basins, fjords, and lakes constitute a transnational problem across Europe (Lucas and Southgate 2012). In BLUE-GREENWAY, the methodologies of the Meso-scale pilots on eutrophication treatment and drainage water quality will be sustainable & transferable to other regions that face similar obstacles in eutrophic and anoxic coastal ecosystems (O'Connor et al., 2012). Solutions will be proposed using innovative geoengineering materials that can adsorb the pollutants and improve water quality. The real-time monitoring system, the early warning system, and the model acting together can safeguard public safety by warning the region of toxic H2S in the air. The transferability of the project's achievements is based on continuous interaction between the project and its target groups through its platform and pilots. The pilots will show the exact methodology to reduce pollutants and improve water quality. The project will develop networking with actors outside the partnership for disseminating project achievements. The exchange of good practices and results with areas outside the territory will benefit more regions beyond the initial study area. An integrated database will be designed to collect critical data for a set of user profile types and needs that will be applicable and replicable to the whole project area, to aid PAs procuring products, develop general directives, and support policy take-up. Stakeholders across Europe will be invited to register to the platform and update its data on their region so that the results can apply and be replicable to the broader Europe area.

The common results of the projects are the development of smart sensors and IoT devices for collecting and transmitting data on water quality, fish health, environmental parameters and the usage of artificial intelligence and machine learning algorithms for analyzing the data and providing decision support, risk assessment and early warning.

4 CONCLUSIONS

Incorporating advancements from both projects, we present an all-encompassing method for monitoring water quality in aquaculture systems. By synergizing the technologies developed, we offer a comprehensive approach that ensures efficient and accurate assessments. This integrated system revolutionizes the aquaculture industry, enabling real-time monitoring, early detection of issues, and prompt responses to maintain optimal conditions for aquatic life (Pedersen and Roppestad 2016). Through continuous data collection and analysis, our solution empowers aquaculturists with invaluable insights, promoting sustainable practices and minimizing environmental impacts. With enhanced precision and ease of implementation, this innovative approach heralds a new era of improved productivity and ecological stewardship within aquaculture operations. It is important to note that these two projects provide advantages in different areas, such as climate, environment, food, energy, health and job creation (European Commission 2020).

ACKNOWLEDGMENT

The work presented in this paper has been funded on Martera iPREMAS -Intelligent PREdictive Maintenance for Aquaculture Systems and the EEA and Norway Grants Fund for Regional Cooperation project BLUE-GREENWAY(No.2018-1-0284).

APPENDICES

Internal documents: iPREMAS Project Proposal, BLUE-GREENWAY Project Description, iPREMAS Scientific and Technical Report

REFERENCES

Retrieved from the section Sensor Guide for Smart Water Xtreme Station on Libelium Website: https://development.libelium.com/smart-water-xtreme-sensor-guide/sensors-probes#opticaldissolved-oxygen-and-temperature-optod-sensor-probe Accessed 18 July 2023

Retrieved from the section Panels Visualization on GrafanaWebsite: https://grafana.com/docs/grafana/latest/panels-visualizations/visualizations/ Accessed 18 July 2023

Cresterea intensiva a sturionului pentru carne si caviar – model de ferma (2011) Retrieved from the website: https://www.cartiagricole.ro/ferma-crestere-intensiva-sturionului-pt/ Accessed 1st August 2023

Creșterea puilor de sturioni în sistem superintensiv, în instalatii industriale (2011) Retrieved from the website: https://agroromania.manager.ro/articole/stiri/creterea-puilor-de-sturioni-in-sistem-superintensiv-in-instalatii-industriale-10623.html Accessed 1st August 2023

Cinar Z.M et al. (2020), Machine Learning in Predictive Maintenance towards Sustainable Smart Manufacturing in Industry 4.0; *Sustainability 2020, 12,* 8211; doi:10.3390/su12198211

European Commission (2020). The EU Blue Economy Report. 2020

Garcia-Poza S., et al.(2020), The Evolution Road of Seaweed Aquaculture: Cultivation Technologies and the Industry 4.0; *Int. J. Environ. Res. Public Health 2020, 17*, 6528; doi:10.3390/ijerph17186528

Granada, L.; et al. Is integrated multitrophic aquaculture the solution to the sectors' major challenges?—A review. *Rev. Aquac.* 2016, 8, 283–300

Guobao Xu et al. (2019), Internet of Things in Marine Environment Monitoring: A Review; *Sensors 2019, 19*, 1711; doi:10.3390/s19071711

Lucas J, Southgate P (2012) *Aquaculture: farming aquatic animals and plants*. Wiley-Blackwell, Chichester

O'Connor, E.; Zhang, D.; Smeaton, A.F.; O'Connor, N.E.; Regan, F. Multi-modal sensor networks for more effective sensing in irish coastal and freshwater environments. In *Proceedings of the 2012 Oceans, Hampton Roads*, VA, USA, 14–19 October 2012;

Oliveira, J., Lima, J. E., da Silva, D., Kuprych, V., Faria, P. M., Teixeira, C., ... & da Cruz, A. M. R. (2021). Traceability system for quality monitoring in the fishery and aquaculture value chain. *Journal of Agriculture and Food Research*, 5, 100169. https://www.sciencedirect.com/science/article/pii/S2666154321000715

Pedersen N.B., Roppestad F.L. (2016), Decision Support for Predictive Maintenance of Exposed Aquaculture Structures; Master of Science in Computer Science; Norwegian University of Science and Technology; Department of Computer and Information Science

Rubio-Tamayo, J. L., et al. (2018). Digital Data Visualization with Interactive and Virtual Reality Tools. Review of Current State of the Art and Proposal of a Model, *Icono 14, 16 (2), 40-65*. doi: 10.7195/ri14.v16i2.1174

Salman, T.; Jain, R. Networking protocols and standards for Internet of Things. 2017 https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119173601.ch13

Su, B., Bjørnson, F. O., Tsarau, A., Endresen, P. C., Ohrem, S. J., Føre, M., ... & Bjelland, H. V. (2023). Towards a holistic digital twin solution for real-time monitoring of aquaculture net cage systems. *Marine Structures*, *91*, 103469 https://www.sciencedirect.com/science/article/pii/S0951833923001028

Troell, M et.al. Ecological engineering in aquaculture—Potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. *Aquaculture 2009*, 297, 1–9

Unveiling low-to-high-frequency data sampling caveats for aquaculture environmental monitoring and management. *Aquaculture Reports*, *20*, 100764. https://www.sciencedirect.com/science/article/pii/S2352513421001800

Voronov S.(2020); *Machine Learning Models for Predictive Maintenance; Linköping Studies in Science and Technology*; Dissertations, No. 2040; Linköping University, Department of Electrical Engineering, Division of Vehicular Systems, SE581 83 Linköping, Sweden; Linköping 2020