Interreg
Co-funded by the European Union
South Baltic

University of Gdańsk

AQUALOOP PILOT PROTOCOL
“TARAS – Testing Algae Applications in Recirculating aquaculture systems (RAS) to improve aquaculture circularity potential in the SB region”

July 2026



aqualoop.edu.pl

AquaLoop - *Aquaculture expert floor for circular economy practice,* Interreg South Baltic
Sep 2023 - Aug 2026

Partner responsible: University of Gdańsk, Poland

Authors: Basia Dmochowska, Joanna Hegele-Drywa, Filip Pniewski. Konrad Bräutigam, Normant-Saremba Monika, Hanna Łądkowska, Marta Gostkowska

Pilot contributing partners: University of Gdańsk, Poland (Lead), University of Rostock, Germany, Klaipeda University, Lithuania

Project partners: University of Rostock, Germany, University of Gdańsk, Poland, Klaipeda University, Lithuania, Gulborgsund Municipality, Denmark, Fish Market Development Association, Poland, Scandinavian Aquasystems AB, Sweden, VKST, Denmark

Date and place: Gdynia, Poland, 23.07.2026

Recommended format for purpose of citation: AquaLoop TARAS, 2026. Testing Algae Applications in Recirculating aquaculture systems (RAS) to improve aquaculture circularity potential in the SB region, Pilot Protocol, 39 pp. https://www.auf.uni-rostock.de/en/professuren/agrarbereich/aquakultur-und-sea-ranching/forschung/laufende-projekte/aqualoop/

TABLE OF CONTENTS

I. INTRODUCTION

The transition to circular aquaculture in the South Baltic region is essential for addressing key environmental, economic, and social challenges. By promoting more efficient resource use, reducing waste, and closing nutrient loops, circular aquaculture contributes to the green transition while supporting regional resilience and competitiveness. It is fully aligned with European sustainability objectives and regional policy frameworks, providing a pathway towards a more sustainable and resource-efficient aquaculture sector.

The **AquaLoop - *Aquaculture expert floor for circular economy practice* Interreg South Baltic** project aimed to develop, promote, and support the implementation of circular aquaculture in the South Baltic region, with a particular focus on nutrient loop closure and the valorisation of aquaculture by-products to foster responsible production and consumption.

To achieve these objectives, the project developed and demonstrated innovative circular aquaculture solutions while strengthening the capacities of current and future professionals, businesses, and consumers to support the sector's transition. The consortium brought together universities, municipalities, industry associations, and SMEs, creating a strong partnership that combined research, education, stakeholder engagement, and practical industry application. This multidisciplinary approach was fundamental to developing and implementing circular economy solutions that can be effectively adopted in practice.

A key element of the project's approach was the close cooperation between partners in the joint development of tailored solutions to strengthen human resource capacities. This was achieved through the design and implementation of **three cross-border pilots** within the range of activities jointly called **PilotLoops**, which tested innovative methods and tools while demonstrating practical approaches to circular aquaculture under real-life conditions in the South Baltic region.

I.1. PilotLoops – Circular aquaculture South Baltic pilots

Three pilots tested and demonstrated innovative production methods aimed at reducing waste and water use, while generating valuable by-products and lowering environmental impacts. The work involved in-depth analysis and close cooperation with associated partners, enabling the exchange of data and practical solutions and supporting testing from lab to farm scale. This collaboration was supported by the use of commercially relevant technologies and enabled a continuous exchange of data and solutions. In addition, the project delivered jointly developed protocols to support further uptake by enterprises. These outputs also provided important input for the project's training and support activities, helping to ensure that the results could be effectively applied in practice.

AquaLoop Pilot 1 – TARAS - *Testing Algae Applications in Recirculating Aquaculture Systems (RAS) to improve aquaculture circularity potential in the SB region*. Coordinating partner: University of Gdańsk (PL). The aim of the pilot was to further develop technology on cultivation of shrimps and specific strains of microalgae, for RAS facilities, processing water purification, while producing high-value algal biomass, and to demonstrate applications of the biomass produced.

- **AquaLoop Pilot 2 - NEMATIC - *Increasing the nutrient efficiency of commercial aquaculture through increased application of circular economy concepts.*** Coordinating partner: University of Rostock (DE). The idea of the pilot was to research and test the unused residues from fish production. Specifically, the biochemical composition of the gonads, livers and skins of African catfish (*Clarias gariepinus*), rainbow trout (Oncorhynchus mykiss) and pikeperch (*Sander lucioperca*) will be investigated, and possible and practical potential paths of utilization will be tested.

- **AquaLoop PILOT 3 – FISHVISA - *Development of the Fish-Shrimp-Vegetables integrated system of aquaponics to showcase the potential of circular economy principles in RAS*,** Coordinating partner: Klaipeda University (LT). The main activities were related to FISHVISA technology testing at the Marine Research Institute Fisheries and Aquaculture Laboratory. The small demo aquaponics system in a glasshouse was developed, and tested with rainbow trout, crayfish and salads, where crustaceans expect to use solid wastes, and vegetables use nutrients from fish and crustaceans, to develop a zero-waste RAS technology.

I.2. TARAS pilot – background and aim

Microalgae-based wastewater treatment has rapidly evolved in recent years, facilitating the development of various technological solutions within the frame of the circular economy (Abdelfattah et al., 2022; Ramírez Mérida & Rodríguez Padrón, 2023). Microalgae remove contaminants due to their flexible physiology, enabling effective treatment of waste- and processing waters (Abdelfattah et al., 2022; Kundu et al., 2024). Recent engineering advances have focused on integrating microalgae into systems such demonstrating efficient nutrient removal (e.g. >50% nitrogen and >60% phosphorus) alongside improved effluent quality suitable for reuse (Díaz et al., 2022; Goh et al., 2022). Further progress has been achieved through the development of microalgal consortia with bacteria or fungi enhancing nutrient recycling due to synergistic metabolic interactions (Abdelfattah et al., 2022; Ugwuanyi et al., 2024). A significant progress in this field was made via the transition of simple pollutant removal to integrated resource recovery, where wastewater nutrients are converted into various added-value products such as biofuel, animal feed or fertilizers (You et al., 2023; Minhas et al., 2026). Despite remaining challenges related to large-scale implementation, light utilisation, and process stability, recent developments clearly position microalgae-based systems as low-energy, circular solutions to water treatment challenges, with strong potential for industrial-scale deployment (Abdelfattah et al., 2022; Ramírez Mérida & Rodríguez Padrón, 2023).

Shrimp aquaculture generates nutrient-rich processing waters characterised by high concentrations of dissolved nitrogen (ammonium, nitrate) and phosphorus derived primarily from excess feed inputs, metabolic wastes, and fertilisers, which can lead to eutrophication if untreated (Iber & Kasan, 2021; Khanjani et al., 2025). Microalgae-based approaches have shown strong potential, with several studies demonstrating high nitrogen removal efficiencies through direct assimilation of ammonium and nitrate into biomass. For example, indigenous microalgae isolated from shrimp ponds (e.g. *Halamphora* sp.) achieved complete ammonia removal within a few days and >70% total nitrogen removal across culture stages of shrimp wastewater (Ghazali et al., 2024). Similarly, cultivation of *Dunaliella salina* in shrimp aquaculture wastewater resulted in >80% total nitrogen removal and substantial reductions in organic load, demonstrating the dual benefits of nutrient removal and biomass production (Barreto et al., 2025). Overall, combining microalgal assimilation with integrated aquaculture systems and engineered biological treatments significantly improves nutrient removal from processing waters in shrimp culture, with emerging emphasis on circular resource recovery and multi-trophic system optimisation. Recent research increasingly demonstrates that microalgae are effective "cleaning" agents for nutrient removal in RAS used for shrimp production, where accumulation of nitrate and ammonium remains a main limitation of conventional nitrification-based designs. Microalgae assimilate inorganic nitrogen and phosphorus released from feed and feces, allowing direct coupling of wastewater treatment with biomass production (Ramli et al., 2020). Their integration addresses the major bottleneck of nitrate build-up in RAS, as microalgae utilise nitrate for growth, thereby reducing the need for water exchange (Ramli et al., 2020; Dong et al., 2026).

The **aim of the TARAS pilot** was to develop and demonstrate within the AquaLoop project a circular aquaculture system in which shrimp RAS was integrated with microalgae-based technologies to improve nutrient recycling and reduce environmental impacts. Specifically, the goal was to optimise shrimp RAS operation by cultivating selected microalgae strains in RAS processing water, enabling efficient removal of dissolved nutrients while simultaneously producing valuable algal biomass that can be further utilised in aquaculture or biotechnology applications. By combining intensive shrimp culture with detailed monitoring and system-level innovations, the pilot aimed to generate data supporting the development of more sustainable, circular aquaculture systems adapted to the South Baltic region.

II. TARAS PILOT IMPLEMENTATION

II.1. Shrimp cultivation

The whiteleg shrimp (*Penaeus vannamei*) (Fig. 1) was cultivated during two breeding cycles in a closed-loop system RAS500 developed withing InnoAquaTech project (Dmochowska et al., 2019) and modified by increasing the number of breeding tanks from one to four (approximately 300 L each) in order to enable replication and comparative analysis of different experimental treatments (Fig. 2A). Tanks were interconnected with main unit, equipped in mechanical and biological filtration, allowing continuous water recirculation and strict control of environmental conditions. Environmental parameters, including salinity (30 PSU), temperature (27 °C), pH (around 7.8) and light regime (15:9 hours of light:dark cycle), were adjusted to mimic optimal tropical conditions required for shrimp growth and maintained during the breeding cycle. Daily operation involved continuous system monitoring, including water quality control, filtration maintenance, feeding regulation, and observation of animal behaviour. Shrimps in the post-larval stage (PL14), sourced from certified hatchery (White Panther Produktion GmbH, Austria), were at first cultivated (to achieve the appropriate size) in an additional tank with mesh walls, placed inside the main tank (Fig. 2B). During the time of rearing, they were fed first with live *Artemia salina* and, as they grew, also with the commercial food Perla Larva 0.3-0.5mm (Skretting, Norway). After approximately seven weeks, the pre-grow-out stages of shrimp were placed in four breeding tanks and fed five times a day (using automatic feeders) with commercial feed of pellet size and quantity adjusted to the size and body weight of the cultured individuals. The breeding cycle lasted approximately 22 weeks until the shrimp reached commercial size (Fig. 2C). Overall, shrimp cultivation in the TARAS pilot was designed not only as a production system but also as a controlled experimental platform for testing improvements in RAS performance, animal welfare, and integration with biological treatment technologies.

A B

Fig. 1. Whiteleg shrimp (*Penaeus vannamei*): A – postlarvae, B- grow-out stage (photos by M. Normant-Saremba).

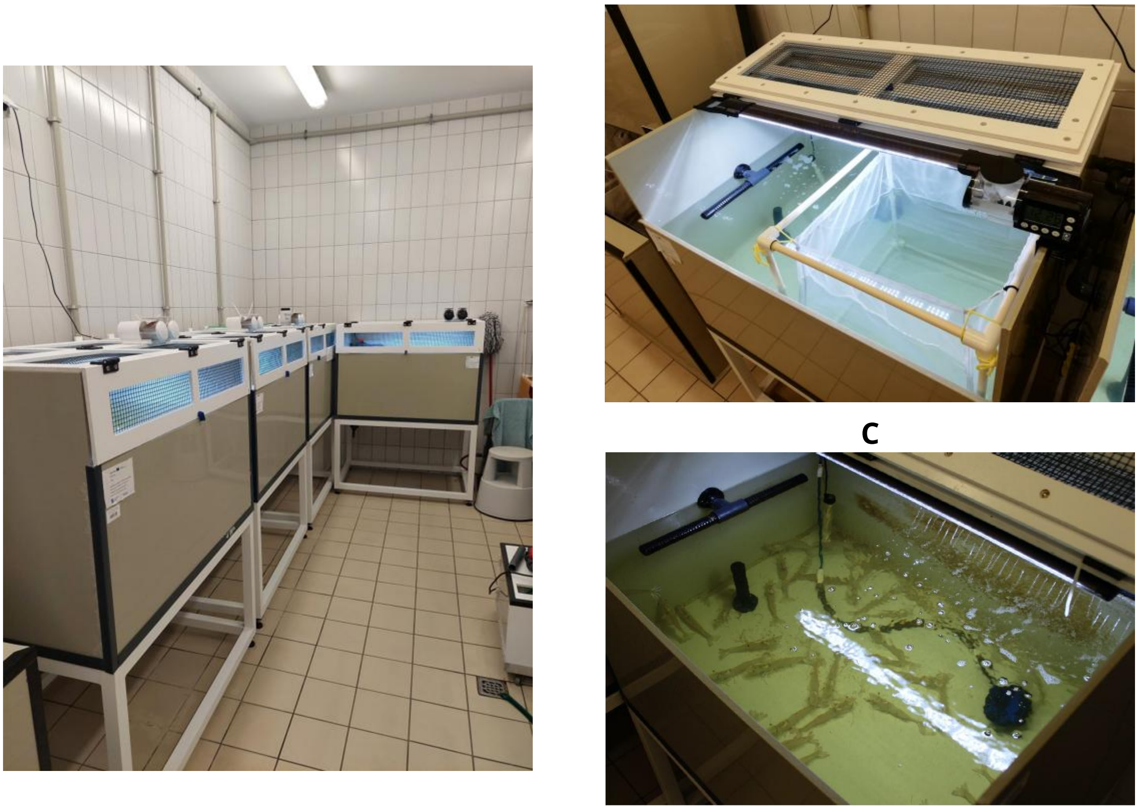

Fig. 2. Reticular aquaculture system (RAS): A – four breeding tanks included in the experimental setup, B – a single breeding tank with a mesh-walled tank inside for rearing post-larvae, C – a tank with shrimp in the grow-out stage (photos A and B by M. Normant-Saremba, photo C by J. Hegele-Drywa).

II.2. Processing water

The water for algae cultivation (processing water) was taken directly from the RAS tank with shrimps in the grow-out stage. it was characterised by high nitrate concentrations (122 mg L^{-1}) and low levels of ammonium, phosphate, and silicate (1–3 mg L^{-1}), indicating efficient nitrification but pronounced nitrogen accumulation and strong nutrient imbalance (high N:P ratio and Si limitation), typical of intensive shrimp recirculating systems (Tab. 1).

Tab. 1. Concentrations of nutrients measured in processing water from shrimp (*Penaeus vannamei*) cultivation.

Nutrient	**Concentration [mg L^{-1}]**
NO_3^-	122
NH_4^+	1
PO_4^{3-}	3
SiO_2	1

The analysed RAS water was strongly nitrogen-enriched, with a calculated N:P ratio of approximately 28:1, indicating pronounced phosphorus limitation relative to classical Redfield stoichiometry. Such conditions are typical of intensive RAS systems where efficient nitrification leads to nitrate accumulation without corresponding phosphorus availability. Ecologically, such nutrient imbalance is expected to limit the growth of microalgae, promoting microalgal selective growth rather than optimal biomass production, with implications for nutrient removal efficiency. In summary, the processing water from shrimp farming was characterized by specific properties such as **high salinity, high nitrate concentration, low phosphates and silica and unbalanced N:P ratio**.

II.3. Selection of microalgae strains

The selection of suitable microalgal strains is a critical step in processing waters remediation. This is due to the fact that nutrient removal efficiency is strongly species dependent. Among the most widely applied taxa, green microalgae such as *Chlorella vulgaris*, *Scenedesmus* (incl. *Tetradesmus obliquus*), and *Parachlorella kessleri* show high adaptability to wastewater conditions and efficient assimilation of nitrogen and phosphorus compounds (Ji et al., 2021; Ungureanu et al., 2021). However, other species can also be applied. For instance, *Phaeodactylum tricornutum* has been shown to efficiently remove nitrogen and phosphorus from livestock wastewater, achieving removal efficiencies of ca. 92% (total nitrogen) and 97% (total phosphorus), together with high ammonium uptake (>98%) under optimized conditions (Jiang et al., 2022). Similarly, benthic *Nitzschia* species (*Nitzschia* sp., *N. palea*) have demonstrated significant nutrient assimilation in aquaculture and municipal wastewaters, including >95% ammonium removal and measurable reductions in total nitrogen and phosphorus during cultivation (Xing et al., 2018; Al-Hassany et al., 2021). In controlled mariculture wastewater systems, marine planktonic diatoms such as *Chaetoceros muelleri*, *Cyclotella atomus*, and *Conticribra weissflogii* exhibit strong growth and efficient utilisation of ammonium, phosphate, and silicate, indicating their suitability for integrated nutrient recovery systems (Shen et al., 2024).

In general, the most effective strategy is to employ local microalgal strains that are well adapted to ambient climatic conditions, as such strains are more likely to maintain stable growth and productivity in outdoor cultivation systems (e.g., high-rate algal ponds), thereby reducing operational costs and energy requirements (Plöhn et al., 2021; Ramírez Mérida & Rodríguez Padrón, 2023). The use of native strains may also be considered part of environmental risk management, in case emergency processing of water discharge would have to be performed, as this would help mitigate harmful effects on local ecosystems (Li et al., 2023). Conversely, the application of strains obtained from algal culture collections - despite their availability and taxonomic characterization - typically requires extensive screening and optimisation prior to large-scale application, as strains of the same species may differ in their ecophysiological properties including growth rates, stress tolerance, and metabolic capacities, resulting in significant differences in cultivation performance and biomass composition under identical conditions (Fig. 3) (Laurens et al., 2014; Cho et al., 2020, Alzahmi et al., 2024).

Fig. 3. Culture collection of microalgal strains (A-B) and agar plate (C) with microalgae colonies during the isolation process (photos by F. Pniewski).

In the TARAS pilot, indigenous Baltic diatom strains were used based on the following criteria: strain origin, growth rate and salinity tolerance range and optimum. The selected strains, including: *Gedaniella* sp. PL1.21, *Amphora* sp. CP3, and *Nitzschia* cf. *aurariae* BA158 (Fig. 4), were characterized by high growth rates and were thus fast and stable throughout the cultivation period. Since the salinity of the Baltic Sea in the southern region is around 8, and the goal of the project was to use high-salinity processing water, the strains were first assessed for their salinity ranges and optima.

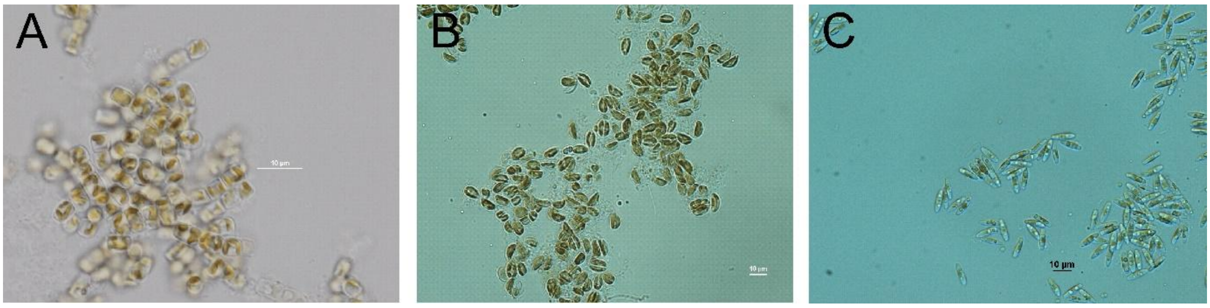

Fig. 4. Diatom strains: A – *Gedaniella* sp. PL1.21, B – *Amphora* sp. CP3, and C – *Nitzschia* cf. *aurariae* BA158 (photos by F. Pniewski).

All the strains were qualified as euryhaline and brackish, with the salinity optimum within the range of 10-17 (Fig. 5).

Fig. 5. Erlenmeyer flasks (A-B) with selected diatom strains during salinity tests (photos by F. Pniewski).

II.4. Experimental culture of microalgae

Tests regarding the usability of selected strains for cleaning processing water were performed in batch cultures in order to observe their growth dynamics. Experimental cultures were performed in 100 ml Erlenmeyer flasks filled with 70 ml of medium prepared from RAS processing water. Processing water was filtered through the Whatman glass filters to remove organic matter particles and microbiological contamination. Several variants of media were prepared, which was necessary due to the fact that certain modifications had to be introduced regarding nutrient proportions – the aim was to obtain the N:P ratio of 24:1, as in the f/2 medium used for long-term diatom strain maintenance. A series of variants with lowered salinity was also carried out. Lower salinity was obtained by mixing processing water with Baltic water in equal proportions (1:1 v/v). Likewise, nutrients were also adjusted to obtain the N:P ratio of 24:1. Additionally, two variants with added silica and Fe-containing microelements were also performed. As a control, cultures with f/2 medium prepared from artificial seawater were used (Tab. 2).

Tab. 2. Composition of culture media variants used for algal cultivation experiments, including control f/2 media and treatments based on shrimp recirculating aquaculture system (RAS) processing water. Variants differ in salinity (adjusted with Baltic water), nutrient composition (modification of the N:P ratio), and supplementation with silica and trace elements.

No.	Variant	Modifications
1	f/2 30 PSU	f/2 medium prepared using ASW
2	f/2 18 PSU	f/2 medium prepared using ASW
3	RAS	Unchanged RAS water
4	RAS+BAL	RAS and Baltic water mixed in the ratio of 1:1 to reach a salinity of 18
5	RASm	RAS water with the increased P concentration to obtain N:P ratio of 24:1 (as in the f/2 medium)
6	RAS+BALm	RAS and Baltic water mixed in the ratio of 1:1 to reach a salinity of 18 with the increased P concentration to obtain N:P ratio of 24:1 (as in the f/2 medium)
7	RASm2.0	RAS water with the addition of silica and microelements (including Fe)
8	RAS+BALm2.0	RAS and Baltic water mixed in the ratio of 1:1 to reach a salinity of 18 with the addition of silica and microelements (including Fe)

Growth of diatoms was monitored every second day until they reached a stationary phase. Cell count was performed using a hemocytometer with the Bürker grid. Subsequently, cell count was recalculated per mg L^{-1}.

II.5. Nutrient removal and diatom yield

Diatom growth

The goal of the project was to assess diatoms' nutrient removal. In most cases, diatom growth was suboptimal and lower than in control culture. The best growth was obtained by *N*. cf. *aurarie* BA158 in the RAS+Bm2.0 variant, in which the diatom reached biomass as in the f/2 30PSU control variant. In the case of *Gedaniella* sp. PL1.21, its growth in the RAS+Bm2.0 variant was ca. 25 and 20% lower than that of f/2 30PSU and f/2 18PSU, respectively (Fig. 6). Despite lower growth rates, diatoms efficiently removed nutrients (Tab. 3). Differences in nutrient removal efficiency among treatments can be explained by strain-specific physiological responses to suboptimal conditions. Nutrient uptake in diatoms is tightly regulated by metabolic state and environmental factors such as nutrient stoichiometry and salinity (Çakirsoy et al., 2022; Bossa et al., 2024). Under such conditions, cells may prioritise the uptake of one nutrient over another (e.g. nitrogen over phosphorus), leading to decoupled N and P removal patterns (Harrison et al., 2025). Additionally, nutrient limitation alters growth and biochemical allocation, reducing biomass yet modifying uptake pathways (Liu et al., 2022). Because physiological tolerance and uptake kinetics differ among taxa, even similar media conditions can result in contrasting removal efficiencies (Le et al., 2023).

Tab. 3. Percentage decrease (%) of removed nutrients: nitrates (DN) and phosphates (DP) in different shrimp recirculating aquaculture system (RAS) processing water variants following cultivation of three diatom strains (*Gedaniella* sp., *Amphora* sp. and *Nitzschia* cf. *aurariae*). Treatments included standard f/2 controls, untreated RAS water, and RAS-derived media modified by dilution with Baltic water (BAL), phosphorus enrichment (m; adjusted N:P = 24:1), and/or supplementation with silica and microelements (m2.0). Dashed lines indicate biomass obtained in the reference f/2 medium (30 PSU). Nutrients removal >50% marked in bold.

Culturing variant	*Gedaniella* sp. PL1.21		*Amphora* sp. CP3		*Nitzschia* cf. *aurariae* BA158	
Nutrients decrease	DN	DP	DN	DP	DN	DP
RAS	34	**66**	**77**	3	10	10
RASm	**52**	48	**77**	34	24	37
RAS+B	**69**	31	**85**	**51**	**56**	**51**
RAS+Bm	**61**	39	**77**	**59**	**53**	**56**
RASm2.0	**50**	**50**	41	48	34	39
RAS+Bm2.0	**68**	32	**57**	**80**	45	**70**

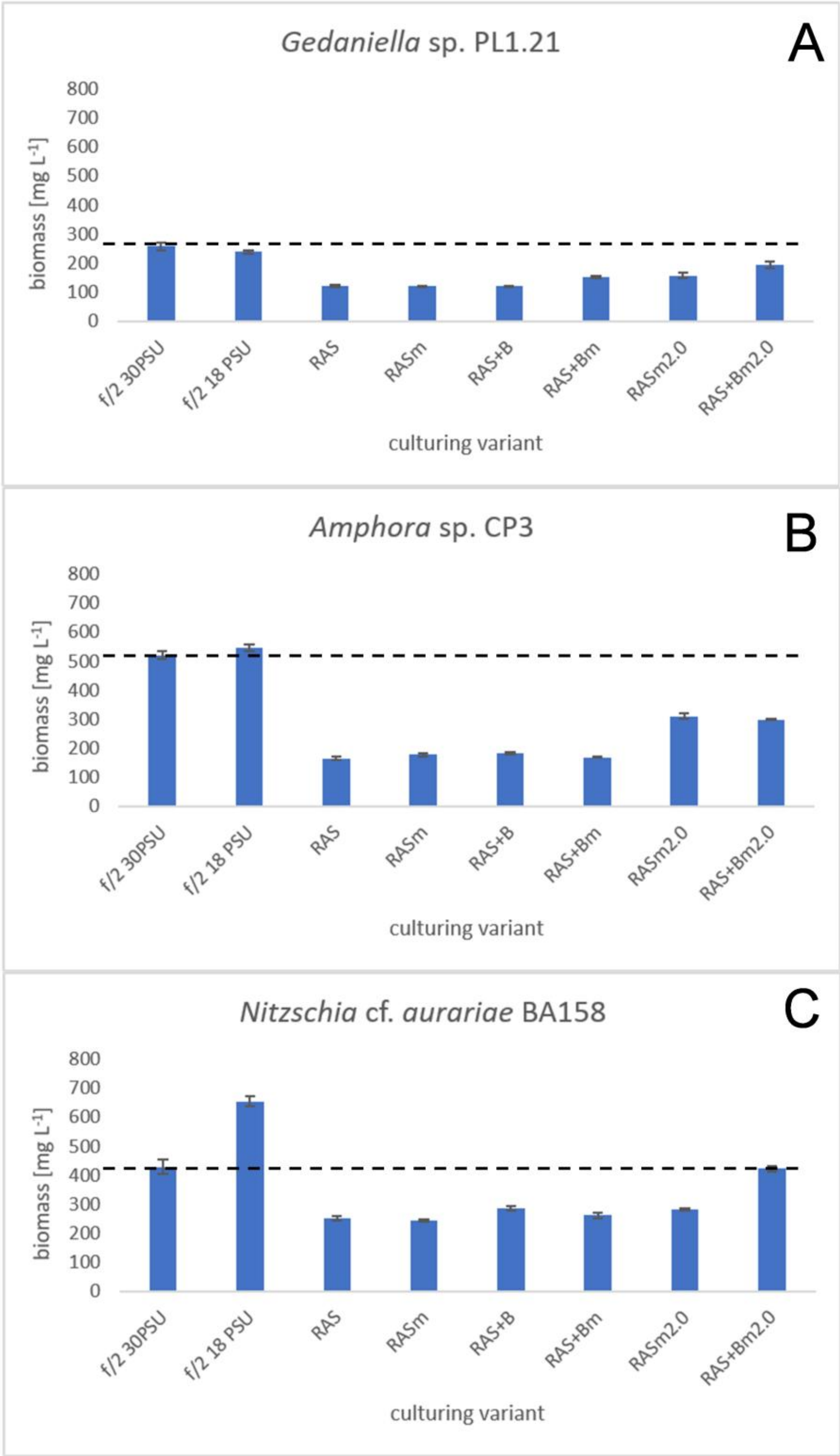

Fig. 6. Biomass production (mg L⁻¹) of three diatom strains (A - *Gedaniella* sp. PL1.21, B - *Amphora* sp. CP3, and C- *Nitzschia* cf. *aurariae* BA158) cultivated in different media variants based on shrimp recirculating aquaculture system (RAS) processing water. Treatments included standard f/2 controls, untreated RAS water, and RAS-derived media modified by dilution with Baltic water (BAL), phosphorus enrichment (m; adjusted N:P = 24:1), and/or supplementation with silica and microelements (m2.0). Dashed lines indicate biomass obtained in the reference f/2 medium (30 PSU). Bars represent mean values ± SD.

Biomass characteristics

The biomass produced during processing water treatment can be further valorised within a circular bioeconomy framework, providing multiple value-added products. Microalgal biomass harvested from nutrient-rich effluents may be rich in proteins, lipids, and carbohydrates, depending on the microalgae physiological condition, enabling its use as animal or aquaculture feed, fertilisers that recycle nitrogen and phosphorus back to agricultural systems (Khan et al., 2023; Ramírez Mérida & Rodríguez Padrón, 2023). In addition, this biomass can be processed into biofuels such as biodiesel, bioethanol, or biogas, due to possible lipid accumulation (Velasquez-Orta, 2023; Zheng et al., 2023). More broadly, integration of wastewater treatment with algal biorefineries allows simultaneous pollutant removal and production of commercially relevant compounds (Arora et al., 2021; Sarma et al., 2021).

Photosynthetic pigments

Across all strains, pigment production was highest in the f/2 controls, while RAS-based media generally resulted in reduced fucoxanthin and chlorophyll *a* concentrations. However, nutrient-modified variants (especially RAS+Bm2.0) enhanced pigment accumulation compared to untreated RAS water, with a particularly strong response in *Amphora* sp. CP3 and *Nitzschia cf. aurariae* BA158. Overall, patterns of fucoxanthin and chlorophyll *a* closely followed growth trends, but remained strongly strain-specific, indicating various physiological responses to RAS conditions (Fig. 7).

Biochemical composition

Biochemical composition differed markedly among strains and culture variants, with lipids dominating in *Amphora* sp. CP3 and *Nitzschia* cf. *aurariae* BA158, whereas *Gedaniella* sp. PL1.21 showed generally lower metabolite production. RAS-based media reduced overall biomolecule content compared to f/2 controls, but supplementation (especially m2.0 variants) enhanced lipid and protein accumulation. Notably, lipid production increased in modified RAS water treatments across all strains, indicating a shift in carbon allocation under suboptimal or nutrient-altered conditions (Fig. 8).

Altered pigment content and biochemical composition observed in RAS-derived media reflect physiological responses to nutrient imbalance and environmental stress. Reduced fucoxanthin and chlorophyll concentrations indicate impaired photosynthetic capacity, as pigment biosynthesis is strongly dependent on nutrient availability, particularly nitrogen and trace elements (Chinnappan et al., 2024; Truong et al., 2024). Under nutrient limitation, diatoms reallocate cellular resources away from protein synthesis and photosynthetic machinery towards storage compounds, resulting in increased lipid accumulation and reduced protein and carbohydrate production (Yang et al., 2013; Cointet et al., 2019). This metabolic shift is further linked to restructuring of central carbon metabolism and lipid biosynthesis pathways under nitrogen or phosphorus deficiency (Alipanah et al., 2018; Lovio-Fragoso et al., 2021). Consequently, RAS water, characterised by suboptimal nutrient stoichiometry and potential micronutrient limitations, induces a trade-off between photosynthetic performance and storage metabolism, ultimately shaping both pigment content and biomass biochemical composition.

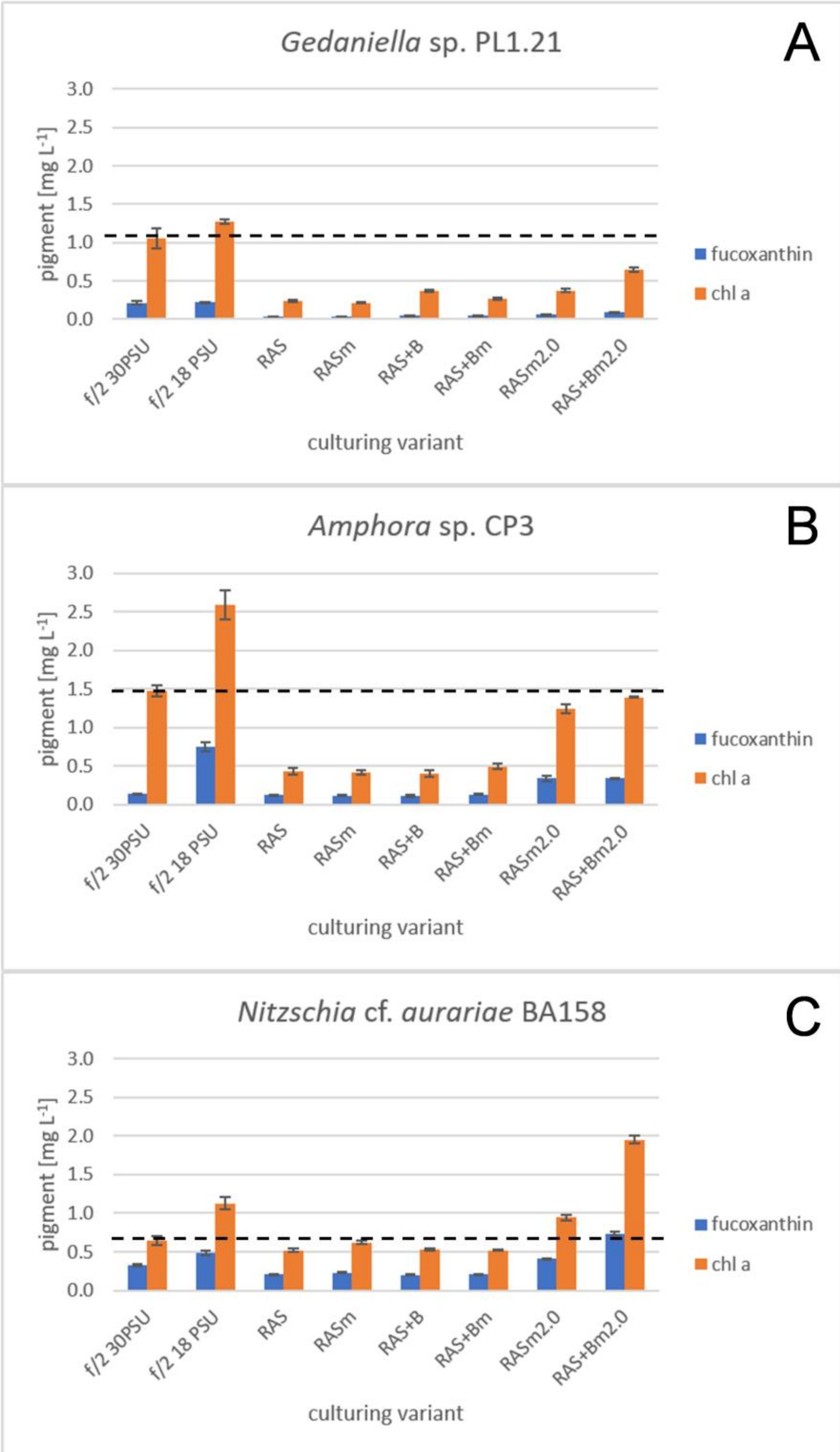

Fig. 7. Fucoxanthin and chlorophyll *a* concentrations (mg L^{-1}) in three diatom strains (A - *Gedaniella* sp. PL1.21, B- *Amphora* sp. CP3, and C- *Nitzschia* cf. *aurariae* BA158) cultivated in different media variants based on shrimp recirculating aquaculture system (RAS) wastewater. Treatments included standard f/2 controls and RAS-derived media modified by dilution with Baltic water (B), phosphorus enrichment (m), and/or supplementation with silica and microelements (m2.0). Dashed lines indicate pigment levels in the f/2 30 PSU control medium. Bars represent mean values ± SD.

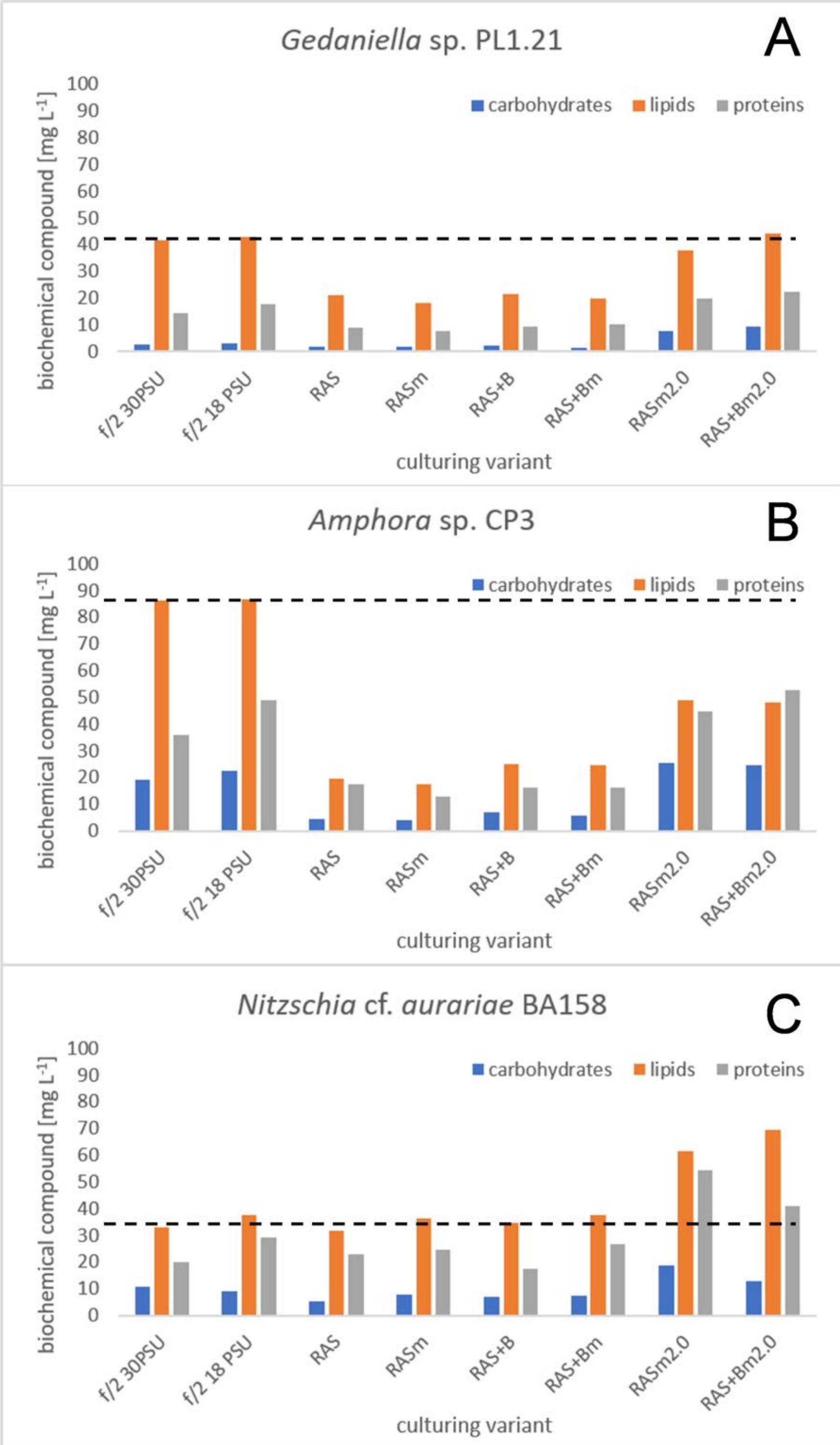

Fig. 8. Concentrations of carbohydrates, lipids, and proteins (mg L⁻¹) in three diatom strains (*Gedaniella* sp. PL1.21, *Amphora* sp. CP3, and *Nitzschia* cf. *aurariae* BA158) cultivated in media based on shrimp recirculating aquaculture system (RAS) wastewater. Treatments included standard f/2 controls and RAS-derived variants modified by dilution with Baltic water (B), phosphorus enrichment (m), and/or addition of silica and microelements (m2.0). Dashed lines indicate lipid concentrations in the f/2 30 PSU control medium.

II.6. Experiment outcomes

- Growth in untreated RAS was reduced, indicating limitation by nutrient imbalance or missing micronutrients.
- Nutrient removal efficiency did not strictly follow biomass trends, showing that high removal can occur even under reduced growth conditions.
- Phosphorus enrichment improved nutrient removal, especially P uptake, and partly enhanced growth in some strains.
- Addition of Baltic water (RAS+B variant) generally increased both growth and nutrient removal, suggesting beneficial effects of salinity adjustment.
- Supplementation with silica and trace elements (m2.0 variants) enhanced performance in selected cases, highlighting the importance of diatom-specific requirements (Si, Fe).
- Clear strain-specific responses were observed, demonstrating that physiological differences drive both growth performance and N vs P removal efficiency under suboptimal conditions.
- Pigment production (fucoxanthin and chlorophyll *a*) was highest in f/2 controls, confirming that RAS-derived media imposed suboptimal conditions for all strains.
- Modified RAS variants (especially m2.0) partially restored pigment synthesis, indicating that nutrient supplementation (P, Si, trace elements) alleviated physiological constraints on photosynthesis.
- Biochemical composition shifted under RAS conditions towards increased lipid accumulation, particularly in modified variants, suggesting stress-induced carbon reallocation.
- Protein and carbohydrate production generally decreased in untreated RAS, reflecting reduced growth and metabolic activity under nutrient imbalance.
- Simultaneous enhancement of lipids and pigments in enriched variants demonstrates recovery of metabolic balance, highlighting the importance of nutrient stoichiometry and micronutrients.

II.7. Summary

Diatoms and other microalgae represent an effective biological approach for nutrient removal from RAS processing water, as they assimilate nitrogen and phosphorus into biomass during growth. However, their efficiency is largely controlled by physiological status, which depends on factors such as nutrient stoichiometry, salinity, and the availability of key elements like silica and iron. Under suboptimal RAS conditions, photosynthesis and growth are reduced, yet nutrient removal can still proceed fairly efficiently, resulting in selective uptake and reallocating carbon to storage compounds. Importantly, optimisation of these conditions -through balancing nutrients and supplementing micronutrients -can restore metabolic activity, thereby enhancing both biomass productivity and overall nutrient removal efficiency while improving biomass quality (Tab. 4).

Tab. 4. Summary of the main advantages and limitations of using diatoms and microalgae for nutrient removal from recirculating aquaculture system (RAS) wastewater. Strengths include high efficiency of simultaneous nitrogen and phosphorus uptake, low-energy cultivation, and the potential for biomass valorisation, whereas limitations arise from sensitivity to nutrient imbalance, dependence on micronutrients (e.g. silica), strain-specific physiological responses, and reduced performance in untreated RAS media.

Strengths	Limitations
High nutrient removal efficiency (N and P uptake simultaneous)	**Highly sensitive to nutrient imbalance** (N:P ratio)
Low-energy system (light-driven, no aeration/chemicals needed at scale)	**Dependence on micronutrients** (e.g. Si for diatoms)
Biomass valorisation (lipids, pigments → feed, fertiliser)	Variable efficiency depending on **strain physiology**
Flexible metabolism → can function under variable wastewater conditions	**Reduced performance under raw, untreated RAS water** → necessary (species-specific) medium modifications

Based on the conducted experiment, the following were developed: (1) a step-by-step practical protocol for microalgae application in nutrient removal from processing and wastewaters and (2) process optimization and troubleshooting guidelines, which are illustrated in the figures below.

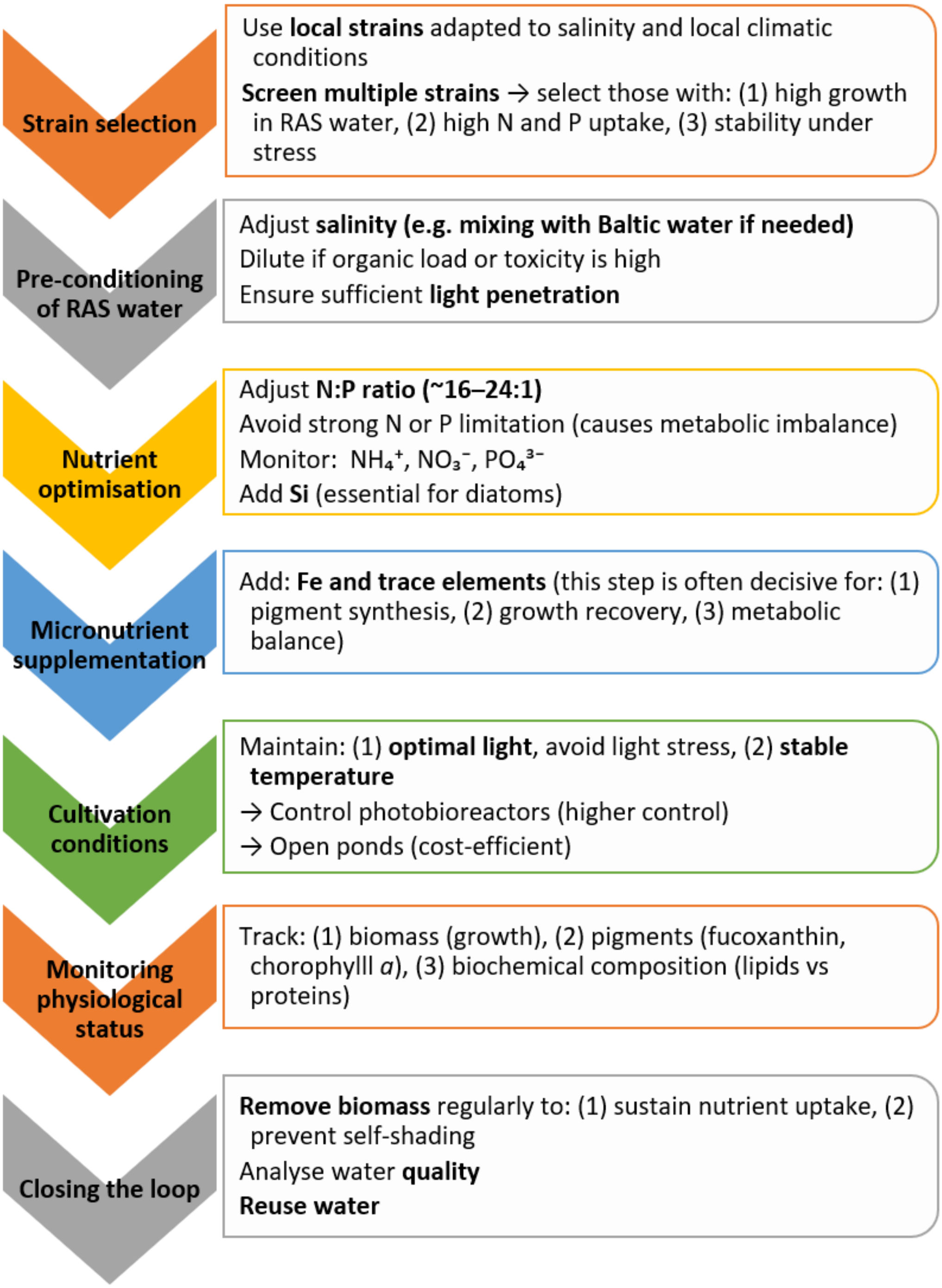

Fig. 9. Step-by-step practical protocol for microalgae application in nutrient removal from processing and waste- waters.

Quick troubleshooting rules

(RAS optimisation)

If:

- **growth low → check salinity and add Si + trace elements (especially Fe)**
- **pigments low → likely nutrient or Fe limitation → adjust N:P and micronutrients**
- **N removal high but P low → increase phosphorus (fix N:P imbalance)**
- **lipids high → system under stress → reduce limitation (add nutrients / balance conditions)**
- **proteins low → nitrogen limitation → increase N availability**
- **no growth + low removal → water inhibitory → dilute or pre-treat RAS water**
- **strain performance inconsistent → re-evaluate strain selection (physiology mismatch)**

Fig. 10. Process optimisation and troubleshooting guidelines.

II.8. References

1. Abdelfattah, A., Ali, S. S., Ramadan, H., El-Aswar, E. I., Eltawab, R., Ho, S.-H., Li, S., El-Sheekh, M. M., Schagerl, M., Kornaros, M., & Sun, J. (2022). Microalgae-based wastewater treatment: Mechanisms, challenges, recent advances, and future prospects. *Environmental Science and Ecotechnology, 13*, 100205. https://doi.org/10.1016/j.ese.2022.100205.
2. Al Hassany, J. S., Alrubai, G. H., & Jasim, I. M. (2021). The potential use of the diatom *Nitzschia palea* for the removal of pollutants from wastewater treatment plant effluents. *IOP Conference Series: Earth and Environmental Science, 779*(1), 012114. https://doi.org/10.1088/1755-1315/779/1/012114
3. Alipanah, L., Winge, P., Rohloff, J., Najafi, J., Brembu, T., & Bones, A. M. (2018). Molecular adaptations to phosphorus deprivation in the diatom *Phaeodactylum tricornutum*. *PLOS ONE, 13*, e0193335.
4. Alzahmi, A., Daakour, S., Nelson, D., Al Khairy, D., Twizere, J.-C., & Salehi Ashtiani, K. (2024). Enhancing algal production strategies: Strain selection, AI-informed cultivation, and mutagenesis. *Frontiers in Sustainable Food Systems, 8*, 1331251.
5. Arora, K., Kaur, P., Kumar, P., Singh, A., Patel, S. K. S., Li, X., Yang, Y.-H., Bhatia, S. K., & Kulshrestha, S. (2021). Valorization of wastewater resources into biofuel and value-added products using microalgal system. *Frontiers in Energy Research, 9*, 646571. https://doi.org/10.3389/fenrg.2021.646571
6. Barreto, A., Luna-Pabello, V. M., Sacristán de Alva, M., Palomino Albarrán, I. G., Arenas, M., & Gaxiola, G. (2025). Valorization of low-nitrogen, high-organic-load shrimp aquaculture wastewater by *Dunaliella salina*: Pollutant removal and high-value biomass production. *Microorganisms, 13*(7), 1484. https://doi.org/10.3390/microorganisms13071484
7. Bossa, R., Di Colandrea, M., Salbitani, G., & Carfagna, S. (2024). Phosphorus utilization in microalgae: Physiological aspects and applied implications. *Plants, 13*, 2127.
8. Çakirsoy, I., Miyamoto, T., & Ohtake, N. (2022). Physiology of microalgae and their application to sustainable agriculture. *Frontiers in Plant Science, 13*, 1005991.
9. Chinnappan, S., Cai, J., Li, Y., Yang, Z., Sheng, Y., Cheng, K., Du, H., & Liu, W. (2024). Light and nutrient conditions influence fucoxanthin production in diatoms. *Applied Sciences, 14*, 5504.
10. Cho, D.-H., Cho, K., Heo, J., Kim, U., Lee, Y. J., Choi, D.-Y., Yoo, C., Kim, H.-S., & Bae, S. (2020). High-throughput in vitro screening of changed algal community structure using the PhotoBiobox. *Journal of Microbiology and Biotechnology, 30*, 1785–1791.
11. Cointet, E., Wielgosz-Collin, G., Bougaran, G., Rabesaotra, V., Gonçalves, O., & Méléder, V. (2019). Effects of nitrogen availability on photosynthetic efficiency and biochemical composition of diatoms. *PLOS ONE, 14*, e0224701.
12. Díaz, V., Antiñolo, L., Poyatos Capilla, J. M., Almécija, M. C., Muñío, M. M., & Martín-Pascual, J. (2022). Nutrient removal and membrane performance of an algae membrane photobioreactor in urban wastewater regeneration. *Membranes, 12*(10), 982. https://doi.org/10.3390/membranes12100982

13. Dmochowska B., Kendzierska H., Łądkowska H., Normant-Saremba M., Szlinder-Richert J., Szulecka O., 2019. Deliverable 5.2: Evaluation of potential of crustacean production in RAS in Pomerania. Technical Report, InnoAquaTech, Cross-border development and transfer of innovative and sustainable aquaculture technologies in the South Baltic area, University of Gdańsk, National Marine Fisheries Research Institute, Gdynia https://www.submariner-network.eu/images/Crustacean_Production_in_RAS.pdf
14. Dong, S., Huang, F., Zou, X., Luo, Q., & Li, J. (2026). Microalgae as a synergistic enhancer for in situ and ex situ treatment technologies in sustainable shrimp aquaculture: A critical review. *Fishes, 11*(1), 60. https://doi.org/10.3390/fishes11010060
15. Goh, P. S., Ahmad, N. A., Lim, J. W., Liang, Y. Y., Kang, H. S., Ismail, A. F., & Arthanareeswaran, G. (2022). Microalgae-enabled wastewater remediation and nutrient recovery through membrane photobioreactors: Recent achievements and future perspective. *Membranes, 12*(11), 1094. https://doi.org/10.3390/membranes12111094
16. Harrison, E., Meeda, Y., Gaikwad, T., Wheeler, G., & Helliwell, K. E. (2025). Nitrogen status exerts dynamic control over phosphorus sensing and acquisition via PSR1 in colimited marine diatoms. *Science Advances, 11*(35), adw8260. https://doi.org/10.1126/sciadv.adw8260
17. Iber, B. T., & Kasan, N. A. (2021). Recent advances in shrimp aquaculture wastewater management. *Heliyon, 7*, e08283. https://doi.org/10.1016/j.heliyon.2021.e08283
18. Ji, L., Ge, Q., Li, Y., Gao, Y., & Xie, S. (2021). A comparative study of the growth and nutrient removal effects of five green microalgae in simulated domestic sewage. *Water, 13*(24), 3613. https://doi.org/10.3390/w13243613
19. Jiang, W., Li, Q., Jiang, L., Huang, Q., Liang, J., Zhou, Y., Lv, M., Wen, L., Li, Y., Ao, Q., Wang, S., & Yang, X. (2025). Red light enhanced nitrogen removal efficiency by bacterial–algae biofilm reactor in recirculating aquaculture systems. *Processes, 13*(11), 3594.
20. Khan, S., Thaher, M., Abdulquadir, M., Faisal, M., Mehariya, S., Al-Najjar, M. A. A., Al-Jabri, H., & Das, P. (2023). Utilization of Microalgae for Urban Wastewater Treatment and Valorization of Treated Wastewater and Biomass for Biofertilizer Applications. *Sustainability*, *15*(22), 16019. https://doi.org/10.3390/su152216019
21. Khanjani, M. H., Zahedi, S., Sharifinia, M., Hajirezaee, S., & Singh, S. K. (2025). Biological removal of nitrogenous waste compounds in biofloc aquaculture systems: A review. *Annals of Animal Science, 25*(1), 3–21. https://doi.org/10.2478/aoas-2024-0060
22. Kundu, P. K., Dutta, N., & Bhattacharya, S. (2024). Application of microalgae in wastewater treatment with special reference to emerging contaminants: A step towards sustainability. *Frontiers in Analytical Science, 4*, 1513153. https://doi.org/10.3389/frans.2024.1513153
23. Laurens, L. M. L., Van Wychen, S., McAllister, J. P., Arrowsmith, S., Dempster, T. A., McGowen, J., & Pienkos, P. T. (2014). Strain, biochemistry, and cultivation-dependent measurement variability of algal biomass composition. *Analytical Biochemistry, 452*, 86–95. https://doi.org/10.1016/j.ab.2014.02.009
24. Le, T. T. Y., Becker, A., Kleinschmidt, J., Mayombo, N. A. S., Farias, L., Beszteri, S., & Beszteri, B. (2023). Revealing Interactions between Temperature and Salinity and Their Effects on the Growth of Freshwater Diatoms by Empirical Modelling. *Phycology*, *3*(4), 413-435. https://doi.org/10.3390/phycology3040028

25. Li, L., Gao, K. G., Yang, M., Zheng, Q., Zhang, M., & Deng, X. (2023). Challenges and potential solutions of microalgae-based systems for wastewater treatment and resource recovery. *Frontiers in Bioengineering and Biotechnology, 11*, 1210228.
26. Liu, T., Chen, Z., Xiao, Y., Yuan, M., Zhou, C., Liu, G., Fang, J., & Yang, B. (2022). Biochemical and Morphological Changes Triggered by Nitrogen Stress in the Oleaginous Microalga *Chlorella vulgaris*. *Microorganisms*, *10*(3), 566. https://doi.org/10.3390/microorganisms10030566
27. Lovio Fragoso, J. P., de Jesús Campos, D., López Elías, J. A., Medina Juárez, L. Á., Fimbres Olivarría, D., & Hayano Kanashiro, C. (2021). Phosphorus limitation and biomolecule accumulation in diatoms. *Biology, 10*, 565.
28. Minhas, A. K., Gaur, S., Sunny, S., Paladugu, C., Ravishankar, G. A., Pereira, L., & Ambati, R. R. (2026). Microalgae-based wastewater treatment processes for the bioremediation and valorization of biomass: A review. *Phycology, 6*(1), 18. https://doi.org/10.3390/phycology6010018
29. Plöhn, M., Spain, O., Sirin, S., Silva, M., Escudero Oñate, C., Ferrando Climent, L., Allahverdiyeva, Y., & Funk, C. (2021). Wastewater treatment by microalgae. *Physiologia Plantarum*.
30. Ramírez Mérida, L. G., & Rodríguez Padrón, R. A. (2023). Application of microalgae in wastewater: Opportunity for sustainable development. *Frontiers in Environmental Science, 11*, 1238640. https://doi.org/10.3389/fenvs.2023.1238640
31. Ramli, N. M., Verreth, J. A. J., Yusoff, F. M., Nurulhuda, K., Nagao, N., & Verdegem, M. C. J. (2020). Integration of algae to improve nitrogenous waste management in recirculating aquaculture systems: A review. *Frontiers in Bioengineering and Biotechnology, 8*, 1004.
32. Sarma, S., Sharma, S., Rudakiya, D., Upadhyay, J., Rathod, V., Patel, A., & Narra, M. (2021). Valorization of microalgae biomass into bioproducts promoting circular bioeconomy: A holistic approach of bioremediation and biorefinery. *3 Biotech, 11*(8), 378. https://doi.org/10.1007/s13205-021-02911-8
33. Shen, J., Zheng, X., Liu, M., Xu, K., He, L., & Lin, Z. (2024). Targeted cultivation of diatoms in mariculture wastewater by nutrient regulation and UV-C irradiation. *Frontiers in Microbiology, 15*, 1371855.
34. Truong, T. Q., Park, Y. J., Winarto, J., Huynh, P. K., Moon, J., Choi, Y. B., Song, D.-G., & Koo, S. M. (2024). Nitrogen availability as a limiting factor for fucoxanthin production. *Marine Drugs, 22*, 93.
35. Ugwuanyi, E. D., Nwokediegwu, Z. Q. S., Dada, M. A., Majemite, M. T., & Obaigbena, A. (2024). The role of algae-based wastewater treatment systems: A comprehensive review. *World Journal of Advanced Research and Reviews, 21*(2), 937–949. https://doi.org/10.30574/wjarr.2024.21.2.0521
36. Ungureanu, N., Vlăduţ, V., & Popa Ivanciu, M. (n.d.). Nutrient removal from wastewater by microalgae *Chlorella vulgaris*. *Journal of Biotechnology Systems Engineering*. [Incomplete citation.]
37. Velasquez Orta, S. B. (2023). Algae for wastewater treatment and biofuel production. In *Algal Systems for Resource Recovery from Wastewater*.

38. Xing, R.-L., Ma, W.-W., Shao, Y.-W., Cao, X.-B., Su, C., Song, H.-X., Su, Q., & Zhou, G.-F. (2018). Growth and potential purification ability of *Nitzschia* sp. benthic diatoms in sea cucumber aquaculture wastewater. *Aquaculture Research, 49*(8), 2644–2652. https://doi.org/10.1111/are.13722

39. Yang, Z.-K., Niu, Y.-F., Ma, Y.-H., Xue, J., Zhang, M.-H., Yang, W.-D., Liu, J.-S., & Li, H.-Y. (2013). Lipid accumulation in diatoms under nitrogen deprivation. *Biotechnology for Biofuels, 6*, 67.

40. You, N., Deng, S., Wang, C., Ngo, H. H., Wang, X., Yu, H., Tang, L., & Han, J. (2023). Review and opinions on microalgae culture technologies for resource recovery from wastewater. *Water, 15*(6), 1192. https://doi.org/10.3390/w15061192

41. Zheng, Q., Ning, R., Zhang, M., & Deng, X. (2023). Biofuel production from microalgae biomass derived from wastewater. *Frontiers in Bioengineering and Biotechnology, 11*, 1250407.

III. PILOT DEMONSTRATIONS

The AquaLoop project aimed to prepare school pupils, students, and professionals for circular economy approaches, with a focus on aquaculture production and consumption. It sought to support their career development while contributing to both ecological and economic progress in the region. TARAS pilot specifically was focused on students training, but also included other groups of stakeholders:

1. Aquaculture, Oceanography and Marine Biology Bachelor's and Master's students from the University of Gdańsk, University of Rostock and Klaipeda University;
2. Researchers and academics from partner institutions: University of Rostock, University of Gdańsk and Klaipeda University;
3. Representatives of NGOs, municipalities, public bodies: Fish Market Development Association (Poland), Gulborgsund Municipality (Denmark), Business Lolland-Falster. (Denmark), VKST (Denmark);
4. SMEs: K2 Fish Farm (Poland), Aquamedic Poland (Poland), and Scandinavian Aquasystems AB (Sweden).

Training based on the pilot was performed within so called **TrainingLoop – Circular aquaculture training pool** activities of the AquaLoop project, whereas **study visits** to the facility were carried out as part of the **SupportLoop – Circular aquaculture stakeholder support** AquaLoop activities.

III.1. University of Gdańsk students involvement in TARAS pilot

The pilot actively involved students from the University of Gdańsk, engaging 4 bachelor's students, 1 master's student, 1 PhD student, and 7 trainees. This collaboration provided valuable support to the project while offering students hands-on experience in applied marine science and sustainable aquaculture.

Students participated in the daily operation and maintenance of the recirculating aquaculture system (RAS), including monitoring water quality, maintaining equipment, observing shrimp health and determining their mass, managing feeding, and documenting system performance (Fig. 11). They also supported experimental work by conducting measurements of feed consumption, respiration, nitrogen excretion, and biological sampling. Four bachelor's students carried out research on the effects of yeast and probiotic feed supplementation in white shrimp (*Penaeus vannamei*), leading to four bachelor's theses focused on shrimp growth, feeding behavior as well as body coloration and exoskeleton condition. In addition, third-year students of the Aquaculture – Business and Technology program visited the pilot facility as part of the course *Environmental Impact of Aquaculture*. They were introduced to the modified RAS500 system, white shrimp farming practices, and the environmental benefits of recirculating aquaculture systems, gaining valuable insight into modern sustainable aquaculture and applied research.

Fig. 11. University of Gdańsk students involved in the TARAS pilot (photos by M. Normant-Saremba and H. Kendzierska)

III.2. AquaLoop cross-border student exchange program

The AquaLoop project established a cross-border student exchange programme between the three partner universities implementing the project pilots: the University of Rostock (Germany), the University of Gdańsk (Poland), and Klaipeda University (Lithuania). The initiative provided bachelor's and master's students in aquaculture and related disciplines with one week of hands-on training based on the AquaLoop three pilot activities. Through experimental and laboratory work linked to the TARAS, NEMATIC, and FISHVISA pilots (Fig. 12), students became familiar with partner institutions, circular economy approaches, and innovative aquaculture practices. The programme also included study visits to commercial aquaculture facilities.

Fig. 12. AquaLoop cross-border student exchange program banner (banner credit: B. Dmochowska).

The TARAS pilot served as a practical training platform for exchange students from the University of Rostock (Germany) and Klaipeda University (Lithuania), who visited the

Faculty of Oceanography and Geography at the University of Gdańsk in January and February 2025.

Under the guidance of the AquaLoop team, students were introduced to shrimp cultivation in recirculating aquaculture systems (RAS) and microalgae production with an emphasis on processing water utilization. Through direct involvement in the pilot activities, students gained hands-on experience in experimental procedures and daily aquaculture operations. Their work included water sampling and analysis, media preparation, experimental setup and growth monitoring, measurements related to shrimp energy balance, feed consumption and feces excretion rates, as well as routine husbandry activities such as water quality monitoring, feeding, behavioral observations, tank cleaning, and water exchange procedures. In addition, the students gained insight into commercial applications of RAS technology through a visit to the K2 Trout Farm, a large-scale recirculating aquaculture facility in northern Poland (Fig. 13, 14).

Interreg South Baltic — Co-funded by the European Union

University of Gdańsk

aqua loop

"AquaLoop cross-border student exchange program"

PROGRAM CURRICULUM
for students from the Klaipeda University
visiting the University of Gdańsk

Program venue: Faculty of Oceanography and Geography, University of Gdańsk, al. Marszałka Piłsudskiego 46, 81-378 Gdynia, Poland
Program start and meeting point: January 27th 2025 (Monday) 8.30 a.m. ground floor, faculty main building

Agenda *Daily agenda might be subject to slight changes. Lunch breaks and any other adjustments will be planned with the participants.	
January 26th, Sunday	Arrival in Gdynia
January 27th, Monday 8.30 – 16.30	Welcome, introduction to AquaLoop project and pilot 1: TARAS, safety instructions for working in the labs Microalgae – Part 1 • Presentation: Introduction to microalgal growth • Presentation: Waste water as medium for microalgal growth • Practical work: Waste water sampling, analyses of water chemistry, media preparation, growth monitoring techniques, setting up an experiment
January 28th, Tuesday 8.30 – 16.30	Shrimps – Part 1 • Presentation: Introduction to the method of determining energy available for growth in shrimps • Practical work: daily routine activities (water parameters monitoring, food preparation, feeding, behaviour observation, tank cleaning, water exchange procedure) • Practical work: Analyses of food consumption and faeces excretion rates • Practical work: Analyses of respiration
January 29th, Wednesday 9.00 – 18.00	Field trip to K1/K2 Trout Farm (RAS facility) Afternoon sightseeing Get together dinner
January 30th, Thursday 8.30 – 16.30	Shrimps – Part 2 • Practical work: Determination of energy and organic matter contents in food • Practical work: Calculation of energy available for growth • Shrimp Section Summary
January 31st, Friday 8.30 – 16.30	Microalgae – Part 2 • Presentation: Microalgal biomass characteristics and its uses • Practical work: Microalgal growth monitoring and finishing an experiment, biomass characteristics. • Microalgae Section Summary
February 1st, Saturday	Departure

Fig.13. AquaLoop cross-border student exchange program agenda at the University of Gdańsk for students from the Klaipeda University (Lithuania)

Interreg South Baltic — Co-funded by the European Union

University of Gdańsk

aqua loop

"AquaLoop cross-border student exchange program"

PROGRAM CURRICULUM
for students from the University of Rostock
visiting the University of Gdańsk

Program venue: Faculty of Oceanography and Geography, University of Gdańsk, al. Marszałka Piłsudskiego 46, 81-378 Gdynia, Poland

Program start and meeting point: January 7th 2025 (Tuesday) 8.30 a.m. ground floor, faculty main building

Agenda *Daily agenda might be subject to slight changes. Lunch breaks and any other adjustments will be planned with the participants.	
January 6th, Monday	Arrival in Gdynia
January 7th, Tuesday 8.30 – 16.30	Welcome, introduction to AquaLoop project and pilot 1: TARAS, safety instructions for working in the labs Microalgae – Part 1 • Presentation: Introduction to microalgal growth • Presentation: Waste water as medium for microalgal growth • Practical work: Waste water sampling, analyses of water chemistry, media preparation, growth monitoring techniques, setting up an experiment Get together dinner
January 8th, Wednesday 8.30 – 16.30	Shrimps – Part 1 • Presentation: Introduction to the method of determining energy available for growth in shrimps • Practical work: daily routine activities (water parameters monitoring, food preparation, feeding, behaviour observation, tank cleaning, water exchange procedure) • Practical work: Determination of energy and organic matter contents in food • Practical work: Analyses of food consumption and faeces excretion rates
January 9th, Thursday 9.00 – 18.00	Field trip to K1/K2 Trout Farm (RAS facility) Afternoon sightseeing
January 10th, Friday 8.30 – 16.30	Shrimps – Part 2 • Practical work: analyses of respiration and ammonia excretion rates • Practical work: Calculation of energy available for growth • Shrimp Section Summary
January 11th, Saturday 8.30 – 16.30	Microalgae – Part 2 • Presentation: Microalgal biomass characteristics and its uses • Practical work: Microalgal growth monitoring and finishing an experiment, biomass characteristics. • Microalgae Section Summary
January 12th, Sunday	Departure

Fig. 14. AquaLoop cross-border student exchange program agenda at the University of Gdańsk for students from the University of Rostock (Germany).

The exchange programs demonstrated the value of the TARAS pilot as a training and knowledge-transfer platform, providing students with practical experience in innovative and sustainable aquaculture technologies. Feedback from both groups was exceptionally positive, with participants highlighting the opportunity to work with novel species and methodologies, gain insight into scientific research, and develop practical skills in shrimp and microalgae cultivation. The programs also strengthened collaboration between the

University of Gdańsk and its international partners, contributing to the development of future aquaculture specialists.

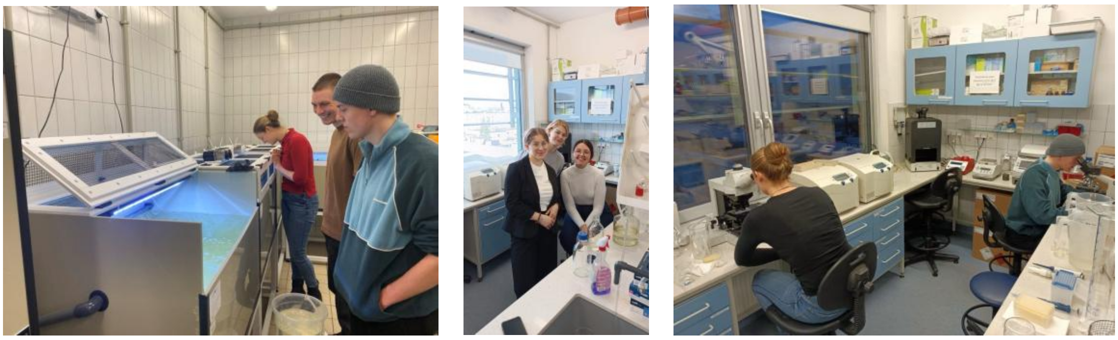

Fig. 15. University of Rostock and Klaipeda University students involved in the TARAS pilot (photos by M. Normant-Saremba and F. Pniewski).

III.3. Research internship at the TARAS pilot

As part of the AquaLoop project, a Master's student in Aquaculture from the University of Rostock completed a two-month research stay at the University of Gdańsk (February–April 2025), contributing to activities within the TARAS pilot (Fig. 16). The student participated in research on the reconditioning of shrimp aquaculture effluent for microalgae cultivation, aimed at improving nutrient removal and supporting circular water use in land-based aquaculture systems.

The work involved screening microalgal strains suitable for saline effluents, evaluating their growth performance, and characterizing the biochemical composition and potential applications of the resulting biomass. The exchange supported the scientific objectives of the TARAS pilot while strengthening international collaboration and providing valuable hands-on experience in sustainable aquaculture research.

Fig. 16. University of Rostock research internship student involved in the TARAS pilot (photos by F. Pniewski and B. Dmochowska).

III.4. Demonstration to professionals

TARAS pilot was listed as one of the facilities to be visited as an example of potential circular-economy solutions. Pilot operation was demonstrated to the AquaLoop project partners representing public research and education institutions, NGOs, and companies: University of Rostock (Germany), University of Gdańsk (Poland), Klaipeda University

(Lithuania), Gulborgsund Municipality (Denmark), Fish Market Development Association (Poland), Scandinavian Aquasystems AB (Sweden), VKST (Denmark) as well as representatives of the project Advisory Board representing Business Lolland-Falster (Denmark), and Aquamedic Poland (Poland), as well as K2 Fish Farm, a partner fish farm contributing to the project (Fig. 15). The meeting and demonstration with aquaculture professionals in the academic and market sector provided valuable expertise and know-how for the pilot further adjustments.

Fig. 17. Group of AquaLoop partners, representatives of academia, research and business sector visited the TARAS pilot facility (photo by the University of Gdańsk).

IV. PILOT RESULT DELIVERY AND COMMUNICATION

The TARAS pilot was extensively communicated throughout the project lifecycle through a wide range of regional, national, and international dissemination activities. To maximise the visibility of the pilot and ensure that its results reached diverse stakeholder groups, the project combined scientific dissemination, industry outreach, stakeholder engagement, and policy dialogue. The pilot and its outcomes were presented at AquaLoop partner and Advisory Board meetings, the AquaLoop International Conference in Bremerhaven, major international aquaculture and blue economy conferences, Interreg cooperation events, regional and international workshops, and key regional conferences. These activities targeted researchers, aquaculture producers, industry representatives, SMEs, policymakers, public authorities, educators, students, NGOs, and innovation support organisations. In addition, the TARAS pilot was promoted through a range of communication materials, including posters, newsletters, scientific and popular publications, brochures, and other dissemination tools, ensuring broad awareness of the pilot's objectives, implementation, and results across multiple audiences.

IV.1. AquaLoop partner and Advisory Board meetings

Throughout the implementation of the TARAS pilot, project communication played a key role in presenting progress, gathering feedback, and refining pilot activities. In addition to numerous online meetings and technical consultations held throughout the project, updates on the pilot were regularly presented during AquaLoop partner meetings held in Rostock, Germany (November 2023), Klaipėda, Lithuania (April 2024), Copenhagen, Denmark (August 2024), Gdynia, Poland (April 2025), Aalborg, Denmark (October 2025), and Malmö, Sweden (June 2026) (Fig. 18).

These meetings brought together researchers and academics from the University of Rostock (Germany), the University of Gdańsk (Poland), and Klaipėda University (Lithuania), representatives of partner organizations including the Fish Market Development Association (Poland), Guldborgsund Municipality (Denmark), VKST (Denmark), and Aquasystems AB (Sweden), as well as members of the AquaLoop Advisory Board (Fig. 19) representing the Ministry of Agriculture of Lithuania, Business Lolland-Falster (Denmark), Aquamedic Poland, and the Technology Transfer Center (ttz) Bremerhaven (Germany), together with other relevant stakeholders.

These exchanges provided an important forum to discuss the progress of the PilotLoops, share implementation experiences, coordinate activities, and identify opportunities to strengthen the practical relevance and impact of the TARAS pilot. In particular, the meeting in Gdynia included a visit to the TARAS pilot facility at the University of Gdańsk, where algae cultivation and circular aquaculture solutions were demonstrated to consortium members and stakeholders.

The partner meetings, Advisory Board sessions, and regular online consultations generated valuable recommendations that were systematically incorporated into the further development of the TARAS pilot. Feedback focused on increasing the practical applicability of the demonstrated solutions, improving the communication of pilot results to the aquaculture sector, and ensuring that research outcomes could be effectively transferred into training and support activities. Participants also highlighted the importance of demonstrating economically viable circular aquaculture practices, strengthening stakeholder engagement through study visits, workshops, and demonstration events, and comprehensively documenting lessons learned throughout pilot implementation.

As a result, both the communication strategy and the technical implementation of the TARAS pilot were continuously refined throughout the project. The regular presentation of pilot results at consortium meetings, complemented by frequent online consultations between partners, enabled the timely exchange of knowledge, validation of experimental approaches, and implementation of adjustments in response to expert recommendations. This iterative process strengthened collaboration among project partners, improved the quality and relevance of the pilot activities, and enhanced the dissemination of results, ensuring that the final TARAS pilot reflected the collective expertise of the consortium and the guidance of the Advisory Board while contributing to AquaLoop's objective of promoting circular economy practices in aquaculture across the South Baltic region.

Fig.18. AquaLoop partner meetings held in Rostock, Germany, Klaipėda, Lithuania, Copenhagen, Denmark, Gdynia, Poland, Aalborg, Denmark, and Malmö, Sweden.

Fig. 19. AquaLoop Advisory Board, including representatives of Ministry of Agriculture of Lithuania, Business Lolland-Falster (Denmark), Aquamedic Poland, and the Technology Transfer Center (ttz) Bremerhaven (Germany).

IV.2. AquaLoop International Conference

The results of the TARAS pilot were disseminated during the final AquaLoop International Conference "Strengthening Circular Economy and Valorisation of Side Streams in RAS

Aquaculture", held on 25 February 2026 at Klimahaus in Bremerhaven, Germany, (with the possibility of online participation). As the final conference of the AquaLoop project, the event brought together more than 70 participants (Fig. 20) representing academia, the aquaculture industry, policymakers, public institutions, and students from across Europe, providing an excellent platform for communicating the outcomes of the TARAS pilot to a diverse international audience.

The TARAS pilot results were presented as part of the conference session *"Closing the Nutrient Loop & Byproduct Valorization"*, which highlighted innovative approaches to improving the circularity of recirculating aquaculture systems. The presentation, entitled *"Utilization Potential of Microalgae Cultivated in Processing Water from Shrimp Recirculating Aquaculture Systems (RAS)"*, showcased the pilot's key findings on algae cultivation, nutrient recovery, and the valorization of aquaculture side streams. The presentation demonstrated the technical feasibility and application potential of integrating microalgae production into RAS operations, while also discussing the environmental and economic benefits of these circular solutions. The pilot results were further communicated through the conference presentation materials, panel discussions, networking sessions, and the conference exhibition, enabling direct interaction with researchers, industry representatives, and policymakers interested in the practical implementation of circular aquaculture technologies.

The conference provided an important opportunity to disseminate the scientific and practical outcomes of the TARAS pilot, stimulate discussion on their applicability within commercial aquaculture, and gather feedback from key stakeholders. The strong engagement of participants and interdisciplinary discussions contributed to increasing the visibility of the pilot, promoting knowledge transfer beyond the project consortium, and supporting the wider uptake of innovative algae-based solutions for improving the sustainability and resource efficiency of recirculating aquaculture systems.

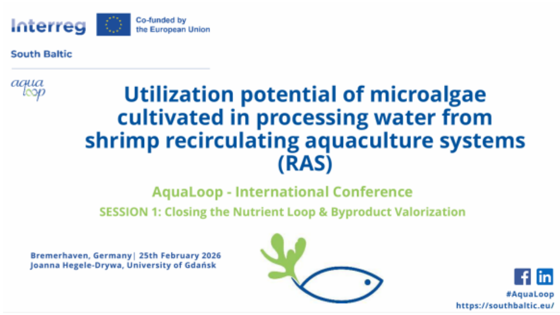

Fig. 20. AquaLoop International Conference participants, and TARAS pilot presentation title page.

IV.3. International branch conferences

The TARAS pilot was communicated to the international aquaculture community during the two largest European aquaculture conferences organized by the European Aquaculture Society (EAS) and the World Aquaculture Society (WAS), ensuring broad dissemination of its objectives, methodology, and research outcomes among key sector stakeholders.

The first dissemination activity took place during AQUA 2024, held in Copenhagen, Denmark (August 2024), where TARAS was presented through an electronic poster and within AquaLoop E-poster presentation introducing the project's circular aquaculture approach (Fig. 21). The conference brought together researchers, aquaculture producers, technology providers, policymakers, students, and representatives of supporting industries from around the world, providing an international platform to raise awareness of the project's objectives and establish contacts with organizations interested in circular aquaculture solutions.

The communication of the TARAS pilot was further strengthened during Aquaculture Europe 2025, held in Valencia, Spain (September 2025). Building on the initial project presentation from the previous year, AquaLoop disseminated the scientific results of the TARAS pilot through the electronic poster entitled *"Improving the Circularity of Aquaculture in the South Baltic Region – A Pilot Study on the Use of Microalgae in RAS Systems with Whiteleg Shrimp* (*Penaeus vannamei*)" (Fig. 18). The presentation showcased results obtained at the University of Gdańsk, demonstrating the potential of integrating microalgae cultivation into shrimp recirculating aquaculture systems to improve nutrient recovery and resource efficiency. Together with three additional AquaLoop presentations covering the project's remaining pilots and educational activities, the TARAS pilot contributed to presenting AquaLoop as a comprehensive framework for implementing circular economy principles in aquaculture. The conference provided valuable opportunities to discuss the pilot findings with international researchers, aquaculture producers, technology developers, policymakers, and other sector stakeholders, increasing the visibility of the developed solutions, promoting scientific exchange, and supporting the wider uptake of innovative circular aquaculture practices beyond the South Baltic region.

Fig 21. TARAS pilot presentation at Aquaculture Europe 2024 and Aquaculture Europe 2025

IV.4. International conferences for different stakeholder groups

The TARAS pilot was promoted at international conferences in 2024–2025, enabling communication with diverse stakeholder groups, including researchers, educators, policymakers, industry representatives, NGOs, and the wider blue economy community. These events increased the pilot's international visibility and created opportunities for knowledge exchange and future cooperation.

In May 2024, the TARAS pilot was presented at European Maritime Day in Svendborg, Denmark, during a workshop on circular recirculating aquaculture. The event brought together maritime experts, policymakers, businesses, and innovation stakeholders, providing an opportunity to communicate the pilot's contribution to circular aquaculture and engage with the European blue economy community.

In September 2024, the project was showcased at the EMSEA Annual Conference in Zadar, Croatia. The conference focused on ocean literacy and the blue economy, allowing the University of Gdańsk to present the TARAS pilot to educators, researchers, and marine science professionals, highlighting its educational and innovation-oriented activities. In September 2025, the TARAS pilot was further promoted at the EMSEA Annual Conference in Ostend, Belgium (Fig. 22). The University of Gdańsk presented educational approaches supporting sustainable aquaculture and the blue economy, reaching an international audience of academics, educators, NGOs, policymakers, and private sector representatives. The conference strengthened the pilot's visibility within the European ocean literacy community and encouraged collaboration on education and capacity-building initiatives.

In November 2025, the TARAS pilot was communicated during the Danish Bioeconomy Conference in Nykøbing Falster, Denmark, alongside other Interreg initiatives. The event gathered researchers, policymakers, industry leaders, and bioeconomy experts, providing a platform to present the pilot's role in supporting sustainable and circular aquaculture and to establish links with stakeholders working on bio-based innovation.

Together, these international events supported the dissemination of the TARAS pilot across Europe, reaching complementary target groups and strengthening cooperation between research, education, industry, and policy communities working towards sustainable aquaculture and the blue economy.

Fig. 22. TARAS pilot communication at the EMSEA conferences.

IV.5. Key regional conferences

The TARAS pilot was promoted at three major aquaculture events in Poland, providing opportunities to communicate its objectives, engage with key stakeholders, and establish new collaborations with representatives of industry, academia, and public institutions (Fig. 23).

In June 2024, during the 10th Fish Congress in Sopot, the University of Gdańsk presented the TARAS pilot, its activities, and opportunities for cooperation with fishery and aquaculture businesses. The event enabled direct discussions with industry representatives and increased the pilot's visibility among key stakeholders.

Also in October 2024, the project was promoted at the XLIX Trout Breeders Conference & Aquaculture Technology Fair, where it reached aquaculture professionals, researchers, businesses, NGOs, and students. The conference and accompanying technology fair provided an excellent platform to present the pilot, exchange experiences, and explore future cooperation with industry partners.

In October 2025, the TARAS pilot was presented during the educational session of the 50th Training and Conference of Trout Breeders, organized by the Polish Trout Breeders Association. The presentation highlighted the pilot's contribution to education, knowledge transfer, and sustainable aquaculture, while engaging fish producers, researchers, technology providers, and policymakers.

Together, these three events significantly increased the visibility of the TARAS pilot, supported knowledge exchange with key stakeholder groups, and strengthened collaboration between academia and the aquaculture sector.

Fig. 23. TARAS pilot communication at the educational session of the Conference of Trout Breeders andFish Congress (photo by Anna Swacha-Polańska and Fish Congress).

IV.6. International and regional workshops

The results of the TARAS pilot were communicated to regional stakeholders through dedicated workshops and blue economy events, providing opportunities to disseminate project outcomes, exchange knowledge, and discuss the practical implementation of circular aquaculture solutions. At the BlueMissionBANOS Mission Arena 4, held in Sopot, Poland (April 2025), TARAS pilot was presented during Blue Foods Workshop, highlighting the potential of sustainable whiteleg shrimp production and circular aquaculture practices developed within the TARAS pilot (Fig. 24). The pilot results were communicated to more than 300 participants, including researchers, aquaculture professionals, policymakers, regional authorities, industry representatives, educators, and organizations involved in the blue economy from across the Baltic Sea Region. Through thematic presentations, workshops, and discussions, the event promoted innovative approaches to nutrient recovery, resource efficiency, and sustainable food production while facilitating knowledge exchange with stakeholders working on maritime and blue bioeconomy challenges.

In June 2025, the TARAS pilot was communicated during the BBT Baltic Hackathon (Fig. 24), hosted by the University of Gdańsk. The pilot contributed a challenge focused on developing energy-efficient recirculating aquaculture systems (RAS) for the Baltic region, engaging 25 master's and doctoral students from 15 European countries, together with mentors, entrepreneurs, startups, NGOs, researchers, and innovation experts. By integrating the pilot into a collaborative innovation event, TARAS reached future professionals and blue economy innovators, encouraging the development of practical solutions for sustainable aquaculture.

Further dissemination of the TARAS pilot results took place during the AquaLoop Workshop "Aquaculture Forum Towards the Development of Circular Economy Practices", organized in March 2026 in Sopot, Poland, as a side event of the 12th Fish Congress. The workshop gathered nearly 30 participants, including trout, sturgeon, and carp farmers, researchers, representatives of public administration, and the Deputy Minister of Agriculture and Rural Development.

Fig. 24. TARAS pilot communication through presentation at the BlueMissionBANOS Mission Arena 4 and BBT Baltic Hackathon.

IV.7. Interreg program events

The TARAS pilot was actively communicated through AquaLoop's participation in major Interreg South Baltic and Interreg Baltic Sea Region cooperation events, providing opportunities to disseminate project results and engage with a broad international audience (Fig. 25).

At the Interreg South Baltic Annual Event – TransformEU: Showcasing Progress and Impact, held in Rønne, Bornholm (September 2025), AquaLoop showcased the TARAS pilot as part of the project's exhibition stand during the event's mini expo. Through face-to-face discussions with visitors, project materials, and presentations of the pilot activities, consortium representatives demonstrated how algae-based solutions integrated into recirculating aquaculture systems contribute to circular aquaculture, sustainable water use, and improved nutrient management. The event brought together Interreg project partners, program representatives, policymakers, and stakeholders from across the South Baltic region, providing an excellent platform for exchanging experiences, promoting project achievements, and discussing the transferability of the developed solutions.

The TARAS pilot was also promoted during the EUSBSR Annual Forum 2026, held in Tallinn, Estonia (May 2026), through the AquaLoop electronic poster (e-poster) and networking activities. The e-poster presented AquaLoop's approach to circular aquaculture, highlighting the TARAS pilot as an example of innovative nutrient recovery and algae cultivation within recirculating aquaculture systems. Discussions with Forum participants increased further the visibility of the pilot, enabled the exchange of knowledge with organisations working on similar challenges, and strengthened opportunities for future collaboration and wider uptake of the developed circular economy solutions. The Forum gathered policymakers, researchers, regional organizations, civil society representatives, and other stakeholders from across the Baltic Sea Region to discuss resilience, sustainability, environmental protection, and regional cooperation.

Fig. 25. TARAS pilot communication through presentations, posters, and stands at the Interreg program events.

IV.8. Online dissemination materials and communication channels

Throughout the project, the progress, activities, achievements, and results of the TARAS pilot were continuously communicated through a range of dissemination materials and communication channels. These included:

- project newsletters,
- project brochures,
- project posters,
- promotional publications.

All materials were made available through the AquaLoop project website and promoted via the project's LinkedIn platform, and University of Gdańsk website ensuring broad accessibility and regular updates for researchers, aquaculture professionals, policymakers, industry representatives, students, and the wider public. This continuous communication supported the visibility of the TARAS pilot, facilitated knowledge transfer, and contributed to the wider dissemination of its innovative approaches and outcomes.

ACKNOWLEGMENTS

The authors of this report thank everyone who contributed to the development, implementation, demonstration, and communication of the TARAS pilot.

Our special thanks go to the University of Gdańsk team for their commitment and work throughout the project.

We also thank all the University of Gdańsk students and visiting students for their valuable contributions.

We are grateful to all AquaLoop partners who participated in the pilot, shared their knowledge and experience, and provided valuable feedback that helped improve the developed solutions.

We thank all associated partners, the Advisory Board, and all the stakeholders for their valuable advice and guidance.

Finally, we acknowledge the financial support provided by the Interreg South Baltic Programme 2021-2027 through the European Regional Development Fund (ERDF).