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2025 *Activity Report*

RESEARCH CENTRE: **Inria Centre at Université Côte d'Azur**

IN PARTNERSHIP WITH: **INRAE, CNRS, Sorbonne Université**

Project-Team

GREENOWL

Generating RENewable resources by Optimisation of Water Living microorganisms

In collaboration with Laboratoire d'océanographie de Villefranche (LOV), Technologies & méthodes pour les agricultures de demain Unité de recherche

Project-Team GREENOWL

Creation of the Project-Team: 2024 December 01

Each year, Inria research teams publish an Activity Report presenting their work and results over the reporting period. These reports follow a common structure, with some optional sections depending on the specific team. They typically begin by outlining the overall objectives and research programme, including the main research themes, goals, and methodological approaches. They also describe the application domains targeted by the team, highlighting the scientific or societal contexts in which their work is situated. The reports then present the highlights of the year, covering major scientific achievements, software developments, or teaching contributions. When relevant, they include sections on software, platforms, and open data, detailing the tools developed and how they are shared. A substantial part is dedicated to new results, where scientific contributions are described in detail, often with subsections specifying participants and associated keywords. Finally, the Activity Report addresses funding, contracts, partnerships, and collaborations at various levels, from industrial agreements to international cooperations. It also covers dissemination and teaching activities, such as participation in scientific events, outreach, and supervision. The document concludes with a presentation of scientific production, including major publications and those produced during the year.

Keywords

Computer sciences and digital sciences

A6.1. – Methods in mathematical modeling

A6.2. – Scientific computing, Numerical Analysis & Optimization

A6.4. – Automatic control

A9.2. – Machine learning

A9.2.6. – Neural networks

A9.2.8. – Deep learning

A9.7. – AI algorithmics

Other research topics and application domains

B1. – Life sciences

B1.1. – Biology

B3. – Environment and planet

B4. – Energy

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1 Team members, visitors, external collaborators

Research Scientists

- Olivier Bernard [Team leader, INRIA, Senior Researcher, HDR]
- Francesca Casagli [INRIA, Researcher]
- Walid Djema [INRIA, ISFP]
- Lionel GUIDI [CNRS, Senior Researcher, from Nov 2025, HDR]
- Arnaud Hélias [INRAE - ITAP, HDR]
- Pierre Jouannais [INRAE - ITAP]
- Tewfik Sari [INRAE, until Aug 2025, HDR]
- Antoine Sciandra [CNRS, Senior Researcher, HDR]

Post-Doctoral Fellow

- Solene Jahan [INRIA, Post-Doctoral Fellow]

PhD Students

- Constanza Andreani [Sorbonne University]
- Javier Innerarity Imizcoz [Université Côte d'Azur (EUR DS4H)]
- Pauline Mazel [Université Côte d'Azur (EUR DS4H)]
- David Morgado [CentraleSupelec, until Jan 2025]
- Manon Pugnet [UNIV COTE D'AZUR]
- Romain Ranini [Inria]

Technical Staff

- Amélie Talec [CNRS, Engineer, from Sep 2025]

Interns and Apprentices

- Domingo Benoit Cea [INRIA, Intern, from Feb 2025 until Apr 2025]
- Baptiste Boerkmann [UNIV COTE D'AZUR, Intern, from Apr 2025 until Sep 2025]
- Sabina Cano [UNIV COTE D'AZUR, Intern, from Feb 2025 until Aug 2025]
- Thomas Garcia [INRIA, Intern, from May 2025 until Aug 2025]
- Miguel Gonzalez Serrano [UNAM, from Sep 2025]
- Jean Leroy [UNIV COTE D'AZUR, Intern, from May 2025 until Oct 2025]
- Athénaïs Vermande [Université Nice Côte d'Azur, Intern, from Jul 2025 until Jul 2025]

Administrative Assistant

- Maeva Jeannot [INRIA]

Visiting Scientists

- Bastien Polizzi [UNIV FRANCHE-COMTE, from Feb 2025 until Aug 2025]
- Alejandro Vargas Casillas [UNAM, from Jul 2025]

External Collaborators

- Hubert Bonnefond [Darewin Evolution]
- Charlotte Gaviard [Darewin Evolution]

2 Overall objectives

Global climate change represents one of the most profound anthropogenic disturbances to our planet, driven primarily by greenhouse gas emissions from fossil fuel combustion and land-use changes. Surface temperatures have already risen by approximately 0.78°C since industrialization and are projected to increase by a further 1.5–4.5°C by the end of the 21st century.

Against this backdrop, the GREENOWL project-team addresses three interrelated scientific objectives: (1) understanding and harnessing the adaptive capacity of microbial ecosystems in a changing world, (2) developing and optimizing innovative microbial-based processes for resource recovery and sustainable production, and (3) advancing methodologies for environmental impact assessment to support the transition to sustainable technologies.

These objectives are interconnected, exchanging models, data, and methodologies, especially the approaches derived from control science and Artificial Intelligence. In the following sections, we detail the long-term research directions that guide GREENOWL developments.

2.1 Study the adaptation capability of microbial ecosystems in a changing world

Aquatic microbial communities exhibit remarkable resilience shaped by their evolutionary history in fluctuating environments. However, rapid anthropogenic changes—including warming, shifting nutrient cycles, and altered hydrodynamics—pose unprecedented challenges to their structure and function.

Our long-term goal is to develop multi-scale models that integrate cellular metabolism, population dynamics, and inter-specific interactions, while accounting for transport and diffusion and environmental variability. Key challenges include:

- Improving the representation of microbial ecosystems by incorporating temperature effects and large-scale metabolic networks, using hybrid approaches that combine mechanistic knowledge with data-driven methods.
- Modeling evolutionary dynamics—such as mutation, selection, and adaptation—to predict how microbial communities will adapt to ongoing environmental changes.
- Coupling biological models with hydrodynamic frameworks to realistically simulate advection, diffusion, and spatial heterogeneity in aquatic systems.

Advances in dynamic metabolic modeling and ecosystem-level approaches (e.g. holobiont perspectives) provide a foundation, but substantial work remains to bridge scales, integrate omics data, and capture evolution processes under non-stationary conditions.

2.2 Develop new sources of energy, proteins and bio-based materials taming microbial ecosystems

Meeting the needs of a growing global population while reducing environmental impact requires innovative solutions for energy, food, and resource recovery. Microbial systems—particularly microalgae and bacteria—offer promising pathways for sustainable production, CO_2 fixation, and wastewater bioremediation.

However, optimizing these systems presents significant scientific challenges:

- Developing tractable models of microbial consortia that capture metabolic interactions, gene regulation, and community dynamics without becoming computationally prohibitive.
- Designing control and optimization strategies for complex, nonlinear bioprocesses, potentially using hybrid models that combine mechanistic knowledge with machine learning.
- Harnessing adaptive dynamics and selection pressures to improve microbial strains and consortia for desired traits, moving beyond traditional genetic engineering.
- Deconstructing and reassembling microbial ecosystems to enhance functionality, resilience, and resource-use efficiency.

Control theory, dynamic modeling, and machine learning are central to taming these systems, enabling the design of robust, efficient, and scalable bioprocesses.

2.3 Contribute to environmental impact assessment

Life Cycle Assessment (LCA) is a widely adopted framework for evaluating the environmental footprint of products and technologies. However, current LCA methodologies suffer from simplifications, uncertainties, and limited spatial–temporal resolution.

GREENOWL aims to enhance LCA by:

- Refining characterization factors and impact models through more accurate ecosystem simulations, capturing nonlinearities, synergistic effects, and dynamic responses.
- Quantifying and propagating uncertainties in LCA outcomes, supporting decision-making under incomplete knowledge and varying future scenarios.

By integrating improved ecological modeling, uncertainty analysis, and scenario-based assessments, we contribute to more reliable and actionable sustainability evaluations, helping to guide the development of low-impact technologies.

3 Research program

The tools from dynamical systems, machine learning and automatic control play a decisive role in addressing GREENOWL's long-term challenges. Here we outline the core methodological research axes that constitute the GREENOWL approaches, highlighting key theoretical challenges and innovations.

3.1 Metabolic modeling with dynamics

Cellular metabolism is a complex, regulated network of biochemical reactions that enables plasticity and acclimation to environmental changes. While constraint-based approaches (e.g. Flux Balance Analysis) and kinetic models (e.g. DRUM framework) offer complementary insights, major challenges remain in scaling these methods to microbial consortia and dynamic environments.

Our research focus on:

- Extending dynamic metabolic models to microbial communities, integrating metabolic interactions, adaptation mechanisms, and temperature responses.
- Developing hybrid approaches that combine mechanistic knowledge with machine learning to overcome limitations in kinetic data and model scalability.
- Validating models with experimental data to improve predictions of community behavior under environmental change.

3.2 Multi-scale multi-physics modeling

Realistic ecosystem modeling requires integration across biological scales (from metabolism to evolution) and physical processes (transport, diffusion, heat transfer). We embed biological models within physical frameworks through collaborations with specialized teams (e.g. Inria Ange, MIO, LOCEAN).

Key objectives include:

- Coupling adaptation dynamics with physical transport models to simulate long-term ecosystem trajectories under climate scenarios.
- Developing scalable modeling strategies that account for evolutionary timescales and spatial heterogeneity.
- Investigating how resource competition, temperature, and pH act as selection pressures in microbial communities.

3.3 Machine learning in biological modeling

Machine learning offers powerful tools for extracting patterns from complex biological data, but purely data-driven approaches often violate physical and biological constraints. We develop hybrid modeling frameworks that integrate mechanistic knowledge with data-driven components.

- Physics-Informed Neural Networks (PINNs) to enforce mass balances and stoichiometric constraints while learning from incomplete or noisy datasets.
- Hybrid architectures where neural networks replace or correct poorly characterized kinetic terms in mechanistic models.
- Improved calibration strategies for high-dimensional models using surrogate models and gradient-based optimization.

3.4 Control and optimal control for biological systems

Controlling microbial communities presents unique challenges due to nonlinear dynamics, uncertainty, and limited measurements. We develop tailored control strategies across four interconnected areas:

1. **Parameter identification:** Developing robust calibration methods for high-dimensional models, with uncertainty quantification and efficient surrogate model strategies.
2. **State estimation:** Designing interval observers and robust state reconstructors that handle model uncertainty and partial measurements while maintaining biological constraints.
3. **Control design:** Exploiting system structures (positivity, cooperativity) to derive stabilizing control laws with robustness guarantees against parameter variations.
4. **Optimal control:** Applying Pontryagin's Maximum Principle and Model Predictive Control to optimize bioprocess performance, using surrogate models for computational efficiency in high-dimensional cases.

These methodological developments are tailored to specific applications in natural and engineered microbial systems, ensuring both theoretical rigor and practical implementability.

4 Application domains

4.1 Application Domains

4.1.1 Estimation of carbon fluxes between ocean and atmosphere

Accurate quantification of oceanic carbon fluxes is critical for climate modeling and predicting the ocean's capacity as a carbon sink. We develop models that integrate microbial community dynamics, particle size distribution, and environmental drivers to improve estimates of carbon export and sequestration. Our work utilizes AI-enhanced approaches and coupling with physical oceanographic models to reduce uncertainties in current assessments and project future changes under climate scenarios.

4.1.2 Biodiversity in microbial ecosystems

Understanding how microbial biodiversity responds to environmental change is essential for predicting ecosystem resilience and function. We study the adaptive dynamics, competitive exclusion, and cooperative interactions within microbial communities using metabolic and evolutionary models. This research aims to explain how biodiversity is maintained or lost under stressors like warming, acidification, and nutrient shifts.

4.1.3 Life Cycle Assessment (LCA)

We advance LCA methodology by integrating more accurate ecosystem models and uncertainty quantification into impact characterization. Our work focuses on refining characterization factors for emissions and resource use, particularly for emerging biotechnologies, to provide more reliable sustainability assessments and guide the design of low-impact processes.

4.1.4 Biofuel production from microbial systems

Microalgae and bacteria offer sustainable pathways for biofuel production through photosynthesis or fermentation. We optimize cultivation systems—including raceway ponds and photobioreactors—using metabolic modeling and control strategies to maximize lipid or biogas yields. Research also explores strain improvement via adaptive evolution and co-culture optimization to enhance productivity and economic viability.

4.1.5 Wastewater treatment and pollutant removal with microbial consortia

Algae-bacteria consortia provide energy-efficient wastewater remediation by removing nutrients, sequestering CO_2, and producing valuable biomass. We develop hybrid models and control strategies to optimize treatment performance, manage microbial interactions, and minimize emissions such as N_2O. Beyond nutrient removal, these microbial consortia also offer promising routes for the biodegradation and bioremediation of toxic compounds, including emerging pollutants such as pesticide- and herbicide-like molecules. Applications include high-rate algal ponds and membrane-coupled systems for municipal and industrial effluents.

4.1.6 Microbial cell factories for high-value bioproducts

Microbial communities such as yeast, bacteria, and algal-based consortia can be engineered and operated as efficient cell factories to produce high-value biomolecules. We develop modeling, optimization, and control strategies to improve productivity by dynamically steering cellular trade-offs between growth and biosynthesis. This includes the optimal allocation of resources in *E. coli* under fluctuating environments, as well as the control of synthetic algal–bacterial ecosystems to enhance biomass production. We also investigate optogenetic control approaches in yeast bioprocesses, where light-driven regulation enables the design of structured control inputs to maximize folded protein production.

4.1.7 CO_2 capture and utilization processes

Microbial systems, particularly microalgae, can capture CO_2 from industrial flue gases and convert it into biomass and bioproducts. We model and optimize these processes for enhanced carbon fixation rates, integrating thermal and chemical dynamics to maintain culture stability under varying CO_2 inputs and outdoor conditions.

4.1.8 Toxic algal bloom (HAB) prediction and management

Harmful Algal Blooms threaten aquatic ecosystems, fisheries, and human health. We develop predictive models that combine hydrodynamics, nutrient dynamics, and algal physiology to forecast bloom formation and toxicity. These tools support early warning systems and inform mitigation strategies to reduce bloom impacts.

4.1.9 Prediction and control of competing cell populations, including cancers

Competition between distinct cell populations is a recurring theme in our modeling and control activities, and it finds a highly impactful illustration in cancer dynamics. Our tools for dynamical modeling, analysis, control, and optimization naturally extend to this setting, where interacting healthy and malignant cell compartments evolve under regulatory feedbacks and therapeutic interventions. Therapeutic control of pathological cell proliferation can then be formulated as an optimal control problem, aiming at maximizing healthy cell recovery while limiting malignant expansion and treatment burden. Within this framework, we study ecosystem-inspired and control-oriented strategies to address drug resistance mechanisms and to design protocols that balance efficacy with clinically motivated constraints.

5 Social and environmental responsibility

5.1 Footprint of research activities

Within the GREENOWL team, environmental awareness and the reduction of our ecological footprint are integral to our research culture. While we do not yet conduct a formal environmental audit of our activities, we have adopted concrete measures to limit our impact.

We actively reduce travel-related emissions by setting a maximum of one international conference outside Europe per researcher per year and prioritizing train travel over air transport whenever feasible. Additionally, team members embrace sustainable commuting practices, such as cycling to work whenever possible.

Beyond operational measures, we contribute to broader environmental awareness through public engagement activities. This includes delivering public lectures (e.g., within the "Sciences pour Tous" framework) on how individuals and organizations can reduce their environmental impact, as well as contributing to popular science articles that explain how to assess and mitigate one’s ecological footprint. These efforts align with our commitment to fostering sustainability both within our team and in the wider community.

5.2 Impact of research results

Since its creation, the GREENOWL team has been committed to advancing sustainable development through the design of inovative processes to reduce our environmental footprint. Our research directly contributes to environmental protection, renewable energy production, and the reduction of industrial pollution. By developing innovative mathematical models, computational tools, and bio-process technologies, we support the transition toward a circular bioeconomy, where living organisms are harnessed to capture carbon, treat waste, and produce bioenergy with minimal ecological footprint.

We collaborate closely with biologists and engineers to build and validate biological models using experimental platforms. Our core application domains include:

- **Bioenergy production:** Development of microbial systems for sustainable lipid (biofuel), methane, and hydrogen generation (in partnership with LOV).

- **CO_2 capture and valorization:** Using microalgae to sequester industrial CO_2 emissions and convert them into valuable biomass (with LOV).

- **Biological waste treatment:** Optimizing microbial bioreactors to recycling carbon, nitrogen and phosphorus, degrade pollutants and minimize emissions.

In addition to our scientific work, we actively support green entrepreneurship and the creation of sustainable value. We maintain strong partnerships with startups such as Darewin (strain selection for industrial microalgae) and Inalve (microalgae-based feed and biofilm technologies), helping them develop low-impact processes that generate employment and social added value.

Several GREENOWL members (O. Bernard and W. Djema) also participate in Inria's Local Committee for Sustainable Development (CLDD) at Université Côte d'Azur, organizing awareness-raising events and promoting sustainable practices within the research community.

Our team regularly contributes to public outreach and science communication initiatives focused on sustainability (see Section 11.3) and ethics in modeling is a strong commitment of the team [29].

6 Highlights of the year

- F. Casagli, GREENOWL co-lead an international group within the International Water Association (IWA), dedicated to modeling algae and phototrophic microbes. This joint international effort, uniting leading experts identified the key challenges hindering phototrophic wastewater valorization, such as biological complexity, environmental variability, and data scarcity. It resulted in a position paper lead by GREENOWL in the high impact journal "Biotechnology Advances" [17] advocating for standardized modeling protocols, advanced hybrid methods, and machine learning to create robust digital twins. This collective work establishes a clear roadmap to bridge the gap between theoretical models and industrial application for sustainable resource recovery.
- W. Djema initiated a collaboration with M. Khammash's group (ETH Zurich) on the control and optimization of optogenetic bioprocesses, bringing advanced optimization tools to highly technical experimental platforms. This line of work opens an innovative and non-standard route to turn model-based optimal policies into robust, feedback-inspired strategies, by exploiting large and low-cost datasets generated from numerical optimization to extract, through data-driven (AI-like) analysis, simple and implementable control rules based on measurable switching indicators and structural patterns, with strong potential for extension to other biotechnology applications ([30], extended work submitted to IEEE TCST).
- In collaboration with Microcosme (Inria Grenoble) and MacBes (Inria Sophia), we formulated and solved an optimal control problem for a synthetic algal–bacterial consortium, where bacteria produce a vitamin essential for algae at a cost to their growth. By optimizing both an optogenetic control and the dilution rate, the optimal dynamic solution exhibits intrinsic pseudo-oscillatory patterns that enhance biomass production beyond a static optimum. This original and never reported behavior in Optimal Control Problems [1] was recently accepted for publication in Automatica.

6.1 Awards

- W. Djema was awarded Inria Exploratory Action (AEx) funding in 2025 (approx. 200 k€ over 2 years) to initiate an experimental platform for glyphosate bioremediation, based on an innovative *in vivo* engineered algae–bacteria consortium.

7 Latest software developments, platforms, open data

7.1 Latest software developments

7.1.1 ODIN+

Name: Platform for advanced monitoring, control and optimisation of bioprocesses

Keywords: Systems Biology, Biotechnology, Automatic control, Monitoring

Functional Description: This application proposes a framework for on-line supervision of bioreactors. It gathers the data sampled from different on-line and off-line sensors. ODIN+ is a distributed platform, enabling remote monitoring as well as remote data acquisition. More originally, it enables researchers and industrials to easily develop and deploy advanced control algorithms, optimisation strategies, together with estimates of state variables or process state. It also contains a process simulator which can be harnessed for experimentation and training purposes. It is modular in order to adapt to any plant and to run most of the algorithms, and it can handle the high level of uncertainties that characterises the biological processes. The architecture is based on Erlang, and communication between modules through a MQTT Broker with Python for running the algorithms. ODIN+ is developed in collaboration with the INRIA MICROCOSME research team.

News of the Year: Several core system enhancements were implemented to improve robustness and usability. A new diagnostic module was introduced to proactively identify faults in both hardware components and inter-module communications. The calibration suite was expanded to include actuator calibration, increasing its versatility. Furthermore, the Python-based priority management system was refined for more efficient resource allocation, and the graphical user interface (GUI) underwent a significant overhaul to improve user experience. These developments were completed as part of the Hooding AMDT project.

Contact: Olivier Bernard

Partner: INRAE

7.2 New platforms

Participants: Amélie Talec, Antoine Sciandra, Olivier Bernard, Francesca Casagli, Solène Jahan.

The experimental Phytopulse platform, located at the LOV and jointly developed with GREENOWL, is made of continuous photobioreactors driven by a set of automaton controlled by the ODIN+ software, a powerful and unique tool which gave rise to a quantity of very original experiments. Such platform improved knowledge of several biological processes, such as lipid accumulation or pigment dynamics under light fluctuation, nitrogen or temperature stress. Amélie Talec is responsible for the Phytopulse Platform.

8 New results

8.1 Experimental developments

Participants: Olivier Bernard, Francesca Casagli, Sabina Cano, Thomas Garcia, Solène Jahan, Antoine Sciandra, Amélie Talec.

Various experiments were carried out in the phytopulse platform for determining the ability of biofilms to grow with different sources of nitrogen [24]. This experimental platform was used to control the long-term stress applied to a population of microalgae using optimal control strategies, generating new strains with enhanced lipid or pigment content [3] through Darwinian selection in selectiostats [4]. These experimental works were carried out within the ISS-incubated DareWin project.

Experimental works were also conducted within the ANR Photobiofilm explorer project, growing microalgal biofilms from lab to pilot scale to track antimicrobial activities. Additional experiments at CentraleSupelec, within the PhD of David Morgado Pereira [39], observed biofilm development from *Haematococcus pluvialis* and astaxanthin production during nitrogen starvation [25].

Within the BARRIER project, a two-month outdoor campaign on our Full Spectrum greenhouse platform was carried out. It consisted in three raceways operated for testing whether a synthetic bacterial consortium (*Halomonas, Alteromonas, Roseibium*) could protect *Chlamydomonas sp.* from copper stress in saline raceways. Results indicated enhanced algal growth but no clear copper protection at 10-20 mg/L concentrations, likely due to copper precipitation or complexation reducing bioavailability.

The internships of Sabina Cano and Thomas García focused on algae-bacteria dynamics under toxic stress for the Ctrl-AB project, investigating organic carbon effects on population balance and copper protection in lab experiments. Results confirmed nutritional mutualism via vitamin B12 compensation but showed no significant protective effect at high copper concentrations.

These works were conducted in collaboration with A. Talec (CNRS/Sorbonne Université - Oceanographic Laboratory of Villefranche-sur-Mer LOV).

8.2 Mathematical analysis of biological models

Participants: Walid Djema, Olivier Bernard, Tewfik Sari.

We studied competition dynamics in simplified environments like chemostats, showing robust coexistence due to temperature fluctuations [9]. We extended classical chemostat models with distinct removal rates and yield coefficients, revealing complex behaviors including Hopf bifurcations and codimension-two bifurcations [36, 35].

We analyzed dispersal-induced growth (DIG) and decay (DID) in spatially structured populations with seasonal migration, providing mathematical conditions for population rescue or extinction under periodic variation [14]. We also examined pathogen-host dynamics in chemostats via an SIS epidemic model, characterizing disease-free and endemic equilibria, multiple stable states, and Hopf bifurcations [32].

8.3 Automatic control applied to bioprocesses

Participants: Domingo Cea Benoit, Baptiste Boerkmann, Francesca Casagli, Olivier Bernard, Walid Djema, Javier Innerarity Imizcoz.

Optimal control formulations were developed for selecting microbial species competing for substitutable substrates, characterizing time-optimal strategies via Pontryagin's Principle [19]. For synthetic algal-bacterial consortia, dynamic control strategies using dilution and optogenetic inputs demonstrated overyielding effects compared to static operation [1], with results accepted for publication in *Automatica*. This work was conducted within the ANR Ctrl-AB project and contributed to the PhD thesis of Rand Asswad (INRIA Microcosme).

Optogenetic control for protein production in yeast yielded bang-bang strategies maximizing folded protein [30], developed in collaboration with T. Bayen (Université d'Avignon) and M. Khammash (ETH Zurich). In agricultural applications, optimal pest control for banana crops against nematodes produced bang-bang quasi-periodic strategies maximizing profit [34], as part of the PhD thesis of Frank Kemayou (EPITAG project-team).

We also developed model predictive control (MPC) strategies for glyphosate bioremediation using algal-bacterial consortia, and investigated observers and control design for anaerobic digestion reactors to maximize methane production under process constraints.

We developed an optimization procedure dealing with the topography of the raceway floor to maximize the algal biomass production over one lap or multiple laps with a paddle wheel, showing that a flat topography is optimal in a periodic regime. We then studied the influence of mixing, assuming that a mixing device can redistribute the algae so that they can have access to light [15].

Interval observer design for biological systems was advanced through conditions ensuring similarity to Metzler matrices [10], extended to systems with measurement delays and applied to an inverted pendulum in collaboration with F. Mazenc (INRIA DISCO).

8.4 Metabolic modelling and resource allocation

Participants: Olivier Bernard, Francesca Casagli, Walid Djema, Javier Innerarity Imizcoz, Antoine Sciandra.

A dynamic metabolic model for *Chlorella vulgaris* was developed using the DRUM framework (Dynamic Reduction of Unbalanced Metabolism) to simulate autotrophic, heterotrophic and mixotrophic growth [2]. This was extended to co-cultures with *E. coli* for lactate and biotin production, showing enhanced lipid accumulation in algae [12, 11].

Optimal resource allocation in bacteria under time-varying environments was investigated using optimal control, revealing complex structures with higher-order singular arcs and chattering phenomena [31], as part of the PhD thesis of Javier Innerarity Imizcoz. Parallel work examined cellular resource reallocation under thermal stress [37, 33].

8.5 Modelling bioreactors

Participants: Olivier Bernard, Francesca Casagli, Solène Jahan, Manon Pugnet, Antoine Sciandra, Walid Djema.

We developed a biofilm growth model incorporating light-harvesting dynamics under light/dark cycles, showing reduced photoinhibition at higher frequencies [21]. For photobioreactors, we coupled Han's photosynthetic model with hydrodynamics, demonstrating marginal hydrodynamic effects in laminar raceway ponds [20].

We proposed models to represent the temperature dynamics in outdoor cultivation systems. Temperature modelling included an auto-adaptive heat-transfer model (SATHE) predicting temperature evolution in various cultivation systems using weather forecasts [22].

A robust chemical model for ionic speciation in saline environments was developed to support the optimization of microbial growth. Chemical speciation modelling transformed algebraic equilibrium systems into differential equations, reducing unknowns from 40 to 5 for accurate pH and ionic strength prediction.

We developed a growth model for outdoor raceway ponds that integrates the effects of light intensity, spectral composition, and temperature [23], demonstrating that green light enhances biomass conversion efficiency due to improved vertical penetration in dense cultures.

A dynamic model for microalgal growth that accounts for photoinhibition and photoacclimation was developed and validated for two species, enabling accurate prediction of growth under varying light conditions. As part of Manon Pugnet's PhD, this light-response model complements the work on the SATHE temperature model [22], providing a comprehensive framework for predicting microalgal productivity in fluctuating environments.

8.6 Modelling carbon fluxes in the ocean

Participants: Olivier Bernard, Lionel Guidi, Romain Ranini, Antoine Sciandra, Amélie Talec.

We developed algorithms for automatic calibration of thermal adaptation models (Cardinal Temperature Model with Inflection (CTMI) and Hinshelwood), revealing correlations between cardinal temperatures and environmental parameters [8]. For oceanic carbon flux estimation, we introduced AI approaches using XGBoost to model particle size distribution from UVP5 (a marine profiler) as a function of environmental conditions, improving vertical carbon flux assessments.

Conventional machine learning validation in marine ecology often leads to overoptimistic performance estimates due to spatially clustered data, which breaks the assumption of sample independence. To address this, we developed a tailored validation framework that ensures true data separation, providing more reliable model evaluation for biogeochemical predictions. This work is carried out within the OceanIA Inria challenge and forms the core of the PhD thesis of Romain Ranini.

8.7 Wastewater treatment and bioenergy production

Participants: Olivier Bernard, Francesca Casagli, Sabina Cano, Walid Djema, Thomas Garcia, Solène Jahan, Jean Leroy, Antoine Sciandra.

We developed hybrid modelling approaches for algae-bacteria systems, combining mechanistic models with artificial neural networks while preserving mass balance constraints [16]. The ALBA model [7] was extended to include microbial community structure and membrane separation (M-ALBA), improving nitrogen removal predictions [18, 13]. The M-ALBA model was developed in collaboration with the Escuela de Ingeniería Bioquímica, Pontificia Universidad Católica de Valparaíso (Chile).

For biological depollution, we created a comprehensive framework [6] integrating biological, thermal and chemical sub-models validated with three years of operational data [16]. This framework, which was also implemented in the ABACO-2 model for coupled biological-chemical dynamics [26], serves as a powerful tool for advanced process control, optimization and scale-up. We quantified benefits of uncoupling hydraulic and solid retention times for nitrogen recycling [5].

We initiated work on glyphosate bioremediation modelling and control during the internships of Sabina Cano (M2) and Jean Leroy (M2), leading to the submission of the Inria Action Exploratoire project GlyphoClean. We also developed supervision strategies for anaerobic digestion reactors including state estimation and optimal control for methane maximization.

8.8 Life Cycle Assessment

Participants: Olivier Bernard, Francesca Casagli, Arnaud Hélias, Pierre Jouannais.

For wastewater treatment, we simulated 72 scenarios using the ALBA model [7] to evaluate microalgae-bacteria processes for digestate treatment, demonstrating environmental benefits compared to conventional treatment [27]. This work was conducted in collaboration with ITAP (Montpellier).

We assessed the environmental impact of microalgal protein production via biofilm processes, showing advantages over fishmeal and soy. This set-up the basis of a more general ex-ante approach where impacts for a not yet existing process are anticipated. We took part to a more general work to popularize LCA and provide keys for its use [38].

8.9 Modelling and control of cell developments

Participants: Walid Djema, Pauline Mazel, Athénaïs Vermande.

We investigated therapeutic control for leukemia using compartmental models of healthy and leukemic cell competition under cytokine-mediated feedback. Analysis revealed turnpike-like solutions and a continuum of coexistence equilibria shaping the optimization landscape [28]. This work, part of the PhD thesis of Pauline Mazel, was conducted in collaboration with T. Stiehl (RWTH Aachen) following a research visit supported by DAAD (the German Academic Exchange Service) and Université Côte d'Azur. The work on Warburg metabolism and combined therapies was initiated during the internship of Athénaïs Vermande.

9 Bilateral contracts and grants with industry

Participants: Olivier Bernard, Antoine Sciandra, Francesca Casagli, Amélie Talec.

9.1 Bilateral contracts with industry

GREENOWL maintains an active exploitation contract with the start-up Darewin Evolution, supporting the development of automated platforms for directed dynamic evolution. The partnership has also led to joint applications for several research grants.

Additionally, GREENOWL has signed licensing agreements with the start-up Inalve, granting exclusive rights for the commercial exploitation of specific patents developed by the team.

10 Partnerships and cooperations

Participants: Olivier Bernard, Antoine Sciandra, Francesca Casagli, Walid Djema, Amélie Talec.

10.1 International initiatives

- We collaborate with M. Morales (List, Luxembourg) for Life Cycle Assesment studies.
- In the framework of the OceanIA project, we work with L. Marti and N. Pi Sanchez from Inria Chile (Santiago, Chile) on hybrid modeling.
- We have long term collaboration with D. Jeison and C. Martinez von Dossow from PUCV (Valparaíso, Chile) on modeling and control of algae-bacteria processes, especially in the framework of the Art'In Blue associate team.
- We collaborate with Alejandro Vargas from the Universidad Nacional Autónoma de México (UNAM), who conducted a six-month research visit in our team. His work focused on modeling and optimizing algae–bacteria consortia for the treatment of fisheries waste, aiming to enhance nutrient recovery and reduce the environmental footprint of aquaculture effluents. This research contributes to the development of sustainable bioremediation strategies for the valorization of organic waste from the fishing industry.
- We collaborate with E. Ficara, Professor at Politecnico di Milano, Department of Civil and Environmental Engineering, DICA (Milan, Italy), on wastewater recovery with algae-bacteria systems.
- We collaborate with Gustavo Henrique Ribeiro da Silva, Professor at São Paulo State University (Unesp), Departamento de Engenharia Civil e Ambiental (São Paulo, Brazil) on wastewater treatment modeling.
- We collaborate with Thomas Stiehl, Head of the Institute of Computational Biomedicine (Disease Modeling) at Uniklinik RWTH Aachen (Aachen, Germany). This collaboration focuses on the dynamical modeling and analysis of the hematopoietic niche, and on the development of optimal control and optimization-based approaches to support the design of novel therapeutic strategies.
- We collaborate with A. Ghouali from the *Ecole Superieure en Sciences Appliquees de Tlemcen (ESSA Tlemcen)*, Algeria. The project focuses on the modeling, supervision, and control of anaerobic digestion bioreactors for methane production, combining observer design, optimization-based operation, and biologically motivated process constraints, and we co-supervized the Master internship work of Farah Kafnemer on this topic.
- We collaborate with Mustafa Khammash, Head of the Control Theory and Systems Biology Laboratory at ETH Zurich (Switzerland), on the modeling and control of optogenetically driven yeast cultures. The goal is to support experimental designs by deriving simple and robust light-based regulation strategies to improve protein production while accounting for growth–stress trade-offs. This work also involved the M2 internship project of Baptiste Boerkmann.
- We initiated a collaboration with Eleonora Sforza (Department of Chemical Sciences, University of Padova, Italy) within the *GlyphoClean* project (Inria AEx 2025), focusing on algae–bacteria consortia for glyphosate bioremediation.

10.2 International research visitors

10.2.1 Visits of international scientists

- We hosted Alejandro Vargas from the Universidad Nacional Autónoma de México (UNAM) for a six-month research stay. During his visit, he worked on the modeling and optimization of algae–bacteria consortia for the biological treatment of fisheries waste. His research specifically aimed at developing sustainable strategies to valorize organic effluents from aquaculture, focusing on nutrient recovery and the reduction of environmental impacts in the fishing sector.

- Carlos Martinez von Dossow (PUCV, Chile) spent one week in December, 2025 to work on hybrid modeling of photosynthetic processes.

10.2.2 Visits to international teams

- F. Casagli and O. Bernard conducted research visits to Inria Chile in Santiago and to the Pontificia Universidad Católica de Valparaíso (PUCV). At Inria Chile, the focus was on advancing machine learning methods for ocean modeling and algal bloom detection within the OceanIA and Predifan projects. At PUCV, the collaboration centered on hybrid modeling of algae–bacteria processes for wastewater treatment, reinforcing long-standing joint work in this domain.
- W. Djema conducted a research visit to ETH Zurich, hosted by M. Khammash's group, to initiate a collaboration on the modeling, optimization, and control of optogenetically driven yeast cultures, with a focus on feedback-inspired strategies for improved protein production.
- W. Djema conducted a research visit to the Federal University of Rio de Janeiro (UFRJ), Brazil, hosted by Prof. Stefanella Boatto, to exchange on dynamical modeling and control methods for bioprocesses and epidemic systems, and to explore future research collaborations in these areas.

10.3 European initiatives

10.3.1 H2020 projects

DigitAlgaesation DigitAlgaesation project on cordis.europa.eu

Title: A knowledge-based training network for digitalization of photosynthetic bioprocesses

Duration: From March 1^{st}, 2021 to February 28^{th}, 2025

Partners:

- INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE (INRIA), France
- IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE, United Kingdom
- MINT ENGINEERING GMBH, Germany
- UNIVERSITA DEGLI STUDI DI PADOVA (UNIPD), Italy
- SIEMENS PROCESS SYSTEMS ENGINEERING LIMITED (SPSE Ltd), United Kingdom
- PROVIRON HOLDING NV (PROVIRON), Belgium
- TMCI PADOVAN SPA, Italy
- DANMARKS TEKNISKE UNIVERSITET (TECHNICAL UNIVERSITY OF DENMARK DTU), Denmark
- UNIVERSIDAD DE ALMERIA (UNIVERSIDAD DE ALMERIA), Spain
- WAGENINGEN UNIVERSITY (WU), Netherlands
- CENTRALESUPELEC, France
- TECHNISCHE UNIVERSITAET DRESDEN (TUD), Germany
- GOTTFRIED WILHELM LEIBNIZ UNIVERSITAET HANNOVER (LUH), Germany

Inria contact: Olivier Bernard

Coordinator: Fabrizio Bezzo (Univ. Padova)

Summary: Microalgae and other photosynthetic microorganisms represent a highly promising source for food, feed, chemicals, and fuels. Europe has been leading world research and industrial deployment of microalgae based technologies. However, despite the enormous potential and the impressive R&D effort, industrial use of microalgae is still at its first developmental stage. A major step forward can derive by the development and implementation of digital technologies, capable of automatizing and optimizing culture conditions at industrial scale. Europe has a tradition of leading researches in the field of automatic control for biotechnological processes. As envisaged by DigitAlgaesation, the widespread definition and adoption of effective tools for better design and operation urgently requires skilled multidisciplinary scientists and engineers, who can develop and implement the next generation of sustainable production process with enhanced productivity, reduced environmental impact and costs, despite climate fluctuations that may strongly affect microalgae productivity. All this demands a European commitment to concerted, inter- and transdisciplinary research and innovation.

DigitAlgaesation will train 15 early-stage researchers (ESRs) in all aspects of microalgae technological innovation to pave the way towards a knowledge-based breakthrough in monitoring methods and instrumentation, biological modeling and simulation, and automatic control. By training in scientific, technical and soft skills, they will become highly sought-after scientists and engineers for the rapidly emerging microalgae-based industry and broader bioprocessing industries of Europe.

10.4 National initiatives

10.4.1 National programmes

- **ANR Ctrl-AB:** The objectives of the Ctrl-AB project (2021-2025) are (i) to develop new control methods for the optimization of the productivity of a microbial community, and (ii) to demonstrate the effectiveness of these methods on a synthetic algal-bacterial consortium. Interestingly, co-culturing of *E. coli* with *Chlorella* leads to higher biomass and lipid productivity. Improved growth of *Chlorella* occurs despite competition of *E. coli* for the same substrates. On top of its ability to produce molecules like vitamins, which are necessary for algal growth, bacteria also produce carbon dioxide (CO_2), which is the substrate of the photosynthesis of the algae. The algae can produce oxygen (O_2) fueling bacterial growth, thus giving rise to a mutualistic pattern of interactions giving rise to several challenges for modeling and controlling this artificial ecosystem. Project coordinated by J.-L. Gouzé.

- **ANR Barrier:** This proof of concept project (2023-2027) with multidisciplinary expertise is willing to demonstrate, from the laboratory to a pilot process, that selected bacteria can protect microalgae when growing in contaminated wastewaters, providing higher algal resilience, productivity and bioremediation efficiency in wastewater treatments. It is coordinated by O. Pringault (IRD, Mediterranean Institute of Oceanography).

- The **ADEME SpiruN2 project** (2025–2028) aims to reduce the environmental footprint of algal biomass production by exploiting a marine, diazotrophic strain of Spirulina capable of fixing atmospheric nitrogen (N_2). This eliminates the need for synthetic nitrogen fertilizers, which are a major source of greenhouse gas emissions in conventional microalgae cultivation. The project focuses on understanding and optimizing the physiology of the strain, which grows naturally in biofilms, and scaling up production in co-culture systems with other microalgae. The work builds on preliminary trials at LOV and targets the development of sustainable, low-impact algal protein production.

10.4.2 Inria funding

- **DareWin, Inria Startup Studio, and CNRS Phycoplus :**(2022-2025). The DareWin project is consolidating the bases of a startup which will develop Darwinian selection approaches in highly controlled bioreactors to naturally select and improve microalgal strains of industrial interest.

- **Inria Exploratory Action (AEx), GlyphoClean:** (2025–2028). The GlyphoClean project supports the development of an experimental and modeling platform based on engineered algae–bacteria consortia for glyphosate bioremediation, with the objective of improving pollutant degradation performance through mechanistic understanding and control-oriented strategies.

- **OceanIA** is a pioneering Inria Challenge project piloted by Inria Chile that aims to unravel the complexities of the global ocean symbiome through advanced artificial intelligence and mathematical modeling. By leveraging large-scale datasets and cutting-edge computational techniques, the initiative seeks to transform our understanding of marine ecosystems, climate change impacts, and ocean biodiversity. This interdisciplinary effort brings together partners such as Inria Chile, the Tara Ocean Foundation, the CNRS GO-SEE group, the University of Nantes, and the Laboratoire d'Océanographie de Villefranche, among others. Supported and coordinated by Inria, OceanIA integrates diverse expertise to generate predictive insights and tools that elucidate the ocean's critical role in sustaining life on Earth.
- **The Art'In Blue** associate team, led by O. Bernard and David Jeison (Pontificia Universidad Católica de Valparaíso), focuses on developing advanced models for microbial ecosystems driven by microalgae and bacteria. The project applies insights from wastewater treatment, aiming to accurately represent these complex, nonlinear systems. In collaboration with Inria Chile and Modela CFD, the team leverages artificial intelligence and large monitoring datasets to enhance model representation and control of microbial processes in aquatic environments.
- **ADT Hooding** for the development of the ODIN+ software within the AMDT support (Action mutuelle de développement logiciel), improving the GUI and connecting ODIN+ to OpenSilex.

10.5 Regional initiatives

- Walid Djema was awarded the **"Booster Junior, IDEX"** (2024–2026) by Academy 2, "Complex Systems," Université Côte d'Azur, for the project titled *OPTI-ABh: Optimization of algae-bacteria consortia via hybrid PMP: Towards new optimal conditions for depollution*.
- PhD grants from the DS4H (Digital Systems for Humans) UniCA IDEX program for Pauline Mazel (2023–2026), Javier Innerarity Imizcoz (2023–2026), and Manon Pugnet (2024–2027), each with a EUR 10k research allowance.

11 Dissemination

Participants: Olivier Bernard, Antoine Sciandra, Francesca Casagli, Solène Jahan, Walid Djema, Amélie Talec.

11.1 Promoting scientific activities

11.1.1 Scientific events: organization

- We organize a monthly scientific seminar together with the MACBES project-team in which external guests and collaborators are regularly invited.
- We organize a yearly seminary with the MACBES project-team where we share our work of the year: this year, it took place mid-november at the LOV, inviting colleagues from the LOV and other Inria research teams.
- F. Casagli is co-chair in the Task Group of IWA (International Water Association) on modeling phototrophic systems.
- F. Casagli and O. Bernard were involved in the coordination and writing of a position paper for the IWA Task Group co-coordinated by F. Casagli.

11.1.2 Member of the organizing committees

O. Bernard was in the organizing committee of the AlgoReseau in Sète which took place in October 9^{th}, 2025.

11.1.3 Chair of conference program committees

- O. Bernard was the head of the academic scientific committee of the AlgaEurope conference which took place in December 9^{th} to 12^{th}, 2025 in Riga (Latvia).
- O. Bernard, together with E. Mémin (Inria Stuod) and M. Barbier (Inria) are organizing a monthly web seminar on the Digital twins of the Ocean.

11.1.4 Member of the conference program committees

O. Bernard is in the scientific committee of the 1st International Conference on Photogranules (17 to 19th Sep. 2025), Delft, Netherlands.

11.1.5 Reviewer

- All GREENOWL members have been reviewers for the major 2025 conferences in our field: Conference on Decision and Control, European Control Conference, International Federation of Automatic Control ...
- The team is reviewing articles for the main journals of Automatic Control (Automatica, IEEE Transactions on Automatic Control, Journal of Process Control), for mathematics applied to biology (Journal of Mathematical Biology, Mathematical Biosciences), and for biology or biotechnology journals (Algal Research, Plos computational Biology, Bioresource Technology, ...).

11.1.6 Invited talks

- O. Bernard was invited as a speaker to give a talk at the University of Mons "Modeling microalgae-bacteria systems for resource recovery from wastewater ", in September 3^{rd} 2025.
- O. Bernard gave a talk at the PUCV (Valparaiso, Chile) in August 21^{st}, 2025: "Simple tips for designing sound dynamical models of bioprocesses ",
- O. Bernard was invited to give a keynote at the POPULATE summer school "A few tips for designing sound models of microbial populations "in March, the 10^{th}, 2025:
- O. Bernard gave a talk at Inria Chile (Santiago, Chile) in August 19^{th}, 2025: "Predicting temperature in microalgae cultivation systems"
- F. Casagli gave a talk at Inria Chile (Santiago, Chile) in August 19^{th}, 2025: "Current challenges for modeling phototrophic ecosystems"
- W. Djema gave a talk in the IM–NanoBioSistema–LNCC–IC seminar series at the Federal University of Rio de Janeiro (UFRJ, Rio de Janeiro, Brazil) on December 8^{th}, 2025: “modeling and optimal control of microbial bioprocesses: a collection of biotech applications”.
- W. Djema gave a talk in the “Interface des maths et systèmes complexes” seminar series at Université Côte d’Azur (Nice, France) on November 21^{st}, 2025: “Modélisation et contrôle optimal de bioprocédés microbiens : quelques applications en biotechnologies”.
- F. Casagli was invited to give a talk at the *Premier colloque sur l’IA en microbiologie*, organized by Prof. Laurent AUSSEL, (November 13^{th}, 2025). "How artificial intelligence can improve the management of artificial ecosystems for wastewater treatment".

11.1.7 Scientific expertise

- O. Bernard is in the Scientific Advisory Board of the "Ferment du futur" Grand challenge of France 2030.
- O. Bernard is in the steering committee of Federal Recherche Institut (IFR) Marine Ressources (MARRES).
- O. Bernard is member of the scientific committees of Inalve and Darewin Evolution.

11.1.8 Research administration

- W. Djema has been appointed as a member of the Scientific Council of Academy 4 "Complexity and Diversity of Life," Université Côte d'Azur (since 2023), representing Inria within the council.
- W. Djema has been elected as a member of the Inria center's committee, Centre Inria d'Université Côte d'Azur (since January 2024).
- O. Bernard is a member of the CLDD (Local Commission for Sustainable Development) of the Centre Inria d'Université Côte d'Azur.
- F. Casagli is a member of the Human Resources Strategy for Researchers (HRS4R) Steering Committee (COPIL), for the strategic guidance and validation of Inria's HRS4R action plan 2024-2027.

11.2 Teaching - Supervision - Juries

11.2.1 Teaching

- Licence: P. Mazel (20h ETD); "Mathématiques pour Biologistes: Analyse et Modélisation", L1 Université Côte d'Azur, France.
- Licence: W. Djema (32h ETD); "Math0: Enjeux", L1 Université Côte d'Azur, France.
- Licence: P. Mazel (32h ETD); "Statistiques pour les Biologistes", L1 Université Côte d'Azur, France.
- Licence: O. Bernard (35h ETD), "Use and optimization of photobioreactors", Université de Pau et des pays de l'Adour, France.
- Licence: P. Mazel (16h TD), "Fondements mathématiques 1 - partie algèbre linéaire", L1, Portail Sciences et Technologies, Université Côte d'Azur, France
- Licence: J. Innerarity (30h EDT), "Mathematical Analysis": Ecole Centrale Méditerranée Nice.
- Master: O. Bernard (25h ETD), Enseignement d'Intégration "modeling biotechnological processes", M2, Ecole CentraleSupelec, Saclay, France.
- Master: O. Bernard (25h ETD), Enseignement d'Intégration "Automatic Control applied to biotechnological processes", M2, Ecole CentraleSupelec, Saclay, France.
- Master: O. Bernard (6h ETD), "Cultivation and use of Microalgae", Master Mares, Université Côte d'Azur, France.
- Master: S. Jahan (20h ETD), "Statistics and modeling" – Lectures, Master MARRES, Sophia-Antipolis (Université Côte d'Azur), Nice
- Master: W. Djema (15h ETD), F. Grognard (15h), "Elements of Mathematics" – Lectures on mathematics and programming Python, and modeling in ecology, Master RISK, IMREDD, Université Côte d'Azur, Nice
- W. Djema gave a one-day lecture on Control Theory to undergraduate students in Applied Mathematics and Mathematical Engineering at the Institute of Mathematics, Federal University of Rio de Janeiro (UFRJ, Brazil), on December 9^{th}, 2025, as part of the Interdisciplinary School on Dynamical Systems and its Applications.
- F. Casagli gave a lecture on *Hybrid Machine Learning-Mechanistic modeling*, within the ECOLE CHERCHEURS-Données et Modèles organized by INRAE in Nantes (06-09/10/25).

11.2.2 Master theses and internships supervision

- W. Djema supervised the Master internship of Domingo Benoit Cea, through the Inria–Chile internship program (3-month visit). Domingo worked on modeling and optimal control problems motivated by microbial bioprocesses.

- W. Djema supervised the M2 internship of Baptiste Boerkmann (5 months). Baptiste worked on optogenetic control strategies for protein production in yeast cultures, combining optimal control analysis and numerical optimization.

- W. Djema supervised the M2 internship of Jean Leroy (5 months). Jean developed mechanistic dynamic models for algae–bacteria consortia dedicated to pollutant degradation, and investigated model-based optimization and MPC strategies to improve bioremediation performance.

- W. Djema supervised the M2 internship of Sabina Cano (6 months). Sabina worked on the biological characterization of algae–bacteria interactions and consortium resilience under pollutant stress, with a focus on glyphosate-related bioremediation.

- W. Djema supervised the Master internship of Farah Kafnemer (6 months). Farah studied modeling, supervision, and control strategies for anaerobic digestion bioreactors, including observer design and optimization-based operation.

- W. Djema supervised the L3 internship of Athénais Vermande (1 month). Athénais initiated a modeling study of cancer cell metabolism by incorporating Warburg-like effects and therapy mechanisms into a leukemia dynamics framework.

- S. Jahan supervised the licence pro internship of Thomas Garcia (UPPA) on "How algae-bacteria ecosystems can mitigate cupper toxicity"

- O. Bernard and F. Casagli co-supervised the master thesis of Miguel Antonio González Serrano (UNAM, Mexico)

11.2.3 PhD students supervision

- PhD: David MORGADO defended on January 30^{th}, 2025, his PhD *Microalgal biofilms : an experimental, monitoring and modeling approach*, where he developed a multi-scale model to predict and optimize astaxanthin production in a rotating algal biofilm system, integrating nitrogen limitation, photoacclimation, and a novel link between chlorophyll and astaxanthin dynamics. The PhD at CentraleSupelec was directed by F. Lopes and co-supervised by O. Bernard, A. Fanesi and S. Tebbani.

- PhD: Jineth ARANGO OVIEDO defended on January, 30^{th}, 2025, her PhD *Decoupling HRT and SRT in Microalgae-Bacteria Consortia: A Model-Based Approach for Improved Wastewater Treatment Efficiency* at Escuela de Ingeniería Bioquímica, Pontificia Universidad Católica de Valparaíso, Chile. Directed by D. Jeison and co-directed by O. Bernard and F. Casagli.

- PhD in progress: R. Ranini. "Deep learning approaches for enhancing models in oceanography", Université Côte d'Azur, since 2022. Supervisors: L. Guidi and O. Bernard.

- PhD in progress: Pauline Mazel. "modeling and control of cancer cell population dynamics", since October 2023. Supervisors: F. Grognard (director, Macbes) and W. Djema (co-director, GREENOWL).

- PhD in progress: Javier Innerarity Imizcoz. "Optimal bacterial resource allocation for metabolite production", since November 2023. Supervisors: Jean-Luc Gouzé (director, Macbes), Francis Mairet (co-director, Ifremer Nantes) and W. Djema (co-supervisor, GREENOWL).

- PhD in progress: Manon Pugnet. "Optimal Control of the competition within microbial communities", Université Côte d'Azur, since 2024. Supervisors: O. Bernard and W. Djema.

11.2.4 Juries

- O. Bernard was member of the Individual monitoring Committee of Mélanie PIETRI (ENS Paris-Saclay) and C. ANDREANI (Sorbonne Université).
- F. Casagli participated to the Individual monitoring Committee of the Ph.D. of Irene MARTíNEZ MENÉNDEZ, from the Doctoral School EDSEVAB n°458. Title of the thesis: "Digital twins for the optimization of bioprocesses", Thesis director: César Arturo ACEVES-LARA, Thesis co-director: TONDA Alberto.
- O. Bernard was reviewer of the HDR thesis of G. Capson-Tojo, "Exploiting gas-based bioprocesses and photosynthetic bacteria for high-value resource recovery." University of Montpellier June 13^{th}, 2025.
- O. Bernard was reviewer of the PhD thesis of M. Carrier, University of Toulouse "Stockage et utilisation du CO2 par précipitation de carbonate de calcium induite par voie biologique dans le cycle phototrophe du soufre" directed by M. Spérandio and C. Dumas, June 17^{th}, 2025.
- O. Bernard was reviewer of the PhD thesis of M. Maton , University of Mons "Metabolic modeling of Cellular Culture Processes - Genetico Microscopic and Macroscopic Scales" directed by A Vande Wouwer and L. Dewasme, September 4^{th}, 2025.
- F. Casagli took part in the INRAE recruitment committee for a research engineer position in advanced bioprocess modeling at the TBI laboratory (Toulouse).

11.3 Popularization

11.3.1 Productions (articles, videos, podcasts, serious games, ...)

- We contributed to a paper [38] to demystify Life Cycle Assessment (LCA) for newcomers in the algae sector, providing clear concepts and best practices to evaluate environmental impacts. It empowers researchers and industry professionals to navigate methodological challenges, fostering the development of truly sustainable algae-based products.
- F. Casagli was selected as testimonial within the framework of the Artificial Intelligence (AI) Action Summit (international summit at the Grand Palais, Paris, 10&11/02/25) and realized a 180-s video interview, highlighting international researchers who chose France and Inria to pursue their work.

11.3.2 Participation in Live events

- O. Bernard gave public conferences on "Introduction of LCA" in the framework of "Science for All 06". Outreach presentations in Saint-Blaise (September 12^{th}, 2025) and Bonson (December 4^{st}, 2025).
- W. Djema participated in the *Fête de la Science* and animated the Inria outreach booth during the event held at the Palais des Congrès in Antibes Juan-les-Pins on October 11^{th}–12^{th}, 2025, including a short local TV interview about Inria's research and outreach activities.
- O. Bernard and F. Casagli participated in a stand for United Nations Ocean Conference, within the Science sur mer initiative (UNOC, June 2025, Nice).

12 Scientific production

12.1 Major publications

[1] R. Asswad, W. Djema, O. Bernard, J.-L. Gouzé and E. Cinquemani. 'Optimization of microalgae biosynthesis via controlled algal-bacterial symbiosis'. In: CDC 2024 - 63rd IEEE Conference on Decision and Control. Milan, Italy: IEEE, 10th Oct. 2024, pp. 1–6. DOI: 10.1109/CDC56724.2024.10886300. URL: https://inria.hal.science/hal-04727571 (cit. on pp. 11, 13).

[2] C. Baroukh, R. Munoz Tamayo, J.-P. Steyer and O. Bernard. 'DRUM: A new framework for metabolic modeling under non-balanced growth. Application to the carbon metabolism of unicellular microalgae'. In: *PLoS ONE* 9.8 (2014), e104499. DOI: 10.1371/journal.pone.0104499. URL: https://hal.science/hal-01123224 (cit. on p. 13).

[3] H. Bonnefond, C. Combe, J.-P. Cadoret, A. Sciandra and O. Bernard. 'Potential of Microalgae'. In: *Green Chemistry and Agro-food Industry: Towards a Sustainable Bioeconomy*. Springer Nature Switzerland, 23rd Apr. 2024, pp. 133–153. DOI: 10.1007/978-3-031-54188-9_6. URL: https://inria.hal.science/hal-04868598 (cit. on p. 12).

[4] H. Bonnefond, Y. Lie, T. Lacour, B. Saint-Jean, G. Carrier, E. Pruvost, A. Talec, A. Sciandra and O. Bernard. 'Dynamical Darwinian selection of a more productive strain of Tisochrysis lutea'. In: *Algal Research - Biomass, Biofuels and Bioproducts* 65 (June 2022), p. 102743. DOI: 10.1016/j.algal.2022.102743. URL: https://hal.science/hal-03668620 (cit. on p. 12).

[5] F. Casagli, F. Béline, E. Ficara and O. Bernard. 'Optimizing resource recovery from wastewater with algae-bacteria membrane reactors'. In: *Chemical Engineering Journal* 451 (Jan. 2023), p. 138488. DOI: 10.1016/j.cej.2022.138488. URL: https://inria.hal.science/hal-03932262 (cit. on p. 15).

[6] F. Casagli and O. Bernard. 'Simulating biotechnological processes affected by meteorology: Application to algae–bacteria systems'. In: *Journal of Cleaner Production* 377 (Dec. 2022), p. 134190. DOI: 10.1016/j.jclepro.2022.134190. URL: https://inria.hal.science/hal-03935662 (cit. on p. 15).

[7] F. Casagli, G. Zuccaro, O. Bernard, J.-P. Steyer and E. Ficara. 'ALBA: a comprehensive growth model to optimize algae-bacteria wastewater treatment in raceway ponds'. In: *Water Research* 190 (Feb. 2021), p. 116734. DOI: 10.1016/j.watres.2020.116734. URL: https://inria.hal.science/hal-03142211 (cit. on pp. 14, 15).

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