

Stability of meta-ecosystems along the land-sea continuum: a modelling approach for restoration

The French National Research Institute for Agriculture, Food, and the Environment (INRAE) is a public research establishment gathering a community of 12,000 people with more than 270 units including fundamental and experimental research, spread out throughout 18 regional centres in France. Internationally, INRAE is among the top research organisations in agricultural and food sciences, plant and animal sciences, as well as in ecology and environmental science. It is the world's leading research organisation specialising in agriculture, food and the environment. Faced with a growing world population, climate change, the depletion of resources and declining biodiversity, the Institute has a major role to play in providing the knowledge base supporting the necessary acceleration of agricultural, food and environmental transitions, to address the major global challenges.

Work environment

You will be primarily based at INRAE Rennes, on the campus of the Institut Agro Engineering school, under the primary supervision of Alain Danet (DECOD, INRAE), but also of Isabelle Gounand (IEES, CNRS) and Sonia Kéfi (ISEM, CNRS). You will further benefit from the national (eg. in Paris & Montpellier), and international network of collaborators (eg. University of Sheffield) which include both theoreticians and empiricists.

You will be integrated in the DECOD research unit, which focuses on the evolutionary biology and ecology of aquatic systems along land-freshwater-sea continuum. DECOD is home to 55 researchers, 13 graduate students, and 11 postdoctoral researchers. A key feature of DECOD is its unique partnership across INRAE, Institut Agro & IFREMER, allowing it to integrate expertise across both continental and marine ecosystems. DECOD provides cutting-edge infrastructures, including access to HPC clusters (local & national), which will be essential for the computational and modelling aspects of the project.

[Rennes](#) is the thrilling capital of the Brittany region and located at 90min from Paris by train. It hosts a vibrant scientific community with 2 Universities, 9 grandes écoles (Institut Agro, ...), 5 national research organisms (INRAE, CNRS...), and recognised for its excellence in ecology and agroecological science. Rennes hosts [support services](#) for international scientists settling in Brittany, and DECOD has excellent internal experience with the administrative processes related to visa procedures.

Scientific context

The concept of the meta-ecosystem has emerged in recent years as a unifying framework for studying the interdependencies between ecosystems linked by spatial flows of energy, matter and organisms¹⁻³. This framework is particularly relevant to the land-sea continuum, where the water cycle links catchment areas to coastal zones, and where many species spend parts of their life cycles across multiple ecosystems. However, despite repeated calls for greater integration^{4,5}, terrestrial, freshwater and marine ecosystems continue to be studied predominantly in isolation, and meta-ecosystem models still lack the incorporation of biodiversity and the complexity of food webs.

Existing meta-ecosystem models are often limited to aggregated functional compartments (producers, consumers, detritivores) which do not account for species diversity and their interactions^{2,3,6,7}. However, recent research in community ecology has clearly shown that species richness and the structure of food webs are major determinants of ecosystem functioning and their stability in the face of disturbances⁸⁻¹³. Ignoring this complexity amounts to neglecting fundamental mechanisms such as trophic complementarity, extinction cascades, or the diversity of responses to disturbances. The RIV2SEA project specifically aims to address this gap by integrating species-rich food webs into a spatially explicit meta-ecosystem model.

The nature of spatial flows (nutrients, detritus, organisms) plays a decisive role in the stability of meta-ecosystems. Nutrient flows between connected ecosystems generally have a destabilising effect, amplifying biomass fluctuations and facilitating the propagation of disturbances across the ecosystem network^{6,14}. Conversely, the dispersal of organisms can have a stabilising effect by allowing excess biomass to be drained from enriched areas to less productive ones^{6,15}. However, these results were obtained from simplified models in which biodiversity is reduced to a few aggregated functional compartments. The RIV2SEA project introduces this complex biodiversity and proposes to systematically assess how the spatial configuration of flows and the nature of these flows between ecosystems influence the stability of meta-ecosystems.

Finally, whilst the need to restore ecological connectivity is now enshrined in major regulatory frameworks such as the European Nature Restoration Law (Regulation 2024/1991, which sets a target of restoring 20 per cent of land and sea areas by 2030), the decision-support tools needed to prioritise restoration actions at the catchment scale are still lacking. Questions regarding the location of actions (upstream vs. downstream, wetlands vs. main watercourses) and the combination of measures (reducing diffuse inputs vs. restoring connectivity) remain largely unresolved. Existing models, which are often too aggregated, do not allow for a detailed assessment of the trade-offs between these different strategies or their effects on the trophic structure and long-term stability of connected ecosystems. RIV2SEA addresses this need by developing a spatially explicit simulation tool capable of assessing the relative effectiveness of different restoration strategies across multiple criteria (trophic structure of ecosystems, nature and strength of flows, spatial configuration).

The project is a direct continuation of [RIVERSEA EU](#) project (2025-2027, funded by Horizon Europe), of which it constitutes a spatially explicit – and therefore more operational – extension. You will develop the meta-ecosystem model as a spatial extension of the [EcologicalNetworksDynamics.jl](#)¹⁶ platform. Whilst RIVERSEA is developing an ‘island-continent’ type meta-ecosystem model (a spatially implicit model in which a local ecosystem interacts with a regional pool), RIV2SEA will generalise this approach to a set of explicitly connected ecosystems, thereby enabling a detailed representation of the spatial configuration of pressures and restoration actions. This complementarity between the two projects ensures overall consistency and the pooling of methodological developments, whilst enabling a higher level of ambition to be achieved than either project could achieve on its own.

References: 1. **Gounand, I.**, *et al.*. Meta-Ecosystems 2.0: Rooting the Theory into the Field. *Trends Ecol. Evol.* 33, 36–46 (2018). 2. Loreau, M. *et al.*. Meta-ecosystems: a theoretical framework for a spatial ecosystem ecology. *Ecol. Lett.* 6, 673–679 (2003). 3. Massol, F. *et al.* Linking community and ecosystem dynamics through spatial ecology. *Ecol. Lett.* 14, 313–323 (2011). 4. Menge, B. A. *et al.* Terrestrial ecologists ignore aquatic literature: Asymmetry in citation breadth in ecological publications and implications for generality and progress in ecology. *J. Exp. Mar. Biol. Ecol.* 377, 93–100 (2009). 5. Kavanaugh, M. T. *et al.* A Salty Divide Within Aslo? *Limnol. Oceanogr. Bull.* 22, 34–37 (2013). 6. **Gounand, I.** *et al.* The Paradox of Enrichment in Metaecosystems. *Am. Nat.* 184, 752–763 (2014). 7. Harvey, E., Marleau, J., **Gounand, I.** *et al.* A general meta-ecosystem model to predict ecosystem functions at landscape extents. *Ecography* 2023, e06790 (2023). 8. Thébault, É. & Loreau, M. Food-web constraints on biodiversity-ecosystem functioning relationships. *Proc. Natl. Acad. Sci.* 100, 14949–14954 (2003). 9. Wang, S. & Brose, U. Biodiversity and ecosystem functioning in food webs: the vertical diversity hypothesis. *Ecol. Lett.* 21, 9–20 (2018). 10. Thébault, E. & Loreau, M. Trophic Interactions and the Relationship between Species Diversity and Ecosystem Stability. *Am. Nat.* 166, E95–E114 (2005). 11. Eschenbrenner, J. & Thébault, É. Diversity, food web structure and the temporal stability of total plant and animal biomasses. *Oikos* 2023, e08769 (2023). 12. **Danet, A.**, Mouchet, M., Bonnafe, W., Thébault, E. & Fontaine, C. Species richness and food-web structure jointly drive community biomass and its temporal stability in fish communities. *Ecol. Lett.* 24, 2364–2377 (2021). 13. **Danet, A.**, **Kéfi, S.**, Johnson, T. F. & **Beckerman, A. P.** Response diversity is a major driver of temporal stability in complex food webs. *Proc. R. Soc. B Biol. Sci.* 292, 20250730 (2025). 14. McCann, K. S. *et al.* Landscape modification and nutrient-driven instability at a distance. *Ecol. Lett.* 24, 398–414 (2021). 15. Ryser, R., Hirt, M. R., Häussler, J., Gravel, D. & Brose, U. Landscape heterogeneity buffers biodiversity of simulated meta-food-webs under global change through rescue and drainage effects. *Nat. Commun.* 12, 4716 (2021). 16. **Lajaaity, I.**, Bonnici, I., **Kéfi, S.**, Mayall, H., **Danet, A.**, **Beckerman, A. P.**, Malpas, T., & Delmas, E. (2025). *EcologicalNetworksDynamics.jl*: A Julia package to simulate the temporal dynamics of complex ecological networks. *Methods in Ecology and Evolution*, 16(3), 520–529. Names of researchers involved in the RIVERSEA and RIV2SEA projects are in bold.

Missions

During this project, you will develop a meta-ecosystem model representing the land-sea continuum across coupled river and coastal ecosystems at the catchment scale. You will investigate the effect of the spatial configuration and the nature of flows on the resistance and resilience of meta-ecosystems in the face of pressures. Finally, you will assess the effectiveness of various restoration strategies in enabling a degraded meta-ecosystem, along the land-sea continuum, to return to a functional and stable state.

Specific project aims include:

- 1) Develop a spatially explicit meta-ecosystem model integrating the dynamics of species-rich food webs, nutrient and detritus fluxes, and species dispersal along an upstream–downstream gradient representing the land–sea continuum.
- 2) Perform and analyse in-silico experiments to assess how the spatial heterogeneity of pressures (nutrient source areas, barriers to dispersion) and the nature of fluxes (nutrients alone, species alone, or in combination) affect the capacity of a meta-ecosystem to withstand an increase in pressure (resistance) and to return to its initial state once pressures have decreased (resilience).
- 3) Simulate and evaluate the effectiveness of various restoration scenarios of degraded meta-ecosystems involving the reduction of non-point nutrient inputs (such as by modelling wetland restoration), the restoration of longitudinal connectivity (removal of barriers such as dams), and the restoration of natural river courses (flow-retardation zones), as well as combinations of these actions, by varying their locations along the land-sea continuum.
- 4) Publish at least one paper (in a major ecological journal) on the effects of spatial fluxes on meta-ecosystem dynamics.
- 5) Dedicate two days a month to the maintenance, documentation of the modelling platform in collaboration with the other researcher of our consortium. This collaborative effort is key to increase the FAIRness of our theoretical tools.

Training and skills sought

The ideal candidate has strong interests in question-based, theory-driven research and has interests for contributing to solve environmental management problems. This research position requires both a strong attraction for concepts in community ecology and ecosystem ecology and for computational tools. We provide internal training opportunities to learn food-web modelling in Julia.

Mobility rule: Eligible candidates must have spent at least 18 months¹ abroad between 1st April 2023 and the beginning of the project, as required per the research program [Bienvenue Bretagne](#), which aims to recruit highly-talented international researchers in Breton laboratories.

We strongly encourage applications from all backgrounds. [We are committed](#) in promoting gender equality, diversity, inclusion and equal opportunities, while preventing all forms of discrimination.

Recommended training: PhD in Ecology with strong quantitative skills or PhD in Applied Mathematics/Physics/Network Science with experience in Ecology.

Desired knowledge:

- Conceptual: biodiversity & spatial dynamics, network science, food-web theory, biodiversity & ecosystem dynamics.
- Programming: Proficiency in Julia or another language. Experience in software development, using forges (eg. Github) and HPCs.
- Theoretical modelling: Experience with spatial dynamics and/or food-web modelling, ODE/PDE/SDE systems.
- Fluency in English (written & spoken).

Skills:

- Ability to work in a team and in an interdisciplinary environment.
- Curiosity, Autonomy, thoroughness and organizational skills.

INRAE's life quality

By joining our teams, you benefit from (depending on the type of contract and its duration):

- up to 30 days of annual leave + 15 days "Reduction of Working Time" (for a full time)
- parenting support: CESU childcare, leisure services
- skills development systems: training, career advise
- social support: advice and listening, social assistance and loans
- holiday and leisure services: holiday vouchers, accommodation at preferential rates
- sports and cultural activities
- collective catering.

¹ With reference to the Marie Skłodowska-Curie mobility rule under the European Union's Framework Programme for Research and Innovation. Accordingly, periods of residence or of carrying out one's main activity (work, studies, etc.) that can be substantiated by supporting documents (employment contracts, study grants, etc.) are taken into account. Short stays, such as holidays, are not taken into account. If maternity and/or parental leave took place during the period under consideration, the latter is extended by the corresponding number of months. For example, for a four-month period of maternity leave taken between 1 May 2023 and the start of the project, the period taken into account for calculating the 18 months spent abroad runs from 1 January 2023 to the start of the project.

Contract details

- i Hosting unit name: DECOD
- i Postal code and city workplace: Rennes (France)
- i Type of contract: Fixed-term contract
- i Duration: 24 months
- i Starting date: February or March 2027
- i Remuneration: ~3 560 € to 3 950 € monthly gross salary depending on professional experiences.

How to apply

Send an email to alain.danet@inrae.fr, isabelle.gounand@sorbonne-universite.fr, sonia.kefi@umontpellier.fr with a CV (2 pages max), a cover letter (1 page max) and the names of three references to contact.

- 🕒 Deadline to apply: 20th of November 2026
- 🕒 Interviews (expected): From 7th to 11th of December 2026

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