EU RIA H2020 Proposal Template

ROBHOOT

Abstract

In nature, biological interactions and traits diversify across multiple scales of organization, from neurons to populations and spatio-temporal scales maintaining a complex ecological balance. This never-ending eco-evolutionary diversification of traits and interactions inspires a new computational approach for a global-sustainable knowledge-based society. We introduce evolutionary diversification-inspired and artificial intelligence solutions for sustainability in natural ecosystems. We validate our approach with a case study focusing on the sustainability of the Oceans in federated networks, where many heterogeneous groups of species, humans, and technologies coexist exploiting resources in complex ecosystems. Knowledge discovery running on a federated network encompasses a hybrid-technology to lay out the foundation of an open- and cooperative-science ecosystem for computation discovery in the face of global sustainability challenges. The project summarized here not only sets out to deliver knowledge discovery computation but also provides fully reproducible open-source software solutions of a science-enabled technology to connect knowledge-inspired societies to global sustainability challenges.

Knowledge discovery in eco-evolutionary diversification-inspired federated networks (ROBHOOT)

1 Excellence

1.1 Objectives

Ecosystems' collapse around the globe is calling for technologies to discover novel ways of sustainable exploitation. Knowledge-based societies place great expectations on data-driven intelligent machines to face global sustainability challenges. In this regard, rapid and real-time discovery computation is currently a major issue revolving around data-driven intelligent machines and knowledge-based societies. Diversification of biological systems offers an unexplored avenue for inspiration of new computational approaches. However, diversifying ecosystems are not used for discovery computation yet, despite the rapid changes of traits and interactions observed in overexploited, experimental and theoretical systems [1–4]. Biological systems are characterized by feedbacks between the ecology and evolution of interacting traits, the eco-evolutionary feedbacks, to produce novel traits with new functionalities [5]. This results in new computational properties, like new cooperation and competition strategies and information processing capabilities. Diversification usually occurs in heterogeneous ecosystems with limited resources where many distinct groups need to develop specialized traits and strategies to obtain resources. The outcome is the formation of consortia and more broadly federated networks composed of phylogenetically and ecologically distinct groups. Conventional Artificial Intelligence (AI) is rapidly moving towards explainable and discovery pattern inference [6] but often avoids evolutionary diversification for exploring new computing capabilities [7]. The same situation occurs for artificial neural networks that also make limited use of novel computing capabilities as a consequence of new interactions and traits [8]. **The goal of this project is to implement eco-evolutionary diversification-inspired solutions to perform discovery computation based on rapidly diversifying traits and interactions**. The exploitation of emerging interactions, strategies and traits will allow us to create novel discovery computation solutions for natural ecosystems facing sustainability challenges like overexploitation of the Oceans, where harvesting renewable resources are beyond the diminishing returns for many species and ecosystem resources [9, 10].

Why should we go deeper into diversifying networks for discovery computation? With connections and traits represented in a spatially distributed network, as found in natural ecosystems, diversification is an avenue to harvest renewable resources. This allows considering not only evolutionary processes changing traits and agents (i.e., plasticity and other sources of variation), but the formation of new entities to quantify new scenarios for sustainability that substantially deviate from evolutionary computation considering only changes and not diversification processes. This also allows representing real-time solutions for ever-changing renewable resources, which is a key problem in many digital and natural ecosystems. To show the capabilities of the ROBHOOT approach, we will address full reproducibility, automation, visualization, and reporting (Figure 1). **The main impact of ROBHOOT is to provide a new technology to improve ecosystem sustainability relevant to community-rich digital and natural ecosystems.** To support this notion, we will perform eco-evolutionary diversification-inspired simulations along the whole life cycle of the project. The central goals of ROBHOOT are:

(G1) To extend existing theories of eco-evolutionary diversification and AI-inspired solutions to decipher the factors driving discovery computation in federated networks. This will allow us to identify novel solutions for ecosystem sustainability.

(G2) To investigate how spatiotemporal evolutionary diversification and AI-inspired networks mimic the empirical patterns of natural and socio-technological ecosystems when heterogeneous human groups, technologies, and species coexist.

(G3) To develop fast, reproducible and automated eco-evolutionary diversification-inspired discovery computation prototypes for real-time information processing tasks.

(G4) To obtain principles of discovery computation for prediction in federated networks when diversification in interactions and traits occurs in a large and heterogeneous set of species, technologies and human groups.

1.2 Relation to the work programme

Scope: Proposals are expected to have their main focus in only one of the following sub-topics: new techniques for modelling and predicting social/environmental evolution across different temporal and spatial scales. These will combine, analyse and interpret data from in-situ and remote (e.g., satellite) sensing technologies, other public data sources (e.g., historical data, planning documents, legislation), and data or models/theories from human behaviour (including gender differences), economics and the social sciences by making recourse to advanced artificial intelligence techniques, if/as needed. The focus is on modelling and tracking of the interplay between natural and societal systems, for example on how policies and economics modelling predict human behaviours' impact on the environment, how explicit or implicit incentives and social norms interact with the environment's evolution and exploitation, how real-time environmental awareness and intelligence can improve behaviour towards more sustainability, or how the decisions based on changes in the environment in turn affect the state of the natural environment.

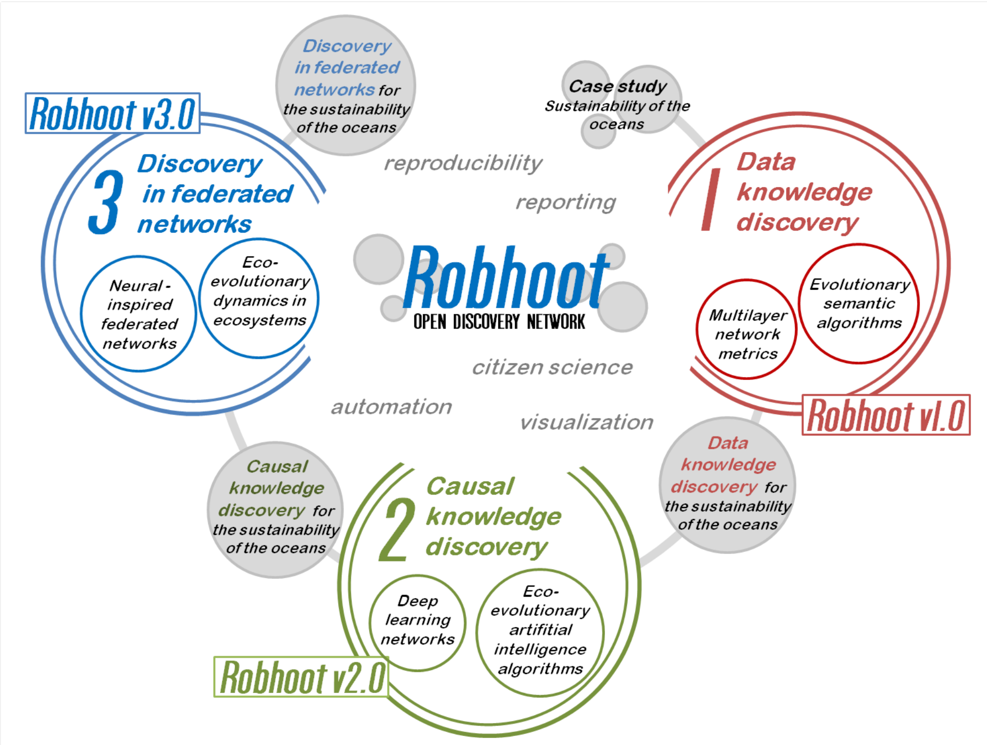

Figure 1: **Discovery in evolutionary diversification-inspired federated networks**. ROBHOOT target knowledge discovery when heterogeneous groups of species, humans and technologies share resources for a sustainable knowledge-based society: It introduces three science-enabled technologies: Evolutionary biology-inspired semantic algorithms for ROBHOOT v1.0 (ESA, data knowledge discovery, red), eco-evolutionary diversification-inspired AI models for ROBHOOT v2.0 (EEDA, causal knowledge discovery, green), and evolutionary neural diversification-inspired federated networks for ROBHOOT v3.0 (ENDI, discovery in federated networks, blue). ROBHOOT uses the sustainability of the Oceans case study in federated networks as an open-source technology with full reproducibility, automation, visualization and reporting for an open citizen science.

ROBHOOT addresses the specific challenge of the call by merging new eco-evolutionary diversification and AI techniques for modeling evolution and diversification in socio-technological-environmental ecosystems. The fusion between modeling and the data will be explored across different temporal and spatial scales for predicting and discovering new sustainability scenarios (MS3, Discovery in federated networks). ROBHOOT uses Ocean sustainability as a case study enriching long-term international core databases (e.g. ices VME: do you mean ice cover time series???). It will merge core databases with new public data sources (e.g., historical, fishing maps, ecosystem habitats, etc) (MS1, Data knowledge discovery). The Ocean is the largest ecosystem on Earth, providing food, and other resources and is a major player in the climate balance and stability of Earth's climate. The Oceans are stressed by human activity in different forms, maritime traffic (which accounts for 90% of the goods transport), fishing, invasions, pollution (plastic, noise), and global warming (e.g. increase temperature, acidification). ROBHOOT will also leverage data coming from sensors and observations to merge them with the core databases, to untangle the interactions among ecosystems, species, human activity with a variety of fishing technologies, and environmental variables (MS2, Causal knowledge discovery). The data will be fed to the eco-evolutionary diversification- and AI-inspired modeling to extract causal relationships among these variables and to discover new paths for sustainability routes in complex ecosystems.

ROBHOOT will be developed as an open-source technology along its whole developmental life cycle to facilitate real-time tracking of the interplay between natural, technological and social systems. It will provide novel routes for exploitation when social, technological and species evolution are taken into account to facilitate behaviour and strategies towards more sustainability. The ROBHOOT approach is based on full reproducibility, automation, visualization, and reporting to accomplish such a mission (Figure 1).

1.3 Concept and methodology

(a) Concept

Describe and explain the overall concept underpinning the project. Describe the main ideas, models or assumptions involved. Identify any inter-disciplinary considerations and, where relevant, use of stakeholder knowledge. Where relevant, include measures taken for public/societal engagement on issues related to the project. Describe the positioning of the project e.g. where it is situated in the spectrum from 'idea to application', or from 'lab to market'. Refer to Technology Readiness Levels where relevant. (See General Annex G of the work programme);
Describe any national or international research and innovation activities which will be linked with the project, especially where the outputs from these will feed into the project;

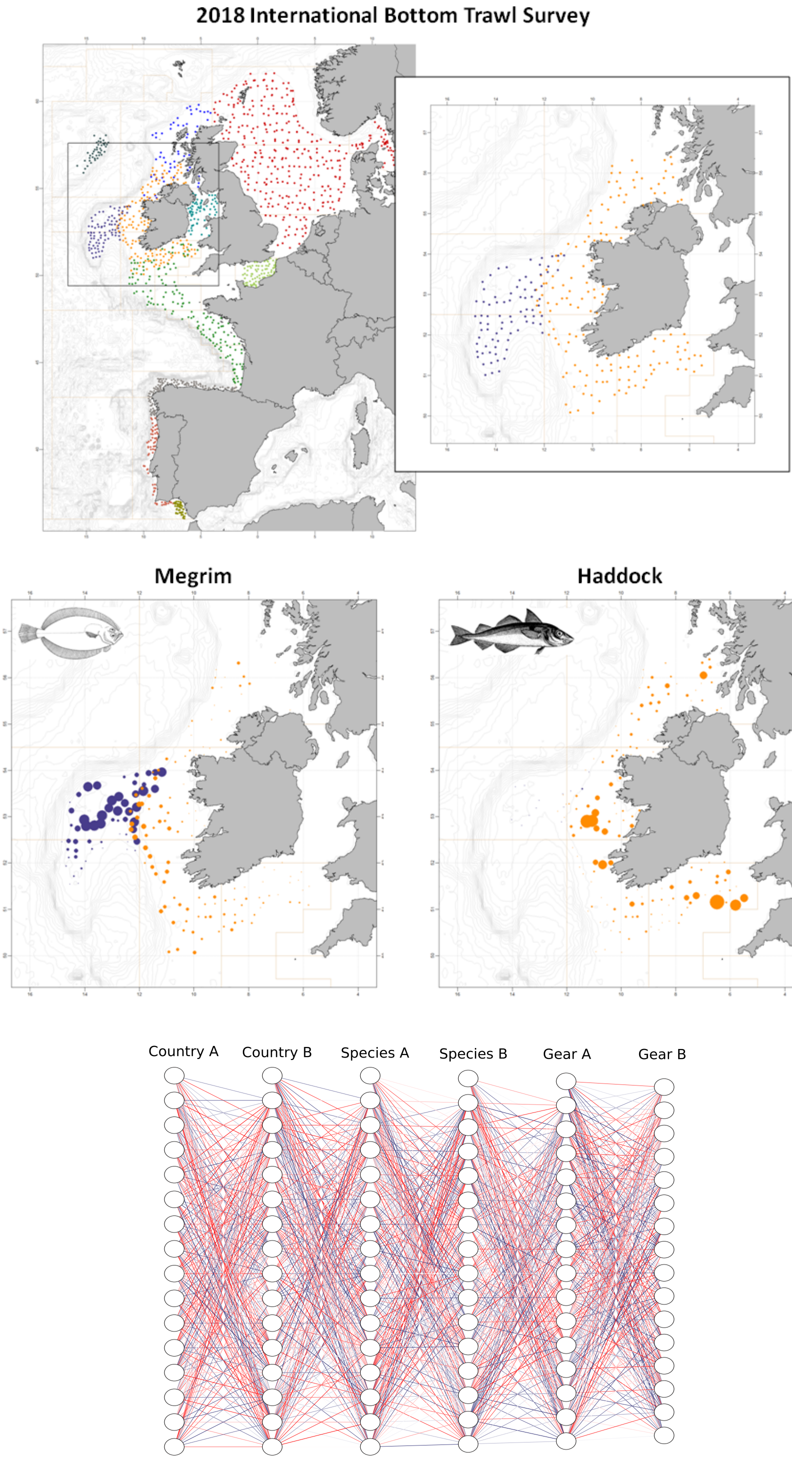

Figure 2: **Discovery for Sustainable Ecosystems**. ROBHOOT target discovery computation for new sustainability paths in complex ecosystems. The sustainability of the Oceans case study [11] will be enriched to validate the technology when many species, human groups and technologies exploit resources (**Top left**, data-color points represent samplings from different countries. Zoomed in is the Irish Ground Fish Survey (IE-IGFS, Orange) and the Spanish Survey on the Porcupine Bank (SP-PORC, Blue). Countries produce strong bias in the distributions maps because they use different gears according to their commercial interest (Megrim, *Lepidorhombus whiffiagonis*, consumed largely in Spain and France, **Center-left**) and Haddock, *Melanogrammus aeglefinus*, highly-priced in northern Europe, (**Center-right**). This generates a strong bias for sustainability in natural resources. ROBHOOT integrates evolutionary diversification-AI-inspired solutions represented as networks with many layers to discover sustainability paths with many coexisting species, human groups and technologies (**Bottom**). Each country, species and gear in this cartoon is composed of many nodes: country contains fishery, environmental agency, stakeholders, etc. Species contains size-classes, habitat preference, species interactions, etc, and gears contain different technologies. Red and blue links mean competition and cooperation links connecting each pair of nodes.

(b) Methodology

Data knowledge discovery (WP1)
Evolutionary biology-inspired semantic algorithms (ESA): Most studies of data discovery focus on advanced analytics functions to gain insights, almost completely ignoring the heterogeneity of data sources. Currently, only a few databases are semantically annotated from many data sources (e.g., gene ontology database, COVID-19). Ontology

development is time-consuming and requires expert knowledge. It is also paired with data-driven research that checks the soundness of the ontology as it simultaneously seeks discovery. Thus, software tools for mapping and linking the terms between different ontologies accounting for many data sources are still not in place [12–14].

Going beyond ROBHOOT will go beyond state-of-the-art to implement ESA. We will explore evolutionary-based functions to find datatype properties from ontologies and raw-data from non-semantic databases. ROBHOOT will also explore algorithms to gain an understanding of the replicability of data heterogeneity contrasting different evolutionary algorithms. ROBHOOT will explore the sustainability of the Oceans database started in 1965 and currently containing 9 million entries, 1612 species (i.e., 50 variables and traits per species), around 20 countries and 11 sampling methods (Figure 2).

Causal knowledge discovery (WP2)

Eco-evolutionary diversification-inspired AI algorithms (EEDA): Causal discovery from observable data has been extensively studied [15]. Many of these studies have used symbolic reconstruction of equations by symbolic regressions or evolutionary methods [16]. A common gap in much of the literature is one where parameters represent eco-evolutionary diversification processes, and thus, discovery can be explored broadly. The classical view on biology-inspired information processing technologies is to consider plasticity without structural changes, or without diversification among many interacting components [17]. Recent experimental evolution studies show that rapid trait changes with new information processing capabilities are far more complex because adaptation and speciation occur even in sympatry forming new species and phenotypes [18]. For example, eco-evolutionary dynamics strongly affect feedbacks between ecological and evolutionary processes, which in turn influences trait changes to open new structural changes with new information capabilities [5]. Furthermore, recent studies suggest that the interplay between trait dimensionality, the covariance structure among traits, and adaptation is key to understand the emergence of new traits and information processing abilities to form novel discovery computation strategies in ecosystems [19].

Going beyond ROBHOOT will, for the first time, employ EEDA to represent spatiotemporal causal inference in systems containing large heterogeneity and dimensionality (Figure 2). EEDA will be extended to deep process-based learning networks including traits and interactions driven by evolutionary changes to understand patterns in these systems. The search for causal knowledge discovery will be applied to the data knowledge discovery generated in WP1 for the sustainability of the Oceans, the largest ecosystem on Earth and key actor of climate change affecting biogeochemical and physical processes. Our approach will explore broad classes of evolving functions combining them to automated Bayesian machines ensuring the search, the evaluation of models, trading-off complexity, fitting to the data and quantify resource usage [20, 21] (Box 1).

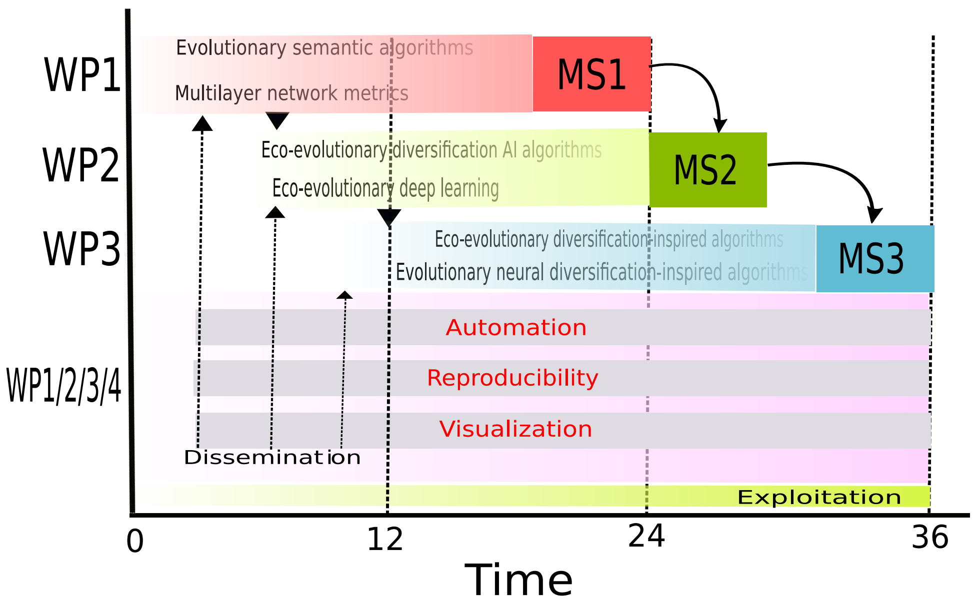

Figure 3: **Project summary**. Timeline of the project shows the gradually increasing complexity of the work. Arrows represent the first moment of information transfer. Automation, reproducibility, visualization and dissemination form part of the whole developmental life cycle. Note that exploitation increases in strength during the development of the project following ROBHOOT.

Box 1: Eco-evolutionary diversification-inspired AI algorithms for the sustainability of the Oceans (WP2) target biodiversity patterns from data collected by different countries to decipher sustainability in federated networks. International programs for exploration of the Oceans involve many countries collecting biodiversity data using different protocols and technologies ([11]). The data is then used to understand the spatiotemporal dynamics of the ecological communities as a baseline to inform the status of the ecosystems and fisheries. Each country collects data with different technology, i.e., gear systems, mostly driven by its commercial interests in specific species. This results in countries collecting heterogeneous and biased data about the same species, making it difficult to obtain accurate distribution maps of species (Figure 2). This is a tragedy of commons situation [22–24] in the context of evolving ecosystems [25]: Many heterogeneous nodes (i.e., countries with different interests, groups, funding and conservation strategies, etc) exploit resources (i.e., species within ecosystems composed by a network of interacting species) using different technologies (i.e., gear systems and others technologies). Many of these ecosystems are overexploited. And yet, science-based technologies, providing forecasting scenarios and accounting for biased biodiversity data (i.e., species and environment), technologies (i.e., gear systems and other), and human groups with different interest within and between countries, to mitigate risks and enhance global cooperation scenarios in such multidimensional ecosystems are not in place. Causal knowledge discovery will develop novel eco-evolutionary diversification-inspired AI models to identify the actors, e.g., species, threats like fishing pressure, environmental, species interaction and habitat data and other data sources to infer causality considering evolving traits of species, human behavior and technologies and their interactions to reach goal 2 (To investigate how spatiotemporal evolutionary diversification and AI-inspired networks can mimic the empirical patterns of natural and socio-technological ecosystems when heterogeneous human groups, technologies species coexist). Our methods will account for diversifying technologies, species and human behaviours. A social group represents a set of actors with multiple traits. In this context, groups are represented with evolving environmental and technological traits. We will formally describe these features as a distribution-fishery cooperation-competition matrix, $\mathcal{C}^2$, as follows:

$$\mathcal{C}^2 = \begin{array}{cc} & \begin{array}{cc} \mathrm{F}^i_{\mathcal{A}_g,\mathcal{B}_g}(c) & \mathrm{F}^i_{\mathcal{A}_g,\mathcal{B}_g}(nc) \end{array} \\ \begin{array}{c} \mathrm{D}^i_{\mathcal{A}_g,\mathcal{B}_g}(c) \\ \mathrm{D}^i_{\mathcal{A}_g,\mathcal{B}_g}(nc) \end{array} & \begin{pmatrix} \mathrm{c}(\varphi) & \mathrm{c}(\Phi), nc(\gamma_{A_g}, \gamma_{B_g}) \\ \mathrm{nc}(\Phi_{A_g}, \Phi_{B_g}), c(\gamma) & \mathrm{nc}(\phi_{A_g}, \phi_{B_g}) \end{pmatrix} \end{array},$$

where $\mathcal{D}^i_{\mathcal{A}_g,\mathcal{B}_g}$, $\mathcal{F}^i_{\mathcal{A}_g,\mathcal{B}_g}$ represent respectively the distribution map and fishery of species i, group g within country $\mathcal{A}$ and $\mathcal{B}$, and c and nc refer to cooperation and non-cooperation, respectively. The evolutionary diversification-inspired functions represent environmental and technological traits with different degrees of complexity in the $\mathcal{C}^2$ matrix: If the two groups within or between the countries cooperate, $c(\varphi)$, then the environmental and technological rate change, φ, is synchronized between groups to evolve towards decreasing Gear bias and make distribution maps and the fishery sustainable. This can be called the neutral scenario. On the other side, if the two groups decide not to cooperate, $nc(\phi_{A_g}, \phi_{B_g})$, then the environmental and technological rate changes are given by ϕ_{A_g} and ϕ_{B_g} respectively with each group following changes of their own gears, i.e., the GOV for the Ireland group and the Baka Gear for Spain group, independently of the other and as a function of their fishery interest. There is no interest in decreasing bias in species distribution maps making fishery potentially non-sustainable in this case. In the last two scenarios groups enter in cooperation for the distribution map of species i, but not in the fishery $(c(\Phi), nc(\gamma_{A_g}, \gamma_{B_g}))$, or they do cooperate in the fishery for species i but not for the distribution map of species i $(nc(\Phi_{A_g}, \Phi_{B_g}), c(\gamma))$. The situation for cooperation in the distribution maps follows agreements between the two groups to technological changes in the Gear but still preserving their GOV and the Baka Gears for fisheries. Our approach will explore broad classes of evolving functions within the cooperation-competition matrix combining them to automated Bayesian machines ensuring the search, the evaluation of models, trading-off complexity, fitting to the data and quantify resource usage [20, 21].

Discovery in federated networks (WP3)

Evolutionary neural diversification-inspired federated networks (ENDI): Technologies in digital ecosystems around federated networks are rapidly increasing and mostly focus on decentralization, scalability and security fronts [26–28]. Yet, the implementation of ENDI type algorithms and their application to forecasting in global sustainability problems is still lacking. Recent studies have shown the importance of evolutionary search of mathematical and symbolic operations as building blocks to discover ML algorithms [7, 20]. ENDI will help to decipher how interactions among heterogeneous groups evolve and learn to solve complex sustainability problems. Evolutionary dynamics explore open-ended language of models with varying trait evolution functions to discover biologically inspired solutions in multidimensional systems [7]. ENDI accounts for heterogeneous agents to discover novel biology-inspired solutions for the sustainability of the Oceans federated network.

Going beyond: Our understanding of the outcomes from diversified information processing systems formed by highly heterogeneous groups, a kind of large-scale meta-learning in the federated setting [29], is currently quite limited. Therefore, new science-enabled approaches accounting for diversifying information processing in heterogeneous and highly dimensional systems are required. This allows the development of science-enabled technologies where heterogeneous agents with different interests find (non-optimal) solutions for the sustainable exploitation of ecosystems. Federated objects can be seen as "neural networks" containing many types of heterogeneous nodes with varying degrees of learning, connectivity and firing probabilities [30, 31]. ROBHOOT v.3.0 connects knowledge discovery to ENDI to study the properties of cooperative forecasting in the face of global sustainability challenges (Box 2).

1.4 Ambition

- Describe the advance your proposal would provide beyond the state-of-the-art, and the extent the proposed work is ambitious.
- Describe the innovation potential (e.g. ground-breaking objectives, novel concepts and approaches, new products, services or business and organisational models) which the proposal represents. Where relevant, refer to products and services already available on the market. Please refer to the results of any patent search carried out.

Don't you think this paragraph is better in section 1.2???

The success of ROBHOOT relies on a multidisciplinary team: evolutionary biology, ecology, computational neuroscience, data science, complex systems and experts in communication and field studies in biodiversity. Data knowledge discovery will be developed by evolutionary biology, computer science and complex system members of the consortium (EBD-CSIC, IFISC-CSIC, and SDSC). Data discovery will be transferred to the causal domain by the other part of the consortium with expertise in ecology, evolutionary biology, data science and causal inference (EAWAG and TARTUR). The whole process will be enriched with full automation, reproducibility and visualization by ICREA, SDSC, and our company-partner SCITE, respectively. Conversely, scientists working on neurobiology and eco-evolutionary dynamics in ecosystems will feed information back on fundamental discovery computational challenges in federated networks (i.e., role of heterogeneity, expanding EEDA and ENDI and adding cooperation and dimensionality). They will explore novel paths to improve existing theories using EEDA and ENDI algorithms. This cross-fertilizing back-and-forth interaction will allow the project to keep high modularity within the WPs while keeping cross-interactions among the groups to run efficiently the project. Bringing together ESA, EEDA and ENDI algorithms require a long stride and this has not been attempted so far. This way, we expect to realize a truly novel, sustainability-driven knowledge-based society technology for which there are no predecessors. Thus, ROBHOOT will not be incremental, but a jump to a new direction for eco-evolutionary diversification-inspired discovery computation.

ROBHOOT represents a novel approach for discovery computation in ecosystems. The transfer of eco-evolutionary diversification-inspired principles onto fully reproducible and automated software, progressing towards a process-based discovery technology, will be a major qualitative step, defining ROBHOOT as a high-risk project, fitting into FET-Open. To achieve the ambitious goals, we will combine expertise from all the involved areas, gradually mitigating risk, following a strict line and increasing step-by-step in the complexity of the problems addressed. We will start with evolutionary biology-inspired semantic algorithms for data discovery applying them to the sustainability of the Oceans case study. This is followed by more complex eco-evolutionary diversification-inspired AI modeling to infer causality in our case study. Then, we will advance to more complex situations, where evolutionary neural diversification-inspired modeling will expand the search along many distinct forecasting schemes to discover sustainability paths. To keep the project technically feasible, and to be able to connect properties from data and causal discovery computation to discovery in federated networks, we will limit methods to three main approaches. All of the above will be done by combining data-driven simulations, theoretical work and numerical simulations with our sustainability of the Oceans case study crossing them all. The knowledge gained will allow us to present ROBHOOT as a compact science-enabled open-source technology. We will use fast computing languages to implement Agent-Based Models (ABM) along with all the theoretical development of the proposal. We will contrast the ABM with differential/difference stochastic equation methods when a large number of agents, traits, and interactions diversify in time and space. This feature represents a very desirable fallback in case of speed and convergence problems for multidimensional and nonlinear systems (Table 1.4a, Critical risks for the research approach). Our implementation activities are all complemented by numerical investigations contrasted for speed and robustness with the sustainability of the Oceans case study (Figure 2). The success of ROBHOOT would represent a breakthrough in the current discovery computation with direct application to the sustainability of ecosystems and beyond. The combination of rapid, heterogeneous database and cooperation for discovery computation based on open-source algorithms will lead to fast implementations of the demonstrators with high flexibility that will permit a rapid transit to the public.

Box 2: Evolutionary neural diversification-inspired discovery for the sustainability of the Oceans in federated networks (WP3) targets the sustainability of large and complex ecosystems where many interacting groups within and between countries have different interests in resource exploitation. Evolutionary neural diversification-inspired discovery will represent neurons as algorithms along heterogeneity gradients. A federated neural network is composed by types of neurons: Species, human groups and technology all containing heterogeneity along many dimensional traits. The goal is to discover new rules representing high sustainability values defined broadly as a high degree of coexistence among many species, diversified technologies and human groups. The dynamics of interacting neurons will be essentially stochastic. The following are the rules governing the dynamics: we start with a population of algorithms extended in a landscape and fitness functions determine birth and deaths of algorithms. We will consider stochastic spiking neurons within nodes to compute how information processing evolves in the network. We will consider a variety of scenarios from strong selection to neutral federated networks to explore sustainability paths. Which scenarios provide the most plausible sustainability paths in federated networks? In the Oceans' sustainability case study this translates in focusing on cooperative-competitive learning as a tool to discover new solutions. For example, whether learning from the most distant strategies in the technological and environmental trait space makes the distribution catchability maps similar. Groups can be represented as environmental and technological traits with evolving traits as a function of the distance between pairs of groups sharing resources. We can formally describe this situation as a distribution-fishery cooperation learning matrix $\mathcal{C}^2$, as follows:

$$\mathcal{C}^2 = \begin{array}{c} \\ \mathrm{D}^i_{\mathcal{A}_g,\mathcal{B}_g}(c) \\ \mathrm{D}^i_{\mathcal{A}_g,\mathcal{B}_g}(nc) \end{array} \begin{array}{c} \begin{array}{cc} \mathrm{F}^i_{\mathcal{A}_g,\mathcal{B}_g}(c) & \mathrm{F}^i_{\mathcal{A}_g,\mathcal{B}_g}(nc) \end{array} \\ \begin{pmatrix} \mathrm{c}(\varphi,\mathcal{L}_d) & \mathrm{c}(\Phi,\mathcal{L}_d), nc(\gamma_{A_g},\gamma_{B_g}) \\ \mathrm{nc}(\Phi_{A_g},\Phi_{B_g}), c(\gamma,\mathcal{L}_d) & \mathrm{nc}(\phi_{A_g},\phi_{B_g}) \end{pmatrix} \end{array},$$

where $\mathcal{D}^i_{\mathcal{A}_g,\mathcal{B}_g}$, $\mathcal{F}^i_{\mathcal{A}_g,\mathcal{B}_g}$ represent respectively the distribution map and fishery of species i, group g within country $\mathcal{A}$ and $\mathcal{B}$, and c and nc refer to cooperation and non-cooperation, respectively, as in Box 1. We here introduce learning functions depending on the distance (or other property) between two groups, $\mathcal{L}_d$. We will search evolving learning functions coupled to environmental and technological traits with different degrees of complexity in the $\mathcal{C}^2$ matrix: For example, if the two groups within or between the countries are sufficiently distant, then learning functions might play a role to cooperate, $c(\varphi,\mathcal{L}_d)$, and the environmental and technological rate change, φ, strongly depend on learning between the interacting groups making distribution maps and the fishery more sustainable. Evolutionary neural diversification-inspired discovery will explore heterogeneity gradients along diversifying functions (i.e., family of functions that can change in their structure and/or expression properties) for species, human groups and technologies to discover novel sustainability paths that might improve the existing paths provided by the empirical patterns analyzed in WP2 (Box 1).

2 Impact

Table 1.4a: Critical risks for the research approach

2.1 Expected impact

(I) **Contribution to the foundation of a new future technology**: ROBHOOT uses the discovery of novel evolutionary diversification-inspired algorithms (EEDA and ENDI) to substantially improve solutions for sustainability in ecosystems. **Discovery of novel EEDA and ENDI in the context of diversifying traits, interactions, technologies and human groups for biodiversity**

Description of risk	Objective	WP	Proposed risk- mitigation measures
ESA insufficiently developed: Medium	2	WP1	Use traditional non-semantic genetic algorithms to infer data connections.
Low number of training data available: Medium	2,3	WP2	Alternative methods focusing on matrix decomposition.
Automated evolutionary-inspired expressions for causal knowledge discovery insufficiently developed: Medium	2,3	WP2	Symbolic regression methods for causal discovery accounting for evolutionary rules.
Extended EEDA in species-rich ecosystems insufficiently developed: Medium	1-4	WP3	Mean-field approximations using classical ODE systems and novel universal differential equations for scientific machine learning.
ENDI in federated networks insufficiently developed: High	1-4	WP3	Alternative neural network models based on deterministic spiking neurons.
Cooperative forecasting mixing EEDA and ENDI in federated networks insufficiently developed: High	1-4	WP3	Combine EEDA and ENDI on a smaller spatiotemporal scale.

maintenance have been hardly been investigated in this context so far. Predictors related to biodiversity, technological and social analysis will be tested and further developed to enable robust predictions. Altogether, this project will lay the foundation for future sustainability studies.

(II) **Future social/economic impact or market creation**: Our approach uses a novel technology to integrate many data types and discovery paths to make ecosystems sustainable. This will allow us to use the technology in public and private industry to generate robust scenarios when facing complex problems including global sustainability challenges (e.g., global health, food and feed production, ecosystems degradation).

(III) **Impact on transparency**: Decision making and governance at local, regional and global scales require access to reproducible information containing viable sustainability scenarios. ROBHOOT consortium brings together different partners in the fields of computer science, neurobiology, complex system, biology, social sciences, evolutionary ecology and one SME, all focusing on reproducibility, automation, visualization and reporting scientific data to different audiences.

(IV) **Ecosystem health impact**: ROBHOOT focuses on discovery solutions for exploited ecosystems. It uses a case study for the Oceans and provides solutions for ecosystem sustainability, thereby connecting ecosystem sustainability and ecosystem health. This feature aligns with the EU Reflection paper towards a Sustainable Europe by 2030 and the UN's Sustainable Development Goals. ROBHOOT can be seen as a horizontal enabler for a scientific-based transition to sustainability-based technology on large amounts of heterogeneous data, artificial intelligence and EEDA solutions.

(V) **Building leading research and innovation capacity across Europe**: This consortium brings together excellent partners from the fields of computer science, machine learning, deep learning networks, neurobiology, complex systems, experimental biology, biology and evolutionary ecology, physics, theory and applications of complex systems in social networks, delivering a highly innovative science-enabled technology focusing on sustainability solutions. All consortium partners exhibit a long-standing experience in interdisciplinary research across the boundaries of the individual disciplines. A web-based sustainability discovery portal will be produced (WP4), which will allow researchers, NGOs, managers and the public to train students in the discovery process to manage overexploited ecosystems. This will also allow us to scale up the number of people participating in the sustainability process thus mobilizing forward-thinking researchers and excellent young researchers to work together and explore what may become a novel paradigm in sustainability research.

2.2 Measures to maximize impact

Dissemination and exploitation

A plan for dissemination and exploitation (PDE) will be developed and managed in WP4. It will address the project strategy and specific actions related to: i) Dissemination: Open Access format; ii) Data Management; iii) Protection: IPR strategy; iv) Exploitation, namely "business models", and v) Communication, the actions to communicate the project results and demonstrators to key groups of end-users.

(I) **Open Access**: Project reports and ISI journal publications will be under the Open Access format. Following the Open Science principles, software and scientific publications will be deposited in the online institutional repositories and on the EC Participant Portal. ZENODO (http://zenodo.org), recommended by the European Research Council and the EC, and supported by EU's OpenAire platform (https://www.openaire.eu/) will be also used for dissemination and communication purposes (publications, presentations, datasets, images, videos/audio and interactive materials such as lectures).

(II) **Open access to research data**: recommended data repositories (e.g. PANGAEA, NASA Goddard Earth Sciences Data and Information Services Center) will be used to share the generated data and software. Open-source codes and analysis of standardized inputs/outputs and software will be made public in an online platform with the aim of becoming *the Reference Point* for any future research in knowledge discovery.

(III) **Data management**: Good research data management practice will ensure all the data is registered, stored, made accessible for use, managed over time and/or disposed of, according to legal, ethical, funder requirements and good practice. This management will provide benefits such as reducing the risk of data loss, improving data workflows and data availability and discovery, visibility of research outputs, attracting new collaborators and research partners, strengthening the research environment and infrastructure. A data management plan (DMP) will be created by the Project Coordinator in close cooperation with the partners and approved by the Steering Board at the start of the Project. The DMP will follow the FAIR principles. The document will describe how to collect, organize, manage, store, secure, back-up, preserve, and where applicable, share data.

(IV) **Innovation and IPR**: The Consortium will benefit from the innovation and technology transfer environment in place at EAWAG and CSIC, which will assist in the patent application process. Support is also available to assist the realization of innovative ideas into efficient business concepts. The necessary precautions will also be taken to protect the IPR of individual institutions. A Consortium Agreement will be signed before the beginning of the project to take into account the different interests of the partners, in particular how to treat pre-existing know-how, the ownership of the results and the intellectual property rights to prevent conflicts during the project. The Steering Board will ensure that all innovations and generated data are exploited to the benefit of the involved partners.

(V) **Exploitation, including business models**: The project's results will be showcased in trade shows (e.g. WebSummit), by communicating through specialized trade press media, and also to a targeted audience (policy makers, funding agencies, industry and SMEs). A detailed business plan will be prepared during the project work in collaboration with the SME and academic partners involved, with the ultimate goal of creating a Start-Up at the end of ROBHOOT. The value proposition of the project is to develop computation discovery solutions for rapidly diversifying traits and complex interactions that improve the sustainability of exploited natural ecosystems.

YEAR					2021				2022				2023			
MONTH					Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
MILESTONE												MS1		MS2		MS3
WP	WP Name	PROGRESS	START	END												
WP1	**Data knowledge discovery (DKD)**															
T1.1	Evolutionary semantic algorithms	17%	1/1/21	31/6/22						D1.1						
T1.2	Multilayer network metrics	34%	1/1/21	31/6/22						D1.2						
T1.3	Automation DKD	51%	1/4/22	1/8/22							D1.3					
T1.4	Reproducibility DKD	68%	1/4/22	30/9/22							D1.4					
T1.5	Visualization DKD	85%	1/4/22	30/9/22							D1.5					
T1.6	Data knowledge discovery SUSO	100%	1/4/22	31/12/22								D1.6				
WP2	**Causal knowledge discovery (CKD)**															
T2.1	Eco-Evolutionary diversification AI Algorithms	17%	1/5/22	31/12/22								D2.1				
T2.2	Eco-Evolutionary Deep Learning	34%	1/5/22	31/12/22								D2.2				
T2.3	Automation CKD	51%	1/10/22	31/3/23									D2.3			
T2.4	Reproducibility CKD	68%	1/10/22	31/3/23									D2.4			
T2.5	Visualization CKD	85%	1/10/22	31/3/23									D2.5			
T2.6	Causal knowledge discovery SUSO	100%	1/10/22	30/6/23										D2.6		
WP3	**Discovery in federated networks (DFN)**															
T3.1	Eco-evolutionary diversification-inspired	17%	1/1/22	31/12/23										D3.1		
T3.2	Evolutionary neural diversification-inspired	34%	1/1/22	31/12/23												D3.2
T3.3	Automation DFN	51%	1/1/23	31/12/23												D3.3
T3.4	Reproducibility DFN	68%	1/1/23	31/12/23												D3.4
T3.5	Visualization DFN	85%	1/1/23	31/12/23												D3.5
T3.6	Discovery in federated networks SUSO	100%	1/1/23	31/12/23												D3.6
WP4	**Dissemination, Knowledge Transfer and Outreach**															
T4.1	Dissemination and exploitation Plan	10%	1/1/21	31/12/23	D4.1							D4.4				D4.5
T4.2	Branding and communication guidelines	15%	1/1/21	31/3/21	D4.2											
T4.3	Website and social media	20%	1/1/21	31/12/23		D4.3										
T4.4	Case study outreach	45%	1/10/21	31/12/23								D4.4				D4.5
T4.5	Knowledge Transfer	70%	1/7/22	31/12/23								D4.4				D4.5
T4.6	Publications and Conferences	90%	1/7/22	31/12/23								D4.4				D4.5
T4.7	Exploitation	100%	1/4/23	31/12/23												D4.6
WP5	**Management**															
T5.1	Project initiation	50%	1/1/21	30/6/21												
T5.2	Other management task (R = Reporting)	100%	1/1/21	31/12/23				R				R				R

Gantt chart:(MS=Milestone,D=Deliverable,R=Project Reporting,T=Task)

Communication activities

ROBHOOT has very general communication targets, from the general public to scientists, decision-makers and to the business community. ROBHOOT's dissemination measures focus on project results and stakeholder engagement through the following activities.

(I) **Write position papers and relevant conferences**: White papers will be produced showcasing the results receive feedback from stakeholders about implementations. Results will also be shown in relevant conferences where scientific, industry, NG and NGO entities meet.

(II) **Website**: A website to reach the general public through social media (Instagram, Twitter, Facebook, LinkedIn, Video-channels), press releases/TV/radio and a public git ROBHOOOT repository (ROBHOOT git repository), will be used for communicating results to all target audiences.

(III) **Hackathons**: we will organize joined activities with on-ongoing EU/International projects to attract multipliers and developers from the community who engage in data analytics and discovery computation. At the end of the project, we will organize a workshop specifically on *Next-generation evolutionary-biology AI-inspired solutions for global sustainability challenges*.

(IV) **Testnet**: ROBHOOT will launch a testnet to disseminate the results of discovery in federated networks. The launch will have invited NGOs and GO across disciplines and social, economical and technological sectors. The ROBHOOT Open Discovery Network will be launched as a Biodiversity and sustainability network. It will offer solutions for the sustainability of the Oceans and the integration of additional public databases and data collections into the open discovery network to facilitate NGOs, GOs and other organizations transparency and governance in ecosystem management. the last part of the sentence is confusing!!!

3 Implementation

3.1 Work plan, work packages and deliverables

The project consists of five work-packages (WP1-WP3: R&D, WP4: Dissemination and WP5: Management). WP1 deals with evolutionary semantic algorithms for data knowledge discovery, WP2 addresses eco-evolutionary diversification-inspired AI models to infer causal knowledge discovery with an implementation for the sustainability of the Oceans' sustainability case study, WP3 addresses evolutionary neural biology-inspired for knowledge discovery to provide cooperative forecasting in federated networks. WP3 also provides an empirical case implementation of cooperative forecasting for the sustainability of the Oceans. **Demonstrators**: The project will create three demonstrators of increasing complexity all containing full reproducibility, automation and visualization capabilities:
1. ROBHOOT v1.0 Software demonstrator with evolutionary semantic algorithms to decipher ontologies for the sustainability of the Oceans data knowledge discovery case study (MS1);
2. ROBHOOT v2.0 Software demonstrator with evolutionary diversification-inspired AI modeling for spatiotemporal causal pattern knowledge discovery (MS2);
3. ROBHOOT v3.0 Software demonstrator with evolutionary neural diversification-inspired modeling for discovery in federated networks (MS3).
The inference of causal mechanisms and the discovery of spatiotemporal patterns in federated networks is a generic problem found in e.g. many agents sharing resources, sustainability, eco-evolutionary networks, biodiversity maintenance, or social networks. Thus, the discovery computation of spatiotemporal patterns represents a ubiquitous computational problem in digital and natural ecosystems, where many evolving and heterogeneous agents and interactions share information to reach sustainability goals. In the demonstrators of ROBHOOT, we will consider different scenarios for each of the software implementations such that agents contain many evolving traits and interactions (MS1, MS2 and MS3). This allows, for example, finding patterns of trait and interaction changes to improve sustainability as a function of the observed empirical patterns in our Oceans' sustainability case study. In the course of the project, more complex context-dependent trait changes of agents and interactions together with different learning functions will be considered to explore how they affect sustainability properties in federated networks.

Table 3.1a: **List of work packages**

WP	Work package title	Lead No.	Lead Name	PMs	Start Month	End Month
1	Data knowledge discovery	2	CSIC	48	1	18
2	Causal knowledge discovery	4	TARTU	24	7	24
3	Discovery in federated networks	6	TU GRAZ	24	13	36
4	Dissemination	7	IEO	24	1	36
5	Management	1	EAWAG	31.2	1	36
			Total PMs	151.2		

Table 3.1b: **Work package description**

Work package number 1	Lead beneficiary CSIC				
Work package title	**Data knowledge discovery**				
Participant number	2	2	8	5	3
Short name of participant	EBD-CSIC	IFISC-CSIC	URV	EPFL	SCITE
Person month per participant	24	24	6	6	6
Start month	1				
End month	24				

Objectives
- To develop an evolutionary biology-inspired semantic framework for data discovery
- To derive semantic functionality rules required for data computation discovery
- To apply data discovery properties for the Oceans' sustainability case study

Description of work
Task T1.1: Evolutionary semantic algorithms (ESA) (M1-M18) *Leader:* ***EBD-CSIC***.
Contributors: 2

ESA will find classes and datatype properties from ontologies, and raw data from non-semantic databases. ESA will infer semantics on the raw data to link them to the ontological terms. We will translate the semantically-annotated databases to a $Neo4j$ graph database by mapping classes to nodes, object properties to links between nodes, and datatype properties to nodes' attributes. The graph database has an architecture flexible enough to get high scalability to accommodate many source data and to infer its properties using multilayer metrics (T1.2). T1.1 provides ESA to allow WP2 and WP3 to implement the models for causal knowledge discovery and discovery in federated networks.

Task T1.2: This task extends T1.1 into multilayer network metrics for general principles of data discovery (M1-M18) *Leader: **IFISC-CSIC**. Contributors: 2*

Multilayer network metrics for ESA will focus on data heterogeneity to explore how data configurations, privacy requirements, formats, dimensions, biases and spatiotemporal resolution affect data discovery properties [32–34].

Task T1.3: Based on the framework developed in T1.1 and T1.2, URV will derive automation procedures for data knowledge discovery (M15-M21) *Leader: **URV**. Contributors: 8*

Automation rules identify the ESA rules for data discovery [20]. URV will complement T1.1 and T1.2 to obtain posterior probabilities of evolutionary expressions that represent the empirical patterns of the data knowledge graph generated in T1.1 and T1.2.

Task T1.4: Reproducible data knowledge graphs (M15-M21) *Leader: **EPFL**. Contributors: 5*

In this task, the EPFL will integrate the work done in T1.1 and T1.2 into reproducible and replicable data knowledge graphs. T1.4 samples the data sources to obtain the robustness of data heterogeneity. Robustness will be analyzed working closely with IFISC-CSIC in T1.2.

Task T1.5: Visualize (M15-M21) *Leader: **SCITE**. Contributors: 3*

In this task the partner SCITE will apply visualization algorithms to the patterns obtained in T1.1 and T1.2. Data knowledge graphs will be represented in static (figures) and dynamic (animations) visualizations using cutting-edge graphic libraries like D3.js, LightGraphs.jl. All animations will be used by SCITE to strengthen the dissemination, communication and exploitation activities.

Task T1.6: All participants apply results from ESA and multilayer network metrics into a fully automated, reproducible and animated Oceans' sustainability case study (M15-M24) *Leader: **EBD-CSIC**. Contributors: 2,3,5,7,8*

ESA and multilayer network metrics will generate the sustainability of the Oceans data knowledge graph integrating many data sources. Fishery data (i.e., global fishing watch), species interactions data, environmental data and social and stakeholders groups data with different interests within each country, etc, will be merged into the sustainability of the Oceans database started in 1965 containing around 9 million entries, 1612 species, 20 countries and 11 sampling methods (Figure 2).

Deliverables

D1.1 Semantic evolving software for data discovery **(M18)**
D1.2 Report on definitions of multilayer network metrics applied to data discovery **(M18)**
D1.3 Automated demonstrator of evolutionary semantic rules for data discovery **(M21)**
D1.4 Reproducible demonstrator of evolutionary semantic rules for data discovery **(M21)**
D1.5 Visualization demonstrator of evolutionary semantic rules for data discovery **(M21)**
D1.6 Demonstrator all parts for the Oceans' sustainability case study **(M24)**

Work package number	2	Lead beneficiary	TARTU		
Work package title	**Causal knowledge discovery**				
Participant number	1	4	5	8	3
Short name of participant	EAWAG	TARTU	EPFL	URV	SCITE
Person month per participant	24	24	6	6	6
Start month	7				
End month	30				

Objectives

- To develop an evolutionary-diversification AI-inspired framework for causal discovery
- To derive functionality rules required for causality-based computation discovery
- To apply diversification rules to mimic the empirical patterns for the Oceans' sustainability case study

Description of work

Task T2.1: Develop EEDA algorithms (M7-M24) *Leader:* ***EAWAG****. Contributors: 1*

T2.1 provides process-based algorithms with diversifying traits and interactions for species, human groups and technologies to allow WP2 to implement this feature in causal knowledge discovery. Causal modeling is particularly relevant in Earth, Ecosystem and Sustainability science where rapid progress of AI in explainable technology [7, 20, 35, 36] will increase our ability to make stronger inferences about future sustainability challenges and solutions [37]. EEDA solutions will be required to explore a broad range of sustainability scenarios, particularly relevant to find diversification rates in species, technologies and human strategies that best represent the empirical observations for the sustainability of the Oceans data knowledge discovery generated in WP1.

Task T2.2: This task extends T2.1 into EEDA deep learning networks metrics for general principles of causal discovery (M7-M24) *Leader:* ***TARTU****. Contributors: 4*

Using as input the knowledge graphs extracted from WP1, the goal of this task is to use deep learning technology to infer sustainability paths. In particular, this task will train graph neural networks (specifically designed to handle network data) to predict the effects of the complex interactions between species, human groups and exploitation technology. Simulations and the Ocean case will be first studied and calibrated. Once the deep learning model is trained, causal perturbations on the inputs and biases towards sparse models will be implemented to give an explainable account for the key causal interactions. Finally, the model will be optimized with respect to human interventions to aim the ecological system under study towards plausible sustainability paths. VME: the last part is confusing!!!

Task T2.3: Based on the framework developed in T2.1 and T2.2, URV will derive automation rules for causal discovery (M21-M27) *Leader:* ***URV****. Contributors: 8*

URV will complement T2.1 and T2.2 to obtain scenarios of EEDA that represent the causal knowledge discovery graphs that best represent the empirical patterns. URV will work together with T2.1 and T2.2 to address the fit-complexity trade-off and to obtain the posterior probabilities for the rules and expressions generated with the EEDA.

Task T2.4: Causal reproducible knowledge graphs (M15-M21) *Leader:* ***EPFL****. Contributors: 5*

In this task, EPFL will integrate the work done in T2.1 and T2.2 into reproducible and replicable causal knowledge graphs. T2.4 samples the causal graphs to obtain the robustness of the inference. Robustness will be analyzed working closely with the URV partner in T2.3.

Task T2.5: In this task, SCITE will apply visualization algorithms to T2.1 and T2.2 (M21-M27) *Leader:* ***SCITE****. Contributors: 3*

Spatial and network patterns will be represented in static (figures) and dynamic (animations) visualizations using cutting-edge graphic libraries like $D3.js$, $Vega.jl$, $NetworkD3.js$, Leaflets, and $ggplot2$. Animations will represent the EEDA and deep learning network patterns. Storytelling techniques will be applied in order to effectively communicate those findings.

Task T2.6: All participants apply results from EEDA and deep learning networks into a fully automated, reproducible and animated Oceans' sustainability case study (M21-M30) *Leader:* ***EAWAG****. Contributors: 1,3,4,5,7,8*

EEDA and deep learning networks will generate the sustainability of the Oceans causal knowledge graph (Figure 2).

Deliverables

D2.1 Report on definitions of EEDA rules for causal discovery **(M18)**
D2.2 Report on definitions of EEDA deep learning networks applied to causal computation discovery **(M18)**
D2.3 Automated demonstrator of EEDA rules for causal discovery **(M21)**
D2.4 Reproducible demonstrator of EEDA AI rules for causal discovery **(M21)**
D2.5 Visualization demonstrator of EEDA for causal discovery **(M21)**
D2.6 Demonstrator all parts for the sustainability of the Oceans' **(M24)**

Work package number	**3**	**Lead beneficiary**	**TU GRAZ**		
Work package title	**Discovery in federated networks**				
Participant number	9	6	5	8	3
Short name of participant	SRC	TU GRAZ	EPFL	URV	SCITE
Person month per participant	24	24	12	12	11
Start month	13				
End month	36				

Objectives

- To develop an evolutionary-diversification inspired framework for discovery in federated networks.
- To derive diversification rules required for computation discovery in federated networks.
- To apply rules to discover novel paths for Oceans' sustainability.

Description of work

Task T3.1: Extend EEDA for discovery in federated networks (M13-M36) *Leader: **SRC**. Contributors: 9*

This task extends EEDA in T2.1 for general principles of discovery in federated networks. T3.1 provides process-based models with diversifying traits and interactions along node heterogeneity gradients. Federated networks are represented as interacting species, human groups and technologies containing heterogeneity gradients and multidimensional properties. Mean-field deterministic models will be developed and contrasted to the stochastic counterparts (T3.2). These features will allow WP3 to implement diversification rules when heterogeneous groups interact and share resources in ecosystems. Extensions of EEDA solutions are required to discover novel diversification rates in species, technologies and human strategies that improve sustainability paths in comparison to the observed empirical patterns in our case study.

Task T3.2: Develop ENDI in federated networks (M13-M36) *Leader: **TU GRAZ**. Contributors: 6*

T3.2 provides computation algorithms for neural diversification-inspired processes to allow WP3 to implement this feature for discovery in federated networks. Neurons will be represented as algorithms along heterogeneity and/or complexity gradients. Links represent cooperation, learning or competition. A federated neural network is composed of types of neurons: Species, human groups and technology all containing heterogeneity along many dimensional traits. The goal is to discover new rules representing high sustainability values defined broadly as a high degree of coexistence among many species, diversified technologies and human groups. The dynamics of interacting neurons will be essentially stochastic. The following are the rules governing the dynamics: we start with a population of algorithms extended in a landscape and fitness functions determine birth and deaths of algorithms. We will consider stochastic spiking neurons within nodes to compute how information processing evolves in the network. We will consider a variety of scenarios from strong selection to neutral federated networks to explore sustainability paths. Which scenario provides higher sustainability-efficiency information processing in federated networks? T3.2 and T3.1 will interact to strengthen deterministic and stochastic solutions for EEDA and ENDI implementations in federated networks.

Task T3.3: Based on the framework developed in T3.1 and T3.2, URV will derive automation rules for knowledge discovery (M25-M36) *Leader: **URV**. Contributors: 8*

URV will complement T3.1 and T3.2 to obtain the scenarios of ENDI that represent the knowledge discovery paths for sustainability trajectories not observed in the empirical patterns of the sustainability of the Oceans case study. URV will work together with T3.1 and T3.2 to automate and discover expressions and rules generated by ENDI.

Task T3.4: Reproducible discovery knowledge graphs (M25-M36) *Leader: **EPFL**. Contributors: 5*

In this task, EPFL will integrate the work done in T3.1 and T3.2 into reproducible and replicable discovery knowledge graphs. T3.4 samples the discovery paths to obtain the robustness of these roads to sustainability. Robustness will be analyzed working closely with the URV partner in T3.3.

Task T3.5: In this task, SCITE will apply visualization algorithms to T3.1 and T3.2 (M25-M36) *Leader: **SCITE**. Contributors: 3*

Spatial and network patterns will be represented in static (figures) and dynamic (animations) visualizations using cutting-edge graphic libraries like *D3.js*, *Vega.jl*, *NetworkD3.js*, Leaflets, and *ggplot*2. Animations will represent the ENDI and the extension of EEDA to federated networks. Storytelling techniques will be applied in order to effectively communicate those findings.

Task T3.6: All participants apply results from extended EEDA and ENDI into a fully automated, reproducible and animated Oceans' sustainability case study (M21-M36) *Leader: **TU GRAZ**. Contributors: 3,5,6,7,8,9*

Extended EEDA and ENDI will generate the sustainability of the Oceans discovery knowledge.

Deliverables

D3.1 Demonstrator on EEDA for discovery in federated networks **(M36)**
D3.2 Demonstrator on ENDI for discovery in federated networks **(M36)**
D3.3 Automated demonstrator of ENDI for discovery in federated networks **(M36)**
D3.4 Reproducible demonstrator of ENDI for discovery in federated networks **(M36)**

D3.5	Visualization demonstrator of ENDI for discovery in federated networks **(M36)**
D3.6	Demonstrator ENDI from all parts for the Oceans' sustainability federated network case study **(M36)**

Work package number	**4**	**Lead beneficiary**	**IEO**
Work package title	**Dissemination, Knowledge Transfer and Outreach**		
Participant number	7	3	
Short name of participant	IEO	SCITE	
Person month per participant	24	15	
Start month	1		
End month	36		

Objectives

- Ensure effective external communication, dissemination and optimal knowledge transfer of ROBHOOT results

Description of work

Task T4.1: *Dissemination and Exploitation Plan (DEP)* (M1-M36) *Leader:* ***IEO***. *Contributors: 3,7*

A DEP will be put in place immediately upon project commencement. Yearly, the plan will be evaluated for effectiveness and adjusted if needed.

Task T4.2: Branding and communication guidelines (M1-M3) *Leader:* ***SCITE***. *Contributors: 3,7*

Create a visual project identity with a logo and templates for presentations, posters, and deliverable documents. Brochures introducing the project aims and expected results will also be produced.VME: do you mean project and aims and results, OR project aims and results???

Task T4.3: Website and social media (M1-M36) *Leader:* ***SCITE***. *Contributors: 3, 7*

A dedicated website and a public git ROBHOOOT repository, (https://github.com/RobhooX/Robhoot), will be used for communicating results and sharing updated versions with all target audiences. Social media accounts will be created and posts will be used to raise attention to project activities and achievements, adapted to the audience.

Task T4.4: Sustainability of the Oceans (M11-M36) *Leader:* ***IEO***. *Contributors: 3, 7*

Ocean research has been proven to capture the imagination of the public. We will work with researchers to communicate outreach activities to ensure engagement with European Citizens. Effective dissemination to the general public will also be achieved through press releases announcing project start and key milestones to provide a public media dimension.

Task T4.5: Knowledge Transfer (M18-M36) *Leader:* ***SCITE***. *Contributors: 3, 7*

Hackathon events, coinciding with the three milestones (Robhoot v1.0, Robhoot v2.0 and Robhoot v3.0), are planned to attract multipliers and developers. We will organize a workshop specifically on "Next-generation evolutionary-biology AI-inspired solutions for global sustainability challenges" for disseminating our results to a broad set of groups and experts in fields related to global sustainability for assessing future exploitation potential, inviting partners from academia as well as industry. Trade media articles targeting companies and end-users will also be published in artificial intelligence magazines, as well as in magazines focused on ocean sciences and sustainability. Once the final prototype is developed, it will be presented in trade shows, such as Web Summit, World Ocean Summit, among others.

Task T4.6: Publications and Conferences (M18-M36) *Leader:* ***IEO***. *Contributors: All*

Around 6 to 8 high-impact scientific publications are expected, as well as the organization of special sessions in international scientific and technological meetings. To raise awareness about this topic for young generations, an article will also be published in "Frontiers for Young Minds".

Task T4.7: Exploitation (M28-M36) *Leader:* ***SCITE***. *Contributors: 3, 7*

We will identify all target groups and key players of the value chain. An Exploitation Plan will be developed and maintained to ensure prompt utilization of project results by relevant stakeholders. This will include (i) SWOT analysis; (ii) definition of business models and plans (based on the lean business canvas); and (iii) efficient IP management to facilitate rapid exploitation. Key stakeholders from all levels of society will be identified as potential beneficiaries of the project outcomes and engaged at an early project stage.

Deliverables

D4.1	Dissemination and Exploitation Plan **(M3)**
D4.2	Brand book, templates and brochures **(M3)**
D4.3	Launch website **(M5)**
D4.4	Progress Report on Dissemination, Knowledge Transfer and Outreach **(M24)**
D4.5	Final Report on Dissemination, Knowledge Transfer and Outreach **(M36)**
D4.6	Business plan **(M36)**

Work package number	5	Lead beneficiary	EAWAG
Work package title	**Management**		
Participant number	1	3	
Short name of participant	EAWAG	SCITE	
Person month per participant	7.2	3	
Start month	1		
End month	36		

Objectives

- Management deliverables of the project during the contractual period.
- Administrative and financial management of the project.
- Ensure the delivery of the project on time and on budget.
- Coordinate the technological and scientific orientation of the project with the scientific and communication advisory teams.
- Secure the quality of the work and of the delivered documents and software

Description of work

Task T5.1: Project initiation (M1-M6) *Leader:* ***EAWAG****. Contributors: 1,3*

Initiation of the project involving a kick-off meeting, definition of the details of the early work (details that go beyond the aspects written here). Planning the early deliverables.

Task T5.2: Coordination and organization of deliverables and communication (M1-M36) *Leader:* ***EAWAG****. Contributors: 1,3*

EAWAG is responsible for the overall coordination, administration and organization of the management structure and will deploy the organizational structure and procedures to ensure the smooth and efficient operation of the project from both the strategic and tactical perspectives.

Task T5.3: Project management (M1-M36) *Leader:* ***EAWAG****. Contributors: 1,3*

To ensure working efficiency, there will be day-to-day operational project management of the project's work overseen by the Project Manager. The Project Manager is overall responsible for the success and smooth running of the project.

Task T5.4: Work package management (M1-M36) *Leader:* ***EAWAG****. Contributors: 1,3*

Coordination and organization of the work package management. The work itself is part of the individual work packages. The main players in this are WP Leaders and WP teams.

Task T5.5: Risk management (M1-M36) *Leader:* ***EAWAG****. Contributors: 1,3*

Management of all risks and issues which are identified in the project. All project participants and external advisors will be responsible for raising any risk or issue they perceive. As the consortium is small, risks can and will be immediately addressed via discussions of the partners.

Task T5.6: Project reporting (M1-M36) *Leader:* ***EAWAG****. Contributors: 1,3*

EAWAG AND IFISC-CSIC will be responsible for producing the formal project reporting documents including the yearly progress reports and the final project report.

Table 3.1c: Deliverable list

Table 3.1b: Deliverable list

Deliverable number	Deliverable name	WP no.	Lead participant name	Nature	Dissemination Level	Delivery date (proj. month)
D4.1	Dissemination and Exploitation Plan	WP4	IEO	R	PU	3
D4.2	Brand book, templates and brochures	WP4	SCITE	O	PU	3
D4.3	Launch website	WP4	SCITE	O	PU	5
D1.1	Semantic evolving software for data discovery	WP1	EBD-CSIC	R	PU	18
D1.2	Report on definitions of multilayer network metrics applied to data discovery	WP1	IFICS-CSIC	R	PU	18
D2.1	Report on definitions of EEDA rules for causal discovery	WP2	EAWAG	R	PU	18
D2.2	Report on definitions of EEDA deep learning networks applied to causal computation discovery	WP2	TARTU	R	PU	18

Continued on next page

D1.3	Automated demonstrator of evolutionary semantic rules for data discovery	WP1	URV	D	PU	21
D1.4	Reproducible demonstrator of evolutionary semantic rules for data discovery	WP1	EPFL	R	PU	21
D1.5	Visualization demonstrator of evolutionary semantic rules for data discovery	WP1	SME	R	PU	21
D2.3	Automated demonstrator of EEDA rules for causal discovery	WP2	URV	D	PU	21
D2.4	Reproducible demonstrator of EEDA AI rules for causal discovery	WP2	EPFL	R	PU	21
D2.5	Visualization demonstrator of EEDA for causal discovery	WP2	SCITE	R	PU	21
D1.6	Demonstrator all parts for the Oceans' sustainability case study	WP1	EBD-CSIC	R	PU	24
D2.6	Demonstrator all parts for the sustainability of the Oceans'	WP2	EAWAG	R	PU	24
D4.4	Progress Report on Dissemination, Knowledge Transfer and Outreach	WP4	IEO	R	PU	24
D3.1	Demonstrator on EEDA for discovery in federated networks	WP3	SRC	D	PU	36
D3.2	Demonstrator on ENDI for discovery in federated networks	WP3	TU GRAZ	D	PU	36
D3.3	Automated demonstrator of ENDI for discovery in federated networks	WP3	URV	D	PU	36
D3.4	Reproducible demonstrator of ENDI for discovery in federated networks	WP3	EPFL	D	PU	36
D3.5	Visualization demonstrator of ENDI for discovery in federated networks	WP3	SCITE	D	PU	36
D3.6	Demonstrator ENDI from all parts for the Oceans' sustainability federated network case study	WP3	TU GRAZ	D	PU	36
D4.5	Final Report on Dissemination, Knowledge Transfer and Outreach	WP4	IEO	R	PU	36
D4.6	Business plan	WP4	SCITE	R	PU	36

3.2 Management structure, milestones and procedures

Management procedures and structure:

ROBHOOT is organized by the Project Manager, with a Steering Board (SB), an external Scientific Advisory Committee (SAC), and a Dissemination and Exploitation Board (DEB). The SB, which will consist of one representative from each partner and the Project Manager, will meet at least once a year. The SB will have the overall responsibility for the technical, financial, administrative, legal, and risk analysis. The SB will also have responsibility together with the DEB for all the dissemination and outreach of the project. The SAC, headed by the coordinator, will consist of senior experts in the respective fields. Prof. M Mercedes Pascual (female), USA (expert in theoretical ecology), Prof. Elisa Thebault (female), France (expert in theoretical ecology and ecological networks) Prof. Catherine Graham (female), Switzerland (expert in biogeography and ecological networks) and Prof. Benoit Baundry, Sweden (expert in software development) have agreed to be members of the SAC. VME please check these figures: 11 people $\neq 8 + 5$; and 5/13 is 38% There are 11 people named for this project. There are 8 men and 5 women (including SAC members). With 36% of the fraction females is above the range being usual in the technical fields. The goal of ROBHOOT is to help younger non-PI and PI females to develop a research career in academia or industry (see section four for Gender balance statement for each institution involved). ROBHOOT includes four out of nine first time participants to FET under Horizon 2020, two young researchers and one SME: SCITE is the SME with all the team memebers in the category of young researchers, and the other three are IEO, EAWAG, and SRC, with a substantial contribution to the development of ROBHOOT.

Management activities:

The project coordinator (CJ Melian, EAWAG) will coordinate the work and its scientific input, communicate with EC, and organize the project reviews with the EC. The Project Manager (To be named) will work on administrative, financial and dissemination activities, and risk management. IPR set-up will be regulated by a Consortium Agreement. WP leaders will be responsible for WP planning, scientific and WP activities. WP groups will meet for the specific needs of each WP.

Methods for monitoring and reporting progress:

Meeting and reporting schedule is planned as follows: Every 3 months (oral and video-conferences) WP leaders report to the coordinator. Every 6 months the coordinator summarizes overall status to the SB. Every 6 to 12 months the coordinator setups SB meetings to review the progress of the project and to critically review the outlook for effective communication and deliverables. At months 12, 24 and 36 the SB prepares consolidated management and annual activity reports and also the coordinator and the Project Manager setup SAC meetings to obtain advice and feedback.

3.3 Consortium as a whole

Core Expertise: The ROBHOOT consortium has been designed to represent the four central project requirements and is, thus, composed of groups with long-standing track records in: (1) IFICS-EBD-CSIC: Data-driven modeling expertise of evolutionary processes including adaptation and coevolution and complex networks; (2) EAWAG and TARTU: Theoretical and numerical expertise in eco-evolutionary dynamics and deep learning networks; (3) SRC and TU GRAZ: Theoretical and numerical expertise in eco-evolutionary dynamics of communities and neural networks including synaptic plasticity, heterogeneity and diversification, and (4) SCITE and IEO: Expertise in data collection for the Oceans' sustainability case study and communication strategy for large and complex projects.

Cross-Expertise: IFISC- and EBD-CSIC partners have worked extensively in the last years on big data and complex spatiotemporal metrics, as well as in co-evolutionary processes shaping resource-consumer interaction networks allowing linking WP1 with WP2. Partners EAWAG and TARTU complement each other in the development of network approaches. They will build eco-evolutionary process-based deep learning networks for causal knowledge discovery allowing linking WP2 with WP3. Partners EBD-CSIC, IFISC-CSIC, EAWAG, TARTU, SRC, and TU GRAZ are all familiar with abstract models allowing linking WP1 with WP2 and WP3. **Table 3.2a: List of milestones**

Milestone number	Milestone name	WP	Due data (months)	Verification
MS1	Data knowledge discovery	WP1	28	OS-Soft, Paper/Conf., website
MS2	Causal knowledge discovery	WP2	30	OS-Soft, Paper/Conf., website
MS3	Discovery in federated networks	WP3	36	OS-Sof, Paper/Conf., website

Table 3.2b: Critical risks for implementation		
Description of risk	**WP**	**Proposed risk-mitigation measures**
Unforeseen changes in cross-expertise synchronization	WP5	Requirements to coordinate in time end-to-start tasks across WPs in an efficient manner
Dissemination message is not under- standable by the targeted audience	WP4	The consortium as a whole will agree on the main message to transmit to the targeted audience and, for this, elaborate the appropriated material
Unforeseen changes in the WPs	WP5	Requirements to provide short monthly reports to the coordinator to allow spotting looming changes soon

3.4 Resources to be committed

Total Budget: The ROBHOOT project runs over 36 months. The total budget amounts to 2380960€, which is the same as the requested EU contribution. Direct personnel costs are 1721059€ and indirect costs 476192€. The budget is well-balanced among partners according to their roles in the project and provides sufficient resources to complete all tasks. Direct cost attributed to staff is 73%. This project is open-source software-heavy, as three full open-source software will be built, which is well connected to the dissemination part from our communication partner SCITE with about 10% of the total cost. Other major cost items of Other Cost cover travel and workshops (7% of the total cost, mostly for technical meetings and integration/evaluation stages).

Table 3.4a: Summary of staff effort	**WP1**	**WP2**	**WP3**	**WP4**	**WP5**	**Total PM**
1, EAWAG	0	**24**	0	0	7.2	**31.2**
2, CSIC	**48**	0	0	0	0	**48**
3, SCITE	6	6	11	**15**	3	**41**
4, TARTU	0	**24**	0	0	0	**24**
5, EPFL	6	6	**12**	0	0	**24**
6, TU GRAZ	0	0	**24**	0	0	**24**
7, IEO	0	0	0	**24**	0	**24**
8, URV	6	6	**12**	0	0	**24**
9, SRC	0	0	**24**	0	0	**24**
Total PM (WP)	**66**	**66**	**83**	**39**	**10.2**	**264.2**

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4 Members of the consortium

4.1 Participants (applicants)

1, EAWAG

Dr. Carlos J. Melian will work for EAWAG in ROBHOOT.
Carlos J Melian takes the official coordinator lead of the ROBHOOT project and takes care of the management.

The Swiss Federal Institute for Aquatic Science and Technology (EAWAG) is an independent research institute within the Swiss Federal Institute of Technology (ETH) domain. As such it is an independent partner in a network of exceptionally strong research and education institutions (2 federal universities and 4 federal research institutes). EAWAG is a world-leading water research institute. EAWAG hosts over 300 research fellows, postdocs and PhD students, who are supported by technical and support staff.

Contributions to ROBHOOT

EAWAG is the coordinator of the project. EAWAG contributes to WP2 and WP5 for eco-evolutionary diversification modeling (EEDA) and management, respectively. EAWAG has a wide experience in theoretical ecology and computational biology with particular attention to diversification processes in ecosystems. In WP2, EAWAG will lead the development of a theoretical model linking diversifying traits and interactions for species, human groups and technologies to allow WP2 to implement this feature in causal knowledge discovery. On the other hand, in WP5, EAWAG will be responsible for the management and work process of the project.

Dr. Carlos Melián (male) is a tenured researcher in Theoretical Evolutionary Ecology at EAWAG and associate professor at the University of Bern. Dr. Melián is widely recognized as an expert in Eco-evolutionary networks where he has contributed with novel approaches combining stochastic modeling and empirical patterns to study the interaction between ecological and evolutionary dynamics in multispecies assemblages. Dr. Melian has made important contributions to the fields of Ecological Networks. Most of his contributions combine stochastic modeling, large empirical datasets, and Bayesian approximations, to quantify the impact of intra- and inter-specific trait variation on species interactions, divergence and the macroscopic properties of ecological networks. He has been Principal Investigator in 15 projects obtained in 5 different countries (Spain, USA, UK, Germany and Switzerland) with a total of approx. 1 Million Euro. He has successfully co-supervised 5 PhD students and supervised 7 postdocs. The feasibility of this proposal is firmly established by his track record further reinforced by his solid and active international network of collaborators. Among others, he works with Prof. S. Allesina (U Chicago, USA), Dr. A. Eklöf (Linköping U, Sweden), Prof. P. Guimares (U Sao Paulo, Brazil), Prof. M. O'Connor (U Vancouver, Canada), and Dr. F. De Laender (U Namur, Belgium). Currently he coordinates a project about coevolving traits in species-rich ecosystems to investigate how feedbacks between interacting traits control the functioning of aquatic ecosystems. This provides a direct link to the work planned in ROBHOOT.

Gender balance

Dr. Melián's Lab has currently three female scientists. Dr. Catalina Chaparro (Colombia), is a postdoctoral researcher working in theoretical ecology. She has been recently funded by the Marie Curie EU grants. Dr. Chaparro is currently working on modeling the eco-evolutionary interactions between overfishing and trait evolution to explore coexistence mechanisms in complex ecological systems. Dr. Cecilia Andreazzi (Brazil) is a postdoctoral researcher working in theoretical ecology with a strong background in evolutionary processes. She is working on how trait coevolution between predators and preys control the functioning of aquatic ecosystems mostly to avoid or decrease the frequency and intensity of algal blooms. Dr. Malena Sabatino (Argentina) is a scientist working in mutualistic networks with a strong component in field studies of plant-pollinator networks. Dr. Sabatino currently explores eco-evolutionary dynamics models of mutualistic networks and specifically the effect of intraspecific interaction and migration trait variation on the coexistence of rare and common plants and pollinators along spatial gradients. Dr. Chaparro, Dr. Andreazzi and Dr. Sabatino will contribute to the development of ROBHOOT with their expertise in eco-evolutionary dynamics in ecosystems.

List of publications

1. Melián C. J., et al. 2018. Deciphering the interdependence between ecological and evolutionary networks. **Trends in Ecology & Evolution** 33,7: 504-512.
2. Andreazzi C., Guimaraes P, Melián C. J. 2018. Eco-evolutionary feedbacks promote fluctuating selection and long-term stability of antagonistic networks. **Proc. R. Soc. B** 285: 20172596.
3. Melián C. J., Seehausen O, Eguiluz V, Fortuna M, Deiner K. 2015. Diversification and Biodiversity Dynamics of Hot and Cold Spots. **Ecography** 38, 393-401.
4. Melián C. J., et al. 2015. Dispersal dynamics in food webs. **American Naturalist** 185, 2: 157-168.
5. Melián C. J., et al. 2014. Individual trait variation and diversity in food webs. **Advances in Ecological Research**. Vol. 50. Academic Press, 207-241.

List of relevant projects

1. 2020 Melián, C. J. (PI) and Ferrão Filho, Aloysio S. Granted: Brazilian-Swiss Joint Research Programme SNSF, Title: Feedbacks between coevolving predator-prey interactions and the functioning of aquatic ecosystems. SFr 228k
2. 2018 Melián, C. J. (PI), Andreazzi, C., and Astegiano, J. Swiss National Science Foundation, Scientific exchange program, Title: Biodiversity Dynamics in Coevolutionary Metaecosystems. SFr 20k
3. 2015 Melián, C. J. (PI) Granted: Swiss National Science Foundation, Division III. Switzerland. Title: A theory for next-generation food web data. SFr 200k.
4. 2012 Melián, C. J. (PI), Klecka, J., Krivan, V., and Altermatt, F. Granted: Sciex, Switzerland. Title: Food webs in space: integrating metacommunity and food web research. SFr 93k.
5. 2012 Pomati, F., and Melián, C. J. (Co-PI). Granted: Swiss National Science Foundation, Division III. Switzerland. Title: An individual-level approach to disentangle niches, drift and dispersal in phytoplankton metacommunity dynamics. SFr 243k

Infrastructure relevant to the proposed work

EAWAG in Kastanienbaum Lucerne offers excellent office, meeting rooms, laboratory and testing facilities in modern, state-of-the-art buildings. EAWAG provides access to first-class research facilities that regularly offer training for the use of equipment, tools and software. Of particular relevance for this research project is the access to two computing clusters "Leonhard" and "Euler" with more than 50 000 processor cores available for scientific computations, and training for their use offered by ETH Zürich.

2, CSIC

The Spanish National Research Council (CSIC) is Spain's largest public research institution and ranks third among Europe's largest research organizations. Attached to the Spanish Ministry of Science and Innovation, the CSIC plays a key role in scientific and technological policy in Spain and worldwide. According to its Statute (Article 4), it has 4 main missions:

- to foster multidisciplinary scientific and technological research,
- knowledge transfer to industry and society,

- education and training of scientific and technical staff,
- creation of Technology-Based Companies (spin-offs).

The CSIC has more than 10 000 employees, including nearly 4 000 staff researchers. Currently, it has 120 institutes spread across the country, of which 67 of them are fully-owned institutes and 53 are Joint Research Units in partnership with other Spanish universities or research institutions. The CSIC supports research and training across a wide range of knowledge, from the most basic or fundamental aspects of science to the most complex technological developments; from human and social sciences to food science and technology, including biology, biomedicine, physics, chemistry and materials, natural resources and agricultural sciences. It carries out research in all fields of knowledge, distributed in three global areas: Life, Society and Materia. The CSIC produces 20% of the national scientific output (over 10 000 publications in high impact international journals in 2017) and remains the first institution in Spain in the generation of patents, with around 200 patent applications in 2017. The Vice-presidency for Technology Transfer assists the CSIC's researchers with patent evaluation and application processes, commercialization of the CSIC's technology offer and with the creation of start-ups. As of December 2019, the CSIC has obtained 643 projects in H2020, with a total EU financial contribution of 270 million euros and is listed as the 1st organization in Spain and the 4th participant by number of projects (E-CORDA).

Contributions to ROBHOOT

Miguel Fortuna and Victor Eguiluz work for CSIC in ROBHOOT. CSIC contributes to WP1 with evolving semantic algorithms (Miguel Fortuna, ESA) and multilayer network metrics (Victor Eguiluz) to decipher processes and patterns in the data knowledge discovery graphs. CSIC team has a wide experience in theoretical evolutionary ecology, computational biology and complex systems with particular attention to data-driven patterns in networks. In WP1, CSIC will lead the development of evolving semantic algorithms to translate the semantically annotated database to graph database to produce data knowledge discovery graphs.

Gender balance

Currently, VME is supervising a female PhD student, is responsible of a female junior postdoc and a male senior postdoc. Including the PI, the lab is gender balanced. The aim of the group is to keep a gender balance by attracting the application of female researchers and offering flexibility to specific needs. The good ratio of female/male researchers, in a field where the ratio is very unbalanced, is an incentive to attract more women. Besides balance, our group hosts a female student from Iran, where she faces great issues to develop her research career and we are taking all the efforts to facilitate her a career in complex systems science.

EBD-CSIC

Dr. Miguel A. Fortuna (male) is an ecologist and evolutionary biologist turned network scientist who thinks differently about problem-solving. He conducts interdisciplinary research by combining mathematical models, computer simulations, and database analysis, to answer questions that go beyond the traditional boundaries among disciplines, merging ecology with evolution, sociology, genetics, software design, and artificial life. His current research line builds on his previous research and is among the few trying to understand how evolution in complex networks of interactions can help us control human diseases. This research line combines, with a solid methodology, community ecology and evolutionary biology in a new fresh way. It has implications in at least three burgeoning fields of biotechnological and biomedical research: 1) cancer research (i.e., recent advances have shown that tumours—like species striving for survival—harbor intricate population dynamics, which suggests the possibility to exploit the ecology of tumours for treatment), 2) phage therapy (i.e., recent findings are showing the success of using phage cocktails to fight antibiotic resistance), and 3) human microbiome (i.e., the manipulation of evolving interactions among bacteria to restore unbalanced human microbial ecosystems).

List of publications

1. Fortuna et al. (2019). Coevolutionary dynamics shape the structure of bacteria-phage infection networks. Evolution, 73:1001-1011.

   This is the first time that the influence of coevolutionary dynamics (i.e., arms race dynamics versus fluctuating selection) on the architecture of an ecological network is quantified in an experimental host-parasite system. This study is the starting point towards integrating coevolution into ecological network approaches.

2. Fortuna et al.(2017). Non-adaptive origins of evolutionary innovations increase network complexity in interacting digital organisms. Philosophical Transactions of the Royal Society B., 372:20160431.

   This was the first study on webs of self-replicating and coevolving computer programs (i.e., digital organisms) aimed at disentangling the ecological and evolutionary mechanisms shaping species interaction networks. I found that host resistance traits arising as exaptations increase the complexity of host-parasite networks.

3. Fortuna et al. (2010). Nestedness versus modularity in ecological networks: two sides of the same coin? Journal of Animal Ecology, 79:811-817.

   This paper was published at a time when researchers thought that the two most pervasive structural properties of species interaction networks, nestedness and modularity, were opposed to each other. I showed that only when the complexity of the network is large enough, network structure can be either modular or nested.

4. Fortuna et al. (2009). Networks of spatial genetic variation across species. Proceedings of the National Academy of Sciences, USA, 106:19044-19049.

   In this paper I explored the consequences of habitat fragmentation for the maintenance of genetic variation. It was the first time that the structure of genetic variation across different species inhabiting the same landscape was compared, opening new research paths in landscape genetics.

5. Fortuna Bascompte. (2006). Habitat loss and the structure of plant-animal mutualistic networks. Ecology Letters, 9:281-286.

   I developed here the first spatially-implicit model to describe the dynamics of mutualistic metacommunities interacting in realistic ways. This study paved the way toward studying the biogeography of species interactions.

List of relevant projects

1. Name of the project: An eco-evolutionary network of biotic interactions. Entity where project took place: Scientific Research Network (WOG) City of entity: Brussels, Belgium Name principal investigator (PI, Co-PI....): Dries Bonte; Luc Brendonck; Erik Matthysen; Hans Jacquemyn; Filip Volckaert; Lander Baeten; An Martel; Frederik Hendrickx; Ellen Decaestecker; Frederik De Laender; Nicolas Schtickzelle; David G. Angeler; Florian Altermatt; Rampal S. Etienne; Rosemary Gillespie; Mark Urban; Erik Svensson; Mathew A. Leibold; Joel White; Alison Duncan; Miguel A. Fortuna; Kerstin Johannesson; Steven Declerck; Michael Begon; Justin Travis. N° of researchers: 25 Funding entity or bodies: Research Foundation Flanders (FWO) Start-End date: 01/01/2016 - 31/12/2020 Total amount: 62.500

2. Name of the project: Dinámica espacio-temporal de redes de flujo génico: unidades de conservación y propagación de enfermedades de anfibios (RNM-8147) Entity where project took place: Estación Biológica de Doñana (EBD-CSIC) City of entity: Seville, Spain Name principal investigator (PI, Co-PI....): Jordi Bascompte; Andrew P. Dobson; Miguel A. Fortuna; Jaime Bosch N° of researchers:4 Funding entity or bodies: Proyecto de Investigación de Excelencia, Junta de Andalucia Start-End date: 01/02/2013 - 31/01/2016 Total amount: 134.242

3. Name of the project: Síntesis Ecológica — Postdoctoral Fellowship JAE-Doc (JAEDOC025) Entity where project took place: Estación Biológica de Doñana (EBD-CSIC) City of entity: Seville, Spain Name principal investigator (PI, Co-PI....): Jordi Bascompte; Miguel A. Fortuna Nº of researchers: 2 Funding entity or bodies: Ministry of Economy and Competitiveness European Social Fund Start-End date: 01/09/2012 - 31/08/2015 Total amount: 82.620,72

4. Name of the project: Unifying ecological and evolutionary networks — Marie Curie International Outgoing Fellowship (IOF) Entity where project took place: Princeton University (USA) City of entity: Princeton, New Jersey, United States of America Name principal investigator (PI, Co-PI....): Miguel A. Fortuna; Simon Levin; Jordi Bascompte Nº of researchers: 3 Funding entity or bodies: European Community (International Outgoing Fellowship (IOF) Type of entity: 7th European Community Framework Programme Start-End date: 01/05/2009 - 30/04/2012 Total amount: 225.036,19

5. Name of the project: Integrando redes espaciales y genética de poblaciones: conservación de dos especies de anfibios autóctonas de Andalucia (RNM-02928) Entity where project took place: Estación Biológica de Doñana (EBD-CSIC) City of entity: Seville, Spain Name principal investigator (PI, Co-PI....): Jordi Bascompte; José A. Godoy; Peter Buston; Miguel A. Fortuna Nº of researchers: 4 Funding entity or bodies: Proyecto de Investigación de Excelencia, Junta de Andalucia Start-End date: 01/08/2008 - 01/07/2011 Total amount: 124.330,12

Instituto de Fisica Interdisciplinar y Sistemas Complejos (IFISC-CSIC)

IFISC (Institute for Cross-Disciplinary Physics and Complex Systems) is a joint research Institute of the University of the Balearic Islands (UIB) and the Spanish National Research Council (CSIC) created in 2007. IFISC has been awarded in 2018 the "Unit of Excellence María de Maeztu" distinction, entering the selective SOMMa Alliance and thus consolidating IFISC as a reference institute in the research field of complex systems. The award has been granted by the Spanish National Agency (AEI), Ministry of Science, Innovation and Universities. Emerging from a backbone transversal research line of exploratory nature on Complex Systems, Statistical and Nonlinear Physics, IFISC has 5 research lines of transfer of knowledge in the interface with other disciplines (Quantum Technologies, Information and Communication Technologies, Earth Sciences, Life Sciences and Social Sciences). These are: i) Biocomplexity, ii) Dynamics and collective phenomena of social systems, iii) Transport and Information in Quantum Systems, iv) Nonlinear Photonics, v) Nonlinear dynamics in fluids.

Dr. V.M. Eguíluz is a complex systems' scientist with an interest in interdisciplinary applications at the interface between Physics, Biology and Social Sciences. Our early studies on co-evolution networks showed the relevance of network plasticity on the emergence of cooperation, and as a generic mechanism leading to fragmentation transitions. The extensive study of the voter model on complex networks is an example of the micro-macro connection in social collective phenomena: how to link microscopic rules to macroscopic emergent phenomena. Recently we combined census data and election results to present the first model based on microscopic rules compatible with the patterns of voting. In Biology, we introduced the first large scale functional network of the brain. Our expertise on complex networks, on the one hand, and the more recent research activity on the connection between ecological-human activity-and environmental factors In connection to the current project supports his contribution to the current proposal. Current research includes the characterization and modeling of the structure-function relationship of real systems. He is Associate Editor of frontiers in Physics (since 2016) and Advances in Complex Systems (since 2007), Young Researcher Award from the Spanish Royal Physical Society (2003).

List of publications

1. GC Hays et al, Key questions in marine megafauna movement ecology, Trends in Ecology & Evolution 31 (6), 463-475 (2006).

2. F Vazquez, VM Eguíluz, M San Miguel, Generic absorbing transition in coevolution dynamics, Physical Review Letters 100, 108702 (2006).

3. A Cózar et al, The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation, Science Advances 3 (4), e1600582 (2017).

4. AF Rozenfeld et al, Network analysis identifies weak and strong links in a metapopulation system, Proceedings of the National Academy of Sciences 105, 18824-18829 (2008).

5. N Queiroz et al. Global spatial risk assessment of sharks under the footprint of fisheries Nature 572, 461–466 (2019).

List of relevant projects

1. Coupled Animal and Artificial Sensing for Sustainable Ecosystems (CAASE). The Red Sea as a CAASE study Project OSR-KAUST. From 2016 to 2020 Coordinator: C. Duarte (KAUST); PI IFISC: V.M. Eguíluz.

2. SPASIMM Spatiotemporality in sociobiological interactions, models and methods. Project FIS2016-80067-P of the MINECO (Spain). From 2017 to 2020. PI: V.M. Eguìluz, K. Klemm.

3. LASAGNE: multi-LAyer SpAtiotemporal Generalized Networks. FP7-ICT-2011-8 Collaborative Project, Grant Agreement 318132. From 2012 to 2015 Coordinator: S. Thurner (Vienna University).

4. MODASS: Modeling and analysis of social systems: structural evolution, temporal correlations and opinion propagation) Project FIS2011-24785 of the MICINN (Spain). From 2012 to 2015. PI: V.M. Eguíluz.

5. IBESINC: Network on Dynamics and synchronization in networks. Complementary action FIS2010-09832-E (subprogram FIS) of MCINN (Spain). 2011. PI: J. M. Buldú (U. Rey Juan Carlos); Coordinator IFISC: V.M. Eguíluz.

3, Scitation Lda (SCITE)

Dr. Miguel Leal (male) and Dr. Charles De Santana (male) will work for SCITE in ROBHOOT. SCITE is a scientific-based communication SME comprising a multi-disciplinary team of scientists, communicators, designers and illustrators committed to convert scientific data into communication outputs to various audiences. SCITE has been providing services to universities, research centres, international non-governmental organizations and to the private sector. SCITE's area of expertise is environmental and applied sciences, particularly to the agrofeed and blue biotechnology sectors.

contribution to ROBHOOT

SCITE will be involved in all WP of ROBHOOT; creating visualizations and animations to represent the models related to WP1-3. SCITE will also contribute to the communication, dissemination and exploitation in WP4.

Miguel C. Leal, has a PhD in marine biology, yet multidisciplinary research interests focused in applied ecology and blue biotechnology. He participated in ¿12 international research projects funded by the EU, NORAD, FAO, and ETH-Switzerland. He is an author of 60 peer-reviewed publications, including high-impact publications in Science, Nature Ecology Evolution, Trends in Ecology Evolution, and Trends in Biotechnology. He is also regularly invited as a guest lecturer about science communication, science writing, and also several ecology and marine biology topics. He founded SCITE – Science Crunchers in 2017, a start-up focused on communicating scientific and technical data to different audiences.

Charles De Santana, PhD has an academic background in computer science, multi-disciplinary research interests also focused in computer modeling in ecology, climate change, neurosciences and bioinformatics using concepts of graph theory, complex systems and artificial intelligence. He has also a trajectory in the data science industry, working with data analysis and data visualization in the area of marketing and data-driven-journalism. He is an author of 13 peer-reviewed publications in a diverse range of journals, from Physics to Neuroscience, Ecology and Remote Sensing fields. He founded in 2017 DataSCOUT, a Brazilian start-up focused in Data Science and Scientific Computing, and in 2019 he founded Dadoscope, a Brazilian data-driven-journalism initiative in which he uses data visualization and storytelling to tell journalistic stories.

Gender balance

SCITE currently has a team of 2 males and 3, thus the company is gender-balanced. The aim of the SCITE is to keep an international gender balance by attracting female researchers and females interested in communicating science. The good ratio of female/male researchers is a plus for SCITE and we are committed to keep it rising in a close future.

List of relevant publications (Miguel Leal)

1. Vieira, H., Leal, M.C., Calado, R. (2020) Fifty Shades of Blue: How Blue Biotechnology is Shaping the Bioeconomy. Trends in Biotechnology in press doi.org/10.1016/j.tibtech.2020.03.011
2. Ishikawa, A., Kabeya, N., Ikeya, K., Kakioka, R., Cech, J. N., Osada, N., Leal M.C. ... Tezuka, A. (2019). A key metabolic gene for recurrent freshwater colonization and radiation in fishes. Science, 364(6443), 886-889.
3. Leal, M.C., Seehausen, O., Matthews, B. (2017). The ecology and evolution of stoichiometric phenotypes. Trends in ecology evolution, 32(2), 108-117.
4. Best, R.J., Anaya-Rojas, J.M., Leal, M.C., Schmid, D.W., Seehausen, O., Matthews, B. (2017). Transgenerational selection driven by divergent ecological impacts of hybridizing lineages. Nature ecology evolution, 1(11), 1757.

List of relevant publications (Charles De Santana)

1. AN Santana, I Cifre, CN De Santana, P Montoya (2020) Using Deep Learning and Resting-State fMRI to Classify Chronic Pain Conditions. Frontiers in Neuroscience 13, 1313
2. O Hagen, L Vaterlaus, C Albouy, A Brown, F Leugger, RE Onstein, CN De Santana, ... (2019) Mountain building, climate cooling and the richness of cold-adapted plants in the Northern Hemisphere. Journal of Biogeography 46 (8), 1792-1807
3. F Leprieur, P Descombes, T Gaboriau, PF Cowman, V Parravicini, CN De Santana, (2016) Plate tectonics drive tropical reef biodiversity dynamics. Nature Communications 7 (1), 1-8
4. CN De Santana, AF Rozenfeld, PA Marquet, CM Duarte (2013). Topological properties of polar food webs. Marine Ecology progress series 474, 15-26
5. CN De Santana, AS Fontes, MAS Cidreira, RB Almeida, AP González, (2009) Graph theory defining non-local dependency of rainfall in Northeast Brazil. Ecological Complexity 6 (3), 272-277

List of relevant projects (SCITE)

Multiple science dissemination and communication projects coordinated within SCITE: 12 projects in 2017, 33 projects in 2018, 59 projects in 2019, and 28 projects thus far in 2020. Some of SCITE's Clients include: AIR Centre, CERN, Evonik, Lisbon Zoo, Olmix Group, Prince Albert II Foundation of Monaco, Virginia Tech University, Wageningen University, World Aquaculture Society, and others.

1. 2016/2018. Ecosystem consequences of eco-evolutionary change. Funded by EAWAG – Swiss Federal Institute of Aquatic Sciences and Technology.
2. 2015/2017 EpiPhysX the physics of epithelium. Funded by the Swiss National Science Foundation (SNSF) SystemsX initiative
3. 2013/2015 FoodWebs: a theory for next generation food web data. Funded by the Swiss National Science Foundation (SNSF)
4. 2012/2014 SymbioCoRe SYnergies through Merging BIOlogical and biogeochemical expertise in COral Research. Funded by the EU FP7 International Research Staff Exchange Scheme
5. 2009/2013 LINC-GLOBAL International Laboratory in Global Changes. Funded by the Spanish National Research Council (CSIC)

Infrastructure relevant to the proposed work

SCITE office in Lisbon (Portugal) is fully equipped for data analysis, visualization, illustration, design and science communication. Computer power is available to all data analysis and visualization tasks involved in this project.

4, TARTU

University of Tartu founded in 1632 is the largest and highest-ranked university in Estonia and with a number of students of approximately 15,000 (2018). University of Tartu is ranked 301 by the QS World University Ranking (2014) and 301-350 by the Times Higher Education World University Ranking (2019). The university is home to more than 1800 international students from 105 countries and 3,500 employees, which includes around 1,700 academics, and close to 200 professors among them. Today, it is a leading centre of research and training, and a member of the prestigious Coimbra Group of European universities.

Contributions to ROBHOOT

Raul Vicente work for TARTU in ROBHOOT. Dr. Vicente is the lead of WP2. TARTU will develop deep learning technology to infer sustainability paths from causal inference in federate networks composed by species-rich communities, human groups and exploitation technology with special focus on the sustainability of the Oceans case study.

Prof. Raul Vicente (male) is full professor of Data Science at the Institute of Computer Science of the University of Tartu. He received the B.Sc. (first honours class) and Ph.D. (Summa Cum Laude) in Physics from the University of the Balearic Islands, Spain, in 2001 and 2006, respectively. In 2004 and 2005 he was a visiting scholar at the Department of Electrical Engineering of the University of California, Los Angeles (UCLA). From 2006 to 2013, he was a postdoc at the Max-Planck Institute for Brain Research in Frankfurt, Germany. In 2014 he became Senior Researcher in Neuroscience at the Institute of Computer Science, University of Tartu. Since 2016 he is Full Professor at the University of Tartu. He also received: 2001 Extraordinary Award for B.Sc. from the Department of Physics of the University of the Balearic Islands; 2006 Extraordinary Award for Ph.D. from the Department of Physics of the University of the Balearic Islands; 2007 QEOD European Physical Society award for the best PhD thesis in Applied Optics in Europe; and 2012 Attendee at the 62nd Lindau Nobel Laureate Meeting. He is also the head of the PhD program in Computer Science at the University of Tartu, and leader of the group of computational neuroscience (3 senior members + 8 PhD students). Founded in 2013, the lab focuses on the intersection between neuroscience and AI, and in particular on implementing and applying insights from brain research into AI solutions for the analysis of biological data.

Gender balance

University of Tartu strictly adheres to the Gender equality Act and Equal Treatment Act that ensure equal rights, obligations, opportunities and responsibility of men and women in professional life, upon acquisition of education and participation in other areas of social life, as well as protecting people against unequal treatment on grounds of primarily nationality (ethnic origin), race, colour, religion or other beliefs, age, disability or sexual orientation.

List of relevant papers

1. Gómez-Herrero, G., Wu, W., Rutanen, K., Soriano, M. C., Pipa, G., Vicente, R. (2015). Assessing coupling dynamics from an ensemble of time series. Entropy, 17(4), 1958-1970.

2. Tampuu, A., Matiisen, T., Kodelja, D., Kuzovkin, I., Korjus, K., Aru, J., ... Vicente, R. (2017). Multiagent cooperation and competition with deep reinforcement learning. PloS one, 12(4).

3. Bzhalava, Z., Tampuu, A., Bała, P., Vicente, R., Dillner, J. (2018). Machine Learning for detection of viral sequences in human metagenomic datasets. BMC bioinformatics, 19(1), 336.

4. Lindner, M., Vicente, R., Priesemann, V., Wibral, M. (2011). TRENTOOL: A Matlab open source toolbox to analyse information flow in time series data with transfer entropy. BMC neuroscience, 12(1), 119.

5. Wibral, M., Vicente, R., Lizier, J. T. (Eds.). (2014). Directed information measures in neuroscience (pp. 3-36). Berlin: Springer.

List of relevant projects

1. H2020-EIC-FETPROACT-2019, with the project TRUST-AI, PI, 600K Eur (2020-2024)

2. Smart Specialisation Grant, RD with Milrem Robotics, PI, 355K Eur (2018-2021)

3. Estonian Center of Excellence in IT, PI, 130K Eur (2016-2023)

4. Personal Research Grant, Estonian Research Council, PI, 190K Eur (2017-2019)

5. Personal Research Grant, Estonian Research Council, PI, 180K Eur (2014-2016)

5, EPFL (SDSC)

Dr. Christine Choirat (female) is the Chief Innovation Officer of the Swiss Data Science Center (SDSC, https://datascience.ch/), where she provides leadership over the lifecycle of sponsored projects in the domains of environmental science, health science and technology, personalized medicine, and open science. She also fosters engagement with partners to facilitate the adoption of FAIR data and workflow sharing platforms nationally and internationally. At SDSC, she leads the strategic development and outreach efforts of the Renku platform (https://renkulab.io/) for reproducible, collaborative and open data-driven science. Dr. Choirat has over 15 years of experience in data science, computational statistics and in industry-standard software development. She is passionate about education in data science and reproducible research. She created a module for the HarvardX MOOC “Principles, Statistical and Computational Tools for Reproducible Science” and is also the instructor of “Computing for Big Data” at Harvard University. Dr. Choirat will advise on best practice in data science to organize FAIR data management, and on creating and distributing high-quality software tools.

The mission of the Swiss Data Science Center (SDSC) is to accelerate the adoption of data science and machine learning techniques within academic disciplines between the Swiss academic community at large, and the industrial sector. In particular, it addresses the gap between those who create data, those who develop data analytics and systems, and those who can extract value from it. The Center is composed of a large multidisciplinary team of data scientists and computer scientists, and experts in select domains, with offices in Lausanne and Zurich (www.datascience.ch).

Contributions to ROBHOOT

Christine Choirat work for EPFL/SDSC in ROBHOOT. Christine will coordinate the full life-cycle reproducibility of ROBHOOT (WP1, WP2, WP3). Christine will also apply and develop techniques for replicability of the data and causal knowledge discovery. EPFL/SDSC team has a wide experience in reproducibility and replicability in data science and reproducible research.

Gender balance SDSC is committed to employ an equal number of women and men, involving both in research and teaching. Currently the ratio of men and women is well balanced with a ratio of 40/60.

List of Publications

Wasfy, J. H., Zigler, C. M., Choirat, C., Wang, Y., Dominici, F., Yeh, R. W. (2017). Readmission rates after passage of the hospital readmissions reduction program: A pre-post analysis. Annals of Internal Medicine, 166(5), 324–331. https://doi.org/10.7326/M16-0185 Di, Q., Wang, Y., Zanobetti, A., Wang, Y., Koutrakis, P., Choirat, C., . . . Schwartz, J. D. (2017). Air Pollution and Mortality in the Medicare Population. New England Journal of Medicine, 376(26), 2513–2522. https://doi.org/10.1056/NEJMoa1702747 Di, Q., Dai, L., Wang, Y., Zanobetti, A., Choirat, C., Schwartz, J. D., Dominici, F. (2017). Association of short-term exposure to air pollution with mortality in older adults. JAMA - Journal of the American Medical Association, 318(24), 2446–2456. https://doi.org/10.1001/jama.2017.17923 Zigler CM, Kim C, Choirat C, Hansen JB, Wang Y, Hund L, Samet JM, King G, and Dominici F (2016) Causal Inference Methods for Estimating Long-Term Health Effects of Air Quality Regulations. The Health Effects Institute, Cambridge, MA. http://pubs.healtheffects.org/view.php?id=453 Henneman, L. R. F., Choirat, C., Zigler, C. M. (Forthcoming). Accountability assessment of health improvements in the United States associated with reduced coal emissions between 2005 and 2012. Epidemiology.

List of relevant projects

1. R01 ES026217 (PI: Zigler) - NIH
   Causal Inference with Interference for Evaluating Air Quality Policies
   02/01/2016 - 01/31/2021

   Public health interventions routinely target upstream determinants of health to advance the health of pop- ulations, but methods for causal inference to evaluate their effectiveness are limited by a current focus on clinical investigations of individual-level therapies. This work develops methods for bipartite causal inference with interference for the evaluation of complex public health interventions. We deploy the newly-developed methodology to compare the effectiveness of regulatory policies designed to reduce health burden associated with pollution emissions from power plants across the US.
   Role: Co-Investigator

2. R01 ES028033 (PI: Laden) - NIH
   Relationship Between Multiple Environmental Exposures and CVD Incidence and Survival: Vulnerability and Susceptibility
   12/15/2017 - 11/30/2022

   The major goals of the proposed project are to study associations of lmultiple environmental exposures on cardiovascular disease (CVD), mortality and survival after a non-fatal CVD event in the context of multiple confounders and effect modifications. We will be developing new statistical methods, assessing air pollution (particulate matter, nitrogen dioxide, and ozone) and weather (e.g. temperature variability) as main effects, and evaluating effect modification by contextual, lifestyle and genetic factors.
   Role: Co-Investigator

3. 83587201-0 (PI: Koutrakis) - EPA grant (ACE Center)
   12/01/2015 - 11/30/2020
   Regional Air Pollution Mixtures: The Past and Future Impacts of Emission Controls and Climate Change on Air Quality and Health

   The overarching goal of this Center is to generate new scientific knowledge on past and future US in air quality and the associated health impacts. Specifically, we will investigate the sources, composition, trends and effects of regional air pollutant mixtures across the US over a relatively long chronological period span- ning past and future years (2000-2040), and will examine the influence of climate, socioeconomic factors, policy decisions, and control strategies on air pollution, human health and economic outcomes.
   Role: Co-Investigator

4. swissuniversities (PI: Choirat)
   01/01/2020 - 21/31/2020
   Easy FAIR: Supporting the adoption of FAIR and reproducible digital scholarship with Renku

   The World Wide Web and digital technologies are fundamentally changing how scientific knowledge is produced, disseminated and preserved. This transformation represents an opportunity to make the scientific en- deavor more transparent, inclusive, collaborative, reproducible and impactful. However, research in the digital age requires new standards, tools and infrastructures, as well as a new set of research skills. The change is reflected by new requirements from funders, journals, from the research community in general, as well as society at large. Supporting researchers active in Swiss institutions in their adoption of digital best practice is necessary to guarantee they produce research results of the highest quality and impact.
   Role: Principal Investigator

5. EPFL Open Science Fund (PI: Unser)
   01/08/2020 - 02/28/2021
   Interdisciplinary Collaborations in Imaging at EPFL: A Pilot Project with RENKU

   The present project is a collaboration between Imaging@EPFL and the Swiss Data Science Center (SDSC). It aims at the evaluation of how the open-source platform RENKU can facilitate the sharing of data, meta- data, and code within the imaging community at EPFL. Concretely, we shall extensively test and improve RENKU in a series of collaborations that will involve two (or more) imaging laboratories with complementary skills. In parallel, we shall build a repertoire of reproducible, reusable, and well-documented image-processing workflows, and make them accessible to the whole imaging community. A range of new features in RENKU will be developed throughout the project to support these objectives. Of central importance is the definition of a common language (ontology) to describe the vast and heterogeneous world of imaging at EPFL. The widespread adoption of a transparent environment for interactive research can have a huge impact for EPFL, as the imaging community represents about a quarter of its laboratories (80+ groups). Role: Co-Principal Investigator

6, TU Graz

The main research areas of the Institute of Theoretical Computer Science at TUGRAZ are algorithm design, machine learning, spiking neural networks, computational neuroscience. It currently has 3 Professors, 3 University Assistants, 1 System Administrator, 2 Administrative Assistants, and 15 Phd students. The focus of the group of Wolfgang Maass is on computation and learning in networks of spiking neurons and other innovative computing paradigms.

contribution to ROBHOOT

Prof. Wolfgang Maass' (male) experience is in research on spiking neural networks (SNNs), co-inventor of liquid computing and reservoir computing, stochastic computing in SNNs, design of unsupervised and supervised deep learning algorithms for SNNs Experience in leading workpackages on brain-inspired computing and learning in 6 FET-projects of the EU. Wolfgang Maass will lead WP3 in ROBHOOT. He will implement the Evolutionary neural diversification-inspired processes to allow WP3 to implement this feature for discovery in federated networks.

Gender balance

TU Graz wants to employ an equal number of women and men, involving both in research and teaching. The Office for Gender Equality and Equal Opportunity supports the university in achieving this by implementing numerous measures, particularly with the aim of increasing the proportion of women at TU Graz. The equal treatment of women and men is rooted in the Universities Act and belongs to the guiding principles and tasks of the University.

List of relevant papers

1. Papadimitriou, C., Vempala, S., Mitropolsky, D., Collins, M., Maass, W. (2020). Brain computation by assemblies of neurons. PNAS, in press.

2. Bellec, G., Scherr, F., Subramoney, A., Hajek, E., Salaj, D., Legenstein, R., Maass, W. (2020). A solution to the learning dilemma for recurrent networks of spiking neurons. Nature Communications, in press (draft on bioRxiv, 738385).

3. Bellec, G., Salaj, D., Subramoney, A., Legenstein, R., Maass, W. (2018). Long short-term memory and learning-to-learn in networks of spiking neurons. In Advances in Neural Information Processing Systems (pp. 787-797)

4. Maass, W., Natschläger, T., Markram, H. (2002). Real-time computing without stable states: A new framework for neural computation based on perturbations. Neural computation, 14(11), 2531-2560. (2777 citations)

5. Maass, W. (1997). Networks of spiking neurons: the third generation of neural network models. Neural networks, 10(9), 1659-1671. (1688 citations)

Relevant projects

1. 2013 – 2023 Human Brain Project (Flagship Project)

2. 2011 – 2014 BRAINSCALES: Brain-inspired multiscale computation.

3. 2010 – 2014 AMARSI: Adaptive Modular Architectures for Rich Motor Skills

4. 2010 –2012 BRAIN-I-NET: Novel Brain-Inspired Learning Paradigms for Large-Scale Neuronal Networks

5. 2008 – 2012 SECO: Self-Constructing Computing Systems

6. 2005 – 2009: FACETS: Fast Analog Computing with Emergent Transient States in Neural Architectures.

Contributions

Description of any significant infrastructure, relevant to the proposed work CPU and CPU clusters for computing are available at the Institute.

7, SPANISH INSTITUTE OF OCEANOGRAPHY (IEO)

The Spanish Institute of Oceanography (IEO), founded in 1914, is a public research organization dedicated to research in marine science, especially in relation to scientific knowledge of the oceans, sustainability of fishing resources and the marine environment. Attached to the Spanish Ministry of Science and Innovation, the IEO is an autonomous body, with its own personality and legal assets, with a workforce of approximately 700 people, of which 80% are research and research support personnel. The IEO budget exceeds 65 million Euros and has a wide geographical coverage and important facilities. It has a central office in Madrid, nine coastal oceanographic centers and five marine culture experimentation plants. Its oceanographic fleet, with more than twenty vessels, has five important oceanographic vessels. The IEO not only conducts basic and applied research, but also provides scientific and technological advice to administrations in matters related to oceanography and marine sciences, being the research and advisory body for the fisheries sector policy of the Spanish Government. Furthermore, it is the scientific and technological representative of Spain in most of the forums and international organizations related to the sea and its resources.

Contribution to ROBHOOT

IEO is the coordinator of Dissemination, Knowledge transfer and Outreach (WP4). IEO contributes to the dissemination and exploitation plan, the communication for the sustainability of the Oceans case study and the publications and conferences outreach. Dr. Francisco Baldó (male) will be the lead of WP4 in ROBHOOT. He works for the Spanish Institute of Oceanography in Cadiz as a Senior Researcher. His main scientific motivation is to understand the biodiversity of marine ecosystems and contribute to the sustainable management of fisheries resources. During many years, he has been involved in long-term ecological research in the Guadalquivir estuary, which has set up a time series of monthly sampling of the aquatic communities of the estuary. The basis for his PhD was theoretical individual-based models based on a high resolution individual-based food web data-set of the Guadalquivir estuary. Since 2008 he is the cruise leader of the Porcupine bottom trawl survey, which takes place every September at the Porcupine bank (West of Ireland) and a member of the ICES International Bottom Trawl Surveys Working Group (IBTSWG), which coordinates the European bottom trawling surveys in the North Sea and the North East Atlantic. Overall, he has extensive experience in field work including over 50 oceanographic cruises. The combination of the empirical and theoretical facets is, perhaps, the most outstanding characteristic of his background.

Gender balance

Gender balance is currently a priority for Spanish society and, therefore, for IEO. The Women and Science Unit of the Spanish Ministry of Science and Innovation is in charge of promoting the proper application of the principle of gender mainstreaming in the scientific, technological and innovation fields. At the IEO there is also a Gender Equality Plan and Commission to ensure the effective promotion of equality between men and women. In addition, since 2015 IEO has carried out the project ”Women and oceanography” (https://oceanicas.ieo.es/) which aims to disseminate the work of scientists dedicated to the study of oceans, both current and past, to publicize their life and work, thus, trying to generate scientific vocations in girls and boys. Currently, approximately half of the researchers of the IEO are women, but they only represent a third of the directive staff.

List of publications

1. Barros-García D, et al. 2020. Phylogeography highlights two different Atlantic/Mediterranean lineages and a phenotypic latitudinal gradient for the Deep-Sea Morid Codling Lepidion lepidion (Gadiformes: Moridae). Deep-Sea Research Part I: Oceanographic Research Papers 157: 103212.

2. Bañón R, De Carlos A, Alonso-Fernández A, Ramos F, Baldó F. 2020. Apparently contradictory routes in the expansion of two fish species in the Eastern Atlantic. Journal of Fish Biology 96, 1051–1054.

3. Carvalho-Souza GF, et al. 2019. Natural and anthropogenic effects on the early life stages of European anchovy in one of its essential fish habitats, the Guadalquivir estuary. Marine Ecology-Progress Series 617-618: 67-79.

4. Melián CJ, Baldó F, et al. 2014. Individual trait variation and diversity in food webs. Advances in Ecological Research. Vol. 50. Academic Press, 207-241.

5. Melián CJ, et al. 2011. Eco-evolutionary dynamics in individual-based food webs. Advances in Ecological Research. Vol. 45. Academic Press, 225-268.

List of relevant projects

1. PIMETAN: The role of penguins in the biogeochemical cycles of trace metals in the Southern Ocean. Project RTI2018-098048-B-I00 of the Spanish Program for Research, Development and Innovation. From 2019 to 2021. 153,670 Euros.

2. ERDEM: Evaluation of demersal resources by direct methods in the ICES area. European Maritime and Fisheries Fund (EMFF). From 2018 to 2020. 70,420 Euros.

3. DILEMA: Oceanografic dynamics in the Gulf of Cadiz and its influence on the planktonic ecosystem. Project CTM2014-59244-C3-2-R of the Spanish Program for Research, Development and Innovation. From 2015 to 2018. 121,000 Euros.

4. ECOBOGUE: Ecology of early stages of anchovy Engraulis encrasicolus: The role of the Guadalquivir Estuary - Gulf of Cadiz coupled system in the recruitment of the species. Project RNM-7467 of the Andalusian Program for Research. From 2013 to 15. 114,885 Euros.

5. TPEA: Transboundary Planning in the European Atlantic. DG MARE (European Commission). From 2012 to 2014. 1,250,000 Euros.

8, URV

Universitat Rovira i Virgili (URV) is a young university that employs around 1.800 professionals, 1.150 of which are researchers and/or academic staff. The URV welcomes annually 12.000 undergraduate students, 1200 masters students, and 1200 PhD students. Despite its youth and small size (it is barely 25 years old), the URV occupies the 5th position in scientific research production at higher education institutions in Spain, and it is ranked within the 100 best universities less than 50 years old worldwide.

Principal team members involved in the proposed research activities Prof. Roger Guimerà (male) is the co-director of the SEES:lab and ICREA professor at the Dept of Chemical Engineering. His research work focuses on the development of methodologies to build probabilistic models for complex systems, and on Bayesian methods for machine learning and automated discovery. According to the Scopus database, Dr. Guimerà has published 68 articles in international journals including top journals such as Nature, Science and Proceedings of the Natural Academy of Sciences USA. He has an h-index of 29 (Google Scholar (GS): 34). His publications have received 9,256 citations (GS: 14,741). In 2010, he received the award Talent Jove by the Generalitat de Catalunya to the best young investigator; in 2012 he received the Erdös-Rényi Prize to the best young researcher on complex networks; in 2014, he received the award to the Best Young Researcher in socio-econophysics by the German Society of Physics.

Prof. Marta Sales-Pardo (female) is the co-director of the SEES Lab and Associate professor at the Dept of Chemical Engineering. Her research focuses on the development of methodologies to model and understand complex and disordered systems in a number of contexts, including, physical, biological, and social. Dr. Sales-Pardo has authored 64 publications in international journals including top journals such as Science, Science Advances or the Proceedings of the National Academy of Sciences, which have received 3,351 citations (GS: 5,022). She has an h-index of 25 (GS: 27). In 2013, she received an ICREA Acadèmia award for excellence in research.

Contribution to ROBHOOT

Roger Guimerà and Marta Sales-Pardo work for URV in ROBHOOT. Roger will coordinate the full life-cycle automation of ROBHOOT (WP1, WP2, WP3). Roger and Marta will also apply and develop techniques for automating evolutionary expressions for the data, causal knowledge discovery and discovery in federated networks. URV team has a wide experience in Bayesian machine scientist and automation of complex systems.

Gender balance

The SEES Lab has 1 male and 1 female PI, which ensures gender balance at the highest scientific level. The SEES Lab actively participates in initiatives to encourage the participation of women in STEM. In particular, during the 2019-2020 academic year, Dr. Sales-Pardo has participated in the Inspira program to inspire girls aged 12-16 to pursue careers in STEM fields. Dr. Sales-Pardo is also responsible for gender issues at the School of Chemical Engineering, URV.

Relevant publications, products, services

1. Reichardt, I, Pallarès, J, Sales-Pardo, M, Guimerà, R. Bayesian machine scientist to compare data collapses for the Nikuradse dataset, Phys. Rev. Lett. 124 , 084503 (2020).

2. Guimera, R, Reichardt, I, Aguilar-Mogas, A, Massucci, FA, Miranda, M, Pallares, J, Sales-Pardo, M. A Bayesian machine scientist to aid in the solution of challenging scientific problems, Sci. Adv. 6 (5) , eaav6971 (2020).

3. Godoy-Lorite, A, Guimera, R, Moore, C, Sales-Pardo, M., Accurate and scalable social recommendation using mixed-membership stochastic block models, Proc. Natl. Acad. Sci. USA 113 (50) , 14207 -14212 (2016).

4. Massucci, FA, Wheeler, J, Beltran-Debon, R, Joven, J, Sales-Pardo, M, Guimera, R., Inferring propagation paths for sparsely observed perturbations on complex networks, Sci. Adv. 2 , e1501638 (2016).

5. Vallès-Català, T, Massucci, FA, Guimera R, Sales-Pardo, M., Multilayer stochastic block models reveal the multilayer structure of complex networks, Phys. Rev. X 6 , 011036 (2016).

6. Guimera, R, Sales-Pardo, M., Missing and spurious interactions and the reconstruction of complex networks, Proc. Natl. Acad. Sci. U. S. A. 106 , 22073 -22078 (2009).

List of related projects

1. Project: Statistical Mechanics for Modeling and Prediction of Human Behavior; Spanish Ministry of Enconomy and Competitivity (FIS2016-78904-C3-1-P); Roger Guimerà PI, (2017-19)

2. Project: Multiplex: Foundational Research on MULTI-level comPLEX networks and systems; EU-FP7 (FET-Proactive 317532); full member of the consortium (2011-2016).

3. Project: Statistical Inference for the analysis of system wide perturbations in complex networks; Spanish Ministry of Enconomy and Competitivity (FIS2015-71563-ERC); Roger Guimerà PI, (2015-16)

4. Activity: Organisation of the European Conference for Complex Systems (ECCS1́3) in Barcelona, Spain ($http://eccs13.eu$).

5. Project: Discovery, decomposition and dynamics of complex networks, James S. McDonnell Foundation Award (USA); Roger Guimerà and Marta Sales-Pardo PIs (2011-2016).

Resources to be committed

The SEES:lab owns a 96-node high performance IBM blade system and has access to a shared 500-node high-performance cluster within the URV. The blade system also hosts a database server for large datasets and a GPU server for massively parallel computations using GPUs. Additionally, the group has access to the facilities of the Barcelona Supercomputing Center (BSC-CNS, https://www.bsc.es/).

9, Stockholm Resilience Center (SRC)

Stockholm Resilience Centre (SRC) was tasked to “make a difference for sustainable development by building a world-leading research centre that would take the interdisciplinary research on linked ecological and social systems significant steps forward” and provide “insights and means for the development of management and governance practices in order to secure ecosystem services”. We took on this task with great excitement, asking new questions, collaborating across disciplinary borders, and generating new findings and insights of relevance for sustainability.

How do we do it? We regularly and flexibly adjust and restructure our research to stay at the frontier. Since the beginning this was essential because the science is moving rapidly. In our first ten years, research has accumulated on what it means to live in the Anthropocene – the age of humanity. Industrialised societies are shaping the Earth system at the planetary scale. Humanity has moved from being part of the biosphere – that thin sphere around the planet which supports all life on Earth – to the prime driver of change in the biosphere. Humanity is truly intertwined in biosphere processes from local to global scales. It is becoming clear that a resilient biosphere serves as the basis for just and sustainable development, for human health and well-being, and transformations towards global sustainability are necessary, definitely possible, and highly desirable.

Contribution to ROBHOOT

Prof. Jon Norberg’ (male) experience is in research on eco-evolutionary dynamics in ecosystems with special emphasis on global change. He combines stochastic and deterministic modeling. Jon Norberg will work in WP3 in ROBHOOT. He will implement the extended Eco-Evolutionary diversification-inspired models in federated networks processes to allow WP3 to implement this feature for discovery in federated networks.

Gender balance

Stockholm Resilience centre has a gender equal leadership team with a women Director. The centre applies a formalised gender perspective on both research as well as internal administrative, human resources and positions.

List of relevant publications

1. Crépin, A. S., J. Norberg, and K. G. Mäler. 2011. "Coupled Economic-Ecological Systems with Slow and Fast dynamics—Modelling and Analysis Method." Ecological Economics: The Journal of the International Society for Ecological Economics.

2. Dakos, Vasilis, Blake Matthews, Andrew P. Hendry, Jonathan Levine, Nicolas Loeuille, Jon Norberg, Patrik Nosil, Marten Scheffer, and Luc De Meester. 2019. "Ecosystem Tipping Points in an Evolving World." Nature Ecology Evolution 3 (3): 355–62.

3. Lindkvist, Emilie, Örjan Ekeberg, and Jon Norberg. 2017. "Strategies for Sustainable Management of Renewable Resources during Environmental Change." Proceedings. Biological Sciences / The Royal Society 284 (1850).

4. Lindkvist, Emilie, and Jon Norberg. 2014. "Modeling Experiential Learning: The Challenges Posed by Threshold Dynamics for Sustainable Renewable Resource Management." Ecological Economics: The Journal of the International Society for Ecological Economics 104 (August): 107–18.

5. Schill, Caroline, John M. Anderies, Therese Lindahl, Carl Folke, Stephen Polasky, Juan Camilo Cárdenas, Anne-Sophie Crépin, Marco A. Janssen, Jon Norberg, and Maja Schlüter. 2019. "A More Dynamic Understanding of Human Behaviour for the Anthropocene." Nature Sustainability 2 (12): 1075–82.

List of relevant projects

1. The role of biodiversity in fluctuating environments, Swedish science foundation 2002-2003

2. Institutional and economic tools for managing biodiversity, Swedish science foundation 2002-2004

3. A general trait-based approach for ecology: Understanding ecosystem dynamics and implications for climate impact predictions, Swedish science foundation 2002-2006

4. Management of coastal recreational fishery with emphasis on biodiversity. 2006-2007 Swedish research council for sustainable development

5. Pollution and ecosystem adaptation to changes in the environment, Research council of Norway 2015-2019 (advisory board)

4.2 Third parties involved in the project (third party resources)

None

5 Ethics and Security

5.1 Ethics

There are no ethical issues concerning the ROBHOOT project.

5.2 Security

1. Activities or results raising security issues: (NO)
2. EU-classified information' as background or results: (NO)