JAEPRE-07: Assessing functional diversity and the structure and robustness of plant-frugivore networks along a Neotropical defaunation gradient

Justification of the relevance of the scientific project in the research area

Defaunation is a process by which vertebrate populations are lost or reduced substantially as a result of habitat loss, fragmentation, and/or hunting. A common signature of hunting-induced defaunation is the asymmetric change in the structure of animal communities by disproportionately affecting large-sized species relative to smaller ones, resulting in a homogenization of community composition and a rearrangement of biotic interactions between animals and plants, which ultimately could lead to changes in ecosystem functioning. Interactions between fleshy-fruit plant species and frugivores are particularly relevant for the natural regeneration of tropical forests which are frequently threatened by different drivers of defaunation such as overhunting. Around 90% of neotropical and 80% of afrotropical woody plants rely on vertebrates to disperse their seeds, with fruits constituting a significant portion of the diet for many tropical birds and mammals. This intricate interdependence between plants and animals highlights the critical role of seed dispersal in these ecosystems. Given that larger hardwood trees produce larger fruits and seeds, and carbon storage is linked to wood density across tree species, the selective loss of large avian and mammalian frugivores could impede natural forest regeneration and carbon sequestration. This shift may also alter community composition, favoring wind-dispersed or smaller-seeded plant species, thereby affecting the functional and taxonomic diversity of tropical forests by extirpating frugivore vertebrates.

Moreover, defaunated areas may experience ecological changes, including the proliferation of smaller frugivores in the absence of larger vertebrates, and an increase in seed predator populations due to the absence of natural predators and competitors. The complex interplay between positive (mutualistic) and negative (antagonistic) interactions, alongside factors like interspecific competition, plays a crucial role in shaping the dynamics of forest regeneration in defaunated areas. However, the precise roles of these interactions in seed dispersal and predation under varying degrees of defaunation remain poorly understood, especially in networks involving diverse plant mutualists and antagonists, such as arboreal primates, birds, herbivorous ungulates, ground-dwelling birds, and scatter-hoarding rodents.

In hyper-diverse tropical ecosystems, the consequences of losing these plant-animal interactions may only become apparent over the long term. In recent decades, community ecologists have relied on ecological network analysis to assess changes in network structure resulting from the loss of interacting partners, providing insight into ecosystem functionality decline. Disruptions in species interaction networks can lead to alterations in structural characteristics that underpin community stability. Key indicators of stability include connectance, which increases network robustness through redundancy, nestedness, common in mutualistic networks, which enhances resilience against specialist species loss, and modularity, which offers local stability in mutualistic networks. However, the topological structure and responses to human disturbance gradients in hybrid networks, encompassing both mutualistic and antagonistic interactions, remain relatively unexplored. Fundamental questions are: (i) What is the role that antagonistic interactions may play in exacerbating the loss/decline of mutualistic interactions in defaunated areas?; (ii) Are both interaction types balanced along gradients of increasing defaunation?; (iii) How does the topological structure of mutualistic and antagonistic networks change along a defaunation gradient?; (iv) What are the drivers of mutualistic and antagonistic interaction networks?

In this PhD project, the student will generate novel insights on the roles of interacting partners, and the drivers and structure of plant-animal mutualistic and antagonistic interaction networks in one of the most diverse areas on the planet, the Brazilian Amazon. Instead of using simulation experiments or a single pairwise site comparison with no replicas, we will leverage on a natural experimental setting where past and current hunting activities have created a defaunation gradient of vertebrate biomass and altered animal composition along different sites, thus ensuring sufficient replications of ecological networks. We will capitalise on existing ecological data on animal abundance, vegetation composition and carbon stocks to select our sites and to derive functional diversity metrics. Then, we will assess the structure of mutualistic (seed dispersal) and antagonistic (seed predation) ecological networks along the defaunation gradient, focused on plant species with diverse fruit and seed traits (large, medium, and

small fruit/seed size), that are consumed by animals with diverse foraging traits (body size, gape size, percent frugivory in diet). Finally, we will assess, for the first time, the drivers shaping the structure of the general network across all study sites at three levels – individual plant traits and species identity, neighbourhood characteristics, and site characteristics – and for multiple plant species simultaneously.

Objectives

The PhD project will address four interlinked objectives, each corresponding to a thesis chapter, which collectively contribute to a comprehensive understanding of the effects of defaunation on functional diversity and the structure of plant-frugivore ecological networks. The student will have intellectual freedom to develop their own ideas and shape up the focus of at least 2 PhD chapters.

- *Objective 1.* Evaluate changes in the topological structure and robustness of mutualistic, antagonistic and combined networks along a defaunation gradient.
- *Objective 2.* Understand the individual role of vertebrates and plant species in plant-frugivore networks along a defaunation gradient
- *Objective 3.* Evaluate the relative importance of functional traits, neighbourhood properties and site characteristics at shaping the structure of plant-frugivore networks in hypediverse tropical ecosystems
- *Objective 4.* Establish linkages between functional diversity of plants and vertebrates, and ecological network structure

Expected impact of the results

The results of this PhD dissertation will lead to at least 4 scientific articles. We expect high international visibility of the scientific outputs, given the previous experience of the PI and the team members' track record, including high-tier peer-reviewed journals. Specialized high-impact journals in the areas of ecology and conservation biology (e.g. Ecology Letters, Functional Ecology, Conservation Biology), as well as high-tier multidisciplinary journals (PNAS, Nature Ecology & Evolution), will be the main venue for publication of our results. Our research will be published in open-access scientific journals so that our results are freely available for academic peers and can contribute to policies. We will disseminate project results in at least two highly-relevant international meetings in the field of ecological networks, frugivory and seed dispersal, tropical ecology, and conservation biology (e.g. ATBC Annual Meeting, SCB International Congress, Symposium of Frugivory and Seed Dispersal, ECONET Symposium). We will also organise a symposium on "Ecological Network Structure along Disturbance Gradients" at an international conference. We will share the project results via seminars at the MNCN-CSIC, EBD-CSIC, NMBU and at RJBG.

Resources available to carry out the research project and the training plan being presented.

This PhD dissertation will receive support from the project '*Characterizing the role of interacting species, the drivers, and the structure of plant-frugivore ecological networks along a defaunation gradient in tropical forests (TROPECOLNET, PID2022-138272NA-I00),*' which I was recently awarded (total: > 200 keuro). Flight costs are covered for 2 field campaigns of 180 person-days, and as well as maintenance expenses during fieldwork, including hosting at Carauari in Jurua, and diverse study sites in research stations in the area. Flights for the PI are also covered for 2 field campaigns of 30 person-days to oversee the onset of each field campaign, and to conduct fieldwork. We further have funding to purchase 100 camera traps to register plant-animal interactions, binoculars for focal observations, hard disks for data storage, and 100 64GB SD cards for camera traps. The project includes funding for the presentation of results at two/three international conferences, as well as funding for cover open access publication of 4 scientific articles as Gold OA. Moreover, the National Museum of Natural Science (MNCN-CSIC) will provide office space for the PhD student. For data analysis, we have access to the CESGA high-performance computer facilities (328 TFLOPS, 44.8 TB of RAM and 1.5 PB of disk capacity which will allow us to speed up computations, particularly for network analysis, which is extremely computationally-demanding.

Training plan for the JAE-PRE candidate

I will seek a predoc profile with an open attitude towards quantitative data analysis and management, as well as theoretical aspects of network and functional ecology. The PhD student will be co-supervised

by me and Dr. Carine Emer, one of my collaborators in the recently awarded project: "*Characterizing the role of interacting species, the drivers and the structure of plant-frugivore ecological networks along a defaunation gradient in tropical forests (TROPECOLNET, PID2022-138272NA-I00*)". The PhD student will be involved in fieldwork activities, data collection, management and analysis, conceptualization of manuscripts, and publication of the results as scientific articles in peer-reviewed journals. The PhD student will enrol in the doctoral program in Ecology jointly offered by the UAM and UCM in Madrid, and will be affiliated with MNCN-CSIC, a leading international institution in the research fields of biodiversity, conservation, global change biology, evolutionary ecology, and biogeography. Here they will benefit from a dynamic and stimulating environment where, besides fortnightly meetings with the PI's group, they will be able to attend weekly seminars on a variety of topics from in-house and external speakers, as well as journal clubs and other events. Monitoring of the PhD progress will be done by regular 45 min weekly one-to-one meetings, plus fortnightly meetings with the whole group. An annual evaluation report will be delivered by both the candidate and the supervisors, followed by a meeting to discuss strong and weak points in the progress, plus actions to tackle any identified issues.

I expect this PhD candidate to find intellectual support in our project for their own scientific career by stimulating research independence, cross-collaborations and opening new opportunities for their training in new research tools. The PhD student will benefit from the network of outstanding international collaborators in the project *TROPECOLNET*, with whom they will carry out short research stays. I expect that the PhD student will carry out a short research stay at Doñana Biological Station (Sevilla) with Prof. Pedro Jordano, a leading expert on plant-animal interactions and the analysis of ecological networks. Prof. Jordano uses complex network analysis in the study of patterns, functions, and consequences of plant-animal mutualisms within ecosystems, both in temperate and mega-diverse tropical ecosystems. His experience on the topic will largely contribute to the study design and data analysis of the data collected on field, which high-skilled mentoring will fuel the training of the PhD student. I further expect that the PhD student will carry out short international research stays with Prof. Carlos A. Peres (University of East Anglia, UK) and/or Dr. Carine Emer (Rio de Janeiro Botanical Garden Research Institute – RJBG, Brazil), who are both members of the TROPECOLNET project, to seek specific training related with the PhD. Dr. Carine Emer is a community ecologist with 15 years' experience in plant-animal interactions and their associated ecological and evolutionary processes. Prof. Carlos Peres is a Professor of Tropical Conservation Ecology who has worked in the Amazon for ~35 years and in the Juruá region since 1987, and has published two books and >400 papers at all scales of ecological organization. He is also the Science Director of Instituto Juruá, a nonprofit conservation NGO that will support this project during fieldwork.

The PhD student will also undertake specialised courses in plant-animal interactions, tropical ecology and particularly the analysis of ecological networks and sampling methodologies, including the course "*Frugivoria e Dispersão de Sementes*", which brings together outstanding researchers in the topic (including Prof. Pedro Jordano), "*Introduction to Network Ecology*" or "*Network analysis in Ecology and Evolution*", depending on availability and the PhD schedule. As part of their training, the PhD will also attend at least two international congresses to present their work, which will be highly beneficial for their academic development and independence, and for building up a solid network of collaborators outside my lab. In this regard, conferences such as the European Tropical Ecology Conference organized by the Society for Tropical Ecology (GtÖ), the Annual Meetings of the Association for Tropical Biology and Conservation and the International Symposium on Frugivory and Seed Dispersal are of relevance since they will allow him/her to to meet and learn from leading experts and peers in tropical ecology from across Europe and around the world.
Although not essential, I expect to recruit one recently graduated student from the MSc program "Biodiversidad en Áreas Tropicales y su Conservación" by UIMP and CSIC with proven experience in tropical settings, so that they swiftly adapt to the demanding fieldwork activities in tropical ecosystems.

Schedule of activities

	1st Year				2nd Year				3rd Year				4th Year				
Field data collection			X	X			X	X									
Literature reading	X	X	X		X	X	X		X	X	X	X	X	X			
Objective and Chapter 1					X	X	X	X	X								
Objective and Chapter 2								X	X	X	X	X					
Objective and Chapter 3										X	X	X	X	X			
Objective and Chapter 4											X	X	X	X	X		
Thesis writing												X	X	X	X	X	