Subhendu Bhandary

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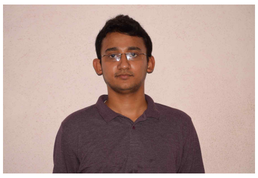

Curriculum Vitae

Personal Profile

Name	**Subhendu Bhandary**
Date of birth	**13 August, 1993**
Nationality	**Indian**

Research Interests

I am interested in understanding the resilience of complex networks under the influence of environmental and demographic perturbations. I have worked on a variety of problems on complex networks ranging from ecological to neuronal networks. Sudden loss of network resilience is known to drive tipping points in natural systems, and hence increases the significance of resilience thinking. In fact, several anthropogenic factors are known to drive the collective dynamics of complex ecological systems which further hamper species persistence increasing the risk of community-wide extinction. Presently, I am working on how networks' structural properties interplay to alter systems' dynamics in static as well as time-varying networks. I have also been working to determine and mitigate tipping points in mutualistic networks in a degrading environment, such as investigating tippings in mutualistic plant-pollinator networks exposed to climate warming. In an ongoing project, I am working on preventing network extinction through strategic interactions via games among species sharing a common niche. I wish to explore further along this direction of research and other related ones with the aim of developing strategies/mitigation policies that can promote the resilience of ecological networks. The basic tools of my research are applied mathematics, dynamical systems, and numerical computations. I also have a working knowledge of theoretical ecology.

Education

2018-2023 **PhD in Applied Mathematics**, Department of Mathematics, IIT Ropar, Rupnagar, Punjab, India - 140 001
Supervised by **Dr. Partha Sharathi Dutta**

2015-2017 **Master of Science in Mathematics and Computing**, Indian Institute of Technology, Guwahati, Assam- 781039

2014-2015 **Master of Science in Applied Mathematics**, University of Calcutta, 87/1, College Street, Kolkata-700 073

2011-2014 **Bachelor of Science in Mathematics** , Ramakrishna Mission Residential College, Narendrapur, Kolkata, West Bengal 700103

RESEARCH EXPERIENCE

August 2025 – Continuing	**Postdoctoral Researcher**, Chair of Network Dynamics, Institute of Theoretical Physics and Center for Advancing Electronics Dresden (cfaed), TUD Dresden University of Technology, 01062 Dresden, Germany Host: **Prof. Marc Timme**
June 2023 – May 2025	**Postdoctoral Researcher**, Department of Evolutionary Biology and Environmental Studies, University of Zurich, Switzerland Host: **Prof. Jordi Bascompte**

Fellowships and Awards

2017 **Cleared Graduate Aptitude Test in Engineering (GATE) with All India Rank 53**
Fellowship for pursuing PhD or M.Tech by the Ministry of Human Resource Development (MHRD), Government of India

2016 **Qualified NBHM M.Sc scholarship written exam.**

2015 **Cleared Joint Admission test for M.Sc (JAM) with All India Rank 198.**
Secured Admission in Indian Institute of Technology Guwahati.

2013 **Qualified MADHAVA Mathematics competition.**

Computer skills

Languages: C, C++, R, Python

Packages: MATLAB, Julia, MATCONT, XP-PAUT

Platforms: Linux, Windows

Languages

English: Fluent
Bengali: Native
Hindi: Fluent

Publications

Papers published, revised and in preprint

1. Narang, A., **Bhandary, S.,** Kaur, T., Gupta, A., Banerjee, T., and Dutta, P.S., *Long-range dispersal promotes species persistence in climate extremes*, **CHAOS**, AIP, Vol. 29, Issue 10, pp 103136 (2019). DOI: https://doi.org/10.1063/1.5120105
2. **Bhandary, S.**, Kaur, T., Banerjee, T., and Dutta, P.S., *Network resilience of FitzHugh-Nagumo neurons in the presence of non-equilibrium dynamics,* **Physical Review E**, APS, Vol. 103 (2), 022314 (12) (2021). DOI: https://doi.org/10.1103/PhysRevE.103.022314
3. **Bhandary, S.**, Biswas, D., Banerjee, T., and Dutta, P.S., *Effects of time-varying habitat connectivity on metacommunity persistence,* **Physical Review E**, APS, Vol. 106 (1), 014309 (12) (2022). DOI: https://doi.org/10.1103/PhysRevE.106.014309
4. Deb, S., **Bhandary, S.,** Sinha, S., Jolly, M.K., and Dutta, P.S., *Identifying Critical Transitions in Complex Diseases*, **Journal of Biosciences,** Springer, Vol. 47, 25, 1-16 (2022). DOI: https://doi.org/10.1007/s12038-022-00258-7

5. **Bhandary, S.**, Deb, S. and Dutta, P. S., *Rising Temperature Drives Tipping Points in Mutualistic Networks*, **Royal Society Open Science**, *The Royal Society Publishing, Vol. 10(2), 221363(17) (2023).* DOI: https://doi.org/10.1098/rsos.221363
6. Deb, S., **Bhandary, S.**, and Dutta, P. S., *Evading tipping points in socio-mutualistic networks via structure mediated optimal strategy*, **Journal of Theoretical Biology**, *Elsevier, Vol. 567, 111494(10) (2023).* DOI: https://doi.org/10.1016/j.jtbi.2023.111494
7. **Bhandary, S.**, Banerjee, T., and Dutta, P.S., *Nonautonomous perturbations and the stability of ecosystems*, **Physical Review E**, APS, Vol. 108(2):024301 (2023). DOI: https://doi.org/10.1103/PhysRevE.108.024301
8. **Bhandary, S.**, and Dutta, P.S., *Effects of adaptive niche based interactions due to strategic identities on metacommunity persistence.* **(Under review)**
9. **Bhandary, S.**, Gawecka, K. A., Pedraza,F., and Bascompte, J.,*Landscape configuration and community structure jointly determine the persistence of mutualists under habitat loss.* DOI: https://doi.org/10.1101/2025.05.28.655631 **(Under review)**
10. **Bhandary, S.**, and Bascompte, J.,, *Local and Spatial Processes Shape the Collapse and Recovery of Mutualistic Networks* DOI: https://doi.org/10.1101/2025.11.25.690369 **(Under review)**
11. Deb, S., **Bhandary, S.**, Jolly, M.K., Dutta, P.S., *Methods for identifying critical transitions during cancer progression, (2025).* **To appear in "Cancer Systems Biology", Edited Book, Oxford University Press**

Participation in Conference/ Seminar / Workshop / Schools

2023 Contributed Talk in **"NADCOM23: International Seminar and Workshop on Non-autonomous Dynamics in Complex Systems: Theory and Applications to Critical Transitions"** held at Max Planck Institute for the Physics of Complex Systems (MPIPKS) in Dresden during 09 - 27 October 2023.

2022 Poster presentation in **"Tipping Points in Complex Systems"** held at ICTS-TIFR, Bengaluru, India during 19-30 September 2022.

2022 Poster presentation in **"ESA & CSEE Joint Meeting Montréal, Québec, Canada"** by Ecological Society of America to be held on August 14 – 19, 2022.

2020 Poster presentation in **"ESA Annual Meeting 2020 Salt Lake City, Utah"** by Ecological Society of America to be held on August 3– 6, 2020.

2019 Poster presentation in in conference **"CNSD Conference"** held in IIT, Kanpur from December 11 - 15,2019.

2019 Poster presentation in **"Mathematical and Statistical explorations in disease modelling and public health (DMPH 2019)"** held at ICTS-TIFR, Bengaluru, India during 1-11 July 2019.

2018 Participated in **"IFCAM Summer School"** held in IISC Bangalore from 17th July to 31st July,2018 and supported by Indo-French Centre for the Promotion of Advanced Research (CEFIPRA), India.

References

1. **Prof. Jordi Bascompte**,

   Department of Evolutionary Biology and Environmental Studies

University of Zurich,
Winterthurerstrasse 190, 8057 Zurich, Switzerland.
Homepage: https://www.bascompte.net
E-Mail: jordi.bascompte@uzh.ch

2. **Dr. Partha Sharathi Dutta**,
Department of Mathematics,
Indian Institute of Technology Ropar,
Nangal Road, Rupnagar Punjab, India - 140 001.
Homepage: https://mathbio.iitrpr.ac.in
E-Mail: parthasharathi@iitrpr.ac.in

Highlights of my Research

- **Effects of adaptive strategic interactions on species persistence**

  Species persistence in ecological communities emerges from the interplay between ecological interactions and behavioral strategies that influence population dynamics. Classical niche theory explains how resource overlap sets the strength of interactions, while evolutionary game theory describes how cooperation and defection emerge from payoff-dependent decisions. However, most ecological models assume fixed strategies over generations, ignoring the potential for rapid behavioral adjustment on ecological timescales. Here, we combine Lotka–Volterra niche competition dynamics with an adaptive strategy framework in which species update their strategies through a payoff-sensitive Fermi rule. We analyze community outcomes across four symmetric games—trivial, snowdrift, stag hunt, and prisoner's dilemma—implemented on networks with differing topologies and connectivity. Adaptive strategy updates markedly reduce species extinction compared to static strategies, enabling coexistence in payoff regions that would otherwise collapse to extinction. Network structure modulates persistence primarily for Snowdrift and Prisoner's Dilemma games: regular networks can show abrupt connectivity-driven extinction, whereas heterogeneous networks, particularly scale-free, promote persistence through cooperative hubs. Overall, our results demonstrate that behavioral adaptation plays a crucial role in sustaining species persistence than network architecture alone.

- **Balancing act: how local structure and spatial diversity shape mutualistic network stability?**

  Complex metamutualistic networks often experience sudden shifts between states of persistence and collapse. These are expected to be influenced by both local and spatial structures. However, their relative contributions remain unclear. This study investigates how local and spatial network structures jointly shape the dynamics of collapse. We examine how dispersal rates affect co-extinctions in isolated patches and find that local structural properties, such as nestedness and modularity, are crucial for species persistence. Yet, spatial structures, particularly when combined with dispersal dynamics, significantly influence collapse timing. Our results show that spatial heterogeneity, coupled with robust local interactions, enhances network resilience, while homogeneous spatial structures are more prone to collapse. These insights underscore the importance of integrating both local and spatial dynamics to fully understand tipping points in ecological networks.

- **Landscape configuration and community structure jointly determine the persistence of mutualists under habitat loss**

Habitat loss poses a major threat to biodiversity. Its effects on ecological communities depend on the complex interplay between the landscape configuration — the patterns of connections between habitat patches, community structure — the patterns of interactions between species, and habitat loss patterns. Despite their individual importance, their joint effect on species persistence remains poorly understood. We explore how these three factors influence the persistence of empirical mutualistic communities. By employing spatially explicit metacommunity models, we find that landscapes with a heterogeneous distribution of connections between habitat patches exhibit high persistence under spatially-uncorrelated habitat loss but are highly vulnerable to spatially-correlated loss, where adjacent habitat patches are destroyed sequentially. Homogeneous landscapes with regularly arranged patches have lower persistence than heterogeneous landscapes but are more resilient to correlated habitat loss. The metacommunity nested structure of species interactions enhances persistence, with varying magnitude depending on landscape configuration and the patterns of habitat loss. These results can guide conservation strategies by identifying landscape and community features that promote species persistence.

- **Evading tipping points in socio-mutualistic networks via structure mediated optimal strategy**

  The threat to large-scale pollinator decline emanates globally under stress from multiple anthropogenic pressures. Traditional approaches have focused on managing endangered species at an individual level, in which the effect of complex interactions such as mutualism and competition are amiss. Here, we develop a coupled socio-mutualistic network model that captures the change in pollinator dynamics with human opinion in a deteriorating environment. We show that the application of social norms at the pollinator nodes is fit to prevent sudden community collapse in representative networks of varied topology. Whilst primitive strategies have focused on regulating abundance as a mitigation strategy, the role of network structure has been largely overlooked. Here, we develop a novel network structure-mediated conservation strategy to find the optimal set of nodes on which norm implementation successfully prevents community collapse. We find that networks of intermediate nestedness require conservation at a minimum number of nodes to prevent a community collapse. We claim the robustness of the optimal conservation strategy (OCS) after validation on several simulated and empirical networks of varied complexity against a broad range of system parameters. Dynamical analysis of the reduced model shows that incorporating social norms allows the pollinator abundance to grow that would have otherwise crossed a tipping point and undergo extinction. Together, this novel means OCS provides a potential plan of action for conserving plant-pollinator networks bridging the gap between research in mutualistic networks and conservation ecology.

- **Stability of ecosystems under oscillatory driving with frequency modulation**

  Consumer-resource cycles are widespread in ecosystems, and seasonal forcing is known to influence them profoundly. Typically, seasonal forcing perturbs an ecosystem with time-varying frequency; however, previous studies have explored the dynamics of such systems under oscillatory forcing with constant frequency. Studies of the effect of time-varying frequency on ecosystem stability are lacking. Here we investigate isolated and network models of a cyclic consumer-resource ecosystem with oscillatory driving subjected to frequency modulation. We show that frequency modulation can induce stability in the system in the form of stable synchronized solutions, depending on intrinsic model parameters and extrinsic modulation strength. The stability of synchronous solutions is determined by calculating the maximal Lyapunov exponent, which determines that the fraction of stable synchronous solution increases with an increase in the modulation strength. We also uncover intermittent synchronization when synchronous dynamics are intermingled with episodes of asynchronous dynamics. Using the phase-reduction method for the network model, we reduce the system into a phase equation that clearly distinguishes synchronous, intermittently synchronous, and asynchronous solutions. While investigating the role of network topology, we find that variation in rewiring probability has a negligible effect on the stability of synchronous solutions. This study deepens our understanding of ecosystems under seasonal perturbations.

- **Rising Temperature Drives Tipping Points in Mutualistic Networks**

The effect of climate warming on species physiological parameters, including growth rate, mortality rate, and handling time, is well established from empirical data. However, with an alarming rise in global temperature more than ever, predicting the interactive influence of these changes on mutualistic communities remains uncertain. Using 139 real plant-pollinator networks sampled across the globe and a modelling approach, we study the impact of species' individual thermal responses on mutualistic communities. We show that at low mutualistic strength plant-pollinator networks are at potential risk of rapid transitions at higher temperatures. Evidently, generalist species plays a critical role in guiding tipping points in mutualistic networks. Further, we derive stability criteria for the networks in a range of temperatures using a two-dimensional reduced model. We identify network structures that can ascertain the delay of a community collapse. Until the end of this century, many real mutualistic networks can be under the threat of sudden collapse, and we frame strategies to mitigate them. Together, our results indicate that knowing individual species thermal responses and network structure can improve predictions for communities facing rapid transitions.

- **Effects of time-varying habitat connectivity on metacommunity persistence**

  Network structure or connectivity patterns are critical in determining collective dynamics among interacting species in ecosystems. Conventional research on species persistence in spatial populations has focused on static network structure, though most real network structures change in time, forming time-varying networks. This raises the question, in metacommunities, how does the pattern of synchrony vary with temporal evolution in the network structure. The synchronous dynamics among species are known to reduce metacommunity persistence. Here we consider a time-varying metacommunity small-world network consisting of a chaotic three-species food chain oscillator in each patch or node. The rate of change in the network connectivity is determined by the natural frequency or its subharmonics of the constituent oscillator to allow sufficient time for the evolution of species in between successive rewirings. We find that over a range of coupling strengths and rewiring periods, even higher rewiring probabilities drive a network from asynchrony towards synchrony. Moreover, in networks with a small rewiring period, an increase in average degree (more connected networks) pushes the asynchronous dynamics to synchrony. On the other hand, in networks with a low average degree, a higher rewiring period drives the synchronous dynamics to asynchrony resulting in increased species persistence. Our results also follow the calculation of synchronization time and are robust across other ecosystem models. Overall, our study opens the possibility of developing temporal connectivity strategies to increase species persistence in ecological networks

- **Network resilience of FitzHugh-Nagumo neurons in the presence of nonequilibrium dynamics**

  Many complex networks are known to exhibit sudden transitions between alternative steady states with contrasting properties. Such a sudden transition demonstrates a network's resilience, which is the ability of a system to persist in the face of perturbations. Most of the research on network resilience has focused on the transition from one equilibrium state to an alternative equilibrium state. Although the presence of nonequilibrium dynamics in some nodes may advance or delay sudden transitions in networks and give early warning signals of an impending collapse, it has not been studied much in the context of network resilience. Here we bridge this gap by studying a neuronal network model with diverse topologies, in which nonequilibrium dynamics may appear in the network even before the transition to a resting state from an active state in response to environmental stress deteriorating their external conditions. We find that the percentage of uncoupled nodes exhibiting nonequilibrium dynamics plays a vital role in determining the network's transition type. We show that a higher proportion of nodes with nonequilibrium dynamics can delay the tipping and increase networks' resilience against environmental stress, irrespective of their topology. Further, predictability of an upcoming transition weakens, as the network topology moves from regular to disordered.