Queensland University of Technology

HHDR Research Proposal Template

Faculty of Science

Research applicants to **Science** disciplines in the following schools should use this template:

- School of Biology and Environmental Science
- School of Chemistry and Physics
- School of Computer Science
- School of Earth and Atmospheric Sciences
- School of Information Systems
- School of Mathematical Sciences

TO BE COMPLETED IN CONSULTATION WITH PROPOSED PRINCIPAL SUPERVISOR

NOTE: The Research Proposal should be 2 to 3 pages in length

Applicant's name	**Kilian BARREIRO**
QUT application ID	**7937703**
Date	**11/10/24**
Degree	**IF49 Doctor of Philosophy**
School	Mathematical Sciences
Principal supervisor's name	**Michael BODE**

1. Research project title:

Provide a clear and brief description of your proposed research project. This is the working / draft title for the project.
"Ecological Geometry: Applying geometric and topological concepts to model species interactions"

2. Objectives of the research project:

What will be investigated, analysed or demonstrated
This research aims to address the limitations of traditional methods, like ODEs and PDEs, in capturing high-dimensional, nonlinear ecological data. By integrating topological and geometrical concepts, it seeks to develop a comprehensive framework that models complex species interactions, enhances predictive capabilities, and provides deeper insights into ecosystem dynamics.

3. Brief overview of the research project:

Provide a brief overview of your project. This should include the reason for undertaking this research and the significance of the topic
The project focuses on applying advanced mathematical tools, specifically topology and geometry, to improve the modeling of species interactions. Traditional approaches often struggle with the complexity of ecological systems, especially when dealing with high-dimensional and nonlinear data. This research aims to uncover

hidden patterns in ecological networks by leveraging topological and geometrical methods/frameworks. The outcomes will contribute to more robust predictions and support sustainable ecosystem management.

4. Proposed methods:

Describe the following in this section: • Approach / methodology • Experimental Design and Investigation: (Include details on equipment you require for this project? Is it available at QUT, or other accessible location?) • Data Collection and Validation: (Include details on access to any specialist software or other equipment that are NOT currently available at QUT) • If the project requires access to external facilities what arrangements have been made for this?
Mathematical Approach: Use geometric concepts (e.g., Voronoi diagrams, Delaunay triangulations, add examples ..) to model the spatial distribution of species and their territories. Apply topological tools (e.g., persistent homology, Betti numbers, again these examples are related to my knowledge) to identify patterns in the connectivity of species and their interactions. Enhance common tools interpretability such as JSDM residuals by integrating new spatial covariates (cited above). Algorithm Development: Develop algorithms for spatial analysis based on geometric structures (with R, Python etc). Create geometrical, topological data analysis (TDA) (and graph theory methods) to study the robustness and stability of ecological networks. Validate the models by comparing them with existing theoretical frameworks in theoretical and integrative ecology.

5. Industry engagement:

Is there any potential for your project to incorporate industry engagement (e.g. through an industry-based internship or sponsorship? Please provide details.
While the primary focus is on theoretical development, there may be potential applications in conservation biology, environmental monitoring, and ecological forecasting. Collaboration with ecologists or institutions interested in the mathematical analysis of ecological data could enhance the relevance and impact of this research.

6. Project alignment:

Describe if and how your project aligns with National priorities, University Research Centres, Faculty Research Centres and Groups.
This research aligns with national and international priorities in mathematical biology, particularly in understanding complex biological systems through mathematical models. It also contributes to the academic focus on interdisciplinary research between mathematics and ecology, aiming to bridge the gap between theoretical mathematics, applied ecological studies and environment-oriented engineering. (NGOs, government agencies and environmental consulting firms can be interested in advances in this field .)

7. Approvals and permits:

Will this project require any of the following approvals, controls or permits?

• Ethics approvals (i.e., utilising Human participants or Animal subjects, including cadaveric materials) • Biosafety (e.g., gene technology, high-risk biologicals) • Export controls (e.g., items on the defence and strategic goods list, export controlled technologies) • Clinical trials or medical devices If so, provide details (see https://www.qut.edu.au/research/why-qut/ethics-and-integrity)
NA

8. References:

List of key references relevant to the research

- **Yehezkel Buba et al., (2024)**. *Evaluating models for estimating introduction rates of alien species from discovery records*. Global Ecology and Biogeography, Vol 33, Issue 8.
- **Václav Snášel, Jana Nowaková, Fatos Xhafa, Leonard Barolli, (2017)**. *Geometrical and topological approaches to Big Data***.** Future Generation Computer Systems, Volume 67.
- **White, C.R. and Seymour, R.S., (2003)**. *Mammalian basal metabolic rate is proportional to body mass2/3***.** Proceedings of the National Academy of Sciences, 100(7), pp.4046-4049.
- **Jeynes-Smith, C., Bode, M., Araujo, R-P. (2024)**. *Identifying and explaining resilience in ecological networks***.** Ecology letters**.**
- **Morimoto, J., Conceição, P., & Smoczyk, K. (2022).** *Nutrigonometry III: curvature, area and differences between performance landscapes.* Royal Society Open Science, 9(11), 221326.
- **Antonelli, P.L. and Miron, R. eds., (2013)**. *Lagrange and Finsler geometry: Applications to physics and biology (Vol. 76)*. Springer Science & Business Media.

9. Research project timeline:

Provide a draft plan of the stages of your research for each year of your candidature. Edit the table below as appropriate (3 years for IF49 PhD, or 1.5 years for IF80 MPhil).

Timeframe	Research activities
0-3 months	*Project design, contextualisation, commence literature review, preliminary outline of mathematical framework*
3-12 months	*Complete literature review, start and refine model framework design, preliminary results and first insights. Develop algorithms for spatial analysis through geometrical frame*
12-18 months	*Develop and calibrate models, integrate topological data analysis tools to capture higher-order interactions. Create advanced algorithms for multi-species interaction modelling. Conduct simulations to predict potential outcomes in theoretical ecosystems.*
18-24 months	*Advanced model development. Optimise computational efficiency. Start drafting papers.*
24-30 months	*Apply the models to a higher range of theoretical scenarios. Validation and last adjustments.*
30-36 months	*Final analysis, ordering results and findings, manuscript writing.*