Title: Proposal for establishing Global Change Ecology Laboratory at National Centre for Biological Science (NCBS) – Tata Institute of Fundamental Research (TIFR)

Biodiversity enables and sustains Earth's habitability. A deeply connected nexus of myriad ecological processes regulate climatic, biotic, and geochemical cycles, shaping our shared world. However, ongoing global changes are propelling these ecological processes towards undesirable trajectories[1]. Few of the most widespread and intact systems like the tropical rainforests, polar and mountain ice, and grassy biomes are in a liminal stage of entering into an undesirable state. These shifts carry far-reaching consequences for global climate patterns, biogeochemical cycles, infectious diseases, and human wellbeing[2,3]. Several global and regional policies have pledged to halt the ongoing degradation, mitigate the ecological damage, and steer towards a resilient trajectory[4]. These policies and targets depend on coherent research on the patterns of global change, their consequences, and evidence-based human actions. In absence of objective fundamental research such global targets tend to remain a dogma. I propose a lab dedicated to comprehending ecology of ongoing global changes and developing nature-based solutions for enhancing Earth's resilience, reinforcing its safe space for life.

As global change ecology is multidimensional and complex, it necessitates comprehensive monitoring and investigation of ecological complexities. Monitoring abiotic parameters like the climate and hydrology has improved significantly by satellite remote sensing, regional ground observatories, enhancing their societal impacts (e.g., reports by the IPCC). Monitoring of biotic components is however geographically disjunct, typically leaving megadiverse regions data deficient. The absence of systematic biodiversity data has undermined the knowledge of the Global South regions like India in global ecological processes. The rates of ecological transformations and their consequences are notably high in the Indian subcontinent but remains ambiguous in absence of scientific approach. Given India's leading initiatives in wildlife surveys, citizen science programs, and disease surveillance, availability of data on biotic components is apparent. However, these datasets are fragmented, requiring systematic harmonization. My past research leveraged on large-scale biodiversity datasets to investigate complex ecological processes and offer novel insights on global changes and nature-based solutions. Furthering the combination of **field ecology and basic sciences**, I wish to establish India's "Global Change Ecology Lab (GCL)" to contribute towards advancements in biodiversity, biogeography, and Earth system research and applications (Figure 1).

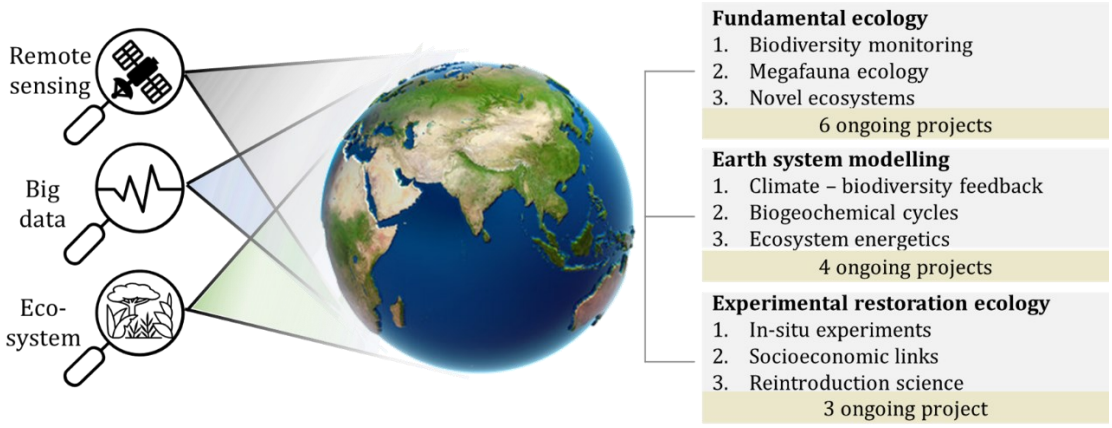

Figure 1: The proposed Global Change Ecology Lab (GCL) uses three primary tools (remote sensing, biodiversity bigdata, and ecosystem sciences) to monitor ecology of the changing Earth and develop science for understanding planetary resilience, offering evidence-based solutions for global challenges.

I wish to operate the GCL based on three major research themes (RT), viz. Fundamental ecology, Earth-system modelling, and Experimental restoration ecology. Each RT will be collaboratively led by a multidisciplinary team of researchers and experts from biological science, data science, and humanities. The lab will operate via multiple projects in field ecology, macroecology, earth system modelling and restoration experiments for enabling positive socioecological outcomes. I discuss each RT using different projects, potential funders, collaborators and justify my candidature in leading these projects by joining the NCBS.

RT1: Fundamental ecology: This RT leverages monitoring biodiversity patterns and process (ecological, climatic, and anthropic) at multi-biome levels. It will help understand the ecology of ongoing changes in species movement, populations, communities, and ecosystem functioning. It will utilize my long-term projects on vegetation dynamics, biological invasions, population and movement of megafauna, and trophic interactions in Trans-Himalaya.

My ongoing projects use datasets from 150,000 vegetation plots monitored every four years since 2006, across 320,000 km^2 natural areas in India. Using nearly 3 million plant records, this project has produced models of plant invasion pathways[11], resistance-resilience spectrum of biomes[16], and vegetation restoration priorities[13]. These datasets are ideal for examining how biotic communities change due to ongoing global changes? How interactions between different plants and their environment (e.g., soil moisture, herbivore, fire) are changing? And how novel selection pressures will result in novel ecosystems? The lab will use this bigdata to map the ecological shifts in vegetation communities, emergence of novel ecosystems, and biogeography of India's new wilderness. Furthermore, I am part of a collaborative research to understand the population recovery of key megafauna (megaherbivores, tigers, leopards, and snow leopards) and drivers of their colonization, extinction, and movement in India. This research utilizes a world-record camera-trap based long-term population monitoring of these megafaunas[9]. The arising manuscripts from this work have received positive review from leading journals like *Science*, and I wish to utilize it further for understanding the movement and population ecology of megafauna in the Anthropocene settings. Similarly, my ongoing collaborative project in Trans-Himalaya is investigating trophic interactions by monitoring climate, vegetation, herbivores, and carnivores over an area of 50,000 km^2 and collaring over 30 animals. Our findings on increasing annual hot days and its link with wildlife and human movement are critical for adapting to climatic changes in the region. Another collaborative research using remote sensing has also indicated climate change induced reduction in small mammals[6,7]. These resource-intensive large-scale projects have generated invaluable information vital for understanding many macroecology, biodiversity and biogeography patterns. The lab will also develop these biodiversity database portals for greater utility.

While several projects aim to launch a national biodiversity database, they are often hindered by unavailability of baseline data. My collaboration with the National Tiger Conservation Authority (NTCA), Wildlife Institute of India (WII), and state forest departments can help in accessing large-scale biodiversity data from India[9]. My work with these agencies has led to the development of MSTrIPES[10] a modern approach to record biodiversity and conservation indicators and now mandated across tiger reserves. Such smart platforms avail ground observations that can be integrated with environmental databases like climate and hydrology. I intend to achieve this integration using a bigdata infrastructure at the NCBS High Performance Computing Facility and establishing mirror data lakes on distinct platforms. This will establish the institute's first spatial ecology facility, offering a novel toolset to existing labs.

Furthermore, I will continue my collaborative research to understand hydrological shifts in Indian deserts, heat stress in rainforests, glacier changes in the Himalaya, flood dynamics in Ganga-Brahmaputra basin[8], and changing climatic patterns of the Sholas. Particularly, my research on mapping spread of infectious diseases and future spillover aligns with One Health research at NCBS and Bangalore Life Science Cluster (BLiSC). Modelling future disease emergence and its links with changing ecology can spur cascading societal impacts via evidence-based applications for global change adaptations. I wish to institutionalize and upscale these projects by streamlining long-term funding. It will support project-oriented teams, and fundamental research on ecology.

RT2: Earth system modelling: This RT involves fundamental research on understanding how abiotic and biotic components of the environment manifest an ecosystem, its resilience to recover from disturbances, regime shifts, and its links with biogeochemical cycles and energy pathways. Ecological patterns arising from RT1 from Indian sub-continent will be viewed and analyzed in global perspective by collaborating with teams from other tropics. Following my past research[11], it will also utilize open-source global biodiversity data (e.g., GBIF) for better planetary ecological models and their ongoing changes. Global goals have recently shifted focus from species and habitat to ecosystem resilience as the unit for conservation/restoration activities. However, the measures of ecosystem resilience are yet to be formalized, and complicated by the dynamic nature of ecosystems and the uncertainty brought by ongoing global changes. The GCL intends to formalize scale-sensitive indicators of ecosystem resilience, map resilience basins of ecosystems worldwide ("permissible limits of fluctuations"), and propensity of regime shifts. My past research on global invasions[11], novel ecological interactions[12], ongoing collaborations with European and African studies, and datasets from RT1 will avail the necessary bigdata for these global studies. Embarking on this bigdata framework, GCL will collaborate with the Stockholm Resilience Center and experts at global forums like the IPBES and IPCC for modelling resilience for planetary boundaries.

The GCL will monitor changes in diverse Indian ecosystems and identify key drivers of ecosystem resilience and shifts. It will use the world's largest systematic data on vegetation monitoring, wildlife survey, and RT1 products to monitor near-real-time ecosystems changes and their impacts. My ongoing postdoctoral research has established the widespread emergence of novel ecosystems across Indian subcontinent[13]. It shows that rapid and intensive climatic changes, pervasive hydrological manipulations, and prevalence of invasive species have propelled ecosystems into a novel trajectory, which in turn will impact the future climatic patterns, ecosystem states, and human wellbeing. I intend to strengthen research on such "feedbacks" that are seemingly becoming apparent and critical for a sustainable future by institutionalizing my ongoing research and establishing a knowledge network on resilience, regime-shifts, and recovery. It complements the research at NCBS on fire-vegetation and nutrient cycles, benefiting multiple research teams and interdisciplinary curiosity.

Within this RT, the GCL will also develop multi-scale energy linkages, where metabolic traits of organisms are upscaled to populations and ecosystems to model energy pathways[14]. This topic is relatively novel and is gaining traction using metabolic scaling theory and energy budgets. Furthermore, my research in Trans-Himalaya on animal mediated nutrient cycles offer critical insights on ecology of with geochemical cycles. I wish to integrate my planned research on these subject at Aarhus and Oxford within GCL, as it might offer a collaborative avenue for many interested evolutionary biologists at the NCBS.

RT3: Experimental restoration ecology: The GCL aims to identify vulnerable ecosystems in India degraded to a less resilient state, and experiment on steering them to a biodiverse and resilient trajectory. This RT will work in-situ on recovery, reintroduction, and reinstatement of lost biodiversity and ecological functions. Insights from my ongoing research on restoring biodiversity in invaded landscapes[13], reintroduction of megaherbivores[15], habitat restoration across tiger reserves, and ecological replacements in multi-use areas can form the foundation for this RT. The proposed work takes an unconventional detour from the widespread practice of chronic human interventions in nature-recovery by instead using nature-based solutions that leverage ecological functions to reinforce resilience. My previous work has determined several functions that inculcate ecological resilience, via vegetational diversity in rainforests[16], megaherbivore densities in mesic savannas[12], and seasonal edaphic aridity in dry systems. The GCL will experiment by manipulating edaphic elements, herbivory, fire, and nutrients to understand the effect on restoration trajectories. My ongoing collaboration for ecological restoration of 16 protected areas can provide fertile avenue for these experiments.

Further, I am developing a project with various state forest departments and The Nature Conservancy to develop inclusive model of ecological restoration by linking socioeconomic benefits with it. This includes collaboration with industrial partners for commodification of invasive plant biomass and participation of local communities, sustainable business entrepreneurship, and market linkage. The GCL can utilize these experiments to understand the socioeconomic feedback, social to achieve a sustainable model of ecosystem restoration.

India is witnessing a surge of nature-recovery prospects (e.g., invasive species management, species reintroductions), which is steering more controversies than solutions. There is an urgency to institutionalize science based on global experience, advance technology, and long-term field experiments. I am working on several ongoing collaborations on allied projects with state forest departments (reintroduction of megaherbivores), NTCA (restoration of tiger reserve and control of plant invasions) and private organizations (restoring Gangetic floodplains). Under this RT, the GCL will model strategies for India's restoration goals, pathways to achieve it, developing indicators for monitoring success, and lead field-based success stories using multi-sectoral participation. This RT may thus form a cornerstone for future nature-recovery policies in India, which have already started surging.

Pedagogy: My commitment to education has been shaped by experiences in training diverse professionals, and curating courses on lesser explored and pertinent topics like ecological modelling and experimental field ecology. I am keen to curate innovative course-modules for master and PhD programs in NCBS. I wish to contribute to the Masters modules on Remote sensing & GIS, Statistics, Community ecology and Biogeography, and curate advance modules on Global changes, Invasion ecology, and Nature-recovery. For PhD courses, I wish to contribute to basic and advanced statistics and fundamental ecology modules. I also intend to supervise MSc and PhD dissertations via proposed projects, lab networks and multi-institutional collaborations. My ongoing projects will facilitate researchers to join GCL and design courses on field ecology, experimental ecology, megafauna monitoring, and developing inclusive models of conservation/restoration – benefiting many inhouse teams at NCBS.

Investments: While I bring a resource-intensive datasets from large-scale long-term biodiversity monitoring, multiple species telemetry, global collaborations, and field experiment permissions, I would need a comparatively small seed grant to further conduct field

experiments, build teams, and publish. I will also utilize support from other faculty for including research on disease ecology, plant-microbe relationships, and plant genomics.

Outcomes: Every RT has aforementioned impacts achieved as deliverables using dedicated projects (Table 1). Deliverables of every RT will befit the objectives of others, nurturing an interactive working atmosphere. It will also garner curiosity on fundamental research on global change, ecosystem science, and experimental ecology, while provisioning emerging professionals with cutting-edge tools like bigdata and field ecology. My global collaborations, access to India's large datasets, and skills of using global biodiversity data can save funds for generating data de-novo in the first 6 years and utilize it for field experiments. I see at least 4 high-impact publications from GCL every year providing novel ecological knowledge and methodologies for global benefit. Apart from direct benefits, the GCL will achieve:

1. Understanding multi-scale (species-population-community-ecosystem) ecological response to ongoing global changes and its links with geochemical and energy cycles.
2. The GCL will enhance understanding of climatic changes and associated risks in India, thereby offering insights on potential adaptations and graded investment priorities.
3. Model novel biogeography of India, considering global changes and conservation scenario.
4. The GCL will provide the first set of global indicators for monitoring ecosystem resilience.
5. Offer scale-sensitive nature-based solutions for global change mitigations and adaptations.
6. Provide evidence-based protocols for managing biological invasions, restoring native biodiversity, reintroducing species, and reinstatement of ecological functions.
7. Identify mechanisms of restoring ecosystems via in-situ experiments.
8. It will spearhead India's ecological restoration agenda and provide actionable guidelines.
9. Linking ecological restorations with socioeconomic benefits and industrial products.
10. A six-year GCL plan will generate investments and support for future research.

Table 1: Proposed plan for the Global Change Ecology Laboratory in six years.

Quarters in 6 years	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Research theme 1: Fundamental ecology																								
Funds consolidation																								
Hiring and training																								
Milestones				a			b					c		a				c		a				c
Deliverables					d			e				d				e		d			e			d
Research theme 2: Earth system modelling																								
Funds consolidation																								
Hiring and training																								
Milestones				a			f					c	a					c	a					c
Deliverables						e			e			g1			e			g2				e		e
Research theme 3: Experimental restoration ecology																								
Funds consolidation																								
Hiring and training		a			a				a				i											
Milestones			h			h		h		h	f				a		f						c	
Deliverables				d		e		d			e				d		e			e		d		e
Pedagogy and knowledge networking																								
Teaching modules																								
Ecology database													j											
Seminar/Conference																								
Public outreach																								

(a: working group hired, b: ecosystem shifts modeled, c: completion report submitted, d: megafauna population and movement modelled, e: Impactful papers published, f: Earth geochemical models established, g: global indicators published (versions), h: field-experiments launched, i: long-term restoration programs and policy uptakes, j: Biodiversity portal launched)

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