Mining long-term datasets to elucidate climate effects on tropical forest species interactions and ecosystem function

Overview

The future of the global carbon cycle and planetary biodiversity depends critically on how tropical forests respond to climate change, which remains poorly understood because tropical forests are complex systems composed of many interacting species. Barro Colorado Island, Panama, is the best studied tropical forest in the world, with a 100-year history of research, a well-known biota, and high quality, long-term datasets on climate, ecosystem function, plant demography, and animal abundances. These datasets offer an extraordinary opportunity for fellows to investigate patterns and mechanisms of direct and indirect effects of temporal climate variation on tropical forest species and their interactions, and the consequences for tropical forest biodiversity and ecosystem function under climate change.

Importance

Tropical forests are disproportionately important for global carbon budgets and biodiversity. Though they occupy only 18% of the Earth's land area, tropical forests account for two-thirds of global biomass carbon stocks, 62% of described vertebrate species, 68% of described tree species, and an even higher proportion of insect species. Thus to understand global effects of climate change on carbon and biodiversity, we must understand effects of climate change on tropical forest species and ecosystem function. And there is good reason to think these effects are nontrivial: multiple studies of stand-level properties, particular species groups, and focal taxa in tropical forests have detected substantial directional change over time. However, we lack a mechanistic understanding of these changes, and thus cannot confidently project future tropical forest trajectories under different global change scenarios.

Tropical forests are not only globally but also locally diverse, with important implications for their responses to climate change. Hundreds of tree species, hundreds of vertebrate species and thousands of insect species co-occur within sites, and these co-occurring species vary widely in their responses to climate. This large interspecific variation complicates the problem of understanding forest-level responses, and it cannot be ignored, because species that do relatively better under future climates will inevitably become more common over time. This variation has the potential to provide substantial resilience at the whole-forest level at longer timescales, as species composition shifts to less vulnerable species. However, the "winners" under novel conditions may differ systematically in their contributions to ecosystem function, which could increase rather than decrease changes in ecosystem function relative to those expected from mean effects of climate change on species present today, and potentially lead forests to cross tipping points into alternative stable states.

The complex web of species interactions in tropical forests provides an abundance of pathways by which climate change can affect tropical species and forest function, complicating efforts to understand underlying mechanisms and project future trajectories. In addition to direct effects of climate on organismal physiology of individual species, there are indirect effects due to climate influences on other species that are competitors, food sources, mutualists, or natural enemies. Increasing or decreasing abundances of herbivores, pollinators, or seed dispersers of a given plant species can dramatically affect plant reproductive success and may eclipse effects associated with direct climate influences. Likewise, animal abundances are probably more strongly affected by climate-driven shifts in the availability of their food resources than by direct climate effects. The potential importance of these indirect effects has long been recognized, but models of tropical forest climate responses still focus almost entirely on direct effects of climate on plant physiological processes, at most including indirect effects associated with shifts in abundances of a handful of competing plant functional types.

POTENTIAL RESEARCH THEMES

The Smithsonian Tropical Research Institute seeks postdoctoral fellows to leverage the extraordinary long-term datasets of Barro Colorado Island, Panama, together with the wealth of knowledge of this flagship Smithsonian study site, to elucidate the effects of temporal climate variation on tropical forest plants, animals, ecosystem services, and biodiversity. We especially encourage integrative proposals that take advantage of multiple datasets to investigate plant-animal interactions and associated indirect climate effects; e.g., climate influences on the activity and abundance of insect pollinators and seed predators, and associated effects on seed production and seedling recruitment.

PROGRAMS AND ASSETS

Barro Colorado Island (BCI), the Smithsonian's flagship tropical research station, has been a focus of research for 100 years, ever since it was first declared a tropical forest reserve for scientific study in 1923. Over 3000 scientific publications provide information on its climate, soils, flora, fauna, and ecosystem processes, making it the best-studied tropical forest in the world. Further, a large, diverse, vibrant, and collaborative scientific community of residents and visitors constitutes a living storehouse of expertise. Today the BCI station is part of the Smithsonian Tropical Research Institute (STRI), with 30 staff scientists and over 1500 scientific visitors per year.

Ongoing, very long-term studies provide an exceptional record of temporal variation in climate, plant demography, animal abundances, and ecosystem function on and near BCI. High-quality on-site microclimate measurements extend over 50 years, and include precipitation, air temperature, solar radiation, wind speed and direction, humidity, and soil moisture. Eddy covariance measurements of evapotranspiration and stand-level CO2 exchange were initiated in 2012, accompanied by additional microclimate measurements including upwelling and downwelling short- and long-wave radiation, direct and diffuse photosynthetically active radiation, and canopy temperature.

A pioneering large-scale forest census plot first censused in 1982 is the focus of multiple long-term studies that provide species-specific data on plants. This 50-ha plot, the first Smithsonian ForestGEO plot, is completely censused every 5 years. That is, every tree with a trunk diameter ≥ 1 cm (> 200,000 trees of >300 species) is tagged, mapped, identified to species, and measured in diameter, providing data on species abundances, recruitment, growth, and mortality. Since 1987, the production of flowers, seeds, and fruits of plants in the plot has been monitored with 200 litter traps that are emptied weekly, with all items counted and identified to species, and separate counts of mature, immature, and damaged fruits and seeds. Since 1991, pollen rain has been monitored annually with 20 pollen traps within the plot, with pollen grains counted and identified to genus or species. Since 1995, seedling recruitment, growth and survival has been censused annually in 600 seedling plots paired with seed traps, with all seedlings identified to species. Since 2008, diameter growth has been measured annually with dendrometers on ~1800 trees. Since 2009, dead wood has been censused annually. Since 2014, high-resolution (<7 cm) drone imagery has been collected monthly and processed into 3D point clouds, providing information on height, sun-exposed crown area, as well as leafing status for every canopy tree on the plot. Since 2016, survival and damage has been assessed annually on ~7000 trees.

Animals have also been the focus of multiple long-term studies on and near BCI. Since 2009, 22 insect groups (including bess beetles, ambrosia beetles, rhinoceros beetles, 3 families of termites, flatids, assassin bugs, 6 families of butterflies, 5 families of moths, sweat bees, orchid bees and ants) have been censused four times annually in or near the 50-ha plot. Non-volant mammals have been censused annually with trail transects since 1978 on Barro Colorado Island as a whole, and terrestrial mammals have been censused annually with camera traps since 2010 in the larger Barro Colorado Nature Monument. Additional data for nearby Parque Nacional Soberanía include annual bird censuses with mist-nets since 1977, and monthly orchid bee censuses 1978-2019.

The large literature of previous observational and experimental studies on and near BCI provides additional information on potential mechanisms of climate responses. Extensive plant and insect functional trait datasets make it possible to explore linkages of climate responses to traits. Experimental studies have evaluated how elevated temperature and CO_2, altered precipitation, elevated light, and nutrient addition affect plant growth, respiration, photosynthesis, and allocation. And many other studies provide information on patterns and consequences of particular species interactions.

ADVISORS

The following Smithsonian staff scientists commit to respond to queries from prospective climate fellows, facilitate access to datasets and project assets, and provide guidance throughout the fellowships: Helene Muller-Landau, S. Joseph Wright, Yves Basset, Stuart Davies, Carlos Jaramillo, David Roubik, and Martijn Slot. Fellows will also have the opportunity to seek additional expertise and collaboration from the broader STRI, ForestGEO, and Smithsonian communities.