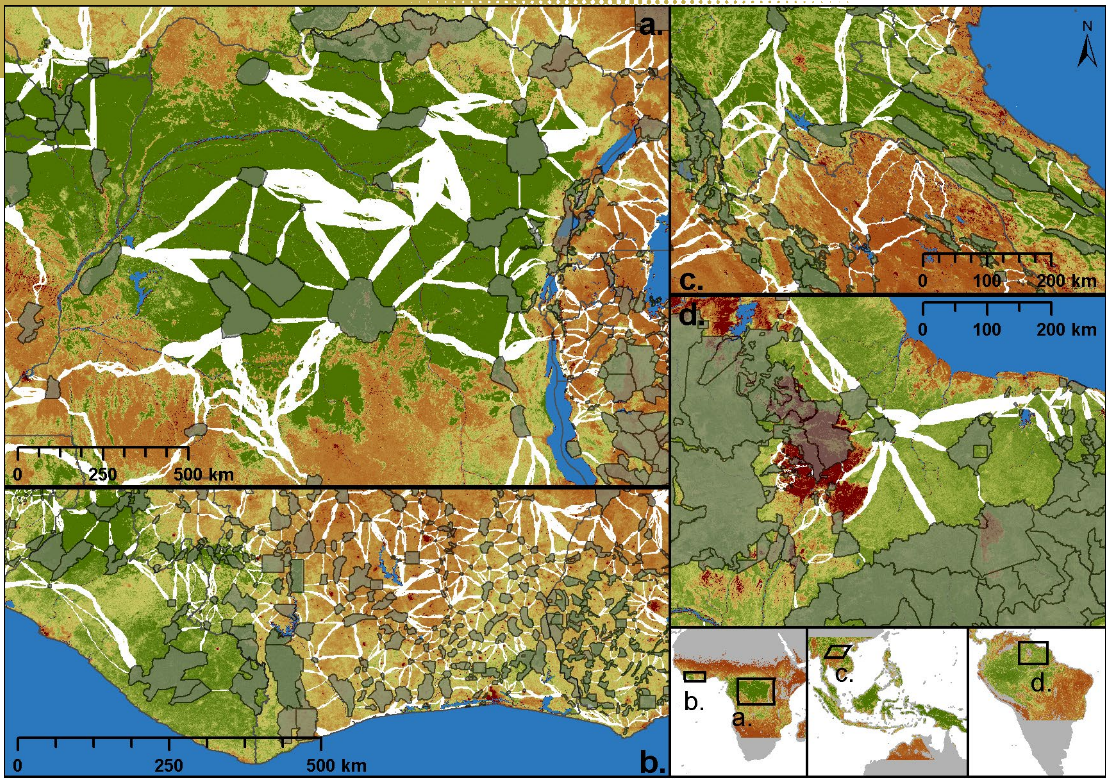

Figure 1a–1d: Corridors passing through the densest biomass between protected areas of western Africa. Corridors are shown in white, protected areas in semitransparent gray, and biomass in red as a gradient from low to high density.

LIDAR AND GIS COMBINED
to Map and Preserve Tropical Forests

Scientists at the Woods Hole Research Center (WHRC) investigate climate change across the globe to identify opportunities for conservation, restoration, and economic development. WHRC has been using Esri geographic information system (GIS) software for more than 30 years. In a recent climate change study, WHRC researchers used lidar data and GIS to analyze biomass density and wildlife habitat corridors across the tropics.

BY BARBARA LEIGH **SHIELDS**

Why lidar and GIS? The combination provides unique ways to assess data using precise measurements and mapping. By using both, WHRC was able to identify vulnerable forest corridors with high biodiversity and high biomass values. The results are helping conservationists drive fact-based policy for habitat protection.

Countries that preserve biomass can get a dollar return from the United Nations Framework Convention on Climate Change (UNFCCC) Programme on Reducing Emissions from Deforestation and Forest Degradation (REDD+). It connects the private sector with governments to exchange carbon credits between industries that emit carbon and forests that sequester carbon. Measuring the carbon of a forest is a means of calculating its credit value. Countries can also get funding from nongovernmental organizations (NGO) to establish conservation lands to protect wildlife habitat. The preserved habitats are fragmented by roads, farms, towns,

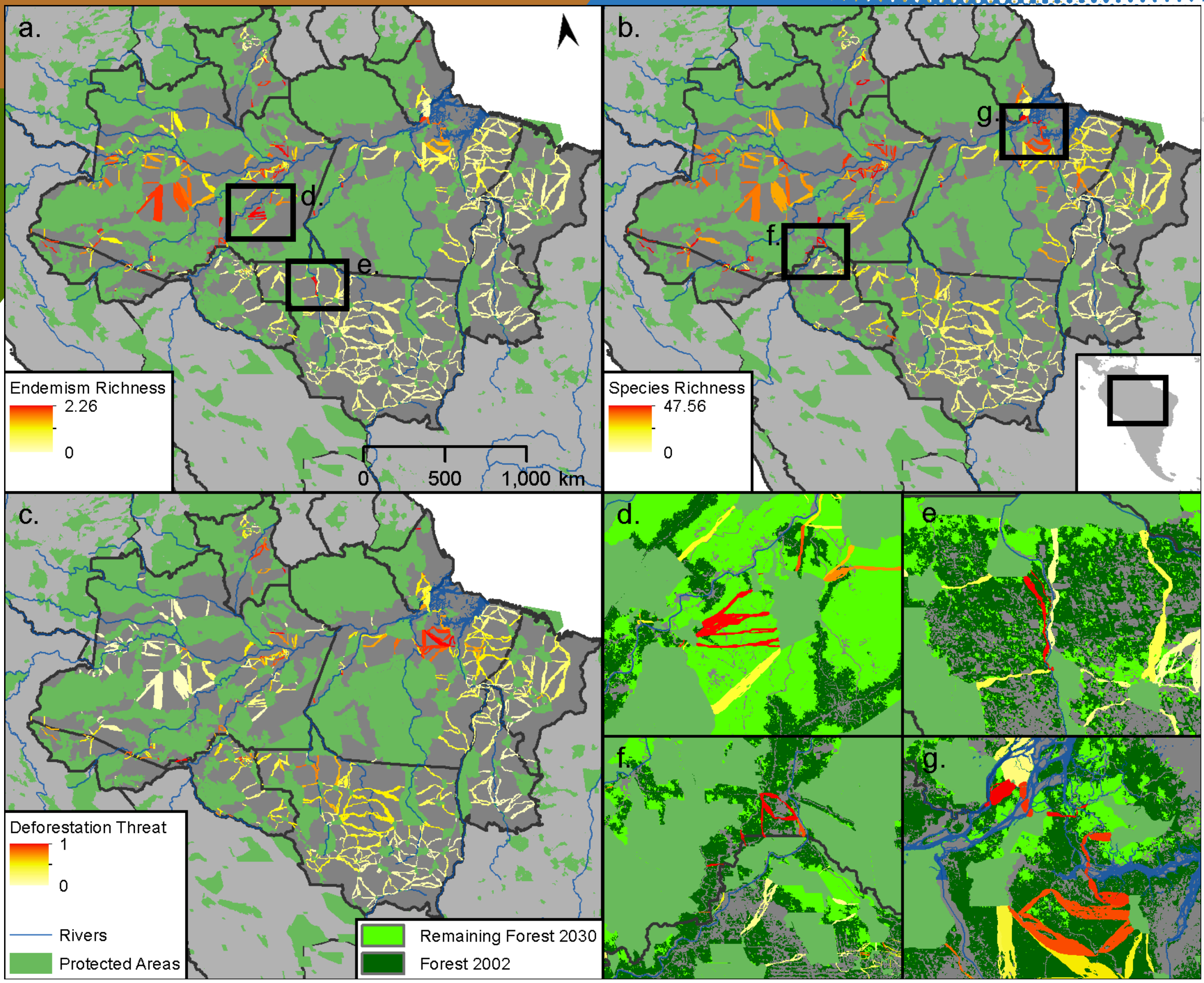

Figure 2a–2g: Multicriteria scoring of corridors in the Brazilian Amazon across three dimensions: Biomass density, mammalian biodiversity, and deforestation threat. Biodiversity was measured as either **(a.)** endemism richness or **(b.)** species richness. **(c.)** Deforestation threat was represented as the fraction of corridor area projected to be deforested by the year 2030 under a business-as-usual scenario. Inset maps show areas along the Madeira River forest cover for the year 2002, and projected remaining forest cover in 2030 is depicted in inset maps (legend is in the lower corner). **(d.)** Northern Mato Grosso. (e.) On the Border of Rondonia. **(f.)** In Para at the Mouth of the Amazon. **(g.)** Forest.

and ranches, so many environmental organizations also fund the protection of networks of wildlife corridors, which allow species to migrate from one protected area to another.

WHRC researchers suggested a two for one proposition. Build wildlife corridors on areas that have the highest carbon density. But, locating corridor routes that meets everyone's requirements is a complex geographic problem. The optimal corridor would contain high carbon density, species richness, and endemism, which means species that live only in a particular location. Researchers also needed to measure the economic opportunity costs local communities would lose if an area became protected.

Lidar and GIS find the best route

A paper written by Patrick Jantz, Scott Goetz, and Nadine Laporte, titled *Carbon Stock Corridors to Mitigate Climate Change and Promote Biodiversity in the Tropics*, explains methods for defining and locating these dense carbon stock corridors and includes carbon stock corridor maps. WHRC researchers measured biomass density, identified corridors, and created detailed maps showing corridors that connect conservation areas. In addition, they created a decision tool that integrates and prioritizes various criteria to propose areas that meet multiple objectives.

The National Snow & Ice Data Center (nsidc.org) distributes lidar data from the National Aeronautics and Space Administration (NASA) Ice, Cloud, and Land Elevation Satellite (ICESat). Attached to the satellite is a sampling instrument called the Geoscience Laser

Altimeter System (GLAS). It captures a 65-meter diameter lidar shot every 180 meters along ICESat's orbital track. As the satellite has orbited around the globe in a polar orbit, with its orbital tracks separated by 150 kilometers, it has gradually built up a data archive that has proved very useful to ecologists, foresters, and climate change scientists.

To use the lidar data, the WHRC scientists first had to calibrate it with field measurements. To accomplish this over many locations, they enlisted the assistance of a network of scholars in 12 countries around the tropics, who collected tree measurements using a standard protocol. The WHRC researchers then calibrated the lidar data by syncing the three-dimensional lidar measurements with the field measurements of forest biomass. They used some 300 ground sites—incorporating measurements of thousands of trees—as the basis for extending the field measurements to millions of samples taken from the satellite lidar data around the tropics.

Researchers input the lidar datasets into a file geodatabase and used ArcGIS to build on a satellite-derived map of pantropic biomass at 500-meter resolution. They then created a pantropic corridors map that included 16,257 corridors between 5,600 protected areas. Corridors covered 3.4 million square kilometers. Protected area boundaries were provided by the United Nations Environment Programme World Database on Protected Areas (protectedplanet.net), which is the largest assembly of data on the world's terrestrial and marine protected areas.

Esri software, ArcGIS, easily executed the repetitive process of measuring corridor surface distances. Using its analysis tools, Jantz identified pairs of protected areas connected by corridors, then estimated the biomass content of both the corridors and the network of protected areas they connect. The WHRC researchers mapped corridors in a variety of contexts including continuous forests (**Figure 1a**), fragmented forests in biodiversity hot spots (**Figure 1b**), and forests in areas with significant environmental gradients (**Figures 1c and 1d**).

The researchers used the Global Human Footprint dataset (WCS-CIESEN—Columbia University) to summarize and compare threat levels in corridors across the tropics. For a regional analysis of Brazil's Legal Amazon, where more detailed data was available, the researchers demonstrated how biological and economic information can be integrated to prioritize corridors within a specific region relative to their carbon and biodiversity co-benefits. The researchers identified 721 corridors in the Legal Amazon and prioritized them to reveal a corridor network that yielded benefits for stabilizing climate and for wildlife conservation. To do this, the researchers applied a common, multi-criteria framework called the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).* The WHRC scientists used TOPSIS to incorporate various stakeholders' objectives and identify where designated criteria fall in the ranking of these objectives.

> "PGIS proved invaluable to generate a set of potential corridor areas, biodiversity and climate change mitigation."

Criteria used for prioritizing corridors in the Legal Amazon included biomass density, mammalian species richness, endemism richness, deforestation threat, and economic opportunity cost. Data from the International Union for Conservation of Nature (IUCN) Red List was used for quantifying mammalian biodiversity in corridors. Endemism analysis is the study of a specific species that thrives in a specific area and nowhere else. Species with smaller ranges have greater priority because of their unique contribution to biodiversity. Another factor important to consider was the vulnerability of corridors to future deforestation. To determine deforestation threat, researchers used estimates of deforestation probability in the Legal Amazon from 2002 to 2030 for business-as-usual patterns of land use (Soares-Filho et al. 2006). Corridors with a higher fraction of projected forest loss were given higher priority in the TOPSIS analysis.

Combining biodiversity, biomass, and deforestation threat in the TOPSIS framework allowed the WHRC researchers to identify highly threatened corridors with high biodiversity and high biomass values. Dividing TOPSIS scores by economic opportunity cost scaled to units of US $10,000 per hectare revealed priority corridors that could be conserved at lowest cost, helping to extend scarce conservation dollars. Economic opportunity cost is the dollar loss to local communities if they do not farm, log, or graze an area. This calculation included values of soy, cattle, and timber rents over a 30-year time span and was adjusted by a 5 percent discount rate (Nepstad et al. 2009). Throughout this project, GIS proved invaluable for incorporating lidar data, satellite imagery, land-use data, biomass datasets, biodiversity information, deforestation risk indicators, economic costs, and statistical scoring methods to generate a set of potential corridor areas that could efficiently promote biodiversity and climate change mitigation.

The lidar and GIS-based study lives on today. Scientists, researchers, and others can access the biomass project dataset and maps on the WHRC website and the Esri ArcGIS Online platform. By combining these with other datasets, anyone can study forest corridors that connect protected-area ecosystems. They can use the wildlife conservation data to evaluate how corridors meet specific species' needs and facilitate species migration. The carbon stock corridor data can be used within contexts of climate change mitigation and REDD+ co-benefits for conservation. Organizations can see where deforestation is impacting carbon emission, highlight hot spots of carbon emission, and point out locations needing intervention. The information will help organizations allocate funding as well as find funding gaps.

Experience the interactive biomass map at Woods Hole Research Center website at whrc.org/mapping/pantropical/habitatcorridors/index.html.

*For future studies, WHRC researchers are considering using the ArcGIS-TOPSIS tool. It aggregates the criterion layers and weights according to TOPSIS decision rules. The user inputs raster layers and runs the tool to display the analysis layer on a map. The user can either manually input weights or use the tool to calculate weights. As the user changes the weights, the tool recalculates the equation and instantly updates the map.

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