Who studies where? Boosting tropical conservation research where it is most needed

Ana L Reboredo Segovia[1*], Donato Romano[2], and Paul R Armsworth[3]

Despite the mounting threats that tropical ecosystems face, conservation in the tropics remains severely under-researched relative to temperate systems. Efforts to address this knowledge gap have so far largely failed to analyze the relationship between an author's choice of study site and that author's country of origin. We examined factors that motivate both foreign and domestic scientists to conduct research in tropical countries, based on a sample of nearly 3000 tropical conservation research articles. Many barriers that have historically deterred foreign research effort appear to have been overcome, although US scientists still respond negatively to safety concerns and distance. The productivity of local scientists is affected by corruption and lack of institutional support. Both foreign and in-country scientists are increasingly working in places with more listed threatened species, but many regions still lack adequate conservation research. Although foreign scientists could be attracted to less-studied areas through targeted grants, the long-term solution must be to train and employ more local scientists.

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The tropics are home to the largest concentration of the world's species, but the destruction of tropical biodiversity and ecosystems is advancing at an alarming rate (Bradshaw *et al*. 2009). This is of urgent concern to the global community, which relies on tropical biodiversity for many ecosystem services (Haines-Young and Potschin 2010), including climate regulation and water resources (Lawrence and Vandecar 2015). However, conservation in tropical ecosystems is understudied as compared to temperate ecosystems. Species distribution surveys, ecological studies, and conservation research in general are skewed toward wealthier geographical locations (eg Feeley and Silman 2011; Martin *et al*. 2012; Wilson *et al*. 2016). Di Marco *et al*. (2017), for instance, found that 40% of the research articles published in three major conservation journals between 2011 and 2015 addressed conservation issues in the UK, the US, and Australia, whereas many African countries received no research attention at all. A lack of knowledge about what threats biodiversity and ecosystems face – and which approaches are most effective in addressing these threats – precludes conservation goal setting in places where informed action is most needed.

In a nutshell:

- Many tropical countries have less scientific information than necessary to set conservation goals or make conservation decisions
- International researchers often choose to conduct studies in tropical nations that possess greater numbers of threatened species
- The number of scholarly publications led by domestic scientists in tropical nations increased with greater numbers of threatened species and decreased with higher perceptions of corruption
- Local scientific training and employment opportunities need to grow; countries such as Cambodia, Haiti, and Equatorial Guinea should receive higher priority through capacity-building programs and research fellowships

Examining where scientists are coming from and where they choose to work is necessary for developing a better understanding of why some areas receive more research focus than others. Foreign scientists publish the majority of studies conducted in tropical locations (Fazey *et al*. 2005; Stocks *et al*. 2008). Nevertheless, researchers have generally sought to understand the amount of attention that tropical countries receive based solely on statistics about the countries being studied (Stocks *et al*. 2008; Wilson *et al*. 2016), instead of examining the relationship between the country where a study takes place and the country that the author(s) came from (ie point-to-point interactions). Clark (1985), for example, suggested that historical (colonial) relationships, distance, and political (in)stability could either foster or reduce research activity by foreigners but did not test these claims. Discovering what drives study location preferences by authors from countries that produce large amounts of tropical research holds implications for policy recommendations that will help to improve the distribution of conservation research effort.

In some areas, however, domination of publication output by foreign researchers is beginning to erode; for instance, Brazilian researchers have recently overtaken US authorship of articles concerning Amazonia (Malhado *et al*. 2014). Therefore, understanding what contributes to higher levels of local

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[1]*Department of Earth and Environment, Boston University, Boston, MA *(rsana@bu.edu); [2]Department of Business and Economics, University of Florence, Florence, Italy; [3]Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, TN*

research – defined as research conducted by scientists working in-country or within a non-sovereign entity (eg an overseas territory) – has implications for how local scientific initiatives can best be supported.

Our approach used statistical modeling of point-to-point interactions between countries to investigate whether factors such as colonial history, common language of instruction, distance, and trade ties influence where foreign researchers work. We also incorporated information about the study country that could or should be relevant to attracting foreign researchers, including health and wealth indices, education, relative safety, the number of threatened species within the country, and perceptions of corruption. In addition, we tested multiple factors that can affect the output of research by scientists in their own countries (as first authors and coauthors), including indices of wealth, academic institutional support, human development, corruption, safety, and the number of threatened species in the country.

Because some countries in the tropics receive much more research attention than others, we highlight several locations that receive relatively less research attention than they should, given the number of threatened species in those countries. On the basis of our results, we also suggest several ways to address these research gaps.

Methods

Data collection

We extracted data from peer-reviewed articles included in all Web of Science (WoS) databases from January 2000 to March 2016. Our search used English-language terms to scan the topic field of each record with strings that were designed to cover a wide range of conservation literature in tropical areas. The process of developing the search strings (WebPanel 1) is shown in WebTable 1.

The search resulted in nearly 35,000 articles, from which we took the first 5000 articles when sorted by relevance as a sample and employed VantagePoint Student Edition (www.vpinstitute.org) text-mining software to clean WoS fields (including the authors' countries of institutional affiliation) while referencing the original articles when necessary. The 5000 article limit was the most that this software could manage at the time of data collection. Study location was then added in Microsoft Excel. After cleaning, the sample contained 2827 records (for more details on data collection and classification, see WebPanel 2).

Our dataset was not intended to be exhaustive but rather to serve as a sample for illustrating the variation in the levels of research attention given to different tropical locations. If empirical research was carried out over multiple sites, each site would be counted separately when determining counts per country, which increased the number of records in the sample. Furthermore, with regard to collaborations, only the presence or absence of a researcher from the country of interest was recorded.

Supporting data

We used multiple factors to analyze patterns in authorship by local and foreign researchers (WebTable 2), with "foreign researcher" defined as someone using data from a place outside of their country of institutional affiliation or any of its dependencies.

We counted the number of higher education institutions offering programs in biological or life sciences (WHED 2016) for each country to examine the relationship between institutional support and local research productivity. To understand how relative wealth contributes to the productivity of local scientists, we used UN Educational, Scientific and Cultural Organization (UNESCO; http://data.uis.unesco.org) and World Bank (http://data.worldbank.org) data on per capita Gross Domestic Product (GDP) at Purchasing Power Parity (PPP) in international dollars, meaning that any unit of currency is standardized to have the same purchasing power as that of the US dollar in the US at the date of comparison. The Corruption Perceptions Index (CPI; Transparency International 2016) allowed us to estimate how corruption might influence publication by local or foreign scientists. We also evaluated whether the UN Development Programme's Human Development Index (HDI; a composite index of health, wealth, and education) is predictive of the number of foreign scientists who conduct research in a particular country, and of local researchers' productivity. We used the 2015 Global Peace Index (GPI) to determine how safety affected the productivity of local and foreign scientists (IEP 2015). The International Union for Conservation of Nature's Red List of Threatened Species (www.iucnredlist.org) was used to examine whether degree of research need attracted foreign researchers and influenced local productivity. For more information on how we determined the number of threatened species for areas that are only partially in the tropics, see WebPanel 3.

The point-to-point interactions that we considered were colonial history, trade, distance, and shared languages. Colonial history data were drawn from the Issue Correlates of War database provided by Hensel (2014), which lists the *principal* former colonial ruler of any previously colonized country. Trade data were drawn from the Central Intelligence Agency World Factbook Export Data on Major Export Partners (https://www.cia.gov/library/publications/the-world-factbook/fields/241.html), and export data from the Observatory of Economic Complexity (Simoes and Hidalgo 2011). We determined shared languages by compiling information on the languages of instruction in primary and secondary schools in all included locations (see WebTable 3 for sources). Distance between location pairs was calculated between centroids using the R package *geospheres* (Hijmans 2015).

Tropical locations lacking data for one or more variables were excluded from the analysis, and therefore all non-sovereign entities and several small countries were excluded, so that only 93 (55%) of the 168 tropical locations remained. Consequently, our analysis did not include most of the Caribbean, Melanesia, Micronesia, and Polynesia, which could weaken the effects of distance and colonial history related to research relationships with these locations (see WebTable 4 for location inclusion in the statistical models).

Data analysis

All statistical analyses were performed in R v3.3.1 (R Core Development Team 2014). We used generalized linear models (GLMs) with a negative binomial distribution to account for skewed article count data for which we could reasonably expect clustering. A log link function was used to relate the response variable to the predictors. Threatened species data were log transformed to allow for a more even spread. We explored potential collinearity between variables that could logically be related for each model; although some collinearity was expected between HDI and GDP per capita, there was enough of a difference to justify keeping both in the models ($r < 0.72$). The models were additive and we did not include interactions because we had no reason to prioritize any interaction among the variables. Model validation revealed outliers, as determined by Cook's distance, but these were allowed to remain in the regression. See WebFigure 1 and 2 for visualizations of the partial relationships of the independent variables.

To facilitate side-by-side interpretation, we ran a single model specification for countries that ranked highest in terms of the number of papers that scientists had coauthored remotely on tropical conservation (that is, the number of papers that were produced in each country about tropical conservation in other countries). We discuss only the results for three of these countries (US, UK, and Germany) because research production decreased quickly along the rank order, resulting in declining model performance.

Results

Research efforts were highly clustered. Several countries – specifically Brazil, Australia, Indonesia, Mexico, and Kenya – received a considerable portion of conservation research effort as compared to other tropical locations (Figure 1; Table 1). Articles about the top 10 locations (Table 1) accounted for 54.6% of conservation research articles focusing on tropical ecosystems.

Publication productivity by local authors declined quickly along the rank order (Table 1). The number of universities offering biological and life sciences and the log number of threatened species were both significantly positively correlated with the number of papers for which local scientists were either coauthors or first authors ($P < 0.001$) (Table 2; see also WebTable 5a for full output), but the number of universities per capita was not significantly correlated with the number of papers (WebTable 5c). The CPI of the country (the lower the CPI, the more corrupt the country is perceived to be) was also significantly positively correlated with the number of articles that local scientists coauthored ($P < 0.01$), indicating that local authors collaborate less frequently in scientific research when their government is more corrupt.

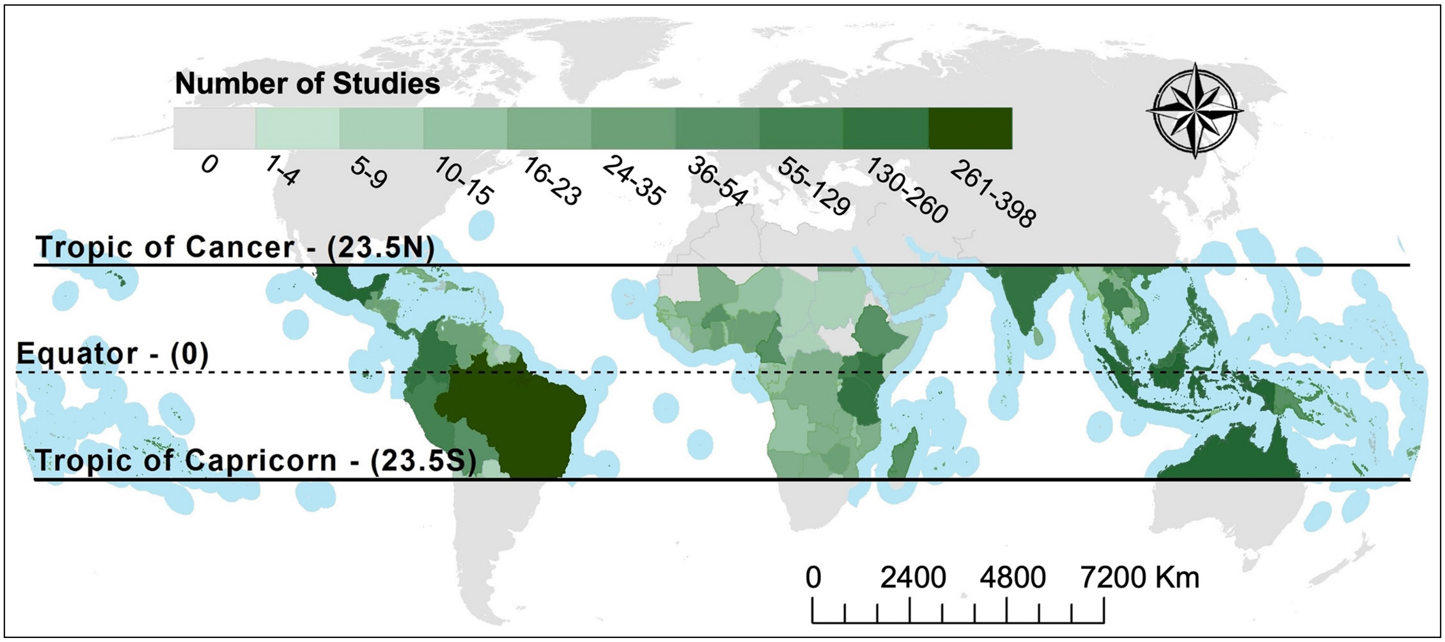

Figure 1. The distribution of tropical conservation research by location. Tropical marine and coastal regions are shown in blue (based on Marine Ecoregions of the World maps; Spalding *et al.* 2007). Class breaks were calculated using the Jenks Breaks algorithm.

Table 1. The top 10 rankings by location for number of studies (column 1), coauthorship by local scientists in articles about their own country (column 2), first authorship by in-country scientists (column 3), and remote contributions by scientists in the tropics (column 4), as well as the top 10 rankings for coauthorship by scientists from any country (column 5), first authorship by scientists from any country (column 6), and remote contributions by scientists from any country (column 7)

		Origin of author's institution: in tropics						Origin of author's institution: all locations					
# Studies		# Coauthors		# first authors		# Remote contrib		# Coauthors		# first authors		# Remote contrib	
1.BR	398	1.BR	348	1.BR	269	1.US	843	1.US	936	1.US	624	1.US	843
2.AU	260	2.AU	253	2.AU	234	2.AU	225	2.AU	479	2.AU	360	2.GB	314
3.ID	168	3.MX	121	3.MX	94	3.JP	61	3.BR	368	3.BR	272	3.DE	255
4.MX	164	4.ID	94	4.US	75	4.ZA	53	4.GB	329	4.GB	190	4.AU	225
5.KE	129	5.KE	89	5.KE	43	5.KE	31	5.DE	255	5.DE	159	5.CA	114
6.CR	89	6.US	80	6.IN	45	6.US-HI	30	6.MX	145	6.MX	101	6.NL	94
6.TZ	89	7.IN	61	7.CN	36	7.SG	25	7.FR	144	7.CA	83	7.FR	92
8.US	84	8.CO	48	8.US-HI	27	8.MX	24	7.CA	144	8.FR	67	8.JP	61
9.IN	74	9.MY	44	9.CO	24	9.BR	20	9.KE	120	9.KE	56	9. BE	58
10.MY	73	10.CN	43	10.ID	23	10.ID	18	10.ID	112	10.NL	51	10.ZA	53
10.PH	73									10.JP	51	10.SE	53

Notes: Country codes listed in alphabetical order – AU = Australia, BE = Belgium, BR = Brazil, CA = Canada, CN = China, CO = Colombia, CR = Costa Rica, DE = Germany, FR = France, GB = United Kingdom, ID = Indonesia, IN = India, JP = Japan, KE = Kenya, MX = Mexico, MY = Malaysia, NL = The Netherlands, PH = The Philippines, SE = Sweden, SG = Singapore, TZ = Tanzania, US = United States, US-HI = US state of Hawaii, ZA = South Africa.

Table 2. The output from generalized linear models on the factors affecting levels of in-country coauthorship and first authorship on conservation research articles (left, local research, *n* = 93), and the factors affecting where authors from the top remotely contributing countries choose to work the most (right, foreign research, *n* = 93)

Local research					Foreign research					
Authorship category/ country	Coauthorship		First authorship		US (*n* = 91)		UK		Germany	
Independent variable	Coeff	*P* value	Coeff	*P* value	Coeff	*P* value	Coeff	*P* value	Coeff	*P* value
GDP per capita (PPP current intl $)										
# Universities offering biology and life sciences	+	***[2]	+	***[2]						
Human Development Index									–	**
Global Peace Index					–	*				
Corruption Perceptions Index	+	**								
Log (threatened species)	+	***	+	***	+	***	+	***	+	***
Trade										
Common language of instruction									N/A	N/A
Colonial history									N/A	N/A
Distance					–		[1]			

Notes: all models are additive. Factors unused in the model specification are shaded. Significance codes: < 0.001***, < 0.01**, < 0.05*. [1] Distance becomes significant if trade is removed as a factor (*P* = 0.027). [2] Universities offering biological or life sciences becomes insignificant if calculated per capita (WebTable 5c). "NA" indicates that the variable is not applicable.

As the publication of articles by local authors declined (Table 1), articles from foreign authors became the largest sources of conservation research. Figure 2 and WebFigure 3 show where foreign scientists most often work, revealing apparent geographical differences in their preferences. As can be seen in WebFigure 3, Australian, Japanese, and South African scientists publish more papers in countries within their regions.

The statistical models suggested that the log number of threatened species is consistently a highly significant positive factor attracting foreign scientists (Table 2; see also WebTable 5b for full output) – this is true even for countries for which we do not show results, such as Australia, Canada, The Netherlands, France, and Belgium. For authors affiliated with US institutions, the GPI of the tropical country (the higher the GPI, the poorer the security level) was significantly negatively correlated with the number of studies ($P = 0.02$), meaning that fewer studies were conducted in areas that were less safe; German scientists were found to conduct more studies in countries with a lower HDI than in those with a higher HDI.

When considering all tropical locations other than the Scattered Islands in the Indian Ocean (no data were available for these islands), the ranked number of threatened species correlated positively with the number of conservation research articles ($\tau = 0.46$, $P < 0.001$, $n = 167$). Figure 3 shows the positive relationship between the log number of studies and the log number of threatened species, allowing for a comparison of conservation research effort.

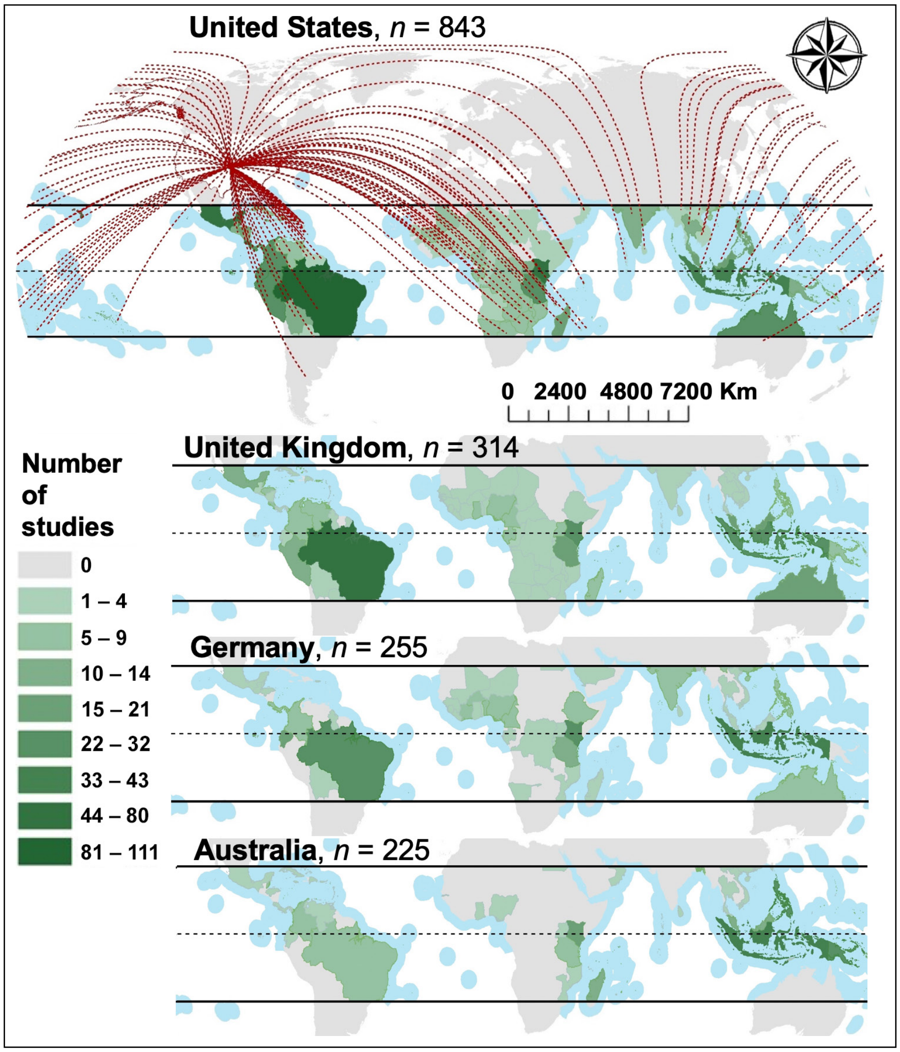

Figure 2. Geographical distribution of where authors affiliated with foreign institutions work in tropical locations. The four countries with the highest level of participation in publications focusing on countries other than their own (US, UK, Germany, and Australia) are shown here. Tropical marine and coastal regions are shown in blue (based on Marine Ecoregions of the World maps; Spalding *et al.* 2007). Class breaks were calculated using the Jenks Breaks algorithm.

Discussion

The point-to-point analysis enabled us to identify where and how to target future research for optimal conservation outcomes. Our analysis indicates that colonial history does not explain conservation research effort by foreign authors from countries that rank highest in tropical conservation research, nor were common languages of instruction or trade ties with tropical countries significant factors. US-based scientists tended to be attracted to safer areas and areas containing higher numbers of threatened species, a finding consistent with that of Amano and Sutherland (2013), who reported links between safety and the amount of biodiversity data collection in a country, and with Doi and Takahara (2016), who found positive correlations between conservation research articles and the number of threatened species. Distance was a significant factor for US-based scientists when trade ties were not included in the model but was not significant for UK or German scientists.

For UK-based scientists, the only significant variable was the number of threatened species. German scientists, in addition to publishing more in areas containing greater numbers of threatened species, also produced more research in countries with lower HDIs, suggesting that German researchers are responding to a perceived lack of research capacity in these countries.

Levels of in-country study, however, were not significantly influenced by HDI or by security (GPI). When HDI was excluded from the model, GDP per capita became significant in explaining local collaboration, a result consistent with that of Wilson *et al.* (2016), who found a positive correlation between research spending as a proportion of GDP and the number of articles published by in-country scientists. The number of higher education institutions that offer biological and life sciences – and presumably the research jobs that they create – was influential in determining local coauthorship of conservation research, but there was no correlation between the number of universities offering these programs per capita

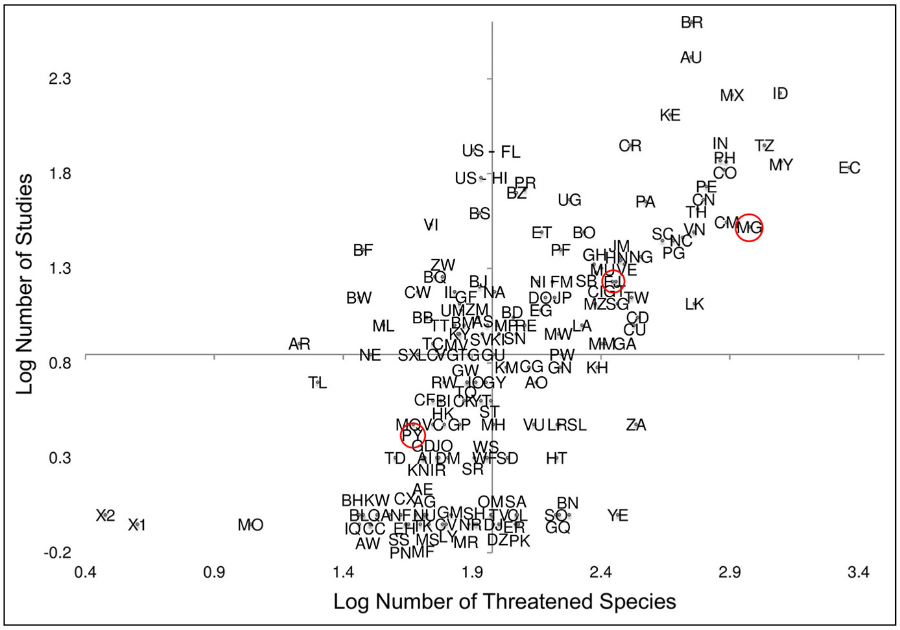

Figure 3. The relative amount of conservation research per tropical location (gray dots), denoted by 3166-1 alpha-2 codes, versus the number of threatened species. Quadrants are drawn with media lines. Location name labels are positioned for legibility but retain their placement about the median and relative to each other whenever possible. Circled codes MG, FJ, and PY refer to the countries mentioned in Figure 4.

and in-country research output, probably because the total number of trained individuals is more predictive of bulk output per country than the proportion of the population that they represent. Higher corruption perceptions also had a negative influence on the number of publications that local authors participated in, which could be due to a lack of encouragement or support for knowledge as a basis for decision making, or a lack of effective investment in science.

Most of the publications in the sample derived from English-language sources, which do not account for gray literature publications. There were also relevant variables that we did not consider due to the difficulty in obtaining data, such as legacy effects, the presence of research stations, institutional partnerships, and the difficulty of bureaucratic procedures. Our models should therefore be interpreted taking these biases into account.

It is encouraging that we found a positive relationship between the number of threatened species and the number of conservation research articles; however, using threatened species to determine research need makes it difficult to assess the direction of causality. Because the number of threatened species is highly correlated with species richness, our results also likely support the notion that conservation scientists tend to work in species-rich areas. Areas that attract initial attention may positively reinforce the amount of biodiversity and threatened species data in that location because increased funding for research leads to more species being discovered and assessed (Ahrends *et al.* 2011). We are therefore not claiming that research is going where it is most needed; rather, research in a particular location is possibly promoting the discovery of more threatened species. There were several areas that nevertheless received less than the median log number of research articles yet had more than the median log number of recorded threatened species (see Figure 3), including Angola, Brunei Darussalam, Cambodia, the Comoros, the Congo, Djibouti, Equatorial Guinea, Eritrea, Guinea, Haiti, Liberia, the Marshall Islands, Sierra Leone, Somalia, Sudan, Vanuatu, and Yemen. Of these, several are relatively unsafe; Somalia and Yemen ranked 4th and 11th in GPI, respectively, among all tropical countries. However, many of the other countries rank as safer than Mexico, which receives substantial conservation research, and could be considered as good places to begin or expand conservation research projects.

Areas where basic knowledge is lacking deserve to be tackled with the same intensity as areas that allow for more nuanced data analysis. Foreign scientists working in locations that receive a substantial amount of external and in-country research attention could be encouraged to consider similar ecosystems in different countries through targeted grants. For example, scientists working in Costa Rica and Panama could be incentivized to do research in less-studied Central American countries, like El Salvador, Guatemala, Honduras, or Nicaragua. Funding could also be targeted to bolster conservation research in regional research hubs. South African scientists tend to conduct research in generally underserved surrounding countries, and could probably produce more with increased external funding for international research (WebFigure 3).

However, the long-term solution is to support the development of local conservation science. Conservation research funding is largely dependent on government investments, but the international community can do more to support scientific development in under-researched countries (including understudied temperate countries, which often face the same challenges as their tropical counterparts). To locate examples of successful capacity-building models that could be used to inform other programs, we looked at efforts in countries spread along the distribution in Figure 3 that, judging from the short deviations from the mean, are receiving an amount of research that is relatively proportional to the number of threatened species. For example, Julia Jones, a professor in conservation science at Bangor University in the UK, has been given funding to help support UK research residencies for Malagasy collaborators, allowing them to access library resources and training in statistical methods, which has improved the quantity and quality of research outputs (Figure 4a). Scientists can help remove barriers to higher education for students from understudied areas, and funding agencies can create fellowship and grant opportunities for training and research. We list some of these opportunities and possible solutions in WebPanel 4.

Private companies can also be local funders of conservation science and can provide collaboration opportunities. For example, researchers with the Smithsonian Institution in the US work with staff biologists from Itaipu Binacional–Paraguay, a hydroelectric company, to develop monitoring plans for protected areas and analyze how to improve connectivity in Paraguay. This collaboration has led to company scientists gaining experience in and receiving support for writing scientific papers (Figure 4b). Collaborations between academics and scientists working with ecotourism companies can also be advantageous; scientists working for ecotourism operations are capable of identifying relevant research questions and carrying out long-term projects but often lack the institutional framework to publish research.

Engagement with government scientists represents another potential avenue for capacity building. For example, scientists from the US-based Wildlife Conservation Society (WCS) collaborate with personnel from the Fiji Ministry of Fisheries to identify problems and develop analyses that will inform decision making. As a result, ministry scientists and staff develop skills in research methods and analysis while WCS scientists generate impactful research that is relevant and linked to national management priorities and policies (Figure 4c).

Conclusions

Viewing the tropical conservation research gap as a discrepancy between where authors choose to conduct research and where those authors currently reside reveals why there is more conservation research in some tropical countries than in others. Many scientists and educational institutions are already working creatively to reduce the research capacity gap (see WebPanel 4), but it is up to each researcher and organization to give serious thought to how they can reduce the research opportunity gap in the places where they work. Scientists at all stages of their careers can use information about which locations receive less research attention to plan their research projects and produce much-needed information and analysis to support conservation decision making.

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J Jones, Bangor University

Itaipu Binacional–Paraguay

S Mangubhai, Wildlife Conservation Society

Figure 4. Capacity-building efforts in (a) Madagascar, (b) Paraguay, and (c) Fiji.

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Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.2146/suppinfo