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REVIEW

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From plots to policy: How to ensure long-term forest plot data supports environmental management in intact tropical forest landscapes

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Societal Impact Statement

The approach that we take to our science is as important as the questions that we address if we would like our research to inform management. Here, we discuss our experience of using networks of permanent forest inventory plots to support sustainable management and conservation of intact tropical forests. A key conclusion is that to maximize the use of data from such large international networks within policymaking, it is crucial that leadership is widely shared among participants. Such an approach helps to address ethical concerns surrounding international collaborations and also achieves greater policy impact.

Summary: Long-term data from permanent forest inventory plots have much to offer the management and conservation of intact tropical forest landscapes. Knowledge of the growth and mortality rates of economically important species, forest carbon balance, and the impact of climate change on forest composition are all central to effective management. However, this information is rarely integrated within the policymaking process. The problem reflects broader issues in using evidence to influence environmental management, and in particular, the need to engage with potential users beyond the collection and publication of high-quality data. To ensure permanent plot data are used, (a) key “policy windows”—opportunities to integrate data within policy making—need to be identified; (b) long-term relationships need to be developed between scientists and policy makers and policymaking organizations; and (c) leadership of plot networks needs to be shared among all participants, and particularly between institutions in the global north and those in tropical countries. Addressing these issues will allow permanent plot networks to make tangible contributions to ensuring that intact tropical forest persists over coming decades.

KEYWORDS
carbon, climate change, conservation, forest management, monitoring, permanent plot, policy impact, tropical forest

1 | INTRODUCTION

Intact tropical forests are home to a wide range of indigenous groups, contain large stores of biodiversity and carbon and provide resources that support local communities and underpin the global economy. However, these ecosystems are highly threatened as alternative land-uses often offer higher economic returns (Edwards et al., 2019; Watson et al., 2018). A key route to promote sustainable management of these landscapes is to increase the value of the ecosystem services that are provided by standing forest (Álvarez Alonso, 2019; Nobre et al., 2016). To achieve this goal, both users and environmental managers need to know the distribution and trajectory of forest resources. Permanent forest inventory plots, where each tree above a given minimum diameter is tagged, identified, and periodically re-measured in a demarcated area, are well suited to providing such ecological information about the tree species within these forests. However, perhaps surprisingly given the obvious value of these data for timber or carbon management (e.g., Condit, 1993; Phillips, Brienen, & RAINFOR collaboration, 2017), the use of permanent plot data to inform environmental policy in tropical forest landscapes remains limited. We therefore review the possible uses of permanent plot data within management, reflect on the bottlenecks for achieving tangible impacts and propose solutions to ensure that they play their part in addressing the many threats that intact tropical forests face today.

Ecological studies in tropical forests using permanent plots initially focussed on addressing questions about how many species were found in these forests (e.g., Murça Pires, Dobzhansky, & Black, 1953). This work led to studies of how estimates of point, or alpha, diversity varied in space (e.g., Gentry, 1988) which then expanded to consider how composition, or beta diversity, varied across tropical forest landscapes (e.g., Hall & Swaine, 1976; ter Steege et al., 2000; Terborgh & Andresen, 1998). Revisiting these plots to remeasure the surviving trees, record those which had died and identify new recruits allowed the first studies of tropical forest dynamics (e.g., Condit, Hubbell, & Foster, 1995; Lieberman & Lieberman, 1987; Phillips, Hall, Gentry, Sawyer, & Vasquez, 1994; Swaine & Hall, 1986; Swaine, Hall, & Alexander, 1987) and the mechanisms that underpin species coexistence (e.g., Harms, Condit, Hubbell, & Foster, 2001; Hubbell et al., 1999; Wills et al., 2006). Subsequently, the ability to use permanent plot data to quantify the carbon stocks of these ecosystems led to the development of plot networks to probe the carbon balance of tropical forest landscapes (e.g., Baker et al., 2004a, 2004b; Brienen et al., 2015; Hubau et al., 2020; Lewis et al., 2009; Phillips et al., 1998; Qie et al., 2017; ForestPlots.net, in press). Permanent plots have also become a key tool within ecosystem science for understanding how tropical forests respond to drought and long-term increases in temperature and atmospheric carbon dioxide (e.g., Esquivel-Muelbert et al., 2019; Fauset et al., 2012; Hubau et al., 2020; Rowland et al., 2015). At the same time, their value to taxonomists for documenting new species, understanding evolutionary processes and how those processes link to ecosystem function has also been recognised (e.g., Baker et al., 2014, 2017; Coelho de Souza et al., 2016, 2019), and their use for validating and calibrating vegetation models and maps of forest structure, composition and change based on remote sensing data continues to increase (e.g., Avitabile et al., 2016; Johnson et al., 2016). Overall, permanent inventory plots have therefore been an important starting point for the development of research in tropical forests, and their establishment has catalyzed scientific advances across a wide range of fields.

However, despite this expansion of the breadth of research using permanent plot data, there is a substantial opportunity to expand the use of these networks to support management. The gap between scientific research using plot data and policy is partly a reflection of the comparatively recent emergence of some current management issues compared to the historical reasons for the establishment of permanent plots. For example, although some of the earliest permanent plots were established to support timber management (Alder, 1995; Jones, 1955; Synnott, 1979), the need for carbon management and strategies to enhance the resilience of ecosystems to climate change are relatively recent developments. The gap between research using permanent plots and the use of these data to inform management is also apparent now because the potential to supply useful information has greatly increased as plot networks have expanded (ForestPlots.net, in press). The expansion of these networks of plots has opened up important opportunities to use these data to inform management within tropical forest landscapes.

2 | THE POTENTIAL VALUE OF PERMANENT PLOTS FOR POLICY

The potential uses of permanent plot data within management in intact tropical forest landscapes can be summarized as quantifying the state and trajectory of a range of ecosystem services. For example, plot data can be used to understand how forest structure and composition varies spatially to address questions such as “how much timber or what quantity of non-timber forest products (NTFPs) are found in this area of intact tropical forest?”. Such questions about provisioning ecosystem services can be extended to consider, for example, “what is a sustainable harvesting level for this species given the risk of climate change?”. This kind of question requires data on the growth, mortality rates, and long-term trajectory of species populations. Secondly, these data may be used to quantify regulating ecosystem services, such as long-term changes in composition and carbon stocks, to ask, for example, whether intact tropical forests are acting as a sink or source of carbon. We consider examples of each of these possible uses in turn.

2.1 | What level of provisioning ecosystem services can be provided sustainably by tropical forests?

Timber and forest products such as fruits and fibres are key provisioning services provided by intact tropical forests (Peters, Gentry, & Mendelsohn, 1989; Piponiot et al., 2019) and the use of growth and mortality data for supporting timber management is perhaps the most obvious potential use of permanent plot data. Some of the oldest permanent plots were established to collect data to predict timber yield and define harvesting limits (Hall, 1977; Jones, 1955) as permanent plot data on the diameter growth rates and survivorship of timber species are ideally suited for use within growth and yield models to predict harvesting levels (Alder, 1995; Vanclay, 1994). Many studies have explored how growth rates vary among species, size classes, and environmental conditions from the perspective of timber management (e.g., Brown et al., 1995; Condit, Hubbell, & Foster, 1993; Finegan, Camacho, & Zamora, 1999; Nebel & Meilby, 2005; Rondon, Gorchov, & Noble, 2009) and permanent plot data have been used to calibrate models of timber yields at regional scales across Amazonia (Piponiot et al., 2019). In some cases, data on forest growth and dynamics have also been integrated within guidelines for timber extraction. For example, in Mexico, yields tropical forests under the *Plan Piloto Forestal de Quitana Roo* depend on the size distribution and growth rates of species that are extracted (Torres-Rojo, Moreno-Sánchez, & Mendoza-Briseño, 2016). However, despite the many ecological and modeling studies, growth and yield models that incorporate how tree growth and mortality rates vary with environmental conditions and among species are often not used as the basis of timber management policy (Andrade et al., 2019; Hubbell & Foster, 1992). For example, in both Brazil and Peru, the only taxa-specific information within the policy framework for timber extraction concerns the definition of minimum harvesting sizes (Andrade et al., 2019; Rondon et al., 2009) which is an approach that excludes much basic ecological information about different timber species. For example, one of the most heavily exploited commercial “species” in the Peruvian Amazon is termed “cumala” and represents any one of > 40 species of tree within the Myristicaceae. Permanent plot data demonstrate that the three principal Neotropical genera of “cumala” (*Virola*, *Iryanthera*, and *Otoba*) have different maximum sizes and diameter growth rates (Figure 1a,b), which implies that different diameter limits and harvesting intensities should be applied to the different taxa. However, this ecological knowledge is not currently incorporated in the management of “cumala” in Peruvian forests.

Permanent plot data are also valuable for supporting sustainable management of species that provide NTFPs. For example, in the Peruvian Amazon stems of the palm *Euterpe precatoria*, or “huasai”, are cut to provide “heart of palm,” a foodstuff consumed locally and sold in regional markets (Kvist, Andersen, Stagegaard, Hesselsøe, & Llapapasca, 2001; Schulz et al., 2019). As harvesting involves killing the plant, sustainable management should only allow harvesting to a level that can be replaced by recruitment. Permanent plot data indicate that in contrast to long-lived, large-statured timber species, populations of *Euterpe precatoria*

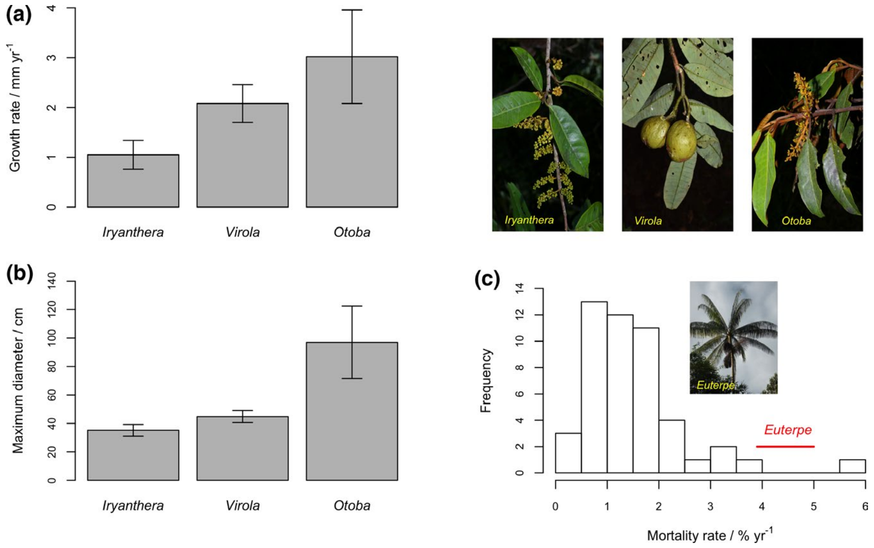

FIGURE 1 Variation in (a) median diameter growth rates and (b) maximum diameter among species within *Iryanthera* (6 species; 321 individuals ≥ 10 cm diameter), *Virola* (5 species; 374 individuals ≥ 10 cm diameter) and *Otoba* (2 species; 621 individuals ≥ 10 cm diameter) from permanent plots covering 44 ha in the Peruvian Amazon. Error bars represent one standard error; data from Dávila, Honorio, and Salazar (2008). (c) Range of recruitment and mortality rates of *Euterpe precatoria* from permanent plot data in the Peruvian Amazon (red line) in comparison to annual mortality rates for 48 genera of trees from across Amazonia. Data from Baker et al. (2014)

turnover rapidly (annual recruitment and mortality rates of 5% and 3.9% respectively for trees ≥ 10 cm diameter, Figure 1c; Esquivel-Muelbert et al., 2018). This species is therefore potentially suitable for sustainable management where densities of this species are high, if harvesting quotas reflect the ecological potential of populations to recover. However, current management plans for this species within Pacaya Samiria National Park in the Peruvian Amazon indicate that communities may harvest up to 20% of the existing stand per year (Ochoa, 2014), which is clearly above the capacity of these systems to regenerate. This example illustrates the broader finding that quotas set for NTFP harvesting may often be ecologically unsustainable (Ticktin, 2004) and raises concerns about promoting NTFP extraction within protected areas. Plots are also a platform for studies of the additional parameters that are also required to support sustainable management of NTFPs, such as seedling regeneration (e.g., for Brazil nut; Wadt, Kainer, Staudhammer, & Serrano, 2008) and the impact of extraction activities (e.g., for reduced impact logging in Brazil; West, Vidal, & Putz, 2014). Overall, for both timber and forest products, permanent plots in intact forest can provide the baseline information on population dynamics within intact forests that can be used to set ecologically informed harvesting limits.

2.2 | What level of regulating ecosystem services are provided by tropical forests?

The key regulating ecosystem service provided by intact tropical forests that can be quantified using permanent plots is their role as a store of carbon (Hubau et al., 2020; Sullivan et al., 2017, 2020). Permanent plot data can be used in conjunction with remote sensing data to calibrate maps of carbon storage, identify forest ecosystems that are hotspots of carbon storage, and crucially, identify whether intact tropical forests are acting as a source or sink of carbon. For example, the wide range of existing and emerging remote sensing technologies require ground-reference data from plots to produce calibrated maps of carbon stocks (e.g., Avitabile et al., 2016; Chave et al., 2019). These maps of carbon stocks can be used in conjunction with maps of deforestation, degradation, and regrowth to quantify emissions from land-use change as part of national reporting to the United Nations Framework Convention on Climate Change (UNFCCC; Melo et al., 2018) and to support the development of national climate change mitigation strategies (e.g., carbon based conservation in Ghana; Forest Preservation Programme, 2013). Of course, plots do not need to be re-visited and therefore established as "permanent" plots to obtain information about spatial variation in forest carbon stocks. However, the standardized methods that these long-term networks apply for data collection and curation are a key advantage of using these data for quantifying carbon stocks, as differences among protocols for measuring large trees or variation in the level of identification of tree species influences the precision and accuracy of estimates of biomass (Baker et al., 2004a, 2004b; Hubbell & Foster, 1992).

The use of plot data to identify and promote conservation of hotspots of carbon storage is exemplified by the recent description and mapping of areas of tropical peatland in Peru and the Congo basin (Dargie et al., 2017; Draper et al., 2014; Lähteenoja, Ruokolainen, Schulman, & Oinonen, 2009). For example, detailed measurements of the below- and above-ground carbon stores in the peatlands of Pastaza Marañon basin in the northern Peruvian Amazon demonstrated that this landscape is the most carbon-dense region of Amazonia (Draper et al., 2014; Lähteenoja et al., 2009). This finding was subsequently used by the Peruvian Fund for Conservation (PROFONANPE) to obtain funding from the Green Climate Fund to implement sustainable management projects in the region (Roucoux et al., 2017), and by the Peruvian Protected Areas Authority (SERNANP) to justify the designation of the 8,689 km^2 Yaguas National Park in the northern Peruvian Amazon (Baker, del Castillo Torres, et al., 2019).

Finally, repeated measurements of changes in carbon stocks over time in permanent plots allow the role of intact tropical forests as a source or sink of carbon to be quantified (Brienen et al., 2015; Hubau et al., 2020). The relatively small changes in biomass that occur over time in intact forests, means that these trends can currently only be reliably detected using permanent plot networks, rather than by using remote sensing technology. Over recent decades, permanent plot data have been used to show that intact tropical forests have acted as a substantial carbon sink (Brienen et al., 2015; Hubau et al., 2020), and at national scales within tropical forest countries, this carbon sink can offset emissions from land-use change (Phillips et al., 2017; Vicuña Miñano et al., 2018). Changes in the carbon stocks of intact forests can be reported by countries to the UNFCCC as part of national inventories of greenhouse gas emissions: average values for different continents (or Tier 1 values), based on permanent plot data, are now available (Requena Suarez et al., 2019), while national-level estimates based on permanent plot networks provide a basis for reporting more refined country-specific (Tier 2 and 3) estimates (e.g., Vicuña Miñano et al., 2018 for Peru). Crucially, recognizing and monitoring the role that intact tropical forests play as a carbon sink presents an opportunity to promote and finance conservation and sustainable management of these landscapes (Vicuña Miñano et al., 2018).

It is important to note that the potential use of plot data for management also extends beyond intact tropical forest landscapes. For example, plot data can provide baseline information to understand the impact of land-use change and pollution events, such as oil spills, on forest structure and composition. In addition, these sites can also be used to identify appropriate species and provide seeds to support plantation development and reforestation projects. As illustrated by the example of "cumala" above, our lack of basic ecological knowledge of much of the tree diversity of these ecosystems, hinders our ability to use species within these kinds of forestry initiatives. Finally, permanent plots will also continue to be crucial to validate and calibrate efforts to map the changing ecosystem services provided by tropical forests at large scales using the expanding range of remote sensing technologies.

3 | BOTTLENECKS AND SOLUTIONS FOR ACHIEVING POLICY IMPACT

Despite the wide variety of potential uses of permanent plot data to support conservation and management in tropical forest countries, these data are rarely utilized fully to inform policy. Calls for greater integration of this kind of ecological data within management are not new. Almost three decades ago, Hubbell and Foster (1992) discussed the value of data on the dynamics of tropical forest species for conservation in the context of the then recently established 50 ha plot on Barro Colorado Island, Panama. In the intervening years, great progress has been made in relation to one of the issues that prevented this goal being achieved—a lack of data—through the expansion of permanent plot networks throughout the tropics (e.g., Anderson-Teixeira et al., 2015; DRYFLOR, 2016; Lewis et al., 2009; Malhi et al., 2002). Cyber infrastructure, such as ForestPlots.net, has been developed to share these data internationally among collaborators (ForestPlots.net, in press; Lopez-Gonzalez, Lewis, Burkitt, & Phillips, 2011; Lopez-Gonzalez, Lewis, Phillips, Burkitt, & Baker, 2012). The reasons for the lack of integration within policy therefore reflect the more general difficulties for achieving tangible impacts of research on environmental management, which involves issues that move far beyond the provision of relevant information (Reed, Stringer, Fazey, Evely, & Kruijsen, 2014). Influencing policy requires more than simply providing data to users or publishing in academic journals (Oliver & Cairney, 2019): it requires ecologists to invest in bridging the gap to policy, or, perhaps more accurately, to occupy the space where interaction with stakeholders is possible (Toomey, Knight, & Barlow, 2017).

There are three principal reasons why policy impact using permanent plot data from tropical forest landscapes is not successfully realized. Firstly, specific opportunities for achieving policy change are often not identified by researchers (Oliver & Cairney, 2019; Rose et al., 2017). Secondly, for the most part, insufficient effort is made to develop the long-term relationships between academic researchers and practitioners that are essential for promoting trust in the use of the information and to allow research findings and policy needs to be linked (Reed et al., 2014). Thirdly, and perhaps most relevant to permanent plot networks in the tropics, leadership needs to be shared among participants, and in particular, be shared equitably among tropical forest countries and with nations in the global north, as well as between academic researchers and practitioners.

Understanding, identifying, and responding to specific "policy windows" is crucial for achieving tangible impacts from research findings (Oliver & Cairney, 2019; Rose et al., 2017). Opportunities for using data from permanent plots can appear fleetingly as political agendas and institutions evolve, and researchers need to be able to respond to opportunities as they appear. For example, the Twentieth Conference of the Parties (COP20) of the UNFCCC in Lima, Peru in 2014 provided a platform for discussing recent work describing the high carbon stocks of the peatlands of the Peruvian Amazon with policymakers (Draper et al., 2014). Peru was simultaneously acting as chair of the steering committee of the emerging Green Climate Fund (GCF) which was set up by the UNFCCC to fund projects to adapt to, and mitigate, climate change. As a result, the Peruvian government was strongly interested in developing carbon conservation projects and the Peruvian Trust Fund for National Parks and Protected Areas (PROFONANPE) drew on the data published in Draper et al. (2014) to apply to the GCF, ultimately successfully, to implement a programme of sustainable management activities in order to protect the high carbon stocks of the Peruvian wetlands (Baker, del Castillo Torres, et al., 2019; Roucoux et al., 2017). Understanding the timing and frequency of policy decisions and meetings is important in order to be prepared to engage with policymakers at both an international level, through the UNFCCC or Convention on Biological Diversity, and at a national level to contribute to the renewal of national biodiversity plans, threatened species lists and protected area and species-level management plans.

More broadly, identifying policy windows needs to be part of a strategy to prioritize engagement activities based on the likelihood that any given opportunity will yield success. As part of this, researchers and policymakers need to evaluate the level of importance of different competing needs for data and the potential benefit for management. Researchers also need to communicate honestly the realities of existing data, as the high diversity and consequent rarity of many species in tropical forests means that precise species-level data on growth, mortality, and recruitment rates are often difficult to obtain. However, it is important to note that findings of ecological research in permanent plot networks can be used to frame appropriate generalizations to inform policy even in the absence of perfect data. Researchers can advise to what extent results from comparable sites, similar functional groups of organisms or higher-level taxa such as genera and families, are appropriate for informing management in any specific setting. Overall, although achieving impact on policy may often include a fortuitous combination of circumstances, researchers need to evaluate which opportunities will most likely lead to tangible, long-term outcomes in order to allocate time and resources appropriately.

Secondly, the well-recognized requirement to develop strong, long-term trusting relationships between generators and users of data is crucial for achieving policy impact (Oliver & Cairney, 2019; Reed et al., 2014). The integration of knowledge into policy depends not on the data itself, but on the networks and relationships that link scientists and practitioners and the social interactions among them (Oliver & Faul, 2018). Strong, long-term relationships allow, over time, the requirements of users to be closely matched to the information that permanent plot networks can provide, policymaking opportunities to be taken when they occur, and the production of knowledge that is tailored to national contexts. For example, over recent decades, permanent plots have recorded how intact tropical forests have acted as a carbon sink and accumulated globally important amounts of carbon (Brienen et al., 2015), but, despite its importance for the carbon balance of many tropical forest nations (Phillips et al., 2017), this finding is typically not included in national-level reporting of carbon emissions. We responded to this need in Peru by expanding the in-country forest plot network with forest monitoring specialists at the Instituto de Investigaciones de la Amazonia Peruana (IIAP), botanical experts at the Jardín Botanico de Missouri (JBM) and colleagues at the Peruvian Protected Areas Authority (SERNANP) who have a responsibility to report on the status of forests within the protected area network. We used the plot data to analyze and publish the trajectory of the carbon sink in intact forests at a national level (Miñano Vicuña et al., 2018). This process allowed us to understand how the findings from the permanent plot data could be fitted within the policy framework and increased the visibility of this key result to policy makers. Ultimately as a result of this work, monitoring the carbon sink of intact tropical forests was made a national priority as part of Peru's activities for responding to climate change (Gobierno del Peru, 2018).

Of course, researchers who invest in long-term relationships with partner organizations to achieve policy impact may not see an immediate benefit, as policy impact may not occur rapidly (Oliver & Cairney, 2019). “Long term” in this context means maintaining relationships far beyond the lifetime of a typical, 3–5-year funded research project: it is an endeavor measured in decades that stretches across multiple periods of funded and informal, unfunded engagement. From a researchers’ perspective, this means prioritizing supporting collaborations even when the focus of funding opportunities shifts, rather than shifting the location of the research. Adopting this strategy imposes a cost on researchers as it takes time to develop and maintain these links, with inevitable trade-offs for other activities. As a result, the time lag for achieving impact can act as a barrier to initiating engagement. However, our experience with permanent plot networks is that investing in these kinds of relationships pays back richly over the long term in terms of the accumulation of shared knowledge and policy impacts. We also note the importance of investment in roles that link scientists and practitioners, or “boundary spanner” positions for overcoming this barrier (Cook, Mascia, Schwartz, Possingham, & Fuller, 2013; Posner & Cvitanovic, 2019). These roles accelerate the process of integrating research within policymaking (Cook et al., 2013), and therefore reduce the short-term costs to researchers of engagement.

Thirdly, and perhaps most fundamentally, is that maximizing policy impact requires research projects to share leadership both among academic institutions in tropical forest countries and the global north as well as between academic institutions and policymaking partners. Their well-established networks of contacts and detailed understanding of the national policymaking context means that scientists in research institutions in tropical forest countries are best placed to engage with national government institutions and NGOs to promote the use of these data. These institutions are also far more able to sustain long-term involvement with the policymaking process, which is essential to ensure that research findings are integrated within management. If leadership of the research is not shared, then opportunities to inform policy will be missed.

Fully recognizing the crucial role of institutions in tropical forest countries for maximizing policy impact is also a means to rebalance the often asymmetrical relationships in international scientific research between researchers in the global north and south (Baker, Eichhorn, & Griffiths, 2019; Malhado, 2011). In terms of plot networks, this asymmetry occurs because data providers are typically located in tropical forest countries, whereas the users of these data, for large-scale ecological analysis, development of vegetation models or calibration of remote sensing products, are often institutions and individuals in the global north. It is important to recognise that similar imbalances between data users and providers also occur both among and within tropical forest countries. This type of asymmetry is found in many fields and demands us to think carefully about the role of international researchers in tropical countries, where their presence is a “privilege and not a right” (Riley & Bezanson, 2018; de Vos, 2020).

Clearly, international networks of permanent plots need ethical working practices that promote enduring and equitable relationships among all participants (Eichhorn, 2019). Firstly, it is incumbent on all of us to recognise and support the task of generating the datasets that underpin all of the research. Secondly, these networks need to promote greater investment of research funding in institutions in tropical forest countries from both in-country and external sources. Thirdly, these networks need to commit to ensure that institutions in tropical countries lead high-level data analysis and outputs. In our experience in Peru, the permanent plot network has endured in part because successive generations of international researchers have committed to investing in data collection and capacity building, which is helping to dissolve the distinction between data users in the global north and data originators in tropical forest countries. This investment in long-term collaborations with researchers and institutions in tropical forest countries has also promoted the integration of these data within policy. Recognizing the value of the policy impact that can be achieved through shared leadership of research within permanent plot networks should be used a lever to generate more equitable relationships among the organizations that are involved. Such a commitment to shared leadership helps to maintain the sustainability of these long-term research networks, addresses ethical concerns surrounding international collaborations and also achieves greater policy impact.

Permanent plot networks in the tropics provide unique information about the structure and long-term trajectory of these ecosystems and act as a platform for an increasing breadth of science. By focussing on how we can integrate the findings within policy, we can also ensure that these data realise their potential for supporting the conservation and sustainable management of tropical forests over coming decades.

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AUTHOR CONTRIBUTIONS

TRB planned and wrote the article. All authors contributed to leading different aspects of our work developing and using networks of permanent plots, discussing this synthesis and editing the manuscript.

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