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Vertebrate biodiversity on indigenous-managed lands in Australia, Brazil, and Canada equals that in protected areas

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ABSTRACT

Declines in global biodiversity due to land conversion and habitat loss are driving a 'Sixth Mass Extinction' and many countries fall short of meeting even nominal targets for land protection. We explored how such shortfalls in Australia, Brazil and Canada might be addressed by enhancing partnerships between Indigenous communities and other government agencies that recognize and reward the existing contributions of Indigenous-managed lands to global biodiversity conservation, and their potential contribution to meeting international treaty targets. We found that Indigenous-managed lands were slightly more vertebrate species rich than existing protected areas in all three countries, and in Brazil and Canada, that they supported more threatened vertebrate species than existing protected areas or randomly selected non-protected areas. Our results suggest that overall, Indigenous-managed lands and existing protected areas host similar levels of vertebrate biodiversity in Brazil, Canada, and Australia. Partnerships with Indigenous communities that seek to maintain or enhance Indigenous land tenure practices on Indigenous-managed lands may therefore have some potential to ameliorate national and global shortfalls in land protection for biodiversity conservation using a mix of conventional protected areas and Indigenous-managed lands.

1. Introduction

Habitat loss and degradation due to human land conversion are key threats to global biodiversity that, to date, have been addressed mainly by expanding protected areas (PAs) globally (Maxwell et al., 2016; Sala et al., 2000). However, this approach has severe limitations because many existing PAs have limited overlap with the geographic ranges of most of the world's threatened species, as PAs have often been placed in regions with relatively low economic value and biodiversity (Rodrigues et al., 2004; Sánchez-Fernández and Abellán, 2015; Venter et al., 2014). In several regions, PAs overlap the ranges of endemic, high-priority species less often than expected if they had been located randomly (Nori et al., 2015; Sánchez-Fernández and Abellán, 2015). Thus, despite a rapid increase in the global extent of terrestrial PAs to meet the Convention on Biological Diversity's (CBD) target of protecting 17% of global terrestrial area, shortfalls in coverage and implementation suggest that 17% will nevertheless be insufficient to prevent further extinctions or meet other area-based conservation goals (Barnes, 2015; Polak et al., 2016; Watson et al., 2014). This implies that many species are destined to extinction unless they can maintain positive growth rates on land in addition to that set aside as conventional PAs. Indigenous-managed land (defined here as land parcels managed or co-managed by Indigenous communities) may represent one such key addition, as some authors conclude that partnerships with Indigenous communities are essential to conserving 17% of global terrestrial area (Jonas et al., 2014). The United Nations Declaration on the Rights of Indigenous Peoples clearly points to Indigenous Rights to Land and resources, thus providing a framework within which conversations about biodiversity conversation on Indigenous-managed lands can take place. Here, we explore the potential for Indigenous-managed lands to contribute positively to national and global goals for terrestrial biodiversity conservation, complementing a related analysis of the global extent of Indigenous-managed lands (Garnett et al., 2018).

Indigenous land management practices have often been shown to result in higher native and rare species richness (Peres, 1994; Redford and Stearman, 1993; Yibarbuk et al., 2001; Arcese et al., 2014) and less

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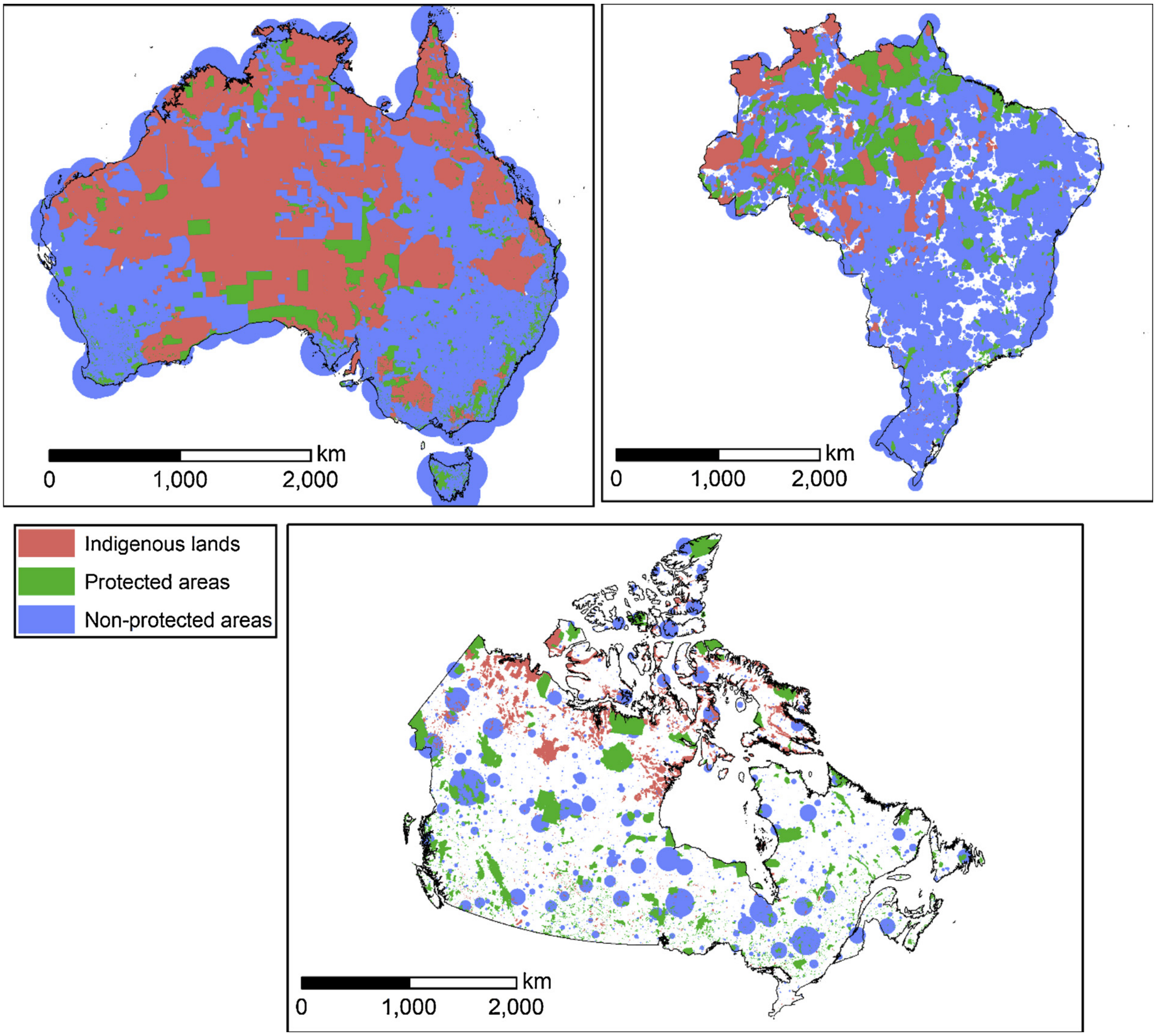

Fig. 1. Location of Indigenous Lands, Protected Areas and non-protected areas in Australia, Brazil and Canada.

deforestation and land degradation than non-indigenous practices (Nolte et al., 2013; Ceddia et al., 2015; Waller and Reo, 2018). However, despite indications of high biodiversity on Indigenous-managed lands, and a recent demonstration that such lands represent > 25% of all land area and intersect with ˜40% of terrestrial PAs and 'ecologically intact landscapes' (Garnett et al., 2018), no study has quantified species richness or occurrence on Indigenous lands or compared metrics in and outside of Indigenous-managed lands, conventional PAs, and unprotected areas at national scales. To address this key knowledge gap, we therefore compared vertebrate biodiversity on Indigenous-managed lands to protected areas and non-protected areas in three countries (Australia, Brazil, and Canada) with relatively large total areas owned or managed by Indigenous communities.

To achieve the above goals, we estimated total richness of amphibians, birds, mammals and reptiles using open-sourced species range maps of the International Union for the Conservation of Nature (IUCN). We then compared estimates among three land types: Indigenous-managed lands (hereafter IL), protected areas with no Indigenous co-management (hereafter PA), and non-protected areas of equivalent area (hereafter NPA). We similarly estimated the richness of species at risk (i.e., classified as 'vulnerable', 'endangered', and 'critically endangered' by the International Union for Conservation of Nature [IUCN]).

If Indigenous-managed lands have the potential to supplement conventional PAs in local, national and/or global efforts to meet conservation targets (Arcese et al., 2014; Garnett et al., 2018; Waller and Reo, 2018), we expect to observe that estimated species occurrence and richness in IL should: 1) meet or exceed levels observed in conventional PAs; and 2) exceed values observed in randomly selected landscapes of similar size.

2. Methods

2.1. Data processing

We based our analysis on an initial set of 26,688 spatial data layers consisting of three basic administrative delineations (country boundaries, protected areas and Indigenous lands), and 26,682 vertebrate species distributions, as described below, with total terrestrial land restricted to the country boundaries of Australia, Brazil and Canada.

2.2. Basic administrative delineations

National boundaries were derived from the Global Administrative Areas database (http://gadm.org/, accessed 2015-10-10). The data on protected areas was based on the September 2016 release of the World Database on Protected Areas (WDPA, https://www.protectedplanet.net).

We extracted the protected areas for each country from the WDPA database by selecting only areas belonging to IUCN protected area categories I–VI and having as status 'designated'. This resulted in totals of 7740, 1117 and 6764 protected areas for Australia, Brazil and Canada respectively. As there is to our knowledge no comprehensive database for Indigenous-managed lands (IL) globally, we created country-specific Indigenous lands layers from several sources. For Australia we used data described in Renwick et al. (2017) including WDPA, Australian Land Tenure (ALT) (Australian Government, 2016a), Collaborative Australian Protected Areas Database (CAPAD) (Australian Government, 2014) and Indigenous Land Use Agreements data, totalling 4982 polygons. For detailed methodology see Renwick et al. (2017). For Brazil, the WDPA specifically delineates Indigenous lands; we utilized the following designations to select polygons: 'Indigenous Area' and 'Indigenous Reserve', totalling 718 polygons. For Canada, the federal government provides a 'Canada Aboriginal Lands' layer (Natural Resources Canada, 2014), which we used here, totalling 3124 polygons. It is important to note that our definition of IL includes protected areas that are managed or co-managed by Indigenous Peoples (Garnett et al., 2018). This definition was not based on a spatial intersect of IL and PA layers, but rather on attributes found in those layers, as we did not want spatial configuration to determine the definition of a polygon.

To compare species richness on Indigenous-managed lands and protected areas with land parcels with neither form of management (Rodrigues et al., 2004; Sánchez-Fernández and Abellán, 2015; Venter et al., 2014), we created 10,000 randomly located points in each of the three countries. We did not exclude urban and peri-urban areas because they are often located in biodiversity hotspots. We chose this number to create random sites in the same order of magnitude as there are PAs and IL. These random points served as the centroids of circular areas, the size of which was determined by creating a list of the sizes of protected areas and Indigenous-managed lands and randomly assigning their sizes to each centroid. This way we ensured the creation of non-protected areas comparable in size to the protected areas and Indigenous-managed lands we investigated in each of the three countries, which themselves differ in size and shape (Fig. 1).

2.3. Species

Our species lists were determined using the IUCN Red List of threatened species, following Pouzols et al. (2014). For mammal, amphibian and reptile species ranges, we used the IUCN Red List website (http://www.iucnredlist.org/, accessed 2016-09-14) and for birds we used the BirdLife International data zone webpage (http://www.birdlife.org/datazone/home, accessed 2016-09-14). These data have certain limitations, including possible underestimation of the extent of occurrence and overestimation of the true area of occupancy (Pouzols et al., 2014), but have been shown to be robust to commission errors as long as the focus is on species assemblages rather than single species, (Venter et al., 2014). They are currently the most frequently used and updated source for vertebrate species distributions (Le Saout et al., 2013); thus, we limited our analyses to vertebrate species.

For each species group, we restricted our analysis to species that fell into the presence category of 'Extant', the origin categories of 'Native' or 'Reintroduced' and the seasonality categories 'Resident', 'Breeding Season' or 'Non-breeding Season', thus only focusing on stationary periods of the life cycle of migratory species. For each country, we first selected each IUCN polygon that intersected its national border and subsequently clipped each polygon by that border. This resulted in the following final numbers of amphibian, bird, mammal and reptile species per country: 219, 736, 270, 178 (Australia); 909, 1748, 621, 160 (Brazil); 50, 443, 157, 41 (Canada). In addition to analysing all species, we also analyzed threatened species only. All species with an IUCN status of 'critically endangered', 'endangered' and 'vulnerable' were assigned to the threatened category. This resulted in the following final numbers of threatened species of amphibians, birds, mammals and reptiles per country: 48, 57, 53, 17 (Australia); 36, 159, 78, 20 (Brazil); 1, 14, 6, 9 (Canada).

2.4. Analysis

The analysis steps for each species in each of the three countries were identical, and consisted of first creating a shapefile for each of the 26,682 vertebrate species distributions from the combined shapefiles or geodatabases for each species group. For ease of processing we then split each of the species polygons into smaller segments of a maximum size of 250 x 250 km. Subsequently we intersected each species shapefile with IL, PA and NPA and retained the areas of overlap (QGIS). We then summarized results and calculated generalized linear regression models (Negative binomial, log link, where each response variable ˜ land type + X coordinate of polygon centroid + Y coordinate of polygon centroid + Area of polygon) comparing IL, PA and NPA for total species richness, species richness by species group, total threatened species richness and threatened species richness by species group. We further created density plots to visualize the relationship between species richness and IL, PA and NPA. Analyses were conducted in R (R Development Core Team, 2016). Data, scripts and full results are available here: https://osf.io/f86wv/

3. Results

Indigenous lands as legally recognized by the three national governments, represent 52.1, 13.3, and 6.3% of terrestrial area for Australia, Brazil and Canada, respectively. PAs represent 9.2, 21.1, and 10.7% of terrestrial area for Australia, Brazil and Canada, respectively. In all three countries, Indigenous lands have the highest species richness in all focal taxonomic groups combined, with randomly selected non-protected areas having the lowest species richness (Fig. 2 a,b,c). Indigenous lands also have higher vertebrate species richness than randomly selected non-protected areas for each focal taxonomic group for all three countries (Appendix A, B), and slightly higher species richness than protected areas (PAs) for all focal taxonomic groups in Brazil, for all groups except birds in Australia, and for mammals and

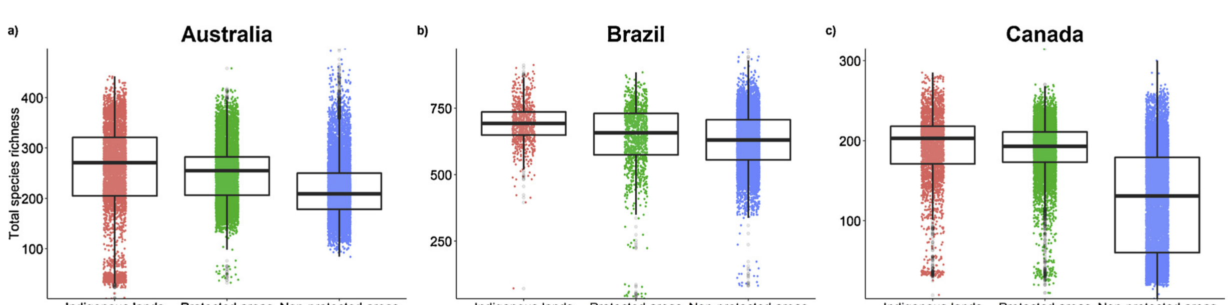

Fig. 2. Total vertebrate species richness for a) Australia, b) Brazil, c) Canada on Indigenous lands, protected areas and non-protected areas. Colored jitter plots show the distribution of the raw data and the boxplots show summarized data in form of median, first and third quartile.

Table 1
Summaries of country-specific linear regressions comparing vertebrate species richness. Each model utilizes a negative binomial error structure and compares species richness on Indigenous lands, protected areas and random sites. 95% confidence interval values are presented in parenthesis. In all cases but one (red listed species in Australia), IL outperforms protected areas. IL further outperforms non-protected areas in all models tested.

All Species	Indigenous Lands	Protected Areas	Non-Protected Areas
Australia	251 (249 - 253)	250 (249 - 252)	218 (217 - 219)
Brazil	692 (683 - 701)	639 (633 - 645)	628 (626 - 630)
Canada	192 (189 - 195)	189 (187 - 191)	126 (125 - 127)
Red Listed Species			
Australia	6.65 (6.54 - 6.77)	7.31 (7.22 - 7.39)	4.19 (4.13 - 4.24)
Brazil	15.88 (15.37 - 16.4)	14.68 (14.3 - 15.07)	15.21 (15.08 - 15.35)
Canada	2.4 (2.34 - 2.46)	2.01 (1.98 - 2.04)	2.37 (2.34 - 2.4)

amphibians in Canada (Appendix A, B). Threatened species richness of all taxa combined was also higher on Indigenous lands than randomly selected non-protected areas for all three countries, and slightly higher than in PAs for Brazil and Canada (Table 1). In addition, threatened species richness was higher on Indigenous lands than PAs for amphibians and reptiles in Australia, mammals in Brazil, and birds and reptiles in Canada (Appendix C).

To rule out potential confounding factors on the results presented in Fig. 2 and speculate on the potential mechanisms underlying the patterns of vertebrate species richness across the three countries investigated, we further evaluated the effects of land patch size and geographic location (lat/long) on species richness in lands identified as Indigenous lands, protected areas, and randomly placed areas (Appendix D). These analyses revealed no consistent patterns in terms of the effects of patch size or location on total species richness or the richness of species at risk across the three countries investigated, meaning that the consistent results across each country presented in Fig. 2 are unlikely to be influenced by these potential confounding factors. Instead, we interpret our results to indicate that Indigenous community land tenure practices may themselves result in higher species richness than random land areas and roughly equivalent species richness to protected areas. However, we note that our data do not allow us to more fully explore the causal links with any specific practices and biodiversity.

4. Discussion

Our results indicate that Indigenous-managed lands represent an important repository of native vertebrate species richness in three of the six largest countries on earth. Moreover, because Indigenous peoples currently manage or have tenure to roughly a quarter of earth's land area (Garnett et al., 2018), collaborating with Indigenous nations and organizations to support and/or enhance Indigenous land management practices clearly represent one potential route to achieving global targets for biodiversity conservation, and simultaneously advancing Indigenous rights to land, sustainable resource use, and human well-being. Specifically, we showed that the distributions of more species, and more threatened species in particular, overlapped Indigenous-managed lands more often than overlapped existing PAs or randomly selected sites over all 26,682 taxa examined here. These comparisons confirm our hypothesis that positive steps to maintain or enhance already existing values on Indigenous-managed lands have the potential to substantially advance global biodiversity conservation.

Although we also found small differences in vertebrate species richness between Indigenous-managed lands and protected areas, our comparisons imply that Indigenous lands and protected areas provide complementary benefits to global conservation initiatives. Indeed, many species are largely dependent on Indigenous lands and land-management practices for their persistence. In Australia, the ranges of two threatened species (Scanty frog [*Cophixalus exiguous*], Northern hopping-mouse [*Notomys aquilo*]) total less than 5000 km^2, but of these areas > 97% is on Indigenous-managed lands. Of all species considered, 42 in Australia, 216 in Brazil, and two species in Canada had > 50% of their range distributed on Indigenous-managed lands, whereas 11 species at risk in Australia, 10 in Brazil, and zero in Canada had > 50% of their range in a focal country on Indigenous-managed lands (see Appendices E–G for full details on species total area, conservation status, and land tenure overlap in each country). Thus, although PAs are a key tool in biodiversity conservation (Watson et al., 2014), other results indicates that Indigenous land management practices and areas co-management by Indigenous communities and federal or state governments can also contribute positively to biodiversity conservation (Gilligan, 2006; Ricketts et al., 2010). Indeed, given high overlap between many threatened species ranges and Indigenous lands, collaborative agreements with Indigenous land stewards may be essential to insure persistence of many species in future, and to meet CBD goals to prevent extinction in Australia, Brazil and Canada.

Examples of mutually-beneficial collaborations between Indigenous nations and other governments have already contributed positively to the conservation of mature forest and the sustained harvest of wildlife on non-Indigenous lands (Waller and Reo, 2018). Large-scale efforts towards such collaborations are advancing elsewhere in the world and providing new insights on the causes of biodiversity loss (Sayer et al., 2013), and despite some failures, successful examples exist (Grossman, 2005; Hatcher et al., 2017; Whyte et al., 2018). Grossman (2005) describes several case studies, including partnerships between sport fishers and Anishinaabe nations in the U.S. to prevent mining development with the potential to harm resources essential to both groups. While such partnerships remain relatively rare (LaDuke, 2017), empirical studies are revealing some potential guiding principles for success. Existing studies provide guiding principles for how to initiate and sustain partnerships between Indigenous nations or groups and non-Indigenous entities including nation-states and NGOs (Dalton, 2011; Reo et al., 2017; Ross et al., 2016; Stevens, 2014; Whyte et al., 2017). Stevens (1997) outlined a series of principles designed to guide the formation of PAs that fully embrace Indigenous rights and land tenure systems. Other authors identify commonalities in successful partnerships between Indigenous and non-Indigenous groups by assessing progress with respect to environmental goals, and determining that partnerships are constituted in ways that respect Indigenous nations' political and governmental authority and cultural distinctiveness (Reo et al., 2017; Whyte et al., 2018).

In contrast to collaborative and co-management approaches, the history of establishment of national parks and protected areas has been accompanied by severe and often negative consequences for Indigenous peoples globally (Stevens, 1997; West et al., 2006). For example, protected areas established based upon Euro-American wilderness ideals typically prohibit Indigenous peoples from exercising their customary land uses, and forcibly removed many Indigenous groups from their homelands (e.g., Sinclair and Arcese, 1995; Barrett and Arcese, 1995). Such removals have led to negative consequences for many Indigenous societies (West et al., 2006) and can extend to the ecosystems that conservationists originally aimed to 'protect.' For example, curtailing Indigenous management involving fire, forestry, fishing, or hunting practices can cause declines in species diversity and ecosystem productivity (Bird et al., 2008; Dunwiddie et al., 2011; Gedalof et al., 2006; MacDougall, 2008; MacDougall et al., 2004), particularly in grassland and early-successional habitats favored by many culturally important species, in addition to all others benefitting from disturbance and heterogeneity at landscape scales (Arcese et al., 2014; Gomez-Pompa and Kaus, 1992; MacDougall, 2008; Stevens, 1997). Although many causal pathways by which traditional management practices influence species abundance and distribution remain uncertain, many examples of successful research partnerships to rediscover, test, and apply such practices now exist (Berkes et al., 2000; Kendrick and Manseau, 2008; Polfus et al., 2014).

Our current results also suggest that Indigenous management is associated with high vertebrate biodiversity, and thus, mutually beneficial collaboration with Indigenous peoples do appear capable of helping countries such as Canada, Australia and Brazil to meet their CBD targets. Collaborative agreements between Indigenous and non-Indigenous land managers could also help to redress historic wrongs by developing new, synergistic relationships capable of advancing conservation, sustainable resource use, and human well-being. Models for such partnerships might include resources to facilitate stewardship and implementation. For instance, the Canadian federal parks agency spends *c* \$282 per km^2 (\$92 M CAD/yr) on programs related to the enforcement, restoration and maintenance of biodiversity in protected areas (Parks Canada, 2016). Similar expenditures to subsidize Indigenous land tenure in Canada would imply a cost of \$176 M CAD/yr based on costs per unit areas. Co-management is already common in Australia, where Indigenous Protected Areas (IPAs) occur wholly on Indigenous lands and make up > 40% of the national protected area system (Australian Government, 2016b). Some IPAs are co-managed with non-Indigenous partners as part of land claims agreements, while others are under sole Indigenous management with funding and technical assistance from non-Indigenous governments (Bauman and Smyth, 2007; Ross et al., 2009).

Our definition of IL included protected areas that are managed or co-managed by Indigenous Peoples (Garnett et al., 2018). This definition has potential implications for differentiating between Indigenous lands with and without any form of protected areas recognized by WDPA. An additional category of Indigenous lands only would have helped differentiate results further, but that was not possible in this study, as we lacked the data necessary to make this distinction.

Although many countries appear to be on track to meet nominal 17% terrestrial targets for land protection under the Convention on Biological Diversity (Butchart et al., 2015), meeting such goals for representativeness and connectivity of protected areas or other effective area-based conservation measures will be challenging, particular in a manner that curtails extinction (Barnes, 2015; Polak et al., 2016). Specifically, because meeting CBD targets to conserve global biodiversity and stem extinction will probably require a much larger protected area network than current anticipated (Barnes, 2015; Polak et al., 2016), we argue that recognizing the role of Indigenous lands and leadership in biodiversity conservation, and facilitating voluntary partnerships to ensure the conservation of habitats on Indigenous lands, may provide crucial opportunities for many countries to meet their international commitments to conservation. Ideally, such partnerships will be led or co-led by Indigenous communities to avoid historic mistakes and support Indigenous land management practices that allow us to meet or exceed global conservation goals.

Author contributions

RS, RRG, and PA conceived the study. RS and RRG collected data and conducted analyses. All authors contributed to writing and editing the paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2019.07.002.

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