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# Information gaps in indigenous and local knowledge for science-policy assessments

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**The need to understand nature's contributions to people and across a broad spectrum of cultures and ecosystems is increasingly advocated in science assessments and policy decision-making for sustainability. However, for services such as food and medicine, gaps in existing studies on indigenous and local knowledge may preclude inclusive assessments. Here, using a large database of indigenous and local knowledge about plant services for New Guinea, we show that there are biological and cultural documentation gaps that will exclude many plant services and indigenous groups from assessments that are based solely on published research. Further, we unveil that, like the common property of 'rarity' in species assemblages, most plant services exhibit high rarity. Gaps and rarity are probably pervasive in other regions and will affect how plant services are conceptualized, assessed and sustainably managed.**

One of the most pressing challenges for humanity is how to improve living standards without degrading nature and the services it provides[1]. To meet this challenge, scientific assessments on the status and trends of biodiversity, ecosystem functions and ecosystem services are being carried out to guide policy decisions[2–4]. The integration of indigenous and local knowledge (ILK) is vital in these endeavours because of the in-depth knowledge on biodiversity and ecosystem trends[5,6] ILK provides and because indigenous people inhabit one-quarter of the world's land surface[7]. ILK is 'a cumulative body of knowledge and beliefs handed down through generations by cultural transmission about the relationship of living beings, (including humans) with one another and with their environment'[5]. Of the 20 'Aichi Targets' that seek to improve the state of biodiversity by 2020 (https://www.cbd.int/sp/targets), Target 18 aims to preserve the traditional knowledge and practices of indigenous and local communities and to implement the Convention on Biological Diversity with their full and effective participation.

Recognizing that dealing with a range of different knowledge systems is challenging, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has created a conceptual framework for achieving a shared understanding on the values of nature across different disciplines, knowledge systems and stakeholders[2]. To include ILK, IPBES has established a Task Force on ILK (https://www.ipbes.net/deliverables/1c-ilk), drawing on information from published and grey literature, online calls for contributions and regional ILK workshops (https://www.ipbes.net/event/ilk-dialogue-workshop-ipbes-assessment-multiple-values-nature). Other efforts of IPBES include facilitation of a network of experts and the delivery of procedures for working with ILK systems across the world. In doing so, IPBES aims to diversify and strengthen the knowledge foundations of the science-policy interface on biodiversity and ecosystem services at and across subregional, regional and global levels. Given that literature reviews are an important pillar of scientific assessments of ILK (ref. [3]), understanding the limitations posed by the published literature is important to inform such efforts; if existing ILK research is limited to a small fraction of ecosystems, this will result in strong biological biases in scientific assessments. Furthermore, if few indigenous groups are represented in the literature, policies that seek to integrate how indigenous and local communities value their surrounding ecosystems could run the risk of basing decision-making on an unrepresentative sample of sociocultural systems[8]. Finally, given that not all knowledge systems face the same extinction risk, understanding the magnitude of research gaps for endangered indigenous groups is critically important for informing policies on biocultural conservation.

Here, we synthesize 130 years of published ILK on plant services in the island of New Guinea and surrounding islands including the Bismarck Archipelago (hereafter 'New Guinea') and quantify the regional-scale distribution of plant services among lands inhabited by indigenous peoples. Specifically, we explore: (1) to what extent information on plant services is unevenly distributed across New Guinea's habitats and cultures, and (2) how the ecology of plant services influences achieving comprehensive assessments. We focus on New Guinea because it is the most bioculturally rich spot on Earth[9] with over 15,000 plant species and 1,100 languages[10], and because much of its indigenous population still draw their livelihoods from forest-based plant services[11]. We define a 'plant service' of a given species as the use associated with a use category and use subcategory for a specific plant part, and a 'use report' as the citation of a 'plant service' in a reference (see Methods). Four components of ILK can be recognized[12]: names of living beings; functions and use; land-resource management systems and institutions that govern them; and world views-cosmologies that guide people's ethics. Because we focus on the first two, our findings should not be extrapolated to the other levels. Our dataset was collected over 12 months and contains information from 488 references (in Bahasa Indonesia, Dutch, English, French and German) representing the largest multilingual synthesis on ILK to date for New Guinea. Our study offers insights into other megadiverse regions where most of the world's 7,097 living languages and biodiversity co-occur[13]; in many such regions, tapping ILK for scientific assessments and policy decision-making will be challenging[8].

## Results

Overall, our dataset has information on 3,434 useful species, 19,948 plant services and 40,382 use reports. We start by exploring the magnitude of research gaps in ILK. New Guinea supports some of the world's richest biodiversity[14] and tropical Asia's greatest habitat

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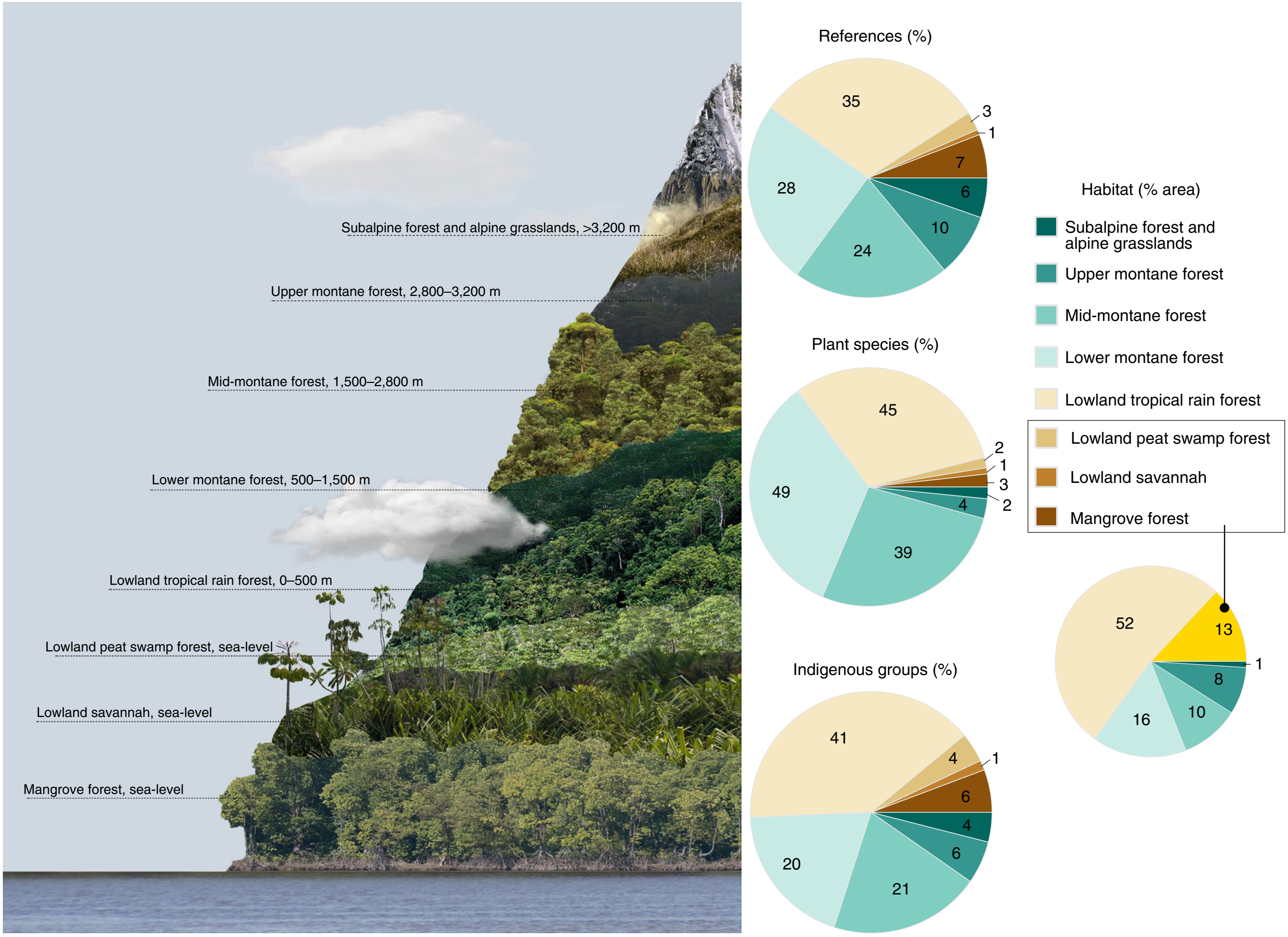


**Fig. 1 | Biological documentation gaps about plant services in New Guinea.** A comparative view of New Guinea's habitats and the percentage of references, species and indigenous groups documented per habitat. Credit: Inés Cámara Leret.

diversity[15], yet only 20% of its about 15,000 species are documented as useful and all of its habitats remain understudied (Supplementary Table 1). Lowland tropical forests and lower montane forests are cited in more studies and have more use reports than all other habitats combined (Fig. 1). However, after accounting for area, we find that montane habitats have received disproportionate attention (Fig. 1 and Supplementary Fig. 1).

To assess the distribution of research across New Guinea's cultures, including those facing greatest extinction risk, we linked our records to Ethnologue's language endangerment classification[10] (see Methods). We used language endangerment as a proxy for cultural endangerment because language is the primary medium of cultural transmission[16]. Thus, the ability of indigenous groups to name, identify, use and share knowledge about their surrounding resources will diminish when languages go extinct[17]. Overall, just 217 or 19% of New Guinea's 1,100 indigenous groups have been studied: endangered indigenous groups make up just 25% of all groups studied, and a staggering 90% of the studied endangered groups have <100 use reports. Consequently, indigenous cultural and intellectual legacy will be under-represented in any assessment that is done on the basis of published research (Fig. 2). Yet, it is possible that gaps in documentation could have a smaller effect on assessments of plant services if ILK were to be shared widely among indigenous groups. To assess this, we identified the number of plant services that are shared among indigenous groups (see Methods). However, we find little support for consensus, as most plant services (89%) were not shared. To visualize the 11% of plant services that were shared, we built an indigenous knowledge network where nodes depict indigenous groups and links represent plant services that are shared by them (Fig. 3a). When comparing endangered and non-endangered groups, we find that most plant services are not shared between them (Fig. 3b). Moreover, even the best-studied indigenous groups (Mianmin, Yali and Dani) that occupy montane habitats with a similar flora shared a minor fraction of plant services (Fig. 3c).

To understand how the distribution of ecosystem services may influence assessment completeness, we applied Deborah Rabinowitz's framework of rarity[18]. Originally, the framework was used to quantify seven forms of rarity in a $2\times2\times2$ or 8-celled block that integrates three characteristics of species: geographic range (large, small), habitat specificity (wide, narrow) and local population size (large, small) (Fig. 4a). Here, we apply it to quantify rarity in plant services as our currency of measurement rather than individual species. We define: geographic range of a plant service as 'large' when the number of indigenous groups who report it is greater than one; local population size as 'large' when the number of references that cite a plant service is greater than one; and habitat specificity as 'wide' when the number of habitats where a plant service occurs is greater than one. We find that most documented plant services (64%) exhibit high rarity (Fig. 4b). This narrow distribution

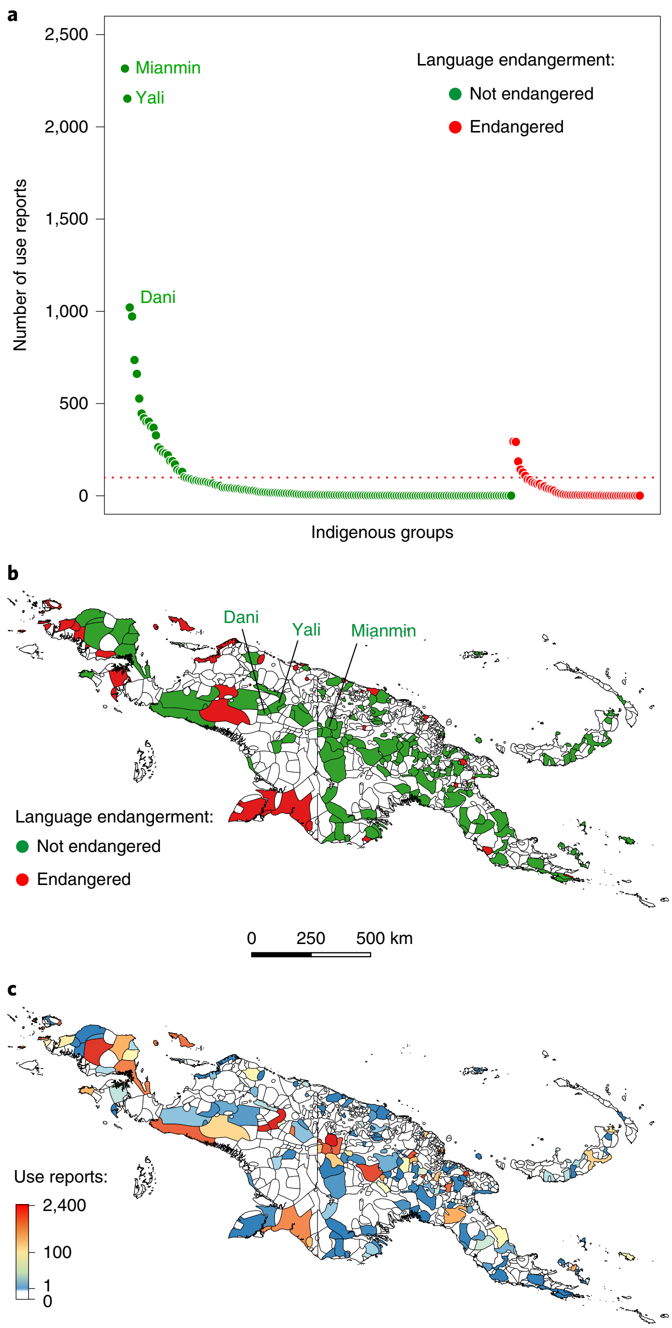


**Fig. 2 | Cultural documentation gaps about plant services in New Guinea.** **a**, The 217 indigenous groups reported in 488 references, their number of plant use reports and language endangerment (sensu Ethnologue[10]). The red horizontal line shows the 100 use-report threshold. **b**, Geographic distribution of New Guinea's languages and their endangerment. **c**, Geographic distribution of use reports across New Guinea's languages.

means that many important services are not yet known and remain unrecorded in the published literature.

**Policy implications.** Our synthesis of ILK of plant services in New Guinea indicates that (1) despite hundreds of studies made over 130 years, major knowledge gaps exist about plant services across biological and cultural scales and (2) most plant services exhibit high rarity. The extinction of biodiversity has received considerable attention[14] but the extinction of our ethnosphere (the sum total of all thoughts and intuitions, myths and beliefs, ideas and inspirations brought into being by the human imagination[19]) remains neglected. Our study shows that research is decoupled from cultural extinction risk, as most of the studied cultures are not endangered. Additionally, rarity in plant services cautions us that many services have highly localized patterns, and that understanding the multiplicity of services in a landscape will often require documenting the perspectives of all the indigenous groups that inhabit it.

While we have focused on a megadiverse region that harbours much of the world's linguistic and biological diversity, mounting evidence suggests that documentation gaps are also found in other tropical regions and even in temperate ones; for example, in plant names and their services (such as for South America[20] and Morocco[21]), agroecological knowledge on landraces (Spain[22]), or climate risk management practices (Nepal[23]). Because ILK is being lost abruptly as societies modernize[24,25], research efforts on these and other components of ILK are urgently needed.

To promote inclusiveness, preserve nature's beneficial contributions and keep opportunities open for enhancing human well-being, nations should strive to find ways to reduce current biases. Participatory approaches (for example, the People's Biodiversity Register in India[26]) offer hope but funding limitations[27] mean that it will be difficult to attain a comprehensive understanding of ILK in the near-term scales that policy-makers need. Setting national-scale priorities to document the knowledge of cultural groups facing the greatest extinction risk could help accelerate our understanding of particular resources (for example, food plants) and hopefully ameliorate such risk. And since global change may lead to shifts in community functional trait composition, species with particular traits known to relate to particular benefits (for example, large fruit size linked to food[28]) could be subject to further comparative work. Apart from learning from indigenous and local people on how ecosystems are valued and managed, it is critical to strengthen indigenous peoples' human rights[29] and amplify their voice in the policy sphere because their lands occupy over a quarter of the world's land surface[7]. Drawing on the entire kaleidoscope of human thought, decision-makers will be better equipped to formulate policies and actions that benefit people and the planet.

## Methods

**Study area.** We consider 'New Guinea' as the region encompassing the main island, Bismarck Archipelago, and the surrounding smaller islands that were connected to mainland New Guinea during the last glacial maximum. We delimit it by selecting areas $\geq -120$ m depth from the General Bathymetric Chart of the Oceans (http://www.gebco.net). The study area spans a latitudinal range of −0.08° to −10.66° and a longitudinal range of 129.42° to 150.21° and excludes the Moluccas Islands to the west and the Solomon Islands to the east. Accordingly, our delimitation corresponds with the Papuasian floristic region[30,31].

**Data collection and organization.** For 12 months, we conducted a literature review by searching Google Scholar and the Kew Bibliographic Database using the following terms and their combination: ethnobotany, food plants, medicine, New Guinea, Papua New Guinea, timber, traditional medicinal plants and traditional use of plants. While we did not include 'West Papua' or 'Irian Jaya' in our search terms, we included references listed in Hide's comprehensive *Preliminary Bibliography of Ethnobotanical Research in West Papua* from 1963 to 2013 (refs. [32–37]), gathered information from references cited in Papuaweb (www.papuaweb.org) and from herbarium specimens ($n = 854$) deposited at K and L (acronyms according to Thiers[38]). This combination of search terms and sources ensured a broad coverage of published and unpublished international articles, books and book chapters and reports in English ($n = 346$), Bahasa Indonesia ($n = 132$), French ($n = 8$), Dutch ($n = 1$) and German ($n = 1$). For a list of the 488 references reviewed, see Supplementary Table 2.

For each bibliographic reference and herbarium specimen we recorded (when available) the name of the country, island, habitat, elevation, scientific name of the species, plant part used, indigenous group, locality and original description of plant use. Each plant service was classified into one of ten use categories and subcategories following the *Economic Botany Data Collection Standard*[39], with modifications explained in ref. [20]: Animal food, Human food, Construction, Culture ('Cultural' in ref. [20]), Environmental, Fuel, Medicine ('Medicinal and veterinary' in ref. [20]), Toxic, Utensils and tools, and Other uses (for a description of subcategories refer to Supplementary Table 1 in ref. [28]). Two subcategories

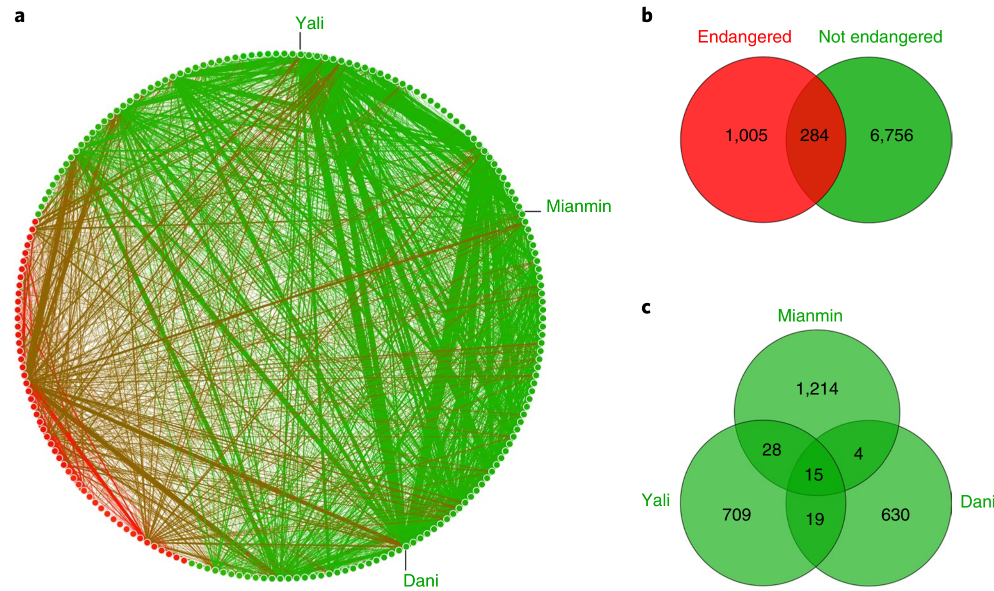


**Fig. 3 | Indigenous knowledge network about shared plant services in New Guinea. a**, A total 157 indigenous groups (nodes) share at least one plant service (link) with another indigenous group. Node colours encode linguistic endangerment (red, endangered; green, not endangered). Links are green when two non-endangered indigenous groups share a plant service, brown when an endangered and not endangered group share a plant service and red if two endangered groups share a plant service. Link width is proportional to the number of shared plant services. **b**,**c**, Venn diagrams depict the number of plant services shared by: endangered and non-endangered indigenous groups (**b**) and the three best-studied indigenous groups (**c**).

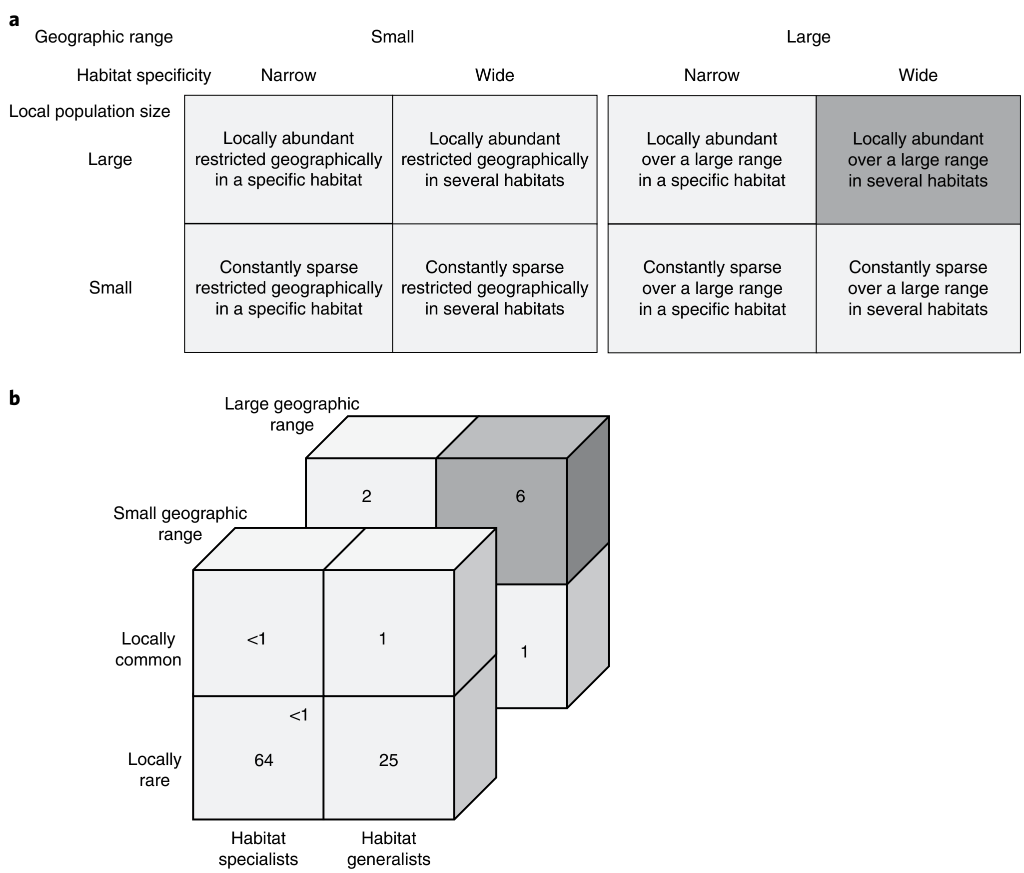


**Fig. 4 | Rarity in plant services. a**, Rarity can be classified into seven forms (sensu Rabinowitz[18]) on the basis of three characteristics: local population size, geographic range and habitat specificity. Plant services in the dark grey box exhibit no component of rarity. **b**, Percentages of plant services ($n = 4{,}462$) in each of Rabinowitz's compartments. A plant service has a large local population size when the number of references that cite it is more than one, a large geographic range when it is cited by more than one indigenous group and wide habitat specificity when it occurs in more than one habitat (see Methods). The value in the upper right corner of the lower left box represents the percentage of plant services that have a large geographic range, small local population size and narrow habitat specificity.

were created for uses not classifiable under the subcategories of Toxic and Environmental: Other-Toxic and Other-Environmental. Plant parts included the root, young shoot, stem, bark, exudate, leaf sheath, petiole, leaf rachis, cirrus, spear leaf, palm heart, entire leaf, flower, inflorescence, bract, fruit, seed and entire plant. Unspecified plant parts were classified as 'not specified'. Where information was available, each use report was assigned to one of the New Guinea habitats defined by Paijmans[15]: mangrove forest, lowland peat swamp forest, lowland savannah, lowland tropical rain forest (0–500 m), lower montane forest (500–1,500 m), mid-montane forest (1,500–2,800 m), upper montane forest (2,800–3,200 m) and subalpine forest and alpine grasslands (>3,200 m). We followed the Plants of the World Online (http://powo.science.kew.org) to unify nomenclature.

We used the definition of indigenous peoples of the International Labour Organization[40] and verified indigenous group names using the Ethnologue (https://www.ethnologue.com)[10] or Glottolog (http://glottolog.org). Many reports lacked indigenous group names ($n=22,153$) or had names that could not be matched ($n=749$). Geographic location of each indigenous group was recorded from the literature or, when coordinates were missing, we first obtained the language ISO-639-3 code from Ethnologue or TransNewGuinea (http://transnewguinea.org) and then matched this code with coordinates available in Glottolog.

**Data analyses.** We defined a 'plant service' for a given species as the use associated with a use category and use subcategory for a specific plant part, and defined a 'use report' as the citation of a 'plant service' from a bibliographic reference or herbarium specimen. Analyses were performed at the species-level. To quantify patterns across New Guinea's habitats, we analysed 17,894 use reports with habitat-level information from 224 references and 756 herbarium specimens.

We calculated the relative area of each habitat in New Guinea using two different datasets: (1) the Shuttle Radar Topography Mission 90 m digital elevation model[41] and (2) World Wildlife Fund (WWF) ecoregions[42]. First, habitats were defined using the elevation ranges cited in Paijmans[15], raster cells in each habitat were summed ($km^2$), and their area was divided over the total area of New Guinea (Supplementary Fig. 1). Three lowland habitats (mangrove forests, lowland peat swamp forest and lowland savannah) were not readily distinguishable from each other or from lowland tropical forests on the basis of elevation. Accordingly, we merged mangrove forests, lowland peat swamp forest and lowland savannah into a class of 0–20 m elevation and classified lowland tropical rain forests as those areas between 20 and 500 m.

To assess the validity of the previous habitat classification on the basis of elevation, we compared it with a classification on the basis of WWF ecoregions. Importantly, the WWF ecoregion classification distinguishes the three lowland habitats that the elevation data does not (WWF ecoregions: mangrove forests, Southern New Guinea freshwater swamp forests and Trans Fly savanna and grasslands), allowing us to assess whether the summed area of these three lowland habitats coincides with that in the elevation classification. We then summed the area of lowland tropical rain forest ecoregions (Louisiade Archipelago rain forests, Southeastern Papuan rain forests, Yapen rain forests, New Britain–New Ireland lowland rain forests, Vogelkop–Aru lowland rain forests, Admiralty Islands lowland rain forests, Trobriand Islands rain forests, Biak–Numfoor rain forests, Southern New Guinea lowland rain forests, Vogelkop montane rain forests, Northern New Guinea lowland rain and freshwater swamp) and compared their area with that of the 20–500 m elevation classification. Finally, since WWF ecoregions do not subdivide montane habitats into elevation classes, we compared the total area of montane WWF ecoregions (New Britain–New Ireland montane rain forests, Northern New Guinea montane rain forests, Central Range montane rain forests, Huon Peninsula montane rain forests) to that of our elevation classification (500–3,200 m). Overall, the relative area covered by each habitat was similar in both analyses: lowland tropical forests (about 52% of total area according to elevation versus 55% according to ecoregions), montane forests (34% versus 26%), other lowland habitats (about 13% versus 17% mangrove, lowland savannah and lowland peat swamp) and subalpine forest and alpine grasslands (1% versus 2%). All analyses were performed in R[43] using commands from the libraries raster[44], rgdal[45] and geosphere[46].

To explore the relationship between documentation effort and language endangerment, we obtained the language endangerment classification for all indigenous groups in our sample from Ethnologue[10] which uses the Expanded Graded Intergenerational Disruption Scale (EGIDS)[47]. The language of indigenous groups in our sample were classified into 8 of the 13 levels of EGIDS: Wider communication, Educational, Developing, Vigorous, Threatened, Shifting, Moribund and Nearly extinct. Of these, the last four levels are considered endangered.

To determine the extent to which plant services are shared among indigenous groups, we counted how many indigenous groups reported the same plant service and defined a shared plant service as that cited by two or more indigenous groups. To explore plant services that were shared among indigenous groups and among endangered and non-endangered groups, we built a knowledge network where each node represents an indigenous group, and a link represents a shared plant service between two indigenous groups. To plot the indigenous knowledge network, and avoid overlapping nodes, we implemented the circular layout option in the Gephi software v.0.9.2 (ref. [48]), colouring nodes according to their language endangerment class.

Deborah Rabinowitz's scheme defines seven forms of species rarity on the basis of three characteristics: geographic range, habitat specificity and local population size[17]. We applied Rabinowitz's scheme to study rarity in plant services as our currency of measurement, rather than species. Thus, we define geographic range of a plant service on the basis of tribal consensus: if a plant service is cited by more than one indigenous group we consider it to have a 'large' geographic range (versus 'small' when a plant service is cited by only one indigenous group). We consider a plant service to have a 'wide' and 'narrow' habitat specificity if it occurs in more than one or only one habitat, respectively. Last, we define the local population size of a plant service as 'large' or 'small' when it occurs in more than one or only one reference, respectively. Our selection of cut-off levels followed Rabinowitz's conservative selection, so that greater indicators of rarity are to be expected with higher cut-off levels.

## Data availability

The data of ILK about plant services for New Guinea that was generated and analysed during the current study is available from the corresponding author on reasonable request. Language data are available from the Ethnologue (ref. [10]), elevation data are available from CGIAR-CSI (ref. [40]) and ecoregion data are available from WWF (ref. [41]).

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## Author contributions
R.C.-L. conceived the study. Z.D. and R.C.-L. collected data. R.C.-L. analysed the data. R.C.-L. wrote the paper. Both authors discussed the results and commented on the manuscript.

## Competing interests
The authors declare no competing interests.

## Additional information
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