Indigenous Knowledge of New Guinea's Useful Plants: A Review

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We present the first large-scale synthesis of indigenous knowledge (IK) on New Guinea's useful plants based on a quantitative review of 488 references and 854 herbarium specimens. Specifically, we assessed (i) spatiotemporal trends in the documentation of IK, (ii) which are New Guinea's most useful ecosystems and plant taxa, (iii) what use categories have been better studied, and (iv) which are the best studied indigenous groups. Overall, our review integrates 40,376 use reports and 19,948 plant uses for 3434 plant species. We find that despite a significant increase in ethnobotanical studies since the first reports of 1885, all islands still remain under-investigated. Lowland and montane rainforests are the best studied habitats; legumes, palms, and figs are the most cited plant families; and *Ficus*, *Pandanus*, and *Syzygium* are the most useful genera. Medicinal uses have received the greatest attention and non-native species have the highest cross-cultural consensus for medicine, underscoring the culturally enriching role of non-native taxa to New Guinea's pharmacopeia. Of New Guinea's approximately 1100 indigenous groups, 217 are mentioned in the literature, and non-endangered groups remain better studied. We conclude that IK can contribute significantly to meet rising demands to make New Guinea's landscapes "multifunctional" and boost the green economy, but ambitious strategies will still be needed to mainstream IK and improve its documentation.

Key Words: Biodiversity, ecosystem services, indigenous people, useful species.

Introduction

Indigenous and local communities occupy over 25% of the world's terrestrial surface (Garnett et al. 2018) and for centuries have interacted with their native ecosystems to discover novel plant sources for foods, medicines, and fibers. The Asia–Pacific region is home to three quarters of the ca. 370 million indigenous people of the world (Dhir 2015), many of whom draw their livelihoods directly from forest-based ecosystem services (FAOSTAT 2017). New Guinea stands out within the Asia–Pacific for being its most bioculturally diverse region (Loh and Harmon 2005), where interactions among 1100 indigenous groups and 15,000 plant species can be studied across relatively short distances. New Guinea's mountainous geography has resulted in steep ecological gradients and isolation among its inhabitants and promoted an unparalleled diversification of plant species, languages, and cultures (Stepp et al. 2005). Humans occupied New Guinea around 50,000 years ago (O'Connell and Allen 2015) and were intensely cultivating bananas (*Musa* spp.), taro (*Colocasia esculenta* (L.) Schott), breadfruit (*Artocarpus altilis* (Parkinson) Fosberg), sugarcane (*Saccharum* spp.), and the greater yam (*Dioscorea alata* L.) 6440 years B.C.E. (Denham et al. 2003; Lebot 1999). Today, many of these plants are still collected, transplanted, and cultivated from wild forms (Denham et al. 2003; Hyndman 1984).

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Despite New Guinea's global significance for biocultural conservation (Gorenflo et al. 2012; Mittermeir et al. 1998), publications on plant utilization by its indigenous groups have remained scattered, making quantitative syntheses difficult. Our current understanding about IK on New Guinea's plants is based on studies that have focused on single plant taxa (Bau and Poulsen 2007; Motley 2004), few indigenous groups (Arobaya and Pattiselanno 2007; C. D. Cook 2016; Johannes 1975), small geographic areas (Avé 1998; Sillitoe 1995; Stopp 1963), and single-use categories like medicine (Holdsworth 1977) or food (Barrau 1959; French 1986). To date, Powell (1976) made the most comprehensive review of useful plants in the region based on 46 studies from mainland New Guinea. This resulted in a total of 146 useful plant families, 470 genera, and 1035 species. However, Powell recognized that the data available in the literature at the time was extremely uneven and inadequate. Subsequent efforts resulted in a series of regional reviews on medicinal (e.g., Holdsworth 1977, 1993) or food plants (French 1986), albeit these were politically restricted to Papua New Guinea. Thus, no comprehensive and up-to-date review on IK about New Guinea's useful plants exists. This limits landscape-scale labeling initiatives, market recognition of useful plants, and publicizing cultural heritage to underpin forest conservation (Ghazoul et al. 2009).

Here, we explore the spatiotemporal evolution in the documentation of IK about plant utilization across New Guinea by quantitatively analyzing 130 years of data. Specifically, we ask (i) what are the spatiotemporal trends in the documentation of IK, (ii) which are New Guinea's most useful ecosystems and taxa (plant families, genera, and species), (iii) what use categories are better studied, and (iv) how well have indigenous groups been studied and does research effort correlate with the extinction risk of indigenous groups. On the one hand, our review contributes to understanding large-scale patterns of IK on plants and paves the way for future documentation with indigenous groups missing in the literature. On the other hand, it sets a baseline for realizing the potential of New Guinea's natural resources before massive habitat degradation occurs (Novotny 2010; Sloan et al. 2019). This is important given recent political commitments, where the Governors of Indonesia's two New Guinea Provinces declared in 2018 to, among other things, conserve 70% of the forest cover for the western half of the island, strengthen the role of indigenous peoples, support indigenous communities to develop appropriate economic development activities, and increase access to markets (Cámara–Leret et al. 2019).

Methods

Study Area

Our study area of "New Guinea" encompasses the mainland New Guinea and the surrounding islands that were connected to the mainland during the last glacial maximum, which corresponds with the Papuasian floristic region (Brummitt et al. 2001; Warburg 1891) (Fig. 1). We delimit it by selecting areas ≥ – 120 m depth from the General Bathymetric Chart of the Oceans (http://www.gebco.net). Thus, our study area spans – 0.08° to – 10.66° in latitude and 129.42° to 150.21° in longitude and excludes the Moluccas Islands to the west and the Solomon Islands to the east. The study area is divided politically between Indonesia and Papua New Guinea and includes some of the world's most biodiverse ecosystems (Mittermeir et al. 1998) and the greatest habitat diversity of Southeast Asia (Roos et al. 2004). According to Paijmans (1976), eight different habitats can be identified: mangrove forests, lowland peat swamp forests, lowland savanna, lowland tropical rainforest (0–500 m), lower montane forest (500–1500 m), mid-montane forest (1500–2800 m), upper montane forest (2800–3200 m), and subalpine forest and alpine grasslands (> 3200 m).

Data Collection

Our dataset was collected during 12 months and combines information from 488 references and 854 herbarium specimens. The literature review was made 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.* This was supplemented with references cited in Papuaweb (www.papuaweb.com), Hide's bibliographies of ethnobotanical research in West Papua (Hide 2014a, 2014b, 2015, 2016a, 2016b, 2017), and ethnobotanical information in herbarium specimens deposited at K and L (acronyms according to Thiers 2019). The combination of search terms and sources resulted in a broad coverage of references in

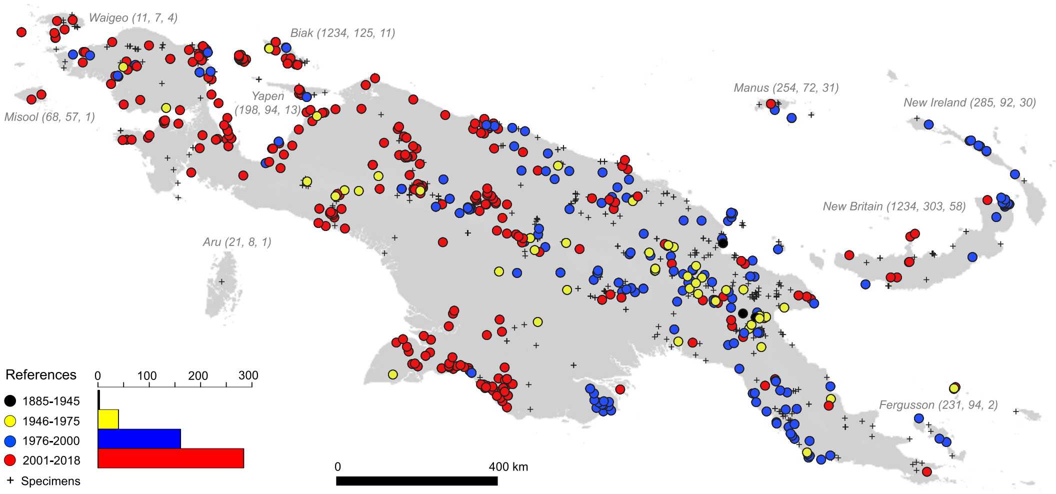

Fig. 1. Spatiotemporal evolution in the documentation of indigenous knowledge about New Guinea's useful plants. Map showing the location of references (circles) and herbarium specimens (crosses) reviewed in this study. The number of use reports, useful plant species, and references for large islands are listed in parenthesis. Bar plot shows the temporal distribution of references in four time periods.

English (*n* = 346), Bahasa Indonesia (*n* = 132), French (*n* = 8), Dutch (*n* = 1), and German (*n* = 1). Thus, our review encompasses a more diverse knowledge pool than Powell's review (1976), which included fewer references (*n* = 46). For a list of the references reviewed, see Electronic Supplementary Material (ESM) Table S1.

Data Organization

For each bibliographic reference and herbarium specimen we recorded (when available), the country, island, habitat, elevation, scientific name of the species, plant part used, indigenous group, locality, and the use description. Each plant use was classified into one of ten use categories and subcategories following the *Economic Botany Data Collection Standard* (F. Cook 1995), with modifications explained in Cámara–Leret et al. (2014): Animal food, human food, construction, culture ("Cultural" in Cámara–Leret et al. 2014), environmental, fuel, medicine ("Medicinal and Veterinary" in Cámara–Leret et al. 2014), toxic, utensils, tools, and other (for a description of subcategories refer to Supplementary Table 1 in Cámara–Leret et al. 2017). Two subcategories 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." Wherever possible, each use report was assigned to one of the New Guinea habitats defined by Paijmans (1976). We followed the Plants of the World Online (http://powo.science.kew.org) to unify nomenclature and classified taxa into native, endemic, and non-native following taxonomic monographs (e.g., Flora Malesiana: https://floramalesiana.org/). We verified indigenous group names using the Ethnologue (www.ethnologue.com) (Simons and Fennig 2018) or Glottolog (http://glottolog.org). Reports that lacked indigenous group names (*n* = 22,153) were classified as "not specified" and those that could not be matched to an indigenous group (*n* = 749) as "unresolved." The 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 use" for a given species as the use associated to a use category and use subcategory for a specific plant part. We defined a "use report" as the citation of a "plant use" from a bibliographic reference or herbarium specimen. To quantify patterns across New Guinea's habitats, we analyzed 17,894 use reports with habitat-level information from 224 references and 756 herbarium specimens. To assess the relationship between documentation effort and extinction risk of indigenous groups, we used language endangerment as a proxy of the extinction risk of indigenous groups. We obtained the language endangerment classification from Ethnologue (Simons and Fennig 2018), which uses the Expanded Graded Intergenerational Disruption Scale (EGIDS, Lewis and Simons 2010). Our sample of New Guinea's languages included eight of the 13 EGIDS levels: *wider communication*, *educational*, *developing*, *vigorous*, *threatened*, *shifting*, *moribund*, and *nearly extinct*. Of these, the latter four are considered to comprise the endangered category.

Results and Discussion

Spatiotemporal Trends

Overall, we reviewed 488 references and 854 herbarium specimens, which contained 40,376 use reports on 3434 plant species, 19,948 plant uses, and 217 indigenous groups. The first reports on useful plants date to the 19th century (Miklouho–Maclay 1886), and the number of references and their geographic coverage has significantly increased in the last two decades (Fig. 1). Most studies have been published after Powell's 1976 review (446 references, 91%) and these contain 38,378 use reports (95% of total). References differed substantially in their quality, with 20 "data-rich" studies containing 53% of all use reports, 66% of plant species, 60% of plant uses, and 18% of all indigenous groups (ESM Table S1). While references contained more use reports than herbarium specimens (30,679 vs. 885), herbarium specimens added 159 species and new localities that were found in references (Fig. 1), illustrating that herbaria are important ethnobotanical repositories (Souza and Hawkins 2017).

Mainland New Guinea—with 442 references, 36,694 use reports, and 3292 species—has been substantially better studied than the next best-studied islands of New Britain, New Ireland, Manus, Fergusson, Biak, and Yapen (Fig. 1). The number of references in Indonesia has increased considerably in the last two decades (Fig. 1) and exceeds that of Papua New Guinea (304 vs. 255), but studies in Indonesia have fewer use reports (12,154 vs. 27,701), plant uses (9083 vs. 17,917), species (1705 vs. 2670), and mean number of use reports per reference (mean ± SD, 38 ± 119 vs. 106 ± 339). Contrasting these results with Ecuador—which has a comparably diverse flora of 17,548 vascular plant species (Ulloa et al. 2017)—we can place research in New Guinea in a global context. Ecuador has more useful species—5172 (De la Torre et al. 2008)—and is the best-studied Neotropical country in taxonomy (Ulloa et al. 2017) and ethnobotany (Cámara–Leret et al. 2014). Given New Guinea's higher cultural diversity (i.e., > 1100 indigenous groups vs. 13), and its vast area that remains underexplored, we expect that additional research will yield thousands of plant species not yet recorded in the literature.

Ecosystems

Our review indicates that lowland tropical forests and lower montane forests have received greater attention and have more references and more useful species and use reports than all other habitats combined (ESM Table S2). These biases may partly result from the fact that under-documented habitats are ecologically marginal environments for human habitation, including alpine areas with extreme temperatures and low fertility soils (Bleeker 1983) and lowland swamp forests with high incidences of malaria (Riley 1983). The most cited plant families in New Guinea were Fabaceae (2355 use reports), Arecaceae (2294 use reports), and Moraceae (2049) (ESM Table S3). Interestingly, these families are also remarkably useful in other wilderness areas like Amazonia (Prance et al. 1987) or the Chocó biodiversity hotspot (Galeano 2000) and deserve special consideration in terms of conservation. *Ficus*, *Pandanus*, and *Syzygium* were the most important genera based on their number of use reports and plant uses (ESM Table S4). Together, these important plant families and genera deserve further attention and represent model groups to investigate cross-cultural patterns in IK.

Landscape-scale labeling schemes can serve to identify goods originating from an ecosystem-provisioning region, publicize cultural heritage, and improve market recognition (Ghazoul et al. 2009). To set a baseline for these initiatives, we sought to identify the most frequently cited useful species within each of New Guinea's habitats (Fig. 2, ESM Table S5). There were 2575 species that had at least two use reports, and the most cited

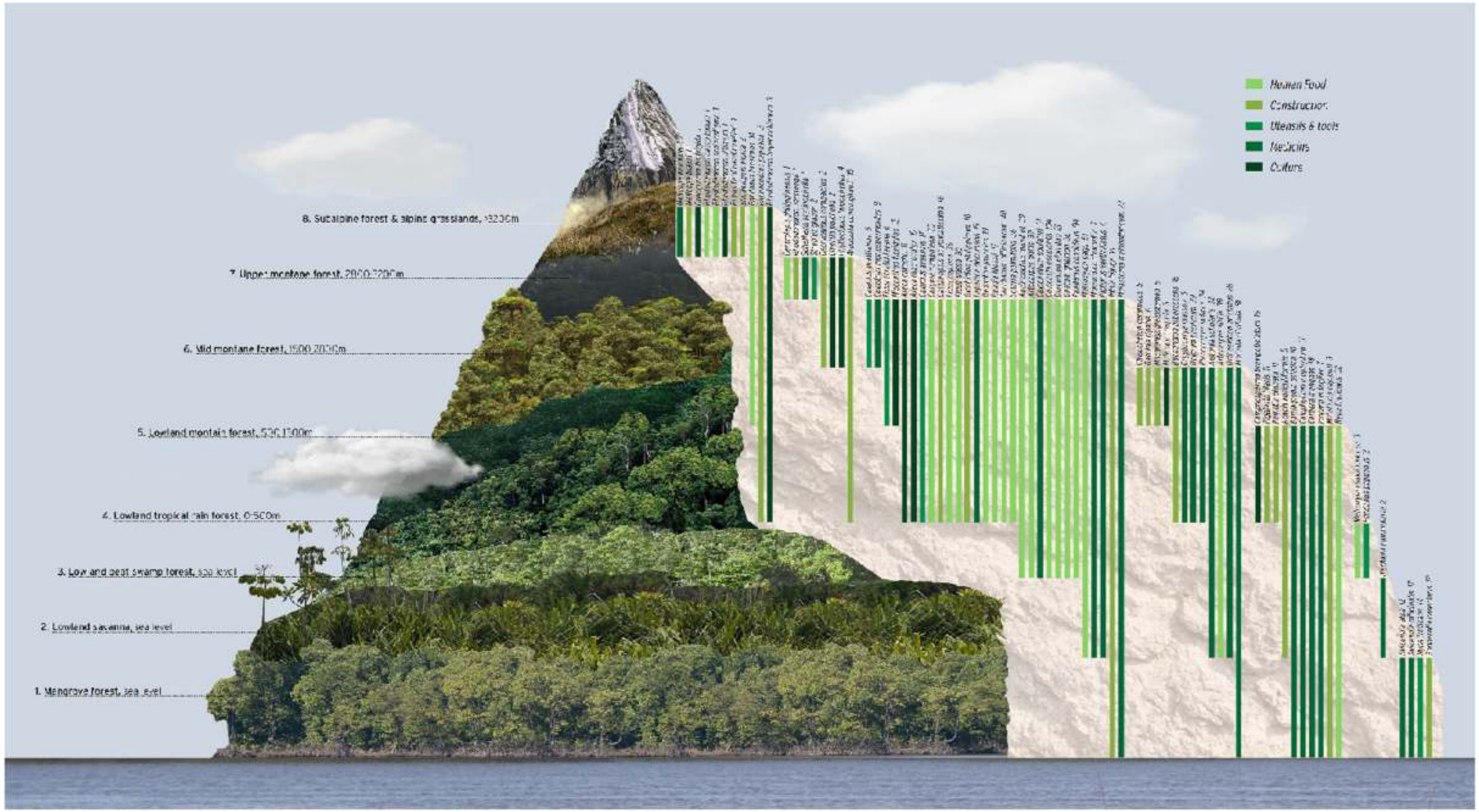

Fig. 2. Ecological distribution of some of New Guinea's useful plant species. Altitudinal and habitat profile of New Guinea showing frequently cited species within each habitat. Bar colors indicate the five most important use categories (see Table 1) and values in parenthesis show the number of use reports for each species in the respective use category. For multifunctional species, only the most cited use category is shown.

TABLE 1. THE MULTIPLICITY OF PLANT USES KNOWN BY NEW GUINEA'S INDIGENOUS GROUPS.

Use category/subcategory	Use reports	Uses	Families	Genera	Species	Indigenous groups	References
Medicine	10,895	5837	191	687	1365	115	282
Blood and cardiovascular system	235	164	58	92	115	27	66
Cultural diseases and disorders	176	77	65	57	65	32	46
Dental health	271	164	54	86	110	35	83
Digestive system	1514	725	129	307	413	60	142
Endocrine system	32	26	16	19	20	7	18
General ailments with unspecific symptoms	1151	481	112	242	315	57	124
Infections and infestations	963	561	109	254	350	51	130
Metabolic system and nutrition	116	85	47	65	71	14	26
Musculo-skeletal system	409	251	78	144	175	37	99
Nervous system and mental health	80	53	35	43	46	8	32
Not specified	496	380	107	199	278	36	107
Poisoning	292	178	59	95	108	25	70
Pregnancy, birth, and puerperal	441	250	78	143	170	47	101
Reproductive system and sexual health	543	314	84	154	207	40	107
Respiratory system	1117	499	106	240	321	50	121
Sensory system	352	208	70	117	147	43	85
Skin and subcutaneous tissue	1944	881	131	331	509	67	153
Urinary system	168	140	34	54	89	14	43
Veterinary	62	50	28	38	42	21	25
Other	533	350	99	175	245	39	120
Construction	6719	3334	142	498	1429	94	204
Bridges	373	262	62	117	256	11	29
Houses	2437	1104	127	382	951	71	139
Thatch	556	300	70	146	257	47	91
Transportation	1001	561	69	183	517	35	73
Other	2352	1107	113	365	1023	34	110
Human food	6515	1959	167	526	1084	131	262
Beverages	187	109	42	55	78	35	57
Food	5889	1625	162	492	982	125	247
Food additives	394	198	73	104	157	36	73
Oils	45	27	16	16	22	11	27
Utensils and tools	5044	2762	167	584	1475	82	212
Domestic	1878	1055	116	351	936	59	140
Hunting and fishing	784	358	91	190	303	51	99
Labor tools	921	613	96	235	576	41	72
Rope	702	337	80	155	268	43	81
Utensils and tools other	228	157	65	101	132	27	62
Wrappers	531	242	73	131	226	38	68
Culture	4255	2219	166	556	1197	111	234
Cloth and accessories	669	355	90	159	307	38	76
Cosmetic	263	192	66	118	165	30	74
Dyes	400	234	63	114	189	36	72
Personal adornment	430	178	82	119	155	33	51
Recreational	989	537	111	242	445	68	132
Ritual	1452	686	130	302	490	72	125
Other	52	37	29	28	35	17	25
Fuel	2314	1128	122	345	890	48	108
Fire starter	302	233	43	86	229	17	29
Firewood	1849	795	120	308	749	38	86
Lighting	163	100	33	48	91	17	31

TABLE 1. (CONTINUED).

Use category/subcategory	Use reports	Uses	Families	Genera	Species	Indigenous groups	References
Environmental	1681	1000	154	429	731	50	122
Agroforestry	111	80	32	52	80	11	25
Fences	627	384	87	199	342	39	72
Ornamental	653	317	105	202	301	23	84
Soil improvers	183	132	43	83	116	19	41
Other	107	87	39	68	84	10	32
Animal food	1658	921	134	370	684	33	98
Bait	79	51	35	42	50	10	18
Fodder	278	194	50	106	160	22	63
Wildlife attractant	1301	676	120	293	544	23	49
Toxic	422	309	64	121	204	30	76
Fishing	189	118	39	60	86	23	49
Hunting	44	39	9	10	33	3	12
Other	189	152	45	81	108	15	41
Other uses	873	479	112	224	375	51	102

Use categories are presented in descending order of use reports and use subcategories in alphabetical order

Human Food plants included the sago palm (*Metroxylon sagu* Rottb.) from the lowland savanna to mid-montane forests, taro (*Colocasia esculenta*), and red pandan (e.g., *Pandanus conoideus* Balf. f.) from the lower montane forest to mid-montane forest. Important plants for medicine include the great morinda (*Morinda citrifolia* L.), Amboyna wood (*Pterocarpus indicus* Willd.), and blackboard tree (*Alstonia scholaris* (L.) R. Br.). For an example of the multiplicity of uses that 50 of the most important species provide, see ESM Table S6. To develop New Guinea's green economy sustainably, more research on the ecology, management practices (e.g., Fedele et al. 2011; Ticktin 2004), and value chains (e.g., Brokamp et al. 2011) of these important taxa will be needed.

MULTIPLICITY OF PLANT USES

A multiplicity of plant uses—spanning the hierarchy of human needs, from starch-rich crops to alkaloid-rich ritual plants—have been discovered by New Guinea's societies (ESM Table S5). The most frequently cited plant parts are the stem (33% of all use reports), the entire leaf (19%), the fruit (9.5%), the entire plant (5.9%), and the bark (5.5%). Medicine is the best-studied use category, as it had more use reports, plant uses, plant families, genera, and references (Table 1). Our list of 1365 medicine species represents a significantly higher number than the 332 species from Powell's review (1976). Skin and subcutaneous tissue appear as the most pressing medicinal concerns to the region's inhabitants (Prescott et al. 2017), and these had the greatest number of medicine use reports, uses, taxa, and indigenous groups with information. Since medicinal plant uses cited by at least two cultures can be indicative of plant bioactivity (Saslis–Lagoudakis et al. 2014), we further identified which species had a high medicine cross-cultural consensus—measured as the number of indigenous groups that agree on a particular plant use. Species with the highest cross-cultural consensus were generally non-native taxa, including *Psidium guajava* L. used for digestive system disorders (n = 9 indigenous groups), *Carica papaya* L. for infections and infestations (n = 7), and *Laportea decumana* (Roxb.) Wedd. for general ailments with unspecific symptoms (n = 6) (ESM Table S7). While studies on non-native species have emphasized their ecological and economic effects, a neglected aspect has been the contributions of non-native taxa to local communities (Pfeiffer and Voeks 2008). Our findings show that non-native species have had a culturally enriching role in local pharmacopeias and together with the list of species with high levels of cross-cultural consensus can be used to inform applied ethnopharmacological research (e.g., Prescott et al. 2017).

New Guinea's Indigenous Groups

Language underpins peoples' ability to identify and use plants, but massive socioeconomic transitions are threatening many languages and weakening the links between nature and human societies globally (Karki et al. 2018). We find 217 indigenous groups (19%) have been studied (152 from Papua New Guinea, 87 from Indonesia), but most remain under-documented (mean ± SD use reports, 80 ± 252). There were 160 studies made with a total of 163 non-endangered indigenous groups (wider communication, 5; educational, 9; developing, 113; vigorous, 36) and 64 studies made with 54 endangered groups (threatened, 34; shifting, 12; moribund, 6; nearly extinct, 2). Non-endangered groups have more use reports than endangered groups (15,525 vs. 1949), useful species (1876 vs. 488), and plant uses (7040 vs. 1289), and 90% of the 54 studied endangered indigenous groups have < 100 use reports (ESM Table S8). But even large indigenous groups remain understudied, e.g., the Asmat of Indonesia who number 40,000 and occupy ca. 20,000 km^2 have only five use reports. These knowledge gaps would be expected for small indigenous groups of New Guinea's remote interior ranges, some of which were first contacted by outsiders only in 1930 and 1954 (Leahy 1991; Matthiessen 2003) but are striking in the case of these charismatic widespread coastal indigenous groups.

Conclusions

Our regional synthesis about IK on plant utilization in New Guinea indicates that despite 488 studies have been made over 130 years, most have been fragmentary. As a result, major knowledge gaps exist about how plants are being used in the world's most bioculturally diverse region. Previous research has emphasized particular ecosystems and has neglected small indigenous groups whose languages (and therefore IK about plants) face extinction risk. Yet given the aim of national governments to preserve the beneficial contributions that nature provides to people and strengthen indigenous peoples' rights, improved strategies to document and mainstream IK will be necessary. Our identification of important taxa according to IK represents a baseline for the local governments of Indonesia and Papua New Guinea to select charismatic taxa to develop the region's green economy. Still, further fieldwork will be necessary to address the discrepancy between documentation effort and indigenous groups' extinction risk.

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