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Knowledge coproduction to improve assessments of nature's contributions to people

Améline Vallet[1,2] | Bruno Locatelli[3,4] | Merelyn Valdivia-Díaz[5] | Yésica Quispe Conde[6] | Gerardina Matencio García[4] | Alejandrina Ramos Criales[4] | Francisca Valverde Huamanñahui[4] | Santusa Ramos Criales[4] | David Makowski[7] | Sandra Lavorel[8]

[1]Ecologie Systématique Evolution, AgroParisTech, CNRS, Université Paris-Sud, Université Paris-Saclay, Orsay, France

[2]CIRED, AgroParisTech, Cirad, CNRS, EHESS, Ecole des Ponts ParisTech, Nogent-sur-Marne, France

[3]Forests and Societies, CIRAD, University of Montpellier, Montpellier, France

[4]Center for International Forestry Research, Lima, Peru

[5]Food and Agriculture Organization of the United Nations (FAO), Rome, Italy

[6]UNALM, La Molina Agrarian University, Lima, Peru

[7]INRAE, AgroParisTech, Université Paris-Saclay, UMR MIA 518, Paris, France

[8]Laboratoire d'Ecologie Alpine, Université Grenoble Alpes, Université Savoie Mont-Blanc, CNRS, Grenoble, France

Correspondence
Améline Vallet, Ecologie Systématique Evolution, AgroParisTech, CNRS, Université Paris-Sud, Université Paris-Saclay, AgroParisTech, 22 place de l'Agronomie, 91120 Palaiseau, Orsay, France. Email: ameline.vallet@agroparistech.fr

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Abstract

Sustainability science needs new approaches to produce, share, and use knowledge because there are major barriers to translating research into policy and practice. Multiple actors hold relevant knowledge for sustainability including indigenous and local people who have developed over generations knowledge, methods, and practices that biodiversity and ecosystem assessments need to capture. Despite efforts to mainstream knowledge coproduction, less than 3% of the literature on nature's contributions to people (NCP) integrates indigenous and local knowledge (ILK). Approaches and tools to better integrate scientific and ILK knowledge systems in NCP assessments are urgently needed. To fill this gap, we conducted interviews with ILK experts from Abancay and Tamburco, Peru, and convened focus groups and workshops during which participatory mapping, a serious game, a Bayesian belief network based on ILK were introduced. We inventoried 60 medicinal plants used to treat different illnesses, and analyzed the spatial distribution of the 7 plants that contribute the most to a good quality of life, and delineated their nonmedicinal uses. Based on the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services conceptual framework, we defined dimensions of a good quality of life according to indigenous and local worldviews. Medicinal plants contributed strongly to health and household security, among other contributions. Climate change and overexploitation were the main perceived threats to medicinal plants, despite the existence of formal and customary institutions to regulate trade. Our approach was flexible enough to integrate diverse forms of knowledge, as well as qualitative and quantitative information from, for example, the Bayesian belief network.

KEYWORDS
Bayesian belief networks, ecosystem services, ethnopharmacology, participatory research, plant distribution mapping, traditional medicine, transdisciplinary research, well-being

Coproducción de conocimiento para mejorar la evaluación de las contribuciones de la naturaleza para las personas

Resumen: La ciencia de la sostenibilidad necesita nuevos enfoques para producir, compartir y utilizar los conocimientos, ya que existen grandes obstáculos para trasladar la investigación a la política y la práctica. Varios actores poseen conocimientos relevantes para la sostenibilidad, incluidos los pueblos originarios y locales que han desarrollado conocimientos, métodos y prácticas a lo largo de generaciones, que deben reflejarse en las evaluaciones de la biodiversidad y los ecosistemas. A pesar de los esfuerzos por integrar la coproducción de conocimientos, <3% de la bibliografía sobre las contribuciones de la naturaleza a las personas (CNP) integra los conocimientos autóctonos y locales (CAL). Se necesitan urgentemente enfoques y herramientas para integrar mejor los sistemas de conocimiento científico y los conocimientos autóctonos y locales en las evaluaciones de los CNP. Para llenar este vacío, realizamos entrevistas con expertos en CAL de Abancay y Tamburco, Perú, y convocamos grupos focales y talleres durante los cuales se introdujeron el mapeo participativo, un juego serio y una red de creencia bayesiana basada en CAL. Inventariamos 60 plantas medicinales utilizadas para tratar diferentes enfermedades y analizamos la distribución espacial de las siete especies de plantas que más contribuyen a una buena calidad de vida y delineamos sus usos no medicinales. A partir del marco conceptual de la Plataforma Intergubernamental Científico-Normativa sobre Diversidad Biológica y Servicios de los Ecosistemas, definimos las dimensiones de una buena calidad de vida según las cosmovisiones autóctonas y locales. Las plantas medicinales contribuían en gran medida a la salud y a la seguridad de los hogares, entre otras aportaciones. El cambio climático y la sobreexplotación fueron las principales amenazas percibidas para las plantas medicinales a pesar de la existencia de instituciones tradicionales que regulan el mercado. Nuestra estrategia fue lo suficientemente flexible para integrar el conocimiento diverso, así como la información cualitativa y cuantitativa, como por ejemplo la red de creencia bayesiana.

Palabras Clave:
bienestar, etnofarmacología, investigación participativa, investigación transdisciplinaria, mapeo de distribución botánica, medicina tradicional, red de creencia bayesiana, servicios ambientales

通过知识共创改进自然对人类贡献的评估

【摘要】可持续科学需要新的方法来生产、分享和利用知识, 这是因为将研究成果转化为政策和实践仍存在重大阻碍。该过程的各方参与者都拥有与可持续相关的知识, 包括土著人和当地人, 他们经过数代人的努力已经形成了生物多样性和生态系统评估所需的知识、方法和实践。然而, 即便人们已在努力将知识共创纳入主流, 但在关于自然对人类贡献的文献中, 仅有不到3%的文献整合了土著和地方知识 (Indigenous and local knowledge, ILK) 。因此, 目前急需建立在自然对人类贡献评估中更好地整合科学知识体系与 ILK 知识体系的方法和工具。为了填补这一空白, 本研究对秘鲁阿班凯和坦布尔科的 ILK 专家进行了访谈, 组织了焦点小组会议和研讨会, 介绍了参与式地图绘制、严肃游戏和基于 ILK 的贝叶斯信念网络。我们整理了 60 种用于治疗不同疾病的药用植物, 分析了对提高生活质量贡献最大的7种植物的空间分布, 并界定了它们的非药用用途。根据生物多样性和生态系统服务政府间科学政策平台的概念框架, 我们按照土著和地方世界观定义了优质生活的各个层面。我们发现, 药用植物除其他贡献外, 还对健康和家庭安全做出了巨大贡献。人们认为气候变化和过度开发是药用植物面临的主要威胁, 尽管已存在正式和惯例的贸易监管体系。我们的方法非常灵活, 可以整合各种形式的知识, 以及来自贝叶斯信念网络等定性和定量的信息。**【翻译:胡怡思;审校:聂永刚】**

关键词: 跨学科研究, 生态系统服务, 福祉, 传统医学, 民族药物学, 植物分布, 贝叶斯信念网络, 参与式研究

INTRODUCTION

Addressing the urgent environmental challenges of biodiversity erosion, natural resource depletion, and climate change requires new approaches to produce, share, and use knowledge, across disciplines and sectors. Transdisciplinary and sustainability scholars propose an inclusive and interactive approach, knowledge coproduction, to integrate academic and nonacademic actors' knowledge to address problem-oriented decision making (Plummer et al., 2022; Vinke-de-Kruijf et al., 2022). Knowledge coproduction is promoted by international science-policy processes, such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), Convention on Biological Diversity (CBD), and Future Earth; networks such as the Indigenous Peoples' Biocultural Climate Change Assessment Initiative (IPCCA) (https://ipcca.info); and national to local initiatives and actors (Brondízio et al., 2021; Hill et al., 2020; McElwee et al., 2020). For instance, in Peru, a collective named Proyecto Andino de Tecnologias Campesinas–Núcleos de Afirmación Cultural Andino-Amazónica was created over 30 years ago to promote the development of alternative approaches to environmental governance including the use of Andean–Amazonian knowledge and perspectives on nature (Gonzales, 2015).

Here, we define *knowledge coproduction* as in Norström et al. (2020): the "iterative and collaborative processes involving diverse types of expertise, knowledge, and actors to produce context-specific knowledge and pathways towards a sustainable future." We define *knowledge systems* as in Díaz et al. (2015): "the body of propositions that are adhered to, whether formally or informally, and are routinely used to claim truth." Multiple actors, including scientists, indigenous, and local people, managers, and practitioners, hold relevant knowledge for decision making oriented toward sustainability (Kadykalo et al., 2021; Wheeler & Root-Bernstein, 2020). Indigenous and local knowledge (ILK) refers to the "body of place-based knowledge accumulated and transmitted across generations within specific cultural contexts" (Jessen et al., 2021).

How to articulate ILK with scientific knowledge from multiple disciplines (natural and social sciences, humanities) in a respectful and ethical knowledge coproduction process is a challenge for transdisciplinary and sustainability research. Over the last decade, sustainability scientists have increasingly engaged with decolonized knowledge coproduction methodologies that recognize, respect, and support indigenous and local aspirations (Greenaway et al., 2022; Maclean et al., 2022). Knowledge coproduction should ideally follow 4 principles: be place based (i.e., consider social, economic, and ecological specificities); identify clear goals; involve plural knowledge systems; and foster frequent and diversified interactions among knowledge holders (Balvanera et al., 2017; Norström et al., 2020). Indeed, integrating multiple sources of knowledge involves significant practical and philosophical challenges because participatory processes are inevitably affected by power asymmetries among actors with diverging worldviews about nature (often colonial legacies) and diverging methodologies and criteria for assessing and validating knowledge (Obermeister, 2017; Vallet et al., 2020). Some have pragmatically observed that knowledge coproduction can also increase transaction costs in the effort to gather actors with diverse views and perspectives and create trust and relationships among them (Norström et al., 2020). Unless power and knowledge validation issues are taken seriously, there is a risk of "scientization and romanticization" of ILK (Löfmarck & Lidskog, 2017). In addition, coproduction is a way to enhance legitimacy and ensure the implementation of knowledge in society (Norström et al., 2020; Tengö et al., 2017).

The knowledge developed by indigenous and local people through experimentation, adaptation, and coevolution over generations provides valuable knowledge, methods, theory, and practices for sustainability. For instance, in Peru and Bolivia, ILK provides accurate information about the water cycle (Oshun et al., 2021), El Niño events (based on the brightness of stars in the Pleiades) (Orlove et al., 2000), and weather patterns (based on plant and animal indicators) (Boillat & Berkes, 2013). It also provides information about ecological processes, such as plant and animal population trends and distribution, ecosystem functions, and evolutionary processes (Jessen et al., 2021; McElwee et al., 2020; Stern & Humphries, 2022). Ethnoecology, a scientific field focusing on the study of the relationships between human societies and their environment, demonstrates how ILK varies depending on social and cultural groups, for instance, in the way people name animals and plants and value the environmental role of species, use biodiversity, implement governance system to govern their access to and use of biodiversity, and integrate biodiversity in the worldviews and cosmologies that guide peoples' ethics (Cámara-Leret & Dennehy, 2019).

Indigenous and local knowledge is, therefore, highly valuable for assessing biodiversity, ecosystems, and their contributions to people and can inform, for instance, IPBES initiatives. Indeed, ILK is central to the IPBES transdisciplinary framework, which integrates diverse worldviews and representations of human-nature interactions (Brondízio et al., 2021; Díaz et al., 2018), and IPBES assessments (ILK-based indicators for food and feed, medicinal plants, or pollination are used) (Kadykalo et al., 2019; McElwee et al., 2020). It also contributes to IPBES scenarios, pathways, and policy options developed to improve environmental governance (Pereira et al., 2020). Despite IPBES's efforts to mainstream knowledge coproduction and ILK in assessments, it is mentioned in less than 3% of articles in the NCP literature, although inclusion has improved over time (Kadykalo et al., 2019).

There is a clear need for new approaches and tools to integrate scientific and ILK knowledge systems in place-based NCP assessments, including a need for guidance on how to operationalize high-quality principles and respectful and ethical knowledge coproduction compiled from empirical experience. In addition to methodological development, IPBES' recent report on the sustainable use of wild species also highlights knowledge gaps such as the need for context-specific information about the multiple uses of wild plants, their spatial distribution, and how to govern their use (IPBES, 2022).

We combined methods from sociology, ethnoecology, and participatory research to coproduce knowledge for integrated NCP assessment. We used the IPBES framework as our conceptual and analytical reference, and we applied our approach to a case of medicinal plants in the Peruvian Andes. We considered medicinal plants because they contribute to the health and livelihoods of millions of people (Hamilton, 2004; Mathez-Stiefel et al., 2012) and are one of the least studied NCP in the literature (Martín-López et al., 2019; Rasmussen et al., 2016; Wolff et al., 2015), despite the existence of ILK-based indicators (Adade Williams et al., 2020; McElwee et al., 2020). Finally, existing ethnoecology studies, which often consist of inventories of plants and their uses, poorly elucidate the links between medicinal plants and human quality of life.

We addressed 5 structural questions for integrated assessments of NCP (Díaz et al., 2015; Vilá & Arzamendia, 2022): to which dimensions of good quality of life do medicinal plants contribute; how and for what purposes are plants used; where do medicinal plants grow and are they harvested; which human inputs make medicinal plants improve quality of life; and what are the direct and indirect drivers that affect medicinal plant availability and use? We do not provide an exhaustive list of methods and approaches, but rather empirically illustrate how knowledge can be coproduced at different steps in the IPBES framework, following general principles from Norström et al. (2020).

METHODS

Overview of the approach

We implemented a 5-step approach following the IPBES conceptual framework (Figure 1). At each step, we, as scientists, coproduced knowledge with ILK holders through various participatory methods such as interviews, focus groups, workshops, participatory mapping, a serious game, and Bayesian modeling based on expert knowledge (timeline in Supporting Information Appendix S1). The information obtained through these activities was complemented by almost 2 years of participant observation by A.V. Some activities (e.g., description of nonmedicinal uses and plant abundance mapping) were conducted for a selection of medicinal plants with the highest contributions to good quality of life.

This work was part of a larger participatory research project focusing on NCPs and sustainable landscape planning in the greater Mariño watershed (Vallet et al., 2019). Our understanding of coproduction sits with the sustainability literature and aligns with the decolonial literature. Indigenous and local experts were full collaborators in the project and, like scientists, could engage in the design of the study and propose conceptual tools (Smith, 2022; Yua et al., 2022). The investigated topics emerged from preliminary discussions about medicinal plants with ILK experts and actors involved in the larger project and from gaps identified in the NCP literature. We applied the IPBES framework to organize the research topics in such a way that would make sense to the scientific community, but this framework did not structure our collaborative research agenda.

This research protocol was approved by the Center for International Forestry Research Ethics Committee (reference FTR044) and endorsed by local authorities, who greatly facilitated research activities (e.g., relaying the call to participate and providing meeting venues). We presented the research project to all participants and asked for their verbal consent including for audio recording. Collected data were anonymized. All communications were conducted in Spanish or Quechua, depending on participant preferences.

The data sets we generated are publicly available on the Recherche Data Gouv repository (https://doi.org/10.57745/7RFNNP). Included are the inventory of plants and their uses, plant names mentioned during freelisting, probabilities used in the Bayesian belief networks, and medicinal and nonmedicinal contributions to a good quality of life. The code used to produce the analyses and figures is available at https://gitlab.dsi.universite-paris-saclay.fr/agata/medicinal_plants/medicinal_plants_coproduction or https://doi.org/10.5281/zenodo.8265455.

Study site

The study was conducted in the greater Mariño watershed (320 km^2) on the eastern slope of the Peruvian Andes in the Apurímac region. Most of its 80,000 inhabitants live in 2 main cities, Abancay and Tamburco. The rural population is dispersed among small communities (INEI, 2018a). Most people (79.05%) identify as members of the Quechua ethnic group, and the Quechua language is the most frequent first language (INEI, 2018b). Around 25% of people live below the poverty line, mostly in rural areas (INEI, 2020). Incomes of the rural population are from agriculture and livestock, sometimes complemented with paid labor. Some women cultivate and harvest medicinal plants for income (de la Cruz et al., 2014; Mathez-Stiefel et al., 2012). Agriculture (10% of land cover) is commercially oriented at low elevations. Small-scale, family and subsistence-oriented agriculture and livestock production occur at high and midelevations, where crops are mixed (Vallet et al., 2019).

Large elevational gradients (1506 m at Pachachaca River to 5216 m at Ampay summit) strongly influence precipitation and vegetation distribution. Mean annual precipitation is 905 mm/year at Abancay, with high intra- and interannual variability (Condom et al., 2011). Vegetation consists of dry forests (in lowlands), shrublands, non-native plantations (e.g., eucalyptus and pine), grasslands, and remnant patches of native *Polylepis* or *Podocarpus* forests in the highlands.

Medicinal plants are important for the health of the urban and rural populations (Vallet et al., 2019), despite the presence of medical facilities in the cities (Figure 2) (De-la-Cruz et al., 2007;

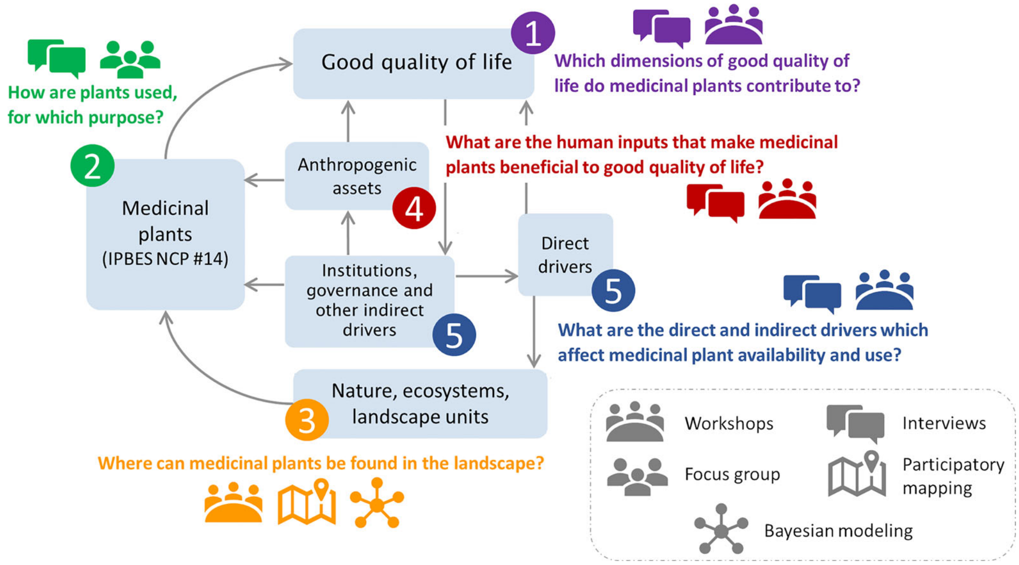

FIGURE 1 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services conceptual framework that represents the complex interactions between the natural world and human societies. Numbers are the different steps of the integrated assessment of medicinal plants' contributions to a good quality of life. Part of steps 2 and 3 focused on a limited number of medicinal plants, selected by Indigenous and local knowledge experts.

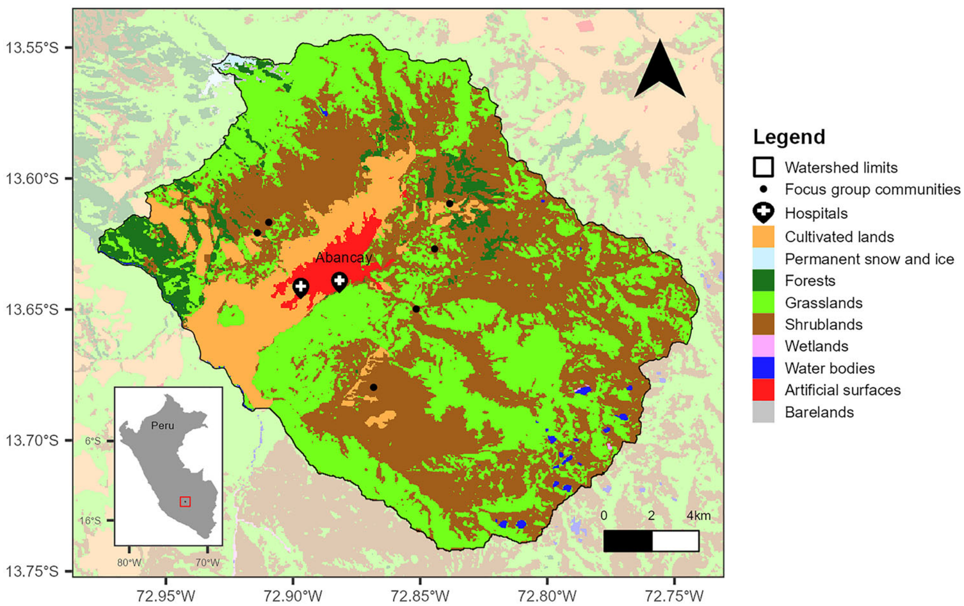

FIGURE 2 Map of the study area in Peru.

Gonzales De La Cruz, 2014; Monigatti et al., 2013). Medicinal plants are mainly harvested in higher-elevation natural areas, but some are harvested and cultivated on agricultural land. They are sold at Abancay and Tamburco daily or weekly markets.

Indigenous knowledge holders

Several people hold valuable knowledge on medicinal plants and traditional medicine in the area: plant gatherers (*hierbaleros*), who harvest and sell plants; plant traders, who buy and sell plants in the markets; indigenous healers (*shaman* or *curanderos*), who treat illness; and midwives (De Feo, 1991; De-la-Cruz et al., 2007). We focused on plant gatherers and traders and referred to them as *knowledge holders*. Plant gatherers collect plants for their personal use or to sell at markets. Traders buy plants from gatherers and sell them to users, sometimes outside the study area. Both hold unique knowledge on plant distribution, use, and contributions to health and livelihoods (i.e., which parts of plants are used, preparation techniques, and where and when to harvest for maximum effectiveness).

Knowledge about medicinal plants varies with experience, seniority, professionalization (personal use vs. commercial activity), and job (gatherer vs. trader) (Raymond et al., 2010). For instance, plant traders know little about plant distributions because they do not collect them, but they do hold, to some extent, knowledge of plant uses. Plant gatherers for personal use often know fewer plants and their associated properties and uses than gatherers who make a living from plant sales at markets.

We identified indigenous knowledge holders in Abancay and Tamburco markets and in the surrounding rural communities through a combination of purposive, snowball, and convenience sampling (Monigatti et al., 2013). For some study activities, we aimed for a high diversity of knowledge holders from different communities and with heterogeneous knowledge and perceptions regarding plants. For other activities, expertise was crucial, so we worked with 4 experienced female plant gatherers over the age of 45 who are coauthors on this article.

Describing the contributions of medicinal plants to a good quality of life (step 1)

During a workshop, knowledge holders were asked to give their own definition of good quality of life or well-being and to detail what being happy or satisfied with life means for them. Some key dimensions of a good quality of life were written on cards and placed on a table. Then, participants were asked to further comment on these dimensions and describe how medicinal plants contribute to maintaining or reinforcing them. Using stickers, participants identified which dimensions of good quality of lifemedicinal plants were important. Each participant was given 10 stickers and could place only 1 on each dimension. We further investigated contributions of medicinal plants to 2 dominant quality-of-life dimensions during interviews: livelihood support (income generation, regularity of income throughout the year, use of income generated by the activity, socioeconomic dependance on the activity) and health (quantity of plant used to cure, frequency of use, main diseases treated, possibilities to replace plants with pharmaceuticals). Interview guides are in Supporting Information Appendix S2.

We identified plants that contributed most to a good quality of life during free-listing interviews with knowledge holders. Interviewees were asked to list the medicinal plants they considered most important for health and livelihoods. We initially aimed to select the 5 most frequently mentioned native plants (Quinlan, 2005; Smith, 1993), but ended up with 7 because 3 were referred to by the same name (*muñas*). We collected samples of each selected plant, including roots and flowers, and sent them for identification at herbariums.

Documenting knowledge about medicinal plants' uses (step 2)

First, we preliminarily inventoried medicinal plants and their medicinal uses and identified rainy- and dry-season species through ethnobotanical interviews with plant sellers at the Abancay weekly market over several months. Each inventoried plant was photographed, and its vernacular name, life form (herb, shrub, or tree), parts used, preparation, and administration were recorded (Supporting Information Appendix S3). Sellers were interviewed several times to identify as many plants as possible. Plants were identified by matching their pictures and local names with existing plant inventories. When no match was found, we sent them to herbariums for identification. Their origin (native vs. introduced) was determined using the Royal Botanical Gardens platform, Plants of the World Online (https://powo.science.kew.org/).

Second, we documented ILK about the 7 plants' uses relative to the 10 categories proposed by Bioversity International & The Christensen Fund (2009): food (fresh, processed, or cooked), food additive (flavoring), fodder or fodder additive, apiculture (nectar or pollen source), material (e.g., fibers, latex, essential oil, dye), fuel, cultural use (religious, ritual), medicinal (e.g., digestive, fever, cough), environmental (e.g., erosion control, barrier, bioindicator), and other (other uses specified by informants). We organized 6 workshops in rural communities to quantify for each plant separately the relative importance of the different uses. Participants were asked to distribute maize seeds on cardboard sheets corresponding to the different descriptors, according to their importance and to describe qualitatively the different uses.

Finally, medicinal uses of the selected plants were further investigated during interviews with knowledge holders. Selected plants were classified according to whether a plant was used to treat cold diseases (hot plant) (i.e., cold causing articulation and muscular pain, pulmonary affections, urogenital problems) or hot diseases (cold plant) (i.e., accumulation of internal heat causing digestive system affections and inflammation), as defined in Andean etiology (de la Cruz et al., 2014). For the analysis of medicinal uses (preliminary inventory and plant selection), we differentiated among 8 disease categories (e.g., digestive, respiratory, skin, subcutaneous tissues) that we further disaggregated into subcategories (e.g., couch, fever, stress, stomachache) (detailed typologies in Supporting Information Appendix S3). One category focused on "culture-bound illnesses" (i.e., illnesses bounded to specific cultural systems not easily translated into biomedical terms, e.g., *susto* and *mal viento* in the Andes) that are deeply rooted in Quechua etiology, sociocultural beliefs, and representations of the world (Carey, 1993; Mathez-Stiefel et al., 2012; Monigatti et al., 2013).

Mapping selected plant abundance in landscape with Bayesian belief networks (step 3)

We used Bayesian belief networks (BBN) to map abundance of the 7 medicinal plants, following Marcot et al. (2006) and Chen & Pollino (2012). Knowledge holders identified variables influencing abundance during interviews and a workshop dedicated to Bayesian modeling (Table 1). Then, 4 experienced plant gatherers estimated plant abundance in different landscape configurations during a serious game (details in Supporting Information Appendix S4).

Using the quantitative information on plant abundance collected during the serious game and qualitative information on

TABLE 1 Variables and data sources included in the Bayesian belief networks used to map medicinal plant abundance in the greater Mariño watershed.*

Variable	Source	Resolution	Criteria for discretization
Elevation	ASTER DEM v3 https://lpdaac.usgs.gov/products/astgtmv003/	30 m	1400–2500 m < 2500–3500 m < 3500–5220 m
Slope			18° (mean slope of agricultural areas)
Land cover	GlobeLand30 http://www.globeland30.org/	30 m	Forests and shrublands vs. other land-cover classes
Precipitation	Chelsa Climatologies v1.2 https://chelsa-climate.org/	1 km	782 mm/y (mean precipitation in the area)
Soil available water content	FutureWater HiHydroSoil version 2.0 https://www.futurewater.eu/projects/hihydrosoil/	250 m	2800 m^3/m^3 (mean soil water content in the area)

*Following Marcot et al. (2006), the variables were arranged into a simple conceptual graph (i.e., no more than 5 layers and 3 parents nodes) that described their causal influences on plant abundance. They were further categorized into different abundance states (e.g., high, medium, low) with thresholds and discretization techniques.

plant ecologies collected during interviews and focus groups, A.V. elicited for each landscape configuration the probabilities of different plant abundance levels with the MATCH Uncertainty Elicitation Tool (http://optics.eee.nottingham.ac.uk/match/uncertainty.php) (details in Supporting Information Appendix S4).

The BBN was constructed using R and bnlearn (R Core Team, 2021; Scutari, 2010) and implemented with biophysical variables (Chen et al., 2015; Karger et al., 2017; NASA, 2019; Simons et al., 2020) (Table 1) in bnspatial (to map the most likely abundance and uncertainty) (Masante, 2016). We used GeNIe Modeler (http://www.bayesfusion.com/) to visualize the BBN and identify influential variables.

Because there is no information on selected plant distribution or abundance with which to conduct a data-driven validation of the developed model, we implemented a 3-step expert-based validation procedure, which consisted of testing that the BBN correctly reproduced ILK by applying different combinations of environmental variables and examining the predicted abundance; conducting a sensitivity analysis to identify variables with the greatest influence on the prediction of plant abundance; and comparing the modeled abundance with distribution maps generated through participatory mapping (details in Supporting Information Appendix S4). Expert-based validation and sensitivity analyses are validation procedures recommended in the literature for data-scare BBN application (Chen & Pollino, 2012; Landuyt et al., 2013).

Identifying anthropogenic assets, governance, and drivers of change (steps 4 and 5)

Information on human inputs (i.e., anthropogenic assets in IPBES framework) and drivers of medicinal plant availability and use were collected during interviews and focus groups in communities. For human inputs, we considered anthropogenic assets from the IPBES conceptual framework that support gathers' capacity to access and appreciate medicinal plants (i.e., built infrastructure, knowledge, physical and procedural technology, and financial assets [Bruley et al., 2021; Díaz et al., 2015]). Governance arrangements were explored during a workshop with 4 experienced plant sellers, interviews and focus groups. In the workshop, participants told us about formal and informal institutions that regulate plant extraction and sales.

RESULTS

Conceptualizing good quality of life in the local context (step 1)

During the workshop, participants mobilized the traditional Andean and Quechua cosmovision to present and discuss elements of a good quality of life in relation to nature. They referred to good quality of life as the *allin kawsay* (*vivir bien*), a holistic concept that highlights balanced interactions between people and nature, social relations in and among families and communities, and mental and physical health (Figure 3). "One cannot be happy and healthy if one does not have a bit of everything," stressed 1 participant. Detailed descriptions of these dimensions are in Supporting Information Appendix S5.

Medicinal plants contributed to several dimensions of the allin kawsay and good quality of life (Figure 3). The first dimension mentioned by participants was health, given that plants can be used to cure a broad range of diseases and be used as food flavoring. Medicinal plants were also said to contribute to household security because of the income that plant sellers use for family and education expenses. Medicinal plants contribute to life satisfaction because of their tranquilizing and relaxing properties. Medicinal plants also contributed to social cohesion because of the reciprocal sharing of plants and traditional knowledge among neighbors. Finally, medicinal plants contribute to agricultural production because they can be used as a medicine for livestock or as a natural pest repellent.

When questioned on the plants with the highest contributions to good quality of life, interviewees most frequently cited muñas (3 varieties were further distinguished by plant sellers: *pachamuña*, *punamuña*, and *rafamuña*), *yawarchonqa*, *palma real*, *manayupa*, and *mullaca* (Table 2). The detailed results of free listing are in Supporting Information Appendix S6.

The main reasons for preferring medicinal plants over biomedicine (i.e., conventional Western medicine) included (Figure 4a) lower cost (plants collection is free); easier access (drugstore or formal medical health care facilities can be far);

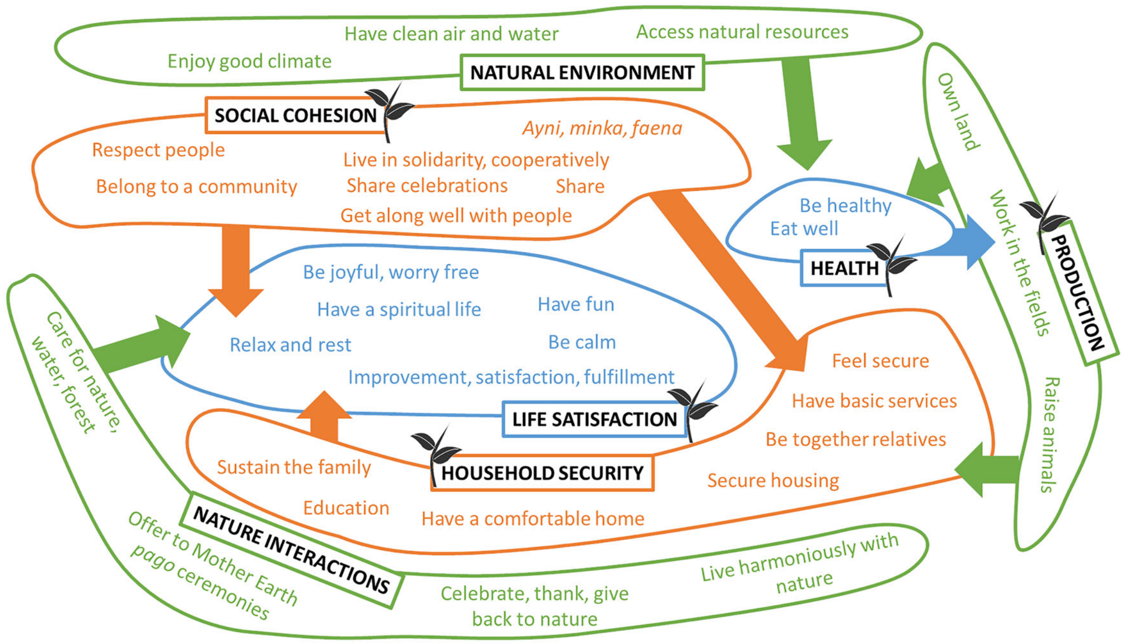

FIGURE 3 Dimensions of a good quality of life identified during a workshop with 4 experienced plant gatherers (plant logo, dimensions to which medicinal plants contribute; green, interactions between people and nature; orange, social relations in and among families and communities; blue, mental and physical health).

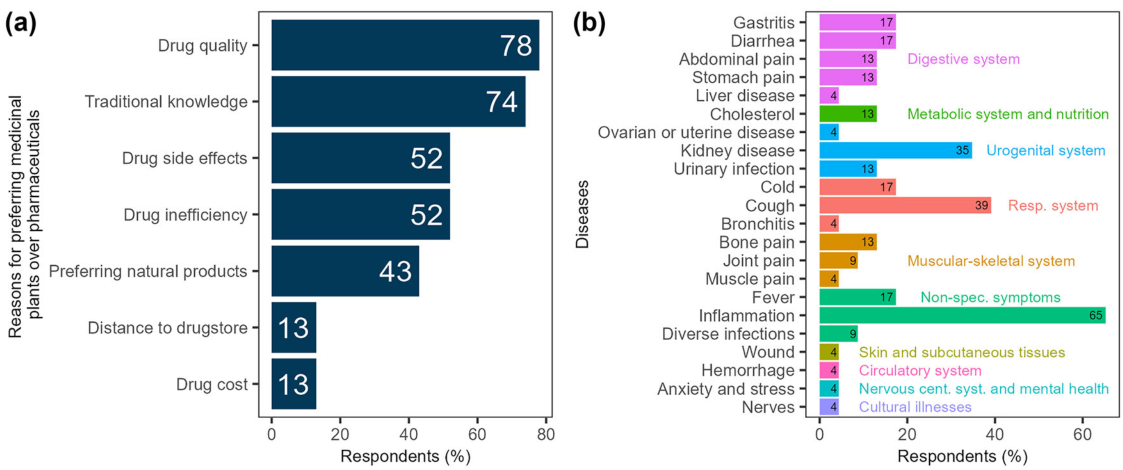

FIGURE 4 Medicinal plants' contributions to health: (a) diseases treated with medicinal plants as mentioned during interviews with plant sellers and (b) reasons for preferring medicinal plants over pharmaceuticals.

a preference for natural products (pharmaceuticals were often described as drugs or hormones); existence of side effects with biomedicine; less efficient treatment of chronic disease with biomedicine (pharmaceuticals were said to soothe the pain, but not to treat the causes; effects were also perceived to be shorter than for plants); traditional knowledge about medicinal plants transmitted across generations (knowledge about biomedicine and pharmaceuticals is limited); and perceived low quality of pharmaceuticals sold in drugstores or prescribed in the formal health care system. Economic reasons alone did not explain plant consumption: 72.7% of respondents indicated that they would keep using medicinal plants even if the price of pharmaceuticals were really low. Regarding contribution to household security, interviewees indicated that they traded medicinal plants to generate income (73%), for pleasure (19%), and to heal people (9%). The detailed results of contributions to health and household security are in Supporting Information Appendix S7.

Description of plant uses (step 2)

Sixty plants and 181 uses were recorded on Abancay markets during the preliminary inventory (Supporting Information Appendix S8). The most common plant families were Asteraceae (22%) and Lamiaceae (17%). Local names were either derived from Spanish (50%) or Quechua (50%). Most species

TABLE 2 Description of the 7 medicinal plants that contributed most to a good quality of life in the greater Mariño watershed.*

Scientific name	Local name	Medicinal uses	Indigenous hot or cold classification	Biophysical characteristics according to plant sellers
Oenothera rosea	yawarchonqa	skin and subcutaneous tissues (healing, inflammation, wounds)	cold	grows from lower to intermediary part of the watershed (up to 3000 m) in places with abundant water and smooth and rich soils (agricultural fields); can grow under sun and moderate shade
Minthostachys setosa	rafamuña	digestive system (gastritis, stomach pain, diarrhea)	hot	grows in intermediary part of the watershed in places with abundant water, smooth and rich soil; tolerant of moderate shade but prefers sun; natural habitats include riversides and *matorrales*; also found in and beside agricultural fields
Hedeoma mandoniana	pachamuña	digestive system (gastritis, stomach pain, diarrhea)	hot	grows in intermediary to high parts of the watershedwhere water is abundant, e.g., along rivers or around springs and wetlands; moderately tolerant of shade but prefers sun; natural habitats include lower *paramo* grassland, or matorrales; also found in and beside agricultural fields
Clinopodium gilliesii	punamuña	digestive system (gastritis, stomach pain, diarrhea)	hot	grows in highest part of the watershed (above 3500 m) on dry soils; not tolerant of humid soils or shade; adaptable to a wide range of soil compaction, from smooth to hard packed; natural habitat paramo grassland
Muehlenbeckia volcanica	mullaca	respiratory system (cough, asthma) digestive system (diarrhea, purgative medication, hepatic affection) urogenital system (renal affections) nonspecific symptoms and general pathologies (inflammation)	mild	grows exclusively in highest part of watershed above 3500 m; not tolerant of shade or moist soils; natural habitats include rocky slopes of high-elevation paramo grassland
Desmodium molliculum	manayupa	urogenital system (renal affections, prostate affections, urinary infection) circulatory system (purify blood) metabolic system and nutrition (cholesterol) nonspecific symptoms and general pathologies (inflammation)	mild	grows in intermediary part of the watershed (2500 to 3500 m); is not tolerant of shade; occurs in pastures, roadsides, agricultural fields and forest edges, and on gentle slopes; moderately tolerant of high humidity
Achillea millefolium	palma real	digestive system (gastritis, stomach pain, diarrhea) cultural illnesses (bad wind)	hot	grows in highest part of the watershed (above 3000 m); requires moist, smooth soils; not tolerant of shade; grows in flat areas; common habitats include wetlands, riversides; also be found along canals and irrigation systems

*This summary was produced with information obtained from the preliminary inventory of medicinal plants, free-listing interviews, and semidirected interviews of knowledge holders focusing on plant contributions to a good quality of life and the workshop on Bayesian belief networks.

were harvested in their natural habitats (60%), few were cultivated (33%) or both cultivated and harvested (7%). Two-thirds of the plants were native to Peru or the Andes; others were introduced.

Plants were used to treat different parts of the body and illnesses, mainly from the digestive and urogenital systems (Figure 5). Plants inventoried in the city markets most frequently targeted ovarian or uterine disease (6% of inventoried uses, 10 plants), cough (6%, 8 plants), prevention of digestive disorders (5%, 9 plants), kidney (5%, 8 plants) and liver (5%, 7 plants) diseases; and urinary infection (5%, 7 plants) (Supporting Information Appendix S8). These diseases were also among the most often mentioned during individual interviews about plant contributions to health (Figure 4b). The consistency of these results

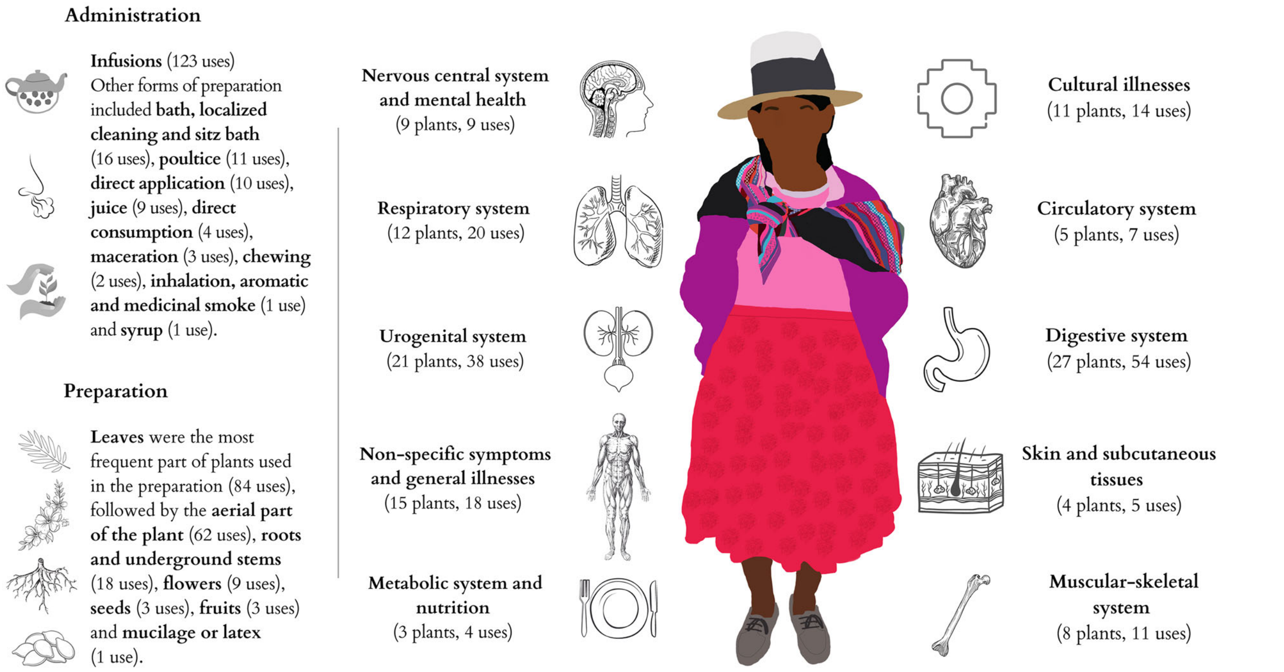

FIGURE 5 Summary of the preliminary inventory of medicinal plants used in the greater Mariño watershed (numbers in right panel, plants used to treat each category of illness and number of different uses listed by interview respondents).

showed the importance of local plants for the treatment of these pathologies.

On average, each plant was involved in the treatment of 1.9 categories of illnesses and 2.6 individual illnesses, but with high variance. Some species were used to treat several types of illnesses (e.g., manzanilla, romero). To the contrary, *mark'u* was specific to the treatment of 3 cultural illnesses; *estrella kiska* was specific to the urogenital system, and palma real, punamuña, and pachamuña were specific to the digestive system (Supporting Information Appendix S8). Five cultural illnesses were treated only with medicinal plants (no pharmaceuticals existed, according to ILK experts): *mal viento* (bad wind), *susto* (fright), *nervios* (nerves), *mal del corazón* (heart pain), and *ccaycca* (contact with the bad energy of the soul of a dead person) (descriptions of these illnesses in Supporting Information Appendix S3).

The inventoried plants were usually mixed for use (several plants with similar properties were combined to balance their effects). For instance, for mal del corazón, nervios, and insomnia, 3 plants are blended (*valeriana*, *pensamiento*, and manzanilla). For ovarian or uterine diseases, *amor seco* is used in combination with *moqo moqo*, yawarchonqa, and estrella kiska. Usually, cold (and mild) plants were used to treat hot diseases such as fever, and vice versa. Some plants were perceived as particularly good for balancing the mixes and lowering the effects of other plants such as manzanilla and *malva*. The ILK experts noted that plant properties (hot or cold) and curative power depended on their environment. They were perceived as more powerful when they grew in their ideal ecological conditions. In the case of parasitic plants (e.g., *tullma*), the properties were also said to vary depending on the host plant species.

The selected plants had a large diversity of uses that encompassed all categories of descriptors, including the most important ones: medicinal (33%) (Table 2), food (18%), environmental (13%), and fodder or fodder additive (10%) (Figure 6a). In 3 communities, the other category was used to quantify the importance of plant commercialization. Muñas species (*Minthostachys setosa*, *Hedeoma mandoniana, Clinopodium gilliesii*) showed lower medicinal relative importance, but more uses, including material (essential oil), food additive (condiment for soup), cultural uses (rituals), and fuel (to light candles or start fire). In contrast, species such as *Desmodium molliculum* and *Oenothera rosea*, were used mainly for medicinal purposes. Appreciation of plant uses varied among communities, especially for descriptors with limited importance (e.g., cultural uses, fuel, material,etc.), highlighting the fact that some uses (or at least the knowledge about some uses) were heterogeneously distributed in the area. Importance in terms of commercialization was mentioned in only 3 communities, suggesting that collection for commercial purposes was not ubiquitous. Medicinal uses are summarized for the most important species in Table 2 and for other species in Supporting Information Appendix S8.

Plant spatial distribution (step 3)

Some areas of the study site, such as the highlands and woody lowlands, showed high medicinal plant richness (Figure 6b) and high abundance of individual species. In contrast, richness and abundance were very low in the Mariño valley, where land cover is primarily built and agriculture is predominant. Similar pat-

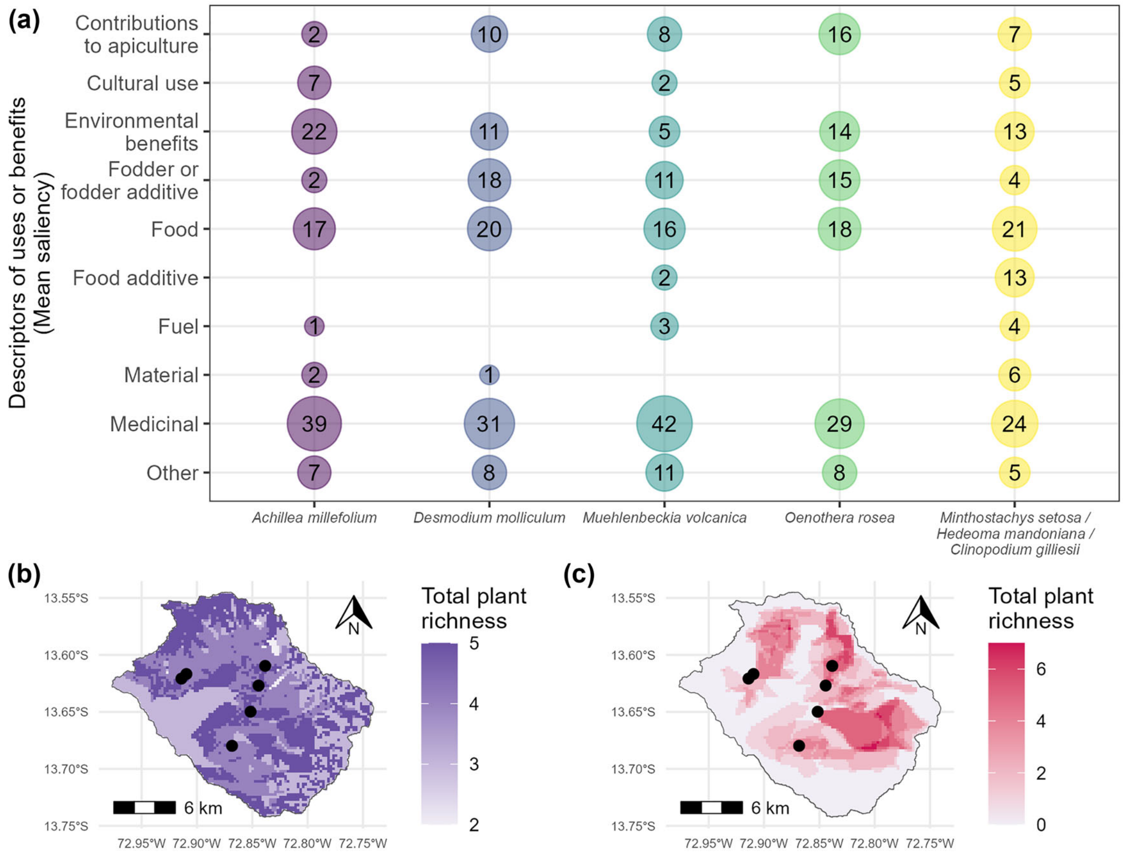

FIGURE 6 (a) Mean saliency for plants that contribute the most to a good quality of life in the greater Mariño watershed as indicated during focus groups in 6 communities of the study area, (b) map of plant richness obtained with the Bayesian belief networks, and (c) map of plant richness obtained with participatory mapping (black circles, locations of the 6 communities where focus groups were hold).

terns were observed with the participatory mapping, although distribution areas were defined more roughly and located near the communities where the focus groups were held (Figure 6c).

Anthropogenic assets and drivers affecting medicinal plants (steps 4 and 5)

Several anthropogenic assets were mobilized by plant sellers to harvest, transport, and sell medicinal plants. Knowledge was crucial for all these steps because plant sellers needed to know where to collect desired plants and how to prepare and use them. Some sellers knew more than others, and those who knew more were respected for it. For instance, not all sellers were aware that certain harvesting practices can have a negative impact on plant abundance and should therefore be avoided.

Most sellers had very limited use of technology. They often carried plants on their backs in an *aguayo o quepe* (i.e., traditional woven blanket) or with a mule and transported plants on foot from the harvest location to their home before selling them in city markets. This considerably limits the quantity of plants that can be harvested. To transport and sell the plants in the markets, sellers often relied on public or shared infrastructure such as the road network, *combi* (i.e., minibuses) transportation system, and marketplaces. Some wealthier sellers were said to use their personal vehicles to access harvest places or transport plants to markets.

The cultivation and acclimation of wild medicinal plants was practiced at a very small scale by some sellers, who mobilized a few technological (e.g., irrigation) and financial assets to develop the activity. Some local NGOs provided technological and financial support to develop this activity, although more as an experiment than a commercial activity.

Climate change and overextraction in accessible places were the direct drivers of plant availability and use most often mentioned by interviewees and focus group participants to explain decreasing plant availability. They reported that people new to the activity (e.g., nonlocal harvesters or young single mothers collecting plants to ensure their livelihoods) usually sold large quantities of plants (often under contract with *emolienteros* [street sellers of medicinal plant hot beverages]) and applied unsustainable collection practices, destroying roots and flowers. Local and experienced plant gatherers from the communities described them as "predators" and recommended better supervision of their activities.

Workshop participants also indicated that formal and customary institutions indirectly regulate plant extraction and sales. The 4 public institutions that control and enforce plant extraction regulations (see Supporting Information Appendix S9) were considered ineffective because small-scale subsistence extraction and trade are tolerated and it is impossible to determine whether traded plants came from the wild or were cultivated. Only SERNANP reportedly monitors plant extraction in the protected area. Plant gatherers explained they did not understand why this traditional activity, practiced for generations, is regulated in the Ampay Sanctuary. Extraction regulations were also said to come from the traditional customary laws of rural communities. For instance, the inhabitants of a community traditionally have the right to benefit from the natural resources from the communal lands (e.g., medicinal plant extraction, grazing, or timber extraction), whereas outsiders are not allowed to use resources without community consent. Respondents said these informal governance mechanisms do not completely prevent outsiders (e.g., from Abancay City) from collecting medicinal plants where they are particularly abundant (e.g., Soccllacasa and Ccorhuani).

DISCUSSION

Documenting knowledge on medicinal plants and their contributions to a good quality of life

Our work on medicinal plants echoes previous studies of the way ILK people name and use medicinal plants and of how they perceive good quality of life. Several identified plants and their uses are also listed in ethnoecological studies from neighboring regions (e.g., Cusco [Huamantupa et al., 2011; Mathez-Stiefel et al., 2012]), which supports previous findings that pharmacopeia is relatively homogenous in the southern Peruvian Andes in contrast to tropical areas (Rehecho et al., 2011). We documented this unique living Andean knowledge and demonstrated its importance for good quality of life (Brauman et al., 2020; Cámara-Leret & Dennehy, 2019).

Our results align with existing literature on Andean cosmovision and its 4 main principles of human-nature interactions (relationality, complementarity, correspondence, and reciprocity [Estermann, 2006; Rodríguez Salazar, 2016]). Our study of medicinal plants sheds light on 2 dimensions of relationality: relationships among people within communities or families and relationships between people and nature. We found that harmony and positive and synergetic relationships between people and nature were important to a good quality of life. Our results also offer insights on complementarity; medicinal plants can restore the equilibrium between cold and hot energies of the body affected by diseases (Gonzales de la Cruz et al., 2014).

Similar to previous studies in the Andes, medicinal plants were used because they contributed to good quality of life beyond health and medicine such as social cohesion. Medicinal plants also provided regular income and contributed economically to the subsistence of the rural poor, as in other areas of the Peruvian Andes (Corroto et al., 2021; Mathez-Stiefel et al., 2012). Our analysis of plant contributions to good quality of life, could have been improved by considering benefits for other actors less directly connected to medicinal plants such as plant buyers and emolienteros.

Although the 2 methods we used to map plant abundance led to similar distributional patterns (Supporting Information Appendix S4), participatory mapping resulted in discontinuous areas, mainly centered around communities where workshops were held. This suggests participants were informed about only the areas surrounding their communities. Participants should, therefore, be carefully selected to avoid such a bias and ensure good coverage of the study area. The BBN was not affected by such continuity issues, but was subject to other biases related to ILK elicitation (e.g., motivational and cognitive bias [Baddeley et al., 2004; Cooke, 1991]).

The knowledge we documented about plant uses, contributions of medicinal plants to good quality of life, and governance systems directly answers IPBES' call for information, data, and indicators related to wild plant gathering (IPBES, 2022). We also collected qualitative information on direct and indirect drivers of medicinal plant use, but additional participatory activities (participatory mapping, transect walks, oral histories, etc.) could improve understanding of past and future trends and drivers (Ramirez-Gomez et al., 2015; Reed et al., 2013). Such analyses might be needed to shed light on plant-based tourism and industry as a driver of plant overextraction or sociocultural transformations in communities (changes in values, worldviews, traditions, and livelihoods). This has been observed, for instance, for psychoactive plants in Latin America such as Ayahuasca (*Banisteriopsis caapi*) or San Pedro (*Echinopsis pachanoi*) (Fotiou, 2014; Salibová, 2020). In the study area, psychedelic tourism is nonexistent, and only muñas could be industrially exploited (essential oil).

Knowledge coproduction for integrated assessment of NCP

We showed how several participatory methods can be combined to coproduce knowledge for an integrated NCP assessment. Our approach proved flexible enough to deal with diverse forms of knowledge and qualitative and quantitative information. Thus, we contributed to filling several gaps identified in the sustainability and transdisciplinary literatures and in IPBES' recent assessment of the sustainable use of wild species by providing an integrated assessment on the medicinal plants, using new methods in an empirical study, operationalizing principles of high quality, and conducting respectful and ethical knowledge coproduction (IPBES, 2022).

Whereas identifying medicinal plant uses and their contributions was relatively easy, mapping plant distribution and abundance was challenging. We showed how BBN can be used to connect ILK and expert knowledge and integrate heterogeneous sources of information, as have others (Barber & Jackson, 2015; Bélisle et al., 2018). Direct elicitation of BBN probabilities by ILK experts would not have been possible because the concept of probability is often misunderstood by Indigenous and local experts (Barber & Jackson, 2015; O'Leary et al., 2009). The elicitation of probabilities by A.V. (a scientist) with qualitative and quantitative information is a good example of how knowledge can be coproduced by actors with different knowledge systems and skills (Raymond et al., 2010). Several techniques have been proposed to consider the experience and preferences of elicitors (Morgan et al., 1990), including visual supports such as the roulette method, probability wheels, and serious games (Celio et al., 2019; Morris et al., 2014). Such techniques were particularly relevant for knowledge coproduction in our study.

Coproduction offers another solution to the problem of BBN validation in data-scarce areas (Landuyt et al., 2013). Knowledge holders, if they were involved from the beginning in the BBN, could assess model output accuracy and help detect unexpected behavior. Sensitivity analyses identified the most influential variables, which were the same as those perceived by ILK holders (Supporting Information Appendix S4). This suggests knowledge coproduction does not necessarily imply validation between knowledge systems, but rather complementarity and validation within each system (Tengö et al., 2017) (i.e., validation of the BBN based on ILK by ILK holders). Such validation approaches are rare in the NCP literature. The IPBES is one of the few assessment initiatives to implement a knowledge coproduction approach that does not rely on the validation and verification of ILK through scientific standards (Obermeister, 2017). Validating model outputs and participatory research activities can be challenging. It requires developing new visualization and communication techniques such as the serious game we used.

In the serious game we developed to complement the BBN study, site pictures were used to illustrate the combination of ecological variables affecting plant distribution in the BBN and to facilitate estimations of plant abundance by ILK holders. Some selected pictures were perceived differently by the experts and the scientists who chose them, which led to possible misinterpretations (representation bias) (Supporting Information Appendix S4). The photos we used were taken during the dry season, during which some of the selected plants do not grow, which led experts to underestimate plant abundance (seasonality bias). Finally, they associated the pictures with specific places in the watershed, which might have affected the generalization to other similar places of the study area (localization bias). We, therefore, recommend using more than 1 picture for each landscape configuration taken during different seasons and asking participants to describe how they interpreted the pictures. These are only examples of the biases resulting from our methodological design, but they illustrate individual and methodological biases that limit a person's judgment during a game or an elicitation. We partially overcame these biases by combining the quantitative information from the serious game with qualitative information on plant distribution before eliciting each plant and landscape abundance probability distribution and integrating them in the BBN.

Toward ethical knowledge coproduction

A primary challenge for us was the difficulty at the beginning of engaging in discussion and collaboration with ILK holders, but local nongovernmental organizations facilitated contacts in the communities. Another challenge was establishing trust. Understandably, ILK holders were suspicious that a group of researchers—including foreigners—were interested in traditional knowledge about medicinal plants. Medicinal plant use and cultivation are sensitive subjects because of plant harvesting regulations and because of the exploitation and abuse of ILK about plants historically by colonists and currently by biopirates (Boumediene, 2022; Smith, 2022).

It was, therefore, essential to develop methods for an ethical coproduction of knowledge about medicinal plants that addressed, to some extent, concerns about the decolonization of knowledge. During the project, ILK experts guided our collective work towards issues they considered important such as how governance restrictions were imposed on local communities and limited their capacity to fully benefit from medicinal plants. We also explicitly recognized and put at the core of our work indigenous worldviews and representation of the world, for example, when analyzing plants' contributions to a good quality of life. Thus, we contributed—to a small extent—to work on decolonialized research about plants (Boumediene, 2022; Maclean et al., 2022; Smith, 2022). It took time and patience to build a common understanding and to set up regular discussions, through participatory activities and participant observation (almost every Sunday in the city markets).

Future coproduction work could more thoroughly reflect the positionality and responsibility of each collaborator so as to contribute to decolonization studies (which was not the ambition of this study as none of the authors had a background in decolonial studies), by analyzing in greater detail the perceived benefits from coproduction. Scientists have their own views and experiences that condition the way they do research and knowledge coproduction (Latour, 1987). There is a need to reflexively analyze how power asymmetries and colonial legacies shape medicinal plant governance and research, natural resource management, and conservation (Castleden et al., 2012; Greenaway et al., 2022; Vallet et al., 2020). Political violence in the 1990s and land confiscation for the creation of Ampay Sanctuary created some trauma, and there is much to learn about how these events relate to attachment to place and traditional activities, such as medicinal plant harvest (Greenaway et al., 2022). There is also a need to propose new structures and processes to ensure ILK holders' sovereignty over plants, their intellectual property over the associated uses, and the transmission and perpetuation of knowledge over generations.

Reflections from ILK holders

What initially motivated ILK experts to participate in the study was the satisfaction of transmitting knowledge to younger and inexperienced people and contributing to A.V. and M.V.-D.'s graduate educations. At the end of the project, during debriefing, experts mentioned they deeply enjoyed being part of a group that regularly met to discuss medicinal plants and loved sharing ideas and experiences, spending time together, playing games, and participating in the activities. They received no economic benefit from their contributions, but they mentioned the following relational, emotional, and cognitive benefits: improved knowledge of plants; recognition of their expertise by scientists and other plant sellers in the city markets; empowerment and building of self-esteem by providing direct input to the research; and building of new social relationships with other plant experts and project collaborators (1 expert even referred to finding new "sisters"). These perceived benefits correspond to high-level needs (self-actualization, esteem, and belonging) in Maslow's theory of behavioral motivation (1943).

During debriefing, experts also highlighted factors that were key to the success of our knowledge coproduction process: friendly relationships among collaborators based on humility and respect (experts had fun, felt happy and cheerful during activities), curiosity and open mindedness about the cultures and knowledge of other collaborators (discussions sometimes deviated from medicinal plants to collaborators experience and life), and sharing of ideas, results, feedback in reciprocal and equitable ways (experts enjoyed having access to results and pictures of the different activities). These factors echo recent work on coproduction with ILK holders that shows the importance of empathetic relationships, respect, trust, and recognition of ethical and high-quality knowledge coproduction (Greenaway et al., 2022; Maclean et al., 2022; Yua et al., 2022). Other experts note that studies that really contribute to collaborators' empowerment are rare and should become mainstream, especially in the search for decolonizing methodologies (Brandt et al., 2013).

ILK as an asset for knowledge and NCP coproduction

Our results also highlight the importance of ILK for knowledge coproduction and coproduction by people and the nature of ecosystem service benefits through social-ecological processes and society-derived inputs such as human, social, manufactured, and financial inputs (Bruley et al., 2021; Grosinger et al., 2021). We found that knowledge is an asset that plant gatherers and traders mobilize to harvest, transport, and sell medicinal plants, as observed for other provisioning services (Outeiro et al., 2017; Vilá & Arzamendia, 2022). Our results, therefore, suggest that ILK might be relevant to coproduction of both knowledge and NCP. Indigenous and local knowledge and NCP coproduction processes are tightly connected because ILK knowledge is a key asset for plant traders to coproduce medicinal plants with nature. Indigenous and local knowledge is perceived as an important and valuable form of knowledge, relevant for knowledge coproduction oriented towards sustainable and equitable management of medicinal plants.

Our work suggests that the definition of coproduction as "a process through which inputs from individuals who are not in the same organization are transformed into goods and services" (Ostrom, 1996) can be extended to cover other kinds of coproduction processes related to NCP and inputs from nonhuman agents, such as the landscape, ecosystems, or biodiversity, which jointly with inputs from humans are transformed into ecosystem goods and services (i.e., NCP coproduction). Our results reinforce the idea that coproduction is an important concept in sustainability science (Miller and Wyborn, 2020).

Imbedding knowledge coproduction in science with society's processes

This study, aimed at coproducing an NCP assessment between scientists and ILK holders, is only 1 first step in informing environmental governance for sustainability. From a broader perspective, knowledge coproduction contributes to the science-with-society process of collaboration and knowledge sharing. Coproduction needs to happen during the multiple tasks of governance and be applied by all governance actors (Raymond et al., 2010; Steger et al., 2021; Tengö et al., 2017).

Translation and communication of results can take multiple forms (e.g., copublication of academic papers, policy briefs, conferences, contributions to local media) and should involve all participants. The translation strategy depends on the purpose and the expected contributions to action (Castleden et al., 2012; Grimshaw et al., 2012). This article, cowritten by scientists and ILK experts, was part of a translation process and was aimed at providing written information to scientists and decision makers. Coauthorship is one way to make ILK experts contributions visible, recognize their intellectual property and sovereignty, and contribute to decolonized research (Castleden et al., 2012; Maclean et al., 2022). There is a demand from ILK experts to develop other ways to inform people about medicinal plants and raise awareness among a wider audience (e.g., with a leaflet in Spanish and Quechua [e.g., Mathez & Huamán, 2018]). Messages should be adjusted to appropriately target specific epistemological communities and group of actors.

Indigenous and local knowledge holders can have an active role in other tasks of governance (Löfmarck & Lidskog, 2017; Obermeister, 2017). In our study, we identified traded plants and ranked them based on their contributions to a good quality of life. These results could facilitate a collective process for negotiating access and harvest rules in the Ampay National Sanctuary (translation and negotiation task of governance). The role of ILK holders for nature conservation is not limited to coproducing knowledge for environmental assessments; it includes landscape governance and management, direct conservation activities, and conservation enforcement (Brondízio et al., 2021).

By identifying the multiple contributions of plants to good quality of life and their use and distribution in the landscape, our findings open pathways to improving medicinal plant management and governance if decision makers can be made aware of the value of this coproduced knowledge. Plant trading, in addition to maintaining traditional knowledge about medicinal plants, contributes in several ways to a good quality of life (health, livelihoods, ILK transmission, social interactions, etc.), which are often ignored by natural resource policies focusing solely on ecological conservation (Sangha & Russell-Smith, 2017). Biocultural approaches to conservation can capture the diversity of place-based human-nature interactions and relational understandings of good quality of life (Pramova et al., 2021). In this regard, our results support calls for a better translation of ILK into policy and decision making (McElwee et al., 2020).

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OPEN RESEARCH BADGES

This article has earned Open Data and Open Materials badges. Data and materials are available at https://doi.org/10.57745/7RFNNP and https://gitlab.dsi.universite-paris-saclay.fr/agata/medicinal_plants/medicinal_plants_coproduction.

ORCID

Améline Vallet https://orcid.org/0000-0002-2731-0098
Bruno Locatelli https://orcid.org/0000-0003-2983-1644
Yésica Quispe Conde https://orcid.org/0000-0002-9592-4657
David Makowski https://orcid.org/0000-0001-6385-3703
Sandra Lavorel https://orcid.org/0000-0002-7300-2811

REFERENCES

Adade Williams, P., Sikutshwa, L., & Shackleton, S. (2020). Acknowledging indigenous and local knowledge to facilitate collaboration in landscape approaches—Lessons from a systematic review. *Land*, *9*, 331.

Baddeley, M. C., Curtis, A., & Wood, R. (2004). *An introduction to prior information derived from probabilistic judgements: Elicitation of knowledge, cognitive bias and herding* (Vol. 239, pp. 15–27). Geological Society.

Balvanera, P., Calderón-Contreras, R., Castro, A. J., Felipe-Lucia, M. R., Geijzendorffer, I. R., Jacobs, S., Martín-López, B., Arbieu, U., Speranza, C. I., Locatelli, B., Harguindeguy, N. P., Mercado, I. R., Spierenburg, M. J., Vallet, A., Lynes, L., & Gillson, L. (2017). Interconnected place-based social–ecological research can inform global sustainability. *Current Opinion in Environmental Sustainability*, *29*, 1–7.

Barber, M., & Jackson, S. (2015). Knowledge making: Issues in modelling local and indigenous ecological knowledge. *Human Ecology*, *43*, 119–130.

Bélisle, A. C., Asselin, H., Leblanc, P., & Gauthier, S. (2018). Local knowledge in ecological modeling. *Ecology and Society*, *23*(2), 14. https://doi.org/10.5751/ES-09949-230214

Bioversity International. (2009). *Descriptors for farmers' knowledge of plants* (pp. 1–13). The Christensen Fund.

Boillat, S., & Berkes, F. (2013). Perception and interpretation of climate change among quechua farmers of Bolivia: Indigenous knowledge as a resource for adaptive capacity. *Ecology and Society*, *18*, art21.

Boumediene, S. (2022). *La colonisation du savoir: Une histoire des plantes médicinales du Nouveau Monde (1492-1750)*. Gallimard.

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D. J., Newig, J., Reinert, F., Abson, D. J., & Von Wehrden, H. (2013). A review of transdisciplinary research in sustainability science. *Ecological Economics*, *92*, 1–15.

Brauman, K. A., Garibaldi, L. A., Polasky, S., Aumeeruddy-Thomas, Y., Brancalion, P. H. S., Declerck, F., Jacob, U., Mastrangelo, M. E., Nkongolo, N. V., Palang, H., Pérez-Méndez, N., Shannon, L. J., Shrestha, U. B., Strombom, E., & Verma, M. (2020). Global trends in nature's contributions to people. *Proceedings of the National Academy of Sciences*, *117*, 32799–32805.

Brondízio, E. S., Aumeeruddy-Thomas, Y., Bates, P., Carino, J., Fernández-Llamazares, Á., Ferrari, M. F., Galvin, K., Reyes-García, V., Mcelwee, P., Molnár, Z., Samakov, A., & Shrestha, U. B. (2021). Locally based, regionally manifested, and globally relevant: indigenous and local knowledge, values, and practices for nature. *Annual Review of Environment and Resources*, *46*, 481–509.

Bruley, E., Locatelli, B., & Lavorel, S. (2021). Nature's contributions to people: Coproducing quality of life from multifunctional landscapes. *Ecology and Society*, *26*(1), 12.

Cámara-Leret, R., & Dennehy, Z. (2019). Information gaps in indigenous and local knowledge for science-policy assessments. *Nature Sustainability*, *2*, 736–741.

Carey, J. W. (1993). Distribution of culture-bound illnesses in the southern Peruvian Andes. *Medical Anthropology Quarterly*, *7*, 281–300.

Castleden, H., Morgan, V. S., & Lamb, C. (2012). I spent the first year drinking tea: Exploring Canadian university researchers' perspectives on community-based participatory research involving Indigenous peoples. *Canadian Geographer*, *56*, 160–179.

Celio, E., Andriatsitohaina, R. N. N., & Zaehringer, J. G. (2019). A serious game to parameterize Bayesian networks: Validation in a case study in northeastern Madagascar. *Environmental Modelling & Software*, *122*, 104525.

Chen, J., Chen, J., Liao, A., Cao, X., Chen, L., Chen, X., He, C., Han, G., Peng, S., Lu, M., Zhang, W., Tong, X., & Mills, J. (2015). Global land cover mapping at 30 m resolution: A POK-based operational approach. *ISPRS Journal of Photogrammetry and Remote Sensing*, *103*, 7–27.

Chen, S. H., & Pollino, C. A. (2012). Good practice in Bayesian network modelling. *Environmental Modelling & Software*, *37*, 134–145.

Condom, T., Rau, P., & Espinoza, J. C. (2011). Correction of TRMM 3B43 monthly precipitation data over the mountainous areas of Peru during the period 1998–2007. *Hydrological Processes*, *25*, 1924–1933.

Cooke, R. M. (1991). *Experts in uncertainty: Opinion and subjective probability in science (Pages xii, 321)*. Oxford University Press.

R Core Team. (2021). *R: A language and environment for statistical computing. R foundation for statistical computing*. Available from https://www.R-project.org/

Corroto, F., Rascón, J., Barboza, E., & Macía, M. J. (2021). Medicinal plants for rich people vs. medicinal plants for poor people: A case study from the Peruvian Andes. *Plants*, *10*, 1634.

De Feo, V. (1991). *Medicinal and magical plants in the northern Peruvian Andes*. Fitoterapia LXIII. Available from https://www.academia.edu/380515/Medical_and_Magical_plants_in_the_northern_Peruvian_Andes

De-La-Cruz, H., Vilcapoma, G., & Zevallos, P. A. (2007). Ethnobotanical study of medicinal plants used by the Andean people of Canta, Lima, Peru. *Journal of Ethnopharmacology*, *111*, 284–294.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikari, J. R., Arico, S., Báldi, A., Bartuska, A., Baste, I. A., Bilgin, A., Brondizio, E., Chan, K. M., Figueroa, V. E., Duraiappah, A., Fischer, M., Hill, R., … Zlatanova, D. (2015). The IPBES conceptual framework—Connecting nature and people. *Current Opinion in Environmental Sustainability*, *14*, 1–16.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., Hill, R., Chan, K. M. A., Baste, I. A., Brauman, K. A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P. W., Van Oudenhoven, A. P. E., Van Der Plaat, F., Schröter, M., Lavorel, S., … Shirayama, Y. (2018). Assessing nature's contributions to people. *Science*, *359*, 270–272.

Estermann, J. (2006). *Filosofía andina: Sabiduría indígena para un mundo nuevo2da ed. (reimp.). Instituto Superior Ecuménico Andino de Teología (ISEAT)*. Anna's Archive.

Fotiou, E. (2014). On the uneasiness of tourism: Considerations on Shamanic tourism in Western Amazonia. In BC Labate, C Cavnar (Eds.), *Ayahuasca Shamanism in the Amazon and beyond*. Oxford University Press.

Gonzales, T. (2015). An indigenous autonomous community-based model for knowledge production in the Peruvian Andes. *Latin American and Caribbean Ethnic Studies*, *10*, 107–133.

Gonzales De La Cruz, M., Baldeón Malpartida, S., Beltrán Santiago, H., Jullian, V., & Bourdy, G. (2014). Hot and cold: Medicinal plant uses in Quechua speaking communities in the high Andes (Callejón de Huaylas, Ancash, Perú). *Journal of Ethnopharmacology*, *155*, 1093–1117.

Greenaway, A., Hohaia, H., Le Heron, E., Le Heron, R., Grant, A., Diprose, G., Kirk, N., & Allen, W. (2022). Methodological sensitivities for co-producing knowledge through enduring trustful partnerships. *Sustainability Science*, *17*, 433–447.

Grimshaw, J. M., Eccles, M. P., Lavis, J. N., Hill, S. J., & Squires, J. E. (2012). Knowledge translation of research findings. *Implementation Science : IS*, *7*, 50.

Grosinger, J., Vallet, A., Palomo, I., Buclet, N., & Lavorel, S. (2021). Collective capabilities shape the co-production of nature's contributions to people in the alpine agricultural system of the Maurienne valley. *Regional Environmental Change*, *21*, 117.

Hamilton, A. C. (2004). Medicinal plants, conservation and livelihoods. *Biodiversity & Conservation*, *13*, 1477–1517.

Hill, R., Adem, Ç., Alangui, W. V., Molnár, Z., Aumeeruddy-Thomas, Y., Bridgewater, P., Tengö, M., Thaman, R., Adou Yao, C. Y., Berkes, F., Carino, J., Carneiro Da Cunha, M., Diaw, M. C., Díaz, S., Figueroa, V. E., Fisher, J., Hardison, P., Ichikawa, K., Kariuki, P., … Xue, D. (2020). Working with Indigenous, local and scientific knowledge in assessments of nature and nature's linkages with people. *Current Opinion in Environmental Sustainability*, *43*, 8–20.

Huamantupa, I., Cuba, M., Urrunaga, R., Paz, E., Ananya, N., Callalli, M., Pallqui, N., & Coasaca, H. (2011). Riqueza, uso y origen de plantas medicinales expendidas en los mercados de la ciudad del Cusco. *Revista Peruana de Biología*, *18*, 283–292.

INEI. (2018a). *Directorio Nacional de Centros Poblados—Censos Nacionales 2017*. Instituto Nacional de Estadística e Informática. Available from https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1541/index.htm

INEI. (2018b). *Resultados Definitivos de los Censos Nacionales 2017—Apurímac*. Instituto Nacional de Estadística e Informática. Available from https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1557/

INEI. (2020). *Mapa de pobreza monetaria provincial y distrital 2018. Page 303*. Instituto Nacional de Estadística e Informática. Available from https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1718/Libro.pdf

IPBES. (2022). Summary for policymakers of the thematic assessment of the sustainable use of wild species of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). IPBES. Available from https://zenodo.org/record/741187

Jessen, T. D., Ban, N. C., Claxton, N. X., & Darimont, C. T. (2021). Contributions of indigenous knowledge to ecological and evolutionary understanding. *Frontiers in Ecology and the Environment*, *2*, 93–101.

Kadykalo, A. N., Cooke, S. J., & Young, N. (2021). The role of western-based scientific, Indigenous and local knowledge in wildlife management and conservation. *People and Nature*, *3*, 610–626.

Kadykalo, A. N., López-Rodriguez, M. D., Ainscough, J., Droste, N., Ryu, H., Ávila-Flores, G., Le Clec'h, S., Muñoz, M. C., Nilsson, L., Rana, S., Sarkar, P., Sevecke, K. J., & Harmáčková, Z. V. (2019). Disentangling 'ecosystem services' and 'nature's contributions to people. *Ecosystems and People*, *15*, 269–287.

Karger, D. N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., Soria-Auza, R. W., Zimmermann, N. E., Linder, H. P., & Kessler, M. (2017). Climatologies at high resolution for the earth's land surface areas. *Scientific Data*, *4*, 170122. https://doi.org/10.1038/sdata.2017.122

Landuyt, D., Broekx, S., D'hondt, R., Engelen, G., Aertsens, J., & Goethals, P. L. M. (2013). A review of Bayesian belief networks in ecosystem service modelling. *Environmental Modelling & Software*, *46*, 1–11.

Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Harvard University Press.

Löfmarck, E., & Lidskog, R. (2017). Bumping against the boundary: IPBES and the knowledge divide. *Environmental Science & Policy*, *69*, 22–28.

Maclean, K., Greenaway, A., & Grünbühel, C. (2022). Developing methods of knowledge co-production across varying contexts to shape Sustainability Science theory and practice. *Sustainability Science*, *17*, 325–332.

Marcot, B. G., Steventon, J. D., Sutherland, G. D., & Mccann, R. K. (2006). Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. *Canadian Journal of Forest Research*, *36*, 3063–3074.

Martín-López, B., Leister, I., Lorenzo Cruz, P., Palomo, I., Grêt-Regamey, A., Harrison, P. A., Lavorel, S., Locatelli, B., Luque, S., & Walz, A. (2019). Nature's contributions to people in mountains: A review. *PLoS ONE*, *14*, e0217847.

Masante, D. (2016). *bnspatial: Spatial implementation of Bayesian networks and mapping*. Available from https://cran.r-project.org/web/packages/bnspatial/index.html

Maslow, A. H. (1943). A theory of human motivation. *Psychological Review*, *50*, 370–396.

Mathez, S.-L., & Huamán, M. (2018). "Qora Hampiyku": Nuestras plantas medicinales en las comunidades de Pitumarca, Cusco, Perú. Centre for Development and Environment (CDE).

Mathez-Stiefel, S.-L., Vandebroek, I., & Rist, S. (2012). Can Andean medicine coexist with biomedical healthcare? A comparison of two rural communities in Peru and Bolivia. *Journal of Ethnobiology and Ethnomedicine*, *8*, 26.

Mcelwee, P., Fernández-Llamazares, Á., Aumeeruddy-Thomas, Y., Babai, D., Bates, P., Galvin, K., Guèze, M., Liu, J., Molnár, Z., Ngo, H. T., Reyes-García, V., Roy Chowdhury, R., Samakov, A., Shrestha, U. B., Díaz, S., & Brondízio, E. S. (2020). Working with Indigenous and local knowledge (ILK) in large-scale ecological assessments: Reviewing the experience of the IPBES Global Assessment. *Journal of Applied Ecology*, *57*, 1666–1676.

Miller, C. A., & Wyborn, C. (2020). Co-production in global sustainability: Histories and theories. *Environmental Science & Policy*, *113*, 88–95.

Monigatti, M., Bussmann, R. W., & Weckerle, C. S. (2013). Medicinal plant use in two Andean communities located at different altitudes in the Bolívar Province. *Peru. Journal of Ethnopharmacology*, *145*, 450–464.

Morgan, M. G., et al. (1990). *Uncertainty: A guide to dealing with uncertainty in quantitative risk and policy analysis*. Cambridge University Press.

Morris, D. E., Oakley, J. E., & Crowe, J. A. (2014). A web-based tool for eliciting probability distributions from experts. *Environmental Modelling & Software*, *52*, 1–4.

Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., Bednarek, A. T., Bennett, E. M., Biggs, R., De Bremond, A., Campbell, B. M., Canadell, J. G., Carpenter, S. R., Folke, C., Fulton, E. A., Gaffney, O., Gelcich, S., Jouffray, J.-B., Leach, M., … Österblom, H. (2020). Principles for knowledge co-production in sustainability research. *Nature Sustainability*, *3*, 182–190.

Obermeister, N. (2017). From dichotomy to duality: Addressing interdisciplinary epistemological barriers to inclusive knowledge governance in global environmental assessments. *Environmental Science & Policy*, *68*, 80–86.

O'leary, R. A., Choy, S. L., Murray, J. V., Kynn, M., Denham, R., Martin, T. G., & Mengersen, K. (2009). Comparison of three expert elicitation methods for logistic regression on predicting the presence of the threatened brush-tailed rock-wallaby Petrogale penicillata. *Environmetrics*, *20*, 379–398.

Orlove, B. S., Chiang, J. C. H., & Cane, M. A. (2000). Forecasting Andean rainfall and crop yield from the influence of El Niño on Pleiades visibility. *Nature*, *403*, 68–71.

Oshun, J., Keating, K., Lang, M., & Miraya Oscco, Y. (2021). Interdisciplinary water development in the peruvian highlands: The case for including the coproduction of knowledge in socio. *Hydrology*, *8*, 112.

Ostrom, E. (1996). Crossing the great divide: Coproduction, synergy, and development. *World Development*, *24*, 1073–1087.

Outeiro, L., Ojea, E., Garcia Rodrigues, J., Himes-Cornell, A., Belgrano, A., Liu, Y., Cabecinha, E., Pita, C., Macho, G., & Villasante, S. (2017). The role of non-natural capital in the co-production of marine ecosystem services.

International Journal of Biodiversity Science, Ecosystem Services & Management, *13*, 35–50.

Pereira, L. M., Davies, K. K., Den Belder, E., Ferrier, S., Karlsson-Vinkhuyzen, S., Kim, H., Kuiper, J. J., Okayasu, S., Palomo, M. G., Pereira, H. M., Peterson, G., Sathyapalan, J., Schoolenberg, M., Alkemade, R., Carvalho Ribeiro, S., Greenaway, A., Hauck, J., King, N., Lazarova, T., … Lundquist, C. J. (2020). Developing multiscale and integrative nature–people scenarios using the Nature Futures Framework. *People and Nature*, *2*(4), 1172–1195.

Plummer, R., Blythe, J., Gurney, G. G., Witkowski, S., & Armitage, D. (2022). Transdisciplinary partnerships for sustainability: An evaluation guide. *Sustainability Science*, *17*(3), 955–967.

Pramova, E., Locatelli, B., Valdivia-Díaz, M., Vallet, A., Quispe Conde, Y., Djoudi, H., Colloff, M. J., Bousquet, F., Tassin, J., & Munera Roldan, C. (2021). Sensing, feeling, thinking: Relating to nature with the body, heart and mind. *People and Nature*, *4*, 351–364.

Quinlan, M. (2005). Considerations for collecting freelists in the field: examples from ethobotany. *Field Methods*, *17*, 219–234.

Ramirez-Gomez, S. O. I., Torres-Vitolas, C. A., Schreckenberg, K., Honzák, M., Cruz-Garcia, G. S., Willcock, S., Palacios, E., Pérez-Miñana, E., Verweij, P. A., & Poppy, G. M. (2015). Analysis of ecosystem services provision in the Colombian Amazon using participatory research and mapping techniques. *Ecosystem Services*, *13*, 93–107.

Rasmussen, L. V., Mertz, O., Christensen, A. E., Danielsen, F., Dawson, N., & Xaydongvanh, P. (2016). A combination of methods needed to assess the actual use of provisioning ecosystem services. *Ecosystem Services*, *17*, 75–86.

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M., & Evely, A. C. (2010). Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management*, *91*, 1766–1777.

Reed, M. S., Kenter, J., Bonn, A., Broad, K., Burt, T. P., Fazey, I. R., Fraser, E. D. G., Hubacek, K., Nainggolan, D., Quinn, C. H., Stringer, L. C., & Ravera, F. (2013). Participatory scenario development for environmental management: A methodological framework illustrated with experience from the UK uplands. *Journal of Environmental Management*, *128*, 345–362.

Rehecho, S., Uriarte-Pueyo, I., Calvo, J., Vivas, L. A., & Calvo, M. I. (2011). Ethnopharmacological survey of medicinal plants in Nor-Yauyos, a part of the Landscape Reserve Nor-Yauyos-Cochas, Peru. *Journal of Ethnopharmacology*, *133*, 75–85.

Rodríguez Salazar, A. (2016). *Teoría y práctica del buen vivir: Orígenes, debates conceptuales y conflictos sociales*. El caso de Ecuador. Universidad del País Vasco.

Salibová, D. (2020). Ayahuasca ethno-tourism and its impact on the indigenous Shuar community (Ecuador) and western participants. *Český lid*, *107*, 511–532.

Sangha, K., & Russell-Smith, J. (2017). Towards an indigenous ecosystem services valuation framework: A north Australian example. *Conservation and Society*, *15*, 255–269.

Scutari, M. (2010). Learning Bayesian networks with the bnlearn R package. *Journal of Statistical Software*, *35*, 1–22.

Simons, G., Koster, R., & Droogers, P. (2020). Hihydrosoil v2. 0-high resolution soil maps of global hydraulic properties. Future Works. [online] Available from https://www.futurewater.eu/projects/hihydrosoil/

Smith, J. J (1993). Using ANTHOPAC 3.5 and a spreadsheet to compute a free-list salience index. *Cultural Anthroplogy Methods*, *5*, 1–3.

Smith, L. (2022). *Decolonizing methodologies: Research and indigenous peoples*. Bloomsbury Academic.

NASA. (2019). ASTER global digital elevation model V003 [Data set.]. *NASA EOSDIS Land processes distributed active archive center*. NASA. Accessed 2023-08-09 from https://doi.org/10.5067/ASTER/ASTGTM.003

Steger, C., Klein, J. A., Reid, R. S., Lavorel, S., Tucker, C., Hopping, K. A., Marchant, R., Teel, T., Cuni-Sanchez, A., Dorji, T., Greenwood, G., Huber, R., Kassam, K.-A., Kreuer, D., Nolin, A., Russell, A., Sharp, J. L., Šmid Hribar, M., Thorn, J. P. R., … Waiswa, D. (2021). Science with society: Evidence-based guidance for best practices in environmental transdisciplinary work. *Global Environmental Change*, *68*, 102240.

Stern, E. R., & Humphries, M. M. (2022). Interweaving local, expert, and Indigenous knowledge into quantitative wildlife analyses: A systematic review. *Biological Conservation*, *266*, 109444.

Tengö, M., Hill, R., Malmer, P., Raymond, C. M., Spierenburg, M., Danielsen, F., Elmqvist, T., & Folke, C. (2017). Weaving knowledge systems in IPBES, CBD and beyond—Lessons learned for sustainability. *Current Opinion in Environmental Sustainability*, *26-27*, 17–25.

Vallet, A., Locatelli, B., Levrel, H., Dendoncker, N., Barnaud, C., & Quispe Conde, Y. (2019). Linking equity, power, and stakeholders' roles in relation to ecosystem services. *Ecology and Society*, *24*, 14.

Vallet, A., Locatelli, B., Barnaud, C., Makowski, D., Quispe Conde, Y., & Levrel, H. (2020). Power asymmetries in social networks of ecosystem services governance. *Environmental Science & Policy*, *114*, 329–340.

Vilá, B., & Arzamendia, Y. (2022). South American Camelids: Their values and contributions to people. *Sustainability Science*, *17*, 707–724.

Vinke-de-Kruijf, J., Verbrugge, L., Schröter, B., den Haan, R., Cortes Arevalo, J., Fliervoet, J., Henze, J., & Albert, C. (2022). Knowledge co-production and researcher roles in transdisciplinary environmental management projects. *Sustainable Development*, *30*, 393–405.

Wheeler, H. C., & Root-Bernstein, M. (2020). Informing decision-making with Indigenous and local knowledge and science. *Journal of Applied Ecology*, *57*, 1634–1643.

Wolff, S., Schulp, C. J. E., & Verburg, P. H. (2015). Mapping ecosystem services demand: A review of current research and future perspectives. *Ecological Indicators*, *55*, 159–171.

Yua, E., Raymond-Yakoubian, J., Daniel, R. A., & Behe, C. (2022). A framework for coproduction of knowledge in the context of Arctic research. *Ecology and Society*, *27*, art34.

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Additional supporting information can be found online in the Supporting Information section at the end of this article.

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