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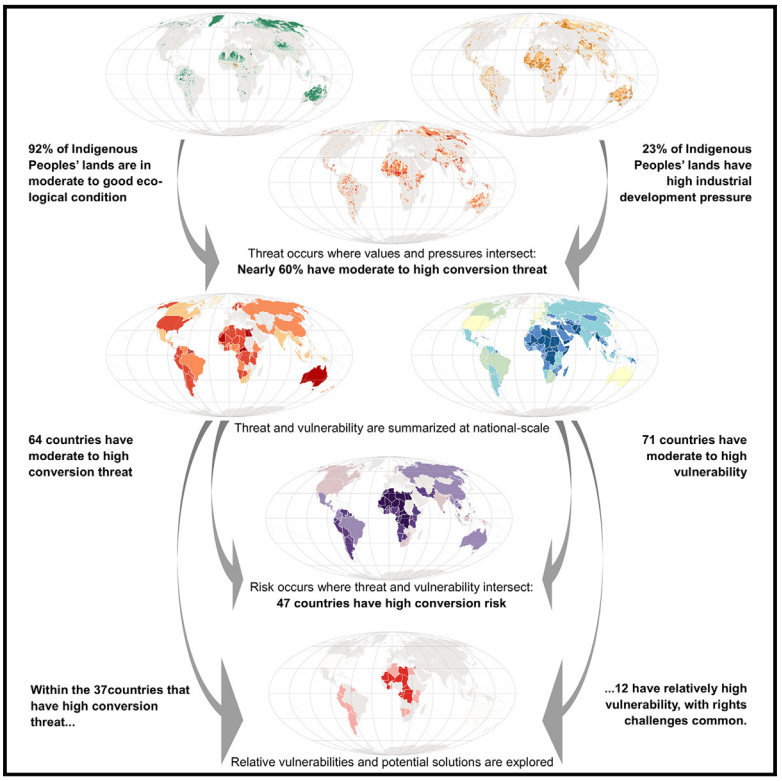
# Indigenous Peoples' lands are threatened by industrial development; conversion risk assessment reveals need to support Indigenous stewardship

## Graphical abstract




## Highlights

- Industrial development threatens nearly 60% of Indigenous Peoples' lands in 64 countries
- 37 countries have highly threatened lands that are vulnerable to conversion
- Vulnerabilities in rights, representation, and capital increase the risk of conversion
- Support of Indigenous governance and stewardship can reduce conversion risk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## In brief

Indigenous Peoples' lands are important for conservation and socio-ecological well-being. Industrial development threatens these lands, but the magnitude and risk remain unclear. Here we employ a global index comprised of rights, representation, and capital indicators to assess conversion vulnerability and explore possible solutions. We find that almost 60% of Indigenous Peoples' lands are threatened, and among the 37 countries with the highest threat, there are multiple vulnerabilities that increase the risk of conversion. To avoid or mitigate risk to both people and nature, it will be crucial to support Indigenous Peoples' self-determination, rights, and leadership.


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# Indigenous Peoples' lands are threatened by industrial development; conversion risk assessment reveals need to support Indigenous stewardship

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**SCIENCE FOR SOCIETY** Indigenous Peoples are critical to the success of global conservation. However, their stewardship is challenged by the expansion of industrial development and national contexts that undermine their capacity to govern and sustainably manage their lands. The variation in industrial development pressure confronted by Indigenous Peoples and the vulnerability of their lands to conversion remains underexplored. We mapped where industrial development pressure intersects with Indigenous Peoples' lands worldwide and explored how socio-economic and political contexts might impact the outcome. We found that a substantial proportion of Indigenous Peoples' lands are threatened by the potential expansion of industrial development and that underlying vulnerabilities increase the risk of conversion. Our findings underscore the need for actions that foster Indigenous Peoples' self-determination and center their rights and leadership in global efforts to address biodiversity loss and climate change.

## SUMMARY

Indigenous Peoples are custodians of many of the world's least-exploited natural areas. These places of local and global socio-ecological importance face significant threats from industrial development expansion, but the risk of conversion of these lands remains unclear. Here we combine global datasets of Indigenous Peoples' lands, their current ecological condition, and future industrial development pressure to assess conversion threats. To assess vulnerability and risk of conversion, we create an index based on indicators of the strength and security of Indigenous Peoples' rights to their territories and resources, their representation and engagement in decisions impacting them, and the capital available to support conservation and sustainable development. We find that nearly 60% of Indigenous Peoples' lands (22.7 million km$^2$) are threatened in 64 countries. Among the 37 countries with the highest threat, socio-economic and political vulnerabilities increase conversion risk, particularly the limited recognition and protection of territorial rights. We suggest strategies and actions to bolster Indigenous Peoples' self-determination, rights, and leadership to reduce this risk and foster socio-ecological well-being.

## INTRODUCTION

Despite accounting for only 6.2% of the global population,[1] Indigenous Peoples formally or customarily govern at least a quarter of the world's terrestrial surface.[2] Their stewardship, which is deeply rooted in their practices, worldviews, knowledge systems, and connections to place, plays a crucial role in contributing to biodiversity conservation,[3,4] climate change mitigation,[5] and provision of ecosystem services.[3,6] However, Indigenous Peoples face mounting pressure from extractive and industrial activities associated with commercial agriculture, mining, energy, and infrastructure projects.[7–9] These challenges pose significant threats to their ways of life and to the environments they inhabit and protect.[6,8,10,11]

Expansion of industrial development can have detrimental impacts on ecosystems and exacerbate climate change and biodiversity loss.[12] It can also lead to social conflicts[10] and perpetuate injustices, such as dispossession,[12] marginalization, and denial of Indigenous Peoples' rights and self-determination.[13] Moreover, the contexts in which this occurs can greatly influence Indigenous Peoples' ability to respond.[7,8] Except for some recent studies of the environmental justice struggles of Indigenous communities[14] and the intersection of mining with "land-connected peoples,"[15,16] industrial development threats to Indigenous Peoples' lands worldwide remain underexplored. Equally underexplored is how national contexts might influence the vulnerability of Indigenous Peoples' lands to conversion and increase the risk of development proceeding without their consent and in ways that undermine their values and visions for the future.

Here we address this knowledge gap by conducting a global conversion risk assessment that utilizes published datasets representing Indigenous Peoples' lands,[2] their current ecological condition,[17] and future industrial development pressure from commercial agriculture, mining, oil and gas, renewable energy, and urbanization.[18] We also create a global composite index from readily available socio-economic and political indicators to evaluate the vulnerability of Indigenous Peoples' lands to conversion from industrial development. We use this composite index to provide a relative assessment of vulnerability to conversion given the variable contexts of different nations and to identify global challenges and opportunities to reduce potential conversion risk to Indigenous Peoples and their lands.

Our results show that close to 60% of Indigenous Peoples' lands are moderately to highly threatened by industrial development expansion globally. When considering national contexts in which these threats are embedded, we further find that 37 countries are highly threatened and have an increased conversion risk from vulnerabilities related to the rights and representation of Indigenous Peoples in decisions impacting their territories and resources and the capital available to support them. Our results highlight the urgent need to foreground Indigenous Peoples' rights, leadership, and agency in implementation of the Kunming-Montreal Global Biodiversity Framework[19,20] and to uphold commitments made through national and international legislation and policy instruments, like International Labor Organization (ILO) Convention 169 and the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).[21,22]

## RESULTS

### Methods summary

Building from established risk assessment processes and frameworks,[23–25] we assess conversion risk to Indigenous Peoples' lands based on a combination of three components: hazard (potentially destructive activity), exposure (location and value of assets), and vulnerability (likelihood that assets could be affected by a hazard) (Figure S1). We define *conversion threat* to Indigenous Peoples' lands by the intersection of hazard and exposure so that a high conversion threat exists where high industrial development pressure (hazard) and good ecological condition (exposure) intersect (see Table S1 for definitions of *italicized* words).

While we acknowledge that there are many ways in which Indigenous Peoples value their lands, we focus on *ecological condition* as an exposure and conservation value, which we proxy using current human modification[17] (Note S1). We consider ecosystem condition given its broad relevance and association with other conservation values (e.g., biodiversity, carbon storage, ecosystem function)[26,27] and its association with provisioning services, traditional livelihoods, and the distinctive relationship that Indigenous Peoples have with their territories and resources, which has been described by Indigenous Peoples as a cornerstone of the full application of their international human rights and cultural self-determination.[3,6,28] We characterize industrial development pressure from future energy, mining, agricultural, and urban expansion[18] as a hazard because numerous case studies illustrate their adverse impacts, which are often misaligned with Indigenous Peoples' values.[6,8,10,11] Even when Indigenous communities are receptive to these types of development, they can and have been disempowered from influencing decisions that generate benefits and avoid negative impacts.[29,30]

We define *conversion risk* by the intersection of *conversion threat* and *vulnerability* so that a high conversion risk exists where conversion threats occur in national contexts that increase vulnerability to conversion. Although we recognize that Indigenous Peoples have unique contexts and their own perspectives on vulnerability and risk,[31–33] for our analysis, we represent vulnerability with a global composite index comprised of indicators that measure the strength and security of Indigenous Peoples' rights to their territories and resources (R), their representation and engagement in the decisions impacting them (R), and the capital available to support conservation and sustainable development (C). We use the inverse of the RRC index to proxy for conversion vulnerability. The specific indicators selected for each dimension of the index and our rationale for their inclusion are shown in Table 1.

National indicators have been widely employed to assess disaster and climate-related vulnerability,[24,25] food insecurity,[48] food system sustainability,[49] commodity supply chains,[50] mining conflicts,[15,16,51] conservation priorities,[52,53] and enabling conditions for community-based conservation.[38,54] The RRC index was informed by these assessments, along with several community-based conservation and sustainable development frameworks[55–57] that identify tenure security,[34,35] strong institutions and leadership,[42] effective forums for multistakeholder engagement,[58] and sustainable economic opportunities[38,59] as key enabling conditions for Indigenous Peoples and local

**Table 1. Information on the national indicators that comprise the RRC index**

| Index domain: Indicator name | Description and rationale for inclusion | Supporting evidence |
|---|---|---|
| Rights: legal security of Indigenous Peoples' lands index (ILS) | An indicator of the strength and security of Indigenous Peoples' rights to their territories and resources derived from LandMark's index of the legal security of Indigenous Peoples' lands.[117] This index was reflected so that higher values indicate the presence of national laws (not necessarily their enforcement) related to recognition of Indigenous Peoples' rights to land and natural resources (e.g., water, trees), and their capacity to enforce them (e.g., right to consent for land acquisition). | • Land tenure security has been linked to sustainable community-based natural resource management and positive human well-being and environmental outcomes.[34–37]<br>• This indicator has been identified as important for predicting the success of community-based conservation.[38] |
| Rights: political stability index (POL) | An indicator that modifies the strength and security of Indigenous Peoples' rights to their territories and resources derived from the World Bank's political stability index.[118] Higher values indicate greater stability in national governance structures and less active conflict (e.g., civil unrest, armed conflict, ethnic tensions), which creates a context more favorable for consistent recognition and enforcement of the rights established in national laws. | • Political instability has been associated with dispossession and re-appropriation of the territories and resources of Indigenous Peoples, resulting in negative impacts to people and nature.[39]<br>• This indicator has been identified as important for predicting the success of community-based conservation and is positively correlated with localized human well-being and environmental outcomes.[38] |
| Representation: control of corruption index (COR) | An indicator of the opportunities for representation and engagement of Indigenous Peoples in decisions impacting their territories and resources derived from the World Bank's control of corruption index.[118] Higher values indicate that problems related to private interests and elite capture are better addressed, which creates a context more favorable for inclusion of local rightsholders and stakeholders in development decisions. | • Corruption and elite capture are frequently cited as challenges to the design, implementation, and success of community-based conservation projects.[40]<br>• This indicator has been linked to improved national-level environmental outcomes.[41] |
| Representation: environmental democracy index (EDI) | An indicator of the opportunities for representation and engagement of Indigenous Peoples in decisions impacting their territories and resources derived from the World Resources Institute's environmental democracy index.[119] Higher values indicate the presence of laws and regulations that increase access to information, participation in decision-making, regulation of extractive industry, and justice in environmental matters. | • This indicator has been identified as important for predicting the success of community-based conservation and is positively correlated with localized human well-being and environmental outcomes.[38] |
| Capital: human development index (HDI) | An indicator of the intrinsic capital available to support conservation and sustainable development as measured by life expectancy, level of education, and standard of living; derived from the UN Development Program's human development index.[120] Higher values suggest a relatively stronger foundation of health, education, and economic well-being in support of conservation and sustainable development. | • Capacity-building and strong human, social, institutional, and financial capital have been identified as important for predicting the success of community-based conservation and are positively correlated with human well-being and environmental outcomes.[38,42–44]<br>• Wealthier countries with higher human development indices have been linked to improved national-level environmental outcomes.[41] |
| Capital: sustainable development goal (SDG) investments | An indicator of the financial capital made available to a country in support of conservation and sustainable development, as derived from AIDData.[45] Higher values indicate greater investments in one or more of the UN's 17 different SDGs. | • Greater financial investments in conservation and sustainable development have been linked to quantifiable biodiversity and human well-being benefits.[46,47] |

The RRC index is a global composite index representing the socio-economic and political contexts that support Indigenous governance and stewardship, the inverse of which is used as a proxy for the vulnerability of Indigenous Peoples' lands to conversion from industrial development.

communities to effectively govern and steward their territories and resources.

Finally, we note that composite indices are frequently constructed to represent various dimensions of a complex phenomenon.[60] Accordingly, we represent conversion vulnerability using indicators reflective of RRC based on their theoretical and empirical support, which include legal security of Indigenous Peoples' lands, political stability, control of corruption, environmental democracy, human development, and investments in sustainable development goals (Table 1; see RRC index).

Our conversion risk assessment helps to identify places where strategic actions and investments might be needed to support equitable governance[20] and Indigenous stewardship and to help Indigenous Peoples safeguard their rights and future.[7,10] We view this effort as a compliment to emerging place-based vulnerability and risk assessments grounded in Indigenous knowledge[32] and Indigenous Peoples' perspectives (Notes S2 and S3).[33,61,62] Based on our findings, we suggest several high-level strategies and actions that could be leveraged by Indigenous communities, conservation and development organizations, governments, companies, funders, and multilateral organizations (Table 2). Most importantly, we advocate for transformative and rights-based approaches that correct the injustices and crimes brought about by various forms of colonialism,[63,64] including a need for increased sensitivity to how Indigenous Peoples' lands are recognized, affirmed, and valued.[19]

## Industrial development pressure

We find that the majority of Indigenous Peoples' lands (~92%, 35.4 million km$^2$) are only marginally modified by human activities and remain in moderate to good ecological condition (Figure 1A). These lands are critical for biodiversity, carbon sequestration, provisioning, and other cultural ecosystem services.[2,6,66,67] At the same time, Indigenous Peoples' lands confront substantial pressure from future industrial development. Based on an overlay of land suitability maps of the potential for expansion by commercial agriculture, mining, oil and gas, renewable energy, and urbanization,[18] we show that nearly a quarter of all Indigenous Peoples' lands have high industrial development pressure from one or more of these sectors (Figure 1B).

## Drivers of high industrial development pressure

Renewable energy is a dominant driver of development pressure on 42% of Indigenous Peoples' lands (3.6 million km$^2$), driven by solar power (81%), wind power, (13%), hydropower (1%) or multiple sectors combined (5%). The potential expansion of renewable energy infrastructure is widely distributed and dominates in Australia and parts of China, central Africa, Argentina, the United States, and Pakistan (Figure 1D). This finding is notable, given growing commitments to a renewable energy transition and low-carbon economy.[68] Though there are obvious environmental benefits and opportunities to help Indigenous communities overcome barriers to energy justice, positive outcomes are far from certain. Like with conventional oil and gas development,[7] Indigenous Peoples have experienced incremental encroachment and wholesale land grabbing associated with renewable energy siting and mining of energy transition materials,[15,16] leading to injustices, conflicts, and associated environmental and socio-cultural impacts.[51,69]

Other dominant drivers of industrial development include oil and gas (18%, 1.6 million km$^2$), commercial agriculture for crops and biofuels (14%, 1.2 million km$^2$), or multiple sectors combined (13%, 1.1 million km$^2$). The potential expansion of oil and gas infrastructure is concentrated largely in six countries (Russia, Norway, Ecuador, Guatemala, Paraguay, and New Zealand), while the potential expansion of commercial agriculture is more widely dispersed in 14 countries (Democratic Republic of the Congo, India, Indonesia, Morocco, Myanmar, Ivory Coast, Malaysia, Vietnam, Nepal, Guyana, Nicaragua, Belize, Sri Lanka, and Burundi). These developments have uncertain outcomes. Palm oil production, for example, has negatively impacted Indigenous Peoples in Indonesia and Malaysia, with evidence of land conflicts and poor living conditions despite modest improvements in employment and income.[70]

Mining for coal and metallic and non-metallic resources is a dominant driver of industrial development on 9% (0.8 million km$^2$) of Indigenous Peoples' lands, and its potential expansion can impose significant negative impacts.[11,71] For example, small- and large-scale mining in the Brazilian Amazon has caused substantial deforestation, exposing Indigenous Peoples to increased rural violence, toxic pollutants, and contagious diseases[71] and threatening the existence of isolated Indigenous societies.[72] These intersections occur primarily in 12 countries: Peru, Greenland, Sweden, Lao People's Democratic Republic (PDR), Finland, the Philippines, Panama, Honduras, New Caledonia, El Salvador, Taiwan (Republic of China), and Costa Rica.

Last, urbanization is a dominant driver on 4% (0.3 million km$^2$) of Indigenous Peoples' lands globally. The potential expansion of urban areas is concentrated primarily in The Gambia and Rwanda and also in Nigeria, Pakistan, Burkina Faso, Senegal, Niger, Indonesia, Mali, China, Democratic Republic of the Congo, India, Ethiopia, and Argentina. Urbanization can radically transform Indigenous Peoples' cultures and lead to intergenerational erosion of language, identity, traditional practices, and knowledge systems.[73,74] As evidence, national resettlement and urbanization programs have led to direct negative impacts for Indigenous Peoples, including dispossession, displacement, and landlessness.[75]

## Conversion threat

When considering the intersection of values and pressure, we find that almost 60% of Indigenous Peoples' lands are either highly threatened (8.6 million km$^2$) or moderately threatened (14.1 million km$^2$) by industrial development expansion. By summarizing mean conversion threat at the national level, we find that 64 countries across all inhabited continents are at least moderately threatened (Figure 1C).

## Vulnerability and conversion risk

Low RRC index scores suggest national contexts that challenge Indigenous governance and stewardship and increase the vulnerability of their lands to conversion. Conversion risk increases where high conversion threat and high conversion vulnerability intersect. Vulnerability can be high where Indigenous Peoples' rights and tenure security are undermined, their representation and engagement in decision-making are challenged, and the capital to support conservation and sustainable development is inadequate. When considering national context

**Table 2. Strategies and example actions to address conversion vulnerability and risk**

| Rights vulnerability | Aspects of FPIC supported[65] |
|---|---|
| Strategy: strengthen and secure Indigenous Peoples' rights to their territories and resources<br>Community-focused action:<br>• Clarify customary rights through participatory mapping and other relevant means of demarcation<br>• Formalize rights through registration and land titling work<br>• Strengthen community capacity for enforcement of their rights<br>Supracommunity-focused action:<br>• Collaborate with Indigenous organizations to identify effective ways to promote rights recognition by governments and private industry<br>• Promote organizational and governmental awareness and commitments to strengthening Indigenous Peoples' rights (e.g., ICCA consortium report, lobbying for land reform, developing treaties on development decision-making)<br>• Develop community-based conservation frameworks, guidance, and practitioner-focused tools for rights-based approaches in conservation and for increasing tenure security | Recognition of the inherent rights of Indigenous Peoples to their lands and resources (consistent with the UNDRIP); clarification of who should be involved in decision-making; authority to decide |
| **Representation vulnerability** | **Aspects of FPIC supported** |
| Strategy: increase Indigenous Peoples' engagement and representation in the decisions impacting their territories and resources<br>Community-focused action<br>• Where needed, create/strengthen Indigenous Peoples organizations and institutions for governance<br>• Raise awareness and build the capacity of Indigenous Peoples organizations and leaders to participate and navigate existing decision-making processes (e.g., training and technical support in negotiation, conflict resolution, and financial management)<br>Supracommunity-focused action<br>• Enforce existing frameworks that call for equity and inclusion of vulnerable groups and marginalized voices in decision-making bodies (e.g., UN Declaration on the Rights of Indigenous Peoples, Article 15; and International Labor Organization's Convention 107 and 169)<br>• Develop and adopt corporate social responsibility standards and best practices in engagement<br>• Negotiate trade agreements that respect Indigenous Peoples' lands, resource knowledge, and cultural heritage to provide for inclusion, equity, and protection of Indigenous Peoples' rights<br>• Encourage process changes that remove barriers to Indigenous Peoples' participation and elevate Indigenous knowledge systems and institutions in consultation, planning, and co-development activities<br>• Develop operational procedures and build multistakeholder platforms to facilitate representation of Indigenous Peoples' interests in local-, regional-, and national-level planning and decision-making processes | Self-determination; support for communities to engage in and inform decision-making forums and processes; policy changes that reduce barriers to engagement and promote equitable representation of Indigenous rights-holders |
| **Capital vulnerability** | **Aspects of FPIC supported** |
| Strategy: provide additional capital to support Indigenous-led conservation and sustainable development<br>Community-focused action:<br>• Provide technical capacity for proactive and inclusive land use and sustainable development planning reflective of community values and visions (e.g., healthy country planning, development by design)<br>• Support the creation of sustainable place-based economic opportunities that compensate for Indigenous Peoples' stewardship (e.g., PES)<br>Supracommunity-focused action:<br>• Enforce adherence to existing social and environmental impact mitigation and land use planning frameworks and processes<br>• Strengthen existing lending standards, licensing processes, and safeguards to ensure an adequate and ongoing FPIC process<br>• Help drive multilateral partnerships and investments that support Indigenous stewardship (e.g., recent multilateral investment in securing Indigenous Peoples' rights to tropical forests). | Commitments and investments in activities that support community-based conservation and sustainable development driven by and consistent with self-determined values, visions, and priorities |

(*Continued on next page*)

**Table 2. *Continued***

| Capital vulnerability | Aspects of FPIC supported |
|---|---|
| • Investment oversight by Indigenous Peoples with emphasis on equity and realization of tangible, community-level benefits. | |

Vulnerabilities identified from interpretation of relative RRC subindex scores (Figure 4B) can be used to suggest potential strategies and actions that might be taken to support Indigenous governance and stewardship and reduce conversion vulnerability of Indigenous Peoples' lands. These strategies are interconnected and should be mutually reinforcing of Indigenous Peoples' rights and their free, prior, and informed consent (FPIC).

alone, we find that 11 countries have very low RRC index scores (ranging from 0.13–0.31 on a 0–1 scale), and all are in Africa and Central/Southeast Asia (Figure 2). When intersecting mean conversion threat (Figure 3A) with RRC index scores (Figure 3B), we found 47 countries to have a high conversion risk (Figures 3C and S2), predominately in Africa (n = 30, 64%), followed by Central/South America (n = 10, 21%), South/Southeast Asia (n = 4, 9%), and the Middle East (n = 3, 6%).

Vulnerability can be assessed for any country with Indigenous Peoples' lands and industrial development pressure using the RRC index. To illustrate, we focused on 37 countries with high conversion threat (Figures 3A and 4A) and found that 12 countries had relatively high vulnerability (>1 median absolute deviation [MAD] below the global median), 16 countries had relatively moderate vulnerability (within 1 MAD of the global median), and 6 countries had relatively low vulnerability (>1 MAD above the global median) (Figures 4A and 4B). The 12 countries with high conversion threat and relatively high vulnerability are primarily in Africa, representing 5.4 million $km^2$ of Indigenous Peoples' lands globally, of which 28% (1.5 million $km^2$) confronts high development pressure largely driven by the potential expansion of renewable energy infrastructure. Given the influence of global demand and the conversion vulnerability suggested by our index, Indigenous Peoples confronting development proposals in those countries are likely to face substantial challenges. Among these are weak or insecure rights to territories and resources (n = 11, 92% high rights vulnerability), inadequate opportunities for representation and engagement in decision-making (n = 7, 58% high representation vulnerability), and insufficient capital to support conservation and sustainable development (n = 7, 58% high capital vulnerability).

The 16 countries with high conversion threat and relatively moderate vulnerability are exclusively in Africa and South America. Of the total area of Indigenous Peoples' lands encompassed by these countries (3.7 million $km^2$), 31% confront high development pressure, the majority due to the potential expansion of renewables followed by agriculture, oil and gas, and urban sectors. Among these countries, rights vulnerability was high in Egypt, Argentina, and Algeria (n = 3, 19%) and still moderate in the rest (n = 13, 81%). Representation and capital vulnerabilities were mostly moderate for all but Peru and Ecuador, which had low capital vulnerability (n = 15, 94%).

The 6 countries with high conversion threat but relatively low vulnerability are Australia, Chile, Norway, Sweden, and the United States. This includes 5.3 million $km^2$ of the total of Indigenous Peoples' lands globally, 29% of which confront high development pressure from renewables, mining, and oil and gas. Although these countries were assessed as having socioeconomic and political contexts that made Indigenous Peoples' lands less vulnerable to conversion than other countries globally, challenges certainly exist. For instance, rights vulnerability was high in Finland and moderate in all other countries; additionally, there was moderate capital vulnerability in Chile.

## DISCUSSION

In line with previous assessments,[2] we find that as much as 39% of the world's most ecologically intact lands are governed by Indigenous Peoples (Note S4). The current ecological condition of these lands reflects a long history of Indigenous stewardship compatible with biodiversity conservation and the provision of ecosystem services.[3,6] Alarmingly, we find that almost 60% of all Indigenous Peoples' lands have a moderate to high conversion threat from potential expansion of industrial development. Increasing demands on these lands from commodity-based, extractive activities are frequently accompanied by negative impacts,[30] including injustices and violence against Indigenous communities[10] that endanger lives and the continuation of Indigenous Peoples' cultures and ways of life.[8,74,76] The conversion threat to Indigenous Peoples' lands is particularly high in 37 countries across Africa; North, Central, and South America; Europe; the Middle East; and Oceania. Considering the context in which these threats occur can point broadly to places where Indigenous Peoples might be especially challenged by the realities they may confront. Such information can be used to proactively support their ability to respond and to encourage equitable and effective engagement of Indigenous Peoples in the free, prior, and informed consent (FPIC) process.[65]

### Rights issues are the most pervasive global challenge

Across all countries with high conversion threat, we found that challenges to the strength and security of Indigenous Peoples' rights were common (Figure 4B). FPIC is critical to self-determination but precluded when Indigenous Peoples' rights are insecure and their authority is not fully recognized.[77] Where Indigenous Peoples' rights to their territories and resources are weak, a range of community- and supracommunity-focused actions might be offered when sought by Indigenous communities (Table 2). For example, community-focused actions might include clarifying customary or *de facto* rights through participatory mapping and other means of demarcation,[78] formalizing rights through registration and titling, or strengthening community capacity to enforce those rights. Such actions underpin many community-based conservation frameworks[56,57] and are undertaken to support Indigenous Peoples' sovereignty[3] and their capacity to govern.[79] Numerous examples have shown that these actions have prevented land grabs associated with commodity-driven development ranging from biofuel production[80] to livestock rearing, mining, and large-scale agrobusiness.[81] In particular, participatory mapping tools[82] and counter-mapping approaches[83] are increasingly used to strengthen Indigenous Peoples' claims to

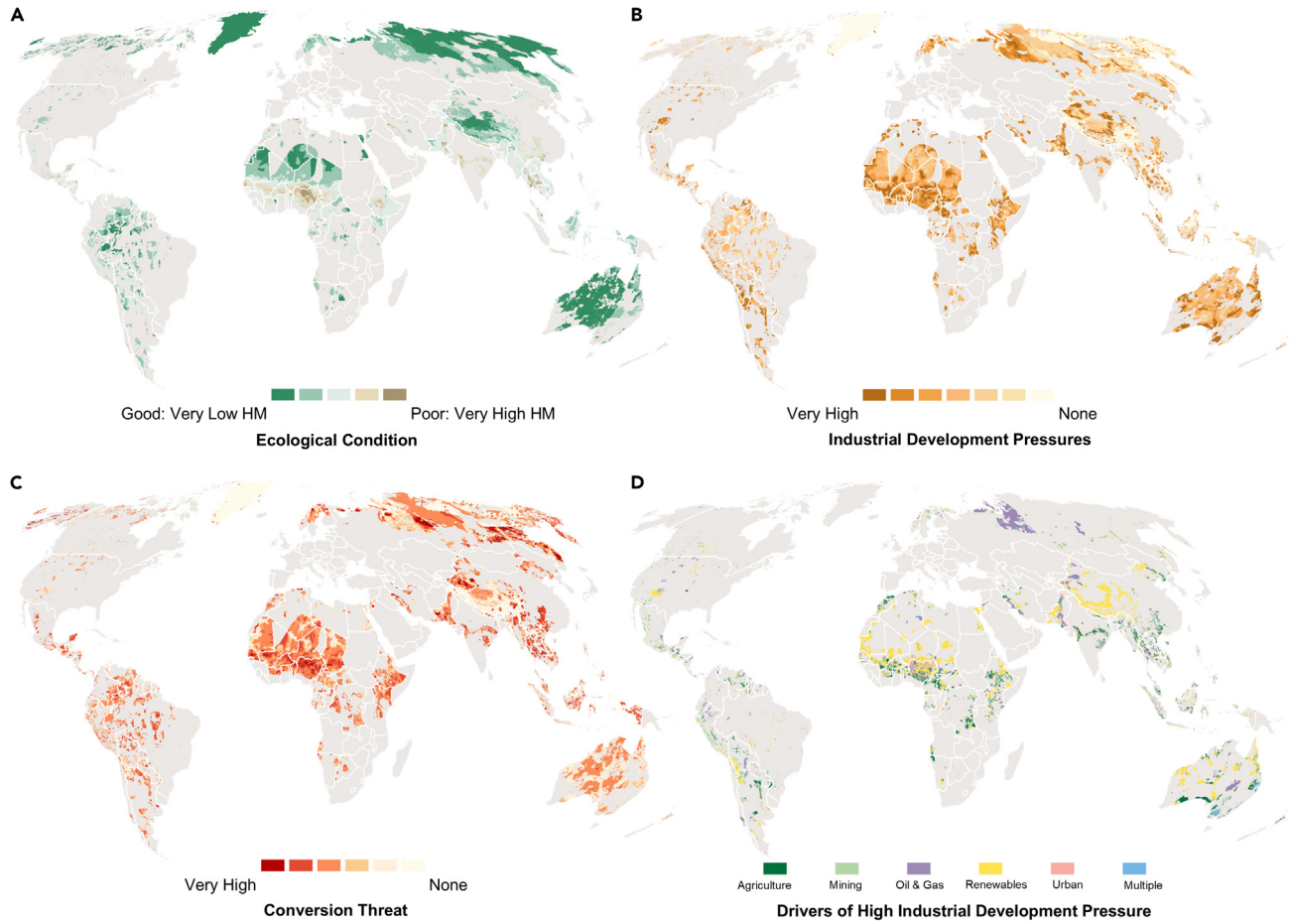



**Figure 1. Conversion threat to Indigenous Peoples' lands**

(A–D) Intersection of Indigenous Peoples' lands[2] with (A) ecological condition proxied by human modification (HM) of terrestrial lands;[17] (B) industrial development pressure derived from development pressure indices mapping the suitability of land for commercial agriculture, mining, fossil fuels, renewables, and urbanization;[18] (C) conversion threat based on the multiplication of the maps in (A) and (B); and (D) drivers of high industrial development pressure.

their territories and resources and to deter corporate land grabbing, as illustrated by examples from sub-Saharan Africa[84] and Central Kalimantan, Indonesia.[85] In the Peruvian Amazon, formalization of customary rights through titling has reduced deforestation and disturbance associated with unsustainable commercial agriculture or "timber mining."[36,37] Actions taken beyond the community might include advocacy for institutional awareness and governmental commitment to strengthen Indigenous Peoples' rights;[3,86] development and implementation of conservation practitioner guidance to strengthen tenure security and support Indigenous Peoples' autonomy, decision-making, and self-determination;[56,87] and increased partnerships and organizational capacity building in technical expertise to document and formalize land rights (e.g., Cadasta).[88]

## Representation issues predominate in the southern hemisphere

Representation vulnerability is commonly observed in countries with high conversion threat, especially those in Africa and South America. Although community-level capacity building is often needed to improve the representation and engagement of Indigenous Peoples in decision-making fora, many countries present supralocal challenges, as reflected by the indicators of our global composite index. Where representation vulnerability is high, variously scaled actions may be needed to create or increase opportunities for Indigenous Peoples to engage and be represented in the decisions impacting their territories and resources (Table 2). As supracommunity-focused actions, we emphasize the need for broad-scale adoption of standards that call for equity and inclusion (UNDRIP, Article 15; ILO 107 and 169),[1,21,22] development of robust corporate social responsibility standards and engagement practices,[89,90] enforcement of trade agreements foregrounded in the protection of Indigenous Peoples' rights,[91] and changes to development planning that remove barriers to Indigenous Peoples' participation and elevate Indigenous knowledge and institutions into all stages and scales of the process.[92,93] Additionally, special provisions should encourage direct participation of Indigenous Peoples in state legislative bodies. Last, multistakeholder forums that facilitate networking and representation in the larger decision-making sphere are also crucial.[58] These supracommunity-focused actions might occur in tandem with community-focused action. For example, local actions might include helping

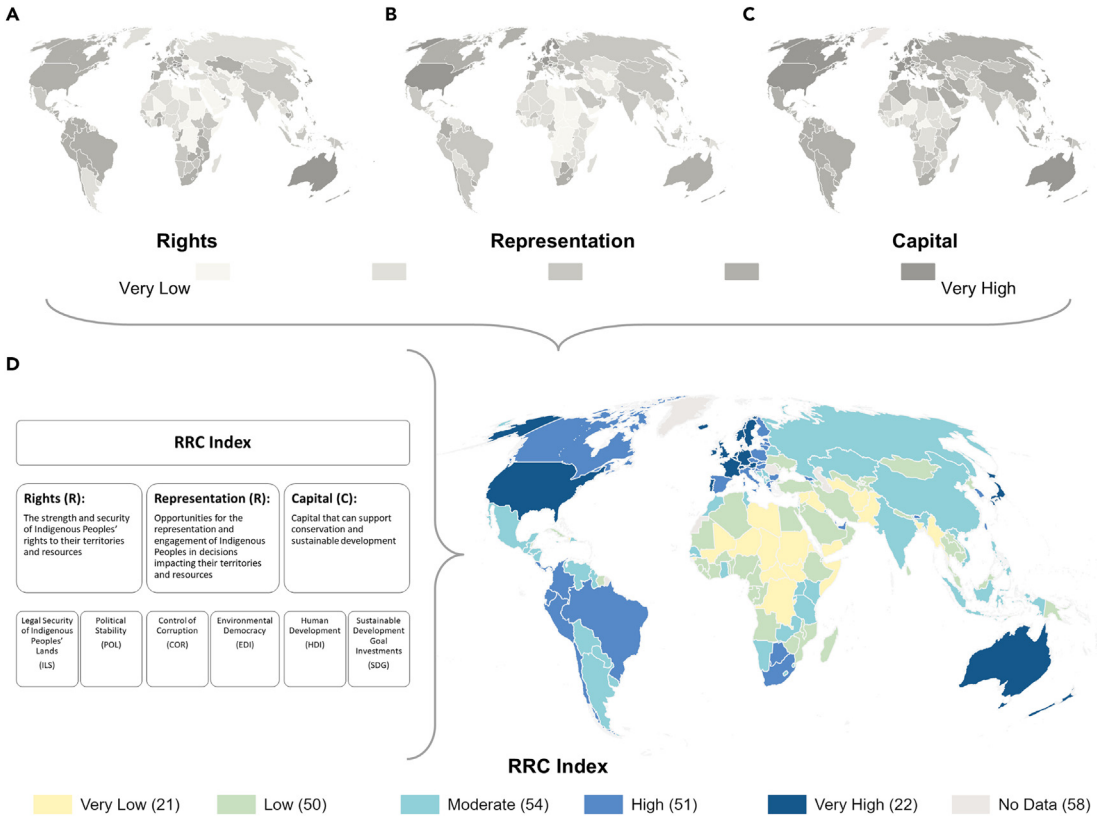



**Figure 2. The RRC index and vulnerability of Indigenous Peoples' lands to conversion**

(A–D) National indicators of rights (A), representation (B), and capital (C) are combined in a global composite index (D) to represent national-level enabling conditions for Indigenous governance and stewardship. The values in each map are displayed by natural groupings using Jenks natural breaks classification. Counts follow in parentheses. A lower RRC index score suggests higher vulnerability to conversion for Indigenous Peoples' lands where they occur.

to create or strengthen community institutions so that Indigenous Peoples can meaningfully participate in regional and national planning processes or providing training and technical support in negotiation, conflict resolution, and financial management.[94] Such actions have allowed Indigenous communities to hold governments and companies accountable for making more than a token effort to consult them.[69,95] Furthermore, efforts to ensure that Indigenous Peoples benefit from the development that occurs on their lands have prompted the commonplace practice of negotiated agreements ranging from compensation to revenue sharing; employment; trade in infrastructure improvements, health, and education services; and co-ownership. Although some instances of co-ownership have allowed realization of direct and local benefits,[96] these agreements in particular must be pursued with a clear view regarding the value proposition and certainty that an equity stake accords with the aspirations of Indigenous landowners.

## Capital issues persist in Africa

Capital vulnerability was also identified, particularly in Africa, where support for conservation and sustainable development is needed to ensure that Indigenous Peoples can influence development trajectories. Human, social, and institutional capital can be built through various means, such as technical support or training for community land use planning, or development of decision-support tools that allow Indigenous Peoples to assess the potential environmental and socio-cultural impacts of proposed development projects.[97] In addition, the same tools could be used by communities to explore alternative development scenarios and livelihoods, like payment for ecosystem services (PES), which offer the possibility of generating financial capital from forms of development that may be better-aligned with their values and ways of life.[98] Strict enforcement and adherence to impact mitigation and land use planning processes by companies, governments, lenders, investment groups, and other developers can also provide support. Multilateral development bank lending standards are meant to provide safeguards, including the World Bank's Environmental and Social Standard ESS7[99] and the International Finance Corporation's Performance Standard 7 on Indigenous Peoples.[100] Environmental and social impact assessments are intended to limit the impacts of development projects and provide a path toward FPIC. However, it is well documented that lending standards and impact assessments have historically failed to deliver necessary protections and will need to be strengthened to ensure that development planning and impact mitigation meaningfully engage Indigenous Peoples[101] and sufficiently manage adverse economic, socio-cultural, health, and environmental impacts.[8,102] Such improvements could be realized through emerging participatory knowledge coproduction approaches.[8,102] The positive impact of these measures can be increased when paired with

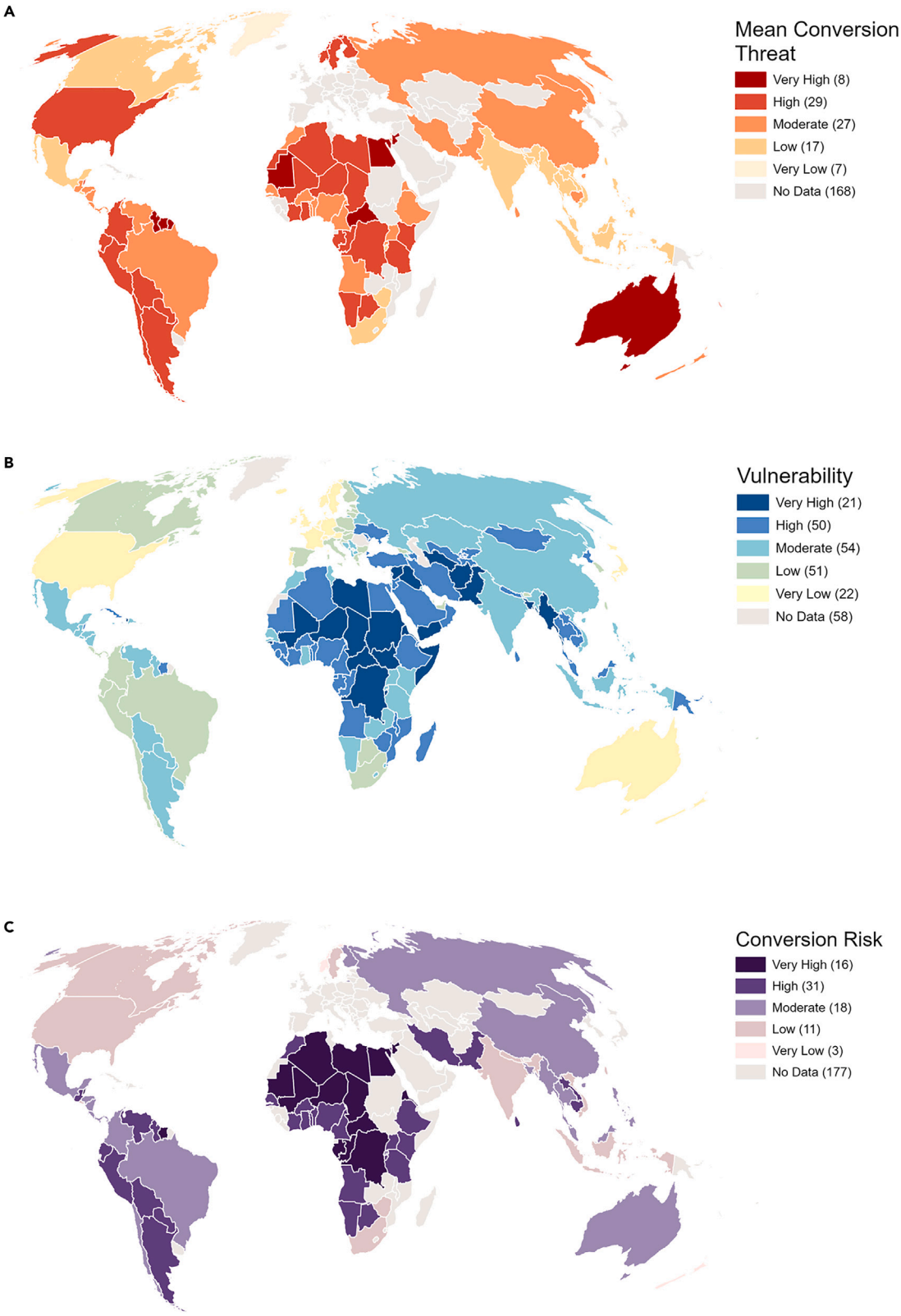
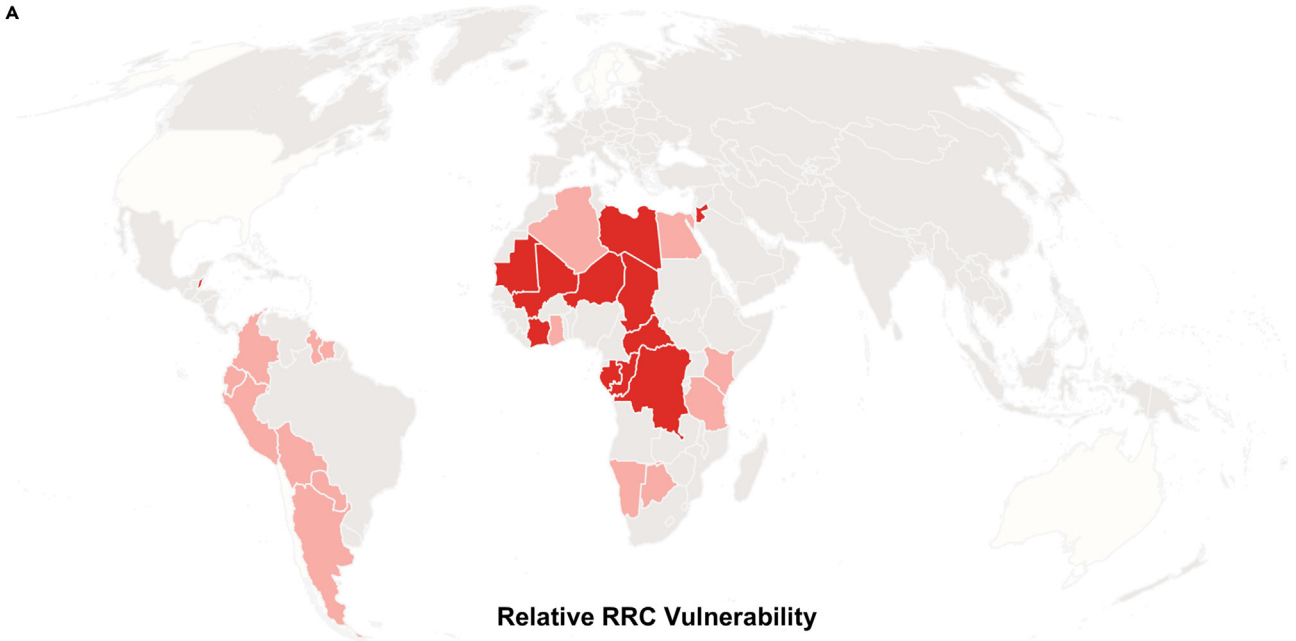



**Figure 3. Conversion risk to Indigenous Peoples' lands**

(A–C) Mean conversion threat to Indigenous Peoples' lands (Figure 1D), (B) vulnerability proxied by the inverse of the RRC index, and (C) conversion risk based on the multiplication of the maps in (A) and (B). The values in each map are displayed by natural groupings using Jenks natural breaks classification. Counts follow in parentheses.

A




B

AFRICA

| ISO CODE | RRC | RIGHTS | REPRESENTATION | CAPITAL |
|---|---|---|---|---|
| BWA | ● | ● | ○ | ● |
| CAF | ● | ● | ● | ● |
| CIV | ● | ● | ● | ● |
| COD | ● | ● | ● | ● |
| COG | ● | ● | ● | ● |
| DZA | ● | ● | ● | ● |
| EGY | ● | ● | ● | ● |
| ESH | | | | |
| GAB | ● | ● | ● | ● |
| GHA | ● | ● | ● | ● |
| GMB | ● | ● | ● | ● |
| KEN | ● | ● | ● | ● |
| LBY | ● | ● | ● | ● |
| MLI | ● | ● | ● | ● |
| MRT | ● | ● | ● | ● |
| NAM | ● | ● | ● | ● |
| NER | ● | ● | ● | ● |
| TCD | ● | ● | ● | ● |
| TZA | ● | ● | ● | ● |

AMERICAS

| ISO CODE | RRC | RIGHTS | REPRESENTATION | CAPITAL |
|---|---|---|---|---|
| ARG | ● | ● | ● | ● |
| BLZ | ● | ● | ● | ● |
| BOL | ● | ● | ● | ● |
| CHL | ○ | ● | ○ | ● |
| COL | ● | ● | ● | ● |
| ECU | ● | ● | ● | ○ |
| GUF | | ● | ○ | |
| GUY | ● | ● | ● | ● |
| PER | ● | ● | ● | ○ |
| PRY | ● | ● | ● | ● |
| SUR | ● | ● | ● | ● |
| USA | ○ | ● | ○ | ○ |

ASIA, EUROPE, AND OCEANIA

| ISO CODE | RRC | RIGHTS | REPRESENTATION | CAPITAL |
|---|---|---|---|---|
| JOR | ● | ● | ● | ● |
| FIN | ○ | ● | ○ | ○ |
| NOR | ○ | ● | ○ | ○ |
| SWE | ○ | ● | ○ | ○ |
| AUS | ○ | ● | ○ | ○ |
| NCL | | | | ● |

**Figure 4. Identification of challenges and opportunities to address conversion vulnerability and risk**

(A and B) Map of the relative vulnerability of Indigenous Peoples' lands to conversion for countries with a high to very high mean conversion threat (Figure 3A) and (B) tables showing relative rights, representation, and capital (RRC) vulnerabilities for countries grouped by region and sorted alphabetically by ISO code. Vulnerability assessments were made relative to the global median. Countries were assessed as having relatively high vulnerability when their RRC index scores were significantly below the global median (red) and as having relatively low vulnerability when their RRC index scores were significantly above the global median (ivory). Significant differences from the global median were defined as greater than 1 median absolute deviation (MAD). Countries were assessed as having relatively moderate vulnerability when their RRC index scores were within 1 MAD of the global median (pink). Corresponding strategies and example actions to address high vulnerability are featured in Table 2.

complementary efforts to address rights and representation vulnerabilities at local and supralocal scales, as demonstrated by a recent pledge of $1.7 billion for tropical forest protection coupled with efforts to formalize Indigenous Peoples' territorial rights.[103]

## Caveats, future direction, and ground truthing

We used the best available global datasets of Indigenous Peoples' lands, industrial development pressure, and national socio-economic and political indicators, but we recognize that each has limitations with respect to spatial accuracy and completeness. Like all maps, our map of Indigenous Peoples' lands is based on a particular definition of Indigenous Peoples (see Indigenous Peoples' lands; Table S1); thus, by nature, it is incomplete and of variable precision across nations.[2] We compare this layer with alternative sources of information on the presence of Indigenous Peoples' lands to explore the implications for our analysis (Notes S3 and S5).[117,104] In general, we find relatively good agreement, but acknowledge that Indigenous Peoples' lands may be excluded in certain regions, such as small islands of Oceania, Madagascar, or parts of central Asia, or under-represented in other regions, such as Canada, where publicly available data are limited.[2] Therefore, future assessments should be updated as new information becomes publicly available, particularly from Indigenous-led mapping efforts.[78,104]

We mapped industrial development pressure on Indigenous Peoples' lands based on high suitability for expansion by commercial agriculture, mining, oil and gas, renewable energy, and urbanization. Suitability was determined by the presence of large reserves of unexploited and viable resources with the necessary infrastructure to support their extraction and transportation.[18] Because of the lack of consistent and reliable global data, these suitability maps do not capture all aspects of feasibility (e.g., property type or ownership), nor do they account for production demands because of uncertainties in predicting them and the ever-changing policies and incentives that affect global supply and demand. Therefore, these development pressure indices may not adequately capture frontier expansion made possible by incentives or investments in new infrastructure, and they may overestimate near-term expansion by sectors like renewable energy. At the same time, the high development pressures we mapped reflect general patterns of expansion when production demands are considered.[105] Thus, our results should be interpreted as the potential for expansion by various industrial sectors and not the exact location of development siting or the total land area that will be converted.

Our RRC index was constructed of national indicators with hypothesized importance to Indigenous governance and stewardship and reciprocally to the vulnerability of Indigenous Peoples' lands to conversion from industrial development (Table 1). The RRC index does show significant correlation with historic rates of land conversion (Figure S3), but despite this justification, we encourage a precautionary approach in the interpretation of our findings. While there is evidence that national contexts can mediate local realities and outcomes,[38,54,106] we recognize that there are variations in local enabling conditions and governance arrangements, particularly in regions with complex histories, where highly variable state, provincial, or territorial policies exist, or rapid shifts in the political climate have occurred.[9] Data limitations required that we rely on national indicators that were not always specific to Indigenous Peoples or developed through Indigenous Peoples' experiences and perspectives on localized conditions. Given that Indigenous communities are frequently among the most marginalized of a nation,[107] the RRC index should be considered a best-case estimate. To illustrate, Australia has a very high RRC index score, indicating relatively low conversion vulnerability for Indigenous Peoples' lands compared with other countries. However, Aboriginal Peoples of Australia still confront severe challenges to their rights, an observation supported by recent failed efforts to stop mining development on their lands.[108] Thus, the RRC index is best used as a relativized global characterization of the vulnerability of Indigenous Peoples' lands to conversion, not as an absolute.

Although global composite indices are not easily validated, we find that country rankings from the RRC index were in general agreement with those derived from Indigenous-led assessments[33] (Note S2). The Indigenous Navigator provides data from a limited set of surveys about how Indigenous communities perceive their situation with respect to several key legal frameworks (e.g., the UN Declaration of the Rights of Indigenous Peoples, the World Conference on Indigenous Peoples, and the sustainable development goals). Given the limited number of countries with Indigenous Navigator data, the comparison is cursory but offers some ethnographic grounding and support that the RRC index reflects the general context and place-based realities reported by Indigenous Peoples. In the absence of similar Indigenous data with global coverage, we believe our index provides a good coarse filter to identify places where strategic actions and investments to support Indigenous Peoples in their efforts to safeguard their rights and futures might be taken.[7] Future directions could take a downscaled approach by engaging Indigenous Peoples in ground truthing or defining their own RRC indicators with Indigenous knowledge and context-specific data (e.g., title, membership in Indigenous federations, presence and strength of community institutions, instances of corruption or elite capture among local or regional leadership, localized investments in sustainability initiatives or conservation programs, etc.).

## Conclusion

Despite the tremendous public good resulting from their stewardship, many Indigenous communities suffer from poverty and lack sustainable development opportunities.[107] Pressures from the expansion of extractive and commodity-driven development have often been exploitive, tacitly oppressive, and with limited local benefits.[7–10] Changing this trajectory requires an understanding of where industrial development could encroach on Indigenous Peoples' lands and how the contexts in which these intersections occur might influence the outcome. Our assessment underscores that a substantial proportion of Indigenous Peoples' lands face threats from industrial development and that lands across west and central Africa are at greatest risk of conversion because of their vulnerable national contexts.

Business-as-usual approaches have clearly fallen short of equitably and meaningfully engaging Indigenous Peoples in determining development futures for their lands.[77,109] FPIC is a human rights imperative, and although it is referenced widely in international law, various conventions and treaties, the domestic laws of a handful of countries,[65,77,110] and many corporate social responsibility frameworks,[89,90,111] its full realization has been limited. While worldwide calls to "defend the defenders" are on the rise,[112] much work remains to prevent continued attacks, intimidation, and harm to the rightful, original, and best stewards of these lands.[7,8] This study underscores that transformative action is needed to support Indigenous Peoples' governance and stewardship in places confronting conversion threat. At levels beyond the community, we need more advocacy for structural, institutional, corporate, and policy change. At the community level, we need tangible actions that strengthen Indigenous Peoples' rights to their territories and resources, improve their representation and engagement in decisions impacting them, and offer adequate capital to support conservation and sustainable development. These actions represent approaches aligned with the movement toward decolonizing conservation[10,63,64,79] — approaches that foster self-determination and center Indigenous Peoples rights and leadership in global efforts to address biodiversity loss and climate change.[19]

## EXPERIMENTAL PROCEDURES

### Resource availability

#### *Lead contact*

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Christina M. Kennedy (ckennedy@tnc.org).

### Materials availability

Maps and graphics generated in this study will be made available upon reasonable request.

### Data and code availability

The high-resolution map of Indigenous Peoples' lands[2] has not been deposited in a public repository because of its sensitivity. To request access to these data, please contact Stephen Garnett (stephen.garnett@cdu.edu.au). The 1-km$^2$-resolution map of human modification, individual development potential indices, and urban growth projection data are available in Figshare: https://doi.org/10.6084/m9.figshare.7283087,[113] https://doi.org/10.6084/m9.figshare.c.4249532,[114] and https://doi.org/10.6084/m9.figshare.9696218.v1.[115] Administrative boundaries for countries used in our analysis are publicly available from Global Administrative Areas (GADM),[116] as are the indicators comprising the rights, representation, and capital (RRC) index, including the legal security of Indigenous Peoples' legal lands,[117] political stability,[118] control of corruption,[118] environmental democracy,[119] human development,[120] and investments in sustainable development goals.[121] Detailed methods on the construction of the RRC index are provided in Methods S1. Country-level data summaries created for this analysis and used to generate maps and figures have been deposited in Figshare: https://doi.org/10.6084/ m9.figshare.23654292[122] and are available at the time of this publication. Any additional information required to reanalyze the data reported in this paper are available from the lead contact upon request.

### Conversion risk assessment overview

To conduct the conversion risk assessment for Indigenous Peoples' lands (Figure S1; Table S1), we used existing spatial datasets at 1-km$^2$-resolution for (1) the geographical extent of Indigenous Peoples' lands; (2) ecological condition, proxied by current human modification of terrestrial lands; and (3) industrial development pressure, derived from individual development pressure indices of suitability for commercial agriculture, mining, oil and gas, renewables, and urbanization (Figures 1A and 1B). From these spatial datasets we calculated conversion threat to Indigenous Peoples' lands by multiplying current ecological condition (our exposure or conservation value, scaled 1–5) and industrial development pressure (our hazard, scaled 1–6) to identify important values within Indigenous Peoples' lands threatened by potential expansion of industrial development. This produced a 1-km$^2$-resolution conversion threat map with scores ranging from 0–30 (0 = low conversion threat, 30 = high conversion threat), which we binned into 6 categories for visualization purposes using Jenks natural breaks (e.g., very low, low, moderate, high, very high, none). We then calculated a mean conversion threat score per country (Figure 3A), which was intersected with the inverse of the RRC index map, our proxy for conversion vulnerability (Figures 2 and 3B; Table 1; Methods S1). Conversion risk was then calculated by multiplying the normalized mean conversion threat map with normalized inverse RRC index scores, resulting in values from 0–1 (0 = low conversion risk, 1 = high conversion risk) (Figure 3C). All geospatial analyses were conducted in the Mollweide projection, an equal-area map projection, using ArcGIS 10.8.1 software with the Spatial Analyst extension. We applied a bilinear resampling method for continuous raster data and nearest-neighbor method for discrete data (vector data were first projected and then converted to raster datasets). For national-level analyses, we used country boundaries sourced from the GADM spatial database v.2.8.[116] Elaboration of the individual elements in the conversion risk assessment is offered below.

### Indigenous Peoples' lands

We used the boundaries of Indigenous Peoples' lands mapped by Garnett et al.[2] for the scope of our analysis, which identifies Indigenous Peoples' lands across 87 countries or politically distinct areas. This dataset represents the most comprehensive assessment of terrestrial lands where Indigenous Peoples have customary ownership, management, or governance arrangements in place, regardless of legal recognition. It is based on 127 publicly available sources, including cadastral records, participatory maps, and census data. We adopt their definition of Indigenous Peoples as those who identify as having "descended from populations which inhabited a country before the time of conquest or colonization [and] who retain at least some or all of their own social, economic, cultural and political institutions" (Table S1). As discussed in Garnett et al.,[2] we note the practical and ethical challenges associated with the various definitions of Indigenous Peoples and the implications for mapping their lands (see their supplemental information for further details). As a result, we compared our layer with other existing data sources (Notes S3 and S5) to identify potential gaps in coverage. Although agreement is good, the Indigenous Peoples' lands map should not be used to identify specific territories or legal claims, nor should areas without delineation be interpreted as lacking Indigenous Peoples' presence, claim, or interest.

### Ecological condition

The ecological condition of Indigenous Peoples' lands is influenced by the extent of their modification by human activities known to negatively impact ecosystems.[27] Thus, we use the global Human Modification (HM) map to proxy for current ecological condition[17] (Figure 1A; Note S4). The HM estimates the intensity of impacts from 13 anthropogenic stressors associated with human settlement (population density, built-up areas), agriculture (cropland, livestock), transportation (major roads, minor roads, two-tracks, and railroads), mining, energy production (oil wells and wind turbines), and electrical infrastructure (powerlines and night-time lights). We note that, although the HM captures many human impacts, it does not include timber production or selective logging, pastureland, recreational use, and hunting. The HM produces a 0–1 metric that reflects the proportion that each 1-km$^2$ cell is modified by human activities based on the median year of 2016. Following published guidance[17,27] and based on the distribution of HM values globally and in protected areas, the modification of each cell was categorized as very low ($0.00 \leq HM \leq 0.01$), low ($0.01 < HM \leq 0.10$), moderate ($0.10 < HM \leq 0.40$), high ($0.40 < HM \leq 0.70$), and very high ($0.70 < HM \leq 1.00$) (Figure 1A). Low-modified lands represent natural or semi-natural areas that are no more than 10% modified and have fewer than two overlapping human stressors, moderately modified lands are more than 10%–40% modified and have fewer than three overlapping stressors, and highly modified lands are human-dominated areas with over 40% modification with five or more overlapping stressors. Based on these categories, we created "ecological condition scores" ranging from 1–5, assigning 5 to the least modified cells (i.e., very low HM, Good condition) and 1 to the most modified cells (i.e., very high HM, poor condition).

### Industrial development pressure

To estimate industrial development pressure on Indigenous Peoples' lands (Figure 1B), we used published development potential indices (DPIs) for (1) renewable energy (concentrated and photovoltaic solar power, wind power, and hydropower), (2) oil and gas (conventional and unconventional), (3) mining (coal and metallic and non-metallic mining), and agriculture (crop and biofuel expansion) sectors[18] and created an urban DPI based on global urban growth projections from 2020–2050[123] (Note S6). DPIs are global, spatially explicit, 1-km$^2$-resolution maps that depict the suitability of land for potential expansion by each of these sectors. Each DPI has standardized 0–1 values indicating low to high suitability based on sector-specific land constraints on development (e.g., suitable land cover, slope), land suitability for sector expansion based on resource availability (sector-specific yields), and siting feasibility of new development (e.g., ability to transport resources or materials, access to demand centers, and proximity of existing development). Where possible, the DPI maps remove previously developed lands (e.g., current mined areas, wind turbines, oil and gas wells, urban areas), but non-proprietary data locating these features are incomplete across the globe. As a result, the DPIs may include some areas already developed, but we minimize this issue by intersecting them with the HM map to isolate areas of future development expansion.

For each DPI, we binned the range of values into six categories based on standardized $Z$ score ranges to characterize development pressure as very low ($\leq$10th percentile), low (>10th–25th percentile), medium-low (>25th–50th percentile), medium-high (>50th–75th percentile), high (>75th–90th percentile), and very high (>90th percentile).[18] We calculated $Z$ scores by mean-standardizing values per country to capture national-level domestic demand coupled with global-level demand likely to drive resource extraction to occur within each countries' highest development suitability for that resource. Because our urban DPI was derived from urban expansion probabilities based on population growth projections that were more restrictive than the DPI values (e.g., excluded suitable areas like flat land, near roads and existing urban areas when demand was met), we binned the upper 50th percentile and

lower 50th percentile of non-zero urban DPI values into high- or very high-pressure categories, respectively. We then assigned development pressure scores ranging from 1 (very low) to 6 (very high) to each DPI, and created the industrial development pressure map used in our conversion risk assessment by retaining the maximum cell score across all individual DPIs (Figure 1B). All lands without a pressure category were assigned a score of 0.

To evaluate sector-specific drivers of industrial development on Indigenous Peoples' lands (Figure 1D), we identified regions of high or very high industrial development pressure and then determined the sector driver based on which of the sectors (i.e., agriculture, mining, oil and gas, renewable energy, urban) had the highest score for that cell. To illustrate, if a given cell had only one sector (e.g., agriculture) with a very high-pressure score (score of 6), then that sector was identified as the driver. If a given cell had multiple sectors with similar development pressure scores, then we identified it as a having multiple sector drivers. We identified a sector as the majority driver in a country when it made up more than 50% of its high development pressure.

### RRC index

To provide contextual information on factors influencing conversion vulnerability, we constructed a global composite index from a suite of national indicators that characterize the strength and security of Indigenous Peoples' rights to their territories and resources (rights), their representation and engagement in decisions impacting them (representation), and the various forms of capital available to support conservation and sustainable development (capital) (Figure 2). Indicators selected for each of these dimensions have broad utilization as well as theoretical and empirical support (Table 1). We used published data from publicly available sources that were global in extent and based on the most up-to-date information (data sources from 2013 [n = 1], 2015 [n = 1], and 2018 [n = 4]). Prior to selecting the final set of indicators, we tested for scale reliability among the full suite of indicators considered for each dimension using Cronbach's alpha ($\alpha$). This test provided a measure of internal consistency and a statistic that allows for evaluation of the suitability of individual indicators as complementary measures of the same dimension. Based on this statistic, internal reliability was considered "acceptable" for rights indicators ($\alpha$ = 0.742) and "good" for representation and capital indicators ($\alpha$ = 0.848 and 0.889, respectively) (Methods S1). We initially considered multiple indicators for each dimension and, in review of their correlation statistics, pruned them to two indicators for each dimension (Figure 2; Methods S1). Correlations of the RRC index with its individual indicators and sensitivity of our relative vulnerability assessment to different index constructions are summarized in Tables S2 and S3.

### Rights indicators

To characterize the strength and security of Indigenous Peoples' rights over their territories and resources, we used LandMark's index of the legal security of Indigenous Peoples' lands[117] and World Bank's political stability index.[118] The LandMark index scores the presence of national laws that recognize Indigenous Peoples' rights to land and natural resources and support their capacity to enforce them.[124] Given that this index is derived from the presence of national laws as opposed to their enforcement, the index may be an overestimation of the legal security experienced in some contexts.

Although the LandMark index captures laws rather than their enforcement, we assume that greater legal security indicates greater support for Indigenous Peoples confronting industrial development by increasing the likelihood that they will have a voice in development decisions, increasing accountability for decisions made, and encouraging sustainable development of their territories and resources; assumptions supported by evidence linking tenure security to sustainable natural resource management and positive human well-being and environmental outcomes.[34–37,125,126] We view political stability as a modifier of rights. The political stability index considers perceptions of political instability or politically motivated violence in addition to instances of civil unrest, ethnic and international tension, armed conflict, violent demonstrations, and internal/external conflicts.[118] We expect political stability to have a positive and complementary effect given that stable governments tend to uphold their constituents' rights and can help enforce and mitigate potential conflicts. Moreover, a recent synthesis found that the indicator itself was a significant predictor of the success of community-based conservation projects and was positively correlated with the localized human well-being and environmental outcomes that projects were able to achieve.[38] In contrast, periodic abuse, loss of recognition. lack of enforcement of Indigenous Peoples' rights, and (re)appropriation of Indigenous Peoples' homelands have been documented with political instability.[39]

### Representation indicators

To characterize the opportunities for representation and engagement of Indigenous Peoples in decisions regarding their territory and resources, we used the World Bank's control of corruption index[118] and the World Resource Institute's environmental democracy index.[119] The control of corruption index reflects perceptions of the extent to which governments address problems with public power exercised for private gain and the potential for capture by elites and private interests. We expect control of corruption to be positively correlated with the representation and engagement of Indigenous Peoples in larger decision-making processes given contexts that discourage power imbalances and favor fairness, equity, and transparency—conditions that have been linked to lower environmental destruction[41] and improved outcomes for conservation and development projects.[40] We view environmental democracy as complementary to representation and engagement. The environmental democracy index characterizes the extent to which a country's citizens enjoy access to information, participation, and justice in environmental matters. It consists of indicators that measure the presence and strength of legislation governing freedom of information, requirements for consultation and environmental impact assessment, and regulations on extractive industries as well as their efficacy in practice.[119] We expect that greater environmental democracy can improve the representation and engagement of Indigenous Peoples in decisions impacting their territories and resources given improved access to relevant information, stricter environmental and industrial regulation, requirements for consultation, and legal means to enforce and seek compensation for damages—conditions that have been identified as important for predicting the success of community-based conservation.[38]

### Capital indicators

To characterize the various forms of capital available to support conservation and sustainable development, we used the United Nation's (UN) human development index (HDI)[120] and country-level investments in the UN's sustainable development goals (SDGs).[121] The HDI is a multidimensional index that describes the capital present within the population at large given measures of life expectancy, education, and standard of living. Higher HDI scores suggest contexts that allow more latitude in response to industrial development proposals, whereas lower HDI scores suggest contexts that increase receptivity given diminished incentives to pursue competing priorities (e.g., biodiversity conservation vs. gross domestic product [GDP]). The importance of capital and capacity building is well documented in community-based conservation.[38,42–44] Use of HDI to proxy for the capital that could be used in support of conservation and sustainable development of Indigenous Peoples' lands is further reinforced by evidence showing that wealthier countries (those with generally higher HDI) exhibit improved environmental conditions.[41] In consideration of financial capital specific to conservation and sustainable development, we also included country-level investments made in support of the UN's SDGs,[45] which totaled nearly $1.52 trillion between 2000 and 2013. Although we are unable to determine the distribution of national investments or to differentiate its beneficiaries, several of the UN's 17 SDGs are relevant to Indigenous Peoples,[28] including those that address socio-economic marginalization (SDGs 1, 2, 8, and 9), health and well-being (SDG 3), equality and social inclusiveness (SDGs 4, 5, 10, and 16), and the environment (SDGs 6, 7, 11, 12, 13, 14, and 15) (Methods S1). We assume that countries with higher SDG investments have greater financial capital to support Indigenous Peoples in successfully navigating industrial development prosposals, an assumption supported by evidence that greater national-level conservation spending can reduce the rate of biodiversity loss[46] and that greater foreign direct investments have had a positive influence on SDG achievements in African countries.[47]

### Constructing the composite index

The RRC index (Equation 1) was constructed as a hierarchical, geometric mean of rights, representation, and capital indicators, according to the formula

$$RRC_i = \text{geomean}\left(\text{Rights}_{\text{geomean}(Ind1:2)};\ \text{Representation}_{\text{geomean}(Ind1:2)};\ \text{Capital}_{\text{geomean}(Ind1:2)}\right) \quad \text{(Equation 1)}$$

where *Ind1* and *Ind2* refer to the two indicators used for each dimension. Similar to the construction of other global composite indices,[127] we used a geometric mean given the non-compensatory nature of indicators and domains and to control for any residual correlations across domains. We excluded within-domain indicators that were closely correlated (Methods S1). Further, each dimension and indicator within it were non-weighted because of a lack of theoretical or empirical justification for differential weighting. This weighting scheme could be revised as new information becomes available or with new opportunities to integrate Indigenous knowledge, values, and priorities. Prior to composite index calculation, we transformed individual indicators with skewed values, reflected their values to ensure consistent valence, and normalized their values from 0–1. Last, an RRC index score was only calculated for countries with all three dimensions represented (n = 199) (Figure 2; Methods S1).

We recognize that individual datasets may contain errors that can be amplified when combined. Our global index was comprised of national datasets that were qualitatively and quantitatively derived and largely lacked associated error metrics. Thus, we were unable to account for errors in our composite index but attempted to mitigate them by minimizing the number of indicators used and ensuring their internal consistency. Furthermore, we believe there is no *a priori* reason for bias other than the possibility of under-estimating the conversion vulnerability of Indigenous Peoples' lands. Methods S1 contain further details on indicators, pre-processing steps, criteria for inclusion/exclusion, and statistics on indicator reliability and inter-correlations.

## SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.oneear.2023.07.006.

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## AUTHOR CONTRIBUTIONS

Conceptualization, data curation, and methodology, B.F., C.M.K., and J.R.O.; formal analysis, B.F. and J.R.O.; investigation and validation, B.F. and C.M.K.; writing – original draft, B.F. and C.M.K.; writing – review and editing, Á.F.-L., B.F., C.M.K., J.E.F., J.K., J.R.O., S.B.-M., and S.T.G.; visualization, B.F., C.M.K., and J.R.O; resources, B.F., C.M.K., J.K., J.R.O., and S.T.G.; supervision, project administration, and funding acquisition, C.M.K. and J.K.

## DECLARATION OF INTERESTS

The authors declare no competing interests.

## INCLUSION AND DIVERSITY

One or more of the authors of this paper self-identifies as an underrepresented ethnic minority in their field of research or within their geographical location. One or more of the authors of this paper self-identifies as a gender minority in their field of research. One or more of the authors of this paper self-identifies as a member of the LGBTQIA+ community. While citing references scientifically relevant for this work, we also actively worked to promote gender balance in our reference list.

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