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Towards inclusive global collaborations in coral reef science

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Protecting and restoring coral reefs demands concerted global efforts that transcend national boundaries. However, equitable participation in coral reef science remains challenging, particularly for researchers from lower-income nations. Through quantitative scientometric analyses and qualitative surveys, we examined global collaboration dynamics in coral reef research. Our findings reveal that high-income countries dominate the research landscape, often sidelining contributions from lower-income regions. While international collaborations were valued for benefits like access to funding, opportunities for professional development, enhanced publication success and improved conservation outcomes, most partnerships were short-term, with limited opportunities for evolving roles. Researchers from developing nations face significant barriers, including undervaluation of contributions, differing expectations around authorship, and ethical concerns like parachute science and tokenism, raising concerns about inclusivity and respect for local expertise. To improve collaborative practices and increase participation in coral reef science we propose actionable recommendations directed towards publishers, funders and the greater coral reef research community. We recommend fostering mutual respect, building long-term relationships, and promoting fair funding and publishing practices. These steps are essential for equitable research collaborations that support coral reefs and the communities that depend on them.

Amidst the complex interplay of environmental and socio-economic challenges, the imperative for equitable and sustainable solutions has become increasingly clear. This realization has driven a paradigm shift in conservation strategies, emphasizing the integration of social equity and justice with ecological goals. The consequences of global change, poverty, food insecurity and biodiversity crises are borne unequally among different world regions and communities[1]. International organizations now advocate for transformative systemic change, recognizing that the well-being of both people and the planet are inextricably linked. For instance, the United Nations Agenda 2030 Sustainable Development Goals (SDGs) and the recently negotiated Kunming-Montreal Global Biodiversity Framework (GBF) underscore the necessity of a collaborative global dialogue and equitable/sustainable collaborations aiming to foster a more open and connected approach to research, pledging to 'leave no one behind'[2,3].

In the context of ocean science, the UN Decade of Ocean Science for Sustainable Development aims to ensure sustainable ocean development through 'transformative ocean science', requiring the global community of ocean scientists to work together[4]. This initiative aligns with the broader goal of increasing diversity in research and fostering cross-regional, cross-cultural, and interdisciplinary collaborations that can significantly enhance the impact of science, R&D, and management outcomes[5,6]. Such inclusive scientific efforts, co-designed and co-produced in partnership with a variety of

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stakeholders and knowledge holders, provide a more comprehensive and multifaceted approach to research and is crucial for achieving sustainability goals.

Tropical coral reefs, crucial yet vulnerable ecosystems, are experiencing unprecedented declines due to climate change, with a risk of catastrophic losses even if the goals of the Paris Agreement are met[7]. These ecosystems are predominantly found in lower income coastal countries in the global South, including least-developed countries and small island developing states, where communities directly depend on reef resources for their livelihoods and cultural identity[8]. Despite contributing minimally to global greenhouse gas emissions, many of these nations are disproportionately affected by climate change impacts, as the loss of coral reefs will affect their food provision, livelihoods, and increase the exposure of their coastal areas to rising sea level and more frequent and intense storms. Hence, the ongoing decline of coral reefs under climate change represents a stark example of global inequality[9]. In social–ecological systems, successful protection of biodiversity relies not only on ecological processes, but also on social and economic factors. This highlights the need for an integrated and equitable approach to coral reef conservation and restoration, emphasizing the critical interconnection between social justice, cultural integrity and ecological health[10,11]. Integrating interdisciplinary approaches that bridge natural and social sciences and fostering equitable partnerships with local communities, researchers, and stakeholders are essential to designing holistic strategies that address these interconnected challenges.

The benefits of collaborations in scientific research are well-documented and widely accepted[12–14]. Collaborative research provides a powerful platform to overcome resource disparities and foster the exchange and sharing of knowledge and skills. Collaborations between local and international researchers, practitioners, and local communities that address on-the-ground priorities can catalyse positive research and conservation outcomes that resonate with all stakeholders[15–20]. For instance, international collaborations between foreign and local scientists that span the whole research process - from inception and design, to data collection, analysis and authorship in international scientific journals-, can be crucial for building and strengthening local expertise[21–23]. In the long term, this contributes to cultivating strong local research capabilities, empowering local researchers to tackle locally relevant issues. Furthermore, integrating indigenous perspectives and traditional ecological knowledge with conventional ecological science can be extremely beneficial, as local knowledge offers novel insights on contextualized appropriate conservation strategies and resource management policies to solve local environmental problems[5,15]. As a result, applying socio-ecological and inclusive principles to research and conservation emerges as not only an ethical imperative but also a necessary pathway to well-designed and appropriate conservation strategies tailored to the realities that these communities/nations face[5,15].

However, the field of coral reef science is fraught with challenges[24–26], including the persistent underrepresentation of lower income nations in coral reef research. Researchers in lower income countries often face barriers such as limited funding opportunities, reduced access to technology and infrastructure, and face exclusion from collaborative networks. This disparity is also exemplified by the phenomenon of "parachute science", where local scientists from the Global South are excluded from international research projects conducted within their home countries[23,25,27]. Scientists from low-income nations may also face situations where they are denied leadership positions or their significant contributions are inadequately recognized, where they are either not included in the research process, not given due credit for their contributions, or tokenized—superficially included to create the appearance of inclusivity while being denied meaningful roles and contributions in decision-making. This leads to skewed authorship patterns and the marginalization of local expertise, further compounding inequalities in and outside the scientific community[24,25].

These issues are particularly problematic because they result in misaligned conservation strategies, affecting outcomes that necessitate locally tailored perspectives, knowledge, and community engagement[28,29]. Therefore, there is an urgent need to align international research collaborations on tropical coral reef science with equitable and inclusive principles. While previous work to date has highlighted persistent challenges in international collaborations[24,25], we presently lack a granular understanding of the specific issues and/or mechanisms that challenge researchers from low-income countries to participate in coral reef research. A deeper understanding of these challenges is, therefore, crucial to pave a pathway for greater participation. To address this gap, we used a mixed-methods approach to comprehensively assess the global pattern of collaboration in coral reef science. By combining quantitative scientometric and network analyses with qualitative survey methods, we collected empirical data regarding publication patterns as well as researchers' perceptions, experiences, and opinions on collaborations. This approach allowed us to identify specific mechanisms and dynamics hindering effective international partnerships. By synthesising these insights, the study aims to contribute actionable recommendations that can guide towards transformative shifts in collaborative practices, ultimately contributing to the preservation and restoration of coral reefs and the communities they support in a sustainable and inclusive manner.

Results

Mapping the collaborative research landscape

Over the past five years, tropical coral reef science has witnessed global engagement, with research contributions from institutions across 129 countries. However, publication rates were unevenly distributed among nations (Fig. 1). For instance, the United States, Australia, and the UK dominated the coral research landscape, contributing towards 39%, 29%, and 9% of all publications, respectively. Among the 95 nations participating in the scientific literature on coral reefs, 57 were high-income nations, 33 of which don't have any coral reefs. There were 31 upper-middle income nations, 32 lower-middle income nations and four low-income nations contributing to publications in coral reef science. Seven of the ten most prolific contributors to coral reef science in terms of article output were all high-income nations, while the remainder were three upper-middle income nations (China, Mexico, and Brazil) (Supplementary Fig. 1). Disparities in publishing become even more striking when looking into lead positions. Regarding first author position, we found that 76% of all papers were led by authors from high-income nations. Another 19% were led by first authors in upper-middle income nations, and the remaining 5% of publications were led by lower-middle income nations. Less than 0.05% of papers were led by authors based in low-income nations.

Less than half of the publications (46%) in our database involved collaborations between different nations, while 34% of the publications involved domestic collaborations between different institutions and the remaining 20% were written by authors affiliated with a single institution. We found six clusters of international collaboration in coral reef science, where the most prolific nations were positioned as central nodes in the collaboration network and frequently collaborated among themselves (Fig. 2). These central nodes were occupied by high income nations including the USA, Australia, Canada, and the UK, forming a dense cluster of interconnected countries from the Global North reflecting their dominant role in global coral reef research. The strongest collaboration links were between the USA and Australia, followed by the dominant partnership between Australia and the UK. While high-income nations dominate the core of the global research network, exhibiting dense interconnectivity and frequent collaborations, key coral reef regions in lower-income nations, including many Pacific and Indian Ocean countries, remain on the network's periphery. For example, several small island developing states and low-income countries are sparsely connected with limited integration into the core research network, indicating their marginalization in global collaborations. This marginalization is particularly striking for regions with critical coral reef ecosystems from low income regions, where ecological significance is not matched by research prominence. The peripheral placement of key coral reef regions underscores systemic barriers to equitable participation, limiting the contribution of researchers from these regions to global scientific efforts.

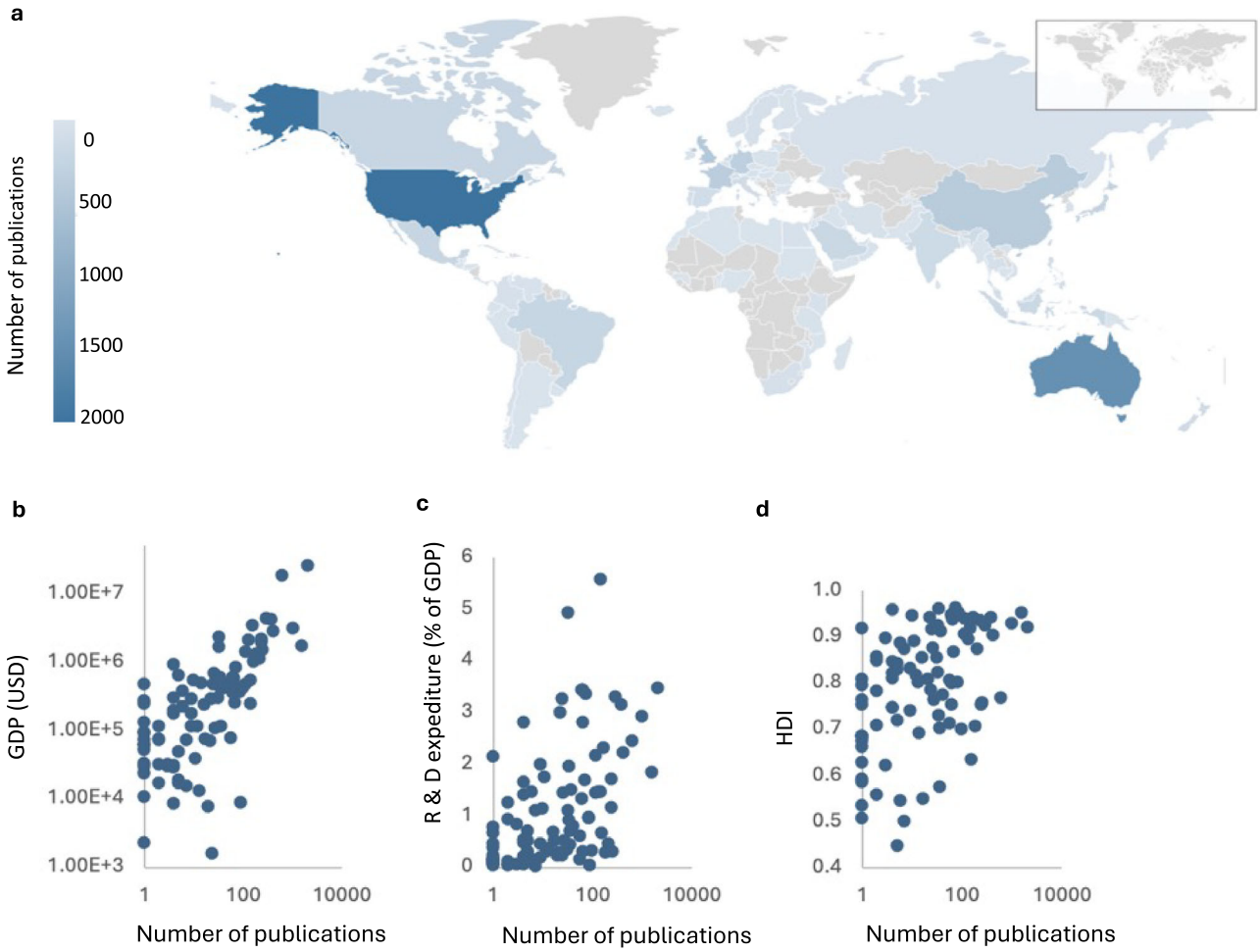

Fig. 1 | Global publication patterns in coral reef science (2018–2022). Geographic representation of authors (**a**). Relationship between publication output per country of the first author affiliation and Gross Domestic Product (GDP) in USD (**b**), Research and Development (R&D) expenditure as a percentage of GDP (**c**), and Human Development Index (HDI) scores (**d**). GDP and R&D expenditure data were extracted from data.worldbank.org for the 2024 fiscal year (accessed on 04.2024). HDI scores were retrieved from hdr.undp.org/data-center for the year 2022.

We analysed a subset of articles that involved fieldwork ($n = 230$) as part of their research efforts to determine the geographical locations of the research sites and the affiliations of the researchers conducting the study. Within this subset, approximately one-fifth of the research ($n = 47$, 20%) was conducted by entirely external teams from foreign institutions, where none of the researchers were affiliated with institutions based in the country where fieldwork was conducted, pointing to a prevalence of parachute science practices. Studies conducted entirely by local teams occurred in 40% of research projects, while collaborations between host countries and foreign researchers occurred in 39% of studies.

Survey population demographics

One hundred and thirty-eight people responded to the survey. Thirty-three were excluded as they did not work in the field of coral reef science or conservation, resulting in a final population of 105 respondents among which 43% were women and 55% were men. Overall, there was good geographic coverage with respondents from 41 countries (Fig. 3a). However, the distribution is skewed towards higher respondents affiliated to high-income nations (64% of respondents), while 32% and 4% were from upper-middle and lower-middle income levels, respectively. 1% did not respond this question. Despite our efforts to maximize accessibility, including co-designing the survey with researchers from low-income nations, offering it in multiple languages, and targeted outreach through regional networks—we received no responses from low income nations. We observe a similar pattern when considering the Human Development Index (HDI), with 63%, 30%, 5%, and 2% for each category (very high, high, medium, and low, respectively). Respondents came from diverse backgrounds, with most respondents working in academia (63%), followed by NGOs (13%), Government (9%), industry (6%), and 9% from other categories (mostly from the tourism and diving sectors).

The Sankey diagram (Fig. 3b) portraying the distribution of research pathways across different economic categories revealed a prominent flow from high-income nationalities to high income institutions and ultimately to projects within high-income nations, indicating a higher volume of collaborations within this economic bracket. In contrast, the flows from lower-middle to upper-middle income categories to their respective institutions and projects are noticeably thinner, suggesting fewer collaborations (Fig. 3b). There is also a substantial flow of researchers from high income institutions towards lower income nations, where they conduct their research projects.

Perceived benefits of international collaborations

International collaborations are clearly important in coral reef science (Fig. 4). In examining the perceived importance of international collaboration, survey participants agreed that collaborating with international researchers is essential for producing high quality publications and enhances the likelihood of publishing in international journals. The participants agreed on the importance of international collaborations for securing funding, facilitating knowledge exchange and capacity building, and formulating meaningful recommendations for conservation and management efforts.

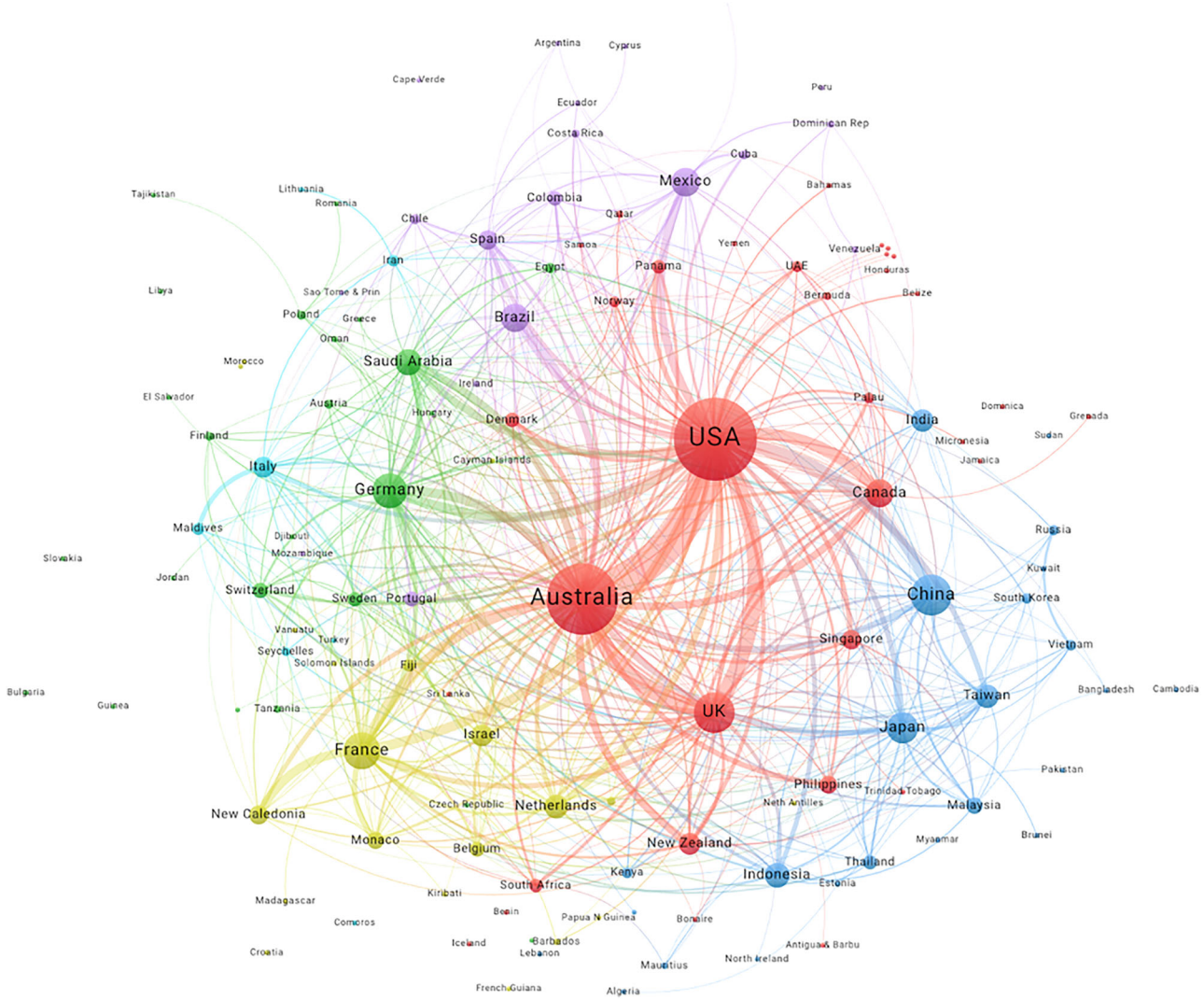

Fig. 2 | Visualization of international collaborative networks in coral reef research (2018–2022). Each node in the network represents a country based on author institutional affiliation, with its size proportional to the total number of articles published by that nation. The thickness of the links between nodes indicates the volume of collaborations between countries, with thicker links representing a higher number of collaborative projects. Principal component analysis determined the colouring of each node, grouping countries into clusters based on patterns in their collaborative relationships. Visualization generated using VOSviewer.

Controlling for gender and career level, respondents from regions with lower HDI scores appeared to attribute greater importance to international collaborations for securing funding and publishing in international journals compared to respondents from regions with higher HDI scores (Fig. 4b). However, logistic regression analysis revealed no statistically significant differences in perceptions between respondents from high and low HDI regions or income nations across any questions ($p > 0.05$ for all questions, Fig. 4), suggesting a consensus and generally positive opinion towards the benefits of international collaborations among the surveyed participants.

Collaboration dynamics and ethics

While respondents agreed that international collaborations are indeed important, their experiences and attitudes toward collaborative practices varied (Fig. 5), reflecting a nuanced landscape of international research collaborations in coral reef science. Most respondents had experienced at least some ethical or equity concerns. In fact, more than 80% of respondents indicated that they do not feel their knowledge and expertise were consistently recognised during collaborations. Similarly, 85% of respondent feel they were not always offered the opportunity to valuably contribute to different research components. Our results show that questionable research practices such as tokenism and parachute science are pervasive in coral reef research. Specifically, more than half of respondents reported experiencing or witnessing parachute science (52%), while 42% experienced tokenism, and 27% experienced both parachute science and tokenism. Collaborations were generally rated as fair and just, although more than half of respondents indicated that they had been excluded from or not adequately recognised for their contributions at least once. Similarly, nearly half (47%) of respondents had encountered disagreements regarding authorship naming.

Nearly all respondents indicated they encountered difficulties related to divergent understanding of local practices, regulations and expectations when collaborating internationally (Fig. 5). Authorship discussions were common within international projects, indicating an awareness of the need for clarity in credit and contribution. However, the frequency of such discussions varied greatly among respondents, presumably depending on the specific situation or project. The survey also showed that the recurrence of international collaborations was not always common (Fig. 5). In fact, 50% of respondents indicated that less than half their collaborations were reoccurring. In cases where collaborations did recur, roles only occasionally evolved to reflect more responsibility within collaborations.

Our analysis revealed that respondents from lower HDI and income nations showed significantly higher odds of encountering specific ethical challenges, highlighting areas where international collaborations would

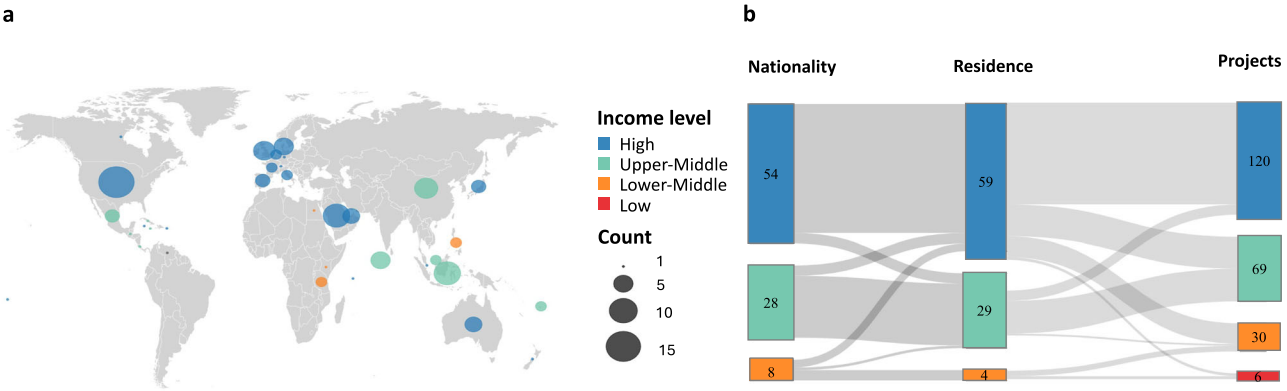

Fig. 3 | Survey respondent demographics. Geographic distribution of survey respondents involved in coral reef research and conservation (**a**). The size of the circles represents the number of respondents from each country, while the color indicates the income level of the country (High, Upper-Middle, Lower-Middle, Low income). Flow of research/conservation efforts by nationality, institution location, and project location (**b**). The diagram traces the path from the respondents' nationality to the countries where their affiliated institutions are based, and to the countries where their coral reef projects are being implemented. The widths of the bands are proportional to the number of professionals working within each income level category. Only those instances where the institution and project countries differ are portrayed. Box sizes are not proportional to category magnitudes, but numerical values are provided for clarity. Link widths, however, remain proportional to the data flow.

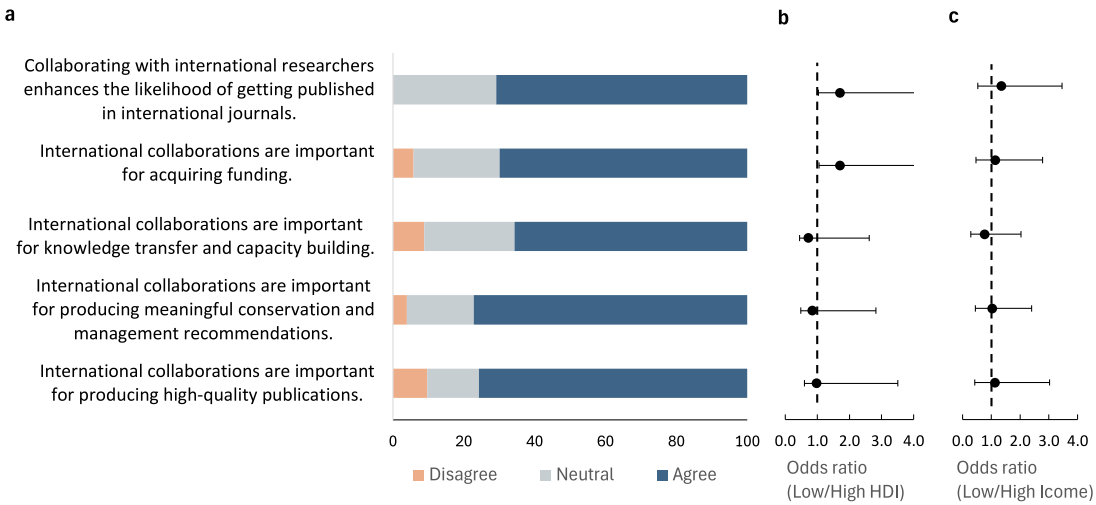

Fig. 4 | Perceived benefits of international collaboration. The distribution of responses on the perceived importance of international collaborations in research, with responses categorized as 'Disagree', 'Neutral' (neither agree nor disagree), and 'Agree' (**a**). Comparative analysis presenting the logistic regression odds ratios comparing the importance ratings between respondents from high and low HDI regions (**b**), and high and low income nations (**c**). In logistic regression analysis, odds ratios below 1 indicate that the odds of the outcome variable occurring are lower for the group being compared (e.g., Lower HDI) to the reference group (e.g., High HDI). Conversely, odds ratios above 1 suggest that the odds of the outcome variable occurring are higher for the group being compared to the reference group. Error bars represent 95% confidence intervals.

benefit from increased awareness and proactive management (Fig. 5). For instance, respondents from lower HDI regions had approximately 3.58 times higher odds of experiencing parachute science than those from high HDI countries. They also had approximately ~64% lower odds of perceiving opportunities for valuable contributions to projects and around three times higher odds of having differing authorship expectations compared to respondents from high HDI countries. Respondents from lower income regions were ~60% more likely to report that their contributions were not adequately recognised in international collaborations compared to high income nations.

Discussion

Our findings show that one in two peer reviewed scientific papers published on tropical coral reef science involve international collaboration, in contrast to 17% that involve work solely within national institutions. International collaborations were greatly valued among survey respondents for their benefits in acquiring funding, facilitating knowledge transfer and capacity sharing, making meaningful conservation and management recommendations, and producing high-quality publications with enhanced likelihood of getting published in international journals. Beyond these direct scientific benefits, international collaboration raises awareness of cultural diversity, and diverse values, broadens perspectives, and fosters bonds and shared practices among scientists, ultimately promoting more inclusive, collaborative science.

Yet, we identified challenges in consistently upholding equity and ethics values across different contexts. Respondents from developing nations report significant barriers to meaningful participation, with their contributions and local expertise frequently undervalued. This is compounded by differing expectations around authorship and recognition, creating a cycle that perpetuates the marginalization of these researchers. These challenges are also reflected in the collaboration networks (Fig. 2) where the clustering of lower-income nations at the periphery underscores

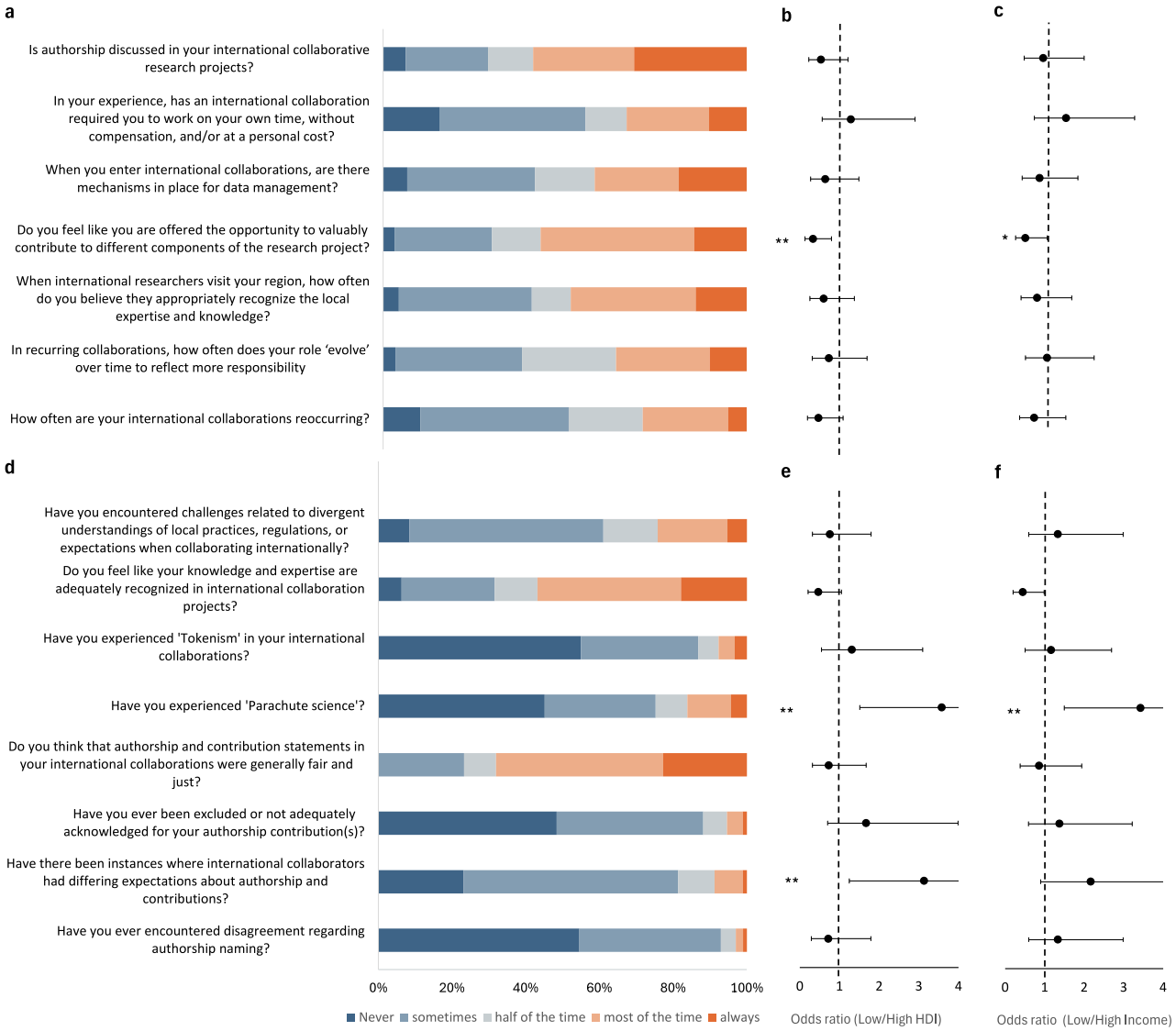

Fig. 5 | Survey Insights on collaborative research experiences in coral reef science. Questions related to collaboration dynamics (**a**–**c**) and ethical experiences in international collaborations (**d**–**f**). The distribution of survey responses, depicting the frequency of specific ethical issues encountered in international collaborations for coral reef research, with frequency levels ranging from 'Never' to 'Always' (**a**, **d**). Logistic regression analysis displaying odds ratios for reporting these experiences or opinions, comparing participants from high and low Human Development Index (HDI) regions (**b**, **e**), and from high and lower-income nations (**c**, **f**). In logistic regression analysis, odds ratios below 1 indicate that the odds of the outcome variable occurring are lower for the group being compared (e.g., Lower HDI) to the reference group (e.g., High HDI). Conversely, odds ratios above 1 suggest that the odds of the outcome variable occurring are higher for the group being compared to the reference group. Error bars indicate 95% confidence intervals and asterisk indicate statistically significant differences, where * indicates $p < 0.05$, and ** indicates $p < 0.01$.

their limited access to international research partnerships. Moreover, respondents have often experienced parachute science and interactions marked by tokenism, with parachute science being evident in one in every five papers among the set of tropical coral reef science papers assessed. This raises critical concerns about inclusivity and respect for local knowledge and risk undermining the effectiveness and sustainability of research efforts by marginalising the crucial contributions of local scientists and communities.

In practical terms, this translates into a lack of reoccurring and evolving collaborations and perpetuates the significant disparities we see in coral reef science[24,30], skewed heavily towards high-income nations where research funding and institutions accumulate. The research landscape is marked by the dominance of high-income nations in publication output, leadership roles, and collaboration networks, while lower income nations remain starkly underrepresented and marginalized to a peripheral role in research collaboration networks. Researchers from lower-income countries often face challenges such as limited access to research funding and infrastructure, language barriers, and the need to conform to the research agendas set by high-income country institutions, which often marginalizes the research interests and needs of lower-income nations. For example, research and collaboration are widespread across low- and lower-middle-income countries, but gaining international recognition remains a significant challenge for researchers from these regions. This underscores a critical gap in the research landscape, emphasizing the persistent exclusivity of the scientific community and its failure to incorporate diverse perspectives necessary for equitable and regionally relevant research. This uneven distribution is not just a reflection of resource availability but rather deeper systemic issues within natural sciences (and most scientific disciplines) and the wider society which hinder effective partnerships in international research collaborations[31].

For conservation and restoration to genuinely embody principles of equity, scientific endeavours guiding these projects must be led in an equitable manner. Accordingly, collaborations stand as the cornerstone of

contemporary research and sustainable development goals, yet our results indicate a need to re-evaluate how international partnerships are formed and nurtured in tropical coral reef science. This underscores the necessity for a framework that fosters scientific progress and ensures mutually beneficial collaborations for advancing sustainable ocean research. This collaborative ethos is pivotal in crafting conservation strategies that are both ecologically sound and socio-economically sustainable[5,21]. Changing these long-standing questionable practices requires a collective effort across the entire research ecosystem. Below, we propose several recommendations for funders, publishers, and the broader research community. These recommendations are derived from a combination of suggestions from co-authors, insights from survey respondents, and lessons learned from published articles in coral reef science and other relevant fields[21,24,25,32–36].

Coral reef science, conservation and restoration must extend across national and political boundaries. This requires international funding programs that foster cross-border collaborations, such as epitomized by the global coral R&D Accelerator Platform (CORDAP.org). CORDAP mandates participation from scientists and organizations in middle- and low-income countries in all funded projects, aiming to increase capacity and leadership in these nations while accelerating coral conservation and restoration under principles of equity and inclusiveness. Indeed, funders play a pivotal role and should emphasize equitable funding distribution by prioritising projects from developing nations where climate impacts are expected to be most severe and where funding is limited[24,37]. In collaborative efforts, consideration should be given to allocating larger portions of budgets to salaries, stipends, and other expenses for researchers from low-income nations to support the leadership of researchers from low-income countries in global research projects[24,38]. Moreover, funders should draft clear guidelines and provide oversight over collaboration dynamics, ensuring that proposals demonstrate meaningful participation of scientists from developing nations[38]. Funding for coral reef research should prioritize greater capacity building by supporting training and education programs that strengthen local research capacities, governance and autonomy which is crucial for the delivery of effective coral reef restoration. This could involve the allocation of specific funds for programs to build research capacity in developing nations, including support for education, training, knowledge exchange workshops, and scholarships.

Respondents highlighted issues concerning accessibility and the administrative burden with funding applications. The general lack of visibility of available funding and the time-intensive nature of applying for grants and compiling reports affects funding accessibility and efficiency[39]. Funding agencies could contribute by providing resources for grantsmanship as well as streamlining and simplifying application processes. For instance, initial applications could be simplified and focus on a summary of the project, with full proposals requested only from shortlisted candidates. Additionally, providing small, fast-track grants to support preliminary work on grant proposals, particularly for researchers from developing nations should be considered. These grants could cover the costs of preparatory research, travel, and consultation to develop strong, competitive applications. Funding accessibility could also be improved, which could come in the form of a centralised platform where funding opportunities are advertised in one place. Having a network of connected funding agencies would also be beneficial to streamline the matching of proposals with the most suitable funding sources, where good proposals could be forwarded to other agencies with a better match of funding criteria, enabling a more cohesive and coordinated approach. Additionally, funding agencies could play a role in connecting projects and researchers.

Limited access to cutting-edge technologies and biases in the reviewing process, may also result in proposals being considered less impactful or not sufficiently innovative. Without compensatory measures, competition simply based on sophistication of proposals and track record will continue to favour applicants from developed nations along the well-known "Matthew effect", or "rich get richer", effect in science[40]. This exacerbates existing inequalities identified in the present study, where scientists from developed nations lead 76% of the published papers, compared to 24% of papers led by scientists from low and middle income countries. There is a need to neutralize biases in funding decisions[41]. Applying a blinded review process and including a diverse scientific board and proposal reviewers from all major reef regions, who possess an understanding of the unique challenges and needs of each region or nation and their communities, could help mitigate bias by incorporating various perspectives. This approach may also facilitate the composition of proposals in native languages, effectively overcoming language barriers that further disadvantage applicants across many developing nations where English is not the primary language.

Funding bodies may also consider establishing guiding criteria/regulations, that promote equitable collaboration while allowing for flexibility in evolving project dynamics. These guiding criteria/regulations could ensure that scientists articulate how they plan to overcome barriers in international collaborations, emphasizing ethical and equitable research practices to enhance the likelihood of successful, locally-tailored research outcomes[42]. For instance, applicants could provide an "equitable collaboration statement" with proof of understanding stakeholders needs, longstanding healthy relationships with collaborators, and if relationships are new, they could demonstrate that they have considered collaboration dynamics and highlight how they plan to address authorship and credit, resolve misunderstandings between collaborators, and manage communication for instance. Grants would then be awarded to scientists who have actively considered these aspects of collaborations, ultimately ensuring the long-term viability of the collaboration. By making these requirements binding, funding bodies can ensure that equitable collaboration becomes a standard practice, thereby promoting more effective and inclusive scientific research.

Publishing agencies and editors play a role in democratising access to publishing[34,43]. Language barriers, the prohibitive costs of publishing, and limited access to scientific journals due to paywalls exacerbate research inequities, further isolating researchers from low- and middle-income countries[44–47]. This can be mitigated by implementing measures such as waiving publication fees and providing open access for institution and researchers from developing nations as part of their corporate social responsibility initiatives as well as commitment to open science and data sharing. They should provide language support and ensure that manuscripts are evaluated fairly based on scientific merit, rather than the quality of the English language.

Additionally, biases in the peer-review process tend to favour researchers from high-income countries, making it difficult for scientists from lower income regions to get their work published in high-impact journals[48]. Promoting equity in the review and editorial process is essential. Enabling a double (or triple-blind) review process, which has been shown to be more robust against biases[49], could help minimize biases arising from author nationalities. In the field of conservation, there is as striking underrepresentation of developing nations among editors in conservation journals[50], so maintaining diverse editorial boards and reviewers can ensure a more equitable decision-making process. For researchers in low-income nations, serving as editors or reviewers can present economic burdens or capacity constraints that limit their ability to volunteer time. Offering stipends or honoraria for editorial and review work would help compensate for the time commitment involved, while introducing collaborative co-editor models—pairing early-career researchers with experienced editors—could distribute workloads and provide valuable mentorship opportunities.

Increasing diversity in editorial boards could also allow for acceptance of multilingual publications. Science needs to be accessible to local policymakers, practitioners, and communities, making it essential to also publish in native languages to ensure that the research can be applied. Furthermore, publishers can contribute to capacity building by providing resources to help navigate the complexities of the publication process effectively.

Journals have a unique responsibility and play a central role in eliminating extractive research practices, such as parachute science. They could achieve this by rejecting articles from research carried out in foreign contexts that do not acknowledge any local collaborators, do not have the required permits, and by prioritizing studies that demonstrate sincere co-design and

co-development with local researchers[25], which should be reflected in authorship positions[34]. However, mandating local involvement can strain local institutions in countries with limited research capacity, potentially diverting them from their own research priorities. Accordingly, exceptions should be allowed where necessary. If local institutions are unable to collaborate but want the research to proceed, researchers could provide documented evidence that local institutions were consulted, gave their permission, and that all raw and processed data will be shared with them.

The scientific community should also take proactive measures to facilitate the participation of scientists from lower income countries in international congresses, conferences, societies and workshops where networking opportunities abound. This could be done by providing financial assistance and scholarships to overcome the financial barriers. For instance, only 12% of the over 900 members of the International Coral Reef Society, the "principal association to which coral reef scientists, managers and enthusiasts from across the world belong", pertain to low- and middle-income countries, likely due to membership fees (ICRS officer pers. comm. on 27.05.2024). Alternatively, providing options to join congresses, conferences and workshops virtually could ensure broader access for those unable to travel or such events should be hosted in developing nations where coral reefs are concentrated. This would result in increased accessibility for local scientists and students and overall enhanced participation due to lower costs. They also provide opportunities to showcase local research and their challenges, potentially inspiring collaboration opportunities. Such events can boost local economies through increased international attention and funding, which can be redirected into coral reef research efforts.

Mentorship programs, where senior scientists in the global north coach junior scientists from the global south to succeed in international science will be highly beneficial for both mentees and mentors. These programs should be encouraged and facilitated by scientific societies, funders and international organizations that include coral reef science within their mission. In the absence of these organized mentorship programs, senior coral reef scientists can take the initiative to establish a peer-to-peer mentorship program, using available resources to deliver and maintain the program.

To enhance the impact and inclusivity of scientific research, it is crucial to adopt a more interdisciplinary approach. Collaborating with social scientists and local communities and stakeholder can provide valuable insights into the social and cultural dimensions of environmental issues, while integrating traditional ecological knowledge can offer unique perspectives and solutions rooted in long-standing local practices[5,51]. Expanding training programs to include indigenous knowledge systems for Western scientists could help develop a deeper understanding and recognition of the value of this knowledge, making it easier to identify pathways for meaningful integration and collaboration. This approach not only enriches scientific understanding but also ensures that research outcomes are more relevant and beneficial to the communities involved. Scientists should respect different types of knowledge, fostering collaborations that bridge scientific and traditional practices for holistic and sustainable solutions.

Our results indicate that collaborations didn't commonly reoccur, suggesting that relationships were neither sustained nor evolved over time. This, combined with issues of misunderstandings and differing expectations, underscores a clear need for improved communication. Collaborative teams must establish clear communication from the outset, ensuring transparency about project goals and priorities, expectations, and the roles of each collaborator. These should be co-defined at the project's inception on mutual terms[5,52]. Prioritizing inclusivity and local engagement by fostering inclusive decision-making processes and actively involving local scientists in all stages of the research process, from proposal writing to publication, ensure that the research is relevant and beneficial to the regional or local context[24,38]. As seen in our survey, the absence of responses from low-income nations underscores systemic barriers such as accessibility issues, cultural differences, and a lack of trust, which likely extend to broader international collaborations. Addressing these barriers will require greater personal outreach, and the involvement of trusted regional advocates and the development of culturally sensitive practices to rebuild trust and create pathways for meaningful participation and inclusion in global collaboration.

Transparency and openness should be fundamental principles of the research process, encompassing the sharing of raw and processed data, results, and resources. Data sharing and handling still face significant cultural, legal, and ethical obstacles for international collaborators and global networks. Frameworks like the FAIR principles while designed to promote data sharing, reuse, and transparency in research, can themselves pose challenges in implementation[53]. These challenges are rooted in decades of inequitable research practices, biopiracy, and exploitation, which have eroded trust. Frameworks like the Nagoya Protocol, designed to govern access to genetic resources and benefit-sharing, aim to address these issues but are not universally ratified. This creates legal asymmetries—such as situations where scientists from non-ratifying countries can collect and relocate samples from countries that are parties to the protocol without being subject to the same access and benefit-sharing obligations required from scientists from ratifying nations. Hence, agreeing on data ownership, access and sharing is not the exclusive decision of the scientists involved, but must also comply with the legal frameworks of the countries under which the scientific collaboration take place. Rebuilding trust, not only among the scientists, but also with the policy makers in developing nations, requires a process of dialogue seeking mutual understanding and finding an agreement that suits all. Such policies must be developed through transparent and inclusive negotiations that respect the rights of local communities, comply with national legal requirements, and account for cultural contexts. At the same time, they should strive to remove impediments for the advancement of science and scientific collaboration that some of these protective legal frameworks have created.

Approaching international collaboration with humility and respect, recognizing that knowledge exchange is a reciprocal process that enriches all parties involved, should be an underpinning for all collaborations[21]. Yet, researchers are rarely trained in fair and collaborative international research or research integrity, providing little or no guidance on how to engage fairly and equitably with collaborators from other nations, particularly with different cultures and different socio-economic contexts. There is a pressing need for educational institutions to incorporate social sciences and ethical considerations into their curricula, providing in depth training on best practices in collaborative endeavours[24], ultimately broadening the perspective of researchers and emphasizing the human dimensions of scientific work. Even if this takes some time to be implemented, professors and research team leaders can take immediate steps to address this gap, by holding seminars or encouraging reading on existing research integrity guidelines, like the Singapore[54] and Montreal[55] Statements and published recommendations on this topic. This would help students become aware of the various aspects of science that are often overlooked in the conventional scientific curriculum, reminding them that science does not exist in isolation from society. Such initiatives can widen their horizons and prepare them to engage more effectively and ethically in international research collaborations.

In conclusion, while it is clear that international collaborations in tropical coral reef science offer substantial benefits, they are also marred by significant inequities and the persistent issue of parachute science and tokenism. For these partnerships to truly foster inclusive and impactful research, systemic changes are imperative across the entire research and conservation ecosystem. Funding bodies must prioritize equitable distribution and capacity building in developing nations ensuring accessibility and support for researchers from low-income countries. Publishers need to democratize access and promote fair review processes, and research teams must commit to transparent, respectful, and inclusive practices. Equally important is the collaboration with social scientists and local communities, who bring valuable perspectives, traditional ecological knowledge, and culturally relevant insights. By embracing these changes, the global scientific community can ensure that coral reef conservation efforts are not only scientifically robust but also contextually grounded, socially just, and

sustainable, empowering all stakeholders —including marginalized voices —to contribute meaningfully to the preservation of coral ecosystems.

Methods

Bibliometric analysis

The Web of Science (WoS) Core Collection was used as the source for bibliographic data to identify published articles in the field of coral reef research in the past five years. The following search terms were used: (coral* reef* (Topic) NOT deep sea (Topic) AND coral* OR reef* (Title) NOT 'cold-water coral' (Topic) and 2022 or 2021 or 2020 or 2019 or 2018 (Publication Years)). These search terms were intentionally broad to ensure the inclusion of a diverse range of study topics, encompassing both natural and social sciences. However, it is important to acknowledge that WoS tends to favour publications in natural sciences, potentially underrepresenting contributions from the social sciences or humanities[56]. We chose to restrict our analysis to the last five years since previous research has thoroughly investigated historical data and examined articles up to 2018[24]. A total of 5791 articles were initially retrieved from the Web of Science (WOS) using the specified search terms. After cleaning the dataset and excluding documents not matching the criteria, 5488 unique papers were included in the analysis. Bibliographic data, such as author affiliation countries were extracted and imported into VOSviewer for visualising co-authorship patterns across nations. Co-authorship patterns can be an informative method to analyse the connectedness of research and intellectual collaboration[57]. InCites (Clarivate) was used for descriptive analysis.

Data extraction

Among this dataset, we selected a subset of 400 randomly selected publications among which 240 involved fieldwork to manually extract further information on fieldwork location and locations of author affiliations. Based on this, we categorised research teams as 1. External, where no local researchers were listed as authors, 2. Collaboration, where at least one author was from a local institution within the country of fieldwork and one author was from a foreign institution or 3. Local, where all authors were affiliated with institutions within the countries where fieldwork was conducted.

Survey design and implementation

We conducted an international survey aimed at evaluating collaboration and authorship practices within the coral reef science/conservation community. This study was conducted in accordance with ethical guidelines and received approval from the Institutional Biosafety and Ethics Committee (IBEC) at King Abdullah University of Science and Technology (KAUST) under protocol 23IBEC062 and 24IBEC024. All participants were informed about the purpose of this research, and their participation was voluntary. Informed consent was obtained from all participants, and they were assured of the confidentiality and anonymity of their responses. Participants were given the right to withdraw from the study at any time without any consequences.

The survey, comprising 58 questions, was open to anyone working with coral reefs and we received responses from people working in academia, NGOs, government, industry, and tourism. The survey addressed a variety of ethical consideration, encompassing critical elements such as authorship naming, the prevalence of "parachute science" and "tokenism" practices, and ethical misconduct. Explanations for concept such as parachute science and tokenism were provided in the survey. Parachute science was described as the practice whereby international scientists from higher-income countries, conduct field studies in a lower income nation, without engaging or acknowledging any local researchers, and tokenisms was described as the practice of making only a perfunctory or symbolic effort to be inclusive to members of minority groups, especially by recruiting people from underrepresented groups in order to give the appearance of racial (or gender) equality within a workplace or educational context. The survey was designed to explore variables such as gender, career rank, nationality/geographic factors, and more, aiming to uncover their influence on collaborative dynamics and ethical practices. To ensure the survey's relevance across diverse cultural and economic contexts, a dedicated webinar was organized in partnership with collaborators (authors), to draft relevant questions attuned to a variety of socio-economic situations. This collective effort significantly shaped the survey's inclusivity and cultural sensitivity. Additionally, the survey was translated into eight different languages, to enhance its accessibility to a broader audience. Translations were done using AI tools (ChatGPT and Google translate) and were later reviewed and corrected by native speakers to ensure comprehensibility.

Prospective survey participants were identified using the WOS database that was used for the bibliometric analysis, from which email addresses of corresponding authors could be extracted. The sample was randomly selected while ensuring broad geographical representation. Using the Web of Science (WoS) as a database inherently introduces biases, as it tends to favour researchers working in the natural sciences and those with higher publication outputs. To mitigate this bias, enhance outreach, and encourage participation from a diverse range of backgrounds, the survey was also promoted on various social media platforms, including Twitter, LinkedIn, and Instagram. Moreover, it was directly shared within the professional networks of all co-authors, and we encouraged people to share the survey in their institutions and networks. We also asked international coral reef organisations to share the survey on their platforms.

The survey was launched in November 2023 and responses were collected over four months (until March 1st, 2024). Overall, we received 138 responses, but our analysis was constrained to 105 respondents who provided complete and comprehensive responses on the selected analytical variables.

Analysis

For comparing the perception of 'fairness' in collaborative work between researchers in developed and developing nations, we used the Human Development Index (HDI) and World bank income status. Income level provides a measure of the country's economic status, while HDI is a composite index which incorporates broader aspects of development such as life expectancy, education, and per capita income, offering a more comprehensive view of socio-economic conditions. Using both indexes combined allows for a more nuanced comparison.

The HDI Index is divided into four categories: very high, high, medium, and low. Similarly, the World Bank classifies income levels as high, upper-middle, lower-middle, and low. Due to insufficient responses across all categories, we aggregated the data for this analysis. For HDI, we combined 'very high' and 'high' into a single group labelled 'high,' and 'medium' and 'low' into a group labelled 'low.' For income levels, we retained 'high' as a category and merged 'upper-middle,' 'lower-middle,' and 'low' into a single 'low' group. These groupings align with the World Bank classification of LMICs (Low- and Middle- Income Countries). We then conducted binary logistic regressions, ordinal logistic regressions and proportional odds logistic regression to distinguish between these two groups. When responses were ranked on an ordered scale (e.g., "always," "sometimes," "never", "agree" "disagree" etc.), we employed ordinal logistic regression. This method was chosen because it is tailored to handle dependent variables with a clear, ordered relationship between categories. It models the likelihood of the dependent variable categories falling at or below a certain level based on the predictors in the model. We utilized the proportional odds logistic regression (plr) function in R from the MASS package. We conducted a Brant analysis to verify if the proportional odds assumptions were met. For questions with binary responses (e.g., yes or no), we utilized binary logistic regression using the glm function with family set to binomial.

Data availability

All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials. Anonymised and deidentified data survey responses and aggregated data are available on Dryad (https://doi.org/10.5061/dryad.d2547d89w).

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Author contributions

Initial concept: S.G.K., C.A.P with input from C.R. Study design and conceptulization: A.A.H., A.N., A.Y.-D., C.M.D., C.A.P., C.R., J.W., N.J., S.G.K., T.A. Survey design: A.A.H., A.N., A.Y.-D., C.M.D., C.A.P., C.R., J.W., S.G.K., T.A. Data analysis: C.R.; Data extraction: C.R., B.A., N.P. Data interpretation: A.A.H., A.N., A.Y.-D., C.M.D., C.A.P., C.R., P.G.-D., S.G.K., T.A. Display figures: C.R. Interpretation and recommendations: A.A.H., A.Y.-D., C.M.D., C.A.P., C.R., J.W., N.J., S.G.K., T.A. P.G.-D. Initial draft: C.R.; Review and edits: A.A.H., A.Y.-D., C.A.P., C.M.D., C.R., J.W., P.G.-D., S.G.K., T.A.

Competing interests

The authors declare no competing interests.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in the writing process to improve the readability and language of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Additional information

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