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The atoll gap: area, governance, and the under-recognition of a major coral reef system

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Global assessments project widespread coral reef degradation under continued ocean warming and acidification, underscoring the urgent need to identify and account for the full diversity of coral reef systems within conservation planning. Atolls are dynamic reef-ocean-land systems whose persistence depends on coral reef sediment production, land-sea connectivity, and cross-ecosystem nutrient subsidies. Some atoll reef environments may also support coral assemblages with elevated thermal tolerance which could mean atolls are, and will increasingly be, important local-to-regional coral sources as global and local impacts continue to limit corals. Using a curated dataset of 310 Indo-Pacific atolls and high-resolution global coral reefscape mapping from the Allen Coral Atlas, we show that 309 Indo-Pacific atolls contain 27,211 km^2 of mapped shallow reefscape, representing 41.5% of all Indo-Pacific reef area and 7.8 percent of global mapped shallow reefscape area. This spatial accounting places Indo-Pacific atolls among the world's major coral reefscape networks by area. We interpret this result alongside literature on atoll ecology, geomorphology, and governance to suggest that atoll-associated reefs merit more explicit consideration in Indo-Pacific coral reef conservation planning, while recognizing that additional comparative evidence on conservation finance, monitoring, protection, and governance would be needed to directly quantify under-recognition.

KEYWORDS
atoll, atoll ecosystem resilience, coral conservation, coral reef, coral reefscape, global coral reefs

Introduction

Atolls are the coral footprint of volcanic islands that have eroded and subsided, leaving an enclosed lagoon surrounded by annular coral reef structures. Many atolls support low-lying islands that develop over time on the surface of the lagoon-facing edge of the circumscribing reef flat (Goldberg and Rankey, 2025). Atolls are shaped by repeated Quaternary sea-level fluctuations, which have reinforced strong ecological and geomorphic connectivity between reefs, islands, and lagoons (Steibl et al., 2024b; Kench et al., 2024). Despite their distinctive ecology, biogeography as mid-oceanic rather than barrier or continental reef systems, and importance for oceanic connectivity, atolls are rarely treated as a coherent conservation unit and remain largely absent from global coral reef conservation and climate adaptation frameworks (GCRMN, 2020; Steibl et al., 2024a).

Although the biodiversity significance of atoll-associated coral reefs remains under-synthesized globally, existing evidence suggests these systems support distinctive biophysical settings, strong cross-ecosystem linkages, and poorly consolidated biodiversity values that warrant greater scientific and conservation attention (Steibl et al., 2024a, 2026).

Global coral reef conservation faces an unprecedented challenge under projected climate change. Warming oceans and acidification will drive continued coral mortality and structural degradation over the coming decades, with major implications for biodiversity, fisheries, and coastal protection (Hoegh-Guldberg et al., 2017). These projections have prompted an urgent search for reef systems and management strategies with higher potential for functional persistence under climate stress, including coral populations with elevated thermal tolerance and adaptive capacity (Lachs et al., 2023). In this context, understanding where such opportunities exist across the global reef estate is a critical conservation priority.

Global coral reef conservation discourse has historically focused on large, recognized reef systems such as the Great Barrier Reef (Richards and Day 2018), Coral Triangle (Veron et al., 2011), Caribbean, and Red Sea (Bohorquez et al., 2025), where scientific visibility, management attention, and funding are relatively concentrated. Atoll-associated coral reefs have rarely been framed similarly, despite their broad distribution, ecological distinctiveness, and importance to many Pacific and Indian Ocean communities. Dispersed across numerous small island nations and territories, they are typically treated as peripheral components of broader regional assessments rather than as a globally significant reef system in their own right (GCRMN, 2020), a mismatch that may contribute to limited conservation attention and resourcing.

One explanation may be that media narratives frequently describe atolls as doomed ecosystems destined to succumb to sea-level rise and climate change (Steibl et al., 2024b). This framing emphasizes low elevation while overlooking evidence that atoll island ecosystems and reefs are dynamic systems whose trajectories depend on reef condition, sediment production, and land-sea connectivity rather than elevation alone (Mclean and Kench, 2015; Steibl et al., 2024b). Process-based projections of future flooding and groundwater salinization under high-emission scenarios have reinforced fatalistic interpretations that risk discouraging long-term conservation investment (Storlazzi et al., 2018).

A growing body of geomorphic and ecological research challenges this deterministic narrative. Global analyses show that most atoll islands have exhibited no net land-area loss over recent decades, with many increasing despite sea-level rise (Kench et al., 2024). Experimental and modeling studies show that overwash during high-energy wave events can move reef-derived sediment landward and raise island crest elevations, providing a mechanism for vertical adjustment commensurate with sea-level rise (Beetham, Kench, and Popinet 2017; Masselink et al., 2020). Indo-Pacific atolls also support approximately one quarter of the world's remaining tropical seabirds, which deliver marine-derived nutrient subsidies to island soils, groundwater and adjacent reefs, enhancing coral growth and resilience, fish biomass and ecosystem functioning where these linkages remain intact (Graham et al., 2018; Benkwitt et al., 2021; Steibl et al., 2024c).

While climate change poses serious risks to atoll reefs through thermal stress, ocean acidification and altered wave regimes, local anthropogenic stressors strongly mediate the severity of climate impacts (Donovan et al., 2021, 2020). Overfishing, dredging, shoreline armoring, pollution and invasive species degrade reef structure, disrupt sediment transport and reduce island capacity to adjust to rising seas, often tipping atoll systems from recovery to collapse under otherwise similar climate forcing (Steibl et al., 2024b). Atoll resilience, like reef-system resilience generally, is therefore an emergent property of interacting global and local drivers rather than a simple function of elevation or exposure (Ateweberhan et al., 2013; Dutra et al., 2021). Recent work also suggests that some atoll reefs may favor corals with higher thermal tolerance, highlighting atolls as potential refugia or sources of climate-resilient coral assemblages under continued warming (Thomas et al., 2022).

Despite growing recognition of atoll resilience mechanisms and their importance to Indo-Pacific atoll communities (Barnett 2001), a fundamental quantitative question remains underexplored: what proportion of the world's shallow coral reef habitat is associated with atoll ecosystems, and how should that magnitude influence conservation priorities? Addressing this question is not intended to elevate atolls above other iconic reef systems, but to assess whether global coral reef conservation attention reflects the full diversity and spatial distribution of major coral reef systems. In the context of anticipated reef degradation under climate change, identifying systems that combine substantial spatial extent with mechanisms that may support persistence or thermal tolerance represents an important opportunity for global coral reef conservation planning (Hoegh-Guldberg et al., 2017; Lachs et al., 2023; Thomas et al., 2022).

Empirical evidence from remote atoll systems further supports this possibility. Long-term benthic monitoring at Palmyra Atoll following the extreme 2015–2016 El Niño revealed widespread bleaching but comparatively limited coral mortality, particularly in shallow reef terrace habitats characterized by large daily temperature fluctuations (Fox et al., 2019). Coral cover declined modestly on fore reefs but remained stable on shallow terraces, suggesting that thermal variability and habitat context can mediate bleaching

outcomes on atoll reefs. These findings reinforce the hypothesis that some atoll environments may favor the persistence or selection of thermally tolerant coral assemblages under repeated heat stress.

This descriptive study asks whether Indo-Pacific atolls, taken together, occupy a shallow reefscape extent comparable to widely recognized reef systems. We quantify their contribution to global mapped shallow reefscape area using a curated dataset of 310 atolls and high-resolution global reefscape mapping from the Allen Coral Atlas (ACA) (Allen Coral Atlas, 2020), while acknowledging known limitations of this resource (Lyons et al., 2024). We define reefscape as the mapped shallow-water coral reef footprint represented by ACA geomorphic classes, including living coral and associated reef substrates such as lagoon, sand, rubble, and rock. We use published estimates for the Great Barrier Reef and Coral Triangle to provide scale comparisons only; we do not infer equivalence in ecological importance, governance needs, conservation urgency, or funding requirements from area alone. By situating these results within literature on atoll ecology, resilience, and governance, we aim to support a more evidence-aligned framing of atolls as a globally significant, but distributed, network of coral reef habitats.

Methods

Atoll reef area dataset

We quantified coral reefscape associated with atoll ecosystems using a curated Indo-Pacific atoll dataset comprising 310 atolls, published by Steibl et al. (2026). This dataset includes per-atoll geomorphic and benthic area measurements derived from the ACA (Lyons et al., 2024), a global coral reef mapping product based on high-resolution satellite imagery and standardized classification methods. Of the 310 atolls in the dataset, 309 had complete reef area data; one atoll lacked ACA coverage and was excluded from area summations.

The 310-atoll dataset was itself curated from the global satellite-imagery atoll checklist of Goldberg and Rankey (2025), retaining only Indo-Pacific atolls with permanent emergent landforms and excluding submerged atolls together with emergent atolls of the Atlantic, Caribbean, South China Sea, and Indonesian archipelago; the resulting set represents the emergent Indo-Pacific subset of the roughly 611 atolls resolvable worldwide in that checklist. Because Atlantic and Caribbean atolls are excluded, our summed total is a conservative lower bound on the mapped atoll reefscape footprint, not a lower bound on live-coral habitat or ecological value.

For each atoll, we extracted the value for total reef area (km^2), which represents the aggregate shallow-water reef footprint across all mapped geomorphic zones. These zones include reef slope, sheltered reef slope, reef crest, outer reef flat, inner reef flat, back reef slope, shallow lagoon, deep lagoon, plateau, patch reefs, and other reef-associated classes defined by the ACA. The total reefscape extent therefore includes both living coral and associated non-living substrates (e.g., sand, rubble, rock) that form part of the shallow reef ecosystem.

Because we relied on these published per-atoll totals, no additional geographic-information-system extraction was performed in the present study; the underlying spatial-intersection workflow is that of Steibl et al. (2026). This total reef extent is drawn from the same ACA geomorphic product and class universe as the global reef estimate used as our denominator (Lyons et al., 2024), so numerator and denominator are methodologically consistent, and it should be read as a mapped geomorphic footprint rather than a measure of live-coral cover.

Throughout the manuscript, we use "reefscape extent" and "mapped shallow reefscape area" to refer to this ACA-derived geomorphic footprint. We use "coral-algae" only when referring specifically to the ACA benthic class that combines coral and algae as a habitat proxy; it should not be interpreted as live-coral cover or as a direct measure of reef condition.

Global coral reef area comparison

To estimate the fraction of global coral reef area associated with atolls, we compared the summed atoll reef extent against the most recent global coral reef area estimates produced by the ACA. We used the ACA global shallow reef extent estimate of 348,361 km^2 (Lyons et al., 2024), which includes all shallow reef geomorphic zones and is methodologically consistent with the atoll-level reef extent metric. Using a consistent numerator and denominator derived from the same remote-sensing platform and classification scheme avoids cross-methodology bias that can arise when combining heterogeneous reef datasets.

As a secondary comparison, we note that older global coral reef area estimates derived from compiled vector polygons (e.g., UNEP-WCMC) yield substantially smaller global totals; however, because these products rely on heterogeneous historical sources and different classification criteria, they were not used as the primary denominator in this analysis.

Contextualizing atoll reef extent

To contextualize the magnitude of atoll-associated reef area, we report published estimates of shallow coral reef area for the Great Barrier Reef (GBR), the world's largest single coral reef system. Roelfsema et al. (2021) report a refined GBR shallow geomorphic reef extent of 28,261 km^2 from Sentinel-2 satellite-derived mapping using methods comparable to those employed by the ACA. These values represent shallow reefs visible in optical imagery and exclude deeper reef structures. We use this published estimate of GBR reefscape extent to provide the best-available point of reference for the scale of atoll-associated reefscape. Additionally, we used the Global Island Database to identify all islands in the Indo-Pacific oceanic basins and manually extracted the total reef extent area for each identified island (n = 1,308 islands including 310 atolls) from ALA to compare the extent of Indo-Pacific atoll reefs to reef area around other Indo-Pacific island types (*e.g.*, volcanic islands, limestone islands). When aggregated at the country-level, total reef area comprises only that of island in the Indo-Pacific oceanic basins. For example, Indonesia or the US have additional shallow

reefscape area outside the target region, but these geographies were not included to the country totals.

Data aggregation and descriptive statistics

We summed total reef extent across all atolls with complete data to obtain cumulative atoll-associated reef area. We additionally calculated reef area per atoll jurisdiction, to characterize the distribution of reefscape across the atoll network. Reef area totals were also summarized by country or territory to illustrate the geographic distribution of atoll reef area and the degree of governance fragmentation across the Indo-Pacific.

Methodological strengths and limitations

This analysis benefits from high internal consistency, as both atoll-level reef areas and global reef area estimates are derived from the same ACA classification system. Dataset completeness is high, with reef area data available for 309 of 310 atolls (99.7 percent coverage). All source data are publicly available via the ACA (Allen Coral Atlas, 2020) and the FAIR² data portal (Steibl et al., 2026).

The resulting estimate represents a lower bound on the global contribution of atolls to coral reef area, as the dataset includes Indo-Pacific atolls only and excludes the few atolls in the Atlantic and Caribbean. In addition, the total reef extent metric includes non-living substrates that form part of the shallow reef ecosystem; restricting the analysis to coral-dominated benthic classes alone would yield a smaller absolute area but require equivalent global coral-only estimates for comparison. Temporal changes in reef extent due to bleaching or disturbance are not captured in this snapshot analysis.

Because our analysis covers 309 of the 310 atolls in the Steibl et al. (2026) dataset rather than a probability sample, inferential statistics such as confidence intervals or significance tests are not the appropriate uncertainty model. The primary uncertainty arises from classification error in the underlying ACA maps. Lyons et al. (2024) report average overall accuracy of 69 percent for ACA geomorphic zonation, with regional values ranging from 46 to 89 percent across 30 mapping regions; accuracy was lower for the finer benthic classification (66 percent). These values measure class-label agreement at validation points and do not translate directly into confidence intervals for mapped area. We therefore interpret them as evidence of the reliability and limitations of ACA geomorphic classes rather than formal error bounds, and identify per-class, per-region error propagation as a priority for future work. Because the numerator and denominator use the same ACA product and geomorphic metric, the estimated atoll share of global reef extent should be relatively insensitive to classification bias that scales uniformly across regions. However, it remains sensitive to non-uniform regional or class-specific error and should be interpreted as an ACA-based descriptive proportion. Where ACA shallow-reef classes include extensive non-coral carbonate banks in non-atoll regions, the global denominator may be inflated, making the atoll share conservative.

Results

Across the 309 Indo-Pacific atolls with complete data, total mapped shallow reefscape extent summed to 27,211.0 km², with a mean reefscape extent of 87.8 km² per atoll (range 1.5-666.0 km²). When compared with the ACA estimate of 348,361 km² for global mapped shallow coral reef extent, Indo-Pacific atolls account for 7.8 percent of the world's mapped shallow reefscape area. Because this analysis is based on mapped spatial extent, these values should be interpreted as a descriptive estimate of area rather than as evidence of ecological condition, resilience, biodiversity value, or conservation performance.

The distribution of reefscape extent across atolls is strongly right-skewed: the median atoll holds 43.8 km² of reefscape, well below the mean of 87.8 km², with an interquartile range of 13.9 to 103.8 km² (Figure 1). Reef area is also concentrated in a small number of large atolls, with the ten largest accounting for 19.3 percent of the total mapped reefscape and the fifty largest for 57.4 percent. The size and spatial distribution of all 309 atolls are mapped in Figure 2. This concentration may be relevant to area-based conservation planning, though it does not by itself identify conservation priority, which also depends on biodiversity, threat, condition, governance, and feasibility.

Pacific atolls (255 atolls) accounted for 19,264.4 km² of mapped shallow reefscape, while Indian Ocean atolls (n = 54) contributed 7,946.5 km² (Table 1). Together, Indo-Pacific atolls represent one of the largest mapped shallow reefscape networks in the world and are of a similar order of magnitude to the GBR, which includes approximately 28,261 km² of shallow reefscape (Roelfsema et al., 2021). This comparison is intended only to contextualize spatial scale. The GBR is a nationally managed, continuous barrier reef system, whereas Indo-Pacific atolls comprise hundreds of dispersed mid-oceanic reef systems across 23 jurisdictions in 19 sovereign nations (Table 1), with governance and conservation investment distributed across multiple institutions and funding pathways rather than coordinated through a single management system (Keppel et al., 2012; Steibl et al., 2024b).

Together, the 1,308 mapped islands of the Indo-Pacific oceanic basins, including both atolls and other types such as volcanic islands, comprise 65,491.9 km² of coral reef area, meaning atolls contribute 41.5% of mapped Indo-Pacific shallow reefscape habitat. The average reef area of atolls is 87.8 km² and therefore, on average, over 2.2 times larger than the mean 38.4 km² reef area surrounding other Indo-Pacific islands. In atoll nations like Maldives or Tuvalu, atoll reefs logically constitute 100% of mapped reefscape, but for many other Indo-Pacific small island countries (e.g. Cook Islands, French Polynesia, Seychelles) atolls also constitute the majority of total reef habitat under their jurisdiction (Figures 3a–c).

To place this extent in broader context, we compare atoll reefscape against other reef systems on the same ACA geomorphic basis where possible. The GBR has a shallow geomorphic reef extent of 28,261 km² (Roelfsema et al., 2021), and a five-nation Coral Triangle country-sum proxy (Indonesia, the Philippines, Papua New Guinea, Solomon Islands, and Malaysia; ACA national extents,

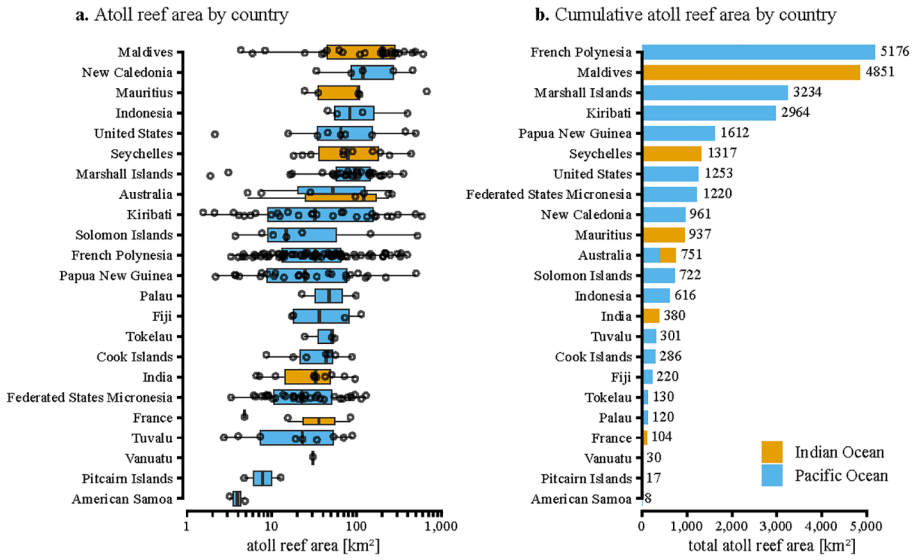


FIGURE 1
Size distribution of mapped reefscape extent across the 309 Indo-Pacific atolls. **(a)** Reefscape area of atolls by country on log-scale. **(b)** Total reefscape area of atolls by Indo-Pacific country containing at least one atoll in its territory.

Lyons et al., 2024) totals approximately 62,350 km². This proxy is not clipped to the formal Coral Triangle (CT) boundary and excludes Timor-Leste. On this like-for-like basis, Indo-Pacific atoll reefscape (27,211 km²) is approximately 96% of the mapped GBR geomorphic extent and approximately 44% of the five-nation CT sum (Figure 3d). These groupings are not mutually exclusive: 36 of the 309 atolls (approximately 2,950 km², 11 percent of the atoll total) lie within CT nations and are counted in both totals, so the two are not additive. The remaining 89 percent of atoll reefscape lies outside the CT, underscoring that atolls form a largely distinct mid-oceanic reef estate rather than a subset of the regions compared here. The GBR comparison does not overlap, since the Australian atolls in our dataset are mid-oceanic reefs in the Coral Sea rather than part of the GBR. Comparable ACA figures are not usable for the Caribbean or Red Sea without a serious metric artifact, because the ACA shallow-reef class there is dominated by non-coral carbonate banks; we therefore note only best-available published coral-reef extents for context, approximately 26,000 km² for the wider Caribbean (Burke et al., 2011) and 13,605 km² for the Red Sea and Gulf of Aden (GCRMN; UNEP-WCMC), which derive from a coarser, earlier mapping method and are not directly comparable to ACA-based values.

Discussion

Our results show that Indo-Pacific atolls collectively constitute a substantial component of the global mapped shallow coral reef estate, accounting for 41.5 percent of all mapped Indo-Pacific island reefs and approximately 7.8 percent of mapped shallow reefscape area globally. This spatial finding supports explicit consideration of atolls in coral reef conservation planning alongside other major reef regions. However, our analysis does not directly measure conservation investment, monitoring effort, protected-area coverage, management effectiveness, biodiversity distinctiveness, or ecological resilience. We therefore frame under-recognition as an evidence-based concern suggested by the combination of large aggregated reefscape extent, dispersed governance, and limited visibility in major global reef narratives, rather than as a directly quantified outcome of this study.

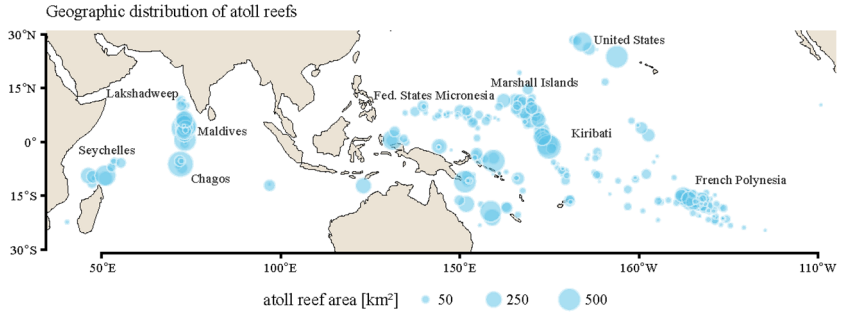


FIGURE 2
Distribution and size of the 309 Indo-Pacific atolls. Symbol area is proportional to mapped reefscape extent.

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TABLE 1 Indo-Pacific atoll reef extent by country and territory.

#	Country/territory	Atolls	Reefscape extent (km²)	% of total	Coral-algae (km²)
1	French Polynesia	78	5,176.3	19.0%	278.7
2	Maldives	25	4,851.1	17.8%	686.2
3	Marshall Islands	30	3,234.0	11.9%	831.0
4	Kiribati	27	2,963.8	10.9%	596.0
5	Papua New Guinea	22	1,611.6	5.3%	113.1
6	Seychelles	10	1,317.2	4.8%	217.1
7	United States	10	1,252.9	4.6%	145.6
8	Federated States of Micronesia	34	1,220.5	4.5%	117.1
9	New Caledonia	5	960.7	3.5%	109.6
10	Mauritius	5	937.3	3.4%	52.0
11	Solomon Islands	10	721.6	3.3%	38.4
12	Australia	7	751.5	2.8%	79.7
13	Indonesia	4	615.6	2.3%	14.1
14	India	10	380.2	1.4%	95.1
15	Tuvalu	9	301.2	1.1%	35.7
16	Cook Islands	7	286.1	1.1%	17.4
17	Fiji	4	219.8	0.8%	44.0
18	Tokelau	3	129.6	0.5%	12.1
19	Palau	2	120.2	0.4%	11.3
20	France (Scattered Is.)	3	104.0	0.4%	6.2
21	Vanuatu	1	30.4	0.1%	2.4
22	Pitcairn Islands	2	17.4	0.1%	1.6
23	American Samoa	1	8.0	0.0%	0.5
	TOTAL	**309**	**27,211.0**	**100%**	**3,505.3**

Source: Steibl et al. (2026), Atoll biodiversity and environments (FAIR²/Zenodo; ODC-By). Reef extent = Allen Coral Atlas reefscape and geomorphic extent (incl. lagoon and non-living substrate); coral-algae = ACA coral and algae benthic class (habitat proxy, not live-coral cover). 309 of 310 atolls have reef data. Bold values indicate the total across all countries and territories.

The significance of these findings is amplified by the broader trajectory of coral reef decline. Climate projections indicate that most reef systems will experience increasingly frequent and severe thermal stress, challenging long-term reef structure and function even under ambitious emissions-reduction scenarios (Hoegh-Guldberg et al., 2017). In this setting, conservation strategies that identify and support reef systems with higher adaptive capacity are increasingly important complements to climate mitigation.

Indo-Pacific atoll-associated coral reefs are distributed across 23 jurisdictions in 19 sovereign nations, with governance and investment dispersed across institutions and funding pathways rather than coordinated through a single management system (Keppel et al., 2012; Steibl et al., 2024b). This contrasts with the GBR, which benefits from coordinated national and state investment exceeding AUD 5 billion from 2014 to 2030 (DCCEEW, 2026). While this comparison is not sufficient to quantify a global funding gap for atolls, it illustrates how institutional consolidation can shape visibility, coordination, and resourcing for reef conservation.

Atolls are also frequently framed as doomed or transient landscapes under sea-level rise scenarios, rather than as resilient coral reef systems with strong biogeophysical land-sea linkages, reinforcing perceptions that conservation investment is unlikely to yield durable returns. Together, these structural and narrative dynamics may help explain why a globally important coral reef system has remained peripheral to major coral reef conservation agendas despite its spatial extent (Figure 2), its distinct biogeography as mid-oceanic reef systems (compared to barrier or continental reefs like GBR, Caribbean), and its ecological significance.

Emerging evidence on atoll resilience challenges the "doomed" framing. Atolls are inherently dynamic marine systems whose persistence depends on intact coral reef sediment production, sediment transport, and strong ecological connectivity between reefs, islands, and surrounding ocean systems (Masselink, Beetham, and Kench 2020; Mclean and Kench, 2015). Seabird-mediated nutrient subsidies and high levels of cross-ecosystem coupling can enhance coral growth, reef productivity, and possibly recovery potential on atoll reefs where local stressors are limited (Benkwitt et al., 2021, 2023). In this context, atoll vulnerability is not an intrinsic property of low elevation, but an emergent outcome shaped by the interaction of global climate forcing and local management of reef and island systems.

The implications for Indo-Pacific coral reef conservation are substantial but should be interpreted as planning implications rather than direct causal findings. Explicitly incorporating atoll-associated reefs into regional and global conservation frameworks could improve representativeness by better reflecting the spatial

diversity and distribution of major reef habitats. It could also help assess whether distributed atoll systems receive attention and resources commensurate with their aggregated scale, ecological distinctiveness, and social importance. Framed in this way, greater attention to atolls is not a call to divert support from other major reef regions, but to broaden the evidence base used to set priorities across the global coral reef estate.

These findings also point to several under-appreciated opportunities for coral reef restoration and climate adaptation research on atolls:

1. Long residence times and limited water exchange in some atoll lagoons may favor the persistence of thermally tolerant corals (Khen et al., 2024)
2. Atoll reefs, being mid-oceanic rather than fringing large continental(-like) landmasses that are generally more impacted by local human land use, offer an example of reef response to climate change in the absence of local human stressors (Baumann et al., 2022)
3. Restoration of atoll islands is achievable and tractable (Franklin et al., 2024) and offers an example of passive (or indirect) reef restoration, which can be compared to, or paired with active reef restoration.
4. Atolls can be important sources of coral larvae to adjacent island systems (Burt et al., 2024)

Atoll-specific ecological studies underscore that these dynamics are not theoretical. At Palmyra Atoll, an extreme thermal stress event caused high bleaching prevalence but limited mortality, with contrasting outcomes between fore reef and shallow terrace habitats linked to differences in thermal variability (Fox et al., 2019). Rapid post-bleaching transitions from turf algae to crustose coralline algae further indicated recovery trajectories conducive to reef framework persistence. Such habitat-dependent responses highlight how intact atoll reef systems can retain function under acute climate stress, particularly where local stressors are minimal.

Future research should better resolve the biodiversity significance of atoll-associated coral reef systems within the global coral reef estate, including their roles in supporting regionally distinctive species assemblages, cross-ecosystem connectivity, larval exchange, and the maintenance of ecological functions across dispersed ocean basins and differing climate-risk scenarios. Additional priorities include testing the extent to which atoll reefs may serve as reservoirs of climate-tolerant coral genotypes or phenotypes, identifying the local management conditions that most strongly support reef and island persistence, and developing governance and finance models capable of coordinating conservation action across the many jurisdictions in which atolls occur.

Recognizing Indo-Pacific atolls as a globally significant network of a distinct mid-oceanic shallow reef system has implications for research, planning, and conservation prioritization. Because local stressors can mediate climate impacts on atoll reefs and islands, targeted interventions such as protecting reef structure, maintaining sediment transport, safeguarding seabird colonies and nutrient subsidies, protecting coastal ecosystems through sustainable harvest management, and reducing land-based pressures may enhance resilience under ongoing climate change (Steibl et al., 2024b; Masselink et al., 2020). Explicitly incorporating atoll-associated reefs into Indo-Pacific conservation planning would help ensure that a substantial and geographically distributed component of the global reef estate is considered in climate-responsive conservation strategies.

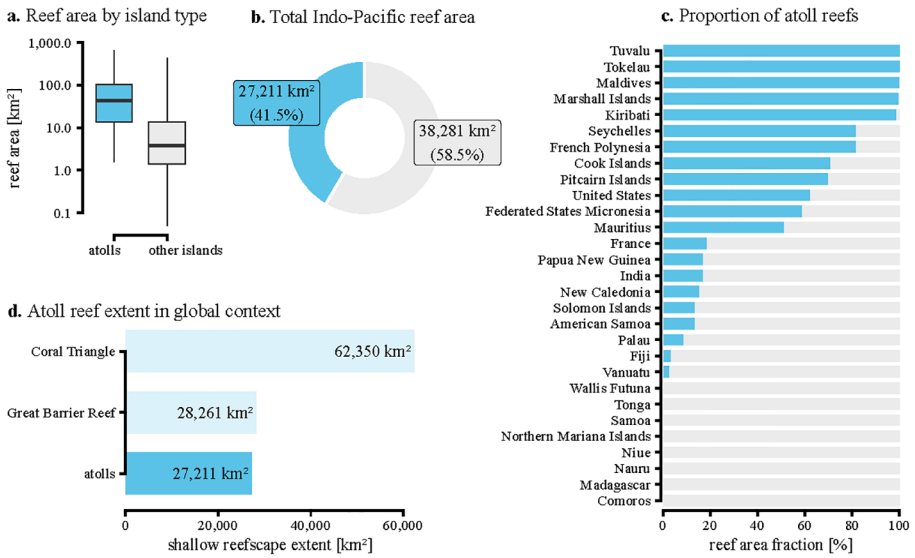


FIGURE 3
Shallow reefscape extent of atolls in the Indo-Pacific and global context. **(a)** Comparison of reef area between atolls (blue) and other Indo-Pacific island types (e.g. volcanic islands) (gray). Boxplot shows median, 5%, 25%, 75%, and 95% quantile range of reef area. **(b)** Total cumulative shallow reef area of Indo-Pacific atolls (blue) and of other island types in the Indo-Pacific (gray). **(c)** Proportion of shallow reef area constituted by atolls (blue) and other island types (gray) for countries of the Indo-Pacific region. Note that reef area is only considered for islands in the Indo-Pacific oceanic basins, see methods. **(d)** Comparison of total atoll reef area with the mapped extent of shallow reefscape habitat for two other prominent coral regions, the Great Barrier Reef (Roelfsema et al., 2021) and the Coral Triangle (ACA 2024), see methods.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

AW: Conceptualization, Visualization, Writing – original draft, Writing – review & editing, Funding acquisition, Investigation, Project administration. GL: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing, Visualization. CA: Writing – original draft, Writing – review & editing, Conceptualization. CB: Writing – original draft, Writing – review & editing, Conceptualization, Visualization. DdK: Writing – original draft, Writing – review & editing, Conceptualization. RH: Writing – original draft, Writing – review & editing, Conceptualization. VH: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. VI: Writing – original draft, Writing – review & editing. HL: Writing – original draft, Writing – review & editing. SM: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. FM: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. TM: Conceptualization, Writing – original draft, Writing – review & editing. JR: Conceptualization, Writing – original draft, Writing – review & editing. IV: Conceptualization, Visualization, Writing – original draft, Writing – review & editing. BK: Conceptualization, Validation, Visualization, Writing – original draft, Writing – review & editing. SS: Conceptualization, Formal analysis, Methodology, Writing – review & editing. HS: Conceptualization, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

Authors GL and VH were employed by Compass Resource Management, author FM was employed by Tahiti Expeditions, and RH was employed by Pohnpei LP Gas Distributing Company.

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