

Supporting Information

Nearly half of reef-building corals face elevated relative risk of extinction

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This Supplementary Information documents the methods, data and supporting results underlying the 2024 reassessment of extinction risk for 892 reef-building coral species (85 Atlantic and 807 Indo-Pacific), an increase of 47 species on the 845 assessed by Carpenter et al. 2008¹. The reassessment retains the overall framework of that first global assessment, fully detailed in its own online Supplementary Material, and updates it based on currently available methods and data for the global scope of this reassessment. The latest IUCN Red List Guidelines (v14 used in this study)² should be consulted for all standard definitions and recommended applications.

The sections that follow first describe the substantive methodological updates and application of key IUCN RL definitions for this assessment: coral taxonomy, the use of coral cover as proxy of habitat decline for population reduction, projected future thermal stress, generation length and the species-traits scoring, followed by the Red List Index (RLI). We then report the results and supporting data.

Methodology updates from Carpenter et al. 2008

The IUCN Red List methodology is grounded in extinction risk theory³ and applies five criteria of extinction risk, each of which is based on a different attribute (Table S11)². These criteria fall into one of two paradigms. The first paradigm is that a given species population is so small, that it is exceptionally vulnerable to threats that can near completely or completely extirpate its existence. The second paradigm is that a given species is experiencing population decline at a rate faster than its ability to recover. This is the primary criterion that was used to assess coral species, as with the vast majority of marine species, their populations are too numerous to fall into the first paradigm.

The quantitative thresholds associated with each criterion determine which (if any) of the threatened categories a species qualifies for, thus producing an objective and standardized assessment. Each species that was not Data Deficient is assigned to one of eight extinction risk categories, selecting the most severe as a precautionary estimate. Precaution is applied as later re-assessment with improved evidence can result in ‘downlisting’, or reducing the estimation of extinction risk, in the future. By contrast, under-estimation of extinction risk may undermine action that results in unnoticed, irreversible extinction^{2,4}.

Data on each species’ distribution, population trend, habitats, traits, use and trade, threats, and conservation measures were compiled/updated and applied to the five criteria. The assessments were reviewed by expert assessors both virtually and at two in-person workshops held in July 2022 and October 2023. Following further standard Red List review processes, the Atlantic assessments were published on the Red List in December 2022 in update 2022-2⁵ and the Indo-Pacific assessments in October 2024 in update 2024-2. Data for 118 (13%) of the 892 species were insufficient for their extinction risk to be assessed, so were classified as Data Deficient (DD), compared to 141 species in 2008 (Table 1). Most DD classifications were due to high taxonomic uncertainty.

Table SI1. Red List of Threatened Species criteria applied to reef-building corals. See IUCN guidelines for full details ².

Criteria & sub-criteria	Evidence base
A. Population size reduction (past, present and/or projected)	
A1 – past changes, causes reversible and ceased	a – direct observation
A2 – past changes, causes continuing or unknown or reversible	b – appropriate index of abundance
A3 – future changes	c – decline in AOO, EOO, and or habitat quality
A4 – past and future changes, causes continuing or understood or reversible	d – levels of exploitation
	e – introduced species, pathogens, pollutants, hybridization, etc.
B. Geographic range in the form of either B1 or B2 AND at least 2 of a, b or c	
B1 – extent of occurrence	a – fragmented or small number of locations (<i>sensu</i> RL Guidelines)
B2 – area of occupancy	b – continuing decline, based on i) EOO, ii) AOO, iii) area, extent and/or quality of habitat, iv) number of locations/subpopulations, v) number of mature individuals
	c – extreme fluctuations in any of: i) EOO, ii) AOO, iii) number of locations/subpopulations, iv) number of mature individuals

Criteria not used in this assessment: C. Small population size and continuing decline of mature individuals including fluctuations ; D. Very small population or very restricted area of occupancy; E. Quantitative analysis of extinction risk (e.g., Population Viability Analysis). **AOO**: Area of Occupancy; **EOO**: Extent of Occurrence

Updates to the methodology are described in the sections below. A foundational property of the IUCN RL is that categories, criteria and their quantitative thresholds form a single standardized instrument that is deliberately held constant, so that assessments of extinction risk remain comparable both among taxa and between successive assessments of the same group ⁶. What is updated between assessments is the data and methods used to estimate the variables tested against the criteria and the latter are applied using the best available information. Accordingly, over the 15 years since the last assessment we incorporated improvements in both analytical capabilities and datasets (including by interpolation/extrapolation methods). Where the 2008 approaches and supporting assumptions remained appropriate, they were retained to maintain consistency and to limit interactions among changes.

The Red List Index (RLI) is used to show real change in extinction risk, so only genuine category changes, resulting from an increased risk of extinction, may contribute to it. Standard practice is to apply the most recent, consistent method across all historical time points. This may result in changes to estimation of risk at past time points that are classified as ‘non-genuine’ as they reflect improvements in data and methods, not in the actual status of species historically. The index ranges from 1, when all species in the set are LC, to 0, when all species in the set are EX or EW. A declining RLI means species are, on average, moving into higher-risk categories. We recalculated the RL categories for each time point (1998, 2008 and 2024), with the resulting non-genuine differences in categories from the 1998 and 2008 Carpenter et al., 2008 assessments reported separately (Table SI5).

Coral taxonomy

For coral taxonomy, we applied standard practice Red List assessments which is to use currently accepted nomenclature in globally standard repositories, which for marine species is as the World Register of Marine Species (WoRMS, <http://www.marinespecies.org/>). Coral taxonomy has been in flux and highly contested for decades, with ongoing disagreements. Nevertheless, a stable higher-level phylogenetic structure has emerged, implemented by WoRMS, enabling robust tracking of further taxonomic changes (see Main Text).

For this study, we use the term ‘reef-building corals’ to apply to zooxanthellate scleractinian taxa in the order Scleractinia plus reef-building octocorals and hydrocorals in the families Helioporidae, Tubiporidae, and Milleporidae. These 892 species represent 28 different families, of which one-third are in Acroporidae (281 species) and another one-third in Merulinidae (146 species), Poritidae (100 species), and Pocilloporidae (46 species) (see Table SI8.-9 and Supplementary Dataset 1).

Coral abundance and extinction risk

Under the IUCN RL framework, extinction risk is expressed through standardised categories that capture different demographic pathways to extinction and the spatial spread of risk. Criteria A–D use population reduction, restricted geographic range, small population size and combinations of these as indicators of elevated risk. Criterion E differs in that it estimates an explicit probability of extinction over a specified period through a quantitative analysis, such as a population viability analysis (PVA). Consequently, a species classified as threatened under Criterion A is not predicted to become extinct within three generations, nor can the probability or timing of its extinction be inferred directly from its Red List category. The classification indicates that the species has experienced, or is projected to experience, a proportional reduction exceeding a *standardized* threshold associated with elevated extinction risk.

Results of the 2008 assessment have been criticised as overestimating extinction risk, based on census data of colonies as a basis for region-wide abundance estimates in the millions of colonies^{7,8}. This misunderstands the concept of population reduction that is a basis of the Red List assessment (see ‘Methodology updates’ above), but also inappropriately proposes regional census data for global application⁹: it is restricted in taxonomic scope (only 318 species assessed), habitat (0–7 m depth), geographic extent (20.5° N–23.9° S and from Indonesia to French Polynesia) and was collected ~25 years ago (1999–2002), before the 2nd, 3rd, and 4th global bleaching events. The data predates the increasing prevalence of compound heatwaves¹⁰ and the elevating trends in all measures of heat stress including frequency and duration¹¹ of prolonged stress observed in 2025, whereby over 30 DHW was recorded at many locations¹². Over this time period, global human population size has also increased by over 2 billion people¹³, with demand for marine resources increasing along with levels of pollution, extraction and habitat destruction¹⁴.

In the current study, we use the best available data to estimate population size based on distribution (Criterion B) and rate of reduction (Criterion A), following standard guidance for the IUCN Red List. Here, as in Carpenter’s et al 2008 assessment, most corals are assessed under Criterion A, where rate of reduction, not population size, is the basis for assessment. Under Criterion A, a species numbering in the millions of colonies can be threatened if it has

experienced, is undergoing or is projected to undergo a sufficient population reduction, and the causes of decline are continuing (Table SI1). Geographic range and high abundance provide greater protection against spatially localized and independent disturbances than against directional threats whose frequency and intensity increase across much of a species' distribution, such as is the case of thermal stress for corals¹⁵. The different axes in which abundance and extinction risk operate under these directional and range-wide threats are evidenced in both the geological record of corals and modern reduction rates of Acroporids in the Caribbean¹⁶. The degree of spatial covariance in the threat nevertheless remains important and the present assessment accounts for this partly by weighting projected thermal exposure across each species' range and excluding portions not projected to experience Annual Severe Bleaching within the three-generation assessment period (see Thermal Stress below).

The RL guidelines further caution against equating colony counts with population size. For clonal, modular organisms such as corals, the relevant unit is the ramet: the smallest entity capable of independent survival and reproduction, that "typically lives, is injured, and dies as a unit"². Colonies below reproductive size or at densities too low for fertilization are excluded, effective population size cannot be substituted, and estimating mature individuals from density and area risks gross overestimation unless carefully parameterised. None of the parameters required for that conversion are available for corals globally. Improving on this will require what is not yet available: large-scale, taxonomically resolved colony densities through space and time, with the demographic rates needed for Criterion E to be applied. Until then, the RL framework to incorporate indirect data and uncertainty associated with it in a standardised and transparent way, remains the most defensible and precautionary global basis, capturing the range-wide reductions a static census cannot.

Coral cover

Coral cover change was used as the basis of this assessment under Criterion A as both index of abundance and proxy for habitat decline where appropriate. Only fifteen species (five Atlantic and ten Indo-Pacific) had species-specific global population estimates. Population data for other species were available for portions of global ranges due to the local-to-regional focus of research groups, but much of this population data were outdated, with intervening global coral bleaching events and highly variable mortality across regions^{9,17}. Accordingly, use of total or gross coral cover as a measure of habitat decline follows standard guidance on the RL methodology for Criterion A2 (population reduction in the past, Table SI1). For species listed under A2, both subcriteria 'b' (species-specific population trend or coral cover trend as an index of abundance appropriate to the taxon) and 'c' (a decline in habitat quality due to climate change) were applied, and sometimes 'e' (effects of disease or pathogens). This follows the approach set in 2008, with the improvement of being able to assess coral cover decline quantitatively rather than through expert knowledge.

Quantitative data on percent total hard coral cover were obtained from the Global Coral Reef Monitoring Network's (GCRMN) 2020 global reef status report¹⁸. This compiled data from 1978 to 2019 from *in situ* monitoring observations of more than 300 data contributors spread across the global distribution of reefs. The study compiled raw data to produce modelled estimates of coral cover accommodating spatial and temporal gaps, outputting median estimates of coral cover (50%), as well as upper (80%) and lower (20%) uncertainty bounds or confidence

intervals for 37 Indo-Pacific and five Atlantic subregions, across the global distribution of coral reefs^{18,19} based on the Marine Ecoregions of the World²⁰. For each subregion, coral cover change was calculated as the difference in percentage cover from the starting value to the current value, over three generations (or 30 years, see below), ending in 2019. The first assessment of coral extinction risk¹ used the same source but at that time estimates of coral cover loss were based on expert judgement aggregated from sub-regions of the globe, divided into the categories “percentage of destroyed” and “destroyed plus declining” reef area²¹. It is thus not possible to directly compare the 2008 extinction risk assessment and resulting Red List categories with these newly updated ones.

For each species we estimated range-wide coral cover decline as a range-weighted change in coral cover across the subregions its distribution range intersects. For each subregion we calculated the proportion of the species’ global range (by area) contained in it. This is a dimensionless weight, with the weights summing to one across all occupied subregions. This was then multiplied by the percent change in coral cover recorded for that subregion, with negative values denoting decline. To inform the choice of the appropriate (i.e., lowest level of uncertainty) of the three percentile declines in coral cover (20%, 50% and 80%), we applied the final trait-based vulnerability score (see below) as follows: for species with high vulnerability (i.e. a trait-based vulnerability score of 3) we applied the 80% estimate of coral cover decline across its range, for species with moderate vulnerability (2) the 50% estimate and for species with low vulnerability (1) we applied the 20% estimate.

Thermal stress

To apply Criterion A3, the population trend was projected three generations into the future using the species’ distribution and climate change models. The subcriteria ‘c’ (a decline in habitat quality due to climate change) was applied, and sometimes ‘e’ (effects of disease pathogens). The projected onset of Annual Severe Bleaching (ASB) represents the date at which corals in a location will likely experience severe bleaching conditions annually, and beyond which coral cover will experience a greater than 80% decline from which recovery is not expected^{22,23}. This date was applied as a proxy to estimate population reduction over three generations into the future (e.g. 2020-2050). ASB is defined as at least eight Degree Heating Weeks (DHW), where a DHW occurs when the sea surface temperature is at least 1°C above the maximum monthly mean for one week^{22,23} within a three-month period. ASB for each species was calculated using IPCC CMIP6 global climate models from 2015 to 2100 on a 0.25° (27 x 27 km) grid using the 2018 WCMC-UNEP global coral reef distribution map (which has a resolution to 30 m depth)²⁴. We applied two climate change scenarios (Shared Socioeconomic Pathways, SSP): SSP5-8.5, a worst-case scenario, and SSP2-4.5, a more moderate climate change scenario that better tracks current policy projections²⁵⁻²⁷. To account for coral adaptation to thermal stress, we calculated two estimates of ASB onset for both SSP5-8.5 and SSP2-4.5, one for species with no evidence suggesting adaptation (0°C above the DHW threshold) and a second assuming a capacity for 1°C of adaptation (e.g. 1°C above the DHW threshold), a level suggested by emerging evidence of capacity for adaptation in some species^{22,28-32}. We clipped each of these four UNEP (2020) spatially-gridded climate scenarios to each species distribution range and calculated the average year of ASB across the species’ full range. Following comparison of the two emission scenarios, we selected SSP2-4.5 for application to Criterion A3 as the most plausible emissions scenario of

the two, generating results most consistent with evidence in the literature on coral responses to thermal stress.

We defined the onset of ASB as corresponding to an 80% or more decline in coral cover across the full range. It is notable that this is conservative, as studies have found that coral populations may experience near complete mortality and are unlikely to recover with just two incidences of severe bleaching per decade²⁵. For species where the onset of ASB occurs within 3 generations, population reduction was calculated as 80% multiplied by two factors: (i) the proportion of the species' depth range that is in the 0-30 m interval (assuming depths > 30 m are unaffected by surface temperature), and (ii) for widespread species, the proportion of grid cells within the species' range that are expected to experience ASB under SSP2-4.5 before 2050 (three generation lengths). The final estimate of reduction was further adjusted by excluding the grid cells within a species range that did not experience the onset of ASB under SSP2-4.5 before 2050. This adjustment reflects the fact that across a wide geographic range, the onset of ASB is not synchronous. The proportion of a species range that overlaps with the onset of ASB after 2050 is indicative of a spatial refuge that buffers range-wide population reduction. The effect is greatest for the most widespread species and accounts for the spatial variability observed in bleaching, especially in the Indo-Pacific.

We decided on the level of adaptation (either none or 1°C) that each species would display by applying the score of the bleaching susceptibility trait (i.e., high, moderate or low susceptibility to bleaching in relation to thermal stress) and whether the depth range was restricted to shallower than 30 m or not. For example, a species highly susceptible to bleaching and restricted to shallow water (<30m) was assigned the 'no adaptation' estimate of ASB, giving an earlier projected onset of ASB, and therefore, higher projected population reduction (A3 and/or A4; see Table SI4). The relative susceptibility to bleaching is based on scientific evidence and species expert knowledge (see Traits section). The application of the species' depth range as an exposure proxy is based on the assumption that severe bleaching is concentrated in the upper part of the water column. We used 30 m as the boundary of this zone (lower depth limit for the UNEP-WCMC coral distribution layer used here), below which surface driven thermal stress rarely (but sometimes does) penetrates. Under this assumption, a coral species predominantly found in shallower depths is more frequently exposed to extreme temperatures and its global population might reduce at a faster rate than a species whose global range extends below 30m^{5,33,34}.

We also reviewed trends in projected ASB for 1998-2028 and 2008-2038 using IPCC models UNEP²⁴. Sea Surface Temperature (SST) data from the Coral Reef Temperature Anomaly Database (CoRTAD) Version 6 were regridded using bilinear interpolation to 0.25° resolution before Degree Heating Weeks (DHWs) were computed. DHWs were computed with the standard procedure by summing up the positive SST anomalies for 12 weeks at the thresholds of 1°C and 2°C above the Maximum Monthly Mean (MMM). Complete ensembles for CMIP6 SSP5-8.5 and SSP2-4.5 were remapped to the same standard grid using CDO function remapbil (resolution of 0.25°) and models were averaged with equal weights. To enable comparison between modelled and observed SST for years in which both are available, the modelled SSTs were adjusted to observed SSTs. The observed and model data were concatenated to get a complete time series of DHWs from 1982-2100 for the four scenarios (two bleaching thresholds and two emission scenarios). The first year of the decade when all years in that decade exceeded 8 DHW of thermal stress was set as the year of onset of ASB. Results show that in the observational period (1982-2022) there are almost no grid cells that show annual severe bleaching. This very narrow

extent of ASB prior to 2022 agrees with general evidence of bleaching since the 1980s. Under the worst case (SSP5-8.5), ASB was first reached for one species in 2034, and affecting all other species by 2038.

Generation length

Generation length is required when assessing a species under Criterion A, which estimates extinction risk by the percent population reduction occurring in the past and/or future. Population reduction is scaled over a time period of three generation lengths, or 10 years if three generations are less than 10. While there is some information on the age at which corals reach sexual maturity, it is largely based on size as a proxy for age^{35,36}, which can be problematic in modular colonial animals because of processes such as partial mortality and fission³⁷. Nonetheless, recent studies rearing corals from larvae have shown that some fast-growing corals (e.g., *Acropora* species), reach sexual maturity within 3-4 years³⁸⁻⁴¹. Overall, many brooding coral species appear to reach sexual maturity at about 1-2 years of age, much earlier than many broadcast-spawners which start reproducing at 3-8 years or more³⁶. Longevity is not known for many corals, but exceeds several decades and even centuries for some species, particularly those with slow growth rates and massive boulder morphologies. Because generation length is the average age of reproducing parents (not simply the age at first reproduction) these uncertainties in both age at maturity and longevity, together with the lack of species specific data, prevent any defensible estimate of generation length (mean, median, mode, or geometric approaches), even for a single species. In the absence of better information, we maintained consistency with the last assessment¹ and applied a generation length of 10 years across all species. This may result in a significant underestimate of generation length for many species, and thus a much lower extinction risk, as sea surface temperatures increase considerably from 2050 (the end of the assessment period used in this study) to 2100 under all emissions scenarios, returning higher extinction risk under Criterion A3.

Species traits

Varied traits for the life history of corals are available in datasets such as www.coraltraits.org, but these are highly variable in values and coverage across species. As was determined in 2008, much of this data could not be used, thus the 3-point scale approach developed in 2008 was applied here, with updates where possible, for 12 traits (Table SI2). Relative vulnerability was scored on the basis of the combination of susceptibility and exposure of each species to critical threats. Thus, a species is classified as vulnerable only where the relevant threat co-occurs with its trait-based susceptibility, scaled to overall trends in coral cover and/or projected sea surface temperature, as appropriate. For each species, each trait was scored as “1” (low vulnerability), “2” (moderate or unknown vulnerability), or “3” (high vulnerability) and an overall vulnerability score (1, 2, or 3) was assigned to each species based on the higher value of the mean or mode calculated across all trait scores.

A separate trait-based analysis of reef corals by Bridge et al. 2020¹⁷ reported incongruence between life-history traits and the first estimates of extinction risk by Carpenter et al. in 2008¹, questioning trait-based approaches for assessing coral's extinction risk. The traits used here differ from theirs and divergent findings are to be expected. Bridge et al (2020) applied a set of life history traits (maximum depth, family, reproductive mode, sexual system, growth rate,

skeletal density, maximum corallite width, maximum colony diameter, reproductive output, and propagule size on release), using what they termed an ‘infilling’ approach to score traits for less-known species based on closer relatives. Only two traits they applied overlap with those applied here, and are quantified differently: depth (they used maximum depth) and family (not used here as a ‘trait’, but in interpretation; Fig. 3). Other traits used by Bridge et al. were not applied here or by Carpenter et al., as they could not be reliably applied across all species. The differences in their vulnerability findings compared to those reported by Carpenter et al. and ours reflect the different input datasets.

For deeper, mesophotic species we applied a further rule to account for the lower limit of the sea surface temperature dataset, and potential depth refugia. If a species’ dominant depth range extended deeper than 30 m, then we assumed that just 80% of the species range was within 0 – 30 m thus multiplied estimates of decline by 80%. This approach accounts for coral species with shallow depth preferences being more frequently exposed to extreme temperatures compared to those that also occur at deeper, cooler depths, though there are some exceptions and corals in deeper depths can have lower thermal thresholds and be impacted by thermal stress^{42–44}.

Given the global scope of the study, and coverage of 892 species we were not able to incorporate any sources of intra-species variation, such as in responses to differing thermal conditions across a species range, or inherited traits among populations at these scales.

Table SI2. Description of the traits used to score coral vulnerability.

Trait	Description	High Vulnerability (3)	Moderate or Unknown Vulnerability (2)	Low Vulnerability (1)
Depth range interval ≤20 m	Species restricted to a narrow depth range interval (≤ 20 m), calculated as the minimum depth subtracted from the maximum depth, were inferred to have a higher risk based on a lower capacity to adapt to temperature change.	depth range interval ≤20 m	depth range unknown	depth range interval >20 m
Preferred depth range ≤10 m	Warming is most extreme in shallow waters, therefore, we inferred species that are most abundant at/prefer depths shallower than 10 m have a higher exposure. If the species had no known preferred depth range, then this value defaulted to its total depth range.	prefers depths ≤10 m	depth range unknown	preferred depth range >10 m
General abundance	Species that are rare were inferred to have a higher vulnerability than those that are common due to demographic and environmental stochasticity.	generally rare	generally uncommon or general abundance unknown	generally common

350 **Table SI2 - Continuation.** Description of the traits used to score coral vulnerability.

Trait	Description	High Vulnerability (3)	Moderate or Unknown Vulnerability (2)	Low Vulnerability (1)
Small range	Species that have a small or highly fragmented range were inferred to have a higher vulnerability than those with large ranges based on inferring that a range-restricted species would experience declines over the majority of its global population due to some disturbance event (e.g., severe bleaching, disease outbreak, etc.) whereas a wide ranging species may only be locally impacted.	does have a small or highly fragmented range	range is poorly known	does not have a small or highly fragmented range
Found off-reef	Species that do not occur in off-reef areas were inferred to have a higher vulnerability than those that can survive outside of reef habitat in rocky or sandy areas adjacent to reefs.	does not occur in off-reef areas	unknown if can occur off-reef	does occur in off-reef areas
Bleaching susceptibility	Species that have a high susceptibility to impacts from bleaching events were inferred to have a higher vulnerability. Relative susceptibility was expert-informed and based on published results of underwater survey observations.	highly susceptible to bleaching	moderately susceptible to bleaching or susceptibility unknown	low susceptibility to bleaching
Disease susceptibility	Species that have a high susceptibility to disease outbreaks were inferred to have a higher vulnerability. Disease susceptibility was based on reported outbreaks and reports of disease in baseline studies (Greta Aeby pers. comm. 2022), and covering all coral diseases ⁴⁵ other than SCTLD (see below).	moderately or highly susceptible to disease	neither moderately or highly resistant/susceptible to disease	moderately or highly resistant to disease
SCTLD susceptibility	This trait was applied to Atlantic species only. Stony Coral Tissue Loss Disease (SCTLD) is a novel highly contagious and pervasive disease that has spread throughout the Caribbean region since 2014, so was scored independently from general disease susceptibility ⁵ .	high or intermediate susceptibility to SCTLD	unknown susceptibility to SCTLD or is presumably susceptible to SCTLD	low susceptibility to SCTLD

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354 **Table S12 - Continuation.** Description of the traits used to score coral vulnerability.

Trait	Description	High Vulnerability (3)	Moderate or Unknown Vulnerability (2)	Low Vulnerability (1)
COTS predation susceptibility	This trait was applied to Pacific species only. Species with susceptibility to predation from crown-of-thorns starfish (COTS), a pervasive consumer of live coral throughout the Indo-Pacific region, were inferred to have higher vulnerability ⁴⁶	highly susceptible to COTS	unknown or moderate susceptibility to COTS	low susceptibility to COTS and/or occurs primarily in mesophotic depths
Coral trade vulnerability	This trait was applied to Pacific species only, as Atlantic species are not significantly traded ^{5,47} . Species that are traded in high numbers to supply the aquarium trade were inferred to have higher vulnerability. The trade values include both maricultured and wild caught and were sourced from Joanna Murray et al. in prep via the CITES website data https://tradeview.cites.org/en/taxon .	"high risk" >10,000 pieces exported per year between 2010-2019	"medium risk" 1,000-10,000 pieces exported per year between 2010-2019	"low risk" not traded or <1,000 pieces exported per year between 2010-2019
Ocean acidification susceptibility	According to the meta-analysis ⁴⁸ : species in the families Pocilloporidae, Coscinaraeidae and Psammocoridae have a low susceptibility to ocean acidification relative to the seven other families included in their study. Species in the families Acroporidae, Poritidae, Merulinidae, Dendrophylliidae, Agariciidae, Astrocoeniidae and Rhizangiidae have a relatively higher susceptibility, and all other families that were not addressed in the paper were assigned a "2" to indicate their susceptibility to ocean acidification is unknown.	in the families Acroporidae, Poritidae, Merulinidae, Dendrophylliidae, Agariciidae, Astrocoeniidae or Rhizangiidae	unknown susceptibility to ocean acidification	in the families Pocilloporidae, Coscinaraeidae or Psammocoridae

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Table SI2 - Continuation. Description of the traits used to score coral vulnerability.

Trait	Description	High Vulnerability (3)	Moderate or Unknown Vulnerability (2)	Low Vulnerability (1)
Recovery Potential	Species that have the potential to recover from both episodic and chronic stressors (i.e., storm damage, thermal stress, etc.). Families Acroporidae,, Lobophylliidae, Fungiidae and Agariciidae had the highest number of species. Families Meruliniidae and Poritidae, had the majority of species scored within “unknown recovery potential”	Species has high recovery potential	Unknown recovery potential	Species has low recovery potential

Red List Index

The Red List Index estimates overall trends in extinction risk based on changes in species' Red List category over time⁴⁹. Because of the updates to methods and datasets to those used in 2008 we re-calculated results for 2008 and ‘initial conditions’ before 1998. This resulted in three groups of results for pre-1998 and 2008 results:

- A. Three species (*Ctenella chagius*, *Dendrogyra cylindrus* and *Porites sverdrupi*) were assessed with the same species-specific datasets in both studies.
- B. For coral cover, Carpenter et al.¹ back-casted the percent of total coral cover loss and critically threatened reefs as reported before the 1998 mass-bleaching event to model a hypothetical Red List category for 1998. We analyzed the GCRMN dataset¹⁸ to estimate percent decline of coral cover within the species' distribution for three three-generation time periods from 1968-1998, 1978-2008 and 1989-2019 (these correspond to our labels of 1998, 2008 and 2024 for figures and tables). As the earliest year for available GCRMN data is 1978, we inferred a zero decline from 1968-1978. Coral cover data in the early years of the GCRMN dataset are typically patchy resulting in wide error margins, which introduces uncertainty into trend estimates during that time¹⁸.
- C. We used the thermal stress projections from climate models, which was not used in Carpenter et al. This dataset dominated assignment of species risk for 2024 (for 93% of threatened and Near Threatened species), and while its impact is likely less during earlier periods (1998-2028 and 2008-2038 for pre-1998 and 2008 time points) it introduces a factor not considered by Carpenter et al.

Due to updated and improved datasets, all differences in species category for 1998 and 2008 between the two studies (Table SI5) are thus “non-genuine”, except for group A. Following IUCN practice, a genuine change is a difference in a species Red List category between assessments that reflects a real change in its extinction risk, whereas a non-genuine change reflects no real change in status but instead arises from other causes (principally new or

improved data, revised methods or application of criteria, taxonomic revision, correction of previous errors, or revision of the criteria itself). Only genuine changes contribute to the RLI.

Data for aggregate results of the Red List Index for comprehensively sampled taxonomic groups (birds, mammals, amphibians, cycads and reef-building corals) are shown in Fig. 1B. Details on this data and calculations can be found at www.iucnredlist.org/red-list-index and <https://www.gbf-indicators.org/metadata/headline/A-3>.

Results

Red List criteria

Red List subcriteria A2, A3, A4, B1 and B2 were used in the assessment (Tables SI3, SI4). Six species were classified under two subcriteria:

- Criterion A – *Millepora striata* VU (A2bce+A3c)
- Criterion B – *Euphyllia baliensis* EN (B1+B2ab(iii,v)), *Porites randalli* EN (B1+B2ab(iii))
- Criteria A and B – *Astreopora monteporina* EN (A3ce; B2ab(iii)), *Pocillopora aliciae* EN (A3ce; B2ab(iii)), *Porites farasani* VU (A2bce+B2ab(iii)).

Table SI3. IUCN Red List Criteria and subcriteria used in assigning species to threatened and Near Threatened categories for 2024. Six species were classified under two sub-criteria (see supporting text).

	NT	VU	EN	CR	Total
A2	10	4	4	5	23
A2bc			1	1	2
A2bce	10	4	3	4	21
A3	3	41	239	27	310
A3c	1	5	6	23	35
A3ce	2	36	233	4	275
A4bc			1		1
B1			2		2
B2ab	3	13	9	1	26

Genuine and non-genuine changes in classification

Differences in the number of species assigned to each extinction risk category in 1998 and 2008 are substantial for this study compared to Carpenter et al. 2008 (Table SI5). As noted in the methods update above these are non-genuine changes due to different methods and data. It is

important to note that this does not undermine the credibility of either analysis, or of the change in risk status over time calculated with the current methods for the Red List Index ^{4,49,50}.

Table SI4. Examples of species assignment under historic (A2) and future projected (A3) decline criteria. The most stringent risk level is selected for the final risk category, following guidance for the IUCN Red List of species methodology.

Species	Coral cover decline (A2) ^a	RL	Future thermal stress (A3) ^b	RL	Final Category	Explanation for example
<i>Pavona chiriquiensis</i>	30%; moderately susceptible to threats	VU	Area decline: <25% Depth: > 30m Bleaching: tolerant Adaptable: yes (+1°C) ASB across full range: - SSP2-4.5: 2073 - SSP5-8.5: 2061	LC	VU A2bce	Red List category determined by coral cover
<i>Acropora arabensis</i>	36%; highly susceptible to threats	VU	Area decline: 57% Depth: < 30m Bleaching: susceptible Adaptable: no ASB across full range: - SSP2-4.5: 2047 - SSP5-8.5: 2043	EN	EN A3ce	Red List category determined by thermal stress, <i>Acropora</i> species restricted range to Western Indian Ocean, Red Sea and gulfs
<i>Mussismilia harttii</i>	50%; direct population estimates from underwater surveys	EN	Area decline: <25% Depth: < 30m Bleaching: tolerant Adaptable: yes (+1°C) ASB across full range: - SSP2-4.5: 2079 - SSP5-8.5: 2059	LC	EN A2bc	Red List category determined by species-level population estimates. Species with restricted range - Brazilian endemic
<i>Fungia fungites</i>	<25%; more resilient to threats	LC	Area decline: <25% Depth: < 30m Bleaching: moderate Adaptable: yes (+1°C) ASB across full range: - SSP2-4.5: 2070 - SSP5-8.5: 2062	LC	LC	Species with low vulnerability score and assessed as LC
<i>Goniopora pendulus</i>	<25%; highly susceptible to threats	LC	Area decline: <25% Depth: < 30m Bleaching: moderate Adaptable: yes (+1°C) ASB across full range: - SSP2-4.5: 2075 - SSP5-8.5: 2065	LC	LC	Species with high vulnerability score and assessed as LC
<i>Pocillopora aliciae</i>	<25%; moderately susceptible to threats	LC	Area decline: 75% Depth: > 30m Bleaching: susceptible Adaptable: no ASB across full range: - SSP2-4.5: 2043 - SSP5-8.5: 2035	EN	EN A3ce; B2ab(iii)	Species with restricted range (eastern Australia; Area of Occupancy (AOO) less than 500km ²) and high projected decline A3+B2

^a Percentage decline in coral cover across the global species range, ^b Percentage of the global species range experiencing Annual Severe Bleaching (ASB) is (> 8 DHW every year for a decade) by 2050. **RL:** Red List Category; **SSP:** Shared Socioeconomic Pathway IPCC climate change scenarios

The non-genuine changes in category included shift of a large number of species from the ‘middle categories’ of NT and VU in 2008, with most species (299) being reclassified as LC. However, the number of species reclassified as EN in 2008 increased (from 25 to 81 species) and as CR (from 5 to 29). An important difference in the results is that by using expert judgement in 2008, a more uniform (though uncertain) decline was estimated across all species. By contrast, using quantitative data on coral cover change and future thermal stress, interpreted across each species range individually, and modulated by trait data, results in a more precise differentiation of risk among species, and both declines and improvements in risk status being found. In our reanalysis five species improved in status from NT in 1998 to LC in 2008, and 24 species improved in status from NT and VU in 2008 to LC and NT in 2024 (Table SI6).

Table SI5. Non-genuine changes in IUCN Red List status of reef-building corals in 1998 and 2008 as calculated by Carpenter et al. 2008 and this study. Percentage values are rounded to the nearest integer (except in the last column).

<i>Threatened categories (CR+EN+VU)</i>	2008				Pre-1998			
	This study		Carpenter 2008		This study		Carpenter 2008	
	n	%	n	%	n	%	n	%
	145	19	231	33	52	7	13	1.8
Critically Endangered (CR)	29	4	5	1	7	1	3	0.4
Endangered (EN)	81	10	25	4	24	3	5	0.7
Vulnerable (VU)	35	4	201	29	21	3	5	0.7
Near Threatened (NT)	33	4	176	25	24	3	20	2.8
Least Concern (LC)	596	77	297	42	698	90	671	95
Total classified	774 (87%)		704 (83%)		774 (87%)		704 (83%)	
<i>Data Deficient (DD)</i>	118 (13%)		141 (17%)		118 (13%)		141 (17%)	
Total assessed	892		845		892		845	

Table SI6 - Genuine changes in coral species extinction risk from 1998 to 2008 (left) and 2008 to 2024 (right). Transitions from the initial (rows) to final period (columns). No change is indicated by diagonals, with increases in risk above, and declines in risk below the diagonal.

		To 2008							To 2024						
		LC	NT	VU	EN	CR	Total			LC	NT	VU	EN	CR	Total
From 1998	LC			14	55	13	698	From 2008	LC			28	167		596
	NT	5	8	3	1	7	24		NT	21	9	1	2		33
	VU			18	3		21		VU	1	2	27	2	3	35
	EN				22	2	24		EN				80	1	81
	CR					7	7		CR					29	29
Total		596	33	35	81	29	774	Total		418	16	56	251	33	774

	>3 categories increase	3 Categories increased	2 categories increased
	1 category increase	1 or more category reduced	No change

Geographic and taxonomic differences

Geographic differences in overall results are shown between the Indo-Pacific and Atlantic realms (Table SI7) and at family levels for the Indo-Pacific (Table SI8) and Atlantic (Table SI9).

Table SI7. Summary of Red List categories by realm (Atlantic vs. Indo-Pacific) for 2024.

Category	Number of species		Percentages (of total)	
	Atlantic	Indo-Pacific	Atlantic	Indo-Pacific
CR	26	7	33.3%	1.0%
EN	5	246	6.4%	35.3%
VU	8	48	10.3%	6.9%
<i>Threatened</i>	39	301	50.0%	43.2%
NT	8	8	10.3%	1.1%
LC	31	387	39.7%	55.6%
Total Assessed	78	696		
DD	7	111		
Grand Total	85	807		

Table SI8. Red List Categories for 2024 for Indo-Pacific reef-building coral species by family. Totals and percentages in threatened categories include all species listed as VU, EN or CR. Families are ordered by decreasing species richness. Families with > 67% species in a threatened category, and the highest levels of Data Deficient (DD) species, are highlighted in bold in the respective columns.

Indo-Pacific	Red List Category						Total	Total Threatened	% Threatened	%DD
	LC	NT	VU	EN	CR	DD				
Acroporidae	11	2	23	191	3	49	279	217	77.8	17.6
Merulinidae	118		3	8		14	143	11	7.7	9.8
Poritidae	64	3	3	9	3	11	93	15	16.1	11.8
Lobophylliidae	40		6	5		7	58	11	19.0	12.1
Fungiidae	42		1	5		6	54	6	11.1	11.1
Pocilloporidae	3	1	7	20		8	39	27	69.2	20.5
Agariciidae	27	2	3	1		3	36	4	11.1	8.3
Euphylliidae	16			1	1	2	20	2	10.0	10.0
Dendrophylliidae	13					2	15	0	0.0	13.3
Plerogyridae	10					4	14	0	0.0	28.6
Psammocoridae	9					1	10	0	0.0	10.0
Coscinaraeidae	8						8	0	0.0	0.0
Leptastreidae	6					2	8	0	0.0	25.0
Milleporidae			1	6		1	8	7	87.5	12.5
Scleractinia <i>incertae sedis</i>	5		1				6	1	16.7	0.0
Astrocoeniidae	4						4	0	0.0	0.0
Caryophylliidae	3						3	0	0.0	0.0
Rhizangiidae	2					1	3	0	0.0	33.3
Plesiastreidae	2						2	0	0.0	0.0
Diploastraeidae	1						1	0	0.0	0.0
Helioporidae	1						1	0	0.0	0.0
Oulastreidae	1						1	0	0.0	0.0
Tubiporidae	1						1	0	0.0	0.0
Totals	387	8	48	246	7	111	807	301		

Table SI9. Red List Categories for 2024 for Atlantic reef-building coral species by family.
 Totals and percentages in threatened categories include all species listed as VU, EN or CR.
 Families are ordered by decreasing species richness. Families with > 67% species in a threatened category, and the highest levels of Data Deficient (DD) species, are highlighted in bold in the respective columns.

Atlantic	Red List Categories						Total	Total Threatened	% Threatened	% DD
	LC	NT	VU	EN	CR	DD				
Faviidae	7	3	3	1	9		23	13	56.5	0.0
Agariciidae	3	1	1		4		9	5	55.6	0.0
Oculinidae	4					5	9	0	0.0	55.6
Meandrinidae	1		1		5		7	6	85.7	0.0
Milleporidae			1	1	4	1	7	6	85.7	14.3
Pocilloporidae	5	1			1		7	1	14.3	0.0
Poritidae	4	1	1			1	7	1	14.3	14.3
Merulinidae		1		2			3	2	66.7	0.0
Rhizangiidae	2				1		3	1	33.3	0.0
Acroporidae					2		2	2	100.0	0.0
Cladocoridae	1			1			2	1	50.0	0.0
Scler. incertae sedis	2						2	0	0.0	0.0
Astrangiidae	1						1	0	0.0	0.0
Astrocoeniidae		1					1	0	0.0	0.0
Dendrophylliidae			1				1	1	100.0	0.0
Montastraeidae	1						1	0	0.0	0.0
Totals	31	8	8	5	26	7	85	39		

Supporting data and results

The full results by species, with supporting data on traits, etc. is supplied in the spreadsheet file “Supplementary Data 1”. Metadata for the data supplied is listed in Table SI10.

Table SI10. Metadata for online supporting data and results.

Variable	Description
Family	Family name in WoRMS (2022)
Species Name	Genus and species name in WoRMS (2022)
Species Name (2008)	Species name used in 2008 assessment (Carpenter et al. 2008), for transparency on changes across the two studies.
RL status (2024)	Final Red List Status in 2024
RL status (2008)	Red List status in 2008, recalculated to obtain Red List Index
RL status (pre-1998)	Red List status before 1998, recalculated to obtain Red List Index
Realm	Indo-Pacific or Atlantic
# Eco-regions	Number of marine ecoregions that the generalized distribution polygon of the species intersects with the Marine Ecoregions of the World (MEOW) basemap, including only ecoregions that >4% of the ecoregion area is intersected; completed for IP species only
EOO (km²)	Area in square kilometers of a minimum convex polygon drawn around the distribution map/polygon of the species; also defined as the extent of occurrence (EOO) according to Red List methodology (to account for the spread of the threat of severe bleaching); completed for IP species only
Coral Area (km²)	Area of coral reef in square kilometers within the species' generalized distribution polygon clipped to the UNEP-WCMC global coral layer
Depth Range (m)	Depth range in meters within which the species occurs/has been recorded
Preferred Depth Range (m)	Depth range in meters within which the species is most abundant; if there is no known preferred depth range then it defaults to the total depth range

478 **Table SI10 – Continuation.** Metadata for online supporting data and results.

Variable	Description
IPCC decline (SSP2-4.5)	% projected decline selected for the species based on the IPCC model; '0' means the projected decline is not suspected to approach 30% (NT) over the next three generations; 'NA' was given to species that are mesophotic (models are not appropriate) or are DD (usually due to taxonomy)
GCRMN decline	Past decline based on the Global Coral Reef Monitoring Network data ¹⁸ using 20, 50 or 80 percentile values based on the final vulnerability score from the traits analysis; 'NA' was given to species that are mesophotic (models are not appropriate) or are DD (usually due to taxonomy)
Depth range interval	Exposure trait; '1' = depth range interval is greater than 20m; '2' = depth range unknown; '3' = depth range interval is less than or equal to 20m
Preferred Depth Range <10m	Exposure trait; '1' = preferred depth range extends deeper than 10m; '2' = depth range unknown; '3' = preferred depth range is shallower than 10m
General Abundance	Susceptibility trait; '1' = species is generally common; '2' = species is generally uncommon or general abundance is unknown; '3' = species is generally rare
Small Range	Susceptibility trait; '1' = no, it does not have a small or highly fragmented range; '2' = range is poorly known; '3' = yes, it does have a small or highly fragmented range; Small/fragmented range species include those that have <2,000 km ² of coral cover within its range according to clipping the species' distribution polygon to the WCMC global coral layer (also means that the species meets the thresholds for criterion B under AOO) and/or are endemic to Brazil or the Red Sea
Found Off-Reef	Susceptibility trait; '1' = yes, the species can occur in off-reef habitats; '2' = it is unknown if the species can occur off-reef; '3' = no, the species does not occur in off-reef habitats
Disease Vulnerability	Susceptibility trait; '1' = the species is moderately or highly resistant to disease; '2' = the species is neither moderately or highly resistant/susceptible to disease; '3' = the species is moderately or highly susceptible to disease; Disease susceptibility based on reported outbreaks and reports of disease in baseline studies (Greta Aeby pers. comm. 2022).
SCTLD Vulnerability	Atlantic species only; susceptibility trait; '1' = the species has a low susceptibility to SCTLD; '2' = the species has an unknown susceptibility to SCTLD or is presumably susceptible to SCTLD; '3' = the species has a high or intermediate susceptibility to SCTLD.
Recovery Potential	Susceptibility trait; '1' = the species has a high recovery potential; '2' = the species' recovery potential is unknown; '3' = the species has a low recovery potential

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481 **Table SI10 – Continuation.** Metadata for online supporting data and results.

Variable	Description
COTS Vulnerability	Pacific species only; susceptibility trait; '1' = the species has a low susceptibility to COTS predation; '2' = the species has an unknown or moderate susceptibility to COTS; '3' = the species is highly susceptible to COTS; mesophotic species receive a low score. ⁴⁶
Bleaching Vulnerability	Susceptibility trait; '1' = the species has low susceptibility to bleaching; '2' = the species is moderately susceptible to bleaching or susceptibility is unknown; '3' = the species is highly susceptible to bleaching
Coral Trade Vulnerability	Pacific species only; susceptibility trait; '1' = "low risk" not traded or <1,000 pieces exported per year between 2010-2019; '2' = "medium risk" 1,000-10,000 pieces exported per year between 2010-2019; '3' = "high risk" >10,000 pieces exported per year between 2010-2019; these values include both maricultured and wild caught and are sourced from Murray et al. in prep working with the CITES website data https://tradeview.cites.org/en/taxon
OA Vulnerability	Susceptibility trait; According to the meta-analysis by Kornder et al 2018 : species in the families Pocilloporidae, Coscinaraeidae and Psammocoridae (the last two families are in Kornder as Siderastreidae which is no longer a valid family) have a low susceptibility to ocean acidification relative to the seven other families included in their study and were assigned a "1"; species in the families Acroporidae, Poritidae, Merulinidae, Dendrophylliidae, Agariciidae, Astrocoeniidae and Rhizangiidae have a relatively higher susceptibility were assigned a "3"; and all other families that were not addressed in the paper are assigned a "2" to indicate their susceptibility to OA is unknown
Mean of Vulnerability Scores	Straight mean across ranks of traits (10 traits for Atlantic species and 11 traits for Pacific species)
Mode of Vulnerability Scores	Straight mode across ranks of traits (10 traits for Atlantic species and 11 traits for Pacific species)
Final Vulnerability Score	The higher value of mode vs. mean

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483 **References**

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