Conservation Letters

WILEY

Conservation Letters
A journal of the Society for Conservation Biology
Open Access

REVIEW OPEN ACCESS

Integrating an Eco-Evolutionary Perspective for Coral Reef Resistance Into Global Conservation Planning and Policy

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Received: 5 September 2024 | **Revised:** 1 May 2025 | **Accepted:** 12 May 2025

Funding: This work was supported by the Minderoo Foundation. K.M.Q. is supported by funding from the Australian Research Council (ARC) DECRA Fellowship to K.M.Q. (DE230100284).

Keywords: acclimatization | adaptation | climate change | conservation | coral reef | evolution | resistance

ABSTRACT

Global responses to climate change vary across ecosystems. Identifying coral reefs that can persist despite extreme warming is crucial for guiding research, policy, and management. Resilience frameworks recommend protecting potential reef sanctuaries with specific attributes, including climate avoidance, rapid recovery, or resistance. However, climate-avoidant reefs are dwindling, and recovery times are lengthening. We propose that resistance should be the cornerstone of reef resilience planning. A literature synthesis reveals that the definition and application of "reef resistance" are highly variable, limiting its effectiveness in management and policy. Over 85% of sources suggest that evolutionary processes contribute to resistance, but there is considerable variability in other cited ecological factors. We highlight a mismatch between implied mechanisms and actual data, with only ~25% of studies linking resistance to relevant coral adaptation or acclimatization data. To address this, we propose a standardized definition of heat-resistant reefs based on adaptation and acclimatization principles: reefs characterized by corals whose underlying genetics enable survival beyond previous thermal limits. This approach will enhance the effective allocation of limited resources for measuring, protecting, and managing reefs, as we strive to halt the human-induced emissions driving their decline.

1 | Introduction

Climate change is placing unprecedented stress on the planet's ecosystems, especially in the oceans. Warming, acidification, and cyclonic storm surge from climate change have had devastating impacts on coral reefs, sea grass meadows, and kelp beds worldwide (Hughes, Kerry, et al. 2017; Krumhansl et al. 2016; Waycott et al. 2009). As a result, management and conservation efforts are striving to incorporate climate considerations into traditional conservation practices (e.g., V. Graham et al. 2019; Morelli et al. 2016; Wilson et al. 2020). Since the impacts of and responses to climate change are not homogenous, identifying and studying sanctuary areas, or geographic areas where ecosystems are increasing and persisting rather than declining, is crucial for prioritizing future-looking research and management efforts (Beyer et al. 2018; McClanahan et al. 2024; Rilov et al. 2020).

To this end, ecosystem resilience has been used as a criterion of choice (McLeod et al. 2021; Sasaki et al. 2015). Ecosystem resilience broadly describes possible areas where an ecosystem shows capacity to persist despite disturbance and is an increasingly popular and colloquially used concept, across science and policy contexts. As the climate change-driven loss of coral reef ecosystems and their vital services gains visibility among scientists and policy makers, incorporating resilience into management frameworks has become essential. Defining, identifying, quantifying, and ultimately building reef resilience into these frameworks now represent a central, multidisciplinary conservation goal for coral reef nations (Hughes, Barnes, et al. 2017; Levy and Ban 2013; Rilov et al. 2020).

Global conservation efforts are currently aimed at protecting 30% of marine ecosystems by 2030 ("30 × 30"), which largely follow an emphasis on quantity over quality (Devillers et al. 2015; Pike et al. 2024). For many locations, this has meant marine protected areas (MPAs) in deep, offshore waters with relatively little fishing pressures (Devillers et al. 2015). Increasingly, there have been initiatives for the adoption of a diversified, risk-spread portfolio that incorporates many types of resilient locations to target for conservation investment (Abelson et al. 2016; Beyer et al. 2018; McClanahan et al. 2024; Webster et al. 2017). This follows on from well-established adoption of finance rules into the terrestrial conservation sphere (Ball et al. 2009), which demonstrate that the spreading of risk holds long-term conservation benefits from species protection to ecosystem function stability (Ando and Mallory 2012).

This has been further developed in recent classifications of coral reef refugia into three key contexts: avoidance, recovery, and resistance (McClanahan et al. 2022, 2024; West and Salm 2003). Reefs that are relatively less impacted by climate stressors ("avoidant") have traditionally been recognized as priorities for conservation (Ban et al. 2016; Chollett et al. 2014; Levy and Ban 2013; Obura 2005; Selig et al. 2012). This designation is mainly driven by local oceanographic conditions such as upwelling and currents that have a cooling effect or a light limiting effect (e.g., high turbidity), due to the known interaction between temperature and light leading to bleaching (Jones and Hoegh-Guldberg 2001). Importantly, these "avoidant" reefs are at times conflated as resilient reefs (West and Salm 2003). A disproportionate investment into only avoidant reefs could be dangerous as climate conditions worsen globally, where once "lucky" regions will effectively perish (A. M. Dixon et al. 2022; Skirving et al. 2019). Ultimately, climate projections forecast that most locations will experience heat stress above the persistence thresholds of corals, leading to drastic reductions in coral cover globally (e.g., Frieler et al. 2013; McManus et al. 2020). These analyses are corroborated by models of global thermal stress projections downscaled to smaller, more local scales (1 km), which show that climate change under 1.5°C emissions will erase the protective effects of local hydrodynamics, reducing thermally "avoidant" reefs from a relative 84% (current climate) to 0.2% (future climate projections; A. M. Dixon et al. 2022).

Recovery reefs are those that show enhanced ecological capacity to return to pre-disturbance levels of coral cover after experiencing mortality, often heat-driven. Studies examining recovery often clearly state or imply the driving mechanisms: shifts in community composition (often toward more competitive or fast-growing species) (Darling et al. 2013; Diaz-Pulido et al. 2009; N. A. J. Graham et al. 2014; McClanahan et al. 2024), high connectivity to surrounding reefs and subsequent recruitment (e.g., N. A. J. Graham et al. 2011), and reduced competition for benthic space (e.g., supported by herbivory and macroalgal control; T. C. Adam et al. 2011; Nash et al. 2016). However, as with "avoidant" reefs, marine heatwaves are eroding recovery capacities globally by driving bleaching events to increased frequencies (Hughes et al. 2018; McWilliams et al. 2005; van Hooidonk et al. 2015). This reduces recovery time between disturbances, a process that takes several years to decades (Connell 1997; Golbuu et al. 2007), even on reefs with high recovery attributes (Diaz-Pulido et al. 2009; McClanahan et al. 2014). Thus, as climate change continues to reduce the capability of both avoidant and recovery reefs to function as future sanctuaries, it is critical to identify and protect resistant reefs (Darling and Cote 2018), that is, those that show higher than average potential to withstand climate stressors.

Resistance is generally associated with reefs composed of corals living under conditions of chronic stress (e.g., Abelson et al. 2016; Rivera et al. 2022). However, mechanisms are nebulously defined in comparison to mechanisms of avoidance and recovery. For example, resistance has been used synonymously with adapted or acclimatized, but without clear linkage to adaptative mechanisms (e.g., Abelson et al. 2016; Mellin et al. 2019; Ramesh et al. 2020). Additionally, definitions have not incorporated a direct implication to evolutionary processes (e.g., Perera-Valderrama et al. 2017; Zhang et al. 2014). This gap may be due in part to the relative lack of information on the genetic architecture of thermal tolerance for most corals (due to the cost and difficulty of its generation), limiting the capacity to understand corals' adaptive potential (Richards et al. 2023). Ultimately, this has blurred how we currently recognize reef resistance. However, if resistance is to be effectively used as a criterion for prioritizing biodiversity conservation and 30 × 30 efforts in coral reef ecosystems, there is a need for clear operational definition and evaluation of effective metrics.

2 | What Is a Resistant Reef?

To understand how the widely used term "resistance" is used in the context of coral reef MPAs, studies were selected from a literature search on Web of Science that included the word resistance; marine protected area, reserve, or sanctuary; coral reef; and climate change (see Supporting Information). Of the 75 relevant papers in the literature search results, ∼27% ($n = 20/75$) explicitly defined the word resistance, either referencing traditional definition from Holling (1973), of a system's capacity to withstand disturbance, or referencing a reef or individual coral's ability to withstand bleaching or mortality during thermal stress. Additional variation in the use of the word resistance is worth noting. First, most studies discussed resistance as a component of resilience ($n = 56/75$, e.g., Baumann et al. 2022; McClanahan et al. 2024), while 12% of studies ($n = 9/75$) distinguished resistance as a separate property from resilience, with resilience referring to strictly recovery-related processes (e.g., Grimsditch et al. 2010; Zhang et al. 2014). Second, ∼67% of studies used the term interchangeably with tolerance ($n = 50/75$, e.g., Ateweberhan and McClanahan 2010; Fox et al. 2021). Approximately 7% of studies did not use the term as broadly, specifying that resistance refers to lack of bleaching, not just lack of mortality ($n = 5/75$, e.g., Obura 2005). These inconsistencies have confounded how we communicate climate change impacts on reefs and take away from the science–policy–management dialogue, flow of information, and opportunities for common ground in goal setting.

Based on the literature survey, there were several reported mechanisms that were used to explain or define resistance that we could organize into groupings. These included (1) extrinsic mechanisms (processes relating to the physical, chemical, or biological environment) and (2) intrinsic mechanisms (processes taking place within the corals themselves). Though relatively few of the studies in our literature search provided an explicit definition of a "resistant reef," most studies directly or indirectly stated mechanism(s) that contribute to resistance ($n = 69/75$). Adaptation and acclimatization were the most frequently implied mechanisms (together 87.5%), followed by a switch in coral species community composition, where tolerant coral taxa are more prevalent after disturbance (26.4%; Figure 1A). The control of local stressors (e.g., nutrients) and presence of unique environmental attributes (e.g., upwelling or currents that buffer heat stress) were also cited (19.4% for both; Figure 1A). In summary, multiple and not necessarily complementary processes are used to define a resistant reef, thereby potentially conflating its meaning and use.

These differences are not merely semantic, as they signify different underlying mechanisms of action. For example, while acclimatization and adaptation imply increased resistance at both the scale of individual coral colonies (former) and the population scale (latter), a community-level switch to stress-tolerant coral taxa driven by past stress events leads to a weeding out of the more sensitive species. This indicates an ecological process (not an evolutionary process) that ultimately results in a more resistant community but not due to underlying adaptive forces. This ecological transition is more likely to result in a degraded or potentially less functionally diverse stable reef state (N. A. J. Graham et al. 2014; Yadav et al. 2018). This does not necessarily indicate that the coral individuals within a population or taxa are more resistant than their counterparts elsewhere or into the future. Importantly for the management of these ecosystems, it cannot be concluded that intrinsic resilience of the organisms or ecosystem has increased.

Differences in data collection may also contribute to differences in definitions and implied mechanisms. When we assessed the same literature regarding reef resistance and climate conservation, a variety of types of data were collected and/or used (Figure 1B). Coral cover and taxonomic composition were the most common types of data collected, followed by studies that primarily looked at coral cover (without including composition), then studies that included a focus on microbial data (with or without the additional collection of other reef benthic data), and finally a variety of other reef traits. Genetic metrics (apart from those related to microbial communities) were analyzed in three studies (Rodríguez et al. 2023; Schoepf et al. 2020; Walsworth et al. 2019). One of these studies examined genetic diversity of a reef in terms of cryptic species (Schoepf et al. 2020), one mentioned the value of characterizing and promoting genetic diversity of corals (Rodríguez et al. 2023), and one modeled reef resistance when differing levels of additive genetic variance were considered (Walsworth et al. 2019). While various studies have examined population genetics of corals and symbionts and heritability of traits, our literature review shows that these studies and others that mention refugia or MPAs are rarely bridged (Box 2 discusses integration of resistance across biological scales).

Given that adaptation, and often acclimatization, involves genetic changes in traits, we document a mismatch between implied mechanisms and data used to infer those mechanisms (Voolstra et al. 2021). There is further geographic variation in terms of primary data types assessed, with studies focused on the Central Indo-Pacific (which includes the Great Barrier Reef) using data sources that can more directly inform adaptation or acclimatization than studies focused on other ecoregions (Figure 1C). This geographic variation may partially reflect the significant barriers that remain to effectively incorporating genetic data collection and analysis at the reef scale. However, adaptation can be assessed through multiple approaches, not just genetic data; the reviewed studies frequently referenced other measures (Figure 1B), which remain essential when genetic data are unavailable. For example, certain environmental characteristics, such as remotely sensed temperature variability and disturbance history (if ground-truthed), can provide reliable context about the likelihood of selection for thermally tolerant genotypes of high resistance. Additional approaches that may be well suited to characterize potential resistance include pairing remotely sensed temperature metrics with in-water surveys (Sully et al. 2019), heat temperature experiments targeting the genetic heritability of heat tolerance (Quigley and van Oppen 2022), and aerial bleaching surveys paired with genetic sequencing (Quigley et al. 2022). Importantly, proxies such as total coral cover do not capture species-level relationships to local stressors, although it is arguably one of the most used metrics for coral reef health and persistence (Baum et al. 2023; Richards and Day 2018; Wooldridge 2014). As highlighted by Bates et al. (2019), it is not an equal comparison between the net change following disturbance from a diverse, mixed assemblage reef that may lose its sensitive coral taxa and the net change following disturbance in a reef with only more tolerant species left. Further, environmental proxies such as hydrodynamics or factors that reduce light stress indicate areas where corals are buffered from heat stress through attenuation of light intensity, but this does not necessarily (and sometimes contrarily) indicate resistance and may more accurately describe avoidance, as described above. Avoidant reefs, though they may harbor diverse coral taxa and genotypes, have not undergone the same selective pressures and are therefore unlikely to be genetically adapted to rising ocean temperatures.

Given these disparate definitions and the current hurdles to the application of genetic data in coral conservation policy, we propose a definition of "resistance" for the purposes of working within the avoidance–recovery–resistance framework for reef protection. We refer to "resilience" as the umbrella term encompassing avoidance, recovery, and resistance (McClanahan et al. 2024), and we focus here on heat resilience, given heat has contemporarily been the main driver of coral reef mortality since 2003 (Muñiz-Castillo et al. 2019). We define resistant reefs to be those composed of corals with the capacity to survive even if exposed to temperature conditions surpassing previous survival thresholds due to their underlying genetics (determined either by in situ or experimental measurements). This definition intentionally excludes one of the most pervasive misnomers: areas where warming has created locally resistant reefs due to the preferential mortality of heat-sensitive species. Coral species vary in their tolerance to heat (Loya et al. 2001), meaning some species will present physiological signs of stress earlier (i.e., partial or

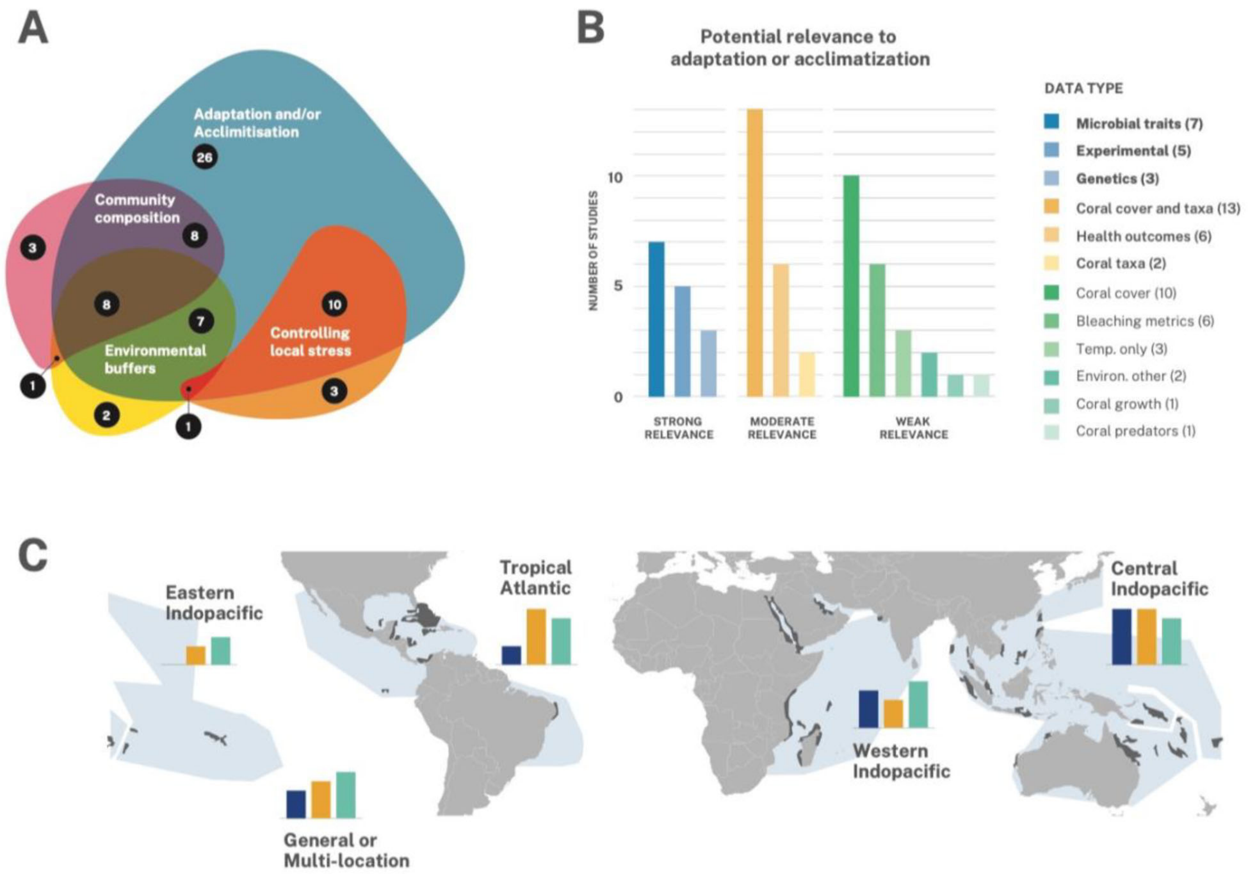

FIGURE 1 | (A) Proportion of studies that reference certain "resistance" mechanisms to explain apparent intrinsic or extrinsic resistance of coral reefs. Colors represent different categories, and numbers within each proportional area indicate the total number of studies within each category or category combination ($n = 69/75$ studies referenced a mechanism). "Adaptation and/or Acclimatization" refers to natural selection over generations or acclimatory processes, of either the coral host or its diverse microbial consortia; "Community Composition" refers to shifts in the proportions of species within the coral community; "Controlling Local Stress" refers to the control (or lack thereof) of local stressors (e.g., nutrient pollution, sedimentation, overfishing) via management actions; "Environmental Buffers" refers to unique environmental attributes (often hydrological conditions) that provide a buffering effect to the stressors from ocean warming. (B) Primary data types collected in studies discussing reef resistance and their relevance to demonstrating coral adaptation or acclimatization ($n = 59/75$ studies collected or used data to discuss reef resistance, see Supporting Information Methods). *Coral cover and taxa*: a combination of coral cover and taxonomic composition was used to characterize the reef benthos across heat waves, with or without additional environmental and human disturbance data. *Coral cover*: coral cover before and after a heat stress event was the predominant focus. *Microbial symbionts*: characteristics (densities, identities, diversity) of either coral-associated Symbiodiniaceae or bacteria collected, with or without additional environmental data and coral composition data. *Health outcomes*: health outcomes of colonies following heat stress, including mortality. *Bleaching responses*: bleaching thresholds or bleaching prevalence during heat stress. *Experimental heat*: heat stress experiments used to assess physiological responses and resistance to heat stress. *Genetics*: genetic data (aside from marker genes for species identification) used to characterize reefs (including gene expression, metrics of genetic variation). *Temperature only*: temperature data were the focus of analysis. *Coral taxa*: presence or absence of "robust" coral taxa documented as focus of resistant reef statements. *Environ.other*: studies that predominantly focused on environmental attributes (nutrients, salinity, turbidity, etc.). *Growth*: growth of coral transplants in different environments measured. *Predator abundance*: densities of coral predators (a local management action) associated with differential bleaching and mortality. Colors display the potential strength of each data type to demonstrate adaptation or acclimatization of reef. (C) Proportion of studies per ecoregion (as defined by Spalding et al. [2008]), colored according to data-type categories in (B).

outright mortality or disease). Although these reefs after the stress may be classified as relatively "resistant"—it may only be due to past mortality of the more vulnerable species and not due to their ability to pass on resistance to future generations (i.e., genetic predisposition to heat tolerance) (Côté and Darling 2010). While these coral community restructuring processes are important to understand future reef trajectories, they should not be automatically conflated with resistance. To classify absolute resistance, there must be evidence that corals can survive above critical levels of heat that surpass previous thresholds for the population, using quantitative ecological thresholds of "survival." Box 1 outlines examples of different data types used to identify resistant reefs consistent with the proposed definition.

3 | Why Identify and Protect Resistant Reefs?

As we near the second half of the Ocean Decade, 30 × 30 conservation planning and action is accelerating. This is an opportunity to prioritize a framework to pick strategic reef areas

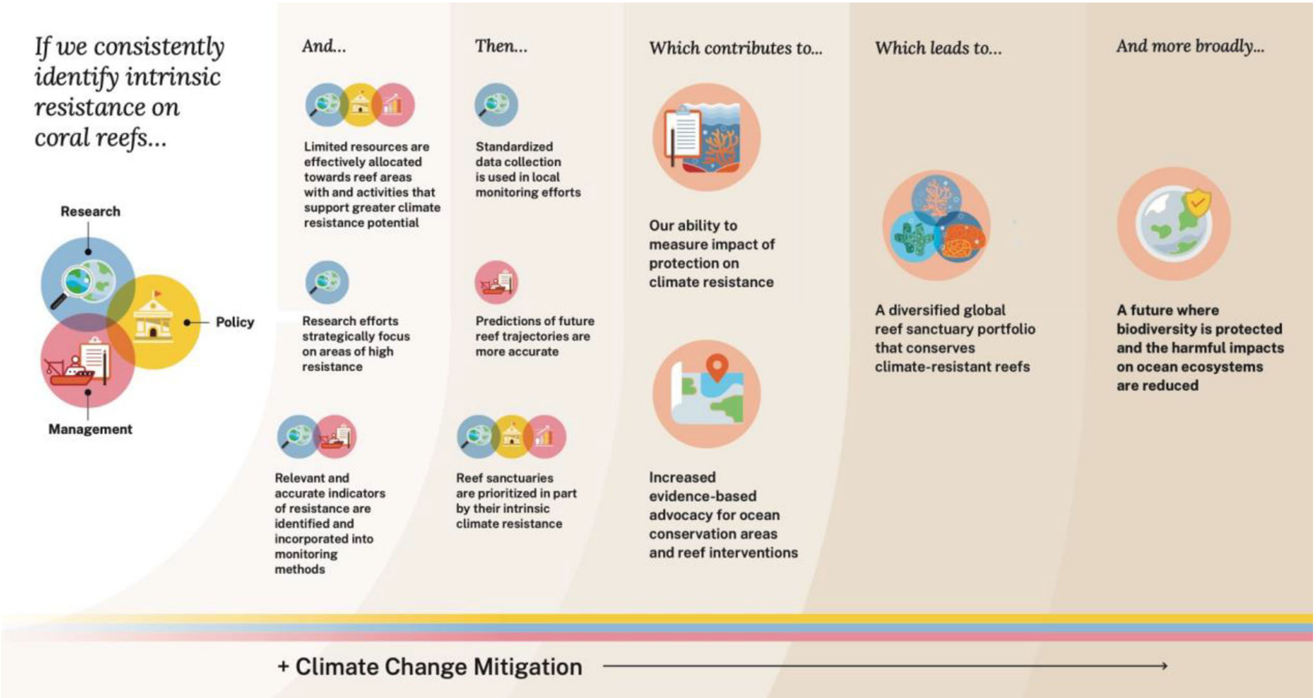

FIGURE 2 | Theory of change outlining how consistent identification of intrinsic resistance on coral reefs contributes to a diversified reef sanctuary portfolio that conserves climate resistant reefs. This impacts and involves research, policy, and management.

with high resistance potential. Communicating the value of new reef prioritization frameworks is key to steering limited resources toward the science and technologies that enable assessment of acclimatization and adaptive potential. The ultimate impact of not adopting a standardized resistance framework is the potential mislabeling of locations—wasting scarce resources and time at this critical juncture for reef futures.

The benefits of enhancing coral climate resilience via MPAs are clouded by numerous factors. Communicating the value of in situ protected areas in the face of climate change remains a challenge regardless of the ecosystem, as even the most stringent and effectively managed reserves cannot fully shield populations sensitive to warming temperatures (Rilov et al. 2020). Ultimately, greenhouse gas emissions must be drastically curbed if coral reefs and numerous other ecosystems have a chance at long-term persistence. This must remain the top priority. Even with drastic reductions, reefs of the future will likely look very different (Abelson et al. 2016; Quigley and Baird 2024). Recent dialogue in the scientific literature communicates this point; climate change is impacting even the reefs most far removed from localized human pressure, with no association between reef remoteness and change in total coral cover after disturbances (Baumann et al. 2022) and no difference in bleaching prevalence in MPA and non-MPA sites, even in large and old MPAs (Johnson et al. 2022). Others communicate a more nuanced interplay among local and global stressors, revealing that commonly used metrics of resilience can obscure species-level patterns of enhanced resistance due to local protection (Baum et al. 2023). Since reefs are vital to the local and global economies, cultures, and survival of millions, the importance of extending the duration that reefs can provide these ecosystem services cannot be overstated.

Contextualizing past patterns within the avoidance–recovery–resistance categorization of reef sanctuaries communicates various narratives. When a global stress event inevitably hits avoidant sanctuaries, which may have higher proportions of sensitive taxa, the subsequent loss of coral cover and/or diversity may be greater than surrounding areas that did not have comparable taxonomic diversity prior to the stress event (Bates et al. 2019). This would give the impression of low coral resilience at the community level and a lack of MPA effectiveness (Côté and Darling 2010). Additionally, the primary framework for the benefit of MPA status on coral resilience is framed around recovery-based processes (Mumby and Steneck 2008). Simplified, this can be summarized as: MPAs reduce fishing efforts, which restore herbivore populations, which control the macroalgae that competes with coral recruits for space on the reef, thus promoting coral recovery following disturbance. A synthesis by Bruno et al. (2019) highlights that the impact of cascading tropic interactions is much more complex, and empirical evidence is scarce for this recovery-based framework. However, there are also cases where recovery-based ecological processes have been demonstrated to enhance coral cover in MPAs (Hughes et al. 2007; Mellin et al. 2016; Strain et al. 2019). A comparable theoretical framework for the role of MPAs in increasing intrinsic coral resistance has not been explicitly communicated in the literature (Darling and Cote 2018).

Despite this, numerous methods have acknowledged that identifying and protecting reefs that demonstrate past climate resistance or indications of future adaptative potential are crucial to prevent reef ecosystem losses over the coming decades (He and Silliman 2019; Mellin et al. 2016; Mumby and Harborne 2010; Olds et al. 2014; Sandin et al. 2008). For example, the control of local stressors may help reduce impacts of heat stress (Baum

Box 1 Operationalizing reef resistance for conservation planning

Many studies that currently discuss "reef resistance" in the context of conservation prioritization employ a measurement of change in coral cover after a single disturbance event or the presence of relatively stress resistant coral taxa (Figure 1). While these data fall short of providing evidence for attributes of absolute resistance, we outline examples of different data types that can be used to identify characteristics of reef resistance for conservation planning.

Data type	Evidence for resistance	Study
Coral cover and composition combined with temperature data across 18 years	Successive decreases in expected mortality from multiple coral taxa (based on past heat responses) across subsequent heat waves in certain reefs around the Phoenix Islands (central equatorial Pacific).	Fox et al. 2021
Physiological responses of corals to acute heat stress assays within and across reefs	Concentrated locations containing a high proportion of corals with high heat tolerance relative to maximum summer temperature conditions in the Great Barrier Reef (Australia).	Denis et al. 2024
Genotype frequencies and historical environmental conditions; Genetic distances between populations and ocean currents	Certain reefs have high predicted adaptive capacity to heat (contain coral genotypes with high heat tolerance), and certain areas have high connectivity to these reefs in the Ryukyu Archipelago (Japan).	Selmoni et al. 2020

et al. 2023; Mellin et al. 2019). Identifying thermally tolerant and genetically diverse coral populations can inform management efforts to enhance connectivity to surrounding areas (A. A. C. Adam et al. 2022; Fox et al. 2021). In situ and ex situ restoration efforts can also synergize with geographic marine protection priorities (Possingham et al. 2015; Shaver et al. 2022; Zoccola et al. 2020). In summary, resistant coral populations should be targets for research, conservation, and restoration efforts, as studying the traits of these populations can inform new strategies that can be employed either at resistant sanctuary areas or reefs in decline (Figure 2).

Under this proposed framework for prioritizing resistant reef locations for conservation, we have the opportunity to standardize metrics in reef monitoring and enable more consistent comparisons to assess and communicate the impact of MPAs on reef resistance. This approach can support a feedback loop

Box 2 Integrating resistance across biological levels

Adaptive potential is central to reef resistance, and as such, a resistant reef framework must incorporate eco-evolutionary processes across biological scales (Bates et al. 2019; Obura 2005). Extensive work has already explored how corals respond to climate stressors, but using common language across disciplines will help connect this knowledge to system-level resistance. Expanding measurements across biological levels, from genes to holobionts to entire communities (van Woesik et al. 2022; Voolstra et al. 2025), will clarify the underlying drivers of resistance, improve predictive models, and ultimately inform conservation efforts (Thorogood et al. 2023). Here, we provide examples of measurements across biological levels that can help identify and operationalize reef resistance. Standardized remote environmental metadata and/or in situ environmental data are crucial to contextualize the biological data (Voolstra et al. 2025).

Genes. *Genetic diversity*: There are scenarios under which a reef has resistant attributes as defined here, surviving when its previous survival heat thresholds are surpassed, but may not retain resistance into the future. For example, genetic diversity can erode faster than species diversity (Hoban et al. 2021; Struebig et al. 2011), potentially reducing a reef's ability to resist continued warming before this change is measurable at the species assemblage level. Monitoring genetic diversity to determine effective population sizes on reefs can help identify scenarios where reefs may have high risk of future decline. *Heat-adapted alleles*: Identification of suites of heat-adapted alleles strongly associated with exposure to high temperatures may help identify adaptive capacity and therefore possible climate resistant reefs (A. A. C. Adam et al. 2022; G. Dixon et al. 2015; Quigley et al. 2020). *Reference genomes*: Annotated coral and Symbiodiniaceae reference genomes will be crucial to operationalizing genetic screening tools for coral reef resistance (Exposito-Alonso et al. 2019; Willi et al. 2022) and ultimately enable lower-resource-intensive genetic approaches such as genome skimming to be informative (Theissinger et al. 2023).

Organismal responses: Metabolic rates (respiration, photosynthesis, calcification) of coral holobionts under stress can help identify individuals that have acclimatized or adapted to warmer temperatures. Standardized experimental approaches such as the Coral Bleaching Automated Stress System (CBASS) enable empirical ranking of corals' thermal resistance (Voolstra et al. 2020, 2025).

Microbial consortia. The nature of coral–symbiont associations (i.e., the holobiont) makes it complex to define and measure resistance. Microbial communities may not display resistant properties, but microbial dynamics may contribute to overall holobiont resistance (e.g., Coffroth et al. 2023). For example, the dinoflagellate symbionts of corals, Symbiodiniaceae, may not be heat resistant, but their drastic loss from a coral during bleaching and replacement with a different symbiont taxon might contribute to holobiont resistance in some cases (e.g., Berkelmans and van Oppen 2006; Quigley et al. 2023). Bacteria communities often display similar patterns, with elevated variation indicating dysbiosis (Beatty et al. 2019; Zaneveld et al. 2017) and can be indicative of thermal resistance (Ziegler et al. 2017).

Populations and communities: *Community reef monitoring data*. When genetic data or experimental heat assays are not possible, species-level community composition monitoring and quantitative temperature records are crucial to identify attributes of resistance. Community reef data monitoring efforts, including MERMAID (datamermaid.org), the Global Coral Reef Monitoring Network (gcrmn.net/), the Allen Coral Atlas (allencoralatlas.org), Reef Cloud (reefcloud.ai), and others, provide a framework through which we can ensure data resolution is fine enough to detect when and where there are likely increases in coral resistance.

between science, policy, and management (Figure 2) that ultimately helps ensure the persistence of functional reef ecosystems. Even if well-managed MPAs ultimately do little to enhance natural reef resistance to climate change, their designation can still raise awareness and focus research and monitoring efforts. Highlighting the rate of their decline may help raise additional red flags, adding pressure for climate action and informing projections of global reef trajectories.

4 | Conclusion

To identify "absolute resistance" in coral reefs, we must be able to quantitatively determine which reefs are composed of corals with the capacity to survive conditions that surpass their previous temperature thresholds. A greater mechanistic understanding of intrinsic reef resistance and consistent parameterization of resistance will help design protected areas that may have a better chance of maintaining the critical ecosystem services that reefs provide. We can start by using available data to identify reef locations with demonstrated evidence of resistance; using these identified locations, we can work to find indicators of resistance by examining the common genetic, microbial, and other characteristics that these organisms of enhanced resistance have in common. While the priority for reefs must remain a drastic reduction in the anthropogenic drivers of climate change (and ultimately real zero emissions), approaches to coral reef conservation planning that focus on the adaptive potential component of resilience may help cut losses to biodiversity and ecosystem services.

Author Contributions

Conceptualization: L. I. Howe-Kerr and K. M. Quigley. Data curation: L. I. Howe-Kerr. Formal analysis: L. I. Howe-Kerr. Methodology: L. I. Howe-Kerr and K. M. Quigley. Visualization: L. I. Howe-Kerr. Resources: K. M. Quigley. Writing – original draft: L. I. Howe-Kerr. Writing – review and editing: L. I. Howe-Kerr and K. M. Quigley.

Acknowledgments

This work was supported by the Minderoo Foundation. The authors would like to thank Emily Darling for insightful feedback on manuscript drafts and Philip McVey for graphical design assistance on the two figures. K.M.Q. is supported by funding from the Australian Research Council (ARC) DECRA Fellowship to K.M.Q. (DE230100284).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Articles and categorical assignments of the literature used in this manuscript are included in the Supporting Information. No new data were collected for this study.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supplementary Materials: conl13108-sup-0001-SuppMat.docx

Supplementary Materials: conl13108-sup-0002-SuppMat.csv