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Perspective

Reconciling urgency and restraint in the coral climate crisis: A philosophy of practice

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SUMMARY

Many ecosystems are unraveling under record-breaking climate stress. Urgent action is essential. However, balancing urgency with reflection on what is feasible, appropriate, and fair remains challenging. Coral reef conservation has seen growing emphasis on bespoke technological interventions—promising solutions that fill a perceived void between inaction and ecological collapse. While technological solutions meet a desire for agency, they may reinforce a narrow logic of action, sidelining strategic re-visioning and deeper shifts. Here, we synthesize emerging ideas that reframe how to approach future social-ecological systems. We term this synthesis Minimum-In Minimum-Out (MIMO). MIMO is a philosophy of practice for stewardship under climate change, centered on ecological and ethical integrity. MIMO aligns long-term resilience with retreat from overengineering, while embracing natural dynamics, bioethics, and novel systems. Far from passive, MIMO provides a framework for navigating complex decisions via deliberate, decisive, and responsible care for climate-impacted systems—and the people who depend on them.

INTRODUCTION

Marine systems support billions of people and sustain major extractive industries, yet many are exceedingly susceptible to climate change.[1–4] Among marine systems at risk, tropical coral reefs appear closest to tipping toward irrevocable losses,[5] with "major threats" to coral reefs considered "virtually certain.[6]" While multiple climate impacts threaten corals and coral reefs—including increased storm activity damaging corals,[7,8] sediment-laden floodwaters smothering corals,[9] and altered ocean chemistry threatening biochemical reef growth[10]—the most widely profiled threat is coral bleaching. In recent years, coral-bleaching events have increased in severity, frequency, and geographic spread, generating growing scientific concern and media attention.[11–15] With record sea-surface temperatures across Northern and Southern Hemisphere summers, April 2024 marked the fourth pan-global coral mass-bleaching event in history identified by the US National Oceanic and Atmospheric Administration (NOAA).[16] It was the second such event in one decade.

Such global-scale coral-bleaching events are caused by a molecular-scale disruption of the symbiosis between two key organisms: corals and photosynthetically active, single-celled algae. When anthropogenic carbon emissions cause episodes of extreme seawater temperature, these algae (dinoflagellates) are expelled from the coral host. This loss of photosynthetic, pigmented dinoflagellates starves corals and fades their color, causing bleaching. If protracted, coral bleaching is followed by coral death.[17] To address the ultimate driver of coral bleaching and to safeguard the future of not only corals but countless social-ecological systems around the globe, radical emissions mitigation through structural socioeconomic change must occur.[18,19]

Yet, progress toward carbon emissions reduction remains painfully slow.[20,21] Despite scientific consensus on the urgency to limit warming to the relative safety of 1.5°C,[22] global emission reduction pledges are currently only sufficient to limit global warming to a range of 2.1°C–2.8°C by 2100[23,24]—and pledges are not actions. The sobering prediction for coral reefs is that: "even if global warming is constrained to 1.5°C" international scientists believe with "very high confidence" that 70%–90% of corals will disappear.[6] This dire outlook and slow progress have stimulated many coral reef scientists and policymakers to shift focus away from addressing the fundamental causes of climate change and toward addressing the immediate symptoms, such as limiting the loss of coral.

While emissions reduction remains routinely prioritized as a communal global task,[15] the emphasis on local interventions to save corals via restoration, bio- or geoengineering is viewed as an immediate stopgap to "buy time[25]"—a direct action, less fraught with geo-political delays, bureaucratic scale, and societal latency. Such interventions focus on local action, not global goals,[26] as reflected in many important local-scale non-governmental organization (NGO), industry-, or community-lead coral restoration projects across tropical and island nations, for example, in Costa Rica,[27] Mexico,[28] Kenya,[29] the Maldives,[30] Indonesia,[31] and Fiji.[32] Beyond such local restoration practices that benefit individual reef sites and/or local communities, a new class of large-scale systemic restoration agenda has also gained momentum—backed by substantial public, private, and philanthropic investment and spearheaded by ambitious national science programs, for example, in Australia, Saudia Arabia, and the US. Having been described as "a race against time," "a fight against climate change," and "the equivalent of a space mission,[33]" such initiatives often prioritize novel, technology-driven interventions and have been motivated and endorsed through international high-profile platforms such the United Nations Decade of Restoration[34] and the United Nations Decade of Ocean Science.[35] The scale of funding, aspirations, and enthusiasm is remarkable—and carries significant influence in shaping the future trajectory of coral reef conservation. National commitments to conserve coral reefs are laudable and tend to garner widespread public, political, and industry support. But, it may be naive to overlook the fact that many countries spearheading modern techno-solution projects are also among the world's highest per capita emitters—i.e., countries that calculate that investment in techno-solutions is cheaper and easier than the costs of avoiding emissions through ambitious decarbonization.[36]

Here, we focus primarily on this newer domain of large-scale, high-profile intervention efforts, because these powerful, well-funded, highly publicized initiatives have the outsized potential to reshape scientific disciplines, steer funding flows, and command political and public attention in ways that can eclipse or distract from smaller, community-led efforts responding to local needs. We reflect on the desire and need to update coral reef conservation strategies to the now omnipresent threat of climate impacts and explore how coral reef science is responding to the urgent question of "what should be done now?[15,37]" We examine the motivations, goals, and assumptions that support the emergence of novel coral-focused intervention technologies and consider how these fit within a broader landscape of climate-adapted conservation.[38] Drawing from emerging science, ethics, and practice, we outline a guiding framework, Minimum-In Minimum-Out (MIMO), that integrates mitigation, restraint, and long-term care. Summarized as five actions for science and policy, MIMO is not a rejection of novelty or action, but a tool to support critical reflection, reveal blind spots, and ultimately broaden the spectrum of possible actions available today to support future social-ecological reef systems under increasingly challenging climatic conditions.

SHIFTING PRIORITIES IN THE PURSUIT OF HEALTHY REEFS

Traditional approaches to reef conservation and management were not designed to protect reefs against the chronic, global, and systemic threats of climate change and ocean heating.[39] The traditional conservation approaches that arose in the 1970s and 80s were designed to respond to immediate, proximate threats caused by local resource use and direct human impact. Through marine spatial planning, temporal closures, gear restrictions, and runoff management, reefs were protected, to various extents, from destructive mining, commercial shipping, overfishing, and land-based agriculture.[40,41] Species-based protection also helped to maintain populations of charismatic species, such as turtles, dugongs, manatees, sharks, coral trout, or snapper. By the 1990s, individual species were not only protected because they were "iconic" or "important," but also because they were "umbrella species," key to conserving habitat and other species occupying the same space.[39] In more recent decades, these ambitions developed further, into protecting biodiversity for its inherent value and for its leveling "portfolio effect" and provision of "resilience" or "multi-functionality.[42,43]" Such process-focused conservation measures included: (1) size limits in fisheries (ensuring the persistence of stocks and populations by protecting reproductively active individuals from exploitation),[44] (2) water-quality standards (reducing excessive nutrient and sediment inputs to maintain favorable reef conditions),[45] and (3) controls on extraction of herbivorous species (protecting herbivore functions and preventing algae from competing with corals for space).[46] More recent, complementary strategies include identifying and protecting climate refugia—critical locations that may buffer against warming due to biogeographic location[47] or depth, such as mesophotic reefs potentially shielded by cooler waters.[48]

Despite the evolving diversity and broadening of conservation strategies,[49] such approaches remained inherently "conservative" in that they did not aim to actively create an aspirational, new state of health, but instead focused on stabilizing or reinstating "good" reference conditions, often for specific commercial species, based on previously observed reef configurations, by removing or limiting external disruption (Figure 1A). However, over the last decades, the drawbacks of such a focus on disturbance removal (be it removing nutrients from rivers or redirecting fishers) became apparent when faced with global climate change. This was because the causes of modern disturbances, i.e., global greenhouse gases and ocean temperatures, remain outside of the jurisdiction of individual governments and the grasp of marine scientists, management agencies, or conservation groups.[39] Today, as ocean heat records continue to be repeatedly broken,[15,16,50–52] novel marine interventions are rapidly gaining global prominence as a hopeful new tool that concerned actors can employ to address unprecedented climate impacts. Indeed, as traditional approaches are increasingly viewed as insufficient for the scale and nature of the climate threat,[53–55] industrial-scale investment in coral interventions is expanding rapidly around the globe, complementing, and in some cases overtaking, earlier small-scale operations. For example, Saudi Arabia's NEOM project,[56] Singapore's 100,000 corals initiative,[57] and the US's "Mission: Iconic Reefs,[58]" and rapid responses to marine heatwaves[59] are all experimenting with large-scale technological interventions. Likewise, consecutive Australian governments have committed a total of A$5 billion over one and half decades (2014–2030), in increasingly large installments (A$1.2 billion in 2022), to similarly "protect and restore" the Great Barrier Reef (GBR) in the face of climate change.[60] Given these countries' scientific influence and policy

Figure 1. Shifting priorities in coral reef conservation

(A) Traditional approaches to reef conservation tended to prioritize the removal of external disturbances. But given the global, transboundary impacts of climate change on coral reefs, such "removal" is no longer considered viable.

(B) In response, active intervention paradigms have gained traction, where human actions aim to support reef systems by directly bolstering specific species and system states.

(C) Here, we synthesize a third option, MIMO, which blends aspects of (A) and (B) to support systemic health in a heating world.

leadership,[61–63] the paradigms they develop are readily exported as reference points and models for best practice for natural resource management—shaping global discourse on how to manage marine systems under climate stress.

Similar to previous taxon- and resilience-focused conservation strategies, active technological interventions also aim to protect the inherent stability of populations or climate-impacted ecosystems. But, rather than focusing on the removal of damaging external influences, active interventions aim to add positive influences internally by bolstering specific species (Figure 1B). These are chosen based on their ecological promise (by being considered foundational within the ecosystem) and pragmatic convenience (by being hardy, feasible to propagate, and fast-growing). Examples of novel intervention approaches include (1) habitat restoration (re-seeding former habitat with target species from nursery brood stock or from remaining habitat patches, for example, *Posidonia* sp. in seagrass beds[64] and *Ostrea* sp. in oyster beds,[65] *Rhizophora* sp. in mangroves,[66] *Macrocystis* sp. in kelp forests,[67] and *Acropora* sp. on coral reefs[25]); (2) bioengineering approaches such as "assisted evolution" (enhancing species through breeding and genetic modification, targeting traits deemed beneficial in future hotter conditions[68,69]); (3) geo-engineering to buffer against proximate climate change impacts such as increased temperatures (managing solar irradiation through shade structures or cloud seeding, or by modifying water temperature through pumping cooler water from depth[70,71]); and (4) pest-control of invasive or natural predators of target species (industrial culling of sea-urchins that overgraze kelp beds[72] and crown-of-thorns starfish that consume live coral[73]).

Proponents of novel active interventions commonly acknowledge the inherent risks of innovations but argue that these risks must be weighed against the risks of not intervening,[54] i.e., the risks of not committing to a promising new way of protecting reefs. The perceived benefits of active interventions are at least 3-fold: (1) they offer direct action that appears independent of global carbon emissions, (2) the principle of managing the survival and reproduction of individual species, or a small handful of species, is a tried-and-tested method used in industrialized agriculture, and (3) as long as the correct species are chosen, their proliferation is expected to kickstart and reinforce ecological dynamics[74] that will, in turn, restore or stabilize system-wide health. Nevertheless, concerns persist. These include (1) moral hazard, i.e., the potential for solution narratives to distract from radical climate mitigation,[18] (2) ineffectiveness, i.e., uncertainty around scalability of interventions,[75–77] and (3) maladaptation, i.e., unresolved social and bioethical consequences.[36,78–81] Other experts call for a data-driven re-consideration of the dynamics of reef loss[82] that must be better understood to drive more responsible action, or challenge the framing of options as limited to either technological solutions or inaction, which narrows the scope of considered responses.[83]

Thus, conservation paradigms are never static; they evolve in response to climate change, shifting values, and the need to attend to critical social dimensions such as equity, livelihoods, and cultural resilience.[84] In this context, we turn to the MIMO approach as an emerging model for rethinking the future of reef systems under climate pressure (Figure 1C).

CLIMATE ACTION THROUGH PURPOSEFUL RESTRAINT: MIMO

MIMO responds to growing concerns about overpromising, overengineering, and underappreciating the ecological limits of reef interventions. MIMO promotes a renewed focus on system function, care, and ethical integrity by asking if and when purposeful retreat—rather than further intervention—might be the more responsible choice. Thus, at its core, MIMO prompts reflection on our underlying goals. If the aim is to rapidly increase coral cover at specific sites, active interventions may indeed be the most direct route. But, if we seek to sustain dynamic, functioning reef systems over decades to come, especially under escalating climate pressure, then MIMO may offer a more durable, albeit challenging, path forward—by reorienting coral conservation toward supporting dynamic, self-organizing systems. As such, MIMO complements a dimension of climate action easily obscured by urgency: purposeful reflection and restraint.

Calls to integrate broader, ethical, and sustainability-focused considerations into coral reef restoration design, practice, and science are not new. These include strong calls to advance diverse stakeholder coordination,[85] to foreground resilience[86] and adaptive decision-making,[87] to learn from established principles from terrestrial restoration,[88,89] and to incorporate Indigenous perspectives.[90] MIMO is not intended to replace these critically important considerations discussed within restoration practitioner communities. Instead, MIMO offers a consolidated framework to elevate their visibility. Intended as practical guidance for navigating conservation decisions under climate pressure, MIMO aims to foster more consistent application—to help ensure that important considerations acknowledged at the strategic level are more readily carried through into practice, higher-level planning, investment decisions, and definitions of success.

Like both traditional and interventionist approaches, MIMO aims to support systemic coral reef health. But, it represents an evolution from traditional philosophies because it fundamentally embraces the new reality of dynamic change caused by climate impacts, rather than defining success as retaining, or returning to, preferred configurations. This acceptance that we are entering a new era of coral reef conservation is also what unites MIMO and traditional and interventionist approaches. All recognize the need for innovation. What distinguishes MIMO is the commitment to reflect on how the goal of supporting systemic coral reef health is defined and how it may be achieved. MIMO stems from an acceptance of our limited capacity to predict and influence specific outcomes within complex natural systems or understand mechanisms of change. It emphasizes humility and reflection in the face of uncertainty, acknowledging that we still know very little about which aspects of climate-impacted marine systems are most important or most at risk.[91,92] Rather than focusing on external manipulation of specific species as leverage points for "health," MIMO shifts the focus toward the conditions that support dynamic, self-organizing systems.

This view parallels emerging paradigms in human medicine that challenge perceptions of "health" as a stable state defined by meeting certain pre-defined target metrics, or by the absence of "disease." Instead health is increasingly defined as an emergent property from interacting, dynamic processes—a balance of metabolism (turnover) and homeostasis (dynamic stability).[93] In natural systems, equivalents to "metabolism" and "homeostasis" are supported by the dynamic processes that shape, build, and stabilize systems, i.e., ecosystem functions, or the "the movement or storage of energy or material.[92]" From a MIMO perspective, these functions are most robust when unnecessary inputs or extractions (of energy or material) are minimized—the very principle reflected in its name: MIMO.[83]

Supporting reef health, then, means supporting the system's inherent capacity to self-organize by enabling the emergence of stable or increasingly complex ecosystem functions—not through pursuing specific target metrics (e.g., high coral cover or extractable tourism and fishery returns), but by reducing external pressures, stepping back from intervention, and allowing functional dynamics to stabilize and evolve (Figure 1C). In response to accelerating climate change, modern interventionist approaches, by contrast, take a different approach to defining and supporting health. They typically focus on bolstering targeted species as the main leverage points and proxies for health, operating under the assumption that the proliferation of select species will lay the foundation for broader ecosystem recovery (Figure 1B). In this view, ecosystem functions, system health, and human-environment values are subsequent by-products of species restoration (Figure 2A). MIMO inverts this logic. MIMO considers ongoing ecosystem functions as the foundation for ecosystem health and views species proliferating as one outcome, or symptom, of health (Figure 2B). In essence, all philosophies have the same goal, but they diverge in how they understand causality: species supporting ecosystems vs. ecosystems supporting species (Figure 2).

Thus, rather than offering a one-size-fits-all solution, a MIMO approach highlights that purposeful restraint and system-oriented thinking may provide distinctive advantages. These advantages include: (1) redirecting the attention of benevolent political and market forces away from technofixes, which require

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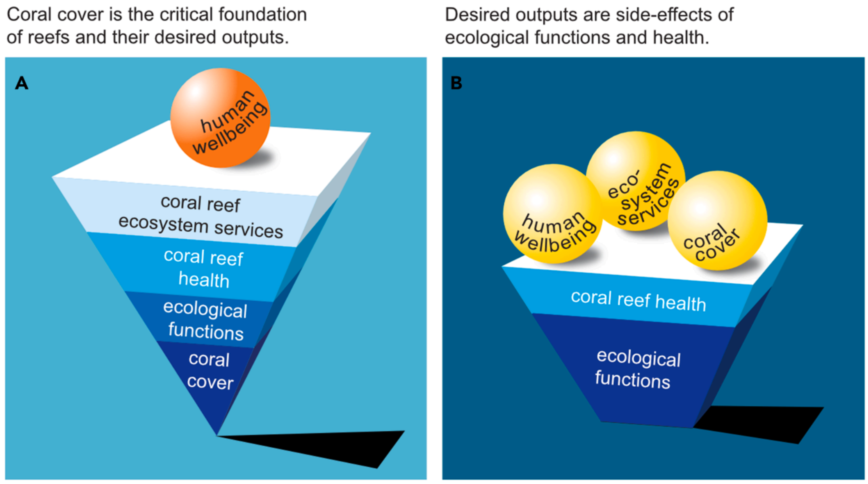

Figure 2. Reimagining how coral reefs work

(A) To date, both traditional and interventionist conservation approaches on coral reefs tend to favor the left paradigm, where corals are the indicator and foundation for health, and thus the leverage for human influence.

(B) By contrast, MIMO-based conservation favors systemic ecosystem protection where high coral cover is just one of the possible desired side effects of a healthy, functioning reef system.

constant input; (2) avoiding the need for premature value judgments on which system states or iconic species are worth saving; (3) supporting natural dynamics in the face of complexity and uncertainty; and (4) reinforcing established, demonstrably effective conservation management approaches that already minimize input or extraction.[62] For example, water-quality regulations and usage permits already limit harmful nutrient loads or unchecked tourism, while National Parks and marine protected areas (MPAs) already limit extractive activities such as mining or fishing. These existing strategies exemplify low-input approaches consistent with MIMO principles.

Crucially, MIMO offers a lens to reflect on what we are trying to achieve, prompts reconsideration of the breadth of options, and guides decisions accordingly. In doing so, it can help clarify when and where traditional and interventionist approaches may be warranted, and when deliberate restraint may lead to more sustainable outcomes. Navigating such complex decisions can ease pressure on science funders, policymakers, and management authorities as they face mounting calls from scientists and communities demanding urgent responses as global temperatures rise (Box 1). To help apply MIMO in real-world coral reef management, and extend its relevance to other climate-impact ecosystems, we offer five guiding principles for applying MIMO as a practical decision-support tool: (1) step forward on climate action, (2) embrace novel social-ecological systems, (3) accept passive recovery as a viable option, (4) identify new ways to define, monitor, and support ecosystem health, and (5) foster an intrinsic ethics of care.

Principle 1: Step forward on climate action

The need to address climate change is routinely acknowledged in almost all communications about traditional, and modern, intervention-based conservation initiatives. Acknowledging the need to address climate change is an important, first step. But, some conservation scientists and managers could be turning climate mitigation into empty calories through inflationary use as a disclaimer. Acknowledging but side-stepping the issue reinforces the well-established notion that scientists, conservationists, and managers have only one "realistic" option based on "common sense": deal with the consequences of climate change, while policymakers and industry shape the path forward on mitigating climate change.[94] These fabricated constraints deny the role, agency, influence, and responsibility of science and conservation in society—and must be categorically rejected.[80,95–97]

While no ecologist or natural resource manager can directly pass legislation that reduces fossil fuel emissions, they can avoid presenting "solutions" that normalize or reinforce rising emissions and resource consumption, such as the development and export of new intervention technologies and industries.[98] Responsible scientists and managers can also avoid providing an apparent, scientifically approved, "ecological absolution" to polluting industries via investments in restoration and offsets.[18] They can equally avoid messaging to the public that science is working on solutions that save coral reefs, thereby inadvertently claiming authority and agency and adding to politicized narratives that "rationalize inaction[99]" by enabling public disengagement with,[100] or opposition to,[101] the seriousness and complexity of climate change. In other words, climate change mitigation must be a core principle embedded into conservation strategies—not a diffuse goal to be taken care of by someone else or in the future.[102] In the emerging MIMO paradigm, a crucial first step is to step forward on climate action. This can occur through rejecting palliative interventions (for example, offsets) that legitimize the status quo of climate inaction,[18] and by incorporating carbon footprints and emissions calculations into feasibility assessments of all management options.[98]

Principle 2: Embrace novel social-ecological systems

Even with aggressive mitigation action, climate change will alter nature as we have known it.[103,104] Accepting this reality carries an uncomfortable connotation of having given up, of being resigned to loss and failure; it can induce anxiety and affect human wellbeing.[105] Humans default to evaluating novel ecosystem configurations as undesirable. We prefer to hold on to what we have or have had and are likely to overestimate the disadvantages of alternative new realities. In economics these phenomena are termed loss aversion, endowment effect, and status quo bias.[106] They are just as relevant in conservation. Indeed, calls to embrace novel ecosystems are not new,[107–109] but in the face of new climate challenges MIMO overturns our

Box 1. Navigating climate-impacted reefs with MIMO

MIMO is a decision-support framework to guide leaders through the complex social-ecological challenges of climate-impacted coral reefs. The scenario below illustrates how MIMO can provide structure and clarity when navigating the moral, ecological, and political complexities of reef conservation in a climate-changed world. After a hypothetical climate-induced coral-bleaching event in 2026, which decimates corals and threatens the livelihoods, cultural heritage, and wellbeing of coastal communities of the Isolated Isles, local leaders are under intense pressure to act. They apply MIMO's five principles to develop a balanced response that accounts for the complexities of the situation, while prioritizing both immediate action and systemic, long-term goals.

(1) In the wake of mass coral mortality, politics and industry push to "Save the Isles" through local coral replacement. Reef scientists and managers appreciate the attention but are wary about climatewashing and the emerging narrative that science can "rescue" reefs. In response, they take a systemic, long-term approach and "step forward on climate action" by making climate mitigation a core principle of decisions. Knowing that marine heatwaves and coral mortality are driven by greenhouse gas emissions, they grapple with concerns about being "too small" to matter. They leverage their position as perceived custodians of the Isles to advocate for global climate action. They challenge decision-makers on the consequences of overpromise and climate inaction, publicly emphasizing that without addressing climate change, local conservation efforts can only, at best, provide short-term relief, not save reefs in the long term. They also adjust their feasibility assessments, openly deprioritizing emissions-heavy strategies, e.g., those that rely on upscaled industrial manufacture and shipping, global imports, or constant technological inputs.

(2) Public campaigns call to "restore the former glory," featuring images of vibrant coral gardens. While these visions are inspiring, reef leaders are concerned that recreating historical conditions is unrealistic under ongoing climate impacts resulting in inevitable disappointment with current and future reefs. Instead of clinging to the past, reef leaders "embrace novel social-ecological systems" shaped by new environmental realities. They shift the narrative, emphasizing that even if these new systems look and function differently, they can still support vital benefits including aesthetic values, fisheries, and coastal protection. Public outreach grapples with these dramatic losses while reframing change as a potential path to a new, resilient future, not a sign of failure. The focus moves from fighting to restore a lost, nostalgic past toward grieving the losses, and then embracing, understanding, and supporting a transformed future.

(3) In the aftermath of the bleaching event, decision-makers face immense pressure to act boldly and "fix" the Isles, often framed as a moral obligation. But they pause, grappling with the weight of their choices and questioning whether human intervention per se is better than natural regeneration. They acknowledge that, in a climate-impacted world, changes are inevitable and that nature's recovery, while imperfect, can sustain vital ecosystem functions without the risks of experimental interventions. Shifting their focus from replacement of, to support for, natural recovery, i.e., from restoration to resilience, leaders "accept passive recovery as a viable option." In doing so, they begin to redefine what success looks like under climate change. Temporary no-fishing zones and reduced reef access provide the reef space to regenerate naturally, while emerging signs of thermal tolerance in some corals offer hope. They embrace their role as stewards of change, prioritizing measures that support natural adaptation, and investing in research to understand and redefine health and conservation goals for an evolving, future ecosystem. They decide that the boldest choice is to actively step back and support nature, not to try to reshape it.

(4) Leaders question whether coral cover captures the full picture of a healthy reef. While coral cover is a familiar and useful metric of change, they recognize that reefs are dynamic systems, and health depends on sustaining key processes like coral recruitment and erosion rates, fish productivity, or the processes provided by other overlooked organisms, for example, reef accretion by encrusting algae, primary productivity by turfing algae, nutrient cycling by seabirds, habitat provision by mangroves, or reef-building and productivity by the myriad of non-coral invertebrates. They advocate for diversifying research efforts to improve health assessments that reflect ecosystem dynamics, using natural dynamics as a unifying theme. This broader view of health helps ensure long-term sustainability, where thriving coral populations are just one of many possible outcomes. Leaders communicate openly that reef "health" depends on the functions they aim to sustain. Through this public agenda setting, they foster a flourishing diverse scientific community, studying how to "identify new ways to define, monitor, and support health" on coral reef ecosystems now and in the future.

(5) Faced with the complex needs of diverse reef stakeholders, leaders reassess their role and mission. Recognizing that functioning reef systems underpin all human uses, they shift their focus toward advocating for reefs as natural entities with inherent value. They "foster an intrinsic ethics of care," valuing reefs not just for their human utility but for their inherent worth. When selecting conservation strategies, they view reefs not as commodities to be managed but as sovereign entities whose rights deserve protection. In doing do, they move away from extractive, technocratic approaches toward stewardship rooted in respect and care. Strategies are co-designed with Indigenous communities, who have long practiced custodianship of natural entities. By fostering inclusive stewardship, leaders emphasize that reef health is a collective responsibility and source of wellbeing, not just for scientists or tourists and policymakers, but for Indigenous peoples, local communities, non-human species, and future generations.

preference for using the derogatory term "degradation" instead of the more neutral term "change."

When it comes to the status of coral reefs, we have been sliding on the so-called slippery slope to slime for decades.[110,111] Even the earliest coral reef science only ever studied coral reefs that were already degraded.[112] Paradoxically we seem to have chosen reefs from the 1980s and 90s as reference conditions—and as restoration goals. The rapid pulses of obvious change, i.e., global bleaching events since 1998, in 2016/17, in 2023/4, and in 2024/5 have contributed to the renewed, yet not novel, sense of having entered the final act for coral reefs.

It is important to be aware of shifting baselines,[113–115] so we can evaluate and record the changes in natural systems that go beyond a human lifetime or personal experience. But critics warn we should also be more cautious of consistent messaging of loss and reduced worth if our goal is to communicate the value of these systems and their conservation. We may want to trigger awe and inspire care by showing what was. But, if we consistently highlight so-called flaws, imperfections, and realities that are better but out of reach, we may in fact stymie interest, engagement, and enjoyment.[116] Indeed, if it is the role of coral reef scientists and managers to preserve coral reefs for people, we must consider who is using these reefs. According to UN projections,[117] in half a decade, by 2030, half of the people (49% ± 1%) in countries with coral reefs[118] will never have experienced a reef unaffected by global bleaching events—because they were born after 1998. A quarter of people (23% ± 1%) will have been born after 2016 and thus only know Anthropocene-era coral reefs (Data S1).

Embracing novel ecosystems is, in other words, not a question of becoming indifferent to loss.[119] But, it is the difference between despairing over the loss of specific manifestations of nature versus embracing the process of grief and memorialization,[120] appreciating nature's dynamics, and moving forward from reactionary "palliative" conservation[18] toward future-oriented stewardship. MIMO acknowledges that we may not have the coral reefs we want, but that we should perhaps learn to appreciate the coral reefs we will have (and, possibly, deserve); turning not to nostalgic memorialization but to action toward a new chapter and different, but no less valid, future.

Principle 3: Accept passive recovery as a viable option

The rationale of active interventions implies that human intervention per se is critical to facilitating recovery, and that we (1) *know* what to modify, (2) are *able* to modify it, and (3) are *responsible* for modifying ecological futures. The implied consequence of inaction is inevitable failure and ecological ruin. Thus, active interventions frame conservation as a heroic narrative that advanced science and technology can fix climate-impacted reefs.[121] Given the motivational benefit of such a valiant narrative, the alternative of intervening less, or not intervening at all, is rarely considered as a serious option.

The reasons behind the prevailing predilection for doing more are likely to go beyond the conservation needs of coral reefs and stem instead from human behavior. Humans prefer solutions that allow them to actively add something new, failing to consider subtraction even when it would be simpler and more efficient,[122] and regardless of evidence on whether any action is likely to improve the outcome.[123] Personal agency, job satisfaction, and confidence in capabilities are key drivers behind such intervention bias.[123] The resulting principle is addition, not reduction—new tools, technologies, and approaches in the hope to make things better.

It is important to note here that the philosophy behind MIMO retains active agency, but this active agency is not in the form of increased intervention. Rather it manifests as *purposeful* reduction in human influence. The center of attention thus becomes not heroic human repair, but the enabling of the natural system's inherent potential for passive recovery (Figure 3). It is critical to emphasize that recovery is always imperfect. Ecosystems around the globe display recovery debt, i.e., "deficits in biodiversity and functions" after disturbances.[124,125] Rather than having "pristine," undisturbed "wilderness" as a target (see Erwin[126]), passive recovery can be understood as a natural process that enables the ongoing existence of stable or increasing ecological complexity—in short, a capacity to continue functioning in a new state. Thus, in MIMO, "recovery" is not a backward-oriented return to a previous state of apparent "normal," but a forward-looking facilitation of ongoing health.

Natural recovery dynamics and ongoing provision of functions and services exist in many disturbed systems, where neither recovery completeness, nor recovery speed, differs between human restoration, compared with natural, unaided recovery.[129] On coral reefs, recent studies reveal the continued delivery of critical functions and ecosystems services in natural, yet "degraded" systems. In reef fish communities, the production of biomass harvestable by human fishers or natural predators is sustained despite intense human use and chronic climate disturbances having changed fish community composition and standing stocks.[130,131] In corals, intra-specific bleaching susceptibility[132] may already have given rise to initial natural adaptive responses, with global coral populations bleaching at higher temperatures than only a decade ago.[133] Recent large-scale coral recovery of fast-growing *Acropora* corals on Australia's GBR,[134] have proved to be an ephemeral bloom in boom-and-bust dynamics, heavily impacted in 2024 by renewed record-breaking summer temperatures.[135] However, high-turnover monocultures of structurally complex and weedy *Acropora* corals are nonetheless a natural output of an altered, albeit functioning, ecosystem. Their provision of *live* coral cover may be ephemeral, but their rapid productivity and death provide a conveyor belt of nutrient turnover, structural complexity, and biogenic carbonate.

MIMO highlights that the reasoning to discount passive recovery, including observed natural re-growth of coral, as "irrelevant" or "insufficient," while promoting untested human interventions to increase cover of the same or similar fast-growing corals as the right tool for "proper" recovery, needs to be carefully interrogated.

Principle 4: Identify new ways to define, monitor, and support health

According to both traditional and interventionist paradigms, a healthy reef is a reef with high coral cover. Indeed, this link is so tight that the fate of corals is commonly extrapolated to reef systems as whole. A recent analysis of nanobiotech engineering for future coral reefs stated, for example, that "although

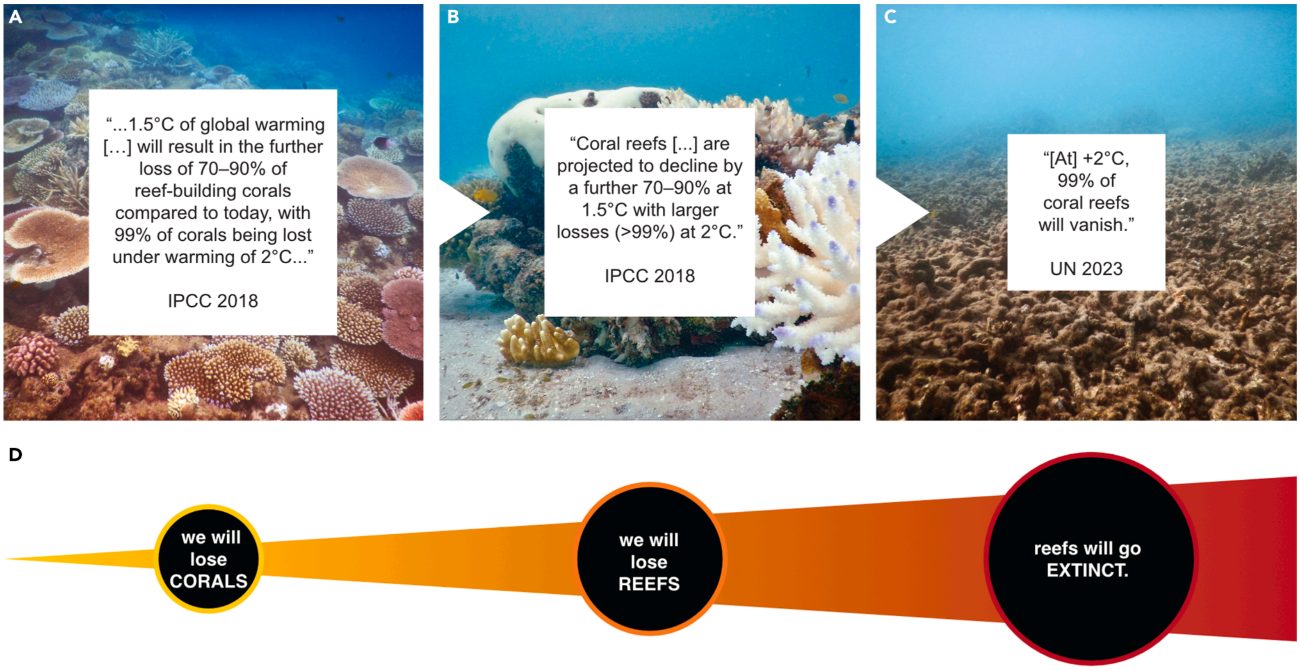

Figure 3. As climate change intensifies, we must work to understand the key differences between coral loss and reef extinction
(A–C) The quote in (A)[6] is the source for (B)[127] and (C).[128] While similar at first glance, they represent subtle but important differences. Directly merging "coral loss" with "coral reef extinction" cements the foundational importance of coral protection for future coral reef ecosystems. This is a powerful tool to communicate urgency. But iconic, important taxa (coral) and complex social-ecological systems (reefs) are not identical.

projections about the rate of coral loss are continuously being adjusted, the unanimous consensus is that climate change is causing the rapid disappearance of tropical coral reefs and threatening their extinction within this century.[136]" Indeed, coral cover has become such a prevalent proxy for reef condition, that "saving corals" and "protecting coral reefs" are treated as synonyms[128] (Figure 3). It is logical therefore that protecting or increasing coral cover is the sole stated focus of many new interventions. MIMO interrogates this popular conflation, which may have emerged from three intertwined facts and assumptions: (1) coral cover is a useful, easily measurable metric to assess changing reef conditions, (2) increased coral cover is central to the existence of coral reefs and the reef values that we may desire (e.g., coastal protection, aesthetic beauty), and (3) increased coral cover will improve reef resilience. Indeed, corals are the key visible factor that links reefs to climate change, the canary in the coal mine. But just as it is ineffective to breed canaries if we want to reduce toxic gases in mineshafts, MIMO underscores that is important to remember that a good metric of change is not automatically a good remedy.

Undoubtedly, coral cover is a useful metric to detect change—coral cover is sensitive to environmental change and readily quantifiable. But, MIMO underscores that the problem lies in trying to manipulate coral cover in the hope it will lead to resilient, self-sustaining reef systems. The assumption is that corals *create* healthy reefs, not that corals are the *product* of healthy reefs. Traditional and interventionist approaches have inadvertently turned coral cover from a metric (we can quantify a symptom of change) into a goal (if we maximize corals, reefs will be healthy). However, there remains a fundamental distinction between (1) a useful indicator of changing conditions and (2) a powerful remedy that engenders health. If the goal is to increase coral cover locally, and in the short term, then engineered coral planting may indeed be the most direct tool available. But, if the goal is to support resilient, self-sustaining reef systems over time, then simply manipulating cover may offer little more than an aesthetic placeholder—especially if key drivers of decline persist.

Given our current causal understanding of coral reefs, identifying which select ecological processes are particularly important for ecological health remains an intensely challenging task.[92,137] Researchers are only now beginning to identify what is required for reef health, growth, and resilience. While coral cover may well be the most satisfactory metric of reef condition available, MIMO highlights that there is an urgent need for research to link this proxy of reef condition to actual outcomes for reef health. Since health dynamically emerges over time, a promising start is to monitor functions, i.e., dynamics, changes, and fluxes through measurements that capture a rate, not a state.[137] Examples are reef accretion and erosion rates,[138–140] coral demographics, such as recruitment and growth rates,[141,142] fish productivity,[143,144] and ecological metabolic rates.[145] A focus on MIMO as a new paradigm would necessitate a significant increase in attention and investment toward the scientific pursuit of better health assessments on reefs.

This shift in investment is critical, because it allows scientific efforts in time and resources to be diversified away from coral-centrism toward a better understanding of the dynamic ecological health of the entire climate-impacted system. Such a changed perspective does not suggest that coral cover is irrelevant to coral reefs. But, it highlights that the relationship between corals and reef condition is more complex than current conservation paradigms imply, where changing coral communities simultaneously threaten, and save, the very existence of reefs. While science addresses critical knowledge gaps, a MIMO approach can enable a process-based view of ecological health, focused on the ongoing provision of ecosystem functions, with low risk and low assumptions. If we focus on protecting reefs as healthy systems, abundant diverse corals may just be one desirable side effect.

Principle 5: Foster an intrinsic ethics of care

Many current and developing interventions to conserve coral reefs are problematic because they focus on use, not care, i.e., on perpetuating the extraction of services from nature for human benefits.[146] Bio- and geoengineering interventions also tend to prioritize elite technical and scientific ability in ecosystem valuation, decision-making, and management; they are inherently technocratic. Social scientists have warned that extractive and technocratic approaches to valuing and restoring reefs can risk perpetuating practices of colonial extraction and ecological imperialism.[147] Such eco-imperialism occurs when more powerful groups, for example, scientists or conservationists, impose extrinsic environmental goals and strategies on less powerful groups, for example, First Nations peoples and local communities. Eco-imperialism becomes evident when immeasurable environmental values of First Nations are acknowledged (e.g., aesthetics or cultural values) but linked to instrumental human use (e.g., food and livelihood security or social license to operate). Interventions that seek to sustain coral reefs for their value and worthiness from being used, exploited, or enjoyed by humans, not from simply existing as an expression of nature, are the logical outcome.

Technocratic worldviews that place technical and scientific feasibility at first priority also tend to seriously overlook the intrinsic act of ethical care for reefs. Indeed, in the biophysical sciences, consideration of ethical care is typically regarded as "non-scientific," as being outside the mandate and authority of scientists, as too sensitive, or too inconvenient. Instead, it is treated as important labor to be handed over to others—to ethics committees, social scientists, permitting agencies, First Nations peoples, and Global South communities who must take on the moral load abrogated by technocratic scientists.[148,149] This withdrawal from care or control becomes especially problematic when marginalized peoples are simultaneously labeled as "vulnerable" and virtuously slugged with the moral overload of ethical care for climate-impacted systems.[150] In doing so, technocratic scientists provide a trifecta of ethically questionable exports: (1) emissions-intensive intervention industries that reinforce climate threats, (2) performative inclusion through sharing of important but inconvenient moral labor, and (3) an economy of technological "solutions" that can or must be monetized, often without an exit strategy.

However, MIMO recognizes that even within technocratic systems, an awareness is growing that care is an important aspect of human sociality that goes beyond the preservation of self-interests.[119,151,152] According to MIMO, an ethics of care approach is not a cumbersome performative addition to conservation, nor is it anti-intervention. Rather, it should be regarded as a source and spring of responsible, active stewardship of ecosystems as they are, and as they will be—rather than what they once were, or how we once used them.[148,149] Such a holistic perspective of stewardship of care, not use, facilitates critical considerations that go beyond biophysical and technological feasibility, for example, how to ensure reef care (1) advances *just* climate futures, (2) protects human and non-human rights and interests,[119,153] and (3) expands agency beyond the human.[154,155] By embracing MIMO as an alternative paradigm for stewardship and conservation, by putting all people and nature in the focus, not just elite scientific abilities, we enable a perspective where we all care for the whole social-ecological system, and avoid enrolling marginalized rightsholders and communities into reinstating our extractive use of it.

ENABLING CONDITIONS AND GLOBAL RELEVANCE

Together, the five actions above offer a structured way to support coral reef futures under climate stress, while avoiding uncritical escalation of interventions or backward-looking approaches. MIMO is a flexible framework centered on long-term care and context-specific futures. Unlike traditional and technocratic models that rely on substantial funding, technological infrastructure, or endorsement by powerful institutions, MIMO can operate within the means of any community, organization, or management body seeking to act with purpose and integrity—empowering small-scale, locally led efforts rather than displacing them. Because it is not anchored in costly technologies or externally imposed metrics, MIMO accommodates a wide range of conservation priorities, from reducing pollution and managing fisheries to establishing culturally meaningful reserves. These efforts may not always maximize biomass or coral cover, but they can maximize self-determination, legitimacy, and long-term relevance. In this way, even modest actions can carry profound conservation value.

MIMO recognizes that more affluent countries may have greater capacity to act but insists that they need not define the targets for all. A small reserve rooted in local cultural priorities may achieve more than a high-tech intervention shaped by foreign benchmarks. The key distinction is that local interventions typically pursue clear, tangible, human-centered goals,[156] while high-tech initiatives often aspire to broad, harder-to-grasp visions of future social-ecological benefits whose feasibility and consequences remain uncertain. Against this backdrop, MIMO offers a way of thinking that prioritizes goals over scale: What matters is not the scale of any single action, but its goals, purpose, relevance, and sustainability. These are the criteria by which we must decide whether any approach—including MIMO—is truly sufficient and effective. In doing so, MIMO invites reflection over prescription, offering a practical yet aspirational path that is as applicable to small island states and low-income nations as to as to large, industrialized reef economies. The message is simple but powerful: doing less can be a valid, even superior, form of climate action—when it is intentional and rooted in care, context, and ethical restraint, and shaped by the communities it affects.

Realizing MIMO at scale, for coral reefs or other Anthropocene conservation challenges, will require deeper institutional shifts: more reflexive governance, sustained investment in system care, and value frameworks grounded in equity and ecological integrity.[36,78,79,157] These shifts are essential to reposition purposeful restraint, not as passive inaction, but as an active form of responsible, radical, and considered stewardship.[18] Crucially, shifts to institutionalize such restraint must also contend with systemic pressures, including economic and political incentives that reward growth, novelty, visibility, and marketable solutions over long-term sustainability.[158] Understanding how such shifts emerge—and how they can be supported across science, policy, and civil society—is a critical research frontier for responsible climate action[36].

CONCLUSIONS

The urgency to act on climate threats to coral reefs is driving new scientific pursuits shaped by a genuine desire to help—but also by human intervention bias, technocratic worldviews, societal expectations, political demands, and financial incentives. Updated conservation strategies are undoubtedly needed in the Anthropocene. But, evocative narratives of urgency, existential threat, and innovative solutions risk narrowing our collective imagination, crowding out genuine consideration of alternatives, and creating a false sense that only backward-looking or speculative options remain. MIMO is challenging this narrowing by offering a viable, ready, alternative, with less risk and potentially far higher long-term yields.

Informed by interdisciplinary principles, MIMO synthesizes an array of options for intervening differently within an integrated conservation philosophy. This integration provides a framework that can be adapted to local cases to guide specific decision-making problems and inspire new management approaches. At MIMO's core lies a redefinition of ecological health: a shift from defining and measuring states and symptoms, toward supporting intrinsic dynamics that foster system-level metabolism and homeostasis as temperatures rise. The guiding principle is simple: "MIMO."

Ultimately, MIMO is challenging our heating world to consider an uncomfortable question, what do we desire more: a new, evolving configuration of an ecosystem shaped by natural dynamics, or a technologically managed display of what we believe nature used to, and should, look like (at the cost of upscaled industry and carbon emissions)? As escalating climate change imposes real, hard limits on both coral reefs' and humanity's welfare, the time has come for scientists, funders, and policymakers to reconsider what needs to be done, and to reappraise what conservation strategies cost, and what they can achieve. Traditional approaches and active interventions can play an important role, especially in clearly defined, bespoke, small-scale, short-term protection of *corals* and the engagement, inspiration, or economic support of local communities and scientists. These are valuable. But, we need to seriously question whether they can deliver large-scale benefits to *global social-ecological reef systems* beyond 2030 or indeed 2050. Embracing ideas like MIMO can open space for other, innovative, radical approaches—ones that are aligned with the future we are entering—and that can support climate-impacted corals, *and* coral reefs, *and* the people who depend on them.

Rather than a single route to success, MIMO offers a shared ethos—one that invites reflection, care, and context-specific stewardship across ecological and cultural landscapes. Where traditional and interventionist solutions dominate the conversation, MIMO offers an entry point for communities and practitioners to ask: what is needed, what is possible, and what should be left alone? MIMO is not about doing less for the sake of it, but about doing what is appropriate, and about widening the conversation on what constitutes serious, viable options for responsible climate action. We are not out of time for reflection and restraint; we are out of time for illusions.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

SUPPLEMENTAL INFORMATION

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