FUNCTION OVER FIDELITY: CORAL REEFS AND THE FUTURE OF CONSERVATION LAW

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Abstract: Coral reefs are among the first ecosystems to cross a major climate-induced threshold soon to be imposed on many more habitats—when ecological function cannot be maintained by remaining fully faithful to recent historical state. In Florida, two of the keystone species—elkhorn and staghorn coral—that built shallow reef structures are now functionally extinct in the wild, and restoration of reefs to historical baselines is no longer feasible. Yet the international, federal, and state laws that govern coral conservation embed a powerful preference for historical fidelity and native composition, discouraging or prohibiting forward-looking interventions—from assisted gene flow to the introduction of non-native ecological replacements—that have better chances of preserving the reef's ecological function.

Using Florida's Coral Reef as a frontline case study, this Article argues that unconditional fidelity to historical and "natural" baselines is no longer a defensible default for conservation law. It surveys the full spectrum of possible interventions and the scientific, legal, and ethical tradeoffs each entails, and it contends that the law should move from categorical native/non-native prohibitions toward a structured, risk-assessment-based framework—one that authorizes interventions in reversible stages, invites meaningful public and cross-jurisdictional participation, and adapts as it learns. Coral reefs are the leading case, but the problem, and the framework we propose, extends across conservation law.

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INTRODUCTION

Coral reefs worldwide are in accelerating decline.[1] Historically among the most biodiverse and economically valuable ecosystems on Earth,[2] over the past decade corals have been subject to successive marine heatwaves producing bleaching events of unprecedented severity and geographic reach. This includes the 2023 event in the western Atlantic, which ranks among the most severe ever recorded.[3] These heatwaves, together with more direct human impacts such as land-based pollution and overfishing, have already led to the loss or severe degradation of fifty percent of the world's reef since 1950, and the rate of loss continues to climb.[4] Although especially acute, these challenges are not unique to coral reefs: anthropogenic climate change is fundamentally altering the habitats of species across the globe.[5]

It is becoming increasingly clear that conservation law and policy must reckon with a difficult choice: (1) allow environmental change to occur with minimal intervention; (2) attempt to maintain the historical status quo, even as a changing climate makes doing so increasingly costly if not impossible; or (3) sacrifice some level of historical fidelity in an attempt to maintain ecosystem function and/or ensure the survival of a threatened landscape, ecosystem, community, or species.

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[1] GLOBAL CORAL REEF MONITORING NETWORK, STATUS OF CORAL REEFS OF THE WORLD: 2020 (D. Souter, S. Planes, J. Wicquart, M. Logan, D. Obura & F. Staub eds., 2021) (reporting an approximately 14% loss of the world's living coral cover between 2009 and 2018 and warning of continuing global decline driven by climate change and local stressors); *see also* T. C. Eddy et al., *Energy Flow through Marine Ecosystems: Confronting Transformation of Coral Reefs and Other Marine Habitats*, 4 ONE EARTH 1278 (2021) (estimating that roughly half of living coral cover worldwide has been lost since the 1950s).

[2] MARK D. SPALDING ET AL., WORLD ATLAS OF CORAL REEFS 14 (1st ed. 2002), https://ia600208.us.archive.org/6/items/worldatlasofcora01spal/worldatlasofcora01spal.pdf, LAURETTA BURKE & JON MAIDENS, REEFS AT RISK IN THE CARIBBEAN 54 (1st ed. 2004).

[3] K. L. Neely et al., *Too Hot to Handle? The Impact of the 2023 Marine Heatwave on Florida Keys Coral*, 11 FRONTIERS IN MARINE SCIENCE 1489273 (2024); M. L. Doherty, J. V. Johnson & G. Goodbody-Gringley, *Widespread Coral Bleaching and Mass Mortality during the 2023–2024 Marine Heatwave in Little Cayman*, 20 PLOS ONE e0322636 (2025).

[4] Tyler D. Eddy et al., *Global Decline in Capacity of Coral Reefs to Provide Ecosystem Services,* 4 ONE EARTH 1278, 1278-79 (2021).

[5] *See, e.g.,* Sarah Cooley et al., *Oceans and Coastal Ecosystems and Their Services*, in CLIMATE CHANGE 2022: IMPACTS, ADAPTATION AND VULNERABILITY 379, 381 (Hans-O. Pörtner et al. eds., 2022).

This choice inevitably comes with tradeoffs. Yet as it stands today, the legal structures governing conservation policy at the state and federal level do not give policymakers the flexibility to consider the tradeoffs of each approach. Instead, laws largely prioritize maintenance of the status quo and bar actions that would depart from an ecosystem's preexisting state.

This Article advocates for a risk assessment-based approach to conservation law and policy that moves away from the goal, long enshrined in state and federal law, of unconditional fidelity to a historical or "natural" state. It focuses on Florida's Coral Reef as a frontline case study of the challenges that conservation policy needs to grapple with immediately as climate change irreversibly alters an increasing number of habitats and ecosystems. The example is especially instructive because Florida's Coral Reef is in a dire state but remains tremendously valuable. Florida's Coral Reef is an iconic element of state identity,[6] and there is pervasive sentiment that the reef ecosystem must be protected and maintained.[7] Yet coral decline has been particularly acute in Florida, where decades of compounding stressors have driven keystone reef-building coral populations to functional extinction, eroding the ecosystem's capacity for self-sustaining recovery.[8] In fact, region-wide decline has already led to unprecedented change in Caribbean reef community structure and function.[9] Scientific consensus following the 2023 bleaching and mortality event[10] suggests that Florida's staghorn and elkhorn corals — the key species responsible for building Florida's Coral Reef in the geological past[11] — are now functionally extinct *in situ* and are unlikely to recover without more radical conservation interventions.[12]

Perhaps more important than these ecological attributes are the legal ones. That is, the existing governance system for managing Florida's Coral Reef is both one of the most legally advanced in the world but nonetheless woefully inadequate for addressing the current and impending management challenges. For well over a century, the largely decentralized, overlapping, and partially coordinated federal and state management regime has primarily focused on "historical preservation" — that is, maintain or restore species and ecosystems to a particular historical baseline.[13] To a lesser extent, certain conservation laws, such as the Endangered Species Act, also promote "natural preservation" or "nonintervention"—prohibiting, or at least minimizing, direct human impacts on and forward-looking management of, ecosystems (and especially vulnerable species).

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[6] BURKE & MAIDENS, *supra* note 2, at 99.
[7] *Id.*
[8] Derek P. Manzello et al., *Heat-Driven Functional Extinction of Caribbean Acropora Corals from Florida's Coral Reef*, 390 SCI. 361, 364-65 (2025).
[9] L.T. Toth et al., *The Unprecedented Loss of Florida's Reef-Building Corals and the Emergence of a Novel Coral-Reef Assemblage*, 100 ECOLOGY e02781, 1 (2019).
[10] In June 2024, scientists counted only 23 surviving native, wild elkhorn corals in the Florida Keys, with none surviving south of Key Largo. ERICH BARTELS ET AL., THE STATUS OF ACROPORA PALMATA FOUNDERS IN SOUTH FLORIDA AFTER THE 2023 MARINE HEAT WAVE 2 (2024).
[11] Ilsa B. Kuffner & Lauren T. Toth, *A Geological Perspective on the Degradation and Conservation of Western Atlantic Coral Reefs*, 30 CONSERVATION BIOLOGY: THE JOURNAL OF THE SOCIETY FOR CONSERVATION BIOLOGY 706, 709 (2016); George Roff, *Evolutionary History Drives Biogeographic Patterns of Coral Reef Resilience*, 71 BIOSCIENCE 30, 36-39 (2021); Manzello et al., *supra* note 8, at 365.
[12] Manzello et al., *supra* note 8, at 361-62.
[13] Alejandro E. Camacho, *Transforming the Means and Ends of Natural Resource Management*, 89 N.C. L. REV. 1405 (2011).

These regimes obstruct consideration and deployment of strategies that may help ecosystems like Florida's Coral Reef adapt to the environmental changes already underway. Undoubtedly, as Florida's Coral Reef has declined, efforts have slowly accelerated to add genetic diversity to its elkhorn population by breeding them with elkhorns elsewhere in the Caribbean and outplanting the offspring to wild reefs.[14] Some are even pushing governmental authorities to allow a broadening of this effort to additional sites and species.[15] Still others argue for exploration of more active interventions like coral "ecological replacement" (ER)—the substitution of native species that have become functionally extinct with more robust non-native species, with the goal of increasing resilience, restoring lost coral cover, and rebuilding a flourishing reef.[16]

However, prevailing natural resources law—including the many international, U.S., and Florida statutes and regulations governing Florida's coral species—and associated ethical perspectives embody a bias in favor of historical preservation that is not well suited to the rapidly changing environmental conditions of today.[17] The future of Florida's Coral Reef depends on an exploration of what, realistically, must and can be done to conserve functioning ecosystems, even if native, preexisting coral species cannot be saved in situ. More broadly, the future success of ecological conservation will depend on an openness to all strategies, even those that do not unconditionally prioritize the survival of certain preexisting species and communities. Crucially, policymakers must begin to explore how to best establish and coordinate a multi-stage process for ex situ and in situ research, testing, and potential deployment of a range of potential management strategies, informed by the best available science and robust involvement of affected interests, including those outside Florida.[18]

The Article proceeds in five parts. Part I surveys the current state of Florida's Coral Reef and the environmental factors driving its decline. Part II explores the tradeoffs of different potential interventions in Florida's coral ecosystems to replace, or otherwise compensate for, the loss of key native species and ecosystem functions. Part III considers the legal rules that control the interventions we discuss in the Article. Part IV explores the ethical dimensions of such interventions. Part V advocates for a new approach to, and legal framework around, conservation policy that employs risk assessment as its lodestar and integrates an adaptive management approach to effectively implement conservation policy under conditions of uncertainty.

I. THE STATE OF FLORIDA'S CORAL REEF

[14] Bailey Marquardt et al., *First outplanting of Caribbean elkhorn corals generated by international assisted gene flow to enhance thermal tolerance*. 16th International Coral Reef Symposium, Auckland, New Zealand, 19 - 24 July 2026 (manuscript on file with authors).
[15] Andrew C. Baker et al., *Proactive Assisted Gene Flow for Caribbean Corals in an Era of Rapid Coral Decline*, 389 SCIENCE 344, 347 (2025).
[16] Michael M. Webster & Daniel E. Schindler, *Ecological Replacement for Reef-Building Corals,* 14 NATURE CLIMATE CHANGE 776, 776 (2024); John C. Briggs, *Atlantic Coral Reefs: The Transplantation Alternative*, 11 BIOLOGICAL INVASIONS 1845–1854 (2009).
[17] *See* Alejandro E. Camacho, *Assisted Migration: Redefining Nature and Natural Resource Law Under Climate Change*, 27 YALE J. REG. 171, 225 (2010).
[18] Mark W. Schwartz, et al., *Managed Relocation: Integrating the Science, Regulatory, and Ethical Challenges*, 62 BIOSCIENCE 732, 738-743 (2012).

Corals are imperiled worldwide by climate change, which is driving devastating episodes of mass coral bleaching, during which corals turn pale or white and die as a result of prolonged heat stress.[19] In most locations, these climate-change impacts are superimposed on local stressors — including declining water quality, loss of herbivorous fish, and disease outbreaks — that exacerbate coral losses and prevent recovery. This is particularly true in the tropical western Atlantic, which includes the Caribbean Sea, Gulf of Mexico, Bahamas, Bermuda, and Florida.[20] Most of these reefs have reached a point at which they are unlikely to recover to their historical states without radical changes in restoration approach, coupled with mitigation of local stressors and meaningful climate action.[21] Since the 1970s, and perhaps earlier,[22] these combined factors have driven dramatic change in reef community composition, accompanied by the loss of fundamental ecological functions, such as the creation of complex habitat and the ability of the reef to accrete vertically.[23]

In the absence of active reef-building, reefs have already measurably eroded and, if these trajectories continue, will have largely disappeared before the end of the century.[24] Without them, the key services they provide to the local communities will also be lost: there will be reduced tourism, fewer nearshore fisheries, and seafront properties will be at 30-fold higher risk of hurricane damage from coastal inundation.[25]

The reasons for the loss of recovery capacity are numerous and continue to be a subject of ongoing research. Multiple environmental factors hamper rapid coral regrowth, such as increasingly frequent heat waves, hurricanes, and emerging coral diseases. Additional local stressors such as pollution, eutrophication, and overfishing have also impacted coral recovery and the recruitment of coral larvae.[26] Further exacerbating these problems, western Atlantic reefs are home to as much as an order of magnitude fewer reef-building coral species than reefs in the Indo-Pacific, with fewer functional groups and less redundancy within groups.[27] For example, western Atlantic reefs lack an entire ecological guild of corals termed "super-recruiters", which some assert are substantially responsible for rapid reef recovery, when it occurs, in the Indo-Pacific.[28] Since the late Pleistocene, shallow western Atlantic reefs have been built predominantly by just a handful of species: elkhorn coral (*Acropora palmata*), staghorn coral (*Acropora cervicornis*), and three sister species of star coral (*Orbicella* spp.).[29] Since the late 1970s, these formerly dominant taxa have

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[19] Hughes et al., *Global Warming Transforms Coral Reef Assemblages*, 556 NATURE 492, 492 (2018); *see also* James R. Guest et al., *A Framework for Identifying and Characterizing Coral Reef "Oases" Against a Backdrop of Degradation*, 55 J. APPLIED ECOLOGY 2865 (2018).
[20] Global Coral Reef Monitoring Network, *supra* note 19. at 3.
[21] Kuffner & Toth, *supra* note 11, at 706–15.
[22] Cramer et al., *Widespread loss of Caribbean acroporid corals was underway before coral bleaching and disease outbreaks*, 6 SCI. ADV. E9395, 2 (2020).
[23] Alvarez-Filip et al., *Flattening of Caribbean Coral Reefs: Region-Wide Declines in Architectural Complexity*, 276 PROC. BIOL. SCI. 3019 (2009).
[24] Toth et al., *supra* note 9, at e02781.
[25] Filippo Ferrario et al., *The Effectiveness of Coral Reefs for Coastal Hazard Risk Reduction and Adaptation*, 5 NATURE COMMUNICATIONS 1, 3-9 (2014).
[26] *See* Robert H. Richmond, Kaho H. Tisthammer & Narrissa P. Spies, *The Effects of Anthropogenic Stressors on Reproduction and Recruitment of Corals and Reef Organisms*, 5 FRONTIERS IN MARINE SCI. 3 (2018).
[27] JOHN EDWARD NORWOOD VERON & MARY STAFFORD-SMITH, CORALS OF THE WORLD (2000).
[28] Roff, *supra* note 11, at 34.
[29] *See* D.R. Bellwood et al., *Confronting the Coral Reef Crisis*, 24 NATURE 827, 829 (2004).

shown declining recruitment and are now disappearing, changing the appearance of contemporary Atlantic reefs.

II. TRADEOFFS AND UNCERTAINTIES OF POTENTIAL INTERVENTIONS

What alternative strategies might be used to address the harm caused by climate change and other stressors? One option is the counterfactual: non-intervention. Do nothing and let the ecosystem adapt on its own, potentially continuing to degrade if adaptation is insufficient. Under the "Resist-Accept-Direct" framework advanced by the National Park Service for assessing potential strategies for managing ecological change,[30] an "acceptance" strategy would essentially accept the demise of elkhorn and staghorn corals and manage the areas to facilitate autonomous transition to different ecological communities. Such management might be motivated by the hope that a novel coral community (perhaps dominated by boulder corals) will naturally emerge to maintain the ecological functions of the reef.[31] Nonintervention is certainly a fundamental goal of numerous other conservation regimes and embedded in countless legal provisions emphasizing preservation of "natural" phenomena.[32]

However, there is so far little indication that such a transition is underway here, and consequently relying on it is likely to be a very risky proposition.[33] In any case, the loss of elkhorn and staghorn would imply a dramatic change in reef structure, most likely cascading into substantial losses of biodiversity that was adapted to the reefs' historical shape and form.[34] For these reasons, this option is widely considered both risky and incompatible with biodiversity goals.

Beyond acceptance of ecosystem transition, Figure 1 presents a range of strategies for scientists and policymakers to consider that progressively depart from historical fidelity and increasingly involve human-directed design.[35] These are more fully explored in the subsections below. Although applying this range of strategies to Florida's Coral Reef may be novel, the interventions themselves have, to varying degrees, already been considered and even successfully implemented in many other ecosystem-management contexts.

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[30] *See* G. W. Schuurman et al., *Navigating Ecological Transformation: Resist–Accept–Direct as a Path to a New Resource Management Paradigm*, 72 BIOSCIENCE 16 (2022); A. L. Sesser et al., *Integrating the Resist-Accept-Direct Framework into Natural Resource Decision-making Processes for Climate Adaptation*, CONSERV. BIOL. e70116 (2025).

[31] Evidence suggests that this hope may be misguided. *See* Katie L. Cramer et al., *Widespread Loss of Caribbean Acroporid Corals Was Underway Before Coral Bleaching and Disease Outbreaks*, 22 SCI. ADV. eaax9395 (2020) (showing that elkhorn and staghorn corals are being replaced by disturbance-tolerant, low-relief "weedy" species that do not maintain equivalent ecological functions).

[32] See Alejandro E. Camacho, et al., *Adapting Conservation Governance under Climate Change: Lessons from Tribal Country*, 110 VA. L. REV. 1549 (2024).

[33] *See* Cramer et al., *supra* note 31.

[34] Alvarez-Filip et al., *supra* note 23, at 3022.

[35] Richard T. Corlett, *Restoration, Reintroduction, and Rewilding in a Changing World*, 31 TRENDS IN ECOLOGY & EVOLUTION 453 (2016).

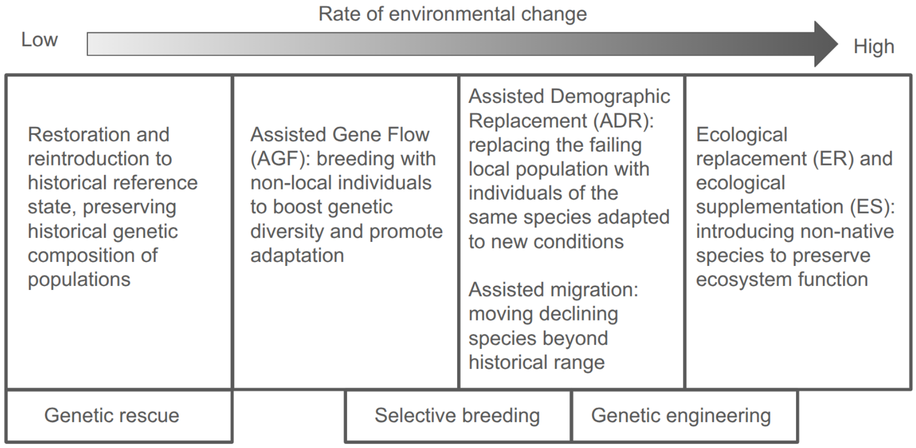

Figure 1. Shift in the choice of conservation measures affected by the rate of environmental change and/or declining ecosystem health. Population-level interventions are in larger boxes; interventions requiring selection and/or modification of individual genotypes are in smaller boxes.[36]

Because these strategies differ not only in kind but in the specific tradeoffs and uncertainties they present, it is useful to compare them along a consistent set of dimensions before examining each in turn. Table 1 summarizes, for each strategy, how far it departs from historical fidelity, its principal ecological risk, its key scientific uncertainty, and how reversible it is once undertaken.

Strategy	Departure from historical fidelity	Principal risk	Key scientific uncertainty	Reversibility
Acceptance (non-intervention)	Large; forfeits historical species and accepts autonomous transition to a novel community	Loss of elkhorn, staghorn, and other coral species; cascading biodiversity loss and structural collapse of the reef	Whether a functional novel coral community would emerge at all	Low — losses likely irreversible
Historical preservation (restoration to baseline)	None; aims to restore the historical assemblage and reef structure using locally sourced stock	Minimal ecological risk, but outplants are increasingly poorly adapted to current conditions	Whether outplants recruit naturally, and whether historically adapted corals can survive present conditions	High, but likely infeasible at meaningful scale
Genetic rescue	Small; aims to maintain same historical species and reef structure, with unrelated individuals added to relieve inbreeding depression	Shared parentage in the first generation post-intervention, leading to even worse inbreeding later generations; unintended carryover introductions (e.g., pathogens)	Not yet applicable to Caribbean *Acropora*, which do not show inbreeding depression and do not breed in the wild	Low: cannot remove the introduced ancestry once breeding starts.
Assisted gene flow (AGF)	Small; aims to maintain same historical species and	Outbreeding depression; unintended	F1/F2 hybrid viability; the risk scales with the adaptive benefit it creates	Partial; effects accrue incrementally

[36] *Id.* at 453-462 (2016); National Academies of Sciences, Engineering, and Medicine, Committee on Interventions to Increase the Resilience of Coral Reefs, A Research Review of Interventions to Increase the Persistence and Resilience of Coral Reefs (2019).

Strategy	Departure from historical fidelity	Principal risk	Key scientific uncertainty	Reversibility
	reef structure, sourced from distant populations to promote adaptation	carryover introductions (e.g., pathogens)		
Assisted migration	Moderate; moves a species outside its historical range to save the species, not its native ecosystem, and does not aim to preserve reef structure in historical location	Impacts on recipient ecosystems (e.g., competition with native species)	Environmental limits at the new range; limited applicability where species are already region-wide	Variable; may depend on whether species was formerly present in new location during the Holocene
Assisted demographic replacement (ADR)	Moderate; forfeits the local historical population while retaining the species and reef structure	Failure of imports to establish; ecosystem disruption; carryover introductions	Whether imports thrive upon translocation; wholly novel, with no precedents or policies	Low
Selective breeding	Small; aims to preserve the native species in its location in revitalized form and thereby the historical reef structure	Low ecological risk, but reduces genome-wide variation (inbreeding; diminished adaptive capacity); high potential for trait tradeoffs	Complex, polygenic traits may change populations unpredictably; whether breeding can keep pace with climate given (at least) 3–5-year generation times	Moderate
Genetic engineering	Moderate; aims to preserve the native species in revitalized form, thereby maintaining historical community structure	Low inherent risk, with greater genotypic control than breeding, but reduces genome-wide variation; public opposition over "unnaturalness"	Requires knowing the genetic basis of target traits, still largely untested	Moderate
Ecological replacement / supplementation (ER/ES)	High; surrenders disappearing native species to focus on preservation of ecological function and similar reef structure	Competition with and displacement of natives; carryover introductions; harm to the recipient ecosystem; public opposition over "unnaturalness"	Whether non-natives survive, settle, form symbiosis, and complete reproductive life cycles in the western Atlantic	Low; irreversible once non-native larvae start to disperse

Table 1. Comparative risks, potential benefits, and uncertainties of the intervention strategies considered in this Part. Strategies are ordered by increasing departure from historical fidelity.

A. Historical Preservation

Traditionally, the goal of ecological restoration has been to return species and ecosystems to their historical state, using locally sourced biological material.[37] This "local is best" approach is the prevailing mindset globally and still dominates the agencies in charge of U.S. coral conservation,

[37] Corlett, *supra* note 35, at 458.

including the Florida Fish and Wildlife Conservation Commission (FWC) and NOAA's Office of National Marine Sanctuaries (ONMS).[38] Mission: Iconic Reefs, the flagship coral-restoration effort in the Florida Keys, best illustrates this approach: it aims to revitalize seven historically prominent reefs with outplanted fragments of nursery-propagated local corals.

However, the environment of Florida's Coral Reef has changed dramatically over the past few decades, and the ocean has warmed significantly.[39] This has led to a precipitous decline in foundational coral species and the broader ecosystem.[40] As such, it appears that the corals that historically grew on these reefs — and which provide the nursery stock for current restoration efforts — are no longer adapted to local conditions. Indeed, most corals outplanted by Mission: Iconic Reefs were killed in the 2023 marine heatwave,[41] even though some had already begun to form new reef structure and to spawn. Even when outplanted fragments grow well and spawn, as is the case for the Fragments of Hope effort in Belize,[42] the critical question — whether such spawning is followed by recruitment at the same location or elsewhere — remains unanswered, in part because recruitment is not a standard metric of restoration success. Yet without successful natural recruitment, corals can persist only at the rate at which we can manually outplant them, which is unsustainable at any ecologically meaningful scale.[43]

At this point, restoration of Florida's Coral Reef to historical baselines appears to no longer be feasible, and this may be broadly true for the rest of the western Atlantic. If so, there will be significant pressure to at least initiate research on restoring ecological function using interventions that are less tethered to historical conditions (Fig. 1).[44]

B. Genetic Rescue

Genetic rescue is a significant departure from natural preservation (as defined above) but only an incremental departure from historical preservation, as it is highly interventionist with the goal of increasing the resilience of preexisting populations to changing conditions. It helps populations that have declined so dramatically that most breeding occurs between genetically related individuals (i.e., that have begun to inbreed). Inbreeding can lead to severe fitness decline as recessive deleterious mutations become homozygous. Genetic rescue consists of importing genetically unrelated individuals to breed with the local population, which alleviates inbreeding and can substantially restore fitness.[45] In doing so, this intervention involves a slight sacrifice of historical fidelity. These genetically unrelated individuals would not historically have been present in the local population, but the species itself remains present. Outwardly, this means the local

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[38] *See, e.g.*, Eric Higgs et al., *The Changing Role of History in Restoration Ecology*, 12 FRONT. ECOL. ENVIRON. 499, 499-500 (2014).
[39] Paul Julian II et al., *Long-Term Patterns and Trends in Water Column Biogeochemistry in a Changing Environment*, 306 ESTUARINE, COASTAL AND SHELF SCI. 1, 2 (2024); *see generally* Ilsa B. Kuffner et al., *A Century of Ocean Warming on Florida Keys Coral Reefs: Historic In Situ Observations*, 38 ESTUARIES AND COASTS 1085 (2015); Derek P. Manzello, *Rapid Recent Warming of Coral Reefs in the Florida Keys*, 5 SCI. REPORTS e16762 (2015).
[40] Toth et al., *supra* note 9, at e02781; Kuffner & Toth, *supra* note 11, at 708.
[41] Manzello et al., *supra* note 8, at 361.
[42] Lisa Carne, *Is It Time to Give Up Trying to Save Coral Reefs? My Research Says No*, 634 NATURE 755 (2024).
[43] *Id.*
[44] Roff, *supra* note 11, at 34.
[45] Andrew R. Whiteley et al., *Genetic rescue to the rescue*, 30 TRENDS ECOL. EVOL. 42, 42 (2014).

ecosystem will appear relatively unchanged. This intervention also entails little ecological risk, as no new locally maladaptive alleles are likely to be introduced. The largest risk is that one of the imported individuals would become a parent of the majority of the first-generation offspring, in which case catastrophic inbreeding is inevitable in the subsequent generations. For corals, genetic rescue is not likely to be applicable yet since populations are not at risk of inbreeding: for example, despite catastrophic declines of Florida's elkhorns, the remaining individuals still represent the genetic diversity of a much larger population prior to the decline.

In practice, genetic rescue has an established track record in animal conservation. The Florida panther noted above is the best-known example: in the 1990s, eight female pumas were translocated into the population to diversify its gene pool and relieve inbreeding depression.[46] Genetic rescue likewise brought the Columbia Basin pygmy rabbit back from near-extinction by introducing other rabbits to restore genetic diversity.[47] And to save the imperiled black-footed ferret, the U.S. Fish and Wildlife Service (USFWS) cloned individuals from the cryopreserved cells of a ferret with no living descendants.[48]

C. Assisted Gene Flow

Assisted gene flow is the first true step away from strict historical preservation (Fig. 1), because it is intended to promote adaptation to environmental change.[49] It consists of importing members of the same species from distant locations in the hope of introducing adaptive genetic variants that will help the focal population evolve. The major theoretical risk is outbreeding depression: foreign alleles may disrupt locally adapted allele complexes, making the focal population less fit to its environment, or may introduce genetic incompatibilities.[50] Unfortunately, the potential benefit of AGF scales with this risk: the more genetically remote the source population, the greater the chance of introducing novel adaptive variants — but also the greater the risk of outbreeding depression.

Assisted gene flow is not merely theoretical. It is used as a core tool of the U.S. Forest Service, through its Assisted Migration Adaptation Trial, to protect whitebark pine by moving seeds from disease-resistant or warmer, lower-elevation stands to colder sites now experiencing warming.[51] Because these were federal actions, they were reviewed under both the Endangered Species Act and the National Environmental Policy Act (NEPA): the ESA weighed the risk of intervention against the risk of inaction through a Species Status Assessment calling for scenario analysis,[52]

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[46] Diana Aguilar-Gómez et al., *Genetic Rescue of Florida Panthers Reduced Homozygosity but Did Not Swamp Ancestral Genotypes*, 122 PROC. NAT'L ACAD. OF SCI. e2410945122, 1 (2025)

[47] Stacey A. Nerkowski et al., *Long-Term Noninvasive Genetic Monitoring Guides Recovery of the Endangered Columbia Basin Pygmy Rabbits (*Brachylagus idahoensis*)*, 16 GENES 956 (2025).

[48] See generally Lauren Corey, *A Black-Footed Ferret and U.S. Law: Lessons Learned from the First Successful Clone of a Native U.S. Endangered Species*, 23 N.C. J.L. & TECH. 338 (2021).

[49] Sally N. Aitken & Michael C. Whitlock, *Assisted Gene Flow to Facilitate Local Adaptation to Climate Change*, 44 ANNU. REV. ECOL. EVOL. SYST. 367, 369 (2013).

[50] *Id.* at 368-69.

[51] Mary I. Williams & R. Kasten Dumroese, *Preparing for Climate Change: Forestry and Assisted Migration*, 111 J. FOR. 287, 289 (2013).

[52] *See, e.g.*, David R. Smith et al., *Development of a Species Status Assessment Process for Decisions Under the U.S. Endangered Species Act*, 9 J. FISH & WILDLIFE MGMT. 302, 306 (2018).

while NEPA required environmental-impact-assessment requirements[53] that were accompanied by opportunities for public comment.[54]

D. Assisted Migration

Assisted migration aims to translocate species from their historical range, where they are struggling under unprecedented environmental change, to a novel habitat where they are expected to thrive because the new conditions match those of their historical environment.[55] Examples include moving species poleward to escape warming[56] or moving them to wetter sites to escape pervasive drought.[57] This is a more explicit departure from historical fidelity as compared to genetic rescue or assisted gene flow, but does not sacrifice historical fidelity altogether. The translocated species continues to exist in an environment that, to some degree, resembles its original environment in terms of its functional niche and/or the community composition.

The potential for this type of intervention in the western Atlantic is limited because the principal coral species already have region-wide distributions, with the exception of *Acropora*, which is absent from Bermuda, and many other taxa missing from Brazil (which also has a high number of endemic coral species). The only viable option for assisted migration is moving corals beyond their current latitudinal range, particularly northwards along Florida's southeast coast, to help them escape increasingly frequent heat waves in their native range. Research in this direction is ongoing, but several environmental limits constrain such movements, such as the lack of natural hardbottom substrate and widespread beach renourishment nearshore. It is important to recognize, however, that the general goal of these efforts is to save the species being moved, and not necessarily to restore its native ecosystem. While assisted migration of corals toward higher latitudes might buy some time for individual species, it is constrained by other factors, such as light[58] and aragonite saturation state,[59] and is not a solution for saving species, or preserving reefs, in their historical range. Additionally, assisted migration may raise concerns about the impact on species or ecosystem function in the recipient ecosystems.

Regulators have likewise begun to embrace assisted migration in practice.[60] When USFWS modernized the Endangered Species Act's §10(j) rules to permit establishment of experimental populations outside a species' historical range even where existing habitat is not irreversibly

[53] Where a major Federal action may significantly affect the environment, NEPA requires the preparation of an environmental impact statement assessing alternatives to and impacts of the proposed action that integrates public comment on such effects and alternatives. *See* 42 U.S.C. § 4336(b)(1); 42 U.S.C. § 4336a(c).
[54] *See generally* Council on Environmental Quality, *A Citizen's Guide to the NEPA*, https://ceq.doe.gov/docs/get-involved/citizens_guide_dec07.pdf (2007).
[55] Camacho, *supra* note 17, at 173-74; O Hoegh-Guldberg et al., *Assisted Colonization and Rapid Climate Change*, 321 SCIENCE 345, 345 (2008).
[56] *See, e.g.*, Pati Vitt et al., *Assisted Migration of Plants: Changes in Latitudes, Changes in Attitudes*, 143 BIO. CONSERV. 18, 18 (2010).
[57] *See, e.g.*, Laura K. Gray et al., *Assisted Migration to Address Climate Change: Recommendations for Aspen Reforestation in Western Canada*, 21 ECOLOGICAL APP. 1591, 1601 (2011).
[58] Paul R. Muir et al., *Limited scope for latitudinal extension of reef corals*, 348 SCI. 1135, 1136 (2015).
[59] Joan A. Kleypas, John W. McManus, and Lambert A. B. Meñez, *Environmental Limits to Coral Reef Development: Where Do We Draw the Line?*, 39 AM. ZOOLOGIST 145, 153-54 (1999).
[60] William M. Twardek et al., *The Application of Assisted Migration as a Climate Change Adaptation Tactic: An Evidence Map and Synthesis*, 280 BIO. CONSERV. e109932, 1 (2023).

altered,[61] it cleared the way to release the Guam kingfisher on Palmyra Atoll—nearly 3,700 miles from its native range, after an invasive predator rendered Guam uninhabitable—where, in 2025, the population laid eggs in the wild for the first time in four decades.[62] The Service has signaled that similar logic may soon apply domestically: with sea-level rise threatening the habitat of the endangered Florida Key deer, it has observed that few options beyond relocation outside the Keys may remain, and that establishing experimental populations outside historical ranges "will become increasingly important for the conservation and recovery of ESA-listed species."[63]

E. Assisted Demographic Replacement

One outcome of rapid environmental change may not be "classical" in-place adaptation (via selection on specific alleles), but rather wholesale demographic turnover: some populations die out and are replaced by immigrants from populations of the same species that are well-adapted to the new conditions. Such turnover is particularly likely for metapopulations with high connectivity and efficient recruitment, as is characteristic of many marine species. It is especially expected for thermal adaptation in marine species inhabiting broad latitudinal ranges: warm-adapted genotypes from lower latitudes can replace conspecifics that are struggling at higher-latitude. To an observer at a single location, this would appear as a change in whole-genome ancestry of the local population, rather than an allele-frequency shift at specific loci.

Assisted Demographic Replacement (ADR) aims to facilitate this process exactly. Superficially, ADR resembles AGF: it involves importing individuals of the same species from a distant location. The goal, however, is different: instead of enhancing the local population's adaptive potential through introgression, maladapted local genotypes are allowed to die out while imported individuals repopulate the site.[64] ADR also imposes different requirements on the choice of source population: whereas AGF is concerned chiefly with the extent of genetic divergence from the focal population, ADR seeks a source location whose environmental conditions best match the projected future of the focal one — not just in the key changing factor (e.g., temperature) but in all biologically important parameters.[65] Unlike AGF, in ADR the imported individuals are not required to interbreed with the local population; indeed, such interbreeding is best prevented, because the imported individuals are already well adapted and crossing them with locals can cause "outbreeding depression in reverse," disrupting coadapted allele complexes in the imported cohort.

ADR has two important advantages over AGF. First, ADR is faster: a few generations may suffice for newcomers to populate the new habitat, whereas under AGF many more generations may be needed for recombination to isolate adaptive alleles from their foreign genetic background. Second, ADR requires no testing of F1 and F2 hybrid fitness with locals, since no interbreeding is intended; the only testing needed is whether the imported genotypes will thrive upon translocation. Both

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[61] U.S. Fish & Wildlife Serv., *FWS Finalizes Revision of ESA 10(j) Regulations*, 77 OUTDOOR NEWS BULLETIN (2023).
[62] Sarah Kuta, *Biologists Rejoice as Extremely Rare Guam Kingfishers Lay Their First Wild Eggs in Nearly 40 Years*, SMITHSONIAN MAG. (Apr. 22, 2025).
[63] Endangered and Threatened Wildlife and Plants; Designation of Experimental Populations, 88 Fed. Reg. 42642, 42643 (2023).
[64] Lukas B. DeFillippo et al., *Assessing the Potential for Demographic Restoration and Assisted Evolution to Build Climate Resilience in Coral Reefs*, 32 ECOLOGICAL APPLICATIONS e2650, 2 (2022).
[65] *See generally* Mikhail V. Matz & Kristina L. Black, *RDAforest: Identifying Environmental Drivers of Polygenic Adaptation*, 25 MOLECULAR ECO. e70002 (2025).

AGF and ADR must take precautions to minimize the risk of unintended introductions, such as pathogens or hitchhiking species. The main problem of ADR that does not apply to AGF is value-based: ADR requires a conscious decision to forfeit the historical population. There is thus a greater sacrifice of the historical status quo involved, though outwardly the post-ADR population may appear identical to the historical population. Further, there exists a risk that the imported organisms fail to adjust to their new environment, or that their introduction disrupts the local ecosystem in an unforeseen way.

ADR is a novel idea, and we are not aware of any practical implementations or formal policies for it. Yet, particularly in the marine environment, ADR may be a viable solution to local ecosystem management, especially when the focal population is in terminal decline and likely beyond rescue (as appears to be the case for Florida elkhorns).[66] Indeed, since the Florida x Honduras trials elkhorn trials currently underway in Florida can include both Florida x Florida and Honduras x Honduras crosses as comparisons, ADR may be a potential outcome if the pure-bred Honduran elkhorns perform better than either of the other two crosses.

F. Selective Breeding

To survive, coral populations must adapt to warming oceans and the increasing prevalence of disease. Tolerance to both varies within populations. One approach, then, is to facilitate adaptation to a changing environment by selectively breeding for specific traits such as heat tolerance.[67] If successful, selective breeding has the potential to preserve a native species in revitalized form, allowing both the species and the ecosystem to be saved. Early evidence shows that selective breeding can improve population resilience in corals.[68] Theoretically, this intervention should also carry little ecological risk, because the characteristics of a selected coral (except the target trait, e.g., heat tolerance) are likely to be very similar to those of the original. Selective breeding also enjoys generally more favorable public acceptance than similar strategies such as genetic engineering (discussed *infra*), as it is perceived as more "natural" and less "hubristic."[69]

On the other hand, many stress tolerance traits are complex, and therefore selectively breeding for a specific trait may change a population unpredictably.[70] Selective breeding is also dependent on the reproductive cycle of the coral. The generation time of coral species— at least three to five years—limits the iterative capability of this intervention,[71] raising the question of whether selective breeding could keep pace with a rapidly changing climate, especially when the genetic drivers of specific target traits remain mostly unknown. In addition, selective breeding will reduce genetic variation across the rest of the genome.[72] In turn, this elevates the risk of inbreeding and limits the

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[66] Manzello et al., *supra* note 8, at 365.
[67] *See* Adriana Humanes et al., *Selective Breeding Enhances Coral Heat Tolerance to Marine Heatwaves*, 15 NATURE COMMUNICATIONS e8703, 1 (2024).
[68] *Id*.
[69] Elizabeth v. Hobman et al., *Genetically engineered heat-resistant coral: An initial analysis of public opinion*, 17 PLoS ONE e0252739, 12 (2022).
[70] Humanes et al., *supra* note 67, at 2.
[71] *Id.*
[72] *See, e.g.*, Madeleine J. H. van Oppen, Building coral reef resilience through assisted evolution, 112 PNAS 2307, 2308 (2015)

population's adaptive capacity.[73] As a result, a selectively bred population is unlikely to survive long in the wild unless additional breeding is performed to restore genetic variation.

G. Genetic Engineering

Another way to promote the appearance of specific traits is through targeted genetic engineering. Unlike selective breeding, which attempts to accelerate "naturally" occurring evolutionary processes, genetic engineering involves making deliberate and specific changes to coral genomes to alter phenotypes.[74] Genetic engineering can involve the insertion of genetic material from another species (transgenic), insertion of genetic material sourced from within the species (intragenic), or modifications of the existing genome, e.g., knocking out (or "silencing") genes or inserting entirely new DNA sequences into genes. Selective breeding and genetic engineering are similar in that they both involve intentionally modifying the genome in order to produce desired traits, but genetic engineering aims to achieve this goal by making only specific targeted genetic modifications.

Genetic engineering shares many of the drawbacks of selective breeding, discussed *supra*.[75] In addition, public opposition to genetic engineering due to perceptions of it being unnatural, "playing God," or hubristic, may make this intervention more controversial and thereby more difficult to implement. Although the public generally perceives genetic engineering as far more radical than selective breeding—particularly when it involves combining genomic material across species that could not occur without human intervention—most scientists agree it is safer because it allows more targeted intervention into the manipulated genotype and is therefore likely to produce fewer unintended genomic changes.[76]

While humans have been selectively breeding animals and plants for thousands of years by simply selecting for desired phenotypic traits, genetic engineering typically requires a thorough genetic knowledge base. One must fully understand the molecular underpinnings of traits to identify candidate modifications and assess viability; this state of knowledge has not yet been achieved for corals.[77]

Genetic modification has already been used as a conservation tool in the United States.[78][79] After the American chestnut was nearly driven to extinction by an invasive fungal blight, researchers

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[73] T.L. Shearer, I. Porto & A. L. Zubillaga, *Restoration of coral populations in light of genetic diversity estimates*, 28 CORAL REEFS 727, 728 (2009).
[74] *Id.*
[75] *Supra* Section II.F.
[76] *See, e.g.*, *supra* Section II.F (describing selective breeding as a strategy to build reef resilience); Antoinette J. Piaggio, *Is It Time for Synthetic Biodiversity Conservation?*, 32 TRENDS ECOL. EVOL. 97, 104-05 (2017); Hobman et al., *supra* note 69, at 12.
[77] *But see* Amanda I Tinoco et al., *Efficient genome editing using CRISPR–Cas9 in reef-building corals*, 21 NAT. PROTOCOLS 2851 (2026).
[78] *See* Ronald Sandler, *The Ethics of Genetic Engineering and Gene Drives in Conservation*, 34 CONSERV. BIO 378, 378 (2019)
[79] Genetic modification has also been employed for purposes other than conservation, which ultimately raise the same concerns about uncertainty and risk we highlight throughout the Article. To manage invasive populations, the U.S. Environmental Protection Agency (EPA) authorized the use of a genetically modified mosquito as an experimental biopesticide. The EPA has allowed for the release of hundreds of millions of genetically engineered mosquitoes across

genetically engineered a blight-tolerant variant; however, it has not yet been released into the wild and is undergoing regulatory review by the EPA, FDA, and USDA.[80]

H. Ecological Replacement and Supplementation by Non-Native Species

If all the foregoing interventions fail to halt reef ecosystem decline, the last remaining option is to replace the disappearing species with non-native ecological analogs. "Ecological replacement" (ER) has recently been proposed for corals in general terms,[81] but the specific idea of using imported Indo-Pacific corals to rescue Caribbean reefs dates back at least fifteen years.[82] It has been reiterated recently,[83] with specific emphasis on importing corals that exhibit the "super-recruiter" life history that has been implicated in rapid reef recovery in the Indo-Pacific.[84] Because hardly any pair of species is fully analogous ecologically, a more appropriate name for the intervention may be "ecological supplementation" (ES), which permits the introduction of non-native species that lack close native analogs but that may nonetheless serve to stabilize the ecosystem and preserve its function. ER and ES are fundamentally different from assisted migration, assisted translocation, and managed relocation in one key respect: they are not undertaken for the sake of the species being introduced, but for the sake of the ecosystem into which the species is being introduced.[85] Accordingly, their indicators of success are not the well-being of the translocated species itself but, rather, the maintenance of key ecological functions of the recipient ecosystem. For western Atlantic reefs, these indicators would be higher rates of recruitment, faster recovery of shallow reefs, the recreation of three-dimensional reef habitat, and a switch from negative reef dissolution to positive reef accretion.

In addition to the concerns over unintended carryover introductions of pathogens or invasive species that they share with AGF and ADR, ER and ES face the further uncertainty of whether the introduced species can survive in the novel environment at all. For corals in particular, these uncertainties include whether the larvae can survive in the water column during dispersal, whether they will respond to local reef cues for settlement, and whether they can establish symbiosis with

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Monroe County, Florida. The introduction of genetically modified mosquitoes was controversial. The initial proposal was met with mostly negative public sentiment, citing questions around ecological safety, human health implications, and mistrust of government or industry as reasons for opposition. *See* Cinnamon S. Bloss et al., *Public Response to a Proposed Field Trial of Genetically Engineered Mosquitoes in the United States*, 15 JAMA 662 (2017); Friends of the Earth, *Community Members and Environmental Groups Denounce Florida Keys Plans to Release Genetically Engineered Mosquitoes*, https://foe.org/news/group-denounce-fl-release-gmo-mosquito/ (Jun. 22, 2020).

[80] *See generally* Taylor M. Wegner et al., *Evaluating Transgenic Darling 54 American Chestnuts for Reintroduction: Insights from Survivorship, Growth, and Respiration in a Common Garden*, 602 FOREST ECOL'Y. MGMT. e123361 (2026) (discussing findings around transgenic chestnuts). This program has not been without hiccups. In December 2023, a lab error caused a financial partner of the project to withdraw and raised furor from skeptics. *See* Lela Nargi, *A Lab Error Just Upended Years of Work on the GMO American Chestnut Tree*, OFFRANGE, https://ambrook.com/offrange/sustainability/GMO-chestnut-controversy (Jan. 20, 2024). Today, a combination of genetic modification and genomic analysis seems to hold the most promise. *See* Catherine Walker, *Resurrecting the American Chestnut*, 12 NATURE PLANTS 485 (2026).

[81] Webster & Schindler, *supra* note 16*,* at 777.

[82] J.C. Briggs, *Diversity, Endemism and Evolution in the Coral Triangle*, 36 J. BIOGEOGRAPHY 2008, 2008 (2009).

[83] Alejandro E. Camacho, David A. Dana & Mikhail Matz, *Coral Species from Another Ocean May be the Only Way to Save Caribbean reefs*, 123 PROC. NAT'L ACAD. SCI. 1, 1 (2026).

[84] Roff, *supra* note 11, at 26.

[85] D.M. Richardson et al., *Multidimensional Evaluation of Managed Relocation*, 106 PROC. NATL. ACAD. SCI. 9721 (2009); Camacho, *Assisted Migration*, *supra* note 17, at 171 (2010); Schwartz et al., *supra* note 18, at 735.

algal symbionts (Family Symbiodiniaceae) found locally. Encouragingly, at least some Indo-Pacific corals have demonstrably, albeit unintentionally from a regulatory perspective, survived in the western Atlantic.[86] In those cases, however, the non-native corals most likely persisted through asexual reproduction; if so, it remains unclear whether they can complete their sexual life cycle at the introduced site — including detecting appropriate spawning cues, being fertilized by a compatible mate, successfully dispersing as a larva, finding an appropriate location to settle, and establishing a successful symbiosis with algae and other partners.

However large the technical uncertainties, the largest problem with ER and ES is arguably value-based: committing to them means giving up not only on the genetic legacy of a local population (as under ADR), but on the native species itself as a major constituent of the ecosystem. Indeed, pursuing these interventions not only does not help local species; the introduced species may in fact contribute to the displacement of their local counterparts due to competition over scarce resources. Extremely difficult decisions such as these may be unavoidable if the native species has declined past any realistic hope of returning to its former ecological prominence in a reasonable restoration timeframe. On the positive side, committing to ER and ES decouples the task of saving a native species from extinction from the task of preserving ecosystem function, which may render both tasks more achievable. In other words, we may successfully preserve wild elkhorn corals on reefs in some locations, where it may even need to be introduced, but we no longer rely on it to form the reef crest structures that formed a bulwark against storms in millennia past.

ER and ES carry some of the same concerns seen with AGF and ADR: introduction of pathogens or hitchhiking species, but also an additional risk: potential unintended harm to the recipient ecosystem when an entirely novel species (especially one with no native ecological analogs) is introduced. This risk is impossible to quantify accurately prior to deployment because it depends on unpredictable emerging ecological interactions. Indeed, it can only be reasonably estimated through a series of preliminary trials, first in mesocosms and then on actual reefs, making sure the newcomer does not sexually reproduce uncontrollably. For many coral species that are candidates for ER, preventing unintended sexual reproduction may be as straightforward as placing different coral genotypes far enough apart to prevent cross-fertilization,[87] although this might not prevent potential inter-specific hybridization with native coral species.

Federal agencies have already attempted ecological replacement of this kind in other contexts. The USFWS, for instance, cites the introduction of giant tortoises in the Galápagos as a guiding example: after an endemic tortoise went extinct on Santa Fé Island—causing the loss of ecological functions such as grazing, seed dispersal, and vegetation trampling—the Galápagos National Park Directorate introduced the Hood Island giant tortoise from nearby Española Island to re-establish those functions.[88]

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[86] *See, e.g.*, Peter W. Glynn et al., *The true identity of* Siderastrea glynni *Budd & Guzmán, 1994, a highly endangered eastern Pacific scleractinian coral*, 35 CORAL REEFS 1399, 1400 (2016); S. L. Bush et al., *Indo-Pacific Mushroom Corals Found on Jamaican Reefs*, 23 CORAL REEFS 234 (2004)
[87] Peter J. Mumby et al., *Allee effects limit coral fertilization success*, 121 PNAS e2418314121, 1 (2024).
[88] Washington Tapia, Harrison B. Goldspiel & James P. Gibbs, *Introduction of Giant Tortoises as a Replacement "Ecosystem Engineer" to Facilitate Restoration of Santa Fe Island, Galapagos*, 30 RESTORATION ECOLOGY e13476, 8 (2021).

I. Precedents and the Governance Gap

There are growing efforts to study and implement novel intervention strategies like those described here in other threatened ecosystems, particularly as climate adaptation strategies. A number of frameworks have been offered in the scholarly literature for assessing the technical, legal, and ethical tradeoffs involved in some of these interventions.[89] Nonetheless, while some policymakers have encouragingly sought to assess at least some of the tradeoffs of introducing new strategies, most have pursued these novel strategies as *ad hoc* experiments or isolated interventions.

Over the past fifteen years, scholars,[90] conservation organizations,[91] international governmental and scientific consortia,[92] government officials,[93] and governments[94] have developed guidelines and best practices for conservation translocations to manage the effects of climate change. Despite these broader discussions and efforts, the coral reef field has lagged behind, notwithstanding the extreme level of climate threat. Consequently, there is a valuable opportunity to consider and craft holistic governance and evaluation frameworks before the deployment of interventions. Doing so may require substantial changes to existing rules and policies, as we discuss in the next section.

III. LEGAL RESTRICTIONS AND UNCERTAINTIES

Few scholars and policymakers have begun to even consider whether the law might allow introductions such as coral ecological replacement or assisted migration to new areas in coral ecosystems. This is in significant contrast to terrestrial ecosystems, where, particularly in the last fifteen years, legal analysis has explored the range of public land, endangered species, invasive species, and other wildlife management laws that might affect the intentional movement of species outside their native range.[95]

The laws potentially implicated by these various conservation strategies–and particularly those with the largest departure from historical baselines–are a thicket of overlapping and often uncoordinated legal regimes. These include international, federal, state, and endangered species laws, invasive species laws, place-based management laws, and other wildlife management laws. Although some federal regulators and regulations would seem to restrict coral ecological

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[89] *See, e.g.*, Jason S. McLachlan, Jessica J. Hellmann & Mark W. Schwartz, *A Framework for Debate of Assisted Migration in an Era of Climate Change*, 21 CONSERV. BIO. 297, 300 (2007); Alejandro E. Camacho, *Going the Way of the Dodo: De-Extinction, Dualisms, and Reframing Conservation*, 92 WASH. U. L. REV. 849, 897 (2015); Ronald L. Sandler, Lisa Moses & Samantha M. Wisely, *An ethical analysis of cloning for genetic rescue: Case study of the black-footed ferret*, 257 BIOLOGICAL CONSERV. e109118, 3 (2021).
[90] *See, e.g.,* Richardson et al., *supra* note 85, at 9721-24; Schwartz et al., *supra* note 18, at 738, 732-743; Camacho, *Assisted Migration*, *supra* note 17, at 236-42; Andrew D. Bower et al., *A Practical Framework for Applied Forestry Assisted Migration*, 7 FRONT. FOR. GLOB. CHANGE (2024).
[91] *See e.g.,* BRENDA C. CLIFTON ET AL., FOREST ADAPTATION NETWORK, NORTHWEST NATURAL RESOURCE GROUP, ASSISTED MIGRATION BEST MANAGEMENT PRACTICES FOR PACIFIC NORTHWEST HABITAT RESTORATION PROJECTS (2024).
[92] *See, e.g.,* INTERNATIONAL UNION FOR CONSERVATION OF NATURE, GUIDELINES FOR REINTRODUCTIONS AND OTHER CONSERVATION TRANSLOCATIONS 16 (IUCN Species Survival Commission eds., 1st ed. 2013).
[93] *See, e.g.,* Williams & Dumroese, *supra* note 51.
[94] *See, e.g.,* U.S. FISH & WILDLIFE SERVICE, PACIFIC REGION CONSERVATION INTRODUCTIONS WORKING GROUP, A DECISION SUPPORT FRAMEWORK FOR CONSERVATION INTRODUCTIONS (2024); K. FRERKER, ET AL., SUPERIOR NATIONAL FOREST ASSISTED MIGRATION PLAN (2023).
[95] Camacho, *Assisted Migration*, supra note 17, at 174.

replacement and other active interventions, international and federal statutory law appear to be more permissive or ambiguous and might support regulatory decisions allowing such interventions.

In the U.S., corals are distributed across just a few states and territories, and consequently there has been little consideration of the possibility of coral introductions. As detailed below, Florida is perhaps the most advanced in this regard, providing an elaborate regulatory program that generally bars introductions unless the introduction is from the same population or at most closely related to a local native population. Importantly, recent proposed regulatory changes in Florida would allow assisted gene flow from a distant coral population if considered sufficiently genetically similar to a native population. However, even these proposals would expressly prohibit introductions of a non-native coral species (or even of a subpopulation of a native coral species if deemed too different from the native population).

A. International Law

International law certainly counsels a precautionary and careful approach to the introduction of non-native species for any reason, but it does not bar such measures. On the contrary, as long as the interventions are conducted in a way in which the risk of unintended ecological harm is reduced to a low level, the overriding goal of the Convention on Biological Diversity—promoting diversity—would seem to support such interventions.[96]

One treaty binding on the United States—the Convention on International Trade in Endangered Species (CITES)[97]—governs the international trade of vulnerable species, including corals. CITES, which has been incorporated into the U.S. Endangered Species Act, restricts international trade in specimens of more than 40,000 species depending on how the species is categorized: (1) those threatened or endangered with extinction (Appendix I); (2) those for which trade must be controlled to avoid use incompatible with their survival (Appendix II); and (3) those protected in at least one nation that has asked for assistance in controlling the trade (Appendix III).[98] Because all Caribbean coral species being considered for introduction in Florida are species listed under Appendix II,[99] CITES only requires an export permit from the source country but no import permit from the U.S. (although filing an import declaration, i.e., USFWS 3-177, is still required). The only standard CITES requires for an export permit of Appendix II species is that it may be issued only if the specimen was obtained legally, the risk of injury is minimized, and the "export will not be detrimental to the survival of that species."[100] Even if detrimental, CITES allows exemptions

[96] *Global Biodiversity Framework*, CONVENTION ON BIOLOGICAL DIVERSITY, https://www.cbd.int/gbf/targets (last visited Nov. 15, 2025).
[97] Convention on International Trade in Endangered Species of Wild Fauna and Flora, March 3, 1973, 27 U.S.T. 1087. [Hereinafter Convention in Endangered Species]
[98] *Id*. at art VI.
[99] Baker et al., *supra* note 15, at 345.
[100] Convention in Endangered Species, *supra* note 97, at art. IV, Sec. 2.

for animals that were "bred in captivity,"[101] or for specimens that are destined for scientific research.[102]

Some international law authorities seem to suggest that coral introductions are or should be permissible if the ecological benefits exceed the ecological risks, and those risks of harm can be assured to be low. An October 2023 Recommendation adopted by the Subsidiary Body on Scientific, Technical and Technological Advice of the Convention on Biological Diversity, for instance, does not counsel against assisted migration but generally urges a precautionary approach for interventions involving introduction of species beyond their native ranges: interventions should "[t]ake into account the precautionary approach when contemplating *ex situ* conservation measures, such as relocation or assisted migration, to avoid unintended ecological consequences, such as the introduction and spread of invasive alien species…."[103] The Preamble to the Convention on Biological Diversity similarly provides that "[w]here there is a threat of significant reduction or loss of biological diversity"—as there is with Florida's Coral Reef today—"lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat."[104]

Beyond these global instruments, one regional treaty that binds the United States speaks directly to introductions in the Caribbean marine environment: the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (the "Cartagena Convention"), and in particular its Protocol Concerning Specially Protected Areas and Wildlife (the "SPAW Protocol").[105] Under Article 12 of the SPAW Protocol, signatories are asked to "take all appropriate measures to regulate or prohibit intentional or accidental introduction of non-indigenous or genetically altered species to the wild that may cause harmful impacts to the natural flora, fauna or other features of the Wider Caribbean Region."[106] Article 13 additionally obliges signatories to consult with the Protocol's Scientific and Technical Advisory Committee when planning activities that could have a negative environmental impact and significantly affect species afforded protection under the Protocol.[107] Numerous of Part II's interventions thus could be regulated or even prohibited if deemed potentially harmful to "natural" Caribbean biota. Nonetheless, the SPAW Protocol merely requires signatories to regulate *or* prohibit. In addition, a more restrictive obligation to ensure "total protection and recovery" of various listed species—including elkhorn and staghorn corals—was agreed upon with reservations only from the United

[101] Convention on International Trade in Endangered Species of Wild Fauna and Flora, *Specimens of Animal Species Bred in Captivity*, Resolution Conf. 10.16 (Rev. CoP19), https://cites.org/sites/default/files/documents/COP/19/resolution/E-Res-10-16-R19.pdf (2019).

[102] Convention on International Trade in Endangered Species of Wild Fauna and Flora, *Non-Commercial Loan, Donation or Exchange of Museum, Herbarium, Diagnostic and Forensic Research Specimens*, Resolution Conf. 11.15 (Rev. CoP18), https://cites.org/sites/default/files/documents/COP/19/resolution/E-Res-11-15-R18.pdf (2019).

[103] Convention on Biological Diversity, *Report of the Subsidiary Body on Scientific, Technical and Technological Advice on its 25th Meeting*, U.N. Environment Programme CBD/SBSTTA/REC/25/6 (2023).

[104] Convention in Endangered Species, *supra* note 97, at preamble.

[105] *Protocol Concerning Specially Protected Areas and Wildlife to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region* (hereinafter "*SPAW Protocol*") 2180 U.N.T.S. 101 (1990) (ratified by S. Exec. Rep. No. 107-8 (2002))

[106] *SPAW Protocol* Art. 12.

[107] *SPAW Protocol* Art. 13.

States.[108] In effect, this means that the SPAW Protocol does not impose restrictions over and above those already imposed under federal law (discussed further *infra*).

More generally, substantial ambiguity remains in the interpretation and application of these authorities to ecological replacement and other introduction strategies. For instance, none of these international legal sources define what "precaution" means precisely, nor does the SPAW Protocol define what makes an impact "harmful." They also do not explicitly address the case in which (as with Florida's Coral Reef) there is ecological risk from inaction as well as from action. The relative weight of these authorities also bears emphasis: the United States is not a signatory to the Convention on Biological Diversity,[109] so the federal government may not accept as binding the precautionary language on which much of the international discussion rests.

B. Federal Law

Similarly, it is not at all clear that federal legal authorities speak directly to whether coral ecological replacement is permissible. National Marine Sanctuaries seem to have discretion to either allow or prohibit interventions (or to delegate that authority), so long as the decision is not arbitrary or capricious and has a reasoned basis (as required by the Federal Administrative Procedure Act[110] and the Sanctuary was not allowing conduct that would violate the Endangered Species Act.[111]

1. Federal Endangered Species Act

The most direct federal environmental statute governing conservation of vulnerable species and ecosystems is the Endangered Species Act.[112] Section 9 of the ESA prohibits the "take," including "harm," of any listed endangered fish or wildlife species.[113] Several Florida coral species, including elkhorn and staghorn corals, are listed as threatened under the ESA, and a special 4(d) rule for these corals applies "all the prohibitions enumerated in section 9(a)(1) of the ESA to elkhorn (*Acropora palmata*) and staghorn (*A. cervicornis)* corals."[114] An introduction might, of course, cause such harm, at least in theory.

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[108] *See SPAW Protocol Art. 11(1)*; *see also* S. Exec. Rep. No. 107-8 (2002).
[109] Other international agreements may be implicated by but not rule out coral ecological replacement. For example, the *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization* requires that owners of genetic resources receive a fair share of any benefits that arise from research conducted with those resources. Although the US is not a signatory, Indo-Pacific nations may nonetheless assert compensation claims for the benefits ER generates.
[110] 5 U.S.C. §706(2)(A).
[111] Endangered Species Act, 16 U.S.C. §§1531-1544 (1973).
[112] 16 U.S.C. §§1531-1544.
[113] 16 U.S.C. § 1538(a)(1); *see also id.* § 1532(19) ("The term 'take' means to harass, harm, . . . or to attempt to engage in any such conduct."); *Babbitt v. Sweet Home Chapter of Cmtys. for a Great Or.*, 515 U.S. 687 (1995) (determining FWS's interpretation of the statutory definition of "harm" to include "significant habitat modification or degradation" that significantly impairs breeding, feeding, or sheltering patterns was reasonable).
[114] NOAA Fisheries, Endangered Species Act 4(d) Rule for Elkhorn and Staghorn Corals, https://www.fisheries.noaa.gov/action/endangered-species-act-4d-rule-elkhorn-and-staghorn-corals#:~:text=We%2C%20NOAA%20Fisheries%2C%20publish%20this,the%20conservation%20of%20the%20species.

The ESA, however, does allow actions otherwise prohibited by section 9, including translocation of a listed species, if they enhance the propagation or survival of the affected species. These might be authorized either as an experimental population under section 10(j)[115] or through section 10(a)(1)(A) "for scientific purposes or to enhance the propagation or survival of the affected species, including, but not limited to, acts necessary for the establishment and maintenance of experimental populations."[116] Under 10(j), the National Oceanic and Atmospheric Administration (NOAA) may designate a population of an ESA-listed species, such as elkhorn or staghorn coral, as an experimental population under the ESA if introduction of that population would further conservation goals and maintain geographic separation from nonexperimental populations. Such designated experimental populations are treated legally as threatened (regardless of their broader listing status), enabling NOAA to implement an even more customized regulation[117] to authorize otherwise prohibited activities (e.g., limited take or release) under defined circumstances.[118] This experimental designation shifts the species' legal status to threatened, which potentially could allow reintroduction or translocation of listed coral species, subject to tailored legal and procedural restrictions, including modified take prohibitions and consultation requirements. Therefore, NOAA does appear to allow case-by-case translocations for reinforcement or reintroduction, at least within a species' known historical or native range, subject to appropriate permitting, federal interagency consultation under ESA Section 7 if applicable, and providing ecological safeguards are put in place.

Yet non-native introductions may raise distinctive issues. There are two general contexts under which the ESA might limit, or at least regulate, non-native introductions in Florida. The first scenario would be if the coral population proposed to be translocated beyond its historical range is itself a listed endangered or threatened species. This might be the case, for example, if Caribbean elkhorn or staghorn corals were proposed to be introduced to Bermuda. However, if introduced non-native corals were also threatened or listed under the ESA (an unlikely scenario), such an assisted migration strategy would have to meet the reasonably stringent requirements of a NOAA regulation that allows such relocations, but with notable conditions: (1) the Secretary must find that the relocation will further the conservation of the species, and (2) must include appropriate management conditions to maintain a separation between the experimental population and non-experimental populations.[119] This second condition could serve as an obstacle to some intervention scenarios.

The second context under which the ESA might apply, is if the introduction of a non-listed species might result in harm to a listed native endangered or threatened species–such as preexisting elkhorn or staghorn corals in Florida.[120] Ecological replacement strategies currently being considered fall into this category. Non-native introductions conducted cautiously to minimize or even eliminate risks to failing native species do not appear to be categorically unlawful. On the

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[115] 16 U.S.C. § 1539(j)
[116] *Id*. § 1539(a)(1)(A).
[117] *See* 73 Fed. Reg. 64264 (Oct. 29, 2008) (setting out NOAA's ESA §4(d) rule for elkhorn and staghorn corals).
[118] Endangered Species Act Legal Policy Review of Interventions to Increase the Persistence and Resilience of Coral Reefs 26 (2020), https://www.fisheries.noaa.gov/s3//2020-09/NAS%20Coral%20Interventions%20ESA%20Legal%20and%20Policy%20Review_508_FINAL.pdf?VersionId=haA78r4iMiR5uaD0KjNEeoMZRdQQy7.u&u.
[119] 50 C.F.R. § 222.502.
[120] 16 U.S.C.A. § 1538; 50 C.F.R. § 226.

other hand, any introductions that would result in populations of native species failing (when they otherwise would not have done so) might be prohibited under the ESA.

2. National Marine Sanctuaries

In the federal landscape, the primarily place-based legal regime governing coral conservation are National Marine Sanctuaries ("NMS"), established to "protect[] special areas of [the] public domain," "maintain . . . natural biological communities" and "protect, and, where appropriate, restore and enhance natural habitats, populations, and ecological processes."[121] The National Marine Sanctuaries Act (NMSA) leaves much of the details on NMS management to NOAA to set forth in regulations and periodically updated management plans. The implementing regulations state the program's purpose is to "identify, designate, protect, restore, and manage areas of the marine environment of special national, and in some cases international, significance."[122]

The Florida Keys NMS is the state's only NMS, the only barrier reef in the continental United States, and the northern hemisphere's largest documented contiguous seagrass community.[123] The NMS plan for the Florida Keys describes the NMS mission as a "commitment to management of marine protected areas within which primary emphasis is placed on the protection of living marine resources and our nation's maritime heritage resources."[124]

The National Marine Sanctuaries Act (NMSA) does not appear to address introductions generally or nonnative introductions specifically. There are no broadly applicable regulations expressly restricting the introduction or translocation of species in *all* NMS, either. However, federal regulations applicable to specific sanctuaries may restrict or allow the introduction of non-native species. Only a few NMS appear to allow it currently, and in narrow circumstances at that. Importantly, the Florida Keys NMS prohibits moving or damaging any coral within ecological reserves and preservation areas.[125] Additionally, it prohibits the introduction of ***exotic*** species, which it defines as any species whose natural zoogeographic range does not include the waters of the Atlantic Ocean, Caribbean, or Gulf of Mexico without passive or active introduction to such an area through anthropogenic means.[126]

NOAA's general permitting authority expressly emphasizes reliance on native species for any introductions. In particular, coral restoration guidelines for NMS emphasize using only native species.[127] Nonetheless, it is possible that such authority could be revised by regulation or possibly even construed by guidance, or in a particular permit, to allow some flexibility for introductions of non-pre-existing species.

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[121] 16 U.S.C. § 1431(a)(1).
[122] 15 C.F.R. § 922.4.
[123] NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, FLORIDA KEYS NATIONAL MARINE SANCTUARY, https://floridakeys.noaa.gov/.
[124] NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, FLORIDA KEYS NATIONAL MARINE SANCTUARY REVISED MANAGEMENT PLAN 1 (2007).
[125] 15 C.F.R. §§ 922.164.
[126] 15 C.F.R. §§ 922.162, 922.163.
[127] UNITED STATES DEPARTMENT OF COMMERCE, RESTORATION GUIDELINES FOR CORAL REEFS AND ASSOCIATED HABITATS IN FKNMS 1 (2021), https://nmsfloridakeys.blob.core.windows.net/floridakeys-prod/media/docs/20210803-restoration-guidelines-for-coral%20Reefs%20and%20Associated-habitats-in-fknms.pdf.

In the context of permitting, NOAA has the authority to issue three types of regulatory permits for a NMS.[128] The first is a survey permit, which authorizes non-intrusive surveys of historical resources.[129] The second is a research permit, which allows the recovery of historical resources for research purposes.[130] The third is a special-use permit, which authorizes commercial activities as long as they align with sanctuary goals and do not harm existing resources.[131] As with the ESA, the key may be whether a non-native introduction could be construed as harming a native coral if that coral is functionally extinct.

Still, existing regulatory authority does provide NOAA discretion that could be construed as allowing translocation of non-native coral into a NMS under certain circumstances Provided an applicant conducts activities in accordance with the scope, purpose, and terms of an issued permit, NOAA's permit system allows individuals to request authorization for activities otherwise prohibited by regulation.[132] However, while NOAA has discretion to issue such permits, there is no known precedent of a permit being granted to authorize the introduction of exotic coral species into NMS. Moreover, the coral restoration guidelines make no provision for exotic coral outplanting.[133]

The Florida Keys NMS, in particular, may allow for non-native introductions, although it would be subject to rigorous scrutiny. It uses a three-tiered framework consisting of "green light," "yellow light," and "red light" categorizations to evaluate coral restrictions and their likelihood of receiving permit approval.[134] "Green light actions are likely to be approved without significant or complex review,"[135] such as outplanting nursery-reared native corals into historically occupied sites. In contrast, "[y]ellow light actions will likely require additional information and analysis to address timing, techniques or other criteria."[136] Most significantly, "[r]ed light actions are considered so novel, potentially risky, or beyond the scope of normal restoration activities that a significant review is necessary," and such actions "may not be eligible for permitting."[137]

The Florida Keys NMS management plan states that Florida statutes make it unlawful to (1) import any marine plant or animal non-indigenous to the area and (2) release into the waters of the state any non-indigenous saltwater species.[138] What qualifies as *non-indigenous* is not defined in the plan. As such, it seems plausible that a proposal involving the introduction of non-native coral species might be classified as a "red light" action.

NOAA National Ocean Service guidance from 2009 related to invasive species management is skeptical of nonnative species but largely only if such species cause harm. It prohibits activities that promote *invasive* species within national marine sanctuaries and advocates for actions to

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[128] 15 C.F.R. §922.166.
[129] *Id.*
[130] *Id.*
[131] *Id.*
[132] *Id.*
[133] UNITED STATES DEPARTMENT OF COMMERCE, *supra* note 127.
[134] *Id.*
[135] *Id.* at 3.
[136] *Id.*
[137] *Id.* at 4.
[138] NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, *supra* note 124, at 101.

remove them and mitigate their impacts.[139] Again, it is debatable whether non-native coral introductions that promote Florida reef ecosystem function would or should be deemed harmful and thus invasive in any meaningful detrimental sense.

Indeed, January 2025 Florida Keys NMS regulations suggest a receptivity to interventions that focus less on historical fidelity and more on long-term future ecological health. These regulations greatly expand restoration zones and create new NMS-specific general and restoration permit categories.[140] NOAA's Mission: Iconic Reefs (2022–2025) explicitly plans to "for the first time… intervene… by removing invasive species and introducing disease-resistant and climate-resilient corals."[141] If suitable disease-resistant or climate-resilient corals can be identified outside Florida, then this initiative suggests future management may include transplantation of coral, including possibly non-native coral, even if such interventions might require specific permit approval.

Accordingly, the current management plan for the Florida Keys National Marine Sanctuary would seem to limit, but not categorically prohibit, the introduction of coral species. This limitation, however, is not specifically mandated by federal statute, and may reflect an assumption that non-native species are invariably harmful and, in that sense, "detrimental," rather than beneficial to the ecology or an enhancement to the ecosystem services that reefs provide. To the extent that the assumption is simply no longer correct, then a flat ban on the careful introduction of non-indigenous coral species could be considered arbitrary and capricious and hence unlawful under the federal Administrative Procedure Act.[142]

3. National Coastal Zone Management Act

Any activity supported by federal resources or pursued by federal agencies impacting Caribbean coral populations in the United States will likely require state consultation under the Coastal Zone Management Act (CZMA), which grants states considerable influence over federal decisions to engage in or permit projects.[143]

The Florida Coastal Management Program (FCMP) is a federally approved management program for CZMA purposes.[144] Hence, any federal action pursued within state coastal waters is subject to consistency review by the Florida Department of Environmental Protection (Florida DEP) and requires a state license.[145] Denial of a license constitutes a finding that the activity is not consistent

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[139] OFFICE OF NATIONAL MARINE SANCTUARIES, INVASIVE SPECIES IMPACT ON MARINE LIFE 1 (2009).
[140] 15 C.F.R. § 922.166.
[141] *Restoring Seven Iconic Reefs: A Mission to Recover the Coral Reefs of the Florida Keys*, NOAA FISHERIES (July 4, 2025), https://www.fisheries.noaa.gov/southeast/habitat-conservation/restoring-seven-iconic-reefs-mission-recover-coral-reefs-florida-keys.
[142] 5 U.S.C. §§ 551–559.
[143] The CZMA requires federal agencies that undertake projects within states with CZMA-approved management programs to ensure that their projects protect coastal resources consistent with the policies of those state programs. States are given the opportunity to review the proposed federal action. If an action is found to be inconsistent with a state program, that action may proceed only with an exemption granted by the President upon a finding that the action is in the paramount interest of the United States. *See* 16 U.S.C. § 1456(a-d).
[144] *See* 28 Fla. Stat. § 380.
[145] 28 Fla. Stat. §§ 380.205(1), 380.23.

with the FCMP and would prohibit the activity unless the action is found to be in the national interest.[146]

The FCMP explicitly prohibits the release anywhere in Florida of any animal species not native to Florida, unless authorized by the FWC. Thus, FWC approval would be required under the CZMA for non-native ER. There is no publicly available information on the standard used for granting approval. There is also a prohibition on the import or possession of non-indigenous marine plants or animals that "may endanger or infect the marine resources of the state."[147] Depending on the interpretation of "may endanger," which is not defined explicitly in statute, AGF, genetic modification of native species, and ER may all fall under this prohibition.

Thus, if a federal agency were to be involved in interventionist activities to boost coral populations in Florida's waters, the Florida DEP would be required to review whether those activities would be consistent with its Coastal Management Plan. The Department has significant discretion in making that determination and could effectively veto any federal intervention if it deems it inconsistent with its state program under the CZMA. Although exceptions exist, as mentioned above, they present an administrative hurdle—special permission from the Secretary of Commerce is required to overcome a consistency objection by a coastal state.[148] As such, state cooperation would significantly aid any federal program. Note that ex-situ research would not take place within state coastal waters and therefore would not be subject to the CZMA.

4. National Park Service

Translocations, particularly non-native introductions, into one of Florida's three federally protected national parks—Biscayne National Park, Everglades National Parks, and the Dry Tortugas National Park[149]—may be restricted. The National Park Service Organic Act requires the Service to regulate national parks so as to "leave [scenery and the natural and historic objects and the wild life therein] unimpaired for the enjoyment of future generations."[150] Courts have not settled on what exactly "unimpaired" means, but the Park Service has largely sought to maintain a "pre-Columbian ecosystem," using active management when necessary to do so.[151] That approach is laid out in the Service's Management Policies. Therein, the Service distinguishes between "native" and "exotic" species. The latter are "those species that occupy or could occupy park lands directly or indirectly as the result of deliberate or accidental human activities."[152] The

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[146] 28 Fla. Stat. § 380.23(1). The CZMA differentiates between activities conducted by federal agencies and activities conducted pursuant to a federal license or permit, or with federal financial assistance, but not performed by federal agencies. The former—activities conducted by federal agencies—must meet a slightly more lenient standard. They must only be consistent with state programs "to the maximum extent practicable." Federally licensed, permitted, or financially assisted activities, on the other hand, must be fully consistent unless determined by the Secretary of Commerce to be necessary in the interest of national security. *Compare* 16 U.S.C. § 1456(c) *with* 16 U.S.C. § 1465(d).
[147] 28 Fla. Stat. § 379.26
[148] 16 U.S.C. § 1456
[149] *See* Leonard G. Pearlstine, Elise V. Pearlstine & Nicholas G. Aumen, *A Review of the Ecological Consequences and Management Implications of Climate Change for the Everglades*, 29 J. N. AM. BENTHOLOGICAL SOC. 1510 (2010); Katherine Degroff, *Coral Calamity*, 95 NAT. PARKS 16 (2021).
[150] 16 U.S.C. § 1.
[151] *See* Eric Biber & Elisabeth Long Esposito, *The National Park Service Organic Act and Climate Change*, 56 NAT. RESOURCES J. 193, 215 (2016).
[152] National Park Service, Management Policies § 4.4.1.3.

Policies specify that exotic species will not be allowed to displace native species *if displacement can be prevented*.[153] In general, the Service disallows the introduction of exotic species.[154] Such species may be introduced only to meet "specific, identified management needs" when "all feasible and prudent measures to minimize the risk of harm have been taken" and where the exotic species is a "closely related race, subspecies, or hybrid of an extirpated native species."[155]

However, some exceptions to this policy exist. For example, introduction of exotic species is allowed where the exotic species is "an improved variety of a native species in situations in which the natural variety cannot survive current, human-altered environmental conditions." If Pacific corals are deemed "an improved variety" of native Caribbean coral, this exception would allow for ecological replacement. Further, exotic species may be introduced where directed by law or expressed legislative intent.[156] Thus, legislative action would take precedence over the Park Service's management policies.

Since the NPS permits the introduction of exotic species determined to be an improved variety of a native species under some conditions, assisted gene flow of existing native species within Florida's Coral Reef would likely face less hurdles than ecological replacement. This option would likely be considered introduction of an "improved" variety of extant species rather than a new species, with the Park Service likely permitting AGF as a form of native species management, subject to the Service's Managed Relocation risk assessment guidelines.[157] In fact, the Park Service has itself begun experimenting with AGF to restore seagrass on the U.S. east coast.[158] Genetic modification is more tenuous. Management policies direct the NPS to maintain the "genetic and ecological integrity" of native plant and animal species.[159] In keeping with this, a genetically modified organism would be treated as a non-native exotic species.[160] Exotic species may be introduced only under specific circumstances.[161] As discussed *supra*, native coral species cannot survive current, human-altered environmental conditions. As such, the condition precedent to allow for the introduction of genetically modified corals in national parks would be met.[162]

5. National Wildlife Refuge System Authorities; BIDEH

Introductions of non-native or genetically modified species may be restricted in federal Wildlife Refuges, although AGF is unlikely to meet obstacles. The U.S. Fish and Wildlife Service manages

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[153] National Park Service, Management Policies § 4.4.4 (emphasis added).
[154] National Park Service, Management Policies § 4.4.4.1.
[155] National Park Service, Management Policies § 4.4.4.1. For more on the treatment of native versus non-native species by the National Park Service, *see* Alejandro E. Camacho & Jason S. McLachlan, *Regulatory Fragmentation: An Unexamined Barrier to Species Conservation Under Climate Change*, 3 FRONT. CLIM. e735608, 3-4 (2021).
[156] National Park Service, Management Policies § 4.4.4.1.
[157] *See* Aviv Karasov-Olson et al., *Ecological Risk Assessment of Managed Relocation as a Climate Change Adaptation Strategy*, NAT. RES. REP. 2021/2241 (Mar. 2021).
[158] National Park Service, *Bridging Genetic Diversity: Seagrass Resilience and Restoration*, https://www.nps.gov/im/ncbn/bridging-genetic-diversity-seagrass-resilience-and-restoration.htm (Jan. 3, 2025).
[159] National Park Service, Management Policies § 4.1.
[160] National Park Service, Management Policies § 4.4.1.3.
[161] *See id.* (discussing how the introduction of exotic species is permitted where the exotic species is "an improved variety of a native species in situations in which the natural variety cannot survive current, human-altered environmental conditions.").
[162] National Park Service, Management Policies § 4.4.1.3.

two Wildlife Refuges that overlap with Florida's Coral Reef: the Key West National Wildlife Refuge and the Great White Heron National Wildlife Refuge. The 1997 National Wildlife Refuge System Improvement Act identifies "wildlife conservation" as the fundamental mission of the National Wildlife Refuge System (NWRS).[163] As part of that mission, the NWRS must ensure that the "Biological Integrity, Diversity, and Environmental Health" (BIDEH) of each refuge are maintained. The U.S. Fish & Wildlife Service's manual stipulates that the Service specifically uses historical conditions as the frame of reference for maintaining biological integrity.[164] Native species are defined as "species that, other than as a result of an introduction, historically occurred or currently [occur] in that ecosystem."[165] In line with those principles, U.S. Fish & Wildlife does not introduce species to refuges outside their historical range, "unless such introduction is essential for the survival of a species and prescribed in an endangered species recovery plan, or is essential for the control of an invasive species and prescribed in an integrated pest management plan."[166] Current Fish & Wildlife Service regulations would thus not permit non-native ecological replacement within areas designated as wildlife refuges unless deemed essential for a listed species. Similarly, the Service does not use genetically modified organisms in refuge management unless their use is determined to be "essential to accomplishing refuge purpose(s)" and the Regional Chief approves their use.[167] No endangered species recovery plan specifically allows for ecological replacement or genetic modification in these refugia as being necessary to overcome this hurdle. AGF does not present the same problem, since it would involve the introduction of a variety of "native" species.

6. Additional Federal Legal Considerations

In addition to the legal hurdles described above, which specifically concern the introduction of additional native, genetically modified, or non-native populations or species into particular marine conservation areas, any planned human intervention on Florida's Coral Reef may also be impacted by legal and procedural requirements that apply to activities within federal waterways generally. For example, any activity within reefs would need to comply with applicable U.S. Army Corps of Engineers regulations,[168] as well as follow the provisions protecting Essential Fish Habitats set out

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[163] 16 U.S.C. § 668dd.
[164] 601 Fish & Wildlife 3.12(B)
[165] 601 Fish & Wildlife 3.6(E).
[166] 601 Fish & Wildlife 3.14(F).
[167] 601 Fish & Wildlife 3.15(C).
[168] Specifically, 33 C.F.R. § 323.1 prohibits the discharge of dredged or fill material into water of the United States (regulated by Section 404 of the Clean Water Act ("CWA"), 33 U.S.C. § 1344), without a permit from the American Corps of Engineers. Any fill placed in waters of the United States requires a permit under § 404, and the broad definition of "fill" could cover new coral introduced as part of a translocation or ecological replacement initiative. Pursuant to 40 C.F.R. § 230.10(a), the Corps may not issue a Section 404 permit "if there is a practicable alternative to the proposed discharge which would have less adverse impact on the aquatic ecosystem, so long as the alternative does not have other significant adverse environmental consequences." Hence, a project would need to show that there is no practicable alternative with less adverse impact on the aquatic ecosystem in order to obtain a permit under § 404. This requirement would present an administrative hurdle, but nothing in the code specifically prohibits the introduction of non-native materials or otherwise presents specific difficulties for ecological replacement. Other interventions, such as AGF or native species translocation, would be evaluated under the same standard. *See* 33 U.S.C. § 1344, 40 C.F.R. § 230.1.

by the Magnuson-Stevens Fishery Conservation and Management Act.[169] These regulations are not necessarily any more restrictive to the proposed interventions outlined in this paper than they are for other marine activities, however.

C. State Law - The Florida Example

1. Florida Fish and Wildlife Conservation Commission

The FWC is a constitutional body with exclusive authority to regulate and manage coral and other fish and wildlife resources in Florida.[170] The FWC is therefore a fairly unique regulatory body because it has wide discretion to enact regulations without direct legislative approval, and the Florida Legislature can only enact statutes that aid the FWC in the performance of its constitutional authority.

By legislative statute, Florida heavily restricts the introduction of non-native species. One statutory provision makes it unlawful to release in the state any non-native animal without prior authorization,[171] notwithstanding any permits granted by federal agencies such as NOAA, the Florida Keys NMS, or the National Park Service. Moreover, a statutory provision prohibits the importation of any non-native marine plant or animal that may endanger the marine resources of the state while granting the FWC authorization to list any species that pose such a risk.[172] This statute also creates a baseline prohibition on release of any non-native saltwater species, regardless of whether it is prohibited by the FWC.[173] However, what constitutes a non-native species, including whether it includes genotypes and subpopulations of a native species that have not previously been present in Florida, is not explained in statutory text. The FWC seems to rely on an informal definition for "non-native species" as "animals living outside captivity that did not historically occur in Florida."[174]

FWC regulations continue these restrictions and somewhat clarify the categories of organisms that may be introduced. "No person shall transport into the state, introduce, or possess, for any purpose that might reasonably be expected to result in liberation into the state, any freshwater fish, aquatic invertebrate, marine plant, marine animal, or wild animal life not native to the state, without having secured a permit from the Commission."[175] FWC regulations thus create a fairly strict legal duality at the state level, allowing the possibility of active interventions for any species native to Florida,

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[169] The Magnuson-Stevens Fishery Conservation and Management Act ("MSA") establishes the framework for federal fisheries management and contains provisions specifically protecting Essential Fish Habitats ("EFH") that may be implicated by coral outplanting activities. Under the MSA, other federal agencies must consult with NOAA if they authorize, fund, or undertake activities that may adversely affect EFH. Much of the Miami coast is designated an EFH for various highly migratory species, and hence coral outplanting sponsored by federal authorities would trigger a consultation requirement if the outplanting would have an adverse effect on said species. *See* 16 U.S.C. § 1855; 50 CFR § 600.910 (defining "adverse effect").
[170] Fla. Const. A. IV §9.
[171] Fla. Stat. §379.231
[172] Fla. Stat. §379.26.
[173] *Id.*
[174] *What Is a Nonnative Animal Species?,* FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION, https://myfwc.com/wildlifehabitats/nonnatives/. The FWC also informally defines an invasive species as an introduced species "that threatens economic or environmental harm to ecosystems, habitats or species." *Id.*
[175] Fla. Admin. Code r. 68-5.003.

but categorically prohibiting such strategies if not native, regardless of the organism's compatibility with existing or future conditions at the target location.

The FWC's regulatory permitting process reaffirms this historical preservation strategy. Authorizations for non-native corals, invasive corals, and corals used for research and restoration are provided by FWC regulation through a Marine Special Activity License (SAL) Program.[176] Stock Collection and Release SALs regulate the collection and/or release of marine organisms for purposes related to restoration and research.[177] Review of any proposed release is mandatory and examines whether the stock is "indigenous," has reproductive capabilities, and whether safeguards are in place.[178] If these factors are satisfied and applicants submit the required management plan documenting the genetic origin and risk-management measures, a release may be authorized.[179]

The FWC has developed a binding flowchart for determining whether to authorize a SAL.[180] The flowchart incorporates by reference the "Florida Fish and Wildlife Conservation Commission Policy on the Release of Marine Organisms," which states that "this policy does prohibit the release of any non-indigenous marine organism, irregardless [*sic*] if it was originally collected pursuant to special authorization from the FWC."[181] Although the scope of the limitation is unclear because "non-indigenous" is not defined in the 2009 Policy, the ban nonetheless likely limits many forms of coral ecological replacement.

In assessing a particular SAL application, FWC staff undertake a risk assessment that weighs the benefits and risks of the proposed intervention. The FWC has currently adopted a genetic differentiation (F_{ST}) of 0.05 as the threshold for introductions of *Acropora palmata* (elkhorn coral),[182] assessing that such a threshold represents sufficient genetic distance that the benefits of increased diversity outweigh the risks associated with outbreeding depression or the introduction of maladapted traits to this species. However, this threshold is contestable as an optimal standard, both as a level for protecting Florida's elkhorn coral specifically or for promoting the broader ecological health of Florida's coral ecosystems more generally.

A provision of the 2009 Policy that requires any non-indigenous marine organism to be either sterile or removed before reaching sexual maturity[183] likely further limits coral ecological replacement. Corals cannot be reliably sterilized, and their management post-release involves removing outplants prior to reaching sexual maturity. However, outplants can be fragmented by storms and other physical impacts, leading to a risk of asexual proliferation and potentially complicating their complete removal. Therefore, proposals involving non-native corals may be

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[176] Fla. Admin. Code r. 68B-8.
[177] *Id.*
[178] Fla. Admin. Code r. 68B-8.010.
[179] *Id.*
[180] FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION (FWC) COMMENTS ON POLICIES AND CONSIDERATIONS REDRAFTS 6 (2013), https://safmc.net/documents/fwc-comments_safmc-policies-and-considerations-redrafts-pdf/.
[181] Fla. Admin Code r. 68B-8.003.
[182] Interview with Mike Tringali, PhD, Researcher at Florida Fish and Wildlife Conservation Commission, (March 26, 2025).
[183] FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION (FWC), *supra* note __. [ELIAS]

challenged by the genetic risk assessment process, making legal authorization through a SAL problematic.

FWC is, however, in the process of finalizing a revision of its SAL program standards, somewhat reconsidering the extent to which corals may be moved. Although statutory or regulatory changes are not anticipated, the revised flowchart may reduce impediments to at least some novel interventions. In particular, it would permit translocation of organisms within the same "genetic conservation unit" ("GCU") as the Florida population, even if that organism is not of the same genotype as those in the Florida population.[184] FWC regulations state that a GCU refers to "a specific population, group of populations, or habitat(s) designated to preserve or maintain genetic diversity, evolutionary potential, and adaptive capacity of a species and/or subspecies."[185] However, what might qualify as a GCU is unclear and contestable, and indeed FWRI staff have indicated that they will consider changes to a GCU determination if peer-reviewed scientific research demonstrates that doing so is warranted.[186] Nonetheless, the guidance explicitly states that while "subspecies and lower taxonomic units (e.g., varieties, stocks, distinct population segments) are encompassed as necessary within GCU designations… *any activity involving the introduction of a non-native coral species, at any life stage, including but not limited to assisted colonization, shall not be authorized* within Florida's Coral Reef and in other waters under the jurisdiction and oversight of the State of Florida."[187] Accordingly, while these proposed SAL program revisions could allow modest assisted gene flow strategies if within a GCU, ecological replacement of coral would still be expressly prohibited under FWRI policy.

2. Florida Department of Environmental Protection

Florida's submerged and coastal lands laws also have the potential to limit the possibility of non-native species introductions, although no specific provision prohibits them[188] The Florida Coral Reef Protection Act,[189] for instance, charges the Department of Environmental Protection (DEP) with managing activities potentially disturbing Florida's submerged land habitats through a Resource Permit program and activities that may alter coastal environments seaward of the mean high-water line through a Joint Coastal Permit program.[190] DEP approval assesses the following criteria for permit approval: (1) whether the project is in the public interest, (2) the extent to which the project avoids or mitigates adverse impacts on marine resources, (3) the project's compliance

[184] TRINGALI ET AL., GENETIC RISK ASSESSMENT AND CONSERVATION MANAGEMENT FOR FLORIDA CORALS (2024)
[185] 51/47 Fla. Admin Reg. (2025).
[186] TRINGALI ET AL., *supra* note 184, at 10.
[187] *Id.* at 35-36 (emphasis added).
[188] Florida's Public Trust Doctrine may pose an additional constraint on ER. Under Florida's Constitution, Florida's rivers, lakes, and tidelands are held in a public trust for future generations. *See* Fla. Const. Art. X § 11. The Public Trust Doctrine protects the public status of navigable water bodies, which includes Florida's oceans. Under the doctrine, Florida has a duty to protect its oceans for the benefit of present and future citizens. If deemed applicable, ecological replacement or other similar interventions in the Caribbean reef could be framed as a way to preserve many of the public benefits generated by the state's waters—fishing, boating, swimming, and so on—to avoid scrutiny under the doctrine. That said, Florida has not historically used the public trust doctrine to protect coral reefs. *See* Elise C. Pauler, *Defending Florida's Marine Treasures: An Argument to Expand the Public Trust Doctrine and Reinforce Florida's Role in Coral Reef Protection*, 43 STETSON L. REV. 151, 182 (2013).
[189] Fla. Stat. §373.
[190] FLORIDA'S CORAL REEF PROTECTION ACT 2 (2009), https://floridadep.gov/sites/default/files/coral-reef-protection-052016.pdf.

with state water quality standards, and (4) the project's consistency with the Florida Coastal Management Program.[191]

The DEP also maintains a Coral Reef Conservation Program managing the northern part of Florida's Coral Reef, from the St. Lucie Inlet to the Kristin Jacobs Coral Aquatic Preserve.[192] This program coordinates research and monitoring and promotes partnerships to protect coral reefs among Florida counties.[193] A designated Reef Resilience Focus Area within this program identifies projects aiming to improve coral reef resilience and restoration, listing as one example projects that support "the research and development of innovative resilience interventions (e.g., assisted migration and gene flow)."[194] A project that supports research and development on ecological interventions such as AGF or ER thus may be compatible with this program.

3. Florida Aquatic Preserve Act

The Florida Aquatic Preserve Act of 1975 designates Florida's aquatic preserves and requires that they be maintained in "essentially natural conditions" with "indigenous" flora and fauna.[195] An "essentially natural condition" is defined by statute as "those functions which support the continued existence or encourage the restoration of the diverse population of indigenous life forms and habitats to the extent they existed prior to the significant development adjacent to and within the preserve."[196] The Florida Office of Resilience and Coastal Protection (ORCP), which is charged with administering aquatic preserves, may refuse to permit an activity in designated preserves if deemed inconsistent with those definitions.[197] "Public interest" factors are weighed in determining whether to grant approval of activities within aquatic preserves, including enhancement or degradation of "natural habitat and function" as well as protection or "harm or harassment" of "endangered/threatened/unique species."[198]

Although crucial terms, "natural" and "indigenous" are remarkably not further defined by statute, regulation, cases, or publicly available guidance. The introduction of a non-native population or species thus could be barred in a designated preserve if pre-existing coral were deemed displaced or if a particular introduction were deemed unnatural. On the other hand, a case could be made that introduction of a new population or species compatible with future climatic conditions was "essentially natural," or more persuasively that interventions in reef habitats serve to support the continued existence of numerous indigenous life forms and habitats aside from native corals.

191 Fla. Stat. §373.414.
192 *Coral Reef Conservation Program*, DEPARTMENT OF ENVIRONMENTAL PROTECTION, https://floridadep.gov/rcp/coral.
193 *Id.*
194 *Id.*
195 Fla. Stat. §§ 258.35-.46 (2024) (Florida Aquatic Preserve Act of 1975). Note that the term "indigenous" is not defined in the statute. An "essentially natural condition" is currently defined as those functions supporting the continued existence or restoration of "the diverse population of indigenous life forms and habitats," with the preserve itself defined as an area "set aside to be maintained in an essentially natural or existing condition of indigenous flora and fauna and their supporting habitat." *See* Fla. Admin. Code Ann. r. 18-20.003(24), (43).
196 Fla. Admin. Code Ann. R. 18-20-003(24).
197 Fla. Admin. Code Ann. R. 18-20.001.
198 Fla. Admin. Code Ann. R. 18-20.004.

Under the plain language interpretations of "natural" and "indigenous," interventions such as AGF are likely to face less scrutiny, though no explicit official guidance exists.

A further hurdle to interventions in reef ecosystems is Florida's tiered Resource Protection Area (RPA) classification system.[199] Areas protected by the Aquatic Preserve Act are allocated tiers that vary restrictions based on their ecological sensitivity. Coral reef areas are designated RPA 1 and carry the most restrictive management standards. Among other actions, aquaculture activities, defined as the "cultivation of aquatic organisms and associated activities," are to be avoided in RPA 1 areas.[200] Any aquaculture must be compatible with the applicable preserve management plan.[201] Furthermore, "cultivation of non-indigenous, or hybrids of non-indigenous" species through aquaculture is outright barred within Florida state waters.[202] Hence, any ecological replacement program would have to avoid characterization as an aquaculture activity to pass muster in such areas. However, non-native ecological replacement, and arguably introduction of new subpopulations and even AGF, could easily be interpreted as aquaculture, as each involves the "cultivation of aquatic organisms."

4. Florida Division of Recreation and Parks

Finally, FDEP's Division of Recreation and Parks (DRP) exercises authority over the submerged lands and waters within state park boundaries under a statutory framework separate from both ORCP and FDEP.[203] The governing statutory regime establishes "natural resource preservation" as the standard against which all park activities are measured, although that specific term is not defined in statute, regulations, or guidance.**[204]** Most relevantly, DRP authorization is required for any scientific research in state parks that involves fieldwork or has the potential to disturb resources, independently of any aquatic preserve or DRP determination.[205] In addition, the statute prohibits introduction of any plant or animal species—native or otherwise—into any state park without DRP authorization.**[206]** Authorization may be granted only where DRP determines the activity is consistent with the management statutes and "in keeping with protection, restoration, and maintenance of natural resources."[207] However, no publicly available definition exists regarding what constitutes "natural" resources for DRP's purposes.

IV. THE NORMATIVE ETHICS OF CORAL ECOLOGICAL REPLACEMENT

[199] *Id*.
[200] Fla. Admin. Code. Ann. R. 18.21-020(j).
[201] Fla. Admin. Code Ann. R. 18-21.020 (aquaculture on sovereignty submerged lands; requiring compatibility with the applicable preserve management plan).
[202] Fla. Admin. Code Ann. r. 18-21.003(9) (defining "Aquaculture Restoration" on sovereignty submerged lands as "the controlled propagation and subsequent planting and husbandry of native, aquatic plants and animals") (emphasis added); Fla. Admin. Code. Ann. R. 18-21.020(3)(h).
[203] Fla. Stat. §§ 258.004, .007, .017, .037.
[204] *Id*. Note that "natural resource preservation" is not explicitly defined in the statute, though it is taken to include "minimizing impacts to undisturbed habitat." *See* Fla. Stat. § 258.004.
[205] Fla. State Parks, *Research and Collecting*, https://www.floridastateparks.org/research-and-collecting (last accessed Mar. 23, 2026).
[206] Fla. Admin. Code Ann. r. 62D-2.013(6).
[207] *Id*.

Whether the law provides sufficient flexibility for the introduction of non-native coral species, a more fundamental issue is whether and in what contexts such introductions and translocations *should* occur. Scientists and policymakers charged with managing non-coral ecosystems at the local, state, national, and international levels have experimented with non-native translocation as a climate adaptation strategy for over fifteen years.[208] However, most scholars and policymakers have focused on the ethics of assisted migration—the intentional movement of members of a species outside the species present or historical range to assist the species in adaptation to the effects of global climate change.[209] There has also been robust discussion of the ethics of genetic modification in conservation efforts.[210] Yet no scholar or policymaker has tackled the many significant ethical issues raised by these approaches in the coral ecosystem context.

Nonetheless, although coral ecosystems are distinctive, and ecological replacement may raise distinct scientific, legal, and ethical issues, the overlap remains substantial. There are at least six significant types of normative issues raised by coral ecological replacement: (1) the comparative ethics of risk under uncertainty; (2) value issues associated with whether to prioritize species or function and individuals or collectives; (3) distributive justice concerns with respect to benefits, costs, and risks; (4) procedural justice concerns with respect to decision-making; (5) the ethics of responsibility and (6) issues in research ethics.

A. Managing Risk

Different ethical frameworks caution different approaches to decision-making under conditions of uncertainty and risk. The direct coral management decisions discussed in this paper each come with advantages and potential risks. Yet the status quo—under which, according to the most recent scientific evidence, threatened species are likely to progress towards extinction and coral reefs will continue to degrade, erode, and lose structure and function—is not without risks either. The question facing decision-makers, then, is how to proceed under conditions of considerable ecological uncertainty. Given the environmental degradation facing Caribbean reefs, there is no risk-free posture that can be adopted.

Since some degree of uncertainty is inherent in any ecological project and, in the case of ecological replacement or genetic modification, those uncertain harms could be irreversible once the non-native species become established, policymakers could choose to advise against action in the face of potential, irreversible harms that otherwise would not occur. On the other hand, a more risk-tolerant approach may counsel weighing the potential harms against the potential benefits of intervention vis-à-vis maintaining the status quo. Other normative frameworks may weigh these risks differently or identify other risks altogether.[211]

One normative issue, then, is whether to weigh risks and benefits differently in different scenarios. A second, related, issue concerns decision-making when risk and benefit quantification is difficult.

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[208] Camacho, *Assisted Migration*, s*upra* note 17, at 188.
[209] *See, e.g.,* Schwartz et al., *supra* note 18, at 732; Richardson et al., *supra* note 85, at 9721-24.
[210] *See, e.g.*, Sandler, *The Ethics of Genetic Engineering*, *supra* note 78; Henk Verhoog, *Naturalness and the Genetic Modification of Animals*, 21 BIOTECH. 294; Ronald Sandler, *Should We Engineer Species in Order to Save Them?* 41 ENVTL. ETHICS 221, 226 (2019); Ronald Sandler, *Gene Drives and Species Conservation*, *in* GENE EDITING, LAW, AND THE ENVIRONMENT (2017, Irus Braverman, ed.).
[211] *See infra* Section V.C.

Should those situations be treated with greater precaution or should they be approached with greater confidence? Should there continue to be a strong presumption against introducing new risks, or should, given the dismal state of the status quo and the timelines involved, conservation innovation be embraced despite high levels of uncertainty?

A third issue is how much to weigh risks and benefits to non-human entities. A great many species, and an even greater number of organisms, will be impacted differentially by management decisions. How much weight should risks to the welfare of sentient marine organisms or the robustness of marine populations be given in evaluating options, for example? Should human well-being be taken as overriding in the context, or should significant consideration be given to potential non-human impacts (organisms, populations, species, and ecosystems)?

B. Value Issues: Species vs. System; Historical Fidelity vs. Function

As climate disruption and other stressors become more severe, for many ecosystems, such as Florida's Coral Reef, historically oriented preservation is increasingly in tension with conserving biodiversity or ecological function. Current scientific evidence indicates that historical fidelity and ecological function of Caribbean reefs can no longer be preserved simultaneously. Faced with this tradeoff, which should be prioritized? Answering this question involves consideration of feasibility and cost, as well as of value: is historical fidelity or ecosystem function more valuable in this context?

Historical fidelity has been foundational to conservation management for over a century. Some of the interventions discussed in this paper, such as coral ecological replacement or genetic modification, might be understood as a reconsideration of this value, in the sense that historical fidelity is not considered to always trump all other considerations. This does not imply that historical ecological and evolutionary relationships are not valuable and worth preserving where possible. It means that they are not the only value operative in conservation and ecosystem management, and that in some contexts – especially those where maintaining historical communities and relationships is not feasible – other values take on greater comparative salience. Some of the strategies considered here would be particularly transformative interventions that, if successful, would make non-native introduction irreversible. Pursuing these might even be understood as an acceptance that preexisting Caribbean coral reefs are—at least in the immediate future—not recoverable to their post-European settlement/pre-1970s form.[212]

The interventions discussed in this paper sit on a continuum in terms of historical fidelity (Figure 1 and Table 1). No single strategy entails a wholesale rejection of historical preservation. Ecological replacement, for example, may displace some native species, but at the same time preserve reef ecological processes that have taken place in the Caribbean since pre-European settlement. Similarly, it may allow other native species to survive in the Caribbean that would otherwise suffer in the absence of a healthy reef ecosystem. By preserving functional aspects of reef ecology— albeit using different reef-building species — it arguably would be "preserving" certain ecological processes or services. Consequently, policymakers should consider first to what degree they wish to prioritize historical fidelity versus ecological function, if at all; and second,

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[212] Roff, *supra* note 11, at 28; Kuffner & Toth, *supra* note 11, at 712.

evaluate various policy choices as sitting on a continuum of trading off historical fidelity against ecological function.

Conservation decisions regarding Florida's Coral Reef also need to grapple with the distinction between species conservation and system conservation. One may wish to focus on conserving specific native coral species but, by conserving these species, lose some other set of related biological functions that a healthy reef would ordinarily support. Or it may require relocating individuals of the native species further north, beyond their current range. Conversely, a focus on preserving the ecological system as a whole may allow the introduction of some non-native species to preserve the historical function of the reef as a whole, while also stressing some historical populations.

As discussed above, until now historical fidelity and historical baselines have been highly valued, and that valuation has been expressed in regulatory regimes and management decisions. Greater comparative valuation of system-level properties and ecological functions would warrant a shift toward more innovative management strategies for both reefs and species.

C. Distributive Justice

Conservation interventions on Florida's Coral Reef raise issues of distributive justice regarding the fair allocation of benefits, burdens, and risks among affected communities. At the domestic level, the ecological and economic benefits of functioning coral reef ecosystems are shared broadly across Florida's coastal communities. Coral reefs provide a critical habitat for "many species of highly specialized aquatic organisms,"[213] and their degradation produces economic losses that fall disproportionately on fishing communities and low-income coastal residents most dependent on reef-derived resources and most vulnerable to the coastal inundation that healthy reefs help mitigate.[214] Inaction, thus, would potentially cause disproportionate harm to specific communities.

At the international level, the distribution of benefits and risks from intervention is likely to be asymmetrical. Introduction of non-native coral species in Florida , or promulgation of different species through species translocation or AGF, may affect reef ecosystems throughout the Caribbean through larval (or pathogen) dispersal. Nations that would be most affected by both the beneficial and harmful consequences of these interventions are those that are most heavily dependent on reef-based fisheries and tourism, such as small island developing states. For the more immediate future, some of these nations may stand to gain less and/or lose more from interventions in Florida's Coral Reef if their reefs are currently rather functional. In addition, compensatory justice concerns arise if interventions in the wider Caribbean impact third parties.

Beyond anthropocentric questions of distributive justice, there are the impacts of conservation interventions on animals and ecosystems. A growing body of legal scholarship challenges the assumption that environmental governance should be structured exclusively around human

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[213] 40 C.F.R. § 230.44(b).

[214] *Florida's Fading Coral Reefs Could Sharply Increase Coastal Flood Risk*, U.S. GEOLOGICAL SURVEY, (Jan. 26, 2026), https://www.usgs.gov/programs/cmhrp/news/floridas-fading-coral-reefs-could-sharply-increase-coastal-flood-risk; *see also* Hanny E. Rivera et al., *Coral Reefs Are Critical for Our Food Supply, Tourism, and Ocean Health*, MIT SCI. POL'Y REV. (Aug. 20, 2020).

interests. Instead, non-anthropocentric frameworks, including ecological justice frameworks, suggest that we should examine the rights and interests of animals, ecosystems, and nature itself.[215] Applied to Florida's Coral Reef, a non-anthropocentric distributive justice framework would suggest that the reef itself (and the species or individuals that compose it), possess interests in continued existence and ecological integrity that should be independently represented in permitting and planning processes, rather than treated merely as inputs into human welfare calculations.

D. Procedural Justice

Policymakers, in deciding whether to implement the reef management options discussed in this paper, will need to grapple with questions of procedural justice—how to design a process that is inclusive and reasonably viewed as legitimate and fair.[216] This involves not just who makes the ultimate decision, but what consultation processes are employed, what information is made available (and in what ways), and how decisions are reached.

Affected stakeholders will reach beyond Florida, and even the United States. If ecological replacement in Florida were a success, non-native coral would likely spread, through larval dispersal, throughout Florida and reach other areas in the Caribbean—even if researchers and policymakers worked diligently to limit introductions to only a particular country or subregion.[217] Thus, the consequences of ecological replacement, genetic modification, or demographic replacement, for example, may not be limited by state, national, or other political boundaries.

This raises the question of who should decide whether to proceed with ecological restoration, population replacement, genetic modification, etc. and what would be the appropriate process for making such determinations. Some of the academic literature on the precautionary principle has focused on transparency and consultation as ultimately key normative elements of any strategy for managing difficult decisions regarding competing and uncertain risks.[218] Florida and the United States could consult with, receive feedback from, consider and, where merited, address the concerns of other nations and communities that might be affected by any potential ecological replacement project. As a matter of justice among nations, such consultation seems to be essential and achievable. Indeed, if ecological replacement were to involve countries that are signatories to the Nagoya Protocol, declarations of intended use, consultations, and agreements might be required before collections and export of corals could proceed. Opportunities for input from local affected communities would also be legally required under U.S. national and state environmental impact assessment laws, such as the National Environmental Protection Act (NEPA).[219]

In this context, what if there is no consensus among the nations and communities that may be affected by the conservation intervention? Governments routinely take actions with potential

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[215] *See, e.g.*, Kai M.A. Chan et al., *Why Protect Nature? Rethinking Values and the Environment*, 113 PROC. NAT'L ACAD. OF SCI. 1462 (2016); Noah Sachs, *A Wrong Turn with the Rights of Nature Movement*, 36 GEORGETOWN ENVTL. L. REV. 39 (2013); Ori Sharon, *Environmental Law's Missing Piece: The Right to Nature*, 36 DUKE ENVTL. L. & POL'Y FORUM 79 (2026).
[216] *See* Lawrence B. Solum, *Procedural Justice*, 78 S. CAL. L. REV. 181, 191-92 (2004).
[217] Carly J. Randall et al., *Larval Precompetency and Settlement Behavior in 25 Indo-Pacific Coral Species*, 7 COMMUNICATIONS BIOLOGY 1, 9 (2024).
[218] *See generally* Cass R. Sunstein, *Beyond the Precautionary Principle*, 151 U. PA. L. REV. 1003 (2003).
[219] 42 U.S.C. § 4336(b)(1); 42 U.S.C. § 4336a(c).

cross-jurisdictional effects without the consent of those that may bear those effects. Yet this does not make it ethically unproblematic. Perhaps if ecological replacement is to proceed, Florida and the United States might coordinate with other potentially affected nations, if not to receive their consent, then at least to learn their perspective and concerns, and attempt to mitigate them, where possible.

At the same time, questions of procedure necessarily involve efficiency and efficacy. Overly extensive consultation processes may generate hold-out problems, delay implementation of necessary solutions, and raise costs. Given the urgency of the coral reef crisis, policymakers will need to wrestle with these trade-offs and strike a balance between procedural legitimacy and process efficiency.

As discussed *supra*, consideration of non-humans is relevant here as well. There is a growing discourse on how to include non-human preferences in decision-making processes, such as proxy and stewardship models.[220] Procedural issues here include who is authorized to represent non-human interests, what mechanisms should be used, and how much weight they should be given in political processes and regulatory contexts. This article will not attempt to map the full terrain of procedural steps that may be taken. Instead, we highlight that there are a number of ways in which policymakers may wish to approach ecological interventions with the goal of procedural legitimacy.

E. Ethics of Responsibility

The most recent scientific evidence suggests that, given human inaction, coral reefs will continue to degrade and increasing species will be at risk of extinction.[221] In this likely scenario, losses would not be caused by direct coral management decisions. By contrast, if coral ecological replacement is undertaken and native species go extinct at the same time or sooner than otherwise would have been the case, it might be said that, in some sense, coral management decisions have been a factual cause of the extinction (or a "sooner-than-otherwise" extinction). If so, one potential ethical question may be whether that matters? Should action that results in extinction carry greater moral culpability than inaction that leads to the same result (although again, perhaps the extinctions would occur sooner with the action in the form of ecological replacement)? To some extent, this differentiation is akin to the legal and moral distinctions between responsibility for the commission and omission of an act.[222] In evaluating this, policymakers should differentiate between blameworthiness and responsibility to act. By pursuing inaction, one may avoid being blamed for the negative repercussions that could result. However, policymakers nevertheless may bear a responsibility to act.

Although the law and some ethical paradigms may acknowledge a general distinction between responsibility for action and inaction, this is certainly not the case when there is a special

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220 *See, e.g.*, MARTHA C. NUSSBAUM, JUSTICE FOR ANIMALS: OUR COLLECTIVE RESPONSIBILITY (2022); SUE DONALDSON & WILL KYMLICKA, ZOOPOLIS, A POLITICAL THEORY OF ANIMAL RIGHTS (2011).
221 *See supra* Section I.
222 Mark Spranca et al., *Omission and Commission in Judgment and Choice,* 27 J. EXPERIMENTAL SOC. PSYCHOL. 76, 95 (1991); Alejandro Camacho, *Assisted Migration*, *supra* note 17, at 225-26 (2010).

relationship or other obligation to act.[223] Undoubtedly, in many legal traditions, sovereign governments have long been understood to carry a duty to protect species and ecosystems within their jurisdiction in trust for their respective publics.[224] Moreover, there arguably is an obligation to take steps to reverse or mitigate harm in contexts in which a preceding act led to such harm.[225] As such, past and future harms from anthropogenic global climate change, shipping, and pollution (among other things) suggest that there in fact may be an affirmative moral and legal duty for public entities to act on behalf of their constituencies. This responsibility generates role-specific duties to act for agents of state and federal government who are in positions of agency and authority.

Another responsibility-oriented issue is the possible creation of moral hazard. The interventions discussed in this paper, if successful, would enable Florida's Coral Reef (and perhaps those in the wider Caribbean) to better withstand the conditions created by anthropogenic climate change and localized pollution. They do not, however, change the underlying behavior that led to these reefs dying off in the first place. By intervening, policymakers may create a permission structure for third parties to continue engaging in behavior that harms reefs or the climate generally, as the visible impacts of that behavior would be reduced.[226] This, in turn, could reduce the urgency to address the underlying causes of reef decline. Past evidence of moral hazard risk from conservation biotechnology is relatively weak.[227] However, there is heightened concern over moral hazard at present due to the Trump administration's unprecedented efforts to substantially weaken species, ecosystem, and landscape/seascape protections while simultaneously promoting de-extinction and other biotechnology-oriented approaches.[228] Moral hazard concerns thus remain a potential second-order effect policymakers should take into account.

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[223] Camacho, *Assisted Migration, supra* note 17, at 171, 227, quoting W. PAGE KEETON ET AL., PROSSER AND KEETON ON TORTS 377, 381-382 (5th ed. 1984) (identifying a repeated process of carving exceptions to the general rule of exempting omissions from liability in tort law).

[224] *See, e.g.,* Joseph L. Sax, *The Public Trust Doctrine in Natural Resource Law: Effective Judicial Intervention*, 68 MICH. L. REV. 471 (1970); J.B. Ruhl & Thomas A. J. McGinn, *The Roman Public Trust Doctrine: What Was It, and Does It Support an Atmospheric Trust?*, 47 ECO. L. Q. 117 (2020).

[225] Damien Shiff, *Samaritans: Good, Bad and Ugly: A Comparative Law Analysis,* 11 ROGER WILLIAMS U.L. REV. 77, 94 (2005).

[226] *See, e.g.*, Jesse Reynolds, *A Critical Examination of the Climate Engineering of Moral Hazard and Risk Compensation Concern*, 2 ANTHROPOCENE REV. 174, 176 (2015) (discussing moral hazard risk as a result of climate engineering).

[227] *See* Christopher H. Lean et al., *De-Extinction and the Risk of Moral Hazard*, 313 BIO. CONSERVATION e111637 (2016).

[228] *Compare, e.g.*, Proclamation No. 11044, 91 Fed. Reg. 45179 (July 13, 2026) (reducing the size of reserved land at the Grand Staircase-Escalante National Monument); *Rescinding the Definition of "Harm" Under the Endangered Species Act*, 91 Fed. Reg. 43300 (July 14, 2026) (rescinding the longstanding regulatory definition of "harm" and declining to offer a replacement, such that significant habitat modification or degradation no longer constitutes prohibited take); *with* U.S. Dep't of the Interior, *Department of the Interior Announces New Partnership to Advance Conservation of Imperiled Species Through Biobanking and Genomic Science*, https://www.fws.gov/press-release/2026-06/interior-announces-new-partnership-advance-conservation-imperiled-species (Jun. 25, 2026) (announcing a plan to engage in the collection and cryopreservation of living biological materials to promote conservation research); Doug Burgum (@SecretaryBurgum), X (Apr. 7, 2025 at 1:42 PM PDT), https://x.com/SecretaryBurgum/status/1909345951069651032 (claiming that "the marvel of 'de-extinction' technology can help forge a future where populations are never at risk").

F. Research Ethics

There are ethical issues associated with conducting the interventions discussed here and the research that lays the groundwork for them. Integrity and transparency are crucial values in this context because of the contested nature of the research. It is important that findings are shared, methods are open, and that processes and data are made available for others to verify and, if possible, replicate.

The research also involves and impacts marine animals, which means considerations of animal welfare are relevant. Minimizing harm to animals, using a minimum number of animals, and post-research caretaking are among the basic standards for animal research ethics. For research beyond the lab, minimizing ecological harms and population impacts are also crucial.

Social science research is also needed to realize procedural and participatory justice standards as well as to identify public values and their salience. This research must be done in accordance with informed-consent standards and needs to be inclusive and representative of stakeholders. None of these research ethics considerations are unique to the coral management context, but they are highly salient given the complex and contested nature of the issue and the novelty of the possible management strategies.

V. PROMOTING INTELLIGIBLE CORAL CONSERVATION GOVERNANCE

Policymakers and practitioners could pursue an array of different conservation strategies in response to Florida's reef decline. Each raises significant uncertainties as well as ecological and ethical tradeoffs not determinable solely by reference to scientific or other expertise. The need to resolve potentially conflicting values is inevitable. Indeed, longstanding conservation laws implicitly but emphatically resolve such tradeoffs in favor of promoting historical conditions — even if to the detriment of promoting current or future biodiversity and ecological health.

In this section, we offer a set of procedural principles to help coral conservation governance adapt. These principles are rooted in the need for governance to help regulators and researchers assess the potential tradeoffs of different conservation strategies, reduce and manage uncertainty, and empower the polity and policymakers as they consider different normative considerations relevant to advancing conservation in light of dynamic ecological change. We draw on our prior work[229] as well as emerging guidelines and best practices developed for conservation introductions.[230] As detailed herein, the core elements include: (1) risk assessment, (2) regulatory experimentalism and empiricism, (3) public participation, in particular involvement of those most affected by any deployment decision, and (4) adaptive management.

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[229] *See, e.g.*, Camacho, *Assisted Migration*, *supra* note 17; Camacho, *Going the Way of the Dodo*, *supra* note 89; Sandler, *The Ethics of Genetic Engineering*, *supra* note 78; Sandler, *Gene Drives and Species Conservation*, *supra* note 210.

[230] Most notably, the International Union for the Conservation of Nature's 2013 general guidelines for conservation translocations suggest that intentional colonization can be justified if undertaken in a gradual way that eliminates "substantial uncertainty about the risks of a translocation outside indigenous range." *See* International Union for Conservation of Nature, *supra* note 92, at 16; *see also supra* Section IV.A.

We use the term *intelligible* deliberately. A central defect of the prevailing native/non-native and natural/unnatural binaries is not merely that they are substantively rigid but that they obscure the choices actually being made: by resolving value tradeoffs silently and in advance, they render conservation decisions unintelligible to the very publics those decisions bind. An intelligible governance regime, by contrast, is one that makes the operative tradeoffs legible—surfacing what is being risked, for whose benefit, against which baseline, and on what contested value premises—so that they can be deliberated and owned rather than smuggled into definitional categories. The four elements that follow are best understood not as a checklist but as a division of labor between two tasks that the historical-fidelity default has long conflated. The first is characterizing the tradeoffs: identifying, as rigorously as the science permits, the costs, benefits, and uncertainties of each strategy relative to the alternatives, including inaction. The second is resolving them: choosing which risks to run and which values to prioritize where reasonable people disagree. Risk assessment and regulatory experimentalism serve the first task; public participation and adaptive management serve the second. Keeping the two analytically distinct is what allows a risk-based regime to be rigorous without pretending that expertise alone can answer questions that are, at bottom, about value.

A. Integrating Risk Assessment

Any legal regime considering whether or when to explore conservation interventions would benefit from integration of risk assessment at each stage of the management process, including research, general standard setting, and case-specific deployment.[231] Such risk assessments might analyze the uncertainties, ecological advantages, administrative costs, and ecological risks associated with that regulatory stage. Inevitably, especially in circumstances in which the introduction has yet to occur, a contextual risk assessment that evaluates the tradeoffs of introduction in a particular case is almost always appropriate.[232]

Such a risk assessment should consider the potential costs of each strategy, both intended and unintended. For example, an ecological intervention may involve programmatic risk by taking away resources from other potential conservation actions, a direct and intended cost. Additionally, it could create the risk of further unintended ecological risks, such as harm to native species. A risk assessment should also consider the potential benefits of pursuing a given strategy. Those benefits should be construed broadly—they could include, for example, the potential contribution of the strategy to the preservation of a given species, the benefits to broader ecosystems, as well as any economic or social benefits that could accrue to stakeholders. The risk assessment should compare the costs and benefits of each strategy to that of alternative management strategies, including inaction.

Importantly, such risk assessments should not categorically bar certain strategies because they involve the introduction of non-native or modified species. Instead, the framework should focus on the tradeoffs of each strategy broadly defined. What exactly counts as a benefit, and how to weigh benefits, will require consideration by policymakers.

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[231] Alejandro E. Camacho, *De- and Re-Constructing Public Governance for Biodiversity Conservation*, 73 VANDERBILT L. REV. 1585, 1632-34 (2020).
[232] Richardson et al., *supra* note 85, at 9721, 9721-9724.

Some regulatory schemes do require some form of risk assessment in the course of licensing certain conservation strategies. Most notably, the U.S. Fish and Wildlife Service, in a recent regulatory change, now requires an evaluation prior to the introduction of an "experimental population" under the ESA of (1) "possible adverse effects on extant populations of [the listed] species," (2) the likelihood of survival for the introduced population, (3) potential effects of the population's establishment on the listed species' recovery, and (4) potential effects of other adjacent activities on the introduced population.[233] This provision is certainly far from perfect. It narrowly focuses on the effects to the listed species alone, missing the broader tradeoffs an introduction may generate. It also only assesses one potential strategy, failing to compare the introduction to any other conservation options. Nonetheless, this regulation shows the potential for more thoughtfully incorporating risk assessments into conservation law and management. Similarly, NEPA requires a consideration of the environmental effects of (and possible alternatives to) proposed major federal actions.[234] Yet NEPA does not require agencies to adopt the least environmentally impactful alternative—it merely asks agencies to consider the environmental impact of the action they do choose.[235] Nor does NEPA require any particular mitigation measures to reduce environmental impacts. As such, there remains room for a more structured approach that requires action based on the results of a risk assessment.

At the same time, many regulatory schemes currently require adherence to historical standards that effectively keep a holistic risk assessment from being feasible. Such regulations reify the terms "native" or "natural," disallowing consideration of actions that may be desirable but depart from a historical baseline set by statute. This codification of historical preservation into statute is visible across public lands and waters, endangered species, and invasive species laws.[236] Where regulations display such a rigid preference, they will need to be amended to allow for the structured risk assessment we recommend in this Article.

That is not to say that the concepts of "native" or "natural" should hold no value to policymakers. They could be used to form rebuttable presumptions against intervention, as the FWS has done in Federal Wildlife Refuges. There, a default presumption against the introduction of non-native plants was implemented, rebuttable only if the Service determines that there is no feasible alternative.[237] Regulations could implement such default rebuttable presumptions if policymakers believe that forward-looking interventions or non-native introductions are likely to be harmful in many instances. Yet we do not believe an absolute prohibition on forward-looking interventions on the basis of these presumptions is warranted, nor do we think a general presumption disfavoring forward-looking interventions is wise based on current scientific evidence.[238] Instead, regulations should allow policymakers to consider alternative approaches in a systematic manner.

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[233] 50 C.F.R. § 17.81(b).

[234] National Environmental Policy Act of 1969 ("NEPA"), Pub. L. No. 91-190 § 102, 83 Stat. 852 (1969) (codified at 42 U.S.C. § 4332).

[235] 42 U.S.C. § 4332

[236] *See* Alejandro E. Camacho, *In the Anthropocene: Adaptive Law, Ecological Health, and Biotechnologies*, 15 LAW, INNOVATION, TECH. 280, 282; Camacho, *De- and Re-Constructing Public Governance*, *supra* note 231, at 1596-1607.

[237] U.S. FISH & WILDLIFE SERV., FISH & WILDLIFE SERVICE MANUAL, 601 FW 3.15C; Camacho, *Going the Way of the Dodo*, *supra* note 89, at 903.

[238] *See* Camacho, *Going the Way of the Dodo*, *supra* note 89, at 904.

Making this shift operational requires more than a general endorsement of risk assessment; it requires identifying, regime by regime, the specific legal changes that would let regulators weigh the tradeoffs we describe. Three of the authorities canvassed in Part III are especially consequential. Under the Endangered Species Act, the obstacle is the treatment of a function-restoring introduction as prohibited "take" or "harm" of a listed native under Section 9 and the elkhorn/staghorn 4(d) rule. That obstacle is not immovable. NOAA could revise the 4(d) rule to provide that carefully conditioned introductions undertaken to restore ecological function do not constitute prohibited harm where the listed native is already functionally extinct *in situ* and the introduction is not the but-for cause of its loss. Alternatively, and more modestly, NOAA could issue enhancement-of-survival permits under Section 10(a)(1)(A) framed at the level of the reef system rather than the single listed species or designate a Section 10(j) experimental population to authorize otherwise-prohibited activity under tailored conditions. Each of these vehicles already exists; what is missing is their deployment for ecosystem- rather than species-level ends.[239]

The National Marine Sanctuaries regime presents a different problem—not a statutory bar but a categorical regulatory presumption. The Florida Keys sanctuary's prohibition on "exotic" species and its "green/yellow/red-light" permitting framework treat non-native introduction as presumptively impermissible regardless of ecological effect. That presumption could be revised to require, rather than foreclose, an individualized risk assessment for candidate introductions that plausibly restore function—converting a categorical red light into a rebuttable one.

Florida's own law may be the hardest obstacle if the statute is interpreted as prohibiting—with no ecological-benefit exception—the release of any non-native saltwater species into state waters. Because the FWC's authority is constitutional, such an interpretation could not be displaced simply by a federal permit. Under such an interpretation, reform here likely requires either a FWC rule creating a defined "conservation introduction" category subject to risk assessment or a narrow legislative amendment authorizing such introductions under FWC oversight.[240]

There is, however, a legal argument that the more categorical of these bars are already vulnerable on their own terms. As we noted in Part III, a flat prohibition on the careful introduction of non-indigenous coral rests on a factual premise—that non-native species are invariably harmful, and therefore "invasive"—that the science increasingly contradicts in circumstances such as a declining ecosystem whose key reef-building coral species are already functionally extinct. An agency that refuses even to consider a function-restoring introduction through individualized risk assessment, and instead relies on a definitional category that presumes harm it does not examine, may be acting arbitrarily and capriciously within the meaning of the Administrative Procedure Act.

The point is not that agencies must permit such introductions; it is that reasoned decision-making requires them to assess the actual ecological tradeoffs rather than to resolve them by fiat through an outdated presumption. This argument has independent force in the current administrative-law environment. As courts extend less deference to agency interpretations of their statutes, categorical rules resting on unexamined factual assumptions are more exposed, not less—though the same

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[239] *See supra* Section III.B.
[240] *See, e.g.*, Fla. Stat. §379.231(1); Fla. Admin. Code r. 68-5.003; Fla. Const. art. IV, §9.

diminished deference also narrows an agency's latitude to authorize novel interventions, which only underscores the value of grounding any intervention in an explicit risk-assessment record.[241]

B. Managing Uncertainty and Promoting Regulatory Learning

Next, we advocate for the adoption of regulatory experimentalism in ecological conservation efforts. As made clear in Part II, conservation law operates against a backdrop of significant uncertainty. Ecosystems are complex, environments change over time, and as a result the ultimate effects of a given strategy are unlikely to be known *ex ante*. To accommodate this uncertainty, policymakers should craft conservation policies as experiments that operate in multiple phases and allow for regulatory adaptation based on earlier findings. A multi-phase experimental strategy might help ensure that any analysis of permissibility assesses the uncertainties, ecological advantages, administrative costs, and ecological risks associated with each regulatory stage. Such a regime would help promote learning, manage risks, and maximize ecological benefits by reducing uncertainties about introduction.[242]

To illustrate how an experimental approach might be designed, we consider a hypothetical public regulator deciding to allow pursuit of coral ecological replacement to protect Florida's Coral Reef. A three-phase process might be adopted. First, initial coral experiments could be performed entirely *ex situ* (in tanks). This could be followed (if/when appropriate) by *in situ* experiments with outplanted corals that could be prevented from sexual reproduction (by removal prior to sexual maturity). Third, if warranted, regulators would oversee *in situ* deployment in the wild. Such is the approach that has already been applied on the Great Barrier Reef to assess the use of heat-evolved algal symbionts as an intervention strategy as part of the Pilot Deployment Program of the Reef Restoration and Adaptation Program (RRAP).[243]

We call this a *staged-authorization* approach, and its logic is driven precisely by the same feature that characterizes many of the interventions discussed here: irreversibility. Once non-native corals complete their sexual life cycle and their larvae disperse across the currents that connect the wider Caribbean, introductions cannot be recalled. Ordinary adaptive management—"learning by doing," with course corrections as information accrues—has limited purchase against an action that cannot be undone. Staged authorization responds by front-loading the learning into the reversible phases. Ex situ research in closed systems essentially carries no escape risk; contained in situ trials with spawning suppressed remain recoverable; only the final phase is irreversible, and it is reached only after the reversible phases have already assessed and/or mitigated the uncertainties that matter most. The sequence thus converts irreversibility from a reason for paralysis into a design constraint that dictates the order of operations.

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[241] *See* 5 U.S.C. §706(2)(A); *Motor Vehicle Mfrs. Ass'n v. State Farm*, 463 U.S. 29, 43 (1983); *Loper Bright Enterprises v. Raimondo*, 603 U.S. 369, 412 (2024).
[242] Camacho, *Assisted Migration*, *supra* note 17, at 250.
[243] Pears, R., Dryden, J., Dungan, A., and Smith, R. (2025) Reef Restoration and Adaptation Program – Intervention risk assessment of the Pilot Deployments Program. Australian Institute of Marine Science, Townsville (pp93). RRAP-Intervention-Risk-Assessment-2025-2030.pdf

1. Ex Situ Research

This stage represents activities investigating the study of corals to be potentially introduced—for example, any non-native corals—in tanks and mesocosms. In most jurisdictions, there are no statutory prohibitions on this work, although resource agency policy or interpretive regulations might require some degree of oversight to ensure escape of organisms is truly restricted.[244]

In light of significant uncertainties, targeted *ex situ* research into the risks and feasibility of potentially introduced corals seems appropriate.[245] This research has effectively zero risk but would provide invaluable information to scientists and policymakers interested in gated decision-making. *Ex situ* research would be potentially useful in quickly identifying the most high-risk activities (e.g., which corals possess allelopathic qualities that are obviously detrimental to certain other species) but are less useful in quantifying absolute risk or demonstrating low or no risk. Indeed, it is the lack of any obvious problems or ”red flags” at the *ex situ* stage that might trigger progression to the next authorization stage (controlled *in situ* research) where a more comprehensive range of ecological conditions and interactions are present.

2. Controlled In Situ Research

A secondary phase of research might be to translate *ex situ* experiments to the field, if indeed the results of *ex situ* research suggest controlled *in situ* research is appropriate. This is a necessary secondary step because no mesocosm can recreate the ecological conditions and inhabitants of the actual reef. In this stage, scientists and practitioners would endeavor to assess whether introduced corals not only cause no harm to the native ecosystem but can actually thrive in local reef environments despite potentially novel stressors and diseases. A key characteristic of these controlled *in situ* trials is their small-scale and temporary nature, allowing for potential reversibility. This stage might include removal of outplanted corals prior to their reaching sexual maturity as a guard against continued spread.

Prior to performing *in situ* research, a key risk analysis for researchers to conduct would be to holistically evaluate the probability of spread of introduced populations beyond the contained trial site. Additional work—informed by *ex situ* findings—may also be needed to fully assess the risk involved in contained *in situ* research for any of the introduction alternatives.

3. Managed Deployment

A third potential stage would expand the spatial scale over which trials occur and remove restrictions over how long the trial might last. Eventually, if the intervention is deemed successful and worthy of expansion, a network of outplanting sites intended to sustain each other through larval recruitment would be an appropriate goal. Any standards for this phase would need to

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[244] Given the 2 million households in the US with saltwater aquaria and the ready availability of Indo-Pacific coral species in the aquarium trade, it is inevitable that uncontrolled *ex situ* experiments are already underway involving corals from different oceanic regions. Despite this risk, it seems unlikely that steps will be taken to regulate the holding of Indo-Pacific corals by private individuals. Consequently, imposing such restrictions on researchers is unlikely to mitigate the overall risk.
[245] Webster & Schindler, *supra* note 16, at 777.

integrate modeling of larval connectivity, genetic planning to ensure genetic diversity is maintained, and coordination of outplanting and monitoring.[246]

For the more aggressive introduction strategies, it is likely that legal changes would need to occur for this final stage to be permissible. As described in Part III, many state and national authorities have adopted prohibitions or restrictions on non-native coral introductions. Moreover, because non-natives might easily spread outside of the immediate area of interest, this phase would likely necessitate multi-jurisdictional coordination. Notably, with multilateral coordination or agreement in place, the initial managed deployment effort could be to multiple reef systems throughout the region, strategically positioned to create multiple independent sources of larvae for the network of recovering reefs.

These stages map onto existing legal authorities more readily than their novelty suggests. The *ex situ* phase, involving no release, generally requires no specific research or scientific-purpose permit. The contained *in situ* phase fits comfortably within the Endangered Species Act's Section 10(a)(1)(A) scientific-purpose and enhancement permits and within the sanctuary research-permit tier, both of which already contemplate closely monitored, condition-laden activity. Only the managed-deployment phase requires the more substantial legal changes canvassed above—a Section 10(j) experimental-population designation, sanctuary special-use authorization, and, in Florida waters, a Commission rule or statutory amendment. Sequencing the intervention this way carries a regulatory as well as a scientific payoff: because each phase generates the record on which the next phase's authorization depends, the framework builds precisely the reasoned, evidence-based foundation that the Administrative Procedure Act requires and that categorical bars conspicuously lack.

C. Public Participation and Governmental Coordination

In addition to replacing simplistic binary categories with risk assessment and adopting multiple regulatory stages that help manage uncertainty and promote learning, conservation efforts should provide substantial opportunities for meaningful participation of affected interests throughout the resource management process. Without a tether of either leaving the ecosystem unmanaged or maintaining/restoring it as it was before recent (and seemingly irreversible) human disturbance, management goals are less easily tied to any objective scientific determination. While scientific data about the many potential tradeoffs of each conservation strategy (both generally and in a particular context) remain vital, whether and under what conditions to pursue a given strategy becomes much more of a decision about value: which ecological constituents, services, or processes to ignore, maintain, remove, and/or introduce. Such priorities cannot easily be made solely on the basis of scientific expertise but rather implicate choices upon which affected parties may reasonably differ.[247]

Accordingly, a foundational component of conservation policy must be to ensure a robust decision-making process. This includes not only the generation of information about ecological, economic,

[246] Ian G. Jamieson, *Founder Effects, Inbreeding, and Loss of Genetic Diversity in Four Avian Reintroduction Programs*, 25 CONSERVATION BIOLOGY 115, 116 (2011).
[247] Alejandro E. Camacho et al., *Reassessing Conservation Goals in a Changing Climate*, 26 ISSUES IN SCI. & TECH. 21 (2010).

and social risks and benefits. It also includes the dissemination of such information to affected parties and ensuring that potentially affected parties are incorporated in initial standard setting, implementation, and enforcement of conservation research and deployment.[248]

Relatedly, the interconnected nature of ecosystems will often require cross-jurisdictional consultation. As we have discussed in the instance of Florida's Coral Reef, an intervention in one locality may have effects that spread beyond state and national boundaries. In light of this possibility, open and cross-jurisdictional consultation processes are likely crucial, particularly before any *in situ* placement of non-native populations. Ensuring inclusion of all potentially affected stakeholder groups (e.g., fishing communities; coastal residents; Indigenous groups) is additionally important from the standpoint of procedural justice.[249] The capacity or even a right to participate in decisions that affect interests may be essential for the process to be viewed as legitimate by those affected parties and others.[250]

The cross-jurisdictional character of the coral reef problem also has an institutional dimension that existing scholarship in this field has largely overlooked. SPAW establishes a standing Scientific and Technical Advisory Committee and obliges parties to cooperate in conserving shared and migratory species—an apt description of coral populations linked by larval dispersal. It thus offers a ready, if underused, forum through which the United States could pursue the multilateral consultation that the interconnectedness of Caribbean reefs makes not merely prudent but, as we argued in Part IV, an obligation of justice among affected nations. We do not suggest that SPAW resolves the hard problem of proceeding absent consensus; we suggest only that a governance regime serious about cross-jurisdictional legitimacy should work through the regional institutions that already exist, rather than treat coordination as an afterthought.[251]

Finally, participatory processes should carry through the concern for non-human interests developed in Part IV. At a minimum, deployment risk assessments should include explicit account of the interests of sentient organisms and ecological collectives at stake. A framework built to make value tradeoffs intelligible should not render this set of tradeoffs invisible by default.

D. Adaptive Management

In pursuing any conservation strategy, policymakers should treat that strategy as an ongoing experiment that requires sustained monitoring and, if necessary, adjustment to address unforeseen circumstances. This view of "policy as experiment" lies at the root of adaptive management, which advocates for "learning by doing" in the implementation of policy.[252] An adaptive approach recognizes that decision-making is an ongoing, iterative process of design, implementation, and evaluation that requires flexibility to succeed.[253]

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[248] Camacho, *supra* note 231, at 1635.
[249] Solum, *supra* note 216, at 275.
[250] *Id.*
[251] *SPAW Protocol*, 2180 U.N.T.S. 101 (1990) (ratified by S. Exec. Rep. No. 107-8 (2002)).
[252] Eric Biber, *Adaptive Management and the Future of Environmental Law*, 46 AKRON L. REV 933, 934 (2013).
[253] *See* Alejandro E. Camacho, *Can Regulation Evolve? Lessons From a Study in Maladaptive Management*, 55 UCLA L. REV. 293, 307 (2007).

The importance of an adaptive management approach becomes clear when considering the range of interventions discussed in this Article. The ultimate outcomes of these interventions are inherently uncertain, due to the dynamic nature of the Caribbean reef system. The practice of adaptive management manages that uncertainty by creating opportunities for learning throughout implementation. The goals of these interventions should similarly be pliable in case novel challenges to implementation arise. This requires procedural flexibility to be built into the regulations authorizing interventions, in addition to robust monitoring and assessment requirements.[254] Prior scholarly work has examined how statutes and regulations should be designed to incorporate adaptive management practices,[255] and we will not revisit their observations in detail here. But given the high degree of uncertainty involved in ecological interventions, we deem it prudent that policymakers adopt these lessons in designing a regulatory framework around coral introduction strategies.

It is important of course to recognize the limits of adaptive management in the context of ecological conservation. Conservation policy—and thus regulatory experimentalism and empiricism—inevitably remains constrained by a scarcity of resources.[256] And ecosystems are dynamic entities that change both over time and in response to conservation efforts. As policymakers settle on even a provisional course of action, the passage of time and effects of the policy may alter the ecosystem, potentially irreversibly. As a result, pursuing a particular strategy may close off implementation of others. Nevertheless, adaptive management—combined with experimentalism and empiricism—remains vital in managing linked socio-ecological systems that are uncertain, complex, and dynamic. Over time, adaptive approaches will generate a knowledge base that future policies can draw on to increase their efficacy.[257]

One limit deserves particular emphasis, because it is the standard and most powerful critique of adaptive management: the approach is frequently invoked but rarely realized. Agencies have too often used the promise to "monitor and adapt" as a rhetorical device for deferring hard choices at the authorization stage, while the monitoring that would make adaptation possible goes underfunded or undone. If adaptive management is to be more than an incantation, it must be built into the authorizing instruments as enforceable structures rather than aspirations: binding monitoring obligations, pre-specified indicators and decision triggers, and—most importantly—the staged-authorization design described above, under which a later phase cannot proceed until the monitoring from an earlier phase has produced the findings the trigger requires. Adaptive management disciplined in this way is not a license to act first and think later; it is the opposite—a mechanism that makes continued action contingent on continued learning.

CONCLUSION

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[254] *See, e.g.*, Alejandro E. Camacho & Robert L. Glicksman, *Legal Adaptive Capacity: How Program Goals and Processes Shape Federal Land Adaption to Climate Change*, 87 U. COLO. L. REV. 711, 722-23 (2016).

[255] *See, e.g.*, *id.*; Camacho, *Can Regulation Evolve?*, *supra* note 253; C.S. HOLLING, ADAPTIVE ENVIRONMENTAL ASSESSMENT AND MANAGEMENT (1978); J.B. Ruhl & Robin Craig, *Designing Administrative Law for Adaptive Management*, 67 VANDERBILT L. REV. 1, 48 (2014); Biber, *supra* note 252, at 939.

[256] *See, e.g.*, Mark W. Schwartz, *The Performance of the Endangered Species Act*, 39 ANN. REV. ECOL., EVOL. & SYSTEMATICS 279, 281 (2008) (describing the underfunding of the ESA).

[257] Alejandro E. Camacho, *Adapting Governance to Climate Change: Managing Uncertainty Through a Learning Infrastructure*, 59 EMORY L. J. 1, 76 (2009).

The rapid rate of anthropogenic climate change is challenging the viability of traditional methods of ecological conservation. Today's wildlife laws largely center on historical preservation, a goal that is increasingly in tension with ecosystem preservation. Safeguarding both is likely to become untenable in many contexts in the near term. The shortcomings of current conservation approaches are clearly visible on Florida's Coral Reef. Native coral species are poorly adapted to rising water temperatures and worsening water quality. Some Florida-native species are functionally extinct, kept alive only by a human-driven, labor-intensive process of outplanting and biobanking. As this Article demonstrates, preserving a resilient reef ecosystem will require an openness to a broader spectrum of ecological conservation approaches. Yet under the current regulatory framework, many of these approaches would be impermissible. This reflects a structural bias for historical fidelity embodied in standing conservation laws: some ecological interventions are treated as impermissible because they imply a departure from historical preservation.

Through the example of Florida's Coral Reef, we demonstrate that historical fidelity should no longer be the overriding default conservation orientation, for both feasibility and normative reasons. Instead, we argue for an evaluation of conservation goals and conservation strategies on their own merits. The strategies discussed here each carry distinct trade-offs, a situation that is not unique to the context of Florida's Coral Reef. In all areas of conservation policy, choices come with costs and benefits. Multiple paths are open to policymakers, the exact outcomes of which tend to be uncertain. That reality requires wildlife and environmental laws that help policymakers reduce and manage these uncertainties, make normative considerations and value tradeoffs visible so they can be considered and resolved, and allow for informed decision-making under conditions of ambiguity. Laws should be oriented towards a structured, normatively informed risk-assessment approach that treats conservation as a set of ongoing experiments from which regulators can learn, rather than an adherence to the rigid binaries of natural or unnatural and native or non-native.

The lesson of Florida's Coral Reef is not parochial. Coral reefs are simply among the first ecosystems to reach the point at which historical fidelity and ecological function can no longer both be secured, but it will not be the last.

Under conditions of massive and rapid anthropogenic change, frontline conservation practice increasingly raises tradeoffs between historical fidelity, ecological function, species conservation, and natural preservation—even as the law continues to limit if not prevent assessment and engagement on such choices. The framework we propose is not a coral reef framework that happens to generalize; it is a general framework for an anthropogenically changed world where a default unconditional commitment to historical fidelity is not always feasible and does not reliably track conservation values and goals such as maintaining ecological function and species preservation.

We of course have acknowledged that loosening the historical fidelity default raises issues. However, these concerns do not warrant maintaining a commitment to historical fidelity and the status quo. They are instead best addressed through the structure of the proposed framework. Staged authorization, individualized risk assessment measured against the baseline of inaction, rebuttable presumptions that still place the burden on the forward-looking intervener, and participatory processes that force tradeoffs into public view and debate are precisely the safeguards that distinguish disciplined intervention from a blank check. A regime that makes its value choices intelligible is far better positioned to resist their abuse than one that resolves them silently through the categories of "native" and "natural."

What we advocate, in the end, is neither wholesale abandonment of the historical baseline nor uncritical embrace of forward-looking intervention, but a change in the default posture of conservation law: from categorical prohibition toward structured, normatively informed evaluation. Concretely, that means integrating risk assessment that compares each strategy against the alternatives, including inaction and strict historical preservation; authorizing interventions in reversible stages that make continued action contingent on continued learning; embedding meaningful participation—across jurisdictions and on behalf of non-human interests—in the decisions that bind affected communities; and treating every strategy as an ongoing experiment subject to monitoring and adjustment. None of these elements are exotic to environmental law; what is new is their assembly into a coherent alternative to the historical-fidelity default.

Florida's Coral Reef is running out of time, and so is the assumption that conservation can be achieved by holding the world in place. The choice ahead is not between a pristine past and a degraded future but between a future shaped by deliberate, accountable choices and one surrendered by default. Choosing function over fidelity, where fidelity is no longer within reach, is not a retreat from conservation's ambitions. It is what keeping faith with them now requires.