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Preserving Reef-Building Coral Genetic Resources With Assisted Migration: Balancing Precaution And Risk

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I. INTRODUCTION

In 2009, the United Nations General Assembly adopted a resolution calling for increased efforts to address the security implications of climate change.[1] In support of this resolution, many countries submitted statements outlining the extensive security risks to their countries from climate change.[2] These risks are diverse, but one that was repeatedly considered was the threat from the possible widespread destruction of coral reefs.[3] While not intuitively linked to global security, coral reefs are critical to the food security, economic stability, and infrastructure protection of many small island and coastal states.[4] With over half of coral reefs projected to die globally in conservative climate models, the impacts on these nations will be severe.[5] Resulting migration, disease and exacerbated natural disasters may lead directly to armed conflict, or act as multipliers of conflict in progressive global destabilization. Coral reefs have huge security, ecological, and intrinsic value to global communities. We argue here that ensuring the protection of reefs and their genetic resources is a high priority national security interest.

Coral reefs are concentrated hubs of marine life and they contain a disproportionately large percentage of marine resources.[6] Despite the fact that coral reefs cover only 0.1-0.5% of the ocean floor, almost a third of marine species are found on reefs.[7] The catch from reef areas supplies 10% of all fish consumed by humans globally[8] and estimates place the value of the world's coral reefs at $375 billion per year.[9] Further, intact coral reefs protect oceanfront property from storm damage: between 70-90% of wave energy is absorbed on reefs—even in abnormal tidal surges

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[1] UN GA Res 63/281, U.N. Doc. A/RES/63/281 (June 3, 2009).

[2] Pacific Small Island Developing States, *Views on the Possible Security Implications of Climate Change to be included in the report of the Secretary-General to the 64th Session of the United Nations General Assembly,*
http://www.un.org/esa/dsd/resources/res_pdfs/ga-64/cc-inputs/PSIDS_CCIS.pdf.

[3] *See e.g.* Tuvalu, *Tuvalu's Views on the Possible Security Implications of Climate Change to be included in the*
report of the UN Secretary General to the UN General Assembly 64th Session,
http://www.un.org/esa/dsd/resources/res_pdfs/ga-64/cc-inputs/Tuvalu_CCIS.pdf.

[4] *Id.*

[5] *Id.*

[6] *See, e.g., See* Robert Costanza et al., *The Value Of The World's Ecosystems Services And Natural Capital*, 387 NATURE 253 (1997); Moberg & Folke, *Ecological Goods And Services Of Coral Reef Ecosystems*, 29 ECOLOGICAL ECONOMICS 215–33 (1999); SUE WELLS ET AL., U.N. ENVIRONMENT PROGRAMME, IN THE FRONT LINE: SHORELINE PROTECTION AND OTHER ECOSYSTEM SERVICES FROM MANGROVES AND CORAL REEFS 24 (2006).

[7] Costanza, *supra* note 6, at 254.

[8] *Id.*

[9] *Id.*

associated with hurricanes.[10] Coral reefs then play a critical economic, infrastructure protection and food security role for the global community.

The impacts of climate change, including sea level rise, ocean warming, and increased ocean acidification, pose a huge threat to coral reefs, which in turn impact recreation and tourism, the economy, and ultimately the stability of our society and partner nations.[11] Corals have particularly high vulnerability to climate change, and as such, reefs necessitate exceptional adaptation measures to climate change to preserve their high societal value[12].

However, because of the complexity of both coral reef ecosystems and global ocean-atmosphere feedbacks, there is and likely always will be uncertainty associated with predicting future climate change impacts and consequent coral decline. In light of this uncertainty, decision makers are faced with the question of what action, and what degree of action, should be taken to prevent future widespread coral die-off. This equation of future risk coupled with uncertainty as to its magnitude is ubiquitous in nearly all policy-making, and numerous strategies are employed to help decision-makers operate in this environment. In the US, cost-benefit type analyses are common tools used to balance risks and management strategies. In the EU and other countries globally, the precautionary principle has strong adherence. Many have argued for a broader application of the precautionary principle, particularly in the realm of environmental issues, given the uncertainty inherent in these complex systems and the potential for irreversible and catastrophic damage. This paper then will look to innovative coral reef management strategies in light of the precautionary principle and general risk management strategies.

Many proposals have been made for adaptive management in the face of climate change. For corals, these strategies range from increased restoration efforts to more global calls to reduce greenhouse gas emissions to prevent ongoing bleaching. This paper, however, will focus specifically on the possibility of translocating highly thermal tolerant corals.

Translocation, or the deliberate movement of organisms from one site to another to achieve a conservation goal,[13] has come to the forefront

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[10] WELLS, *supra* note 6.

[11] *See* U.S. DEP'T OF DEF., NATIONAL SECURITY IMPLICATIONS OF CLIMATE-RELATED RISKS AND A CHANGING CLIMATE 1–14 (2015).

[12] Constanza, *supra* note 6, at 256.

[13] *See* INT'L UNION FOR CONSERVATION OF NATURE SPECIES SURVIVAL COMMISSION, GUIDELINES FOR REINTRODUCTIONS AND OTHER CONSERVATION TRANSLOCATIONS 1–57 (2013).

of scientific discussion in recent decades.[14] Often thought to be fraught with risk, the human intervention in a species' natural range must be supported by strong evidence that a threat exists to the species and a potential benefit that exceeds the risk of translocation.

Corals seem to be an ideal candidate for translocation. Here, the term staged withdrawal is put forth to describe intentional translocation of corals within the species range but from different temperature regimes. The thermal adaptations of corals to their respective temperature regimes are highly relevant given the reality of warming oceans under climate change. Corals that with adapted thermal tolerance may be able to survive in warming areas when other corals could not. However, the natural rate of coral migration, due to the physically fixed nature of coral colonies that are only mobile during brief planktonic life stages, occurs on the order of centuries. This note evaluates concerns of staged withdrawal of coral thermal tolerance related to risk analysis and risk perception, given the precautionary principle and the increasingly dire outcomes of inaction due to global climate change.

Risk is inherent to any decision-making process, and its consideration is especially relevant in environmental issues—such as climate change adaptation—because the science is involved is complex and full of uncertainties.[15] However, under the precautionary principle, inaction due to the unknown risks of coral translocation may be unacceptable given the increasingly known risk of serious or irreversible damage if such measures are not taken.[16] Climate modeling studies have suggested that severe coral loss due to bleaching will occur if comprehensive adaptive measures are not taken.

Moreover, the ancillary risks of global trade and commerce has prejudiced corals extensively from the carbon emissions that have caused anthropogenic climate warming, and have introduced invasive species that have had negative effects on coral reefs after being transported in ship ballast water[17] or released from the aquarium trade. It is only presumed that these risks will increase over time as conditions become less favorable to native species and the furtherance of global trade brings the opportunity for further inter-oceanic introduction. However,

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[14] *See e.g.,* Ove Hoegh Guldberg et al., *Assisted Colonization and Rapid Climate Change*, 321 SCIENCE 345 (2008); Ben A. Minteer & James P. Collins, *Move it or Lose it? The Ecological Ethics of Relocating Species Under Climate Change,* 20 ECOLOGICAL APPLICATIONS 1801 (2010).

[15] *See* Markus Wagner, *Taking Interdependence Seriously: The Need For A Reassessment Of The Precautionary Principle In International Trade Law*, 20 CARDOZO J. OF INT'L & COMP. LAW 713 (2012).

[16] *Id.*

[17] Hoegh Guldberg, *supra* note 14.

computing the probability of these events is just as complex as estimating the risk of coral translocation, given volatility in the global economy, changing shipping patterns, and changing forms of practices and technologies.

This paper then explores what are appropriate ways to assess risks associated with coral translocation and how these assessments can be used to inform decision making from a the broader institution and narrower management entities. Part II of this paper will examine the scientific basis of the impacts of climate change on coral reefs and show that the threats to the world's coral reefs are devastating large. Part III examines the possibility of coral translocation as a solution to this problem, as well as the risks associated with this strategy. Part IV builds on the concrete risks identified in Part III to examine how management decisions can, and should, be made in the face of scientific uncertainty and future risk.

II. SCIENTIFIC EVIDENCE OF CLIMATE CHANGE IMPACTS ON CORALS

A. Impacts on Imperiled Corals

A barrage of local and global factors threaten coral reefs. Reef-building corals in particular are vulnerable over their worldwide range—currently and in the future; temperature stress from warming oceans constitutes the top threat in the near to mid-term future for corals, with ocean acidification and disease associated with climate change also among the top factors exacerbating the possibility of coral species extinctions over the course of the next century.[18] Warming temperatures above the normal site-specific maximum temperature may cause coral bleaching,[19] which is a breakdown of the obligatory coral-algal symbiosis in the corals' epidermal tissues. Although coral bleaching may instigate the uptake of more heat-resistant algal symbionts, prolonged temperature stress or widespread bleaching events have devastating effects on the functioning of the ecosystem.[20] Climate change vastly

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[18] *See* Kent E. Carpenter et al., *One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts*, 321 SCIENCE 560–63 (2008).

[19] *See, e.g.*, T.R. McClanahan et al., *Predictability Of Coral Bleaching From Synoptic Satellite And In Situ Temperature Observations* 26 CORAL REEFS 695 –701 (2007); S. J. Weeks et al., *Improved Predictions Of Coral Bleaching Using Seasonal Baselines And Higher Spatial Resolution* 53 LIMNOLOGY AND OCEANOGRAPHY 1369–75 (2008).

[20] *See, e.g.*, Peter W. Glynn, *Coral Reef Bleaching: Ecological Perspectives*, 12 CORAL REEFS 1–17 (1993); John M. Pandolfi et al., *Global Trajectories of the Long-Term Decline of Coral Reef Ecosystems*, 301 SCIENCE 955–58 (2003).

increases the chance of such bleach events occurring, with some models predicting that less than 50% of current coral reefs would survive by 2100.[21] The effects of local reef exploitation or degradation further intensify the vulnerability and potential decline of corals.[22]

Although local factors are more controllable than mitigating global climate change, they often conflict with societal goals and agendas, especially in the context of reefs that are proximate to large agriculture or population centers.[23] For example, shore reclamation or dredging projects affect reef ecosystem function on large spatial and temporal scales.[24] Land modifications can have long-lasting effects on coral reef ecosystems if the changes entail changes to the natural water flow or sediment distribution patterns.[25] Accidents such as ship groundings and oil spills affect a limited area, but the effects can also pervade in the ecosystem for long periods of time due to the slow rate of reef accretion.[26] A large-scale disaster such as the Deepwater Horizon oil spill has direct effects on nearby reefs as well as a profound impact on the food web, which affects the ecological regulation of reefs.[27]

Coral populations have already suffered dramatic declines in past decades due to local perturbations, storm damage, disease, the cascading effects of overfishing,[28] and anomalous heating events.[29] The National

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[21] *See* R.V. Cruz et al, *Asia: Cases Studies in* CONTRIBUTION OF WORKING GROUP II TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE 493 (Martin Perry et al. eds. 2007).

[22] Carpenter, *supra* note 18.

[23] Local threats are easier to mitigate- conflicting with social agendas.

[24] Shore reclamation projects in tropical areas, which are often built on top of coral reefs due to the convenience of shallow water and hard substrate, have similar incidence and affects of port dredging, due to the plume of fine sedimentation clouds the water during and after the construction process. The coral colonies affected by these projects are also of particularly high conservation priority because they are more affected by—and thus more resilient to—human impacts on the environment. *See, e.g.,* Simon Wilson et al. *Status of Coral Reefs of the Persian/Arabian Gulf and Arabian Sea Region*, STATUS OF CORAL REEFS OF THE WORLD 53–62 (2002).

[25] *See* Jonathan Gardner et al. *Conservation Management Options And Actions: Putative Decline Of Coral Cover At Palmyra Atoll, Northern Line Islands, As A Case Study*, 84 MARINE POLLUTION BULLETIN 182–190 (2014).

[26] *See* Andrew P. Negri et al., *Understanding Ship-Grounding Impacts on a Coral Reef: Potential Effects of Anti-Foulant Paint Contamination on Coral Recruitment*, 44 MARINE POLLUTION BULLETIN 111–17 (2002).

[27] *See, e.g.,* Helen K. White et al., *Impact of the Deepwater Horizon Oil Spill on a Deep-Water Coral Community in the Gulf of Mexico*, 109 PROCEEDINGS OF THE NAT'L ACAD. OF SCIENCES 20303 –8 (2012); Brian R. Silliman et al., *Degradation and Resilience in Louisiana Salt Marshes After the BP–Deepwater Horizon Oil Spill*, 109 PROCEEDINGS OF THE NAT'L ACAD. OF SCIENCES 11234–39 (2012).

[28] *See* Jeremy Jackson et al., *Historical Overfishing And The Recent Collapse Of Coastal Ecosystems*, 293 SCIENCE 629–37 (2001).

Oceanic and Atmospheric Administration (NOAA) declared a worldwide coral bleaching event in 2015-2016 in association with a strong *El Niño* warming event in the central Pacific.[30] It is now the third time that such a global bleaching emergency has occurred since 1988.[31]

Climate change does not affect all reefs uniformly, and modeling studies are only beginning to identify areas that are the most critically vulnerable to future population declines. Also, certain areas of the world have experienced a greater degree of coral decline, such as the Caribbean, which has lost over 80% of hard coral cover in the last 30 years.[32] A regional climate model study for the Caribbean indicated that temperatures are predicted to exceed the coral bleaching threshold—alarmingly—within several decades.[33]

Given the continued incidence of decline, the risk of inaction is likely greater for biodiversity than managed relocation.[34] Scientific studies informing the assisted migration debate are of utmost concern for coral reefs, especially given its inherent complexities as a holobiont with dynamic symbiont communities and morphological responses to different environmental factors. While the exact roles of the symbiont, host genotype, and environment are not fully understood, symbiont type was found to carry the most significant holobiont fitness implications.[35] Further, microbial communities have been demonstrated to influence the macro-ecology of coral reefs.[36]

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[29] *See, e.g.,* Peter W. Glynn and L. D'croz, *Experimental Evidence For High Temperature Stress As The Cause Of El Nino-Coincident Coral Mortality* 8 CORAL REEFS 181–91 (1990).

[30] NOAA uses satellite data of sea surface temperature to calculate time-integrated risk of bleaching based on the comparison to the average summertime temperature at each location. The previous global coral bleaching events were in 1988 and 2010, which corresponded to two El Niño events. *See* Press Release, National Oceanic and Atmospheric Administration, NOAA Declares Third Ever Global Coral Bleaching Event (Oct. 8, 2015), *available at:* http://www.noaanews.noaa.gov/stories2015/100815-noaa-declares-third-ever-global-coral-bleaching-event.html.

[31] *Id.*

[32] *See* T. A. Gardner et al., *Long-Term Region-Wide Declines in Caribbean Corals.* 301 SCIENCE 958–60 (2003).

[33] *See* Ruben van Hooidonk et al., *Downscaled Projections Of Caribbean Coral Bleaching That Can Inform Conservation Planning.* 21 GLOBAL CHANGE BIOLOGY 3389–401 (2015).

[34] *See* J Kreyling et al., *Assisted Colonization: A Question of Focal Units and Recipient Localities*, RESTORATION ECOLOGY (2011).

[35] *See* J. C. Mieog et al., *The Roles And Interactions Of Symbiont, Host And Environment In Defining Coral Fitness*, 4 PLOS ONE 1 (2009).

[36] *See* T. D. Ainsworth et al., *The Future of Coral Reefs: a Microbial Perspective*, 25 TRENDS IN ECOLOGY AND EVOLUTION 233–40 (2009).

B. Staged Withdrawal as a Tool for Climate Change Adaptation

Current coral management strategies focus on local actions that can be taken to increase reef health. These include measures such as creating marine protected areas, increasing herbivore coverage, and restoring corals from coral nurseries. Additionally, effective management plans often work to reduce the impact from human actions on land by limiting runoff and imposing stricter controls on pollution. These measures can dramatically increase the health of reefs over time, but many have recognized that they will not be sufficient to protect corals in the face of global climate change.

Corals are on the forefront of policy concerns, and now is the appropriate time to plan anticipatory and innovative strategies to stave off coral decline due to climate change. One such strategy is staged withdrawal. The intentional translocation of corals, even though it is within the species range and not into novel habitat, breaks from the status quo coral reef management approach. In the case where species diversity and ecosystem function must be saved before the habitat becomes inhospitable and populations are unable to move on their own due to effects including habitat fragmentation, physical barriers, or sheer speed of environmental changes, human-assisted migration of the population outside of its historical range has been proposed as a climate change adaptation strategy.[37] Assisted migration represents a departure from traditional conservation philosophy of restoration and ecological integrity;[38] however, in drastic cases such as corals, it may be the only option to guard against species extinctions and maintain the ecosystem functions and services.

Staged withdrawal does not translocate corals beyond the fringes of the species range—although there is evidence that coral populations could move north naturally with warming temperatures.[39] Fossil evidence suggests that the two primary reef-building corals in the Caribbean—staghorn and elkhorn—were limited to Biscayne Bay south of Miami during the early to middle Holocene (10,000–6,000 years ago) while in recent decades these corals have dominated reefs as far north as Palm

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[37] *See, e.g.,* Ove Hoegh-Guldberg et al. 2008, *supra* note; *D*. M. Richardson et al., *Multidimensional Evaluation of Managed Relocation*, 106 PROCEEDINGS OF THE NAT'L ACAD. OF SCIENCES 9721–24 (2009); M. W. Schwartz et al., *Managed Relocation: Integrating the Scientific, Regulatory, and Ethical Challenges,* 62 BIOSCIENCE 732– 43 (2012).

[38] *See* Minteer & Collins, *supra* note 14.

[39] *See* William F. Precht & Richard B. Aronson, *Climate Flickers And Range Shifts Of Reef Corals*, 2 FRONTIERS IN ECOLOGY AND THE ENVIRONMENT 307–14.

Beach County.[40] Instead, it is thermal adaptations that have developed in areas of extant coral range that could be lost due to rapidly rising ocean temperatures. These thermally tolerant coral colonies would be beneficial for the populations at the destination site, and ultimately valuable for the species protection against extinction. Importantly, recent research has indicated that thermal tolerance in corals extends to the next generation of progeny following sexual reproduction, which substantiates the use of translocation to improve local thermal tolerance.[41]

For species—including coral species—that are vulnerable to climate change with poor dispersal, rarity, low fecundity or long generation times, habitat restoration and connectivity may not be reliable safeguards.[42] As such, the translocation of coral resources is paramount. Genetic resources for temperature tolerance is only one of the many potential local adaptations that coral colonies may harbor; however the rise of temperature is currently the most significant threat to coral populations worldwide,[43] and thus thermal tolerance should be the highest priority for adaptive management. Corals have a limited ability to migrate to novel habitats because of long generation times and population fragmentation that diminishes the capacity of sexual reproduction. Although corals may reproduce by asexual reproduction, this mechanism is not ideal for long-range migration.[44]

III. ASSOCIATED RISKS WITH CORAL TRANSLOCATION

The study of risk, risk management, and risk perception has increasingly been recognized in both the scientific and the policy communities as a discrete analytic field.[45] In order to effectively make decisions about future threats, risks must be placed into a framework that allows decision-makers to compare the likelihood, magnitude and addressability of different risks. This need has led in recent decades to

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[40] This represents a migration distance of approximately 70 miles. *Id.*

[41] *See* Groves B. Dixon et al., *Genomic Determinants of Coral Heat Tolerance Across Latitudes*, 348 SCIENCE 1460–62 (2015).

[42] *See* Nina Hewitt et al., *Taking Stock Of The Assisted Migration Debate*, 144 BIOLOGICAL CONSERVATION 2560–72 (2011).

[43] Carpenter et al., *supra* note 18.

[44] Asexual propagation from wave-carried fragments may have a limited ability to exercise migration-like properties; however, the recruits are genetically identical and have limited dispersal when compared to sexual reproduction. This is especially true for fast-growing branching species of coral. *See* K. J. Miller & D. J. Ayre, *The Role Of Sexual And Asexual Reproduction In Structuring High Latitude Populations Of The Reef Coral Pocillopora Damicornis*, 92 HEREDITY 557–68 (2004).

[45] Sheila Jasanoff, *Bridging the Two Cultures of Risk Analysis*, 13 RISK ANAL. 123 (1993).

the explosion of discourse on risk analysis. Some have distinguished between three main ways of evaluating risk- risk as feelings, risk as analysis, and risk as politics.[46] These differing streams show the important role that emotional, social and political considerations may play in addition to quantitative analyses in determining societal response to risk. Others have illustrated this distinction as one between "hard" quantitative analyses and "soft" qualitative ones.[47]

Understanding both the quantitative and qualitative risks associated with coral translocation is the first step then in determining whether this may be a viable adaptive management strategy. There is strong scientific criticism against coral translocation, citing the unknown ecological risk factors of genetic inbreeding,[48] cryptic maladaptation,[49] and unforeseen extinctions associated with moving species to a new environment.[50] This builds on a long legacy of both intentional and inadvertent species introductions that have led to damaging impacts on native species as well as human interests.[51] The outcry against assisted coral migration heavily appeals to this previously observed potential for invasive species. Deciding whether to go forward with a managed relocation approach depends on a careful analysis of risk.

Moreover, the current scientific understanding of the risks to corals outside of the context of assisted migration is mired with uncertainty. Research over the last decade on temperature tolerance of coral symbionts has indicated that dynamics in symbiont communities may offer a certain degree of temperature resilience[52] and small-scale variation in oceanographic and/or bathymetric parameters may serve as genetic reservoirs after catastrophic disturbances.[53] Conversely, modeling studies indicate that even larger scale temperature refugia are

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[46] P Slovic et al., *Risk As Analysis And Risk As Feelings*, 24 RISK ANAL. 311 (2004).

[47] Jasanoff, *supra* note 45, at 124.

[48] *See* S. van der Veken et al., *Garden Plants Get a Head Start on Climate Change*, 6 FRONTIERS OF ECOLOGICAL ENVIRONMENT 212–16 (2008).

[49] *See* M. Benito-Garzón et al., *Habitat Restoration and Climate Change: Dealing with Climate Variability, Incomplete Data, and Management Decisions with Tree Translocations*, 10 RESTORATION ECOLOGY 1–7 (2013).

[50] *See* A. Ricciardi & D. Simberloff, *Assisted Colonisation is not a Viable Conservation Strategy*, 24 TREE 248–53 (2009).

[51] *See* A. K. Sakai et al., *The Population Biology of Invasive Species*, 32 ANNUAL REVIEW OF ECOLOGICAL SYSTEMS 305–32 (2001).

[52] *See* Andrew C. Baker, *Flexibility and Specificity in Coral-Algal Symbiosis: Diversity, Ecology, and Biogeography of Symbiodinium*, 34 ANNUAL REVIEW OF ECOLOGY, EVOLUTION, AND SYSTEMATICS 661–89 (2003).

[53] *See* Bernhard Riegl & W. E. Piller, *Possible Refugia for Reefs in Times of Environmental Stress,* 92 INT'L J. OF EARTH SCIENCE 520–31 (2003).

ephemeral;[54] coral reef senescence due to rising ocean temperatures coupled with the increasing frequency of intermittent temperature anomaly events are severely concerning. The evaluation of the negative impacts, associated risks, along with economic and social considerations is vital in determining whether coral translocation and staged withdrawal is appropriate at a given location.[55]

A. Quantifiable risks

1. Climate Risks

Although global climate change affects all coral reefs, even those not proximate to population centers and in otherwise isolated systems,[56] the degree of future risk varies over space and time. In fact, modeling indicates that certain parts of the world may act as refuges for corals under global climate change.[57] Climate risks form the basis of translocating corals, however climate change does not affect the globe in a uniform manner, and marine systems are no exception. Nonetheless, the onslaught of rapid climate change will subject on third of coral species to an elevated extinction risk[58] and is predicted to cause annual severe bleaching in 90% of worldwide reef systems by 2055.[59]

However, climate change is not the only climate risk to consider in coral translocation; the natural variability of local climate phenomena may have a considerable effect on the survival of a translocated coral.[60] For example, warm water anomaly events from El Niño giving effect to local bleaching,[61] cold anomaly events from winter fronts,[62] and rainfall events causing freshwater intrusion[63] can differentially affect

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[54] *See* Ruben van Hooidonk et al., *Temporary Refugia for Coral Reefs in a Warming World*, 3 NATURE CLIMATE CHANGE 508 (2013).

[55] IUCN *supra* note 14, at 4.

[56] *See, e.g.,* Terry P. Hughes et al., *Climate Change, Human Impacts, and the Resilience of Coral Reefs*, 301 SCIENCE 929–33 (2003).

[57] Van Hooidonk et al., *supra* note 54.

[58] Carpenter, *supra* note 18.

[59] *See* Ruben van Hooidonk et al., *Opposite Latitudinal Gradients in Projected Ocean Acidification and Bleaching Impacts on Coral Reefs*, 20 GLOBAL CHANGE BIOLOGY 103–12 (2014).

[60] *See* Emily J. Howells et al., *Historical Thermal Regimes Define Limits to Coral Acclimatization*, 94 ECOLOGY 1078–88 (2013).

[61] Glynn, *supra* note 29.

[62] *See* Stephen L. Coles & Yusef H. Fadlallah, *Reef Coral Survival and Mortality at Low Temperatures in the Arabian Gulf: New Species-Specific Lower Temperature Limits*, 9 CORAL REEFS 231–37 (1991).

[63] *See* John C. Andrews & Miles J. Furnas, *Subsurface Intrusions of Coral Sea Water Into the Central Great Barrier Reef—I. Structures and Shelf-Scale Dynamics*, 6 CONTINENTAL SHELF RESEARCH 491–514 (1986).

translocation source and destination sites, and the corals at these sites may have different adaptation mechanisms of dealing with each stress. The predictive capacity of these potential global and local climate stressors is essential in identifying potential sites and balancing the risk of a potential translocation.

2. Invasive Species Risks

The principal cause of concern in the scientific discussion of assisted coral migration is the introduction of invasive exotic species.[64] The risks of moving the diversity to a new location are even less understood, and mistakes made due to lacking understanding could be severe and environmentally persistent. In the case of salmon restocking in the Pacific Northwest, genetic factors were not seen empirically until several successive generations, by which time the genetic depression effects were well established within the populations.[65]

However, the scientific perception of at least some assisted-migration-associated risks may be over-inflated. The classic cases of destructive impacts of invasive species resulted from trans-continental migrations; assisted coral migration would likely entail the movement of target populations to areas in relative close proximity to their former range.[66] Further, climate change may increase the likelihood of invasive aquatic species independent of human intervention, through opening new corridors for species exchange in warmed water temperature, shortened ice cover, increased flooding events and enhancing competitive and predatory effects of invasive species.[67] This would thus undermine the invasive species risk associated with assisted migration, as other risks would be naturally present in the environment.

Some researchers believe these uncertainties alone are grounds to avoid assisted migration projects altogether.[68] On the other hand, a survey of assisted migration literature suggests that 60% of the papers between 1985 (when the term was coined) and 2010 argued in favor of assisted migration to protect biodiversity given climate change.[69]

Further analysis of the current uncertainties surrounding assisted migration would provide opportunities to inform the debate and optimize any potential projects.

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[64] Hewitt, *supra* note 42.

[65] *See* A. P. Hendry et al., *Rapid Evolution of Reproductive Isolation in the Wild: Evidence from Introduced Salmon,* 290 SCIENCE 516–18 (2000).

[66] Hoegh-Guldberg, *supra* note 14.

[67] *See* F. J. Rahel & J. D. Olden, (2008) Assessing the Effects of Climate Change on Aquatic Invasive Species, 22 CONSERVATION BIOLOGY 521–533 (2008).

[68] A. Ricciardi & D. Simberloff, *supra* note 53.

[69] Hewitt, *supra* note 42.

Translocation of individuals has been proposed as a method of bolstering the population sizes of rare species.[70] However, the argument can be made that unusual or uncommon genetic traits within a species of coral—especially when those traits are useful in adapting to climate change—should also be favored.

The introduction of novel genotypes also has the potential to facilitate the spread of accompanying diseases or pathogens that are endemic to the source area, but novel to the relocation site. This could pose risks to native flora and fauna, which may be novel to these influences. In addition, translocated corals might also bring with them a variety of metazoan organisms whose ecological interactions must be considered. The risks to redistributing species could have negative consequences that would outweigh the potential benefits. However, even in the absence of intentional assisted colonization efforts, marine epizootics have been documented to spread rapidly, particularly in the Caribbean. Examples of invasive species include the Pacific lionfish invading the western Atlantic,[71] the spread of the *Tubastraea* "sun coral" in the Caribbean and South Atlantic,[72] and invasive barnacle species in the Pacific.[73]

3. Genetic Risks

Translocation of corals from distant areas might also result in outbreeding depression, or the weakening of progeny fitness. This is due to the dilution of site-specific genetic adaptations as a result of the disruption of coevolved gene complexes.[74] This disruption of local genetic structure can result in significant risks to target populations. However, in some cases the potential risks may be outweighed by the benefits to habitat construction, because target coral species (such as staghorn and elkhorn corals) have low levels of sexual recruitment,

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[70] *See* Kelly Gravuer et al., *Population Differentiation and Genetic Variation Inform Translocation Decisions for Liatris scariosa var. novae-angliae, a Rare New England Grassland Perennial*, 124 BIOLOGICAL CONSERVATION 155–67 (2005).

[71] *See* Paula E. Whitfield et al., *Biological Invasion of the Indo-Pacific Lionfish Pterois volitans Along the Atlantic Coast of North America*, 235 MARINE ECOLOGY PROGRESS SERIES 289–97 (2002).

[72] *See* Pablo Riul et al., *Invasive Potential of the Coral Tubastraea coccinea in the Southwest Atlantic*, 480 MAR. ECOL. PROG. SER (2013).

[73] *See* Chea J. Zabin, *Battle of the Barnacle Newcomers: Niche Compression in Invading Species in Kaneohe Bay, Oahu, Hawaii*, 381 MARINE ECOLOGY, PROGRESS SERIES 175–82 (2009).

[74] *See* Lisèle Crémieux et al., *Gene Flow from Foreign Provenances into Local Plant Populations: Fitness Consequences and Implications for Biodiversity Restoration*, 97 AM. J. OF BOTANY 94–100 (201).

therefore minimizing the risk of outbreeding depression in the first place.[75]

It is extremely difficult to decipher the specific adaptations found in corals because the coral colony itself is actually an inter-connected assemblage of symbiotic species, collectively referred to as the coral holobiont. The components of the holobiont include the coral animal that forms the skeleton and structure of the colony, the algae that inhabit coral tissues, giving the corals their characteristic bright colors and providing a good source via photosynthesis, which may ynamic symbiosis paired with morphological plasticity under different environmental conditions. The introduction of new genotypes to a reef may cause genetic hybridization of any component of the holobiont, along with outbreeding depression, or the weakening of unknown genetic site-specific adaptations. However, next-generation sequencing techniques have been emerging and becoming more financially available,[76] which provides increased opportunities to understand the specific genetic effects at targeted conservation sites.

A conservation case study of Pacific salmon reveals the inherent dangers of genetic depression when redistributing individuals from different habitats.[77] The native salmon with high phenotypic adaptation to the local stream conditions faced the dilution of these traits due to the introduction of vigorous stocks that originated from other streams, whose effect on the local populations was not realized until several generations after the introduction effort.[78] Corals, which have a considerably longer generation time than salmon, may not demonstrate the deleterious genetic effects associated with assisted migration for several decades. As the scientific understanding of genotypic adaptations of corals and their symbionts is an emerging field, perhaps the initial focus should be ensuring the largest possible gene pool in assisted migration projects.

It is important to understand the degree of connectivity of coral reefs when deciding what areas to protect or potentially translocate. However, in many cases the diversity in specific factors, such as high temperature adaptation, are mostly unknown, especially when differentiated between symbiont temperature resistance or dynamics in symbiont communities. One way to overcome these unknowns would be to translocate fragments

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[75] *See, e.g.*, D. E. Williams et al., *Recruitment Failure in Florida Keys Acropora palmata, a Threatened Caribbean Coral*, 27 CORAL REEFS 697–705 (2008).

[76] *See* Elaine R. Mardis, *Next-Generation DNA Sequencing Methods*, 9 ANNU. REV. GENOMICS HUM. GENET. 387–402 (2008).

[77] *See* Anthony Gharrett et al., *Outbreeding Depression In Hybrids Between Odd-And Even-Broodyear Pink Salmon*, 173 AQUACULTURE 117–29 (1999).

[78] *See* Andrew Hendry et al., *Rapid Evolution Of Reproductive Isolation In The Wild: Evidence From Introduced Salmon*, 290 SCIENCE 516–18 (2000).

from a broad variety of genotypes and habitats as opposed to selecting for certain traits. Coral fragments instead of whole colonies for the translocations would further minimize metazoan hitch-hikers. Further, the optimization of source and destination areas for coral translocations based on the analysis of current and future climatologies and thermal gradients would lower the cost of implementation as well as lower the risk of invasive species and translocating drastically different genetic assemblages in translocations.

4. Mitigating Risks

The minimization of risks involved in the translocation of corals can further the risk balance in favor of staged withdrawal. Using existing infrastructure of coral nurseries for translocation projects greatly reduces the impact on the source coral populations. Climate risks can be mitigated by prioritizing areas with the must vulnerable thermal tolerance, *i.e.*, the reef areas where warming is occurring the fastest. Also, within a reef area there are a wide variety of habitats.[79] A broad sampling from habitats will prevent against risks of in-breeding depression, allowing for some degree of natural selection at the destination site. Further, the mitigation of local concerns including overfishing, pollution, sedimentation, and water quality impairment at the translocation destination site is imperative to ensure increased resilience of the translocated corals and the native coral populations.

Both the risks of invasive species and genetic out-breeding depression can be mitigated by limiting the distance between coral translocations and preventing inter-oceanic translocations or translocations between distinct biological regions.[80] Under this methodology, a stepping-stone series of successive translocations might further minimize invasive species concerns and contribute to a natural migration corridor. Also, population genetics techniques can be used to analyze how connected the source and destination coral populations are. A population with strong connectivity will likely have similar thermal tolerance due to the propensity of genetic exchange in a highly connected population. As such, these site pairs are not ideal for translocation because the financial resources could be used in an area that would receive a better conservation outcome. However, translocations between two completely unconnected populations would carry higher risks of disruptive genetic effects. Thus, two populations that are connected but

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[79] *See* Peter J. Edmunds et al., *Effects of Depth and Microhabitat on Growth and Survivorship of Juvenile Corals in the Florida Keys*, 278 MARINE ECOLOGY PROGRESS SERIES 115–24 (2004).

[80] Ove Hoegh-Guldberg et al., 2008, *supra* note 14.

have a long interaction distance or weak degree of connectivity may be ideal in harboring novel thermal genetic traits with lower risk of outbreeding depression.

B. Qualitative Risks

Value judgments surrounding the decisions to translocate corals involve tradeoffs between the different value factors of the reef ecosystem and the costs of the management program, which can be quite large. The value of species – economic or otherwise – must exceed that of the cost of undergoing the translocation project, or the opportunity cost of not using the resources elsewhere.[81] Because of prohibitive costs, management difficulties, political boundaries, there is a pervading low likelihood of achieving intended goal of a coral relocation project without substantial regulatory momentum.[82]

The ecological value of a species as being a foundational or keystone species within the ecosystem integrity provides convincing justification for translocation efforts.[83] In the case of coral reefs, the capacity of reef accretion may be a strong indicator in the prioritization balance; different species grow at different rates, with branching coral species normally growing faster and being more sensitive to temperature stress than their massive counterparts.[84] However, the presence of diverse coral species in the composition of a reef allows for an increased number of niches for reef species to occupy[85] and increases the resilience of reefs against destructive factors, such as climate change.[86] Reef-building corals, despite the large costs of translocation, and the potential risks, should be strongly considered for translocation because they are keystone components of the ecosystem that ensure its integrity and habitat structure.

Further, environmental responsibility is an ethical concern inherent to the consideration of coral translocations. Namely, the efforts should be assured to not undermine the long-standing commitment to preserve ecological integrity or weaken the resolve to address the actual causes of climate change.[87] The ethical framework used to evaluate assisted

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[81] *See* R. Sandler, T*he Value Of Species And Ethical Foundations Of Assisted Colonization*, 24 CONSERVATION BIOL. 424–31 (2009).

[82] Hewitt *supra* note 42.

[83] Kreyling *supra* note 34.

[84] *See, e.g.,* Nicholas A. J. Graham et al., *Dynamic Fragility of Oceanic Coral Reef Ecosystems*, 103 PROCEEDINGS OF THE NAT'L ACAD. OF SCIENCES 8425–29 (2006).

[85] *See* D. R. Bellwood et al., *Functional Versatility Supports Coral Reef Biodiversity*, 273 PROCEEDINGS OF THE ROYAL SOC'Y OF LONDON: BIOLOGICAL SCIENCES 101–7 (2006).

[86] *Id.*

[87] Minteer & Collins, *supra* note 14.

migration projects should not be mired in whether or not the project should exist, but rather what are the appropriate ecologically and politically sound approaches.[88]

Certain populations of corals may have to be prioritized for preservation by evaluating the biological and ecological consequences of extinction, prioritizing those stocks that have the highest combined extinction risk and biological consequences of extinction.[89] Due to this reality, a clear analysis of the ecological risks of losing coral reefs at specific sites must be performed. A regional cost/benefit analysis of assisting the migration of coral reefs would allow for a more targeted valuation effort, useful in resource allocation decisions on local and national, and international scales.

IV. ADDRESSING RISK AND PRECAUTION IN CORAL TRANSLOCATION

The risks associated with coral translocation present serious questions about whether this is a viable adaptive management strategy, but these risks must be weighed against the potentially far greater risk of massive coral die-off if no action is taken. Having established the ecological and genetic risks inherent in coral translocation, the question then moves from the realm of science to one of policy. Evaluating the viability of coral translocation as a policy decision requires a greater understanding of how risk and precaution are balanced societally, and what cognitive barriers may exist to a risks management strategy such as translocation.

Despite a call for increased data relating to the natural migrations capacity of corals,[90] such data on a wide scale for reef ecosystems would be incredibly cost prohibitive. Thus, at some point a moral judgment and subsequent intent must be made[91] when the evidence sufficiently indicates a resolute need for human intervention. A robust conservation decision can be made amidst severe uncertainty by using probabilistic models to propagate uncertainties and rank management options.[92] In addition to the risks *per se*, the cognitive psychology underpinning the

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[88] *Id.*

[89] *See* Fred Allendorf et al., *Prioritizing Pacific Salmon Stocks For Conservation*, 11 CONSERVATION BIOLOGY 140–52 (1997).

[90] *See* L. R. Iverson & D. McKenzie D, *Tree-Species Range Shifts in a Changing Climate: Detecting, Modeling, Assisting,* 28 LANDSCAPE ECOLOGY 879–89 (2013).

[91] *See* T. M. Jones, *Ethical Decision Making by Individuals in Organizations: An Issue-Contingent Model*, 16 ACAD. OF MANAGEMENT REV. 366–95 (1991).

[92] *See* H. M. Regan et al., *Robust Decision-Making Under Severe Uncertainty for Conservation Management*, 15 ECOLOGICAL APPLICATIONS 1471–77 (2005).

perceptions of these risks to scientists and policy makers is vital in understanding the regulatory framework for coral staged withdrawal—or lack thereof. Apart from the scientific underpinnings discussed above, the very researchers as well as the policy makers are subject to a host of cognitive biases and mechanisms—cryptic psychological symbionts paramount in the understanding of the capacity for human institutional ecology to enact climate change adaptation measures. The following discussion will analyze construal level theory, confirmation bias, and framing effects in the context of assisted coral migration, identifying potential opportunities for policy windows and a framework for a changing tide of managed coral reef adaptation to climate change.

A. APPLYING PRECAUTION TO CORAL TRANSLOCATION

Understanding risk in a policy context requires moving beyond relatively clear-cut scientific and economic risk evaluation to consider the cognitive and political bases for risk management. In the case of coral translocation, this calculus involves balancing the risks associated with translocation with a precautionary approach that would argue for protecting coral ecosystems before it is too late.

Precaution as an approach to environmental management has been enshrined in various policy mechanisms globally, must notably in the European Union.[93] The precautionary principle in particular forms the basis for this risk management ideology. Definitions of the precautionary principle vary greatly in strength, but at its most basic, the precautionary principle requires policymakers to act in advance to minimize risk and effectively institutionalizes caution.[94] In some strong forms of the precautionary principle, regulators are *required* to act to prevent future risks, even when there is scientific uncertainty about likelihood or magnitude of the risk.[95]

This is directly applicable to the case of coral translocation. Current data suggest that in the absence of extreme and innovative measures to protect coral reefs, we can expect to lose at least 50% of the world's coral in the next 100 years. While there is uncertainty about the magnitude and location of these die-offs, a precautionary approach

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[93] *See e.g.* Michael D. Rogers, *Risk Analysis Under Uncertainty, The Precautionary Principle, And The New EU Chemicals Strategy*, 37 REGUL. TOXICOL. PHARMACOL. 370 (2003).

[94] James Cameron & Juli Abouchar, *The Precautionary Principle : A Fundamental Principle of Law and Policy Environment*, XIV B.C. INT'L & COMP. L. REV. 1 (1991).

[95] Jonathan B Wiener & Michael D Rogers, *Comparing precaution in the United States and Europe Comparing precaution in the United States*, 5 J. RISK RES. 37–41 (2011).

suggests that action should be taken now to minimize the risk of this occurring. If we do not take measures immediately to protect coral reefs and develop novel management strategies, irreversible harm is the likely outcome. Precautionary approaches aim to avoid such irreversible harm at all costs. Balanced against the relatively small risk of translocating corals, we argue here that a precautionary approach necessitates the real consideration of coral translocation as an option to prevent catastrophic damages in the future.

It is worth noting here though, that the precautionary principle could be construed to cut against the viability of coral translocation as an option. In some forms of the precautionary principle, the burden of proof is shifted onto risk-generators to show that their proposed action has acceptable levels of risk.[96] Such forms have been used in the EU's REACH program for chemical regulation, among others.[97] In these forms, then, the status quo for risky activities is effectively not to do them, until it can be proved that they are safe or accompanied by only minimal risk. Given that the risks of coral translocation are unclear, and may cause harm to the environments that corals are moved into, this interpretation of the precautionary principle would place the burden on scientists and managers to show that there were no risks associated with translocation. Until then, no action should be taken.

However, even in cases where a burden-shifting or no-action default precautionary principle is followed, it is recognized that acceptable risk levels do exist. In all cases of precautionary action, whatever action is taken should be appropriate and proportional to the inherent risks. Given that the magnitude of the risk of future coral die-off is much greater than any risks associated with coral translocation, we argue here that precaution warrants action to mitigate this larger risk. Taking small risks to carry out translocation is appropriate given the far greater risk if these actions are not taken. Precautionary and future-looking action is needed to ensure that coral reefs remain healthy, and associated food security and economic stability are not negatively impacted.

B. Perceptions of the Risk of Coral Translocation

This precautionary argument for coral translocation though may be difficult to enact, given the risk perceptions and cognitive biases of both the policy-making and scientific communities. The way an individual conceptualizes the surrounding world is an important and dynamic factor in his decision-making and judgment formation. Humankind only possess the capacity to physically experience immediate spatial and

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[96] *Id.*

[97] Rogers, *supra* note 93.

temporal stimuli, however the simulation (construal) of future experiences for the purpose of assessing distant hypothetical alternatives is accomplished through the abstraction of the mental horizon.[98] In this discussion, construal level theory will be dichotomized as low and high construal, which corresponds to the level of abstraction, temporal, spatial, social, and hypothetical psychological distances.

A high-low construal distinction is characterized by the abstraction level and distance in approaching an issue, causing respective favor of gain maximization or loss minimization.[99] In a high construal level, an individual may think abstractly of the engagement in a behavior, focusing on the central dimension, causing greater psychological distance from the event and propensity for distraction by the abstract goal. Though the benefit maximization lends to risk-prone activities, an individual in a high construal mode is less likely to make compromises.

Conversely, a low construal level elucidates concrete details and one is more likely to consider peripheral dimensions. The focus on minimizing losses is inherently risk-averse, though the mode lends to careful consideration of tradeoffs. From the introductory discussion on assisted coral migration above, the focus on hypothetical and abstract factors indicates the prevalence of high construal level in the literature. Despite the risk aversion exhibited by some scientists as a preventative factor in assisted coral migration, this very belief acts to instigate greater psychological distance from the idea, maintaining a high construal. Only concretely analyzing individual risks and making tradeoffs between risks associated with status quo conservation vs. assisted coral migration would indicate a low construal and higher likelihood of accomplishing an adaptation program.

Given only the experiential capacity for the present and perhaps the effects of increased psychological distance from abstract ideas, humans are much more effective at combating problems using a low construal level. Perhaps the human psyche responds better to the intrinsically programed effect of change only when it is in reaction to an immediate and proximate threat.

Further, there is a human propensity to interrelate psychological, spatial, and temporal distance;[100] the abstract and long-term nature of climate change thus increases its psychological distance, especially among non-experts. Accordingly, climate change-related policy behavior exhibits cognitive patterns indicative of a high construal, which is an

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[98] *See* Y. Trope & N. Liberman *Construal-Level Theory of Psychological Distance*, 117 PSYCHOLOGY REV., 440–63 (2010).

[99] *See* U. Kahn et al., *When Trade-Offs Matter: the Effect of Choice Construal on Context Effects*, 48 J. OF MARKETING RESEARCH 62–71 (2011).

[100] Trope & Liberman *supra* note 98.

ineffective mode to promote change and results in an unrealistic outlook. Egocentrism, an overly discounted future, effort to maintain the status quo, lack of personal experience of the problem, and future optimism bias as cognitive explanations that result in predictable decision-making errors pervasive in public policy pertaining to climate change.[101] These outcomes in an assisted coral migration context may include discounting of program cost based on temporal timescales, increased psychological distance of physically distant regulation authorities, and an exacerbation of social distance inhibiting the communication stream between reef-adjacent stakeholders and centralized policymakers.

As climate change becomes an imminent threat and the negative effects on coral reefs become more salient, the construal level of assisted coral migration may become innately lower. Unfortunately, the threat raised to a point of regulatory awareness for coral reef decline may entail a marked event of catastrophe, such as a hurricane or strong *El Niño* event[102] that cause provocative coral reef mortality. This mortality is exacerbated by the gradual loss of resilience due to local pressures and the confluence of climate change pressures.

The perception of risk and factual beliefs are inherently based on moral evaluations, i.e., a morally honorable activity is thought to be beneficial while a morally base activity is thought to be detrimental.[103] Further, individuals seek information based on predisposed views and recognize experts by cultural affinity.[104] For example, political ideology has been shown to impinge on the selection of household products with greater overall efficiency due to the replacement of a psychological value-based framing in lieu of a utilitarian evaluation.[105] Cultural cognition of coral reef science then may be strongly linked to an individual's inherent processing and prioritization of its major cause of decline–climate change.

Further, among communities of experts, which in this case are coral reef scientists, there exists epistemic uncertainty based on advanced knowledge of the system state that may cause a different interpretation of data that clouds the actual utility of the expected outcome, especially in

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[101] *See* M. H. Bazerman, CLIMATE CHANGE AS A PREDICTABLE SURPRISE, 77 CLIMATE CHANGE 179- 93 (2006).

[102] Both hurricanes and *El Niño* belong to—and regulate—the long-term dynamics of coral reef systems; however on short time horizons these events can have devastating impacts on coral reefs. *See, e.g.,* Nancy Knowlton, *Thresholds and Multiple Stable States in Coral Reef Community Dynamics*, 32 AM. ZOOLOGIST 674–82 (1992).

[103] *See* D. M. Kahan et al., *Cultural Cognition of Scientific Consensus*, J. OF RISK RESEARCH 1-28 (2010).

[104] *Id.*

[105] *See* D. M. Gromet, (2013) *Political Ideology Affects Energy-Efficiency Attitudes and Choices*, PROCEEDINGS OF THE NAT'L ACAD. OF SCIENCES 10.1073.1218453110 (2013).

cases where data are scarce.[106] For example, a shifting baseline trend,[107] as seen in the case of coral reefs over the past 30 years[108] perhaps accentuates a generational gap between burgeoning and established coral reef scientists, the latter of which are in many cases making crucial management decisions based on previous community assemblages and population densities, the restoration of which may be quite unlikely given the existing and future challenges.

Overcoming cultural cognition involves attending to the cultural meaning–as well as the scientific content–of the information.[109] Tackling the discrepancies of overall climate change risk perceptions due to cultural cognition may be a worthy effort, however the resources required are too extensive for use on one adaptation measure, namely assisted coral migration. The solution then, is to focus on policy makers, whose relevant cultures may entail not merely the right/left political dichotomy, but rather regional politics, different levels of governance, and the influence of major industrial lobbies or non-governmental organizations, either or both of which could be instrumental in the financing and undertaking of projects approved or mandated by the government. After taking into account the opportunity of a policy window qualified by the identification of relative players and how to reconcile their confirmation bias and cultural cognition, the next section will discuss the strategic framing of assisted migration effects to overcome political impediments to enacting climate change adaptation measures.

C. Policy Windows and Changing the Regulatory Tides

Policy and science have traditionally operated in separate streams, however certain events of sudden change, if identified accurately and opportunely, can offer a policy window for conservation innovation.[110] The policy and science worlds are perhaps akin to dancers of two different genres, who only rarely would find occasion to promenade to the same ballad. Key players in the policy window dance are the scientific elites, which in the case of coral reef conservation consist of

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[106] *See* H. M. Regan et al., *Robust decision-making under severe uncertainty for conservation management*, 15 ECOLOGICAL APPLICATIONS 1471–77 (2005).

[107] *See, e.g.*, D. Pauly D, *Anecdotes and Shifting Baseline Syndrome of Fisheries*, 10 TRENDS IN ECOLOGY AND EVOLUTION 430 (1995); Terry P. Hughes et al., *Rising to the Challenge of Sustaining Coral Reef Resilience*, 25 TRENDS IN ECOLOGY AND EVOLUTION 633–42 (2010).

[108] Gardner et al., *supra* note 32.

[109] Kahan, *supra* note 103.

[110] *See* D. M. Hart & D. G. Victor, *Scientific Elites and the Making of U.S. Policy for Climate Change Research*, 1957-74, 23 SOCIAL STUDIES OF SCIENCE 1993 643–80 (1993).

tenured researchers in marine science who have accompanied the marked coral reef decline throughout their careers and now occupy influential posts in reef management or academic institutions.[111] Their counterparts are high-level policy-makers who normally engage with a variety of issues not necessarily pertaining to coral reefs or even the environment, but must prioritize their resources and political capital among a broad field of issues.

Examples of events that have punctuated policy changes include industrial accidents, human-induced conflict, dramatic political changes, and natural disasters. For example, the political fall-out from the Fukushima disaster of Japan instigated a dramatic abandonment of nuclear-based power in Germany and feed-in-tariffs for photovoltaics in Japan, offering apt incentive for the future development of green energy sources.[112] The September 11th terrorist attacks famously prompted the creation of the U.S. Department of Homeland Security and Transportation Security Administration, and caused an international restructuring of aviation security.[113] A Chilean *coup d'état* in 1990 paired with the collapse of several important fishery stocks brought forth new legislation and fishery protections, which in turn allowed for the recovery of several fisheries. Hurricane Katrina and the subsequent disaster response failure necessitated the restructuring of the Federal Emergency Management Agency,[114] providing better response for future natural disasters.

In the decision-making process, when assessing multiple choices, outcomes are perceived as positive or negative in relation to a neutral reference outcome, and preference reversal may result when the reference shift transforms gains to losses[115] showed that a loss is more significant than its equivalent gain (Prospect Theory) and a certain gain is favored over a probabilistic loss (certainty effect). Similarly, a probabilistic loss is preferred to a definite loss, which is known as the pseudo-certainty effect. Also, the system is especially sensitive to framing in terms of monetary outcomes or loss of human life. Further, the perception of risk changes over time and is moderated by both

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[111] *Id.*

[112] *See* J. Huenteler et al., *Japan's Post-Fukushima Challenge – Implications from the German Experience on Renewable Energy Policy*, 45 ENERGY POLICY 6–11 (2012).

[113] *See* T. A. Birkland, *"The World Changed Today": Agenda-Setting and Policy Change in the Wake of the September 11 Terrorist Attacks*, 21 REV. OF POLICY RESEARCH 179–200 (2004).

[114] *See* R. J. Burby, *Hurricane Katrina and the Paradoxes of Government Disaster Policy: Bringing About Wise Governmental Decisions for Hazardous Areas*, 604 ANNALS OF THE AM. ACAD. OF POLITICAL AND SOCIAL SCIENCE 171–91 (2006).

[115] *See* A. Tversky & D. Kahneman, *The Framing of Decisions and the Psychology of Choice*, 211 SCIENCE 453–58 (1981).

increased caliber of scientific understanding and societal perceptions based on cultural phenomena that are not necessarily in accordance with scientific findings.[116]

It quickly becomes apparent that potential risks of assisted coral migration, which are likely overvalued, favor recalcitrance in adaptation measure innovation due to an undervalued ecological system. Changing the tide of assisted migration by effectively commencing assisted migration pilot studies and later full-scale programs may depend in part on the strategic use of framing to evoke an appropriate construal level among the relevant players with respect to innovative policy decisions.

The instrumental value of coral reefs in terms of economics and human health can be further accentuated. There has been an effort over the past decade to value ecosystems to assist in mainstream conservation, however the scientific basis and mechanisms of science and policy are not yet developed.[117] In juxtaposition to the incapacity to value ecosystems from a policy perspective, the overall loss of marine biodiversity impairs the ocean's capacity to provide food, maintain water quality, and recover from perturbations.[118] The key goal is to generate quantifications and evidence palatable to a policy maker–involving economics and human lives. For example, the number of people who depend directly on reefs as a protein source could be re-contextualized to the equivalent percentage of overall food consumption in that country that comes from reefs, and given reef ecological demise, this quantity would have to come from another source. Further, using studies of reef valuation in the livelihoods of those who directly or indirectly profit off of coral reefs, the overall percentage of the GDP reliant on reef function could be calculated. These data, paired with more salient expression of the magnitude and probability of the risk associated with not engaging in coral reef climate adaptation would make gains in the coercion of policy makers, diminishing the cognitive effects of distant impacts, hyperbolic discounting, and intangible effects of climate change.

In a broader sense, there is a correlation between water conditions that are necessary for coral reef survival and desirable for tourists who traveling from far-flung locales, providing an influx of capital to the reef-adjacent local economy. For example, in a study of the potential tourist ramifications of climate-change-induced sea level rise and loss of marine biota in Bonaire and Barbados, 80% of surveyed tourists would not be

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[116] *See* P. Slovic, *Perception of Risk*, 236 SCIENCE 280–85 (1987).

[117] *See* Gretchen C. Daily et al., *Ecosystem Services in Decision Making: Time to Deliver*, 7 *Frontiers of Ecological Environment* 21–28 (2009).

[118] *See* Boris Worm et al., *Impacts of Biodiversity Loss on Ocean Ecosystem Services*, 314 SCIENCE 787–90 (2006).

willing to return for the same price.[119] Though the idea of planning for ecosystem loss due to climate change would be a longer timescale, a more abstract problem and thus a higher construal, the long-term strategy and investment of the area would be significantly affected were the coral ecosystem to become functionally absent.

In order for the call for assisted coral migration to become commonplace in worldwide reef management, perhaps likened to the regular stocking of freshwater sport fish, coral scientists must provision concrete data to policy makers that elicits a low construal level and ability of immediate implementation of adaptation measures. To prevent the loss of local ecosystem function where assisted migration candidates exist, it may be necessary to provision a formal network of coral diversity donor and receptor institutions to ensure that reef A donating corals to a cooler reef B also receives corals from a warmer reef C. Only in few extreme cases would a reef exist that does not have a cooler or warmer receptor/donor reef in assisted migration.

V. CONCLUSION

Coral translocation in the form of staged withdrawal represents a defense against extinction that exceeds the protections already afforded to corals under the ESA and protects coral species from extinction risk as well as preserves the ecological function of coral reefs. Although the ESA framework has specific language that prevents species extinction at all costs, looking to preventing the ecological extinction of reefs would be a better goal. Gradually moving genetic resources for coral thermal tolerance to cooler waters within each species range in staged withdrawal is an essential function to protect both individual species and their ecosystems.

The staged withdrawal strategy is a mid-range thinking strategy, but gains in regulatory momentum involving the staged withdrawal of coral thermal tolerance must happen quickly; if it is not realized, rising ocean temperatures will claim these valuable temperature adaptations before the genetic traits are able to move to new populations via natural sexual reproduction. Intervening human measures speed up the natural process of migration of corals from warmer climates to cooler climates—even within their range.

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[119] *See* M. C. Uyarra et al., *Island-Specific Preferences of Tourists for Environmental Features: Implications of Climate Change for Tourism-Dependent States*, 32 ENVIRONMENTAL CONSERVATION 11–19 (2005).

Pilot studies are required to gain specific scientific understanding—and proffer evidence for regulatory decision-making. Innovation of the legal system paired with understanding the current framework of domestic and international law. These studies first must identify the relevant gaps in knowledge on coral connectivity, the passing of resilient traits to the next generation, and potential effects on local genetic complexes.

Scientific innovations must also be paired with psychological understanding of the regulatory agencies and the citizens who support them. The timing of the cognitive psychology strategies must align with a favorable political climate as well as a policy window, which in the case of coral reef conservation could be a catastrophic bleaching or mortality event. Coincidentally, in 2015-2016 the Pacific is experiencing the largest *El Niño* in recent decades and a global bleaching event. The priming effect of these events will serve as an ephemeral means of increasing the saliency of coral reef decline, which in turn may catalyze a legacy of legal or management protection. To take full advantage of a policy window, an assisted coral migration proposal should addresses factors mentioned in the literature, including candidate species or populations, relevant stake-holding institutions, authorization authority, motives/scale of the project, and the party ultimately responsible for the continued existence of the conservation program.[120] It is important to engage and convince all relevant stakeholders and levels of governance[121] and use an appropriate framing, the selection of which represents a conscious ethical decision[122] based on the formation of a moral judgment necessitating the protection of coral diversity and ecosystem function given the grim reality of climate change. A staged coral withdrawal would buy time and offer a potential reduction in the severity of genetic diversity loss with climate change warming, however it does not address the underlying climate change.

Curbing climate change is the only way that corals will ultimately survive. Staged withdrawal may incentivize high-latitude coral refugia for the time being, but these populations are threatened by the onset of ocean acidification, which occurs on a longer time horizon than ocean warming. Though the coral reef, due to its vociferous response to climate change as voiced through the scientific outcry in response to recent declines, may be considered a proverbial canary in the coalmine, this is not a constructive metaphor as the humble canary succumbs to the toxic

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[120] Minteer & Collins *supra* note 14.

[121] *See* I. Pérez et al., *What is Wrong with Current Translocations? A Review and a Decision-Making Proposal*, 10 FRONTIERS OF ECOLOGICAL ENVIRONMENT 494–501 (2012).

[122] Tversky & Kahneman *supra* note 115.

air in the end; humankind cannot allow coral reefs to perish. Our instrumental and intrinsic dependence on the continued function of coral reef ecosystems should merit newfound regulatory frameworks and climate change mitigation.