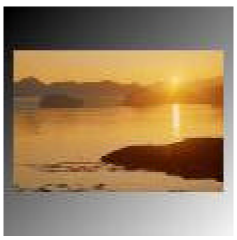
The Possible Impacts of Climate Change on Pacific Island State Ecosystems

March 2000



William C.G. Burns
Director of Communications
Pacific Institute for Studies in Development, Environment, and Sec

An occasional paper of:

Pacific Institute for Studies in Development, Environment, and Security
654 13th St.
Oakland, CA 94612 USA
510.251.1600 (Ph.)
510.251.2203 (Fax)
pistaff@pacinst.org
www.pacinst.org

As we are all aware, mini-ecosystems are amongst the most fragile. Such fragility today places small island states in the frontline of nature's reaction to humanity's overuse and abuse of the environment.

Maumoon Abdul Gayoom, President of the Republic of Maldives

1. Introduction

While it is anticipated that most nations will ultimately suffer adverse consequences from climate change,[1] small island states may face the most dire and immediate consequences. A previous piece by this author focused on the socioeconomic and cultural ramifications of climate change on Pacific Island Developing Countries (PIDCs).[2] This article will examine the possible impacts of climate change on the ecosystems of PIDCs. In this pursuit, I will: first, provide a brief overview of PIDCS, second, outline present assessments of climate trends, both globally and regionally, that may have an impact on PIDCS, third, assess some of the potential ecosystem impacts of climate change on islands in the Pacific region, and finally, assess the possible role of the United Nations Framework Convention for Climate Change in ameliorating these impacts.

2. Pacific Island Developing Countries: An Overview

PIDCs consist of 22 political entities, of which 15 are politically independent.[3] There are well over 1,100 islands and islets in the region, of which approximately 500 are inhabited.[4] With the exception of Papua New Guinea and Fiji, all PIDCS fall within the United Nations' definition of "small island states," which are islands with less than 10,000 square kilometers in land mass and with less than 500,000 inhabitants.[5] The majority of countries in the

[1] Margaret S. Torn, Evans Mills & Jeremy Fried, *Will Climate Change Spark More Wildfire Damage?,* LBNL Rep. No. 42592, November, 1998, SCAR Global Change Programme, *A Summary of Global Change in the Antarctic,* <http://www.antcrc.utas.edu.au/scar/newsletter2/2summary.html> (1998); Kenneth Blackman, *Global Warming Worries Indigenous People,* INTER PRESS SERVICE, August 13, 1998; William C. Burns, *The Second Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change: More Heat than Light?,* 1996 COLO. J. INT'L ENVTL. L. & POL'Y Y.B. 153, 153-54.

[2] William C.G. Burns, *The Impact of Climate Change on Pacific Island Developing Counties in the 21st Century, in* CLIMATE CHANGE IN THE SOUTH PACIFIC: IMPACTS AND RESPONSES IN AUSTRALIA, NEW ZEALAND, AND SMALL ISLAND STATES 113-121 (Alexander Gillespie & William C.G. Burns eds., 2000).

[3] J.R. Campbell, *Contextualizing the Effects of Climate Change in Pacific Island Countries, in* CLIMATE CHANGE: DEVELOPING SOUTHERN HEMISPHERE PERSPECTIVES 354 (Thomas W. Giambelluca & Ann Henderson-Sellers eds., 1996).

[4] *Id.*

[5] John C. Pernetta, *Impacts of Climate Change and Sea-Level Rise on Small Island States,*

region fall well below these thresholds, with populations of less than 200,000 and land areas well below 1,000 square kilometers.

The physical geography of PIDCs can be divided into two broad categories, high and low islands, with a further division into continental and volcanic islands on one hand and atolls and limestone islands on the other. Most PIDCs, however, do not fall into discrete categories, but rather are a combination of island types.[6]

3. Global and Regional Projections of Climate Change

Incorporating the Intergovernmental Panel on Climate Change's (IPCC) "business as usual" projections for greenhouse gas emissions over the next century into a general circulation model, the Hadley Centre for Climate Prediction and Research recently predicted an increase in global mean surface temperatures of 3° C by 2100,[7] while Wigley's most recent assessment, incorporating the IPCC's latest "marker" scenarios, yields a range of 1.3-4.0° C over the next century.[8] Based on varying assumptions of future population and economic growth, land-use patterns, and energy policies, the IPCC projects an increase in sea levels of between 15 and 95 centimeters by the year 2100, with a best estimate of 49 centimeters.[9] This is a rate two to four times greater than that experienced in the previous century.[10] Moreover, levels could

---

GLOBAL ENVTL. CHANGE, March, 1992, at 20; John France Bequette, *Small Islands: Dreams and Realities*, UNESCO COURIER, March, 1994, at 23.

[6] Campbell, *supra* note 3, at 354.

[7] Hadley Centre for Climate Prediction and Research, *Climate Change & Its Impacts*, <http://www.meto.govt.uk/sec5/CR_div/Brochure98/science.html> (1998); Global Network of Environment & Technology News, *Global Warming Forecast Raised One Degree*, <http://www.gnet.org>, December 19, 1998.

[8] Tom M.L. Wigley, *The Science of Climate Change,* Report of the Pew Center on Climate change (1999), at 21. These results are a shift upwards from the IPCC's projections in its Second Assessment of 0.8-3.5° C by 2100 and reflect projected lower SO_2 emissions in scenarios being developed for the IPCC's upcoming Special Report on Emissions Scenarios. *Id.*

[9] Intergovernmental Panel on Climate Change, Contribution of Working Group I to the IPCC Second Assessment Report, IPCC-XI/Doc. 3 (1995), at SPM.35. As the IPCC notes, its projections are premised on the assumption of minimal melting of the Greenland and Antarctic ice sheet. If this assumption proves incorrect, which the IPCC admits is a possibility, ocean levels could be elevated much more than originally predicted. *Id.* One researcher at Victoria University in New Zealand recently warned that the Western Antarctic Ice Sheet may be on the point of melting, which could result in a *six-meter* rise in sea levels in less than a century. *Ice Sheet 'On Point of Melting,'* THE PRESS (New Zealand), January 28, 1999, <http://www.press.co.nz/04/99012833.htm>. *See also* Grover Foley, *The Threat of Rising Seas,* 29(2) THE ECOLOGIST 76, 76 (1999); Leonie Haimson, *Concerns Grow Over West Antarctic Ice Sheet,* GLOBAL CHANGE, Winter, 1999, at 5.

[10] IPCC, *Third Assessment Report of Working Group 2* (Draft) (1999), at 4.

continue to rise for several centuries after greenhouse gas emissions are stabilized.[11]

In projecting climate trends in the PIDCs over the next century, it must be emphasized at the outset that regional assessments of climate change remain fraught with uncertainty:

> [General circulation models] have difficulty in reproducing regional climate patterns, and large discrepancies are found among models. In many regions of the world, the distribution of significant surface variables, such as temperature and rainfall, are often influenced by the local effects of topography and other thermal contrasts, and the coarse spatial resolution of the GCMs can not resolve these effects.[12]

Indeed, given the massive expanse of the Pacific island region and substantial topographical variations, it is likely that climate change will result in markedly different manifestations across the region.[13]

Climate researchers have developed several strategies to conduct regional assessments. Nested models seek to simulate regional climates by the application of limited area models nested in a general circulation model.[14] In recent years, some of these models have yielded high correlations between regional climate predictions and observed climatic phenomena, including precipitation, thermal inertia of water bodies, and temperature.[15] Downscaling by statistical means, deriving statistical relationships between observed local climatic variables and large-scale variables, have also proved successful, *inter alia,* in linking large-scale spatial averages of precipitation and surface temperature to local precipitation and temperature-time series.[16]

However, most efforts to project changes in the region are still conducted with atmosphere-ocean GCMs with insufficient horizontal resolution

---

[11] IPPC, *The IPPC Assessment of Knowledge Relevant to the Interpretation of Article 2 of the UN Framework Convention on Climate Change: A System* (1995), at sec. 3.16.
[12] Silvina A. Solman & Mario N. Nunez, *Local Estimates of Global Climate Change: A Statistical Downscaling Approach,* 19 INT'L J. CLIMATOLOGY 835, 835-36 (1999). *See also* John T. Everett & Suzanne Bolton, *Lessons in Climate Change Projections and Adaptation: From One Living Marine Resource to Another,* International Whaling Commission Seminar on Climate Change and Cetaceans, SC/M96/CC11 (1996).
[13] Campbell, *supra* note 3, at 360.
[14] Hadley Centre, *The Greenhouse Effect and Climate Change* 14 (1999); K. YA. KONDRATYEV & A.P. CRACKNELL, OBSERVING GLOBAL CLIMATE CHANGE 381 (1998).
[15] Kondratyev & Cracknell, *supra* note 14, at 383-84; Norman Miller, *Climatically Sensitive California: Past, Present, and Future Climate, in* POTENTIAL IMPACTS OF CLIMATE CHANGE AND VARIABILITY FOR THE CALIFORNIA REGION, Report to the United States Global Change Research Program National Assessment (1998), at 25-26.
[16] Solman & Nunez, *supra* note 12, at 836.

to simulate island climates.[17] Moreover, future climate projections will most likely continue to be dominated by uncertainties in radiative feedbacks associated with responses of water vapor, cloud cover and sea ice to warming.[18] At the regional level, these feedbacks may be substantially influenced by systemic nonlinearities that may prove extremely difficult to forecast.[19]

With these caveats in mind, recent research by New Zealand's National Institute of Water and Atmospheric Research (NIWA) in collaboration with France's meteorological service, Meteo France, concludes that there has been a significant change in the Pacific climate in the past 20 years, including an eastward movement of the South Pacific Convergence Zone (SPCZ), consistent with model predictions. The study reveals that central and western Kiribati, Tokelau, and north-eastern French Polynesia became 0.3° C warmer between 1977 and 1994, with a 30 percent increase in rainfall compared with pre-1977 averages. New Caledonia, Vanuatu, Fiji, Tonga, Samoa and the southern Cook Islands experienced a strong warming of 0.4 – 0.6° C from 1900-1977, which has since slowed to 0.1° C, with average rainfall declining by 15 percent after 1977.[20] Based on data from 34 stations in the Pacific, New Zealand's Meteorological Services concluded that surface area temperatures have increased by 0.3-0.8° C this century, with the greatest increase in the zone southwest of the SPCZ.[21]

Over the next century, the IPCC's most recent assessment predicts that PIDCs will experience "moderate warming."[22] However, a recent experiment with a global coupled ocean-atmosphere GCM projected increases of sea surface temperatures in the Pacific region (under conditions of CO_2 doubling) of 3.49° C in eastern Pacific and 2.21° C in the western Pacific.[23] These results "resemble not only the climate anomalies associated with present day El Niño-related events in many areas, but also the decadal timescale climate anomalies observed during the 1980s."[24]

In terms of projected sea level rise in the region, most sea level monitoring sites in the South Pacific are recording accelerated rises of up to 25 mm/year, more than ten times the trend this century, findings that have been validated by satellite data showing 20-30 mm rises from Papua New Guinea

---

[17] Robert T. Watson, et al., *The Regional Impacts of Climate Change,* Special Report of IPCC Working Group II (1998), at 340.
[18] D. Rind, *Complexity and Climate,* 284 SCI. 105, 106 & 107 (1999).
[19] *Id.* at 107.
[20] South Pacific Regional Environmental Program Press Release, *Research Shows Major Change in Pacific Climate*, August 6, 1998.
[21] IPCC, *supra* note 10, at 5.
[22] Watson, *supra* note 17, at 340.
[23] Meehl, *supra* note 10, at 142-43.
[24] *Id.* at 145.

southeast to Fiji.[25] While these dramatic increases may be attributable to ENSO,[26] recent research indicating that regional climate change in the future may closely track the effects of El Niño[27] leads to the inference that sea levels may increase substantially over the next century in the Pacific. The IPCC projects that thermal expansion alone will raise sea levels in the southwest Pacific by 28-32cm at the time of CO_2 doubling,[28] although regional projections in this context remain highly speculative because dynamic ocean effects have yet to be effectively modelled.[29] Projected buildups in greenhouse gas emissions will likely raise ocean temperatures and ocean surface water temperatures to above 26º C in the next century.[30] This could result in a greater exchange of energy and add momentum to the vertical exchange processes critical to the development of tropical typhoons and cyclones.[31] Therefore, some researchers estimate that the occurrence of tropical typhoons and cyclones could increase by as much as 50-60%,[32] and their intensity by 10-20%.[33]

However, there is by no means universal agreement that climate change will visit an increase in violent weather events on PIDCs. Some researchers believe that the purported linkage between increased ocean temperatures and violent weather events is overly simplistic, citing other factors that influence storm development, including atmospheric buoyancy, instabilities in the wind flow, and vertical wind shear.[34] Moreover, some climate scientists argue that

---

[25] Chairpersons of the Third SPREP Meeting on Climate Change and Sea Level Rise, *South Pacific Climate Change,* 26 TIEMPO (1997), http://www.cru.uea.ac.uk/tiempo/floor0/archive/issue26/t26art2.htm.

[26] *Id.*

[27] Scott Curtis & Stefan Hastenrath, *Long-Term Trends and Forcing Mechanisms of Circulation and Climate in the Equatorial Pacific,* 12 J. CLIMATE 1134, 1144 (1999); Meehl, *supra* note 10, at 145-46.

[28] Watson, *supra* note 17, at 341.

[29] Richard J.T. Klein, *Assessment of Coastal Vulnerability to Climate Change,* 28(2) AMBIO 182, 182 (1999); Stefan Rahmstorf, *Shifting Seas in the Greenhouse?,* 399 NATURE 523, 523-24 (June 10, 1999).

[30] NASA Goddard Institute for Space Studies, *How Will the Frequency of Hurricanes Be Affected By Climate Change?,* http://www.giss.nasa.gov/research/intro/druyan.02/ (1999); Thomas R. Karl, Neville Nicholls & Jonathan Gregory, *The Coming Climate,* SCI. AM., http://www.sciam.com/0597issue/0597karl.html (1997).

[31] *Insurers Refuse to Cover Global Warming Risks,* THE INDEPENDENT, May 8, 1992, at 11.

[32] NASA, *supra* note 30; M.E. Schlesinger, *Model Projections of CO_2-Induced Equilibrium Climate Change*, in CLIMATE & SEA LEVEL CHANGE: OBSERVATIONS, PROJECTIONS & IMPLICATIONS 186 (R.A. Warrick, E.M. Barrow & T.M. Wigley eds., 1993); R.J. Haarsman, *Tropical Disturbances in a GCM,* 8 CLIMATE DYNAMICS 247 (1993).

[33] IPCC, *supra* note 9, at 341; Thomas R. Knutson, Robert E. Tuleya & Yoshio Kurihara, *Simulated Increase of Hurricane Intensities in a CO_2 -Warmed Climate,* 279 SCI. 1018, 1018, February 13, 1998. *See also* Leonard M. Druyan, *A GCM Investigation of Global Warming Impacts Relevant to Tropical Cyclone Genesis,* 19 INT'L J. CLIMATOLOGY 607, 616 (1999) (Increased instability of lower troposhere under doubling of CO_2 scenario in GCM "significantly more favorable" for tropical cyclone genesis over tropical oceans).

[34] Karl, *supra* note 30; G.J. Holland, *The Maximum Intensity of Tropical Cyclones*, 54 J. ATMOSPHERIC SCI. 2519-2541 (1995).

ocean circulation changes associated with climate change may counter the effects of added warmth.[35] In its most recent regional assessment, the IPCC concluded that "model projections suggest no clear trend, so it is not possible to state whether the frequency, intensity, or distribution of tropical storms and cyclones will change."[36]

4. Possible Ecosystem Impacts of Climate Change on PIDCS

4.1. Coral Reefs

4.1.1. Temperature impacts

Coral reefs are rocklike ridges, composed of calcium carbonate in the form of aragonite, formed from the harder outer skeletons, or polyps, of coral animals.[37] Most polyps sub-divide as they grow and their skeletons fuse together, creating complex coral colonies.[38] Reefs have been termed the "tropical rainforests of the ocean." While covering less than 0.2% of the ocean's area, they serve as the home for up to one-quarter of all marine species.[39] Additionally, reefs protect coastal areas from erosion and storms,[40] and serve as a "sink" or absorber of carbon dioxide, helping to reduce the level of this potent greenhouse gas in the atmosphere.[41]

---

35 Bette Hileman, *Climate Observations Substantiate Global Warming Models,* CHEM. & ENG. N., November 27, 1995, http://pubs.acs.org/hotartcl/cenear/951127/pgl.html.

36 IPCC, *supra* note 9, at 341. *See also* J.F. Royer et al., *A GM Study of the Impact of Greenhouse Gas Increase on the Frequency of Occurrence of Tropical Cyclones,* 38 CLIMATIC CHANGE 307, 322 (1998) (Study using high resolution atmospheric model found substantial *reduction* in number of tropical storms, especially in the Southern Hemisphere, in doubled carbon dioxide simulation); David Schneider, *The Rising Seas,* SCI. AM. 112, 117, March, 1997. *But see* Knutson, *supra* note 33, at 118.

37 SUE WELLS & NICK HANNA, THE GREENPEACE BOOK OF CORAL REEFS 14 (1992).

38 Roger Highfield, *Why Coral Reefs Matter,* DAILY TELEGRAPH, March 1, 1995, at 16. Other constituent elements of reefs include shells, foams, and calcareous algae. John W. McManus, *Coral Growth and Sea-Level Rise,* United Nations University Electronic Seminar on Global Warming, November 20, 1995 (Internet document available from author).

39 C.M. Roberts, et al., *The Distribution of Coral Reef Fish Biodiversity: the Climate-Biodiversity Connection,* fourth Session of the Conference of the Parties of the United Nations Framework Convention on Climate change, Buenos Aires, Argentina, November 2-13 1998. A single reef may contain as many as 3,000 different species of marine life. *Fact Sheet: The Coral Reef Initiative,* DEPT. STATE DISPATCH, December 26, 1994. Overall, coral reefs support 1-9 million species and a far greater number of phyla than rainforests. Peter F. Sale, *Recruitment in Space and Time,* 397 NATURE 25, 26 (1999).

40 LYNNE T. EDGERTON, THE RISING TIDE 32 (1991).

41 *Coral Reefs Act As Sponge For Carbon Dioxide,* NIKKEI WKLY., August 7, 1995 (LEXIS, World Library). Coral reefs absorb approximately 1.1 billion metric tons of carbon dioxide per year, equal to approximately 2% of annual discharges. *Id.*

In the context of small island nations, coral reefs are "an extensive and vital"[42] component of the ecosystem. Coral reefs serve as a buffer against coastline erosion,[43] a function which will become even more critical in the future if climate change intensifies storm surges[44] and sea-level rise threatens coastal regions of PIDCs.[45] Reefs provide habitat for fish species that meet 90% of the protein needs of PIDC inhabitants,[46] as well as support the livelihood of small-scale fishers in the region.[47] Moreover, coral reefs are the primary source of carbonate sand that constitutes the majority of beach deposits on PIDCs.[48]

The projected temperature rise over the next century associated with climate change may pose the greatest long-term threat to coral reef ecosystems in PIDCs. Coral reefs have extremely narrow temperature tolerances of between 25-29,º with some species in PIDCs currently living near their threshold of thermal tolerance.[49] Water temperature increases of 1-2 Cº over an extended period can result in coral "bleaching," whereby dinoflagellates, endosymbiotic algae species that live in coral fish, are expelled

---

42 Dexter Hinckley, *Assessing the Condition of Tropical Island Ecosystems and their Responses to Climatic Change,* unpublished report supplied to the author, at 7.

43 Laura Tangley, *Will Coral Reefs Be the First Victims of Global Warming?,* EARTHWATCH, April 1991, at 27.

44 "Storm surge is the elevation of water generated by strong wind-stress forcing and a drop in atmospheric pressure." Pierre Daniel*, A Real Time System for Forecasting Hurricane Storm Surges Over the French Antilles,* in MAUL, *supra* note 4, at 146. *S*ee also, Graeme D. Hubbert & Kathleen L. McInnes, *A Storm Surge Inundation Model for Coastal Planning and Impact Studies,* 15 J. COASTAL RES. 168, 168 (1999).

45 *Coasts at Risk,* GLOBAL CHANGE, Oct. 1998, at 10; Hubbert & McInnes, *supra* note 44, at 184; Steering Committee of the Climate Change Study, *Climate Change Science: Current Understanding And Uncertainties* 46 (1995).

46 Ismail Serageldin, *Coral Reef Conservation: Science, Economics, and Law,* in CORAL REEFS: CHALLENGES AND OPPORTUNITIES FOR SUSTAINABLE MANAGEMENT 5 (Marea E. Hatziolos, Anthony J. Hooten & Martin Fodor eds., 1998); David N. Zurick, *Preserving Paradise: Environmental Degradation in South Pacific Island Countries,* 85(2) GEO. REV. 157 (1995). Reefs surrounding Palau support more than 2000 species of fish. Donald Hinrichsen, *Requiem for Reefs?,* INT'L WILDLIFE, March 13, 1997, at 12.

47 Michael E. Huber, *An Assessment of the Status of the Coral Reefs of Papua New Guinea,* 29 (1-3) MARINE POLLUTION BULLETIN 69, 69 (1994); Sarah Lonsdale, *Hopes Rise for Coral Rainforests of the Sea,* THE OBSERVER, April 25, 1993 (LEXIS, World Library). The fishing industry is one of the three primary economic sectors in most PIDCs. Canadian International Development Agency, *Environmental Change, Vulnerability and Security in the Pacific,* 1 AVISO, Jan. 1999, http://www.gechs.org/aviso/January1999.html. In Micronesia, fish products as a percentage of export revenues increased from 43% to 86% during the period of 1988-1993, and in the Marshall Islands this figure increased from 20-80%. Anjali Acharya, *Small Islands: Awash in a Sea of Troubles,* 8(6) WORLD WATCH 24 (1995). Stocks are already declining in many PIDCs as a consequence of overharvesting. Zurick, *supra* note 36, at 160; Simon Haydon, *For Pacific Islands, Global Warming Could Mean Extinction,* REUTERS, June 6, 1992 (LEXIS, World Library).

48 SPREP, *ICRI Pacific Regional Workshop* 92 (1995).

49 IPCC, *supra* note 9, at 342; J. Legget, *The AOSIS Summary of Scientific and Policy Issues,* February, 1991.

or reduced.[50] Because coral derive most of their food from dinoflagellates,[51] they can quickly die in their absence.[52]

In 1998, with global mean surface temperature reaching its highest level in recorded history, and sea surface temperatures increasing 2-3º C in many tropical areas where reefs are found, and as much as 4-6º C in some areas,[53] the world's reefs "appear to have suffered the most extensive and severe bleaching and subsequent mortality in modern record."[54] Approximately 95% of shallow water corals in the Maldives died, as well as 75% of corals in the Seychelles Marine park system.[55] Massive bleaching also occurred on the coasts and islands of India, Kenya, Tanzania and Australia's Great Barrier Reef.[56]

It is difficult to definitively link reef bleaching and mortality to temperature increases because other stressors can also contribute to the phenomenon, including pollution, sediment loading, a reduction in marine salinity, intense solar radiation, and exposure to the air.[57] However, a U.S. Department of State report on the 1998 events concluded that only warming could have caused such extensive bleaching throughout virtually all of the disparate reef regions of the world, including remote areas.[58] Moreover, the authors of a multi-factorial analysis of coral bleaching events in the 1980s recently concluded that "of all stresses which could potentially cause

---

50 Clive Wilkinson, et al., *Ecological and Socioeconomic Impacts of 1998 Coral Mortality in the Indian Ocean: An ENSO Impact and a Warning of Future Change?*, 28(2) AMBIO 188, 191 (1999); Sarah Carpin, *Global Warming Killing the Spectacular Seychelles Reefs,* SAN ANTONIA NEWS-EXPRESS, January 12, 1999, http://www.mcbi.org/maritimes/news05.htm; Anette E. Chadwick-Furman, *Reef Coral Diversity and Global Change,* 2 GLOBAL CHANGE BIO. 559, 566 (1996).

51 Dinoflagellates, such as zooxanthellae, live within coral fishes and engage in a symbiotic relationship. Dinoflagellates, such as zooxanthellae, live within coral fishes and engage in a symbiotic relationship. Coral polyps provide shelter for the zooaxanthellae and their waste provides a source of nutrients; in turn zooxanthellae supply the coral polyps with carbohydrates for food and construction of the limestone skeletons in which they live. LOUISE B. YOUNG, ISLANDS: PORTRAITS OF MINIATURE WORLDS 202 (1999); WELLS & HANNA, *supra* note 27, at 14.

52 Hinckley, *supra* note 42, at 8. *See also* Robert W. Buddemeier & Daphne G. Fautin, *Coral Bleaching as an Adaptive Mechanism: a Testable Hypothesis,* 43 BIOSCI. 320, 322 (1993).

53 *Id.*

54 Rafe Pomerance, *Coral Bleaching, Coral Mortality, and Global Climate Change,* Report to the U.S. Coral Reef Task Force by the Bureau of Oceans and International Environmental and Scientific Affairs, March 5, 1999, http://www.state.gov/www/global/global_issues/coral_reefs/990305_coralreef_rpt.html.

55 Wilkinson, *supra* note 50, at 191.

56 *Id.,* at 188; R. Berkelmans & J.K. Oliver, *Large-scale Bleaching of Corals on the Great Barrier Reef,* 18 CORAL REEFS 55, 58 (1999).

57 G. Parker-Muller & C.F. D'Elia, *Interactions Between Corals and their Symbiotic Algae,* in LIFE AND DEATH OF CORAL REEFS 96-113 (C. Birkeland ed., 1997); M. Warner & W.K. Fitt, *Mechanisms of Bleaching of Zooxanthellate Symbioses,* 31 AM. ZOOL. 28 (1991).

58 Pomerance, *supra* note 53; Bette Hileman, *Case Grows for Climate Change,* 77(32) CHEMICAL & ENGINEERING N. 16, 18 (1999).

widespread mass bleaching, only excessively high temperature was present in all cases."[59]

Reefs can recover from bleaching if conditions improve, with coral larvae settling on the reef structure to renew the building process. However, if elevated sea surface temperatures and bleaching persists, new building will not occur and the reef frame can gradually erode, resulting in habitat destruction and mortality.[60] For example, one year after the 1998 mass-bleaching incident, 80-90% of the bleached corals in the more severely affected areas of the Indian Ocean had died, including previously resistant species.[61] Moreover, the synergism between rising sea levels and anthropogenic damage to reefs, such as destructive fishing practices[62] and pollution,[63] may impede reef recovery.[64]

3.1.2 Sea-level rise impacts

Most researchers believe that reefs' maximum sustained vertical accretion rate of 10 millimeters per year will be adequate to keep up with sea-level rise of one meter or less,[65] and that even slowly accreting reef flats should be able to cope with projected sea-level rise over the next century.[66] Historical evidence supports this conclusion, with most reefs keeping up with sea level rises of 20 centimeters per decade between 14,000 and 6,000 year ago.[67]

---

[59] The Global Coral Reef Alliance, *Coral Reef Bleaching and Sea Surface Temperature,* http://www.fas.harvard.edu/~goreau/bleach.intro.html (1998). *See also* Michael Perry, *South Pacific Reefs Seen Dying as Oceans Heat Up,* REUTERS WORLD SERVICE, August 1, 1994.

[60] Clive Wilkinson, et al., *Ecological and Socioeconomic Impacts of 1998 Coral Bleaching in the Indian Ocean: An ENSO Impact and a Warning of Future Change?,* AMBIO, in press; U.S. Global Change Research Program, *Coral Reef Bleaching: Ecological and Economic Implications,* Environment-L, February 7, 1996.

[61] Wilkinson, *supra* note 50, at 191.

[62] SPREP, *supra* note 48, at 82 (dynamite fishing); Nancy MacKinnon, *Destructive Fishing Practices in the Asia-Pacific Region,* in Hatziolos, et al., *supra* note 46, at 32; Marla Cone, *A Toxic Solution: The Growing Use of Cyanide to Stun and Catch Tropical Fish is Killing Off Coral Reefs, Researchers Say,* L.A. TIMES, Orange County Edition, November 13, 1995, at Metro B:2.

[63] United States Geological Service, *Hurricane Effects on Wildlife and Ecosystems,* <http://biology.usgs.gov/pr/newsrelease/1998/12-8.html>; SPREP, *International Coral Reef Initiative Pacific Region Strategy*; March 1996, at 3; Ruth Flanagan, *Corals Under Siege,* EARTH, May, 1993, at 28.

[64] Phillip Dustan, *Coral Reefs: Harbingers of Global Change?,* in Hatziolos, *supra* note 46, at 140; Wilkinson, *supra* note 50, at 554. Moreover, even sub-lethal stressing of reefs increases their susceptiblity to infection by opportunistic pathogens; epizootics can result in significant reef mortality. Pomerance, *supra* note 53.

[65] McManus, *supra* note 38; Prepared Statement of Fred T. Mackenzie, *Global Climate Change and the Pacific Islands,* Hearing Before the Senate Committee on Energy and Natural Resources, S. Hrg. 102-664 (1992), at 16.

[66] A.J. Edwards, *Impact of Climate Change on Coral Reefs, Mangroves and Tropical Seagrass Ecosystems, in* CLIMATE CHANGE: IMPACT ON COASTAL HABITATION (D. Eisma ed., 1994), at 209.

[67] Clive R. Wilkinson, *Global Change and Coral Reefs: Impacts on Reefs, Economies and Human Cultures,* 2 GLOBAL CHANGE BIO. 547, 553 (1996).

Indeed, some researchers argue that rising sea levels may be beneficial for coral reef ecosystems by inducing vertical growth.[68] However, under the stress of rising sea levels, reefs are likely to develop at deeper average depths in the future, exposing coastlines to greater wave and current effects.[69]

3.1.3 Other climate impacts on reefs

Should climate change in the region result in an increase in violent storm activities,[70] surges could further degrade already weakened coral reef ecosystems.[71] In addition, heightened carbon dioxide levels in the atmosphere may increase the acidity of surface ocean water, reducing the concentration of calcium carbonate ions, thus making it more difficult for coral-forming organisms to create their skeletons.[72] It has been recently projected that a doubling of CO_2 could reduce reef calcification rates by approximately 17% in 2065 and 35% by 2100.[73]

3.2 Mangroves

3.2.1 Sea-level rise

Mangroves, also known as mangals, are a group of 34 tree species that grow in sheltered conditions in shallow tropical and subtropical waters.[74] There are over 343,000 hectares of mangroves in the Pacific, with the largest stands occurring in Papua New Guinea, the Solomon Islands, Fiji, and New Caledonia.[75]

In addition to providing a range of products for humans, including construction material, firewood, tannin, and herbal medicines,[76] mangroves are

---

68 IPCC, *supra* note 9, at 342; C.M. Roberts, *Coral Reefs: Health, Hazards and History,* 8 TRENDS IN ECOLOGY & EVOLUTION 425 (1993).

69 Robert W. Buddemeier, *Coral Reef Responses to Climate Change: Issues for Pacific Island Nations,* in HAY & KALUWIN, *supra* note 13, at 98.

70 *See supra* notes 34-36 and accompanying text.

71 Peter K. Weber, *Saving the Coral Reefs,* FUTURIST 28, 32 (July-August 1993); Nobuo Mimura, *Vulnerability of Island Countries in the South Pacific to Sea Level Rise and Climate Change,* 12 CLIMATE RES. 137, 139 (1999).

72 John Roach, *Coral Reefs Threatened by Increasing Carbon Dioxide,* nationalgeographic.com, http://www.ngnews.com/news/1999/05/051799/coral_3210.asp; *Global Warming a Threat to Barrier Reef,* DEUTSCHE PRESS-AGENTUR, April 2, 1999 (LEXIS, World Library).

73 J.A. Kleypass, et al., *Geochemical Consequences of Increased Atmospheric Carbon Dioxide in Coral Reefs,* 284 SCI. 118 (1999).

74 Hinckley, *supra* note 42, at 8.

75 SPREP, *supra* note 48, at 118.

76 Clive R. Wilkinson & Robert W. Buddemeier, *Global Climate Change and Coral Reefs: Implications for People and Reefs,* Report of the UNEP-IOC-ASPEI-IUCN Global Task Team on the Implications of Climate Change on Coral Reefs (1994), at 72; Joanna C. Ellison & David R. Stoddart, *Mangrove Ecosystem Collapse During Predicted Sea- Level Rise: Holocene Analogues and Implications,* 7 J. COASTAL RES. 159, 159 (1991); P.B. TOMLINSON, THE BOTANY OF MANGROVES 231-32 (1986).

a critical ecosystem in many PIDCs. Mangroves serve as important nursery and feeding sites for nekton, including many fishery species, with surveys of fish and crustacean assemblages around mangroves recording high levels of diversity and abundance.[77] Also, mangrove trees serve as filters for sediment that threaten coral reefs,[78] and island pests and exotic insects,[79] and help to detoxify contaminants in PIDC waters.[80]

Mangrove communities can often cope with sea-level rise where sedimentation rates are commensurate with or exceed local sea-level rise.[81] However, most small island states are characterized by microtidal, sediment-poor environments. Stratigraphy from low island mangrove systems in the Pacific, including Tongatapu, Tonga, the Marshall Island, Kiribati and Tuvalu, reveal sediment accumulation rates of only 12 centimeters per 100 years.[82] Thus, low-island mangroves are expected to suffer reductions in geographical distribution from projected sea-level rise over the next century.[83] Should the IPCC's middle-range estimates of sea-level rise come to fruition over the next century, high island mangroves with sediment accumulation rates of 45 centimeters per century could also be threatened.[84] Increased salinity caused by sea-level rises may also result in decreased net productivity and stunted growth in certain species. Changes in competition between mangrove species can also be anticipated.[85]

3.2.2 Temperature impacts

Warming in the future should prove beneficial to PIDC mangrove ecosystems. Increased temperatures will increase the diversity of higher latitude marginal mangroves, facilitating expansion into mangrove margins only occupied currently by *Avicennia* species, as well as expansion of mangroves

---

[77] S.Y. Lee, *Tropical Mangrove Ecology: Physical and Biotic Factors Influencing Ecosystem Structure and Function,* 24 AUSTRALIAN J. ECOLOGY 355-361 (1999).

[78] Huber, *supra* note 47, at 71; Danielle Knight, *Warmer Oceans Destroying Coral Reefs,* INTER PRESS SERVICE, DECEMBER 3, 1998 (LEXIS, World Library).

[79] IPCC, *supra* note 10, at 15.

[80] Vance P. Vincente, *Littoral Ecological Stability and Economic Development in Small Island States: the Need for an Equilibrium, in* SMALL ISLAND STATES: MARINE SCIENCE & SUSTAINABLE DEVELOPMENT 274 (GEORGE MAUL ed., 1996).

81 M.D. Hendry & G. Digerfelt, *Palaeogeography and Palaeoenvironments of a Tropical Coastal Wetland and Adjacent Shelf During Holocene Submergence, Jamaica,* 73 PALAEOGEOGRAPHY, PALAEOCLIMATOLOGY, PALAEOECOLOGY 1 (1989).

[82] J.C. Ellison, *Pollen analysis of mangrove sediments as a sea level indicator: Assessment from Tongatapu, Tonga*, 74 PALAEOGEOGRAPHY, PALAEOCLIMATOLOGY, PALAEOECOLOGY (1989), at 327 341; J.C. Ellison, *Mangrove retreat with rising sea-level, Bermuda*, 37 ESTUARINE COASTAL & SHELF SCI. (1993), at 75-87.

[83] Hinckley, *supra* note 42, at 10; Joanna Ellison, *How South Pacific Mangroves May Respond to Predicted Climate Change and Sea-Level Rise*, in Burns & Gillespie, *supra* note 2, at 299.

[84] Joanna Ellison, *How South Pacific Mangroves May Respond to Predicted Climate Change and Sea Level Rise,* in Gillespie & Burns, *supra* note 2, at 294.

[85] *Id.* at 296.

into salt marsh environments. Warming can also be expected to increase mangrove productivity, characterized by increased growth and litter production.[86]

3.2.3 Other climate impacts on mangroves

Mangroves operate in the C_3 pathway of carbon fixation for photosynthesis.[87] Research indicates that increases in atmospheric CO_2 increase the productivity and efficiency of water use by C_3 plants.[88] Thus, it's anticipated that projected increases in CO_2 will enhance mangrove tree growth and litter production.[89]

Climate models predicts that islands north of 17º S may experience increases in annual rainfall, while islands south of 17º may see rainfall decline.[90] Snedaker postulates that increased rainfall may benefit mangroves by reducing salinity and exposure to sulphate, while increasing delivery of terrigenous nutrients.[91] Conversely, he contends that decreased rainfall in some regions, with an attendant increase in evaporation, will reduce the extent of mangrove areas, particularly with the projected loss of the landward zone to unvegetated hypersaline flats.[92]

3.3 Seagrasses

3.3.1 Temperature impacts

Seagrass ecosystems are valuable resources in coastal waters worldwide, including in the shallow, inter-tidal environments of many island states. Seagrass communities provide habitats for a wide variety of marine organisms, including meiofauna and flora, benthic flora and fauna, epiphytic organisms, plankton, and fish.[93] Additionally seagrass plants provide food for waterfowl,

---

[86] *Id.* at 298.

[87] B.F. Clough, T.J. Andrews, & I.R. Cowan, *Physiological processes in mangroves*, MANGROVE ECOSYSTEMS IN AUSTRALIA, Australian Institute of Marine Science & Australian National (B.F. Clough ed., 1982), at 193-210.

[88] E.J. Farnsworth, M.A. Ellison & W.K. Gong, *Elevated CO_2 alters anatomy, physiology, growth* and reproduction of red mangrove (Rhizophora mangle L.), 108 OECOLOGIA (1996), at 599-609.

[89] Ellison, *supra* note 84, at 298.

[90] Campbell, *supra* note 3, at 360.

[91] S.C. Snedaker, *Mangroves and climate change in the Florida and Caribbean region: scenarios and hypotheses,* 295 HYDROBIOLOGIA (1995), at 43-49.

[92] *Id.*

[93] Murdoch University, *The Significance of Seagrass Ecosystems,* <http://possum.murdoch.edu.au/~seagrass/signif.htm> (1997).

bind and stabilize bottom sediments, and improve water quality by filtering suspended matter.[94]

Seagrass species living near the upper limit of thermal tolerance, as is true in many coastal regions of PIDCs, may experience declines in productivity and distribution as sea surface temperatures rise in the future.[95] Increased temperatures could also alter seagrass distribution and abundance by affecting seed germination.[96]

3.3.2 Sea Level Rise and Seagrasses

Elevated sea levels will reduce available light, which may limit plant photosynthesis and result in reduced distribution and decreased productivity.[97] The project 50-centimeter increase in water depth due to projected sea level rise over the next century may result in a 30-40% reduction in seagrass growth.[98]

Higher sea levels may also increase tidal currents, especially in areas of restricted tidal flow. Increased tidal currents can restrict the depth in which plants grow by exacerbating the stress attendant to light limitation. This may result in a withdrawal of the deep edge of seagrass beds, which could result in a diminution of total seagrass area.[99]

Rising sea levels will result in increased inland and upstream penetration of salt water in tidal systems. Under high levels of salinity, some seagrass species experience declines in seedling growth, limiting both reproduction and distribution. Seagrasses may also suffer from salinity stress resulting from high external osmotic potentials, ion toxicity from excessive salt intake and nutrient imbalances resulting from inadequate carrier selectivity during ion uptake.[100]

---

[94] J.D. Bell & D.A. Pollard, *Ecology of Fish Assemblages and Fisheries Associated with Seagrasses,* in BIOLOGY OF SEAGRASSES: A TREATIES ON THE BIOLOGY OF SEAGRASSES WITH SPECIAL REFERENCE TO THE AUSTRALIAN REGION (A.W.D. Larkum, ed. 1989); F.T. Short & C.A. Short, *The Seagrass Filter: Purification of Estuarine and Coastal Water,* in THE ESTUARY AS A FILTER 395-413 (V.S. KENNEDY, ed. 1984).
[95] Frederick T. Short & Hilary A. Neckles, *The Effects of Global Climate Change on Seagrasses,* 63 AQUATIC BOTANY 169, 172 (1999).
[96] *Id.* at 174.
[97] R.J. Orth & K.A. Moore, *Distribution of Zostera marine L. and Ruppia maritime L. sensu lato Along Depth Gradients in the Lower Chesapeake Bay, USA,* 32 AQUATIC BOTANY 291 (1988); E.A. DREW, *Physiological Aspects of Primary Production in Seagrasses,* 7 AQUATIC BOTANY 139, 141 (1979).
[98] Short & Neckles, *supra* note 95, at 178.
[99] E.W. Koch & S. Beer, *Tides, Light and the Distribution of Zostera marina in Long Island Sound, USA,* 53 AQUATIC BOTANY 97 (1996).
[100] Short & Neckles, *supra* note 95, at 182; J. Gorham, R.G. Wyn Jones, E. McDonnell, *Some Mechanisms of Salt Tolerance in Crop Plans,* 89 PLANT & SOIL 15-40 (1985).

3.4 Impacts on flora and fauna species

Beyond the potential adverse consequences for marine species from damage to coral reef and mangrove ecosystems, there may be other climate change-related ramifications for PIDC flora and fauna species.

Endemic species on islands are exceptionally vulnerable to extinction or extirpation for several reasons, including the fact that island populations are usually small, isolated and often endemic to a single island, and have often evolved with minimal competition, predators, or disease.[101] Moreover, on most islands they face severe threats from pollution, overexploitation and poor management.[102] Thus, it is not surprising that PIDCs may have the world's greatest rate of endangered species (per capita or per unit of land area),[103] including one out of every three threatened plant species,[104] as well as a very high number of avian species.[105]

Climate change could exacerbate threats to island endangered species in several ways. Increased temperatures may result in a diminution of some species, as well as alter species distribution and composition in unpredictable ways.[106] Moreover, clam and sea turtles in coastal areas of PIDCs may be particularly susceptible to temperature change.[107] Warmer waters in bays and lagoons might also stimulate the growth of toxic algae, threatening predator avian species, such as cormorants and pelicans.[108] Inundation of low-lying wetlands could also reduce the abundance and diversity of freshwater species, as well as deltaic species such as turtles and crocodiles.[109]

While non-tropical forests probably will be most adversely affected by climate change,[110] PIDC forests may also face threats in the future. In addition to possible forest losses from rising sea levels,[111] temperature rises and changes

---

101 Christopher S. Lobban & María Schefter, TROPICAL PACIFIC ISLAND ENVIRONMENTS 257 (1997).
102 IPCC, *supra* note 10, at 16.
103 Campbell, *supra* note 3, at 357.
104 IPCC, *supra* note 9, at 343.
105 IPCC, *supra* note 10, at 16. "Among birds, approximately 23% of the species found on islands are threatened, compared with only 11% of the global bird population."
106 *Id.*
107 E.D. Gomez & C.A. Belda, *Growth of Giant Clams in Bolinao, Philippines, in* GIANT CLAMS IN ASIA AND THE PACIFIC, Australian Centre for International Agricultural Research Monograph No. 9, (J.W. Copland & J.S. Lucas eds., 1988), at 178; J.S. Lucas et al., *Selecting Optimum Conditions for Ocean-Nursery Culture of Tidacna Gigas,* in COPLAND & LUCAS, *id.*, at 129.
108 Hinckley, *supra* note 42, at 3-4.
109 Pernetta, *supra* note 5, at 24.
110 Roger Sedjo & Brent Sohngen, *Impact of Climate Change on Forests,* Resources for the Future Climate Issue Brief # 9 (2d Ed., 1998), at 1420. Existing boreal forest cover could decline by as much as 50-90%, Kevin Jardine, *Finger on the Carbon Pulse,* 24 THE ECOLOGIST 220-23 (1994). *See also* Mary E. Clark, *Consequences of Global Change for Earth's Biosphere,* in GLOBAL WARMING AND THE CHALLENGE OF INTERNATIONAL COOPERATION: AN INTERDISCIPLINARY ASSESSMENT 51 (Gary C. Byner ed., 1992) (shift of deciduous forests in U.S. to Canada); Simon Retallack, *Wildlife in Danger,* 29(2) THE ECOLOGIST 102, 102 (1999); Jerry M. Melillo, *Warm, Warm on the Range,* 283 SCI. 183, 184 (1999).
111 Connell & Lea, *supra* note 13, at 151.

in soil water availability could have adverse implications for PIDC forests.[112] Moreover, increased temperatures may result in more frequent outbreaks of pathogens and pests deleterious to forests, as well as the frequency and intensity of fires.[113] However, increased amounts of carbon dioxide may enable some forest species to use water and nutrients more efficiently, ameliorating or wholly offsetting some of the negative impacts of climate change.[114]

4. The United Nations Framework Convention on Climate Change and Small Island States

The primary legal instrument to confront the possible ramifications of climate change is the United Nations Framework Convention on Climate Change (FCCC),[115] which entered into force in 1994.[116] However, while the parties pledged to "achieve . . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system,"[117] their record to this point has been disheartening.

Initially, the major greenhouse gas emitting states agreed to "aim" to reduce their greenhouse gas emissions to 1990 levels by 2000. Yet, all industrialized nations flouted this pledge, leading the OECD to conclude that emissions from industrialized nations would actually rise by 11-24% over the next fifteen years.[118]

At the Third Conference of the Parties of the FCCC, the parties adopted the Kyoto Protocol,[119] under which industrialized nations agree to reduce their collective emissions of six greenhouse gases by at least 5 percent below 1990 levels by 2008- 2012.[120] However, hostility to the Protocol by powerful sectors in the United States, including organized labor, fossil fuel producers, and

---

[112] IPCC, *supra* note 9, at 343.

[113] IPCC, *Climate Change Impacts on Forests,* Working Group II (1998), http://www.usgcrp.gov/ipcc/ html/chap01.html. Heightened temperatures in Siberia, Canada and Alaska have resulted in increased infestation by pests of spruce and pine trees. Clive Cookson, *UN Conference on Climate Change: Case for Action Strengthens as Signs Point to Global Warming,* FIN. TIMES, March 28, 1995, at 8.

[114] IPCC, *supra* note 9, at 343. However, recent research indicates that carbon dioxide's stimulatory effects may decrease as trees age. *Report: High Carbon Dioxide Boosts duke Forest Growth By 25 Percent,* <http://www.eurekalert.org/releases/dumc-rhc051099.html> (1999).

[115] 31 ILM. 849 (1992).

[116] The UNFCCC had been ratified by 179 nations as of June 1999, <http://www.unfcc.de>.

[117] UNFCCC, *supra* note 115, at art 2.

[118] *US Greenhouse Gas Emissions Continue to Climb,* GLOBAL ENVTL. CHANGE REP., April 26, 1996, at 2. The UNFCCC Secretariat has recently projected that emissions from developed countries will rise by 18% 1990 levels by 2010 absent effective action. UNFCCC Secretariat, Press Release, October, 1999, http://www.unfccc.de/text/media/pressre.html.

[119] *Kyoto Protocol to the United Nations Framework Convention on Climate Change,* FCCC/CP/ 1997/L.7/Add. 1, Dec. 10, 1997.

[120] *Id.* at art. 3 (1). For a detailed analysis of the Third Conference of the Parties, *see* Peter G.G. Davies, *Global Warming and the Kyoto Protocol,* 47 INT'L & COMP. L. Q. 446 (1998).

influential members of the Senate,[121] may thwart its adoption.[122] This would severely undercut the treaty's effectiveness, as the United States is responsible for approximately one-quarter of greenhouse gas emissions.[123] Moreover, U.S. refusal to adopt the Protocol might result in European nations and Japan also balking.[124] This could doom the agreement, as it requires ratification by Annex I nations producing at least 55% of greenhouse gas emissions before it will come into effect.[125]

Additionally, even full implementation of Kyoto Protocol would have very little impact over the next century. Because many greenhouse gases persist in the atmosphere for decades, "their radiative forcing – their tendency to warm Earth – persists for periods that are long compared with human life

---

[121] *Mine Workers Gore's Treaty Will Cost 1.7 Million U.S. Jobs; Union Bosses Should Quiz Veep on 'Economic Armageddon,'* PR NEWSWIRE, February 19, 1999 (LEXIS, World Library); Rebecca Sultana, *Campaign Against Global Warming: The Differing Positions,* THE INDEPENDENT, February 13, 1999 (LEXIS, World Library); *A New Disinformation Campaign,* RACHEL'S ENVIRONMENT & HEALTH WKLY., April 30, 1998; Gretchen Vogel & Andrew Lawler, *Hot Year, But Cool Response in Congress,* 280 SCI., June 12, 1998, at 1684.

[122] It is anticipated that the Protocol will not even be submitted to the Senate for consideration until after the 2000 presidential election. *International Energy Agency: There is No Time to Lose,* PETROLEUM ECONOMIST, May 12, 1999 (LEXIS, World Library). Recently, the Clinton administration and industry have been emphasizing voluntary programs and tax incentives to reduce emissions. *GCC Industry Voluntary Actions Highlighted; Administration Focus, Legislative Efforts in Congress Emphasize Importance,* PR NEWSWIRE, April 22, 1999 (LEXIS, World Library); *Clinton Calls for Clean-Air Fund to Tackle Greenhouse Gas Emissions,* POWER ECON., March 31, 1999; Danielle Knight, *Industry and Greens Debate Climate Change Bill,* INTER PRESS SERVICE, February 11, 1999 (LEXIS, World Library). Congress has recently evinced its contempt for Kyoto by slashing FY 2000 appropriations for renewable energy and energy efficiency programs by 10% from 1999 levels while substantially increasing funding of fossil fuel programs. *Renewable Energy Funding Takes a Hit,* May 28, 1999, http://www.enn.com/news/enn-stories/1999/05/052899/energy_3460.asp.

Even if the U.S. ultimately ratifies the Protocol, it faces an imposing task to meet its target of a seven percent reduction of greenhouse gas emissions below 1990 levels by 2008-2012. Given a projected 23 percent increase in emissions between now and 2010, the U.S. would have to slash emissions by 30% or make heavy use of the emissions trading system being developed under the Convention. *U.S. Economic Growth Seen Forcing Emissions Cuts,* REUTERS, September 15, 1999.

[123] Alex Barnum, *Can World Unite, Halt Climate Threat?,* S.F. CHRONICLE, November 28, 1997, at A21.

[124] Robert A. Reinstein, *In the News,* FED. NEWS SERVICE, April 29, 1999; *Risky Business,* GLOBAL CHANGE, Oct. 1998, at 2. Moreover, recent evidence indicates that the EU has yet to formulate climate policy measures to effectuate the commitments it made at Kyoto. Environment News Service, *Europe Faces Climate Policy Credibility Gap,* May 22, 1999, http://ens.lycos.com/ens/may99/ 1999L-05-19-06.html.

[125] Kyoto Protocol, *supra* note 119, at art. 24. The Protocol will enter into force 90 days after "not less than 55 parties to the [UNFCCC], incorporating Parties included in Annex 1 which accounted in total for at least 55% of the total carbon dioxide emissions for 1990 of the Parties included in Annex 1" have ratified it. However, as of August 1999, while 84 parties to the UNFCCC have signed the Protocol, only 14 parties, all developing nations, have ratified it. UNFCCC Secretariat, Kyoto Protocol, Status of Ratification, <http://www.unfccc.de/resource/kpstats.pdf> (1999).

spans."[126] Thus, the legacy of greenhouse gas emissions from the past few decades will persist for many decades to come no matter what policies we adopt.

Additionally, the FCCC currently only binds developed countries and economies in transition to the reduction of greenhouse gas emissions.[127] However, given the tremendous projected increases in greenhouse gas emissions in developing countries over the next century,[128] the future effectiveness of the FCCC is contingent on engaging these nations in the regime's mission.[129] Yet, there is great trepidation among developing countries about possible economic impacts associated with reducing emissions, as well as a sense of unfairness given the tremendous disparity in per capita emissions between industrialized and developing nations.[130] Developing countries repulsed an effort at the Third Conference of the Parties in Kyoto to establish emission limitation objectives for wealthier developing states.[131] At the Fourth Conference of the Parties in Buenos Aires, Kazakhstan announced its intention to join Annex I and thus assume commitments under the Protocol. However, Argentina's effort to place the issue of voluntary commitments on the agenda was rejected by the G77, most of which declined even to join in informal talks

---

[126] Bette Hileman, *Climate Observations Substantiate Global Warming Models,* CHEMICAL & ENGINEERING N., November 27, 1995, http://pubs.acs.org/hotartcl/cenear/951127/pgl.html *See also,* Thomas R. Karl, et al., *The Coming Climate,* SCI. AM., May, 1997, at 224 ("as much as 40 percent of [carbon dioxide] tends to remain in the atmosphere for centuries"); Silvio Kusidio, *Climatic Changes are no Longer Preventable, Warn Experts,* DEUTSCHE PRESSE-AGENTUR, March 22, 1995 (LEXIS, News file) ("Even a worldwide stabilization of the emissions would not a prevent a rise in the greenhouse gases . . . for the next 200 years . . .").

[127] UNCED, Framework Convention on Climate Change, opened for signature, June 4, 1992, *reprinted in* 31 ILM 849 (1992), at art. 4(2) & Annex I; Kyoto Protocol, *supra* note 119, at art. 3.

[128] "Though projections vary substantially with assumptions about rates of economic growth, it appears that sometime between 2010 and 2020 China will overtake the United States as the world's largest greenhouse gas emitter, and that sometime thereafter emissions in the developing world will exceed those of the developed world." William L. Thomas, *The Kyoto Protocol: History, Facts, Figures and Projections,* 137(8) PUBLIC UTILITIES FORTNIGHTLY, April 15, 1999, at 48. Two-thirds of greenhouse gas emissions between 1995-2025 may be produced by developing countries. *Carbon Emissions to Rise Over Next 20 Years,* MODERN POWER SYSTEM, January 31, 1999, at 3 (LEXIS, World Library).

[129] Clare Breidenich et al., *The Kyoto Protocol to the United Nations Framework Convention on Climate Change,* 92 AM. J. INT'L L. 315, 331 (1998); *Kyoto Protocol: The Unfinished Agenda,* 39 CLIMATIC CHANGE (1998), at 9.

[130] William K. Stevens, *Climate Talks Enter Harder Phase of Cutting Back Emissions,* N.Y. TIMES, April 11, 1995, at 4; Davies, *supra* note 120, at 457. "20 per cent of the world's population is responsible for 63 per cent of carbon dioxide emissions, while another 20 per cent is responsible for only 2 per cent of these emissions." Robert Engelman, *Population, Consumption and Equity,* TIEMPO, December, 1998, at 5. *See also* MICHAEL GRUBB, CHRISTIAAN VROLIJK & DUNCAN BRACK, THE KYOTO PROTOCOL. A GUIDE AND ASSESSMENT 265-269 (1999).

[131] *Id.*

on the topic, and the Argentine proposal was formally excluded from the Fourth Conference agenda.[132]

As a consequence of the factors discussed above, Martin Perry recently projected that full implementation of the Kyoto Protocol will reduce projected warming by a mere one-twentieth of one degree C, and have a minimal effect on elevation of sea levels.[133]

Ultimately, the major greenhouse gas producing nations may find it cost-beneficial to enact more stringent measures to reduce emissions.[134] As Cline suggests, under a "moderate-central" assumption of the damages caused by climate change, benefits ultimately begin to exceed abatement costs on a global scale in 2050, with the benefits of damage avoidance rising to about 1% of world gross domestic product (GDP) by 2050, and 5% of GDP by 2275.[135] Unfortunately, by that time, most small island states may have paid a terrible price, and some may even have ceased to exist. If the FCCC's mandate to "prevent dangerous anthropogenic interference with the climate system" is to be complied with equitably, i.e. in a manner that seeks to protect all nations from the most serious ramifications of climate change, then major greenhouse emitting nations should not wait to act until they deem it expedient. However, given the record of industrialized states in confronting climate change over the past few decades, it is difficult to be sanguine about the future. In a world governed more by realpolitik than international law, small island states will likely remain hostages to forces far beyond their control.

---

[132] GRUBB, *supra* note 130, at 251-52; *The Buenos Aires Tango,* GLOBAL CHANGE, Summer, 1999, at 2. Argentina subsequently announced its intention to enter into a binding commitment to reduce greenhouse emissions.

[133] Martin Parry, et al., *Buenos Aires and Kyoto Targets Do Little to Reduce Climate Change Impacts,* 8 GLOBAL ENVTL. CHANGE 285, 285 (1998).

[134] For analysis of how nations' cost-benefit analyses have hindered development of an effective emissions reduction regime, *see* Sean Fox, *Responding to Climate Change: The Case for Unilateral Trade Measures to Protect the Global Atmosphere,* 84 GEO. L.J. 2499, 2509 (1996); Martin J. LaLonde, *The Role of Risk Analysis in the 1992 Framework Convention on Climate Change,* 15 MICH. J. INT'L L. 215, 236 (1993).

[135] William R. Cline, *Socially Efficient Abatement of Carbon Emissions,* in CLIMATE CHANGE & THE AGENDA FOR RESEARCH 102 (Ted Hanisch ed., 1994). However, even if the major emitters of greenhouse gases ultimately decide to make a serious commitment to emissions reductions, the task of stabilizing emissions will be extremely imposing. As Hoffert et al. recently concluded: "Stabilizing atmospheric CO_2 at twice pre-industrial levels while meeting the economic assumptions of 'business as usual' implies a massive transition to carbon-free power, particular [sic] in developing nations. There are no energy systems technologically ready at present to produce the required amounts of carbon-free power." Stabilizing atmospheric CO_s at double pre-industrial levels will require about 15 terawatts of carbon-free power by 2050, and even more thereafter. By comparison, total world energy consumption is currently only 13.5 terawatts. Martin I. Hoffert, et al., *Energy Implications of Future Stabilization of Atmospheric CO_2 Content,* 395 NATURE, October 29, 1998, at 884. *But see,* David G. Victor, *Strategies for Cutting Carbon,* 395 NATURE, October 29, 1998, at 837 ("if policies to improve energy efficiency could accelerate the 1% annual decline in energy use per unit of economic output to 1.5%, then the carbon-free energy required would be cut in half").

Climate change is producing drastic changes to Earth processes and changing Earth's environmental status quo. Especially pertinent to human development is the threat of climate change on island nations. As sea levels continue to rise, island peoples and cultures are being threatened. As the former President of the Republic of the Marshall Islands, Christopher Loeak, noted "In the last year alone, my country has suffered through unprecedented droughts in the north, and the biggest ever king tide in the