Potential Implications of Climate Change for the Coastal Resources of Pacific Island Developing Countries and Potential Legal and Policy Responses

William C.G. Burns

As one commentator has observed, "one ironic and tragic aspect of this environmental crisis of greenhouse emissions is the fact that those parts of the world least responsible for creating the global warming problem will be the first to suffer its horrifying consequences."[1] Pacific Island Developing Countries (PIDCs) are responsible for only 0.03% of the world's carbon dioxide emissions, and the average island resident produces only one quarter of the emissions of the average person worldwide [2]. However, it is anticipated that these nations will experience some of the earliest and most severe consequences of climate change over the next two centuries [3]. Some of the most serious ramifications for these nations may be for built and natural coastal resources.

There are nearly 30,000 islands in the Pacific Ocean, 1000 of which are populated [4]. The three dominant ethnic groups are Polynesian (Tonga, the Cook Islands and French Polynesia), Melanesian (Papua New Guinea, Solomon Islands, Vanuatu, and New Caledonia), and Micronesian peoples (Micronesia and the Marshall Islands). PIDCs consist of 22 political entities, 15 of which are politically independent [5]. spread out over 11 million square miles of ocean [6]. The combined population of PIDCs in the region are slightly over six million, with the lion's share in Papua New Guinea [7].

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Pacific islands are traditionally classified as "high" or "low," with a further subdivision into continental and volcanic islands in the former category and atolls and raised limestone islands on the other [8]. In most cases, PIDCs are a combination of these island types [9]. Five countries in the Pacific are comprised entirely of low-lying atolls [10].

The latest assessment by the Intergovernmental Panel on Climate Change (IPCC) [11] concluded that rising concentrations of greenhouse gases are the primary cause [12] for the increase in average global temperatures of about 0.75º C in the past century [13]. In the Northern Hemisphere, "the increase in temperature in the 20th century is likely to have been the largest of any century during the past 1000 years."[14] Seventy percent of the increase of anthropogenic greenhouse gas emissions has occurred since 1950, as has the lion's share of warming since the late 19th Century [15]. In the South Pacific, surface air temperatures have increased by 0.3-0.8º C during the 20th Century, with the greatest increase in the zone southwest of the Southern Pacific Convergence Zone [16]. Temperature increases in this region are well in excess of global rates over the past century [17].

Unfortunately, the unprecedented increases in temperatures over the last century are likely to be ratcheted up dramatically over this century, including in PIDCs. Predicting future climate is an extremely imposing task because it requires an assessment of the future state of a wide array of complex climatic components, including the atmosphere, the ocean, the cryosphere, land surfaces, the stratosphere and the sun [18]. The only practical method to make such projections is through the use of mathematical models, derived from weather forecasting, to represent the physical, chemical and biological processes that determine climate [19]. The most sophisticated of these models are general circulation models (GCMs). With the caveat that regional climate assessments remain speculative, the following section summarizes current projections of climate change in PIDCs by the IPCC and Commonwealth Scientific and Industrial Research Organization (CSIRO).

The IPCC in its Third Assessment Report projects that temperatures in the Pacific will rise by approximately 2.0º C by 2050 and 3.0º C by 2080 [20]. While it is anticipated that temperatures in the region will rise less than global mean averages over the next century [21], it will constitute a dramatic increase over the substantial rise witnessed in the 20th century. CSIRO's projections are consistent with this assessment, though its analysis reveals differential temperature increases in the region, with the greatest increases in

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north Polynesia (0.7-0.9º C) and the least warming in south Polynesia (0.7º C) [22].

The IPCC Third Assessment projects that sea levels may rise in the region by as much as 5 millimeters per year over the next century [23], and continue to rise in the 22nd Century due to lags in the climate effect [24]. Moreover, sea-level rise will raise the baseline for storm surges [25], significantly increasing the vulnerability of coastal areas to inundation [26].

Several GCMs also predict more frequent El Niño/Southern Oscillation (ENSO)-like patterns [27]. This could result in a 26%-200% increase in rainfall over the central and east-central Pacific, with possible decreases in the Melanesian and Polynesian regions [28]. Additionally, warming could also lead to increased extreme rainfall intensity and frequency.

Projected buildups in greenhouse gas emissions will likely raise ocean temperatures and ocean surface water temperatures to above 26º C in the next century [29]. 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. Therefore, some researchers estimate that the occurrence of tropical typhoons and cyclones could increase by as much as 50-60 percent under a scenario of the doubling of atmospheric carbon dioxide concentrations from pre-industrial levels [30], and their intensity by 10-20 percent [31]. Even small increases in storm event severity can result in substantial increases in damage by exceeding critical thresholds [32], with a 10-20 percent increase in intensity, creating potentially catastrophic impacts from waves, storm surges and wind [33].

However, there is by no means universal agreement that climate change will cause 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 [34]. Moreover, some climate scientists argue that ocean circulation changes associated with climate change may counter the effects of added warmth [35]. In its most recent regional assessment report, the IPCC concluded that "[t]here is no consensus regarding the conclusions of studies related to the behavior of tropical cyclones in a warmer world … current information is insufficient to assess current trends, and confidence in understanding and models is inadequate to make firm projections." [36] The IPCC did conclude, with "moderate confidence," that the intensity of tropical cyclones is likely to increase by 10-20% in the Pacific region when atmospheric levels of carbon dioxide reach double pre-industrial levels [37].

As indicated above, it is anticipated that sea levels will rise substantially in the Pacific region over this century.

This has foreboding implications for both human built resources in coastal areas of PIDCs. Low-lying atoll states in the South Pacific are extremely vulnerable to even small rises in sea level. For example, a one-meter rise in sea level could result in the loss of 80 percent of the Majuro atoll in the Marshall Islands, home to half the nation's population, as well as 12.5 percent of the landmass in Kiribati [38], and two-thirds of low-lying islands of Vanuatu [39]. Erosion associated with sea level rise and storm surges would further reduce land area, as well as increase the swampiness and salinity of land that remains above sea level [40].

The ramifications of land loss for PIDCs are particularly serious. With the exception of some of the larger Melanesian islands, most urban and rural settlements, including capitals, are in coastal areas [41]. Moreover, most economic activities in PIDCs are carried out in coastal regions [42], and many of the powerhouses in the region are located within 100 meters of the ocean [43]. Also, Pacific islanders are highly reliant on subsistence farming for food and cash crop production; unfortunately, virtually all crop production takes place at or near coastal regions threatened by inundation and increased storm activities associated with climate change [44].

Coral reefs have been termed the "rainforests of the ocean," occupying less than 0.2 percent of the ocean's area, while serving as critical habitat for approximately one quarter of all marine species [45]. In the context of small island nations, coral reefs are "an extensive and vital" component of the ecosystem [46]. In the Pacific region, reefs provide habitat for fish and other marine species that meet 90% of the protein needs of PIDC inhabitants [47] "and represent almost the sole opportunity for substantial economic development for many of the small island nation." [48] Moreover, coral reefs serve as a buffer against coastline erosion and storms in the Pacific [49], a function that will become even more important as climate change increases the threat of both these phenomena [50]

Coral reefs have extremely narrow temperature tolerances of between 25-29º, with some species in PIDCs currently living near their threshold of thermal tolerance [51]. Projected sea temperature rises in the Pacific region over the next century are likely to result in a "catastrophic decline" in coral cover [52]. Beyond the ramifications this phenomenon would have for regional ecosystems, the loss of coral would have serious economic implications for PIDCs. For example, during the El Niño event of 1998-1999 sea surface temperatures in the Pacific rose to a level that may be common in the future under many climate change scenarios. This resulted in a massive coral bleaching event that wiped out one third of the Pacific island state of Palau's coral reefs, with coral reef species populations plummeting by as much as 99% [53]. The associated economic loss was estimated at approximately $91 million [54], a devastating blow for a small island economy [55]. It has also been estimated that a single island in Fiji, Vitu levu, could face economic losses of $14 million or more by 2050 as a consequence of the loss of coral reefs associated with climate change [56].

Increasing levels of carbon dioxide can also result in markedly reduced calcification rates for organisms such as corals, weakening reef infrastructures [57]. Projected increases in carbon dioxide levels during this century as a consequence of anthropogenic activities could result in a 40% decline in calcification rates [58], significantly exacerbating the threat to reef integrity from rising temperatures and sea levels [59]. Finally, climate change may increase the virulence of pathogens that threaten coral reefs since the optimal temperature for many of these diseases is at least 1ºC higher than that for their coral reef hosts [60].

Mangroves, also known as mangals, are a group of 34 tree species that grow in sheltered conditions in shallow tropical and subtropical waters [61]. In addition to providing a range of products for humans, including construction material, firewood, tannin, and herbal medicines [62], 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 [63]. Also, mangrove trees serve as filters for sediment that threaten coral reefs [64], and help to detoxify contaminants in PIDC waters [65]. Overall, economically, mangroves provide about $10,000 per hectares annually [66].

Low-island mangroves are expected to suffer reductions in geographical distribution from projected sea-level rise over the next century [67]. Should the IPCC's middle-range estimates of sea-level rise come to fruition over the next century, high island mangroves could also be threatened [68]. Increased salinity caused by sea-level rises may also result in decreased net productivity and stunted growth in certain species [69].

On the other hand, climate change should also prove beneficial in some ways 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 into salt marsh environments. Warming can also be expected to increase mangrove productivity, characterized by increased growth and litter production [70].

Increased precipitation in some parts of the Pacific region could also benefit mangroves by reducing salinity and exposure to sulphate, while increasing delivery of terrigenous nutrients [71]. Conversely, decreased rainfall in some regions, with an attendant increase in evaporation, will likely reduce the extent of mangrove areas, particularly with the projected loss of the landward zone to unvegetated hypersaline flats [72].

Climate change would also threaten an array of other species in the region. For example, projected temperature increases may denude the productivity of fisheries in some areas, such as shallow lagoons, by increasing hypersaline conditions [73]. It may also alter the migratory patterns of commercially important tuna species, reducing access fees that fishing companies pay to PIDCs for the privilege of fishing in their EEZs [74]. Clams and sea turtles would be directly threatened by increased temperatures in the region [75]. Finally, habitat destruction associated with storm surges and rising sea levels may affect several avian species, including the Brown Booby, the Masked Booby and the Red-Tailed tropicbird [76].

PIDCs are characterized by severely limited, even sometimes life threateningly low, supplies of unpolluted freshwater supplies [77]. Moreover, the vulnerability of many PIDCs, particularly low-lying atoll States, is exacerbated by their reliance on a single source of water [78]. Climate change may further imperil these resources in several ways.

First, projected sea-level rise in the region could result in the intrusion of saltwater into freshwater lenses, basal aquifers that percolate through islands and float on denser salt or brackish water [79]. Groundwater is the primary source of water for some PIDCs [80], such as Kiribati, and an important supplementary source to rainwater on many others [81]. Also, the intrusion of saltwater into freshwater lenses could result in severe reductions in several subsistence crops in PIDCs, including taro [82], breadfruit, coconuts [83], and sugarcane [84] as well as lowland forests [85]. If the width of small islands in the region is reduced by inundation or erosion, as we anticipate in many areas, it is anticipated that groundwater lenses will shrink beneath larger islands and "virtually disappear" under smaller islands [86].

A policy framework for responding to the threats posed by climate change in PIDCs must include both mitigation and adaptation components.

A second threat is posed by the projected changes in precipitation patterns throughout the region over the next century. Increased rainfall in the central and eastern tropical Pacific will likely result in a substantial increase in flooding [87], resulting in the intrusion of seawater through the aquifer recharge zones of islands, substantially reducing potable water supplies and threatening crops grown in coastal regions [88], Many PIDCs suffered saltwater intrusion into freshwater lenses during recent ENSO events [89]. Heavy rains could also diminish water in freshwater lenses through losses by run-off into the sea [90].

An increased incidence of ENSO events could substantially reduce freshwater supplies in nations such as Micronesia and the Marshall Islands, where rainwater is the primary source of supply [91]. Decreased rainfall could also diminish the volume of groundwater supplies. For example, a 25% reduction in rainfall in Kiribati could result in a 64% reduction of lens thickness on the island of Tarawa [92]. Declining rainfall could also contribute to drought conditions in PIDCs, which in the past have been associated with devastating reductions in production of major agriculture export commodities such as sugar cane in Fiji, squash in Tonga [93], and copra and giant taro in Kiribati [94]. Additionally, serious outbreaks of cholera in PIDCs have been associated with inadequate water supplies during ENSO events [95].

Freshwater resources may be further imperiled if the incidence and/or intensity of storms increase in the Pacific region as a consequence of climate change. Storms can generate waves that result in seawater inundation of groundwater resources, though they can also bring heavy rains that recharge these resources [96].

Higher temperatures may result in an increase in potential evaporation (atmospheric water demand) rates in tropical regions [97]. This may accelerate the drying out of soil and vegetation, increasing water demand [98]. Additionally, streamflow on some PIDCs could be affected by the cumulative effects of increased evaporation from watersheds [99].

A policy framework for responding to the threats posed by climate change in PIDCs must include both mitigation and adaptation components. As outlined below, the former strategy may prove wholly inadequate, at least for the immediate future. For the purposes of this analysis, "mitigation" is defined as "policy, actions and other initiatives that reduce the net emissions of 'greenhouse gases," [100] while "adaptation" is defined as "institutional, technological, or behavioral changes taken to reduce vulnerability to climate change or ameliorate its impacts." [101]

Given the intransigence of major greenhouse gas emitting States [102], as well as the fact that historic levels of greenhouse emissions ensure some impacts of climate change will inevitably be visited upon PIDCs [103], there is a compelling need for adaptive responses to climate change in the region.

One overarching concern is whether PIDCs have adequate financial resources and capacity to develop effective adaptive programs. Five of the PIDCs, the Solomon Islands, Kiribati, Tuvalu, Samoa and Vanuatu, were recently classified by Huq, et al. as among the 49 least developed countries in the world, based on GDP per capita income under $900, human resource weakness criterion and economic vulnerability criterion [104]. Moreover, islands nations typically suffer from limited adaptive capacity as a consequence of a variety of factors, including their physical size, extremely limited access to capital, and technological and human resource shortages [105]. Finally, overseas development assistance to small island states plummeted by 50 percent in the 1990s [106].

Thus, there is a compelling need for additional funding and capacity-building programs to assist PIDCs in ameliorating the impacts of climate change. Unfortunately, while the United Nations Framework Convention on Climate Change (UNFCCC) calls for funding of programs to assist those nations most vulnerable to the impacts of climate change [107], including small island states, the Parties have been slow to provide for adaptation assistance in developing nations. During the 1990s, the Parties largely limited themselves to funding the preparation of progress reports required under the treaty [108].

In more recent years, there has been some expansion of adaptation funding commitments. At the 6th Conference of the Parties, the Parties to the UNFCCC established an Adaptation Fund, the Special Climate Change Fund and a least developed countries fund in the Marrakech Accords [109]. However, as some have observed, it is difficult to be sanguine about the potential of these funds because (a) they are voluntary, (b) they are to be managed via the still-controversial Global Environment Facility (GEF) which has inspired little confidence in the developing countries because its governance and agenda remains "northern-dominated," and (c) they remain poorly funded [110]. The Assessments of Impacts and Adaptations to Climate Change project funded by the Global Environment Facility seeks to involve scientists from developing countries in research on climate change vulnerabilities and possible adaptation responses [111]. However, the funding for this program is also very limited [112], and the requirement that the funds can only be used for "incremental costs of global benefits" may substantially limit its utility since adaptation will yield primarily local, rather than global, benefits [113].

There are also a number of regional and international organizations that provide funding for research and adaptation programs in the region, including the World Meteorological Organization, the United Nations Environment, the South Pacific Applied Geoscience Commission, the Asia-Pacific Network for Global Change Research, the South Pacific Regional Environment Program (SPREP) and the Pacific Island Climate Change Assistance Program of the United Nations Development Program/SPREP. However, funding for these programs is extremely limited, and in some cases is declining [114]. Given the fact that many adaptive strategies may require lead times of between 20-50 years [115], it is critical that developed nations and intergovernmental institutions substantially increase their commitment to PIDCs to help them ameliorate the impacts of climate change in this century and beyond.

In the context of protecting coastal resources from the potential impacts of climate change, among the adaptive strategies that PIDCs should pursue are the following:

1. Development of effective metrics for measuring the vulnerability [116] of small island States' human institutions and natural systems, and enhancement of the resilience of these sectors [117] At this point, development of vulnerability indices by organizations such as the South Pacific Applied Geoscience Commission [118] in the South Pacific and the European Commission Humanitarian Office's Composite Vulnerability Index for the Caribbean [119] remains in the early stages. Even effort should be made to accelerate this process [120]. Moreover, such assessments must also simulate and assess the interactions of non-climatic changes with climate change to develop a more realistic context for adaptive responses; [121]
2. Acknowledgment that technologies are often assessed only for their effectiveness on a global level, with very little regard for their appropriateness for PIDCs [122]. A clear priority should be the establishment of an assessment system that takes into account the unique environmental and socio-economic circumstances of island states in the region;
3. Development of programs to increase the resilience of critical coastal ecosystems, such as coral reefs, through approaches such as development of additional no-take areas and more emphasis on regional management approaches [123];
4. Exploration of means of enhancing the adaptability and resilience of agricultural sector in coastal regions, including the viability of crop diversification, the development of new crop varieties that can be used under conditions of water stress; the use of new farming techniques, such as advanced irrigation systems to facilitate taking advantage of changing climates, and the use of more natural fertilizers to reduce pollution of the surrounding environment, making it more resilient to climate change impacts [124];
5. Promotion of programs to reduce loss of water through leakage. Aging and poorly installed infrastructure results in the loss of 50-70% of water supplies from the reticulation system of PIDCs [125];
6. Exploration of the potential synergies of promotion of sustainable development goals and climate change adaptation projects, sometimes termed "mainstream adaptation [126]." Some of the potential projects that may further and reinforce both these objectives would include promotion of ecosystem practices such as reforestation and grassland management and expanding the use of renewable energy resources [127].

Of course, an emphasis on adaptation responses is not without its perils from a political perspective. Adaptation must never be viewed as a primary response to climate change, because the nations of world, and most particularly, small island States, cannot "adapt" themselves to "business as usual" scenarios that could see greenhouse gas concentrations ultimately triple or quadruple above pre-industrial levels after 2100 [128]. Adaptation must be consistently couched as a "bridge" strategy that buys us time while we structurally decarbonize the world's economy [129]. To ensure that adaptation strategies do not become an end in themselves, it is critical that the Parties to the UNFCCC quickly establish long-term mitigation objectives for the decades that follow after the first commitment period of the Kyoto Protocol is completed in 2012. This should also include clear incremental targets to ensure that mitigation efforts are being pursued in good faith.

For endnotes, see online supplement (S1).

William C.G. Burns is an assistant professor in the Department of Environmental Studies at the University of Redlands in Redlands, California. He is editor-in-chief of the Journal of International Wildlife Law and Policy.