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Promoting the confluence of tropical cyclone research

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Contributions of biologists to tropical cyclone research may improve by integrating concepts from other disciplines. Employing accumulated cyclone energy into protocols may foster greater integration of ecology and meteorology research. Considering experienced ecosystems as antifragile instead of just resilient may improve cross-referencing among ecological and social scientists. Quantifying ecosystem capital as distinct from ecosystem services may improve integration of tropical cyclone ecology research into the expansive global climate change research community.

The study of large scale, stochastic disturbances by biologists has a lengthy history. Tropical cyclones (TCs) are among those disturbances that have been heavily studied. I have recently communicated concerns about the extreme research focus on Atlantic TCs that affect continental localities at the expense of research on Pacific TCs that affect island localities.[1] Suggestions for how to move forward in a manner that corrects this bias mirror those of Habel et al.[2] concerning the need to improve collaborations between scientists from affluent and developing countries in tackling global biodiversity issues. These authors argue that unequal academic benefit sharing whereby institutions in developed countries benefit more than institutions in developing countries may hamper knowledge transfer and sustainable biodiversity conservation. Historical and ongoing efforts to stop biopiracy through international biodiversity policies have constrained biodiversity research, and more workable solutions are needed to transgress the barriers toward a more fair sharing of benefits arising from biodiversity research. Similarly, capacity for TC research is constrained in developing countries for various reasons, and affluent countries with adequate research capacity have ignored the international value of conducting TC research in these developing countries. One solution is to acknowledge the value of contemporary Pacific island TC research for informing future global change issues, thereby bringing international relevance to this localized research.

The propensity for TCs to illuminate inadequate government policies and incite politician reactions garners attention from political pundits. Moreover, a TC may also cause a natural disaster where international relief responses are mobilized, which attracts the attention of social scientists. Meteorologists model and form predictions about TC behavior, and rarely consider the biological components such as influence of future integrity of coastal ecosystems on potential TC damage. Indeed, minimal cross-fertilization has occurred among these and other disciplines within the study of TCs.

Interfacing research issues from ecological, economic, humanitarian, political, and social stakeholders can be highly complex.[3,4] But attempts to integrate these various disciplines may lead to synergism in generating beneficial outcomes in relation to future TC research. One means of improving this integration may be to foster migration of key concepts within one discipline into the workings of the other disciplines.

Antifragile

Balancing ecological and social outcomes of conservation actions is recognized in global conservation policy development. Social scientists studying natural disaster recovery frequently call on

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the term "fragile" to describe human systems that are vulnerable to and compromised after natural disasters. For example, people with physical or mental disabilities or individuals who are culturally different from the mainstream population within a disaster zone may be extremely fragile components of the population.[5] The antonym "antifragile" is arguably a highly relevant term for biologists to use for describing recovery potential of ecosystems that claim a history of frequent TC disturbance.

A resilient system is one that absorbs a disturbance and has the ability to stay the same. The antifragile system is one that benefits from disturbances.[6] Species in any given ecosystem are adapted to the local environmental stressors, and continued exposure to those stressors offers opportunities for those species to reveal their evolved optima. Indeed, paleo-ecological research indicates localities with a history of TCs exhibit greater TC resilience than localities with less frequent TCs.[7] If we use a naïve ecosystem that has not experienced recent TCs as the benchmark, and an experienced ecosystem recovers more quickly and to a greater degree than a resilient naïve system,[7] then the response of the experienced ecosystem is better than resilient. Antifragile would be an appropriate term for biologists to begin using to describe the recovery of experienced ecosystems following TC disturbance.

Accumulated Cyclone Energy

Accumulated cyclone energy (ACE) is founded on the square of the wind speed recorded every 6 h during the life of TCs,[8] and is useful for integrating cumulative destructive potential of a single TC, a season of TCs, or the collective TCs that impact a specified locality. A comparison of 40 y of ACE reveals the value of the western Pacific region for studying TCs, in that the annual ACE of the western Pacific greatly exceeded that of the Atlantic.[1] The annual ACE mean was 276 $knots^2$ *10,000 in the western Pacific TC basin, and only 99 $knots^2$ *10,000 in the Atlantic TC basin. The Pacific ACE was greater than the Atlantic ACE even in 1992 when Hurricane Andrew and in 2005 when Hurricane Katrina impacted the Atlantic coastal regions. Furthermore, in 6 of the 40 years, the Pacific ACE was more than 10-fold greater than the Atlantic ACE.

Most non-economists can grasp the bottom line on a spreadsheet even if they don't understand the models and data used to get to that bottom line. The ACE emerges as a parallel, in that within a single number one can integrate the complex factors that integrate to quantify damage potential. For example, a TC that persists for many days but never reaches catastrophic wind speeds may exhibit a relevant and accurate low ACE despite its longevity. Alternatively, a TC that is short-lived but powerful may exhibit a relatively high ACE despite its short life. Biologists may aid in cross-referencing their TC research with meteorology and climatology research if ACE were more frequently used as a metric in ecology research.

Ecosystem Capital

How humans use the natural environment and how much they do so without threatening its sustainable integrity is a fundamental issue in environmental conservation.[9] Within this context, ecosystem services are defined as the benefits people obtain from ecosystems on earth.[10] For coastal regions where TCs exert their greatest damage, owners and managers of land are both producers and consumers of many of these services. Although the total value of the ecosystem services provided by the coastline is great, land owners may perceive their only direct benefit is from saleable products. In western Pacific islands, this is partly causal of the ongoing large-scale alteration of coastal zones to aquaculture.[11] Thus, incentives from government and the larger community are needed to interest land owners in adopting practices that benefit society as a whole. Toward that end, the political and socio-economic relevance of ecosystem services has fostered growing knowledge on the subject.[12]

The future integrity of coastal ecosystems will be determined by complex interactions among various effects of climate change and globalization. Some of the mediating factors will be state and regional governance, global and regional environmentalism, economic policies, availability of financial resources, technological advances, and cultural values. In cases where land owners do not perceive a direct benefit from maintaining the full range of environmental services obtained from natural coastal ecosystems, these land owners may require compensation for revenues foregone from the decision to maintain natural areas. In countries like the Philippines this may be further complicated by highly diverse groups of indigenous peoples, because the fate of indigenous peoples and maintenance of indigenous rights is typically tightly linked to local biodiversity.

The Convention on Biological Diversity was the first global agreement aimed at conservation and sustainable use of biological diversity.[13] In recent years a strong focus on biodiversity governance has generated standardized biodiversity assessment, monitoring, and conservation using market-based instruments. However, biodiversity is not the only facet of coastal ecosystem services that would benefit from an integrated global approach. Innovative market-based instruments targeting all facets of what the ecosystem has to offer mankind would benefit various countries which seek to offer incentives to local communities.

The European Environment Agency (EEA) has recently summarized the economic importance of coasts and the immense pressure to which they are subjected.[14] While the term ecosystem services has a long history in ecology research,[15] the EEA is introducing the term "ecosystem capital" as a means of quantifying the changes to coastal habitats over time. Integrating ecosystem capital metrics in coastal planning generates more relevant knowledge and improves collaboration of diverse actors. Indeed, if discussions can shift from ecosystem services to ecosystem capital, perhaps policy makers from the countries such as the United States that carry the most blame for historical emissions involved in global climate change[16] will more fully embrace their responsibilities to the most vulnerable countries like the Philippines.[17] This will involve moving more resources from affluent perpetrators to the vulnerable countries in order to help them address their own mitigation actions that sustain their ecosystem capital. Enforcement mechanisms of a multilateral treaty are arguably required[18] and these mechanisms may take on more strength if the growing knowledge of ecosystems services is employed to quantify an ecosystem capital framework. Biologists are positioned to play a critical role in that process.

Conclusions

Efforts to mainstream concepts from various disciplines into TC ecology research may improve contributions of biologists to understanding aspects of global climate change. This goal may be met by expanding the lexicon of ecology research. Embracing the concepts of fragility and antifragility may help integrate key ecological concepts with humanitarian efforts and social sciences. Employing ACE metrics in ecosystem and biodiversity response to TCs may foster better cross-referencing between ecology and climatology literature. Contributions by biologists to the quantification of ecosystem capital may better position those biologists as moral actors in climate justice efforts to alleviate unequal burdens created during climate change. Increased use of these concepts by biologists may cultivate conceptual confluence among disciplines and help reconcile deficiencies in coordination between anthropo- and ecocentric motivations.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

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