Chapter 21
Promoting Resilience of Tomorrow's Impermanent Coasts

Lynn Donelson Wright and Bruce G. Thom

Get the Black Beauty Kato. Those clowns are in trouble.
—The Green Hornet- c. 1950

21.1 Anticipating and Preparing for the Future

There are three categories of actions that humans need to take in order to minimize the detrimental impacts of global change on tomorrow's coastal systems. The first, of course, is to cause less harm by reducing our carbon footprint and ceasing to do destructive things like polluting, dredging, severing sediment supply, withdrawing groundwater, overdeveloping etc. Much has been written and spoken about this even though we have said relatively little about it in this book. The second category of actions, which has received minimal attention from the popular media but has been the motivating theme of this book, involves promoting deep enough understanding of the myriad complex interconnections of coastal processes to allow long-term predictions of what may lie ahead. Such predictions are essential to evolving effective strategies for adapting and remaining resilient. The third action is to ensure that to the extent possible we embed coastal science, including matters related to future impacts of climate change, into state and federal policies and law. The aim must be to ensure that regional coastal strategies are based on the best available science to reduce risk to built and natural assets from the adverse effects of short-term practices driven by local vested interests.

Regardless of how diligently we may undertake actions of the first category, changes are underway and accelerating so actions of the second and third categories are crucial to our future. However, unless the first category actions are deliberate

L. D. Wright (✉)
Southeastern Universities Research Association (SURA), Washington, DC, USA
e-mail: ldwright@bellsouth.net

B. G. Thom
School of Geosciences, University of Sydney, Sydney, NSW, Australia
e-mail: bruce.thom@sydney.edu.au

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and effective, the challenges of adaptation may be overwhelming in many parts of the world. For example, the likely range of future rates of warming and sea level rise as described in Chaps. 2 and 3 depend strongly on the degrees to which greenhouse gas emissions are reduced beginning in the near future. Regrettably the withdrawal in 2017 of the USA from the Paris Climate Accord significantly dims the likelihood of the "best case" climate change scenario prevailing. This increases the urgency of developing robust adaptive strategies based on reliable numerical models supported by improved observations and monitoring. Hopefully, aggressive and widespread "grassroots" efforts by individuals, cities, businesses, counties and states to reduce carbon emissions as advocated most recently by Bloomberg and Pope (2017) will make a significant difference. But, whether extreme or modest, future changes as described in Parts 1, 2 and 3 of this book are inevitable and we must plan accordingly to ensure the resilience of tomorrow's coasts. In this final chapter, we offer *opening* perspectives on some of the things that the global community might undertake in a collaborative spirit in order to enhance the resilience of tomorrow's coasts. This chapter builds on the contributions of authors to this book, and on the outcomes of two workshops on this subject that the Southeastern Universities Research Association (SURA) led in 2014 and 2015 (SURA 2015; Wright et al. 2016a, b). We intend for future workshops to assist broad based communities of scholars, managers, politicians and stakeholders to further evolve and refine regional strategies for adapting to changing but uncertain futures. While we expect improvements to our understanding and predictive capabilities to take advantage of the global brain trust, resilience must be implemented locally and regionally and the solutions must be fluid and adaptable.

21.2 Summary of Some Future Challenges

In Chap. 1 of this book, we noted that effective solutions to the complex challenges faced by tomorrow's coasts and coastal communities will require not only improved and coupled predictive models along with more accurate, frequent and spatially comprehensive observational data but also, and probably more importantly, finding ways to overcome a range of cultural challenges. Included among these challenges are (1) obstacles to a trans-institutional collaborative environment; (2) attitudes and beliefs of local regulators and policy makers; (3) the extent to which educators understand and communicate environmental science; (4) economic pressures, legal systems and political ideologies; (5) conflicting pressures from environmental and business advocacy groups; and (6) the awareness of the general public. Finding effective approaches to all of these factors represents a suite of serious challenges for the immediate future. Meeting these challenges can only be accomplished by collaborative partnerships that include the general public, educators, planners and managers, politicians and decision makers and the global scientific community. Successes will undoubtedly be incremental and will depend on *communication* and adaptability. In a complex world, models, and even understandings are possibly as impermanent as the coasts themselves. In other words, we still have much to learn from each other and our future resilience will require collective mindfulness. Trans-disciplinary strategies for facilitating collaborations in support of enhanced coastal resilience were outlined by Wright et al. 2016a, b). Collaborations at grass roots levels involving the public and numerous non-governmental organizations have been established by The Nature Conservancy (TNC).

21.3 Resilience as It Relates to Coastal Systems

In the introduction to this book, we stated that: ***A high priority vision for future coastal science should be to enhance resilience of coastal communities by anticipating and mitigating hazards to human health, safety and welfare and reducing economic harm to coastal industries such as tourism, fisheries and shipping.*** As pointed out in Chap. 1, *resilience* is the capacity to change and adapt continually yet remain viable. Humans and nature are interdependent and, through collaboration, natural and social scientists, and stakeholders can improve coastal resilience. According to the Stockholm Resilience Centre, "Resilience thinking embraces learning, diversity and above all the belief that humans and nature are strongly coupled to the point that they should be conceived as one social-ecological system." Low risk is not necessarily requisite for high resilience but risk and resilience should both be considered in planning future mitigation strategies. Coastal risk assessment is considered in detail in a recent NRC report (National Research Council 2014). Considering the complex interdependence of many factors described in the foregoing chapters, community resilience and ecosystem resilience must be considered together, not as separate problems. Furthermore, since the built infrastructure and related services are integral components of communities, infrastructure resilience must be considered in relation to both communities and ecosystems (National Institute of Standards and Technology 2015).

For natural ecosystems, such as wetlands, biodiversity is a source of enhanced resilience. Similarly, economic diversity probably results in increased community diversity. One well-known vulnerability index considers vulnerability to environmental hazards (Cutter 1996). Arkema et al. (2013) discuss the roles that natural habitats can play in enhancing natural resilience of communities. As noted by the National Research Council (2006), the loss of coastal wetlands over the decades preceding Hurricane Katrina, substantially enhanced the vulnerability of New Orleans to that event. The Louisiana Coastal Protection and Restoration Authority (2007) is attempting to address this problem (Chap. 13).

The US Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC) is developing a tiered set of coastal resilience metrics that integrate engineering, environmental and community resilience (Rosati et al. 2015). Rosati et al. (2015) describe expert elicitation, data driven, and tiered methods to quantify resilience. Expert elicitation is somewhat subjective while the data-driven methods rely on a combination of historical data and numerical modeling. The USACE's approach considers preparation, resistance, recovery, and adaptation depending on factors such as need, time, space, and available funding. The three-tiered approach includes expert elicitation, field data and simple models, and rigorous assessment based on probabilistic analyses (Schultz et al. 2012). An important aspect of any viable long-range resilience program is that it must enable continually evolving adaptive management strategies underpinned by advanced numerical modeling. The USACE has provided extensive guidance for engineering responses to sea level rise including regionally specific estimates of change (US Army Corps of Engineers 2014).

21.4 Global Scientific Collaboration Is Essential and Feasible

According to Marinez-Moyano (2006) "Collaboration is a function of the recursive interaction of knowledge, engagement, results, perceptions of trust, and accumulation of activity over time." If the collaborations we envision are to be successful and persist over a long enough timeframe to make a difference, the collaboration strategies and methodologies that we build must be as rigorous as the models and understanding they are designed to facilitate. The intent is not only to facilitate collaborations within the academic community but, most importantly, among universities and federal, state and local governmental agencies, non-governmental organizations (NGOs) and stakeholder organizations. To accomplish this we must ensure that rigorous and broadly embraced protocols are established and followed. Collaboration involves much more than simply talking to and helping each other. To be effective it must involve mutual acceptance of a common set of goals, critical assessments of diverse approaches, iterative updates and incremental improvements to understanding and predicting, promotion of new paradigms and effective communication with a hierarchy of operational end users. In a true collaborative team or consortium, each member must enable and support, not compete with, the other members. A fairly comprehensive collection of essays on collaboration can be found in a book edited by Schuman (2006). Since 2007, The Nature Conservancy has led the development of **Coastal Resilience, an approach and online decision support tool** to help address the effects of climate change and natural disasters on specific coastal regions around the world (Coastal Resilience.org). For the climate science community, fairly mature global collaborative networks, such as the World Climate Research Programme (WCRP; https://www.wcrp-climate.org/) have played crucial roles in advancing improved climate prediction models for many years (Merryfield et al. 2017; see Chap. 2 for other examples). Coastal sciences can benefit measurably from the creation of comparable global networks of consortia.

Rigorous and generally accepted standards are crucial to collaborative modeling. To date, coastal modeling testbed programs have adopted the standards of the Open Geospatial Consortium (OGC; http://www.OpenGeospatial.org) and, until a more robust successor emerges, this approach should be followed for the near future. The OGC is an established consensus standards organization and an international consortium of 371 companies, government agencies (including NOAA), and universities that develop publicly available interface standards. These services make complex spatial information and data services accessible, interoperable and useful to multiple applications. An ongoing OGC testbed activity is focused on Urban Climate Resilience. Recent collaborative research projects conducted by investigators from different disciplines in the natural sciences have successfully created new conceptual, theoretical, methodological, and translational innovations that address complex coastal problems by integration. With funding from NOAA's U.S. Integrated Ocean Observing System Program (IOOS®), SURA has facilitated strategic collaborations to build and guide the Coastal and Ocean Modeling Testbed or COMT (Luettich et al. 2013, 2017). The COMT has demonstrated considerable success in orchestrating collaboration among more than 20 universities along with agency representation from NOAA, Navy, EPA and the U.S. Army Corp of Engineers. The resulting COMT is now one of 11 official NOAA testbeds with the goal of accelerating the transfer of research results to improve operational modeling skill. Among other things, this has involved maintaining a web site, a data archive, providing high-performance computing resources, and custom code to perform tasks such as skill assessment and format conversions.

Unfortunately, many universities are not yet up to the task of true interdisciplinary research. Part of the problem relates to the accreditation system and its discipline-specific standards. This impedes interdisciplinary work at many traditional universities. Multi-discipline papers with many authors are not really valued and young untenured faculty who engage in too much interdisciplinary work may be denied tenure. The discipline-based distribution of faculty on campuses is also a discouraging factor: social scientists and natural scientists may be based on opposite sides of large campuses or even on different campuses of multi campus state universities. Another part of the problem involves simple competition among universities, which tends to stifle multi-institutional altruism. The world is likely to be very different in 2050, as will the missions of universities that remain relevant. Centers and institutes are one way to promote collaboration among disciplines and are not as constrained as traditional university departments. "Enterprise" entities that promote interdisciplinary synergies but also are designed to evolve as science and needs change may be better models. One model is that of a *Center for Research, Education and Innovation* to facilitate the inclusion of industry and governmental entities along with academics. In Australia, the Wentworth Group of Concerned Scientists performs such a role through the engagement of experienced scientists in public policy (www.wentworthgroup.org.au). An example of the work of this group can be found in the formulation of a method of environmental accounts based on natural asset condition measurements involving a range of different disciplines (Wentworth Group 2015). In Australia, this work is now being incorporated into a national system of environment accounts.

Beyond the confines of individual universities or federal agencies, an independent community-shared consortium can help the global community to take a first step in addressing questions of risk and resilience by facilitating the creation of an open-source base of empirical and numerical model data along with a rigorous set of data standards and an extensible cyber infrastructure for managing, and accessing the necessary information. This will support a combination of discipline-specific and cross-disciplinary numerical modeling, coupling the outputs from physical process models with ecosystem and socioeconomic models, and statistical analyses of socioeconomic factors that might ultimately determine the resilience of communities to expected stressors. In addition, modeling protocols could be extended to enable the potential impacts (positive or negative) of engineering approaches or management decisions to be assessed. Several researchers (e.g., Plag et al. 2015) have stressed the need for international collaboration and virtual research environments to enable knowledge creation in response to societal needs. Cloud computing technologies facilitate the creation of cyber-supported "playing fields" where it is easier to work with others. The supporting cyber services should include successive generations of HPC resources for running and coupling models, platforms for accessing, sharing and archiving data and model outputs as well as for accessing and sharing open-source model codes, and a catalogue of and access to analysis routines and visualization tools. Over the course of the next few years, it should be possible to accommodate most or all of the cyber needs.

21.5 Local and Regional Collaboration Is Essential to Strategic Planning

From the foregoing chapters in this book, it should be clear that natural coastal environments as well as coastal communities are highly diverse and there can never be a "one size fits all" strategy for adapting to future changes. The need for local "bottom up" solutions is discussed by Colander and Kupers (2014) and is dictated in part by the pronounced geographical variability of coastal systems and in part by the simple fact that problems related to coastal flooding, land loss and ecosystem degradation are more immediately apparent- and seemingly urgent- at local and regional scales than at national or global scales. In the year 2017, this is especially true in the U.S.A. where the stated position of the Federal Administration is denial of climate change, sea level rise and attendant environmental changes. Some state governors also share these positions (e.g. Florida). On the other hand, the need for aggressive action is so obvious in threatened localities that some state, county and municipal governments are making significant investments in, and assigning high priorities to, planning in advance for resilient futures. At the state level, prominent examples are Guangdong Province, China (Chap. 12), New South Wales, Australia (Chap. 19), and Louisiana's Coastal Protection and Reclamation Authority (CPRA; Chap. 13). As described in Chap. 14, the coastal problems facing Broward County Florida have mandated the establishment of the county's *Environmental Planning and Community Resilience Division.* In smaller communities with fewer resources, local emergency management officials are taking increasing responsibility for resilience planning- but they need help and guidance from the academic community as well as regional planners, operational agencies (NOAA, FEMA, DHS etc.) and politicians.

Adaptive regional strategies are required to reduce risk of harm to valued coastal assets and to overcoming the numerous barriers to long-term planning at different spatial scales as outlined in Chap. 19. In addition, such strategies must be incorporated into a well-understood public policy and legal framework that has within it climate change adaptation policies that recognize the need for action at certain threshold or trigger points. Communities must understand why there needs to be action at such points when changes in coastal conditions determine the need for action. Without clear and accepted policies embedded in law, supported by an implementation plan and enforcement processes, there will always be the temptation to accept pressures from vested interests driven by ignorance and greed.

To be effective, local and regional collaborations need to involve the broadest possible pool of talent and perspectives; they should be community inclusive. Initially, workshops or a series of "town hall meetings" should assess the concerns, needs and expectations of local residents and stakeholders (e.g. property owners, commercial and recreational fishers, emergency managers, tourist industry representatives etc.). Before academics offer their thoughts or advice, they need to listen carefully to the concerns and perceptions of the citizens. As explained in the previous subsection, true collaboration must involve recursive interaction of knowledge, engagement and perceptions. Community leaders, and, where appropriate, clergy should be part of the collaborative planning process. All members of collaborative teams must be respected as equal partners. In the U.S., representatives of state Sea Grant programs should participate in and, in many cases, lead discussions.

21.6 Finding Common Ground

Formulating a comprehensive plan for an enduring coastal resilience program can begin with determining areas where interdisciplinary synergies can be most readily applied, facilitating the infrastructural advances that are needed to accommodate future modeling and communication and preparing a research plan for moving forward as a community. The scientific community at large can initiate and evolve a network of interdisciplinary scientists and supporting cyber-infrastructure with emphasis on understanding and modeling complex coastal systems and communicating the results to operational end users. A key role for the facilitating consortia will not be to execute models but to provide the virtual environments within which modelers and non-modeling scholars from different disciplines can interconnect. Quite simply, coastal systems science must bring together different components of the system and integrate them.

Some crucial steps in this process summarized by Wright et al. (2016a) include the following:

Step 1: Articulating the interconnections of socio-ecological systems and identifying the societal, legal, biophysical and biogeochemical criteria needed to model resilience in specific coastal regions.

- Refine understanding and articulation of interconnections of human and natural coastal processes.
- Advance understanding of the linkages between regional and ocean systems and scale-dependent inter-connections among societal, biophysical and biogeochemical factors.
- Develop criteria for assessing changes in *ecosystem services* and the impacts that these changes may have on rural and urban socioeconomic systems.
- Following the International Geosphere Biosphere Programme example, develop an analytical framework that is relevant to policy and decision-making at different levels and takes account of legal issues and constraints.

Step 2: Identifying the systems science requirements for future coastal risk and resilience programs.

- Catalyze interdisciplinary collaborations.
- Prioritize coastal threats (by region).
- Identify well-defined, integrated research questions and the required modeling, analysis and visualization products to address these questions.
- Identify and prioritize legal factors that may impact community resilience or vulnerability.
- Assess and refine social resilience indices as they pertain to both urban and rural coastal communities.
- Develop feasible data management structures for trans-disciplinary integration and communication.

Step 3: Creating an accessible and extensible cyber infrastructure for cross-disciplinary communication and collaboration.

- Identify design criteria for a collaborative web portal for cross-disciplinary communication.
- Identify the search tools needed to effectively access existing data sets and model outputs.
- Develop a cyber template(s) to enable social and natural scientists, managers and legal scholars to share information in mutually understandable formats (e.g., utilization of NOAA big data for decision making).
- Define the needs for more effective data and model output visualization.

Step 4: Evolving and validating predictive models to reduce uncertainty and coupling models across disciplines to assess complex interactions among future physical, ecological and socioeconomic processes.

- Couple hydrologic and ocean models to improve predictions of compound flooding such as that caused by Hurricane Harvey.

- Improve decadal time scale models of future coastal environmental and socioeconomic outcomes of multiple climate change scenarios.
- Improve regionally specific predictions of the potential outcomes of alternative strategies to mitigate vulnerability of coastal communities.
- Improve the accuracy and accessibility of coastal observation and monitoring data, especially satellite data and improve techniques for assimilating observational data into numerical models.

21.7 Outreach to Policy Makers, Politicians and the Public

As *Hurricane Katrina* bore down on New Orleans in 2005, numerical models, were predicting high storm surges and waves for Coastal Louisiana (via the now discontinued *Open IOOS* website and NOAA's NWS; e.g. Bogden et al. 2007). Data buoys and integrated observing systems such as Wave-Current-Surge Information System for Coastal Louisiana in the Gulf of Mexico verified wave predictions. Those predictions were readily accessible in real time on the Internet in the form of color-coded animations and numerical data, but they were largely ignored by local, State and Federal leaders as well as by many emergency managers. In 2017, long-range scientific projections of climate-related phenomena and their impacts continue to be widely denied by many politicians and decision makers as well as by the U.S. President and many members of his cabinet. Fortunately, in 2012, short-term wind, storm surge and wave forecasts were heeded as Super Storm Sandy moved up the U.S. East Coast and approached New York Bight and this undoubtedly saved many lives. Similarly, in 2017, predictions of the impending impacts of Hurricanes Harvey, Irma and Maria were trusted and heeded. But substantial improvements in communication and trust are still needed.

The scientific community at large must nurture the enlightenment of politicians and decision makers. This may be the largest challenge of all, but the scientific community must work diligently to persuade emergency managers, land use planners and leaders at all governmental levels to trust science-based model predictions. This will require careful and well-articulated, non-jargonized communication over a prolonged period combined with clear and repeated demonstrations that numerical models really work and are not a hoax. So the question is: How do we do that? On the local level, one obvious way is to get to know the local leaders and gain their trust through one on one visits, open forums involving bi-directional exchanges (but not "lectures") and clear demonstrations of mutual respect among academics, local, state and federal government officials and politicians. Such demonstrations must reflect an understanding by credible scientists of past conditions including observations of geomorphic history and impacts of past extreme events. And, of course, patience and persistence are essential. Consortia and NGOs should be able to greatly broaden the scope of outreach to officials by developing accessible and extensible web sites and cyber tool kits that serve clear graphical and textual explanations of coastal evolution as well as long-and short-term model results.

As pointed out in Chap. 18, a critical, and commonly overlooked, facet of outreach to enhance resilience involves educating the general public, particularly lower income and undereducated vulnerable communities, about hazards and how to respond to them. A few U.S. universities already offer programs focused on helping communities become more disaster resilient through practical education. A prominent example is the *Center for Hazards Assessment, Response and Technology (CHART)*, an applied social science hazards center at the University of New Orleans (http://scholarworks.uno.edu/chart). Among other activities CHART staff provide risk literacy as a component of more general adult literacy programs. A network of collaborating university-based coastal resilience researchers and educators could provide web-accessible resources to other programs that share the goals of UNO's CHART.

21.8 Identifying and Engaging Potential Beneficiaries

As of 2017, one of NOAA's stated goals is that of *Resilient Coastal Communities and Economies*. The collaborative consortia that we envision can contribute to this goal but the effectiveness of the contribution will require a thoughtful, and possibly lengthy, process involving an uncommonly diverse assemblage of social and natural scientists, engineers, legal scholars, health scientists, stakeholders and decision makers. For the ongoing COMT program described in Sect. 21.4, the target beneficiaries have been operational agencies (particularly NOAA) and the main product has been the transfer of methodologies and models from research to operations. For future consortia, the potential stakeholders may include the State Sea Grant Programs, re-insurers, county governments, state governments, health workers, emergency managers, resource managers, FEMA, NGOs such as Nature Conservancy and the Sierra Club, educators, the general public- and operational agencies (particularly NOAA, DHS and USACE). Although the specific needs of each of these stakeholders differ, the universal nature of the most urgent questions should enable the facilitating consortium (or consortia) to focus firstly on problems that are important to a broad range of beneficiaries. In some cases, however, it may be necessary to concentrate on a subset of stakeholders who have a narrow definition of "acceptable benefits" that communities actually value. Risk reduction is one such benefit. County and local government agencies charged with planning for future threats may be among those most willing to engage with the consortium.

21.9 Educating Future Generations

Most of the people who will have to adapt to and live with the coasts of tomorrow have not yet been born and, among those who have, few have so far completed their formal education. There is still time to transmit the essential understandings that future generations will need in order to be resilient in a complex and changing world. The essential education process should begin with preschoolers and continue through higher education and beyond. Appreciation of natural environments and humanity's dependence and impacts on them should be instilled in children at the earliest possible age and reinforced throughout their lives. For children in their formative years, it is important for parents and educators not to perpetuate the dualistic notion that humanity and nature are distinct and that the former must conquer the latter. Instead, the idea of "*intelligent co-operation with nature*" should be promoted as a human virtue. And, of course, if the crucial collaborations that we envision are to succeed, the "me first" mind set must be discouraged, in fact, disdained. Armed with this new, holistic and altruistic set of values, the students of tomorrow should be receptive to a formal education that places greater emphasis on natural complexity and change in the *Anthropocene.*

In future classrooms, environmental science, social sciences and geography as well as arts and humanities need to be elevated to the same priority level as STEM subjects. Environmental ethics should be part of the middle school and high school curriculum. Conceptual understandings of processes and connectivities should be emphasized over facts and data, which are transient. Pragmatists may ask: How do arts and humanities fit in here? The answer is that students should be taught to understand that there is more to humanness than money and material things. They also must learn about and celebrate the diversity of both nature and humanity. They must get to know their local area, its history, its geology, its beauty. At the University level, more students should be attracted to rigorous studies of atmospheric, ocean and environmental sciences and especially interdisciplinary studies that integrate natural and social sciences. For those with technical aptitudes, numerical modeling and coupling of models across disciplines should be encouraged at the graduate level. By whatever educational pathway that works and regardless of the educational level that is ultimately attained, future communities should intuitively realize and embrace the axiom with which we opened Chap. 1: "***All things are connected. Whatever befalls the earth befalls the children of the earth***". (Chief Seattle of the Suquamish Native American people, c. 1835).

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