Final Draft
of the original manuscript:

Holdschlag, A.; Ratter, B.M.W.:

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In: Anthropocene (2016) Elsevier

DOI: 10.1016/j.ancene.2016.03.002

Caribbean Island States in a Social-Ecological Panarchy?
Complexity Theory, Adaptability and Environmental Knowledge Systems

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Abstract

Many social-ecologically sensitive Small Island Developing States (SIDS) increasingly face global (climate) change risks to sustainable development. However, the validity of factors said to contribute toward vulnerability is disputed in light of the differing economic success, enormous heterogeneity, divergent paths of development, and varying potential for adaptability displayed by small islands. Research on uncertainty, vulnerability and resilience of coupled social-ecological systems (SES) can provide a valuable contribution to the sustainability debate. Based on the fundamentals of complexity theory, and the notions of social-ecological adaptability and panarchy, this article highlights the role of context-based, hybrid, and limited environmental knowledge and risk knowledge systems and cultures. The modes of organization of disaster management in Grenada (Eastern Caribbean) and environmental governance in The Bahamas (Western Caribbean) on various spatio-temporal scales act as case studies. The production and communication of knowledge, the difficult (cross-scale) integration of diverse knowledge systems and claims, the role of experience and memory, as well as social/institutional learning and inertia appear as crucial factors concerning the strengthening of social adaptability. The findings further demonstrate that significant challenges remain for Caribbean SIDS. These include long-term, socially, locally, and sectorally differentiated vulnerabilities; deficits in governance and communication; and the diverging and spatially-temporally bounded nature of knowledge systems.

Keywords

complexity theory, social-ecological systems, islands, environmental knowledge, Grenada, The Bahamas

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1. Introduction

Twenty years after the first international conference on small island states was held in Barbados, the problems of small islands have reached center stage and attracted international attention. Diverse global change processes increasingly threaten the sustainable development of Small Island Developing States (SIDS), as sensitive social-ecological spatial systems (Hay 2013; IPCC 2014). Research on the scientific and technological uncertainty, vulnerability, and resilience of coupled human-environment systems can make a valuable contribution to the sustainability debate concerning small islands. Yet the

further development of integrating concepts for the analysis of social-ecological systems (SES) remains a challenge. The resilience perspective - developed largely within the discipline of ecology (Holling 1973) - considers the dynamically adaptive ability of a system to withstand and recover from stressors and further develop. Despite criticism for undertheorizing political, social and cultural dynamics, this approach to analyzing human-environment relations has become increasingly important in risk and sustainability research (Brown 2014; Xu, Marinova, and Guo 2015). It is embedded in theories of complex systems that focus on dynamic systems, conceived of as nonlinear, unpredictable, and multiscale interdependent due to interactions between agents. Various process phases and speeds, as well as significant types of interaction and feedbacks may be described, as, for instance, in the heuristic models "adaptive renewal cycle" and "panarchy" (Gunderson and Holling 2002; Allen et al. 2014). Research on social-ecological resilience and adaptability emphasizes the importance of knowledge systems and processes of learning (e.g., Berkes 2009; Wilson 2015), a standpoint that conceptually informs this article. Such SES concepts, however, require further refinement as regard to the role of social specifications for constructive transformation, such as mental models and knowledge systems of risk and environment as well as social network formation (see Luthe and Wyss 2015; Xu, Marinova, and Guo 2015).

It appears crucial for SIDS to integrate and link sectoral social and economic policy and planning on the national, island and municipal levels with environmental and natural hazard policies. Strengthening social-ecological resilience is commonly understood as an important element of sustainable development strategies. So far, few resilience related investigations have used small-island case studies to examine adaptive cycles and panarchical relations (e.g., Bunce et al. 2009; Holdschlag and Ratter 2013). Small and in particular flat islands are generally seen and represented as being especially vulnerable to external stressors and environmental changes, thus global "canaries in the coalmine". Numerous SIDS are threatened by rapid extreme events such as volcanic eruptions, earthquakes, tsunamis, storms, and flooding, as well as by increasing air and sea surface temperatures, climate variability, rising sea levels, coastal erosion, saltwater intrusion, ocean acidification and changing currents (Pelling and Uitto 2001; IPCC 2014). Characteristics that indicate increased vulnerability toward stressors include limited natural, financial and human capital, (post-)colonialism, (post-)conflict and peripheralization, exposed economies with little diversification, cost-intensive infrastructures, insufficient planning capacities, and the dominant influence of financially strong governments and firms.

Although economic, political, and technological globalization is not a new phenomenon for small islands and there are many examples of resilient island societies, the recent dynamics of globalization have created new, widely recognized challenges, especially for local coping and adaptability capacities

(Hay 2013). Moreover, SIDS are strategic actors at the heart of political debates on local effects of global climate change (e.g., Alliance of Small Island States, AOSIS). However, major research deficits concerning SIDS remain. There has, for example, been insufficient investigation of the indirect and long-term effects of natural hazards on states and especially on local communities. In particular, the significance of local contextual ties and historicity has often been neglected, resulting in a corresponding emphasis on the necessity of local and historical research approaches and of long-term data analyses (see Forbes et al. 2013). Concurrently, the general validity of factors said to contribute toward vulnerability is disputed in light of the differing economic success, enormous heterogeneity, divergent paths of development, and varying potential for adaptability displayed by small islands (Connell 2013). In the Caribbean, topics of valuable research include the fields of tension between global change, natural hazards, resource exploitation, and vulnerability, as well as issues of environmental perception and the production and integration of knowledge (Ratter and Rettberg 2009; Mercer et al. 2012; Rhiney 2015).

This article aims to contribute toward a deeper integrative understanding of how, in the global context of uncertainty and recurrent stressors, natural and social-cultural processes of interaction between (sub-)system elements influence the development path of the complex socio-ecological island system. The focus is on how resilience and adaptability may be strengthened and on identifying the interactions that are significant in this context. It is thus important to clarify how interacting social agents react to natural processes and stressors, and how they produce, integrate, and learn to use environmental knowledge. Using the examples of disaster management in Grenada (Eastern Caribbean) and environmental governance in The Bahamas (Western Caribbean), different knowledge systems are investigated with reference to the organizations, networks, and forms of communication of knowledge production on various spatial-temporal scales. Firstly, the fundamentals of complexity theory, notions of social-ecological adaptability, and panarchy are used to scrutinize the importance of knowledge systems. Empirical findings about environmental knowledge, learning, and governance are then discussed. We argue that context-based and hybrid knowledge systems and cultures, resulting from panarchical relations, play an important role for sustainable development. Along these lines, we intend to demonstrate the value of complexity theory to island research in the context of global (climate) change.

2. Complex Social-Ecological Systems (SES)

From our epistemological point of view, transdisciplinary research and integrative syntheses of knowledge that are problem and practice oriented and that provide cross-disciplinary understandings seem indispensible. A suitable option in the ontological and epistemological continuum from realism

to constructivism is provided by the meta-frames of complexity theory (e.g., Montuori 2013). As a multidisciplinary project, complexity science makes the epistemological claim of being open to other knowledge forms. It values combining different ways of thinking and methodologies and thus seems particularly suitable for the analysis of multilayered human-environment relations. Ideas drawn from the "complexity turn" (Urry 2005) are also increasingly used within the environmental sciences.

Complexity theory deals with nonlinear dynamic system processes and relationships between continually changing entities. It investigates how systems are shaped over time due to interactions between their constituting elements (Manson 2001, 406). The focus is on interactions on and between different levels of scale, with an emphasis on the influence of numerous feedback processes and spatially and temporally nested hierarchies. Complexity highlights the existence of diverse, multiply interconnected, spatial-temporal development paths and the frequently disproportionate relations between cause and effect. Investigation especially concerns the qualitative characteristics of the behavior of system elements, which primarily takes place on the local scale but develops far-reaching and interacting effects. Interactions between elements vary dependent on locality. Complex systems are thus defined more by relations than by their components (agents) (Ratter 2012). Indeterminism, unpredictability, irreversibility, path dependency, emergence, uncertainty, leaps, and surprises in system behavior are typical and can cause qualitative changes in system conditions. Processes of self-organization and learning change the characteristics of relations both of the microscopic elements or subsystems and on the macroscale. Complex systems thus have the capacity to adapt to disturbances (complex adaptive systems, Holland 1995). Exceeding certain thresholds or tipping points can lead to a fundamental change of system conditions known as a regime shift or phase shift.

One branch of complexity research into the human-environment system is the increasingly prominent work on adaptive SES and social-ecological resilience (see, e.g., Brown 2014; Xu, Marinova, and Guo 2015). The resilience of a complex system can be understood as its capacity to cope with disturbances or shocks, preserving the qualitative identity of the existing regime and the functionality of the system. In addition, continual system change and disturbances within the system give rise to processes of new internal (self-)organization, i.e. the ability to learn and adapt, to further develop, or to transform. This latter dimension, the ability to influence resilience, is also termed adaptability (see Folke et al. 2010). Significant factors influencing resilience and adaptability are processes of interaction between diverse agents on and between the various spatial-temporal scales. These processes have been captured by the heuristic models of adaptive renewal cycle and panarchy (Gunderson and Holling 2002). The models present different system process phases and speeds, and also important types of interaction (Figure 1). The adaptive renewal cycle describes four functions or phases of adaptive change. The *r* phase (exploitation) represents a phase of growth and exponential change, analogous to ecological colonization. It is followed by the *K* phase (conservation), characterized by accumulation of material

and energy, organizational consolidation, and reduced flexibility. The subsequent rapid Ω phase (release) describes the collapse or creative destruction of the system. The fourth α phase (reorganization) stands for restructuring and renewal and signifies the start of a new cycle. The break depicted graphically in Figure 1 symbolizes a possible leap to another system or a new system condition (regime shift). The resilience of the system falls when the cycle enters the K phase. It increases in the α phase of reorganization. The model has been extended by the notion of panarchy, which portrays an interdependent, cross-scale, and spatially and temporally nested macrosystem. In semantic contrast to the term hierarchy, which implies a rather rigid, top-down structure, panarchy emphasizes the creative and destructive, adaptive, sustaining and evolutionary dimension of nested system dynamics. The model describes interactions between small and fast structures on the one hand and large and slow structures on the other hand. Figure 1 shows two typical panarchical connections that can be important for system adaptability. The arrow labeled "revolt" symbolizes a cascading effect, whereby a small and fast event triggers significant change in the development of a large and slow system. The arrow labeled "remember" promotes the restructuring of a small and fast system based on the increasing maturity of a large and slow structure.

In complex social systems, which are indivisibly connected by feedbacks to natural systems, human individuals are the agents on the so-called microscale. They possess limited, locally accessible information about the entire system and have diverging characteristics and views, as well as differing aims and functions. They primarily act on the local scale in a dispersed fashion according to certain behavioral rules (Ratter 2006, 2012). Collective processes of self-organization occur through the building of communications, institutions, and networks, allowing vital system functions such as resource allocation, information processing, and decision making to be carried out. This requires certain kinds of knowledge, which are influenced by changing cultural identities, worldviews, values, norms, and (unequal) power relations. The literature on social-ecological resilience considers changes in key process functions and factors like numerical and functional diversity, cross-scale connectivity, short feedback loops, different flexible and multiscale governance systems, innovation, coordination, cooperative action, and conflict resolution capacities. Moreover, there is a particular focus on the role of knowledge systems and processes of learning (e.g. Berkes 2009; Wilson 2015). The production and communication of knowledge, the (cross-scale) integration or bridging of different, often competing knowledge systems and knowledge claims, the role of experience and memory, social learning, and inertia are viewed as central elements in social development processes. Nonetheless, further insights, especially empirical research, are required into the role of systems of knowledge and information, power, and agency (Cote and Nightingale 2012; Tàbara and Chabay 2013).

3. Environmental Knowledge Systems

The crisis surrounding the scientific concept of knowledge through the twentieth century was associated with the upgrading of unscientific kinds of knowledge and has led to the diversification and acknowledgement of different forms, cultures, and scopes of knowledge, and also to the decentralization and horizontality of knowledge production. Knowledge is increasingly understood less as consisting of theories and facts and is rather seen as an open, social resource of agency. In addition to cognitive-intellectual, scientific knowledge produced by academics it is possible to distinguish between, for instance, experiential and lay/amateur knowledge, citizen science, instrumental knowledge, everyday and general knowledge, knowledge of art and private sector knowledge (Fahrenwald 2011; Lave 2015). There are also forms like instinctive knowledge, emotional-sensual knowledge, and transrational knowledge (Gloy 2007). In addition, interconnections with the possibility and function of fallacy, doubt, ignorance, un-knowing, not-knowing, not-yet-knowing, and no-longer-knowing should be noted (Abel 2008). Following Tàbara and Chabay (2013, 73), knowledge is understood here as what enables individual agents or societies to understand, address and solve problems, and to assign meaning to particular situations. The assigning of meaning within the context of a specific worldview can transform information into knowledge. Learning can be viewed as comprising both this process and the ability to meaningfully use knowledge. A knowledge system may be understood as what structures the interaction between knowledge carriers, and is characterized by relatively strong cohesion and delimitations (ibid.).

From the perspective of complexity theory, knowledge comes into being within an emergent, dynamic, unclearly bounded network of interactions, as an interdependent and continually changing, endlessly systemic interrelationship (Cilliers 2005). The classic dichotomy between objective and subjective, between reality and representation, is suspended here; context, historicity, and temporality are important. Knowledge is understood as being situative, transactive and limited. Reality and knowledge belong in the same complex system. In SES knowledge emerges in interaction with human and nonhuman agents. Different, path-dependent “knowledge-reality-systems” thus exist on different levels and with different agents, and their expansion and/or integration are contextually variable. The way in which knowledge is understood by complexity theory also encourages focusing on contexts. The role of local knowledge is important, in particular the local and local-temporal boundedness of knowledge and the local conditions of knowledge production (Geertz 1983). Admittedly, the conceptualization of local knowledge (or situated knowledge) remains contentious due to controversial moral, cultural, and political connotations and fundamental epistemological problems (Briggs 2005). Sandkühler (2009) provides a broader understanding of knowledge contexts, describing knowledge cultures and belief systems. Such socially produced knowledge cultures represent contexts of

recognition and understanding. They are hybrid and may be described as complex networks of perceptions and experiences, observations and experiments, beliefs, (re-)presentations, and knowledge, or as the conditions of the possibility of cognitive and epistemic processes. The geography of knowledge also highlights the significance of the embeddedness, spatiality, and politics of the production, legitimation, dispersion, and application of knowledge systems (e.g., Meusburger, Welker, and Wunder 2008; Goldman, Nadasdy, and Turner 2011).

Knowledge forms are essentially bound to the form of communication (Knoblauch 2010). Communication of knowledge should not be conceived as a simple transfer. As knowledge is based in meaning, a precondition of communication is that the interaction is constituted as meaningful, e.g. through the existence of pre-knowledge or code. Whether and how learning can occur via communication is dependent on many factors. A useful tool in this context is Meusburger's (2009) communication model, which identifies numerous factors influencing knowledge exchange. These include the willingness to share knowledge, the ability to verbalize and codify knowledge, the code and medium of transfer, and the willingness of the receiving party to accept new information. Such factors lead to spatially and temporally diverse processes of diffusion for different knowledge forms and to social-spatial disparities in knowledge.

Dealing with stressors of the social system, with complex ecological systems, or with the sustainable use of limited natural resources requires various comprehensive kinds or systems of knowledge. These are dynamically dispersed among different agents affiliated to different scales and different interests, as well as particular institutional configurations (see Lave 2015). "Higher level" regulatory and development interests are of equal importance to the knowledge systems and cultures of those affected by decisions, those subject to planning, and those who are required to implement strategies. The integration or bridging of knowledge involves a learning process, which carries with it the risk of exacerbating inequalities in power relations, so that initially the focus can or must be on the acknowledgement or maintenance of other knowledge systems. Scientific research, resource management, conservation, development, and autonomy are legitimate drivers for the integration of knowledge systems, although deficits in implementation are still evident (Bohensky and Maru 2011). The collaborative production of new knowledge through various agents and their communication is important (Tengö et al. 2014). Necessary integration, for instance of local knowledge and science, can be furthered by creating connective organizational forms, e.g. to foster trust and responsibility, communal learning, vertical and horizontal cooperation, or goal-finding and conflict solution (Berkes 2009).

4. Social-Ecological System Dynamics of Caribbean SIDS: Stressors and Environmental Knowledge

In the following we examine disturbances to the system and the resulting processes of new (self-)organization that constitute the ability to learn, adjust, and further develop (adaptability). The characteristics of adaptive renewal cycles, panarchy, knowledge systems, and knowledge cultures discussed above are used as analytical categories. The focus is on the organizations, networks, and forms of communication involved in knowledge production in the fields of disaster management and environmental governance, all of which carry out functions vital to the system such as resource allocation, information processing, decision making, and implementation. Two Caribbean SIDS, which have been subject to relatively little research in this regard, act as case studies. Both these complex SES are confronted with multiple stressors. Attention is first directed toward the interactions of hurricanes and disaster management in Grenada using the example of Hurricanes Ivan and Emily. Next, elements of environmental governance in The Bahamas are considered. Here various forms of ecosystem degradation are problematic and an invasive species (Indo-Pacific red lionfish, *pterois volitans*) acts as a (potential) stressor to the ecosystem and the social system.

The methodology included the analysis of existing materials, as well as qualitative and quantitative field surveys. In Grenada the focus was on issues of social-ecological adaptability in the context of hurricanes. Meteorological data, socioeconomic statistics, historical documents, and records from the authorities and nongovernmental organizations (NGOs) were analyzed. Twenty-one semi-structured, in-depth interviews were also conducted with scientific and policy experts from government authorities and civil society (NGOs) who had direct or indirect influence on disaster management (St George's, Grenada, March-April 2011). The interviewees represented the sectors disaster management, education, health, housing, water management, agriculture and forestry, meteorology, and history. Data collection on environmental governance in The Bahamas (understood here as environmental regulations that include a range of actors, institutions, and structural contexts) was carried out during two field trips to Nassau, New Providence in March 2010 and September-October 2011. In addition to analysis of the records, fifty-one semi-structured, in-depth interviews were conducted with influential, environmental-sector experts active in environmental planning, environmental management, conservation, agriculture, fisheries, tourism, disaster management, water management, energy provision, transport planning, and cadastral management, and also with academics from the sciences, humanities and social sciences. A semi-structured population survey (including standardized and open questions, n=307) on environmental awareness and behavior was also conducted. Furthermore, three focus group discussions were held in public and private schools,

and a standardized survey of students (aged 8-18, n=235) investigated their environmental knowledge, behavior and education.

4.1 Case Study 1: Disaster Management in Grenada

The small island state of Grenada is exposed primarily to North Atlantic hurricanes from the east. In recent decades great progress has been made in predicting storms, but nonetheless meteorologists, disaster managers, and private individuals largely make decisions in a context of uncertainty as regards the strength, track, and (long-term) effects of approaching hurricanes. Varying storm events and uncertainty create continual challenges for the adaptability of the social subsystem, and memory, experience, communication, and external connectivity play an important role (Handmer and Dovers 2013). The resilience of the system depends on the cyclical way in which the subsystems, i.e. the hurricane event and disaster behavior/management, have interdependently evolved via feedback processes (Berkes 2007). On 7 September 2004 the category 3 Hurricane Ivan hit the island state with its approximately 100,000 inhabitants. The consequences included twenty-eight fatalities, 353 injuries requiring hospital treatment, damage to over 90 percent of buildings, and significant adverse effects on livelihood systems, particularly those of the rural and vulnerable population. The damage was quantified in monetary terms at U.S. $1.2 billion (250 percent of GDP) (Government of Grenada et al. 2006, 3; figures vary by source). The effects cascaded and included all consequences typical of catastrophes: dead and injured people, shock, trauma, homelessness, losses and collapse in all economic sectors, destruction and deterioration of infrastructure, and damage to ecosystem services (coastal protection, flooding regulation, fishing, tourism) (see OECS 2007). The entire population was affected. The national system of public order disintegrated and external help in the form of security forces from neighboring states was required.

The agricultural subsystem suffered a serious collapse. A large proportion of the export-oriented nutmeg and cocoa cultivation and the entire banana production was destroyed. Total damage (including fishing, livestock and infrastructure) was reported to exceed EC $120 million (Government of Grenada n.d.). Numerous farmers subsequently gave up their land, also due to the effects of Hurricane Emily in 2005 (discussed below). It seemed impossible for them to regenerate their agricultural structures to produce a yield and income in the short to medium term. Hindrances to reconstruction were said to include the state of knowledge about soil degradation, limited compensatory capacity and slow regeneration of plants, rising prices of agricultural inputs, low wages, intense export competition, and lack of effective state incentives after the hurricane, e.g. access to cheap credit. Agricultural production sank from EC$59.7 million in 2003 to EC$39.6 million in 2007, and only began slowly to rise again from this date (Grenada Statistics Department 2011). Local

estimates suggest that the number of nutmeg farmers fell from about 8000 before Hurricane Ivan to about 2500 (2011, interview G16, 07.04.11). GIS-based comparison of land use in Grenada between 2000 and 2009 demonstrates that 34 percent or 6203 ha of agricultural land fell into disuse during this period (Figure 2). The abandoned areas became overgrown with weedy vegetation (e.g. *ipomea* and *machembe*) and thus were very susceptible to the spreading plague of rats (Barnes and Riverstone 2008, 27-28). Grenadian agriculture is in any case structurally weak, receives little funding, is subject to top-down control, and suffers from the aging of those in key roles (ø 54 years, Grenada Land Utilization Survey 2005 quoted in IFAD 2010, 4). The sector was unable to regenerate for years, a situation exacerbated in the long term by the increasing rejection of agricultural occupations by younger generations.

Hurricane Ivan was assessed not only by local judgment as a historical and cultural event of outstanding importance, somewhat comparable with independence in 1974, the revolution of 1979, and the U.S. invasion of 1983. Unsurprisingly, according to the interviews (2011) the most important reason for the comprehensive social-ecological collapse was that the social agents of Grenada had not predicted an event of this sort and were thus (almost) completely unprepared. The social subsystem had developed no resilient structures. This view is supported by the prime minister of the time (Keith Mitchell, 1995-2008, G3, 25.03.11). The assertion is valid across the field: for academic circles, specialists, public authorities, and the rest of the population. Indeed, "it surprised everyone," (G12, 29.03.11). Even organizations like the National Emergency Relief Organization (NERO), established in 1985 but inexperienced and insufficiently equipped, the National Water and Sewerage Authority (NAWASA), and the state housing and agricultural departments admitted they had no serious contingency plans or databanks suitable for dealing with such an event. For instance, the building code issued by the supranational Council of Caribbean Engineering Organizations (CCEO) was tailored to Caribbean conditions including hurricanes, but was said to be "just a piece of paper" (head housing-authority agent, G7, 28.03.11). The majority of the population was not covered by appropriate (expensive) insurance.

Alongside crucial large-scale structural political and economic conditions (see e.g. Grove 2013 for the case of Jamaica), the lack of preparedness can be explained by the local knowledge system and knowledge culture of Grenada, based on memory and experience. The last devastating storm to affect Grenada before 2004 was Hurricane Janet, which took the lives of 120 people (Steele 2003, 340) and destroyed or damaged over 20,000 houses (Anonymus 1956, 39-40) in the night from 22-23 September 1955. People were equally unprepared and similarly did not take warnings seriously. A contemporary commented: "on experience and by repute, Grenada lay outside the hurricane zone and no provision for battening down existed" (Anonymus 1956, 38). The interviews conducted in 2011

furthermore show that in the almost fifty years between the two extreme events, the hazard experience of Hurricane Janet was collectively forgotten or superseded. This is also true of earlier strong storms (e.g. August 1901, September 1921, August 1931, and October 1938). More than a generation lacked experience of a devastatingly strong storm and had thus been unable to develop and sustain adaptive hazard knowledge. In addition, emphasizing the importance of locality, Hurrican Janet impacted primarily areas outside the capital city St George's and played only minor role in the memory of the urban population and the central decision makers. Rather, the "pre-Janet perspective," according to which approaching storms regularly move north and spare Grenada, became re-entrenched. This mental model of hazard knowledge can be explicitly termed a "culture issue" (G14, 30.03.11), i.e. a local culture of behavior and knowing (or no-longer-knowing) that encompasses many fields of life and is largely shaped by the (too) low event frequency and probability of occurrence. Thus "culture is part of the problem" (G1, 21.03.11), or as the Grenadian author Worme (2005, 8) more generally describes it as "our careless happy-go-lucky attitude to crucial events".

Despite notable community efforts by a "small highly politicized and increasingly polarized societ[y]" (Lewis 2005, 234), emergency aid and reconstruction were only possible in Grenada thanks to diverse external human, material, technical, technological, and financial aid (see World Bank 2005; UNDP and OECS 2007; Table 1). Organized along the usual bilateral and multilateral lines, emergency aid workers and migrant workers (e.g. doctors, nurses, craftspeople, instructors, engineers, disaster managers, advisors, trainers, security forces, NGOs, and businesses) came to Grenada particularly from neighboring Caribbean and South American countries and the United States, Canada, and Great Britain. External information and kinds of knowledge thus flowed into the country and promoted notable cross-sector processes of cooperation and learning. This resulted, e.g., in organizational restructuring, as with the Agency for Reconstruction and Development (ARD), which was composed of external experts and local agents and until 2009 coordinated reconstruction under the motto "build back better." New NGOs were also founded. NERO was given increased political support, restructured to focus more strongly on communities and stakeholders, significantly enlarged in terms of human resources, communications, and networks, and renamed the National Disaster Management Agency (NaDMA). NaDMA aims to develop an enduring (internationally promoted) "culture of safety" (G2, 22.03.11), yet a notion that may be criticized for various reasons (see Grove 2013). The meteorological service, founded in 1994, was also given increased technological and human resources. The Ministry of Agriculture now has a hurricane precaution department, and the water authorities have emergency plans and materials. New directives such as a new building code were also introduced (although implementation is poor). Contingency plans have been included in superordinate and sectoral development planning, and new forms of institutional, intersectoral cooperation, e.g. with NGOs and church institutions, initiated. Part of the institutional reorganization was an externally

funded remote sensing and GIS-based Hazard Mapping Project (2006) documenting the extent of flooding risk in many places (Figure 2). Generally, improved forms of communication and technologies (including VHF and satellite), particularly mobile phones, were very important for the exchange of information and the integration of knowledge during reconstruction. Furthermore, the Grenadian diaspora (especially in the United States, Great Britain, Canada, Trinidad and Tobago) was significant. Foreign transfers of money, which account for almost a third of Grenada's gross domestic product, doubled after Hurricane Ivan compared to the preceding years and remained at a higher level for another two years (IFAD 2010, 6). Aid for reconstruction was unexpectedly restructured following the 2004 Indian Ocean tsunami, as numerous external agents abruptly left Grenada – a local, negative feedback effect of another rapid, unexpected event.

On 14 July 2005, almost a year after Ivan, Hurricane Emily hit Grenada. This was a different kind of hurricane with greater rainfall but lower wind speeds. The extent of the damage was significantly less. There was only one fatality and the destruction of buildings, agriculture and infrastructure was primarily limited to the north of the island, an area largely spared by Hurricane Ivan. The damage was estimated at U.S. $200 million (Grenada Airports Authority 2005). The reported fatality can be explained by the difference between the two hurricane systems. The man concerned took his mother to an emergency shelter and noticed that the wind was less strong than with Ivan. Drawing on this memory knowledge, he decided to return home and was then killed by a falling tree uprooted during a landslip caused by heavy rain (G14, 30.03.11). Despite this individual example of a misinterpretation of experiential knowledge, the survey indicates an overall increase in adaptability in Grenada in the case of Hurricane Emily. Social risk awareness was significantly greater and precautions improved. Thanks to the error analyses and institutional processes of learning, management reaction times were shorter, the quality of reactions better, and the availability of resources improved. Public order was maintained. Despite these acknowledged improvements however, experts identify continued social vulnerability to the dangers of hurricanes, flooding, landslides, and seismic activity, for instance among many poor and vulnerable sections of the population (poverty rate: 37.7 percent, Kairi 2008). They also specify deficits in hazard knowledge and disaster management on the island. Particular problems are said to exist in hazard awareness, hazard protection (social and institutional), and hazard education, community participation, institutional cooperation and exchange of information ("traditional institutional jealousy," G16, 07.04.11), the legal framework, finance, and implementation of measures. Furthermore, the population mistrusts the state authorities due to irregularities and information deficits that occurred during reconstruction (see also Government of Grenada 2013). A recurrence of the "only every fifty years" attitude has even been noted among several leading political decision makers. The demand of one of the disaster managers is typical: "Bring the scientific knowledge in" (G6, 28.03.11).

In June 2015 NaDMA executed the two-day exercise “Operation Ready” in order to test Grenada’s preparedness and capacity to cope with and respond to the effects of hazards. Continuous testing of plans is one way for NaDMA to engage its partners as the agency strives to build resilience and maintain a culture of safety. The mayor Caribbean hurricanes of the season 2015 Danny (category 3) in August and Joaquin end of October (category 4) caused considerable damage in Dominica and respectively in The Bahamas but passed Grenada unaffected.

The empirical findings concerning disaster cycles in Grenada can be analyzed with the help of panarchy theory. Hurricane Ivan was surprising in its manner and effects and can be seen as an external and rapid “revolt” event that caused the abrupt change or even collapse of the larger SES of the small island. Numerous ecological and important political and socio-ecological functions collapsed (Ω phase). The functions of governance, communication, and cooperation, which are so important for resilience and adaptability in social subsystems, were weak, inflexible and poorly differentiated, as were associated resources and hazard knowledge based on memory and experience (K Phase). Reaction and feedback mechanisms failed to function or were too slow. The path-dependent and limited local culture of hazard knowledge (or no-longer-knowing) led to a “behavioral lock-in” characterized by passivity (see Scheffer 2009), which curtailed abilities to react to stressors and processes of change. Anarchy was followed by panarchy. Cross-scale “remember” interactions ensured that the social system could stabilize, reorganize, and further develop (α Phase). External agents, resources and knowledge systems increased the functional diversity, proactivity, and connectivity of the island system. Corresponding interactions led to emergent states and structures. Of course, in disaster management cross-scale interactions of this kind can also have negative effects on system resilience, for instance by perpetuating social inequality and vulnerability (see, e.g., Gotham and Campanella 2011 on post-Katrina New Orleans) or strengthening international interests of control. However, although such developments can be identified in Grenada (e.g. the increased vulnerability of disadvantaged groups, growing mistrust in state institutions), the findings show primarily positive feedback effects. The (creative) collapse and the intensified, extended, and accelerated panarchical relations triggered social and institutional processes of cooperation, learning, innovation, and transformation that have undoubtedly strengthened adaptability to a new stressor. A decisive role was played by the cross-scale and cross-sector communication, bridging, and new production of knowledge, which led to a transformation of mental risk models and behavior, thus a hybrid knowledge culture. Issues that still challenge this new self-organization include preserving the experiential knowledge and continuing the cooperative and cross-scale development of a comprehensive and trusting hazard culture. An enduring vulnerability remains, albeit socially, locally and sectorally differentiated. The findings, of course, also demonstrate the diverse nature of the social-

ecological subsystem dynamics and phases that followed the collapse. While disaster management was speedily and adaptively extended in a knowledge-based fashion, the path-dependent top-down agricultural system of the island was only able to reorganize slowly and with difficulty, not least due to various negative feedbacks and cascade effects. There is, however, to date no clear indication of a regime shift here. The established emergency response structures' reliabilities are yet subject to reality check.

4.2 Case Study 2: Environmental Governance in The Bahamas

The island state of The Bahamas may be concisely described as "high income – unsustainable use of natural resources" (Roberts and Ibitoye 2012, 87). The terrestrial and marine ecosystems perform diverse ecosystem services. Banking and the financial sector play an important role in the economy, as do the closely linked sectors of tourism and construction. In common with many small islands (Lane et al. 2013), The Bahamas is characterized by the tense dichotomy between, on the one hand, increasing building construction along the coast catering in the short term for tourism and commercialization, and long-term conservation strategies oriented toward natural coastal and marine resources on the other hand. Equally typical of many SIDS is the fact that proactively tackling natural hazards and environmental problems has little social relevance. Violent crime in particular (58 percent, n=307), but also drug trafficking and consumption, unemployment, and social disparities (16 percent) are viewed as more urgent threats than natural and environmental hazards (8 percent). Nonetheless it is valuable to empirically investigate environmental knowledge systems, social processes of identification and learning, and resulting patterns of behavior in The Bahamas, as "in the construction of Bahamian identities, environment is fundamental" (Bethel 2002, 242).

Processes of anthropogenic, often interdependently connected environmental damage in the flat archipelago include: damage to coastal ecosystems (such as mangroves, coral reefs), wetlands and woods, habitat fragmentation, changes to sedimentation processes and surface runoff, sand mining, the deepening of navigation channels, water pollution, oil spills, overfishing, illegal garbage dumping, and the introduction of "nonindigenous" species (Holdschlag and Ratter 2013; Sealey, McDonough, and Lunz 2014). The interviews with experts also reveal concern for the increasing contamination and overuse of fragile freshwater lenses in the karst groundwater, which represent a significant drinking-water resource in the light of increasing water shortages. Unsustainable use has already led to saltwater intrusion on New Providence. Desalination plants have been operational since the early 1960s to tackle the lack of water on this urbanized island, and since the mid-1970s freshwater has been imported from Andros, today accounting for between 20 and 50 percent of total consumption (Ratter and Holdschlag 2012). Various experts believe that new, targeted, medium- to long-term concepts and

possibly restrictive regulations are necessary to ensure the sustainable provision of freshwater. However, there is a local, historically rooted culture of water use, according to which freshwater has always been freely available and a public water supply is taken for granted (B4, 11.03.2010).

Environmental issues are addressed by the Bahamas Environment, Science & Technology (BEST) Commission, established as a public authority in 1994 following external pressure in the context of "Rio 1992". The Commission is now part of the Ministry of Environment and Housing, which in 2008 was also founded in reaction to international deployments but which lacks both a clear legal basis for its responsibilities and the corresponding powers. BEST uses Environmental Impact Assessments (EIA) to represent ecological conservation interests in development and building projects (seen as a "big issue in the country," B18, 18.03.2010). Construction is usually backed by foreign investors with commercial interests and includes tourist resorts, second homes, access roads, canals, and harbor basins. The EIAs have a compensation approach but in practice the few compensation measures signally fail to balance out the environmental impacts and damage. BEST lacks the power to reject or completely prevent building projects. Indeed, there is no desire to do so, as the country's economy is dependent on foreign investment. Within the commission there are also conflicts of interest, with knowledge claims differing between the various divisions (environment, science and technology), for instance in the field of energy policy. Another factor that tends to benefit more economically powerful external agents is the lack of an established land law, as there is very little by way of a land register or land-use planning.

Effective environmental governance on the part of the state is hindered not only by the diverging interests of local and external, and public and private agents, but also by deficits in cooperation, coordination, and communication between government departments. There is only limited exchange and horizontal integration of environmental knowledge between authorities due to institutional rivalry and mistrust ("files are not shared," B4, 11.03.2010). This state of affairs exists in a context of strongly partisan interests and the politicization of factual issues ("everything in the country is politicized," B19, 19.03.2010). One example of the problematic nature of interdepartmental cooperation is that of the Bahamas National Geographic Information Systems (GIS) Center, which was founded under the authority of the prime minister in 1998 and now forms part of the Ministry of the Environment. According to the head of the center (B16, 18.03.2010), political and administrative disputes have prevented it fulfilling its function as a geodata pool for other authorities. Such limitations on cooperation and knowledge integration hinder the establishment of effective institutions and the development of cooperative learning processes and thus restrict the adaptability of public-sector environmental governance. This situation is criticized by civil society, as is the impotence of BEST and the very asymmetric power relations.

Much scientific environmental knowledge about The Bahamas is externally produced and is codified, rendering it difficult to communicate and restricting its accessibility. Domestic financial resources for this are most limited, and (environmental-)scientific job opportunities are rare and unattractive due to low salaries. NGOs and (new/social) media are therefore of great significance in the production and communication of environmental knowledge and in increasing connectivity. Organizations like the semi-governmental Bahamas National Trust (BNT), in existence since 1959, the Bahamas Reef Environment Educational Foundation (BREEF), the national branch of the Nature Conservancy, Friends of the Environment in Abaco, and the Andros Conservancy and Trust (ANCAT) are key in shaping civil-society environmental debate in The Bahamas. They are also active, if at times criticized, agents of environmental governance involved in the development of concepts for national parks and (marine) reserves, and also in environmental education. The notable range of views represented by stakeholders and other interest groups, the relevance of local knowledge systems, and the possibilities of adaptive social and institutional learning become particularly clear during the designation of protected areas (see, e.g., Stoffle and Minnis 2007; Broad and Sanchirico 2008; Wise 2014). Recent critical media debates, for instance about building projects and infrastructure development and their environmental impacts (e.g. thenassauguardian.com, bahamapundit.com), demonstrate increased civil-society engagement with environmental governance and a rise in environmental awareness, albeit both socially differentiated and controversial. This view is also expressed by local experts, who yet discuss the continuing challenges of a post-colonial, stratified society and traditional paternal culture ("consciousness is the biggest impediment," B13, 17.03.2010; "action is missing because the people have never been organized," B12, 16.03.2010).

This assessment is supported by findings on the awareness of processes of environmental change. In response to the question: "Which environmental changes have you observed in recent years?", only 10 percent (n=307) answered "none". 23 percent of replies explicitly mention environmental damage like the anthropogenic extinction of many animal and plant species, the destruction of coral reefs, overfishing, deforestation, and garbage dumping. 8 percent refer directly to the rapid construction of houses, streets and canals. Interestingly, just as many replies (32 percent) refer to climate change, a media topic but one that (at the time of the questionnaire) plays a negligible role in everyday life and (daily) politics and planning. There is less awareness of positive or desirable environmental change (8 percent), for instance connected to conservation measures. The results of the survey of school students on New Providence are also enlightening. They reveal great awareness of both the value of the coastal ecosystem and of its endangerment. No statistical correlations to age, gender, or type of school (state or private) are found. It is striking that environmental problems and dangers are seen as equally important as the social problem of criminality, although the latter receives a great deal more attention

from the rest of society and the media. Despite the influence of the U.S. lifestyle with its high consumption of resources in The Bahamas, students make diverse proposals concerning sustainable behavior. The ideas range from everyday action such as waste prevention, to technical solutions like energy-efficient vehicles and buildings, to political measures for promoting renewable energies. In both the questionnaires and the discussions, however, the students express how little influence they have in social-political debates and discuss the enormous communication problem that exists between the generations. Thus, the diverging knowledge and belief systems of different age groups are apparent in Bahamian society, too.

Reactions to the successful migration of the Indo-Pacific red lionfish (*pterois volitans*) to coastal areas of The Bahamas are an intriguing current phenomenon of human-environment interaction and an example of environmental governance. The recent global proliferation of the lionfish through the subtropical western Atlantic, the Caribbean, and the Mediterranean now counts as one of the fifteen nascent conservation issues worldwide that could affect the conservation of biological diversity (Sutherland et al. 2010 quoted in Anton, Simpson, and Vu 2014). The species was first observed in Bahamian waters in the mid-1990s and has been subject to documentation since 2004; by 2006 the population was estimated to have doubled (Albins and Hixon 2008; Department of Marine Resources, The Bahamas and College of The Bahamas & Environmental Studies Institute 2009). The lionfish is found today, in some cases in high densities, in almost all habitats and water depths of the archipelago. It is a predatory fish with few natural enemies, feeds on a wide variety of reef fauna, and reproduces very rapidly, displacing indigenous species of fish that are important for both local and export markets (e.g. *lutjanus spp.*, e*pinephelus striatus*). It thus concerns both the international science community and national fishing interests and authorities. Upon appearance of the lionfish in The Bahamas, expected negative effects for biodiversity and reef resources, even to the extent of ecological regime shifts (see Anton et al. 2014), were disseminated among the Bahamian population, along with information about the lionfish's potential to injure humans with its venomous spines. Although the sandy beaches are usually not directly affected (B22, 26.09.2011), the lionfish was thus introduced as a dangerous invasive species and potentially threatening for tourism. As we show below, this first introductory information remains strong among lay-people albeit scientific knowledge is constantly increasing (at a rate of approximately three to four scientific papers per month). A healthy ecosystem with a vivid shark and grouper population contribute to the limitation of lionfish spreading, no health-risking incident could be reported along Bahamian sandy beaches, and lionfish being an ordinary food fish in South-Asian regions of origin, but the threatening and poisoning stigma of lionfish persists among lay-people.

Social agents and institutions react to this stressor in diverse ways, so that it can be seen as "a sort of emergent [metaphorical] keystone species for fisheries conservation and research in The Bahamas" (Moore 2012, 679). It represents "alien" invasion and the threatening of fishing resources, but also an economic commodity. In 2007 a web portal for reporting sightings was established, while in 2009 a National Lionfish Response Plan was drawn up (Department of Marine Resources, The Bahamas and Marine & Environmental Studies Institute, College of The Bahamas 2009), and workshops and town meetings were held. Currently numerous media campaigns focusing on information, education, and cooking are underway and repeated "lionfish derbies" seek to control the species (Figure 3). Overall a remarkable basis for problem oriented cooperation and innovation has been created, bringing together many different sectors including government institutions (Depts. of Marine Resources, Public Health, Tourism, Ports, Education, BEST, Defense Force), the College of The Bahamas, NGOs, the fishing industry, and restaurants. However, problems with integrating different knowledge systems and cultures are also manifest. While expert knowledge presents the lionfish as "a new dish", large segments of the population display reservations, doubts, mistrust, and even fear toward its consumption, as "people are very particular about the fish that they consume," (B21, 22.03.2010). Food culture is enormously important in The Bahamas (Brown 1992), with everyday knowledge and social practice having developed in a culturally adaptive fashion with the regional marine resources over time. This behavioral lock-in is confirmed by the population survey. Of responses to the question: "What comes to your mind when you think about the lionfish?" 41 percent (n=307) can be classed as in the "poisonous/dangerous" category, 16 percent as "invasive species/predator", and 16 percent as "unknown", while the category "food/edible" accounts for only 5 percent (Table 2). This skeptical finding is confirmed by the question "Would you eat lionfish?" to which 64 percent replied "no" and only 36 percent "yes". We may state here that these complex cross-scale interrelations of knowledge production, path-dependent knowledge cultures, emerging discourses of threat concerning invasive species, social anxieties, and the respective roles of scientist and policy-makers need further in-depth examination.

Using the terms of panarchy theory, the empirically identifiable environmental stressors can be described as changes within the SES corresponding to the *r* phase of exponential transformation and intensive exploitation of resources. The migration and rapid population growth of the lionfish represent an unforeseeable, initially small, externally induced process. (Local) Knowledge about the consequences remains limited and uncertain; however, it seems probable that destructive cascading effects, collapses and regime shifts of specific ecosystems may result ("revolt"). Climate change and impaired marine ecosystems play an influencing role here. The dynamics are also influenced in a number of anthropogenic adaptive ways. Interactions between the rapid, internationally managed construction along the coast, fishing, and ecosystem degradation can be seen as the transition to the

K phase, in which adaptability sinks and local subsystems approach a state of collapse. Indeed, collapsed ecosystems and regime shifts are already evident on the local scale (e.g. overfished reefs, coral bleaching, destroyed mangroves and woodland) (Ω phase). Within the realm of environmental governance there have been constructive but not necessarily successful initiatives; these include institutional reform, increased participation, and strengthened cooperation. Such approaches can often be traced to external feedbacks or reorganization processes at a higher (international) level. Overall the significance of cross-scale interaction and diversity is clear, as is the relevance of communication and the bridging of diverging, context-based knowledge, affects and belief systems. The national scale of environmental governance, on which structuring framework conditions are created or fail to materialize, seems dominant as yet. This level is, however, of limited suitability for system analysis due to its sheer size, diversity of agents, and the differing dynamics of subsystems. The deficits illustrated and local social-ecological path dependencies demonstrate that the local scale and time-tagged dynamics of change should be given greater prominence in both research and planning. This would improve the possibility of achieving new forms of adaptive management and multilevel governance in interaction with (inter-)national regulations, as well as of tackling detrimental imbalances of interests and power.

5. Conclusion

In the globally embedded development path of the small island system, resilience and adaptability seem dependent on the interaction of system-defining elements, not in the sense of determinants but rather as emerging states arising from the interaction. The case studies of Caribbean SIDS demonstrate the complexity of SES relations over different spatial-temporal scales (panarchy). Such complex processes decidedly influence the vulnerability and adaptability of these sensitive spatial systems. The empirical findings on disaster management in Grenada and environmental governance in The Bahamas make clear that, in a context of uncertainty, continual change and multiple system stressors, the factors cross-scale connectivity, numerical and functional diversity, short feedback loops, innovation, cooperative action, and emergent forms of organization contribute to an increase in system adaptability. A system collapse can open up desirable development options.

The results further show the relevance of the evolution, maintenance and renewal of context-based environmental knowledge(-reality-)systems and hybrid knowledge cultures. The (intended) production and communication of knowledge, the difficult (cross-scale) integration of different knowledge systems and knowledge claims, the role of experience, memory and affects, social/institutional learning, and inertia are important factors in strengthening social adaptability and for constructive transformation. Nonetheless, significant challenges remain for Caribbean SIDS. These include long-

term, socially, locally, and sectorally differentiated vulnerabilities; deficits in governance and communication; and the diverging and spatially-temporally bounded nature of knowledge systems. Analysis should be focused more closely on cross-scale connections and local, path-dependent contexts. It is the locally active social agents who react in an interactive manner with natural processes and stressors, and who produce and integrate environmentally specific knowledge, learning to use such knowledge only when it is kept active. Resilience and adaptability can only be increased when these processes on the microlevel and on the scale of those affected receive as much attention as emergent states on the macrolevel and on the scale of decision makers.

The empirical analysis of coupled SES and the further development of corresponding theoretical and governance concepts remain challenges for (complexity-theory-based) human-environment research. Despite weaknesses that have been the subject of controversial discussion (see e.g. Brown 2014), the resilience perspective and panarchy theory seem well suited to providing a better understanding of the social-ecological dynamics of small islands and of governance structures and processes in the context of global (climate) change. Identifying specific process phases and key (cross-scale) connections or interactions allows management intervention and thus innovation and transformation. To develop adaptive structures that take continual change and multiscale nesting seriously, a closer focus on different and competing knowledge systems, knowledge contexts, and learning processes is indispensible. Knowledge and learning are thus integral elements of complexity-based governance and management concepts for SES. Such concepts target new, flexible, and multiscale forms of interaction and emergence, such as adaptive management, co-management, institution building, polycentric or multilevel governance, and network-based governance. Approaches of this kind, which also emphasize aspects of social inequality like equitable resource access rights, seem appropriate for promoting long-term adaptability to counter continual, multiple system disturbances, and for supporting sustainable (climate-resilient) development processes in SIDS.

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Table 1: Selected external agents and modes of emergency aid and reconstruction in Post-Ivan Grenada

Agent	Mode
Antigua and Barbuda Defence Force	Security
Aquabox	n.a.
Barbados Defence Force	Security
Barbados Rotary Club	Financial aid
Bernard van Leer Foundation	Financial aid
BWIA West Indies Airways Ltd.	n.a.
Canada, Government	Financial aid
Canadian International Development Agency (CIDA)	Disaster management, emergency relief, livelihood restoration
Canadian Relief Foundation	n.a.
Caribbean Agricultural Research & Development Institute (CARDI)	Agricultural research and development
Caribbean Broadcasting Union (CBU)	Fund raising
Caribbean Community (CARICOM)	Emergency relief
Caribbean Development Bank (CDB)	Disaster management, livelihood restoration
Caribbean Disaster Emergency Response Agency (CDERA)	Disaster management, emergency relief
Caribbean Epidemiological Centre (CAREC)	Scientific evaluation
Caribbean Electric Utility Services Corporation (CARILEC)	Provision of electricity
Caribbean Tourism Organization (CTO)	n.a.
China, Government	Emergency relief, financial aid
Condor	n.a.
European Union (EU)	Financial aid
Evangelistic Churches of the West Indies	n.a.
Faith With Action, Barbados	n.a.
Food and Agriculture Organization of the United Nations (FAO)	Livelihood restoration
Guyana Defence Force	Emergency relief
Habitat for Humanity	Housing
Inter-American Institute for Cooperation on Agriculture	Agricultural recovery

(IICA)	
International Federation of the Red Cross (IFRC)	Emergency relief
International Fund for Agricultural Development (IFAD)	Rural enterprise development
International Monetary Fund (IMF)	Interest rate reduction, loans, technical assistance
Operations Mobilization	n.a.
Organization of American States (OAS)	Housing
Organization of Eastern Caribbean States (OECS)	Damage assessment, emergency relief, security
Oxfam	Emergency relief, livelihood restoration
Pan American Health Organization (PAHO)	Cash grant, emergency relief
Regional Security Services Ltd.	n.a.
Rotary Club International	n.a.
Salvation Army International	n.a.
Samaritan's Purse	n.a.
Taiwan, Government	Emergency relief, financial aid
Telecommunication without Borders	Provision of communication
Trinidad and Tobago Defence Force	Emergency relief, security
Trinidad and Tobago Solid Waste Department	Cleaning up operation
United Kingdom Department for International Development (DFID), Caribbean	Education and health recovery, emergency relief
United Kingdom Royal Navy	Emergency relief
United Nations Children's Fund (UNICEF)	Emergency relief
United Nations Development Fund for Women (UNIFEM)	n.a.
United Nations Development Programme (UNDP) (Bureau of Crisis Prevention and Recovery BCPR, Eastern Caribbean Donor Group for Disaster Management ECDG DM, Regional Bureau for Latin America and the Caribbean RBLAC, United Nations Disaster Assessment and Coordination UNDAC)	Coordination, emergency relief, livelihood restoration
United Nations Economic Commission for Latin America and the Caribbean (UNECLAC)	Socio-economic impact assessment
United Nations Educational, Scientific and Cultural	Reconstruction

Organization (UNESCO)	
United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA)	Cash grant
University of the West Indies (UWI)	Extra salaries
USAID / Office of U.S. Foreign Disaster Assistance (OFDA)	Housing, livelihood restoration
Venezuela Defence Force	Emergency relief, housing
Venezuela, Government	Financial aid, emergency relief
Virgin Atlantic Airways	n.a.
Watermark Ltd.	n.a.
West Indies Cricket Board (WICB)	Relief supplies
World Bank	Financial aid
World Health Organization (WHO)	Cash grant, emergency relief
World Relief (Disaster Response Team)	Emergency relief, housing
WRB Enterprises, Inc.	Fund raising

Source: Authors' own compilation based on various sources and authors' own survey (n.a. = no details available)

Table 2: Bahamians' answers to the question: "What comes to your mind when you think about the lionfish?"

Category	Spectrum	Percent
Poisonous/ dangerous	Caution, danger, dangerous, deadly, death, don't touch, harmful, I'm afraid, I'm warning tourists, kills, painful, poison, poisonous, poisonous species that already killed people, safety hazard for humans, scare, toxic, venomous	41
Invasive species/ predator	Carnivorous, changing nature, danger to marine organisms, death of the fishing industry, destroys other fishes, detrimental to coral reefs, eat everything, invasion, invasive pest, invasive species, no Bahamian fish, no indigenous predators, not natural to the environment, plague, predator, threat to all marine life, too many of them	16
Unknown	I'm not familiar with it, I don't know it, I know nothing about it, never heard of it	16
Food/ edible	Becomes a delicacy, cut the right parts off, delicacy in some places, eatable, edible, food, good for eating, hard to prepare it for eating, I ate it	5

	once, meat is safe, never bought one, said to be edible, you can eat it, tastes delicious, tasty, they are trying to teach people how to prepare and eat it, we don't know how to eat it, we eat it	
Beautiful	Attraction for sea life, (very) beautiful, beautiful look, beauty, cute, (very) pretty	4
Endangered species	Endangered, endangered species, save the lionfish	4
Other	Fish with lion head, good, interesting, it's ok, large, looks like a lion, part of the water, (very) rare, read about it, saw one once, saw them on TV, sea animal, spiky, strange looking fish, ugly, unsure about development, we need more education on it	15

Source: Random population survey (2011), sample size = 307, number of answers given = 294

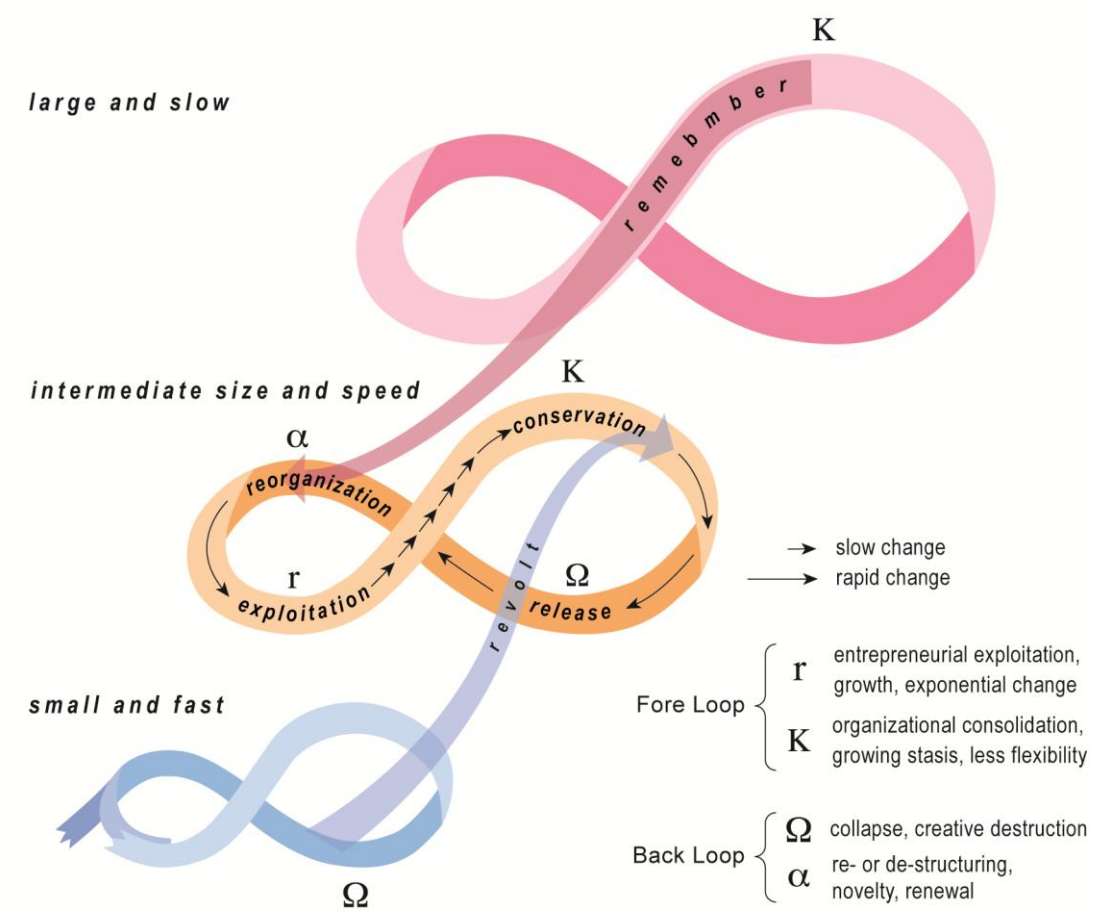
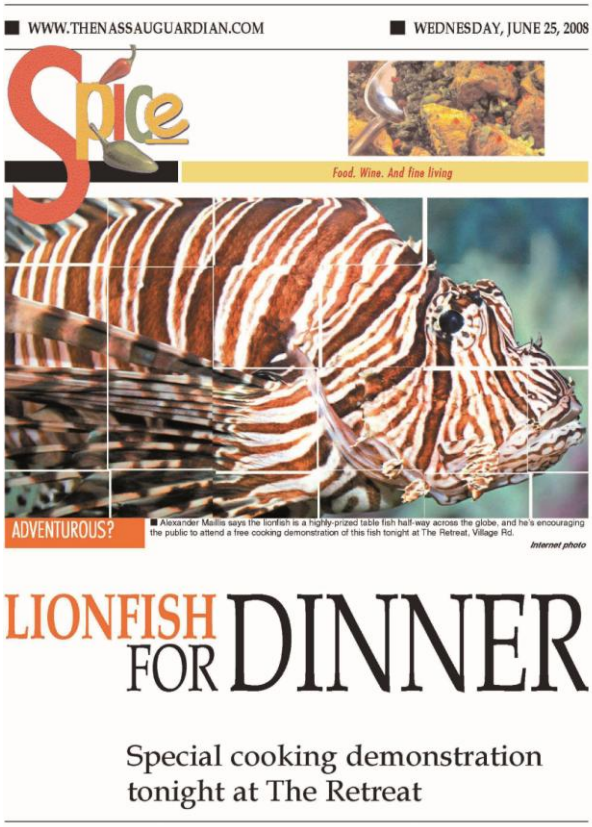


Figure 1: Heuristic models of the "adaptive renewal cycle" and "panarchy" (Source: Modified from Gunderson and Holling 2002)

Figure 2: Grenada – land use and flood hazard zones (Draft: Author 1, Source: Govt. of Grenada)

a) **Government** – Report campaign

b) **Education** – Childrens drawing



c) **Media** – "Eat lionfish" campaign

d) **Tourism** – "Lionfish derby"

Figure 3: Four forms of feedback to lionfish invasion in The Bahamas (Source: Authors' own compilation)