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Syndromes of sustainability of development for assessing the vulnerability of coupled human–environmental systems. The case of hydrometeorological disasters in Central America and the Caribbean

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Abstract

Syndrome analysis seeks to capture socio-ecological dynamics of interaction by addressing clusters of symptoms rather than isolated variables. This paper identifies the main symptoms of vulnerability to hydrometeorological disasters in Central America and the Caribbean by building on the results of 14 postdisaster assessments. A syndrome representation for this region is proposed, including 13 symptoms and their causal interrelations. These symptoms are manifested in the spheres of biology, hydrology, soil, population, economy, social organization, and knowledge. The linkages of this syndrome representation to other syndromes, its degree of generality across places, and its causal loops are analyzed and discussed. Three vicious circles increasing vulnerability to hydrometeorological disasters in the region are identified. Two of them point to the importance of breaking urbanization cycles marked by the absence of effective land-use planning which lead to the occupation of hazardous areas by poor people. The third causal loop goes far beyond the urban context and establishes ecosystem degradation and conversion as its main driving force. This latter vicious circle supports the notion that vulnerability should be understood in the context of human–environmental interactions. Overall, the paper illustrates how syndrome analysis delivers integrated, and relatively generalizable, assessments of vulnerability.

Keywords: Syndromes of global change; Vulnerability assessment; Hydrometeorological disasters; Sustainable development

1. Introduction

Vulnerability has been used in different research traditions (Adger, 2006) but there is no consensus on its meaning. However, vulnerability of a system (social, ecological, or socio-ecological) is most often conceptualized as being constituted by components that include: (1) sensitivity to perturbations or external stresses, (2) the capacity to cope or adapt, and (3) exposure to the perturbations. Sensitivity is in general (Gallopín, 2006), the degree to which the system is potentially modified or affected by a disturbance. Capacity of response, coping capacity, or adaptive capacity is the system's ability to adjust to a disturbance, moderate potential damage, take advantage of opportunities, and cope with the consequences of transformations. Exposure means in general the degree, duration, and/or extent in which the system is in contact with, or subject to, the perturbation. Exposure in most formulations is seen as one of the elements constituting vulnerability, thus making vulnerability a property of the relation between the considered system and the perturbation, rather than a property of the system; however, Gallopín (2003) proposed that vulnerability is a property of the system (and therefore one can distinguish between systems that are vulnerable and those which are not), and keep exposure as a relational property of the system/perturbation relationship.

Vulnerability is generally viewed as being specific to perturbations that impinge on the system; in other words, a

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system can be vulnerable to certain disturbances and not to others. Two other widely accepted points are: (1) the multi-scale nature of the perturbations and their effects upon the system, and (2) the fact that most socio-ecological systems are usually exposed to multiple, interacting perturbations (Turner et al., 2003). As it regards to disasters, vulnerability has been defined as the probability of damage occurrence in the economy, human life and the environment as a result of the intensity of an external event and the fragility of the exposed elements (Zapata and Caballeros, 2000).

The differences between sensitivity, response capacity, and exposure can be illustrated with a very simplified example, referring to the effects of a flood on a community. The most precarious homes are hit harder by a flood than the solid ones (sensitivity). Oftentimes, the poorest homes are located in the places most susceptible to flooding (exposure). The families with the greatest resources have a greater availability of means to repair water damage (response capacity). The magnitude of the final impact will also depend on the intensity, magnitude, and permanence of the flood (attributes of the perturbation).

2. Assessing the vulnerability of socio-ecological systems to environmental change

Vulnerability assessment emphasizes the consequences of environmental changes upon exposed human collectivities or groups (e.g. rural livelihoods, fishermen, tourist industry). The aim is to provide with options and strategies for reducing exposure and sensitivity and increasing adaptability to change. A common method for assessing vulnerability consists of building "indicator frameworks" (i.e. sets of proxy indicators and indexes) which are often aggregated into a vulnerability index (Yohe and Tol, 2002; Luers et al., 2003). A general practice is to compile data in social and environmental variables at the national or regional scale within a particular country. The resulting database is usually transformed into some sort of standard scores and mapped in order to rank the vulnerability of places and identify geographic "hot spots" (O'Brien et al., 2004). Following this general scheme, institutions such as the World Food Program have developed systems of analysis and vulnerability maps that, depending on data availability, have been very useful for improving food security (Vogel, 1997). Despite its usefulness and broad application, indicators-based methods face some important limitations.

First, there are limitations regarding the design and measurement of vulnerability indexes. On one hand, indicator selection and weighting is often supported by untested assumptions about the factors and processes leading to vulnerability (Brooks et al., 2005). Although the process of selection is normally linked to some conceptual framework, this linkage is often weak or merely descriptive (Ziervogel and Downing, 2004). On the other hand, lack of data at various scales (particularly in developing countries) leads to inaccurate calculations mostly based in literature review and approximate estimations (Villa and McLeod, 2002). To make things worse, the effectiveness of indicator frameworks are rarely tested or validated. However important these limitations may be, they are not inherent to indicator methods and can be tackled analytically and practically given enough resources.

A second, more inherent, limitation suggests that the complexity and variability of multiple vulnerability factors and stressors across places should prevent us from seeking for standard indicator frameworks. Fraser et al. (2003) argue that national-based vulnerability indicators disguise intra-country variability and use artificial or social boundaries to measure processes that actually operate within environmental borders. From this limitation, it is concluded that vulnerability indicator frameworks should either be place-based or, at least, be complemented by locally contextual indicators. As a corollary, little room would be left for comparing vulnerabilities across places.

A third limitation is that indicator frameworks not always succeed in capturing the dynamics of interaction operating within a place or system. Vulnerability can be characterized by a huge diversity of variables, as well as by their interactions, relationships, and cumulative effects. Indicator frameworks inevitably focus on a limited portion of the human–environment equation and, more significantly, are usually conformed by lists of isolated indicators that do not utilize the potential of systemic and inter-disciplinary approaches.

Despite the undeniable importance of vulnerability indicators and indexes, the outlined limitations suggest a need to expand the scope of available frameworks, methods, and tools (UNFCCC, 2004; Ziervogel and Downing, 2004; Fussel and Klein, 2006). This paper contributes to these developments by exploring the application of the syndrome approach to the analysis of vulnerability within the framework of coupled human–environment systems (Turner et al., 2003). That is, emphasizing the interactions between the human and biophysical subsystems (Polsky et al., 2003).

Syndrome analysis provides a system's methodology for operationalizing vulnerability in the context of multi-causal and cumulative stressors. We argue that syndromes are particularly useful for describing and understanding the vulnerability of coupled human–environment systems in ways that are meaningful to policy makers (i.e. as a useful approach for communicating modeling results to policy makers). We further suggest that syndrome representations might be used for discussing and designing integrated policies which address clusters of symptoms rather than isolated aspects of hydrometeorological disasters. First, we present the syndrome approach in the context of the global change research program. Second, we identify the main symptoms of vulnerability to hydrometeorological disasters in Central America and the Caribbean, and propose a generalization of their causal interrelations, into a syndrome representation, by drawing from ECLAC's comprehensive assessments of disasters in the region. Third, we analyze the resulting syndrome representation by exploring its linkages to other syndromes, discussing its degree of generality across places, and identifying causal loops. Finally, we outline some recommendations for policy and future research. Overall, the paper illustrates how syndrome analysis delivers integrated and relatively generalizable assessments which contribute to the global change research program.

3. The syndrome approach to global change research

The idea that global change complex phenomena are the result of multilayered interactions and cannot be addressed from the perspective of a single sector or discipline is part of the "hard core", in Imre Lakatos' sense, of the global change research program. Interdisciplinary systems approaches, such as the syndrome approach, are based on sets of methodological rules which are crucial for the progress of this research program. In other terms, the paper adopts an integrative approach in the sense discussed by Holling (1998) in the realm of ecological systems (as differentiated from the analytical approach). The premise of the integrative approach (or stream) is that knowledge of the system is always incomplete, that critical tests to reject invalid hypothesis are often not feasible, and that there will rarely be unanimity of agreement among peers—only an increasingly credible line of tested argument. The understanding of the complex socio-ecological systems often requires the adoption of an integrative approach in Holling's sense (Gallopín, 2004).

The origin of syndrome analysis is the "syndromes of global change" (SGC) approach developed by the Potsdam Institute of Climate Impact Research (PIK). SGC represent a global view on local and regional dynamics of environmental degradation (WBGU, 1997; Lüdeke et al., 2004). The replication of functional patterns of human–nature interaction at the global level are identified by global change experts and then illustrated and validated through specific constellations in concrete situations. The basic elements for a systematic description of syndrome dynamics are called symptoms. The term "syndrome" refers to a typical co-occurrence of different symptoms that describe complex natural or anthropogenic dynamic phenomena. Syndromes are more than causal networks of specific situations. They are repeatable patterns that can manifest in different parts of the world.

The UN Commission for Latin America and the Caribbean (ECLAC) modified the syndrome concept in order to adapt it to the regional context of sustainable development in Latin America. Unlike the "syndromes of global change," the syndromes of sustainability of development (SSD) are not limited to the global scale. The characterization of SSD proceeds from the bottom-up in that it identifies place-based patterns of sustainability of development which, if they happen to replicate in several places, can constitute a syndrome. Therefore, even if the analysis is place-based, SSD do not discard the goal of finding some meaningful degree of generality across the world in the causal complexes involved in the sustainability of development, at least in their main traits. Another difference is that the SSD are not restricted to "pathologies" as they may also include positive, healthy unfoldments. SSD are defined as functional patterns of causal interactions in coupled socio-ecological systems, or characteristic constellations of natural and anthropogenic trends of change and their respective interactions, affecting (in negative but also in positive ways) the sustainability of development.

The SSD approach is closer to the Swiss National Center of Competence in Research (NCCR) north–south conceptual framework known as "syndrome mitigation research" (Hurni et al., 2004). This framework defines "syndrome contexts" as the specific local circumstances, typically exposed to similar driving forces and underlying causes, in which a syndrome occurs (Hurni et al., 2004).

Downing and Lüdeke (2002) have proposed the use of SGC for assessing local vulnerability to land degradation and desertification. Their work suggests that the 16 SGC described in WBGU (1997) can be used for conceptualizing the linkage between local vulnerability and larger-scale processes.

We build on ECLAC's experience with both SSD, and the comprehensive assessment of disasters in Latin America and the Caribbean, in order to advance the global change research program. We propose, in Holling's sense, as an increasingly credible line of argument that a syndrome representation can explain the phenomenon of vulnerability to hydro-meteorological disasters in more than one place. In other words, a limited number of symptoms and interrelations are able to explain the vulnerability of different coupled human–environmental systems to hydro-meteorological disasters. This line of argument supports ad hoc the "hard core" of the global change research program (i.e. global change phenomena are the result of multilayered complex interactions).

4. Syndromes and vulnerability to hydrometeorological disasters in Central America and the Caribbean

Central America and the Caribbean are two of the most disaster-prone regions in the world. Hydrometeorological disasters take a huge toll in terms of human lives and damages to property, infrastructure, and services. Between 1961 and 2001, 10 large-scale hurricanes resulted in 18.816 dead, 3,783,279 displaced, and almost 14 billion US dollars in economic losses only in Central America (Girot, 2002, p. 285). Furthermore, each year hundreds of small and medium-scale events provoke, together, more damages and disruption than most large-scale events (IDB, 1999). Table 1 gives an idea of the magnitude of the disasters assessed by ECLAC in terms of human lives and housing.

The magnitude of the damage caused by the 1998 hurricane Mitch, as well as the 2004 and 2005 hurricane seasons, questioned the effectiveness of isolated emergency

Table 1
Population and housing impacts of hydrometeorological disasters assessed by the United Nations Economic Commission for Latin America and the Caribbean

Event	Assessed country	Affected population (% of total population)	Deaths	Evacuated or resettled population	Affected houses (% of the affected houses totally destroyed)
Stan (2005)	El Salvador	—	69	72,000	5533 (34)
	Guatemala	3,500,000 (31)	>669	42,941	17,760 (31)
Frances and Jeanne (2004)	Bahamas	8000 (2.6)	2	2500	6682 (10)
Jeanne (2004)	Dominican Rep.	1,855,760 (22)	27	32,554	7500 (19)
	Haiti	298,000 (4)	3000	—	54,510 (8)
Ivan (2004)	Cayman Islands	35,189 (83)	90	6,000	13,535 (4)
	Grenada	81,553 (79)	28	18,000	28,000 (36)
	Jamaica	369,685 (14)	31	>493	102,000 (0,8)
Keith (2001)	Belize	57,400 (23)	10	>5000	35,355 (10)
Mitch (1998)	Costa Rica	20,000 (0.6)	4	16,500	2135 (11)
	El Salvador	346,910 (5.7)	240	84,316	10,372 (22)
	Guatemala	730,000 (6.3)	268	105,000	26,000 (23)
	Honduras	1,500,000 (24)	5657	617,831	85,000 (41)
	Nicaragua	867,752 (19)	3,045	368,261	144,000 (35)

Sources: ECLAC (1999, 2000, 2004a–d, 2005a–c), OECS (2004).

and reparation actions. These extreme events evidenced the need for a comprehensive understanding of the reasons for the increased vulnerability of the region. The causes that make the region vulnerable are diverse and complex, but their study is essential to achieve the sustainable development of Central America and the Caribbean. The characterization of common patterns shared by the drivers and consequences of extreme hydrometeorological events through the SSD approach provides and explicit analysis of the links between sustainability and vulnerability. While loses caused by disasters pose serious problems on the possibilities for sustainable development, sustainable patterns of development can, in turn, decrease vulnerability.

4.1. Causal structure of the syndrome of vulnerability to hydrometeorological disasters

The review of the literature on the factors causing hydrometeorological disasters reveals a vast number of potential symptoms of vulnerability at the regional scale in Central America and the Caribbean (e.g. SICA, 1999; ECLAC and IDB, 2000; IDB, 2000; Pielke et al., 2003). Within the syndromes literature, Tudela (2004) identified the following symptoms of a potential syndrome of vulnerability to hydrometeorological disasters for Mexico: (1) population increase, (2) urbanization process, (3) poverty relative increase, (4) economic expansion, (5) deficient land and ecological planning, (6) non-fulfillment of legal frameworks, (7) water management, (8) elimination of natural vegetation cover, (9) reduction of insurance, funds, and other ‘‘buffering’’ financial instruments, and (10) deterioration of historic memory of disasters.

Building on ECLAC's experience in assessing disasters (ECLAC, 1999, 2000, 2004a–d, 2005a–c; OECS, 2004), we have identified 13 interrelated and recurrent factors for explaining vulnerability to hydrometeorological disasters in Central America and the Caribbean (Fig. 1): (a) poverty and socio-economic marginalization, (b) institutional and democratic weakness, (c) rapid, unregulated, and unplanned urbanization, (d) formation of slums and occupation of hazardous areas, (e) population growth, (f) migration from rural to urban areas, (g) increasing population affected by disasters, (h) ecosystem conversion, (i) erosion, (j) increasing intensity of hydrometeorological events causing disasters, (k) increasing economic damage due to disasters, (l) failure to communicate scientific knowledge effectively, and (m) expansion of agriculture.

These symptoms are to be understood as the main mechanism of a potential syndrome of vulnerability to hydrometeorological disasters in Latin America and the Caribbean. They serve as an entry point for a broader open-ended interdisciplinary discussion and negotiation with regional experts. For instance, the symptom ‘‘climatic change’’ or ‘‘increasing climatic variability’’ might be included if experts agree that the number or intensity of extreme hydrometeorological events is significantly increasing, and that this increment is not part of a natural cycle. Both social actors affected by disasters and decision makers might eventually use the results of this on-going scientific discussion for designing integrated actions and policies.

4.2. Social organization and population dynamics

The symptom of poverty and socioeconomic marginalization (Fig. 1a), together with the formation of slums and occupation of hazardous areas (d), are two main direct causes of increasing population severely affected by disasters (g). In general, economic constraints force the poor to live in precarious homes, made of flimsy and non-permanent

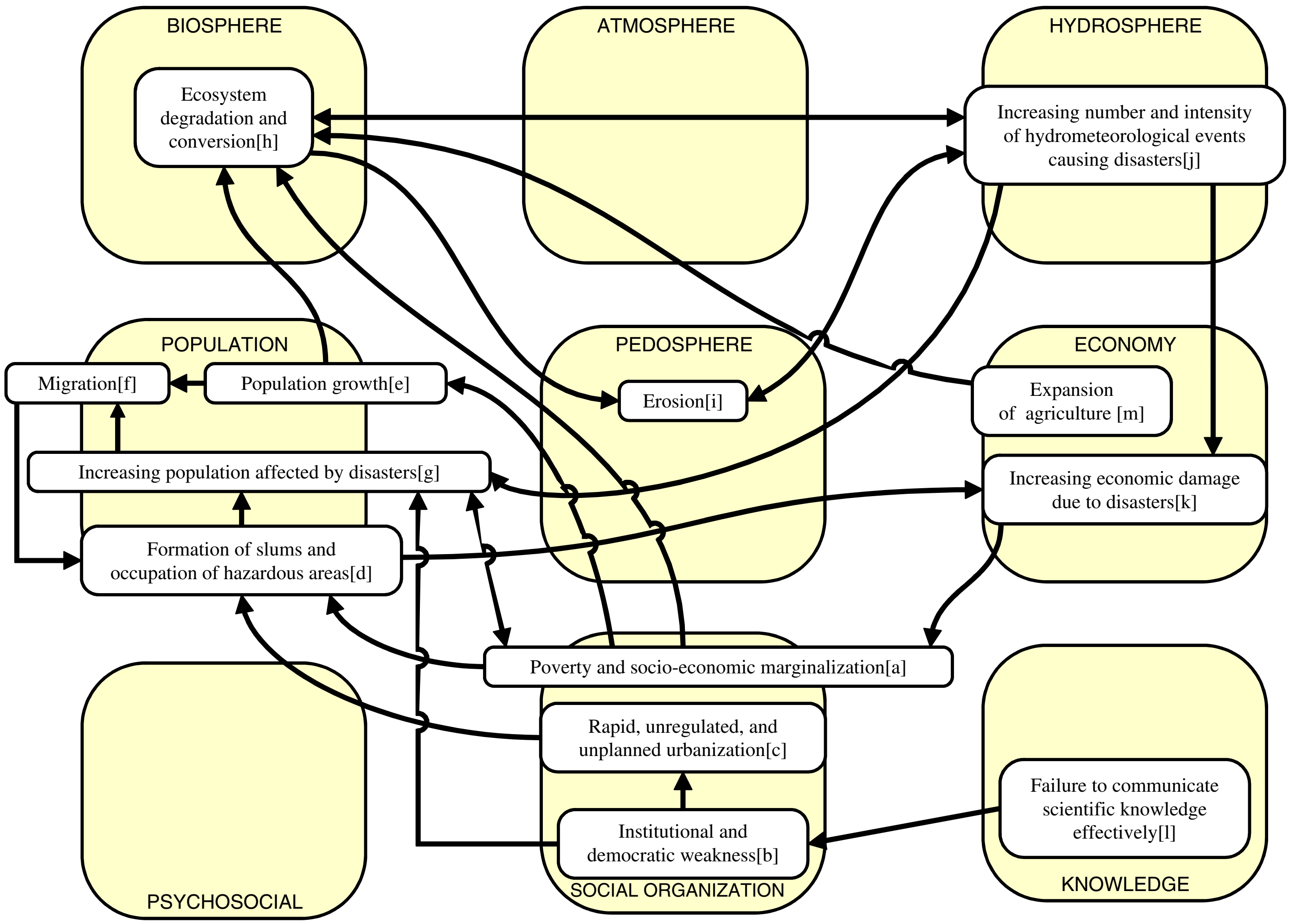

Fig. 1. Causal structure of the candidate to syndrome of vulnerability to hydrometeorological disasters in Central America and the Caribbean region.

materials. Poverty also contributes directly to increasing population affected by disasters in that it often implies lack of productive and subsisting alternatives, which tend to exacerbate the already difficult post-disaster situation. Urban poor people settle where land is cheap, including disaster-prone areas such as steep hillsides, floodplains, and floodways. In these areas, extreme hydrometeorological events are commonly accompanied by slope failure, and floods are often aggravated by blocked sinkholes and heavily silted channels. Most informal residential settlements do not include either disaster resistant construction or basic low-cost community level mitigation measures, such as retention walls and adequate surface drainage. The close link between poverty, slums, and communities being disproportionately affected by natural hazards was observed in practically all the countries assessed by ECLAC. Effectively, those dwellings that resulted completely destroyed were generally made of flimsy materials, had often been precariously built by their very owners, and many times in illegally occupied lands. The link between poverty and affected population was observed even in the relatively well-off Costa Rica or Grenada. The only exceptions were found in the wealthier Bahamas and Cayman Islands where all statuses were reported to have been generally affected alike. However, a closer and more detailed observation of the differential impacts between rich and poor on these two islands might shed a different conclusion.

An important spin-off of poverty and socio-economic marginalization (a) comes from its influence on population growth (e). Poverty is often associated with lack of women's emancipation, low school enrolment rates and the need of using children as workforce for subsistence. In turn, population growth in rural areas favors migration (f) from rural to urban areas, which in turn, promotes the formation of slums (d). This loop was observed by ECLAC's assessments across the entire region either within countries or between countries. Urban areas attract people from the country-side seeking employment and livelihoods. These people are part of the continuous internal migration streams which flow from the countryside to town. They often find themselves cut off from family ties, living in precarious circumstances and in overcrowded squatter communities. This phenomenon was observed within El Salvador, Grenada, Guatemala, Haiti, and Nicaragua. In Belize and Dominican Republic internal migratory movements are augmented by international immigration flows from poorer countries. Finally, in Cayman Islands, Costa Rica, and Bahamas the phenomenon is less relevant and is mostly fed by international immigrants.

In the case of Central America and the Hispaniola Island, increasing population affected by disasters (g) increases, in turn, rural to urban migration (f), and poverty and socio-economic marginalization (a). For instance, at the aftermath of Hurricane Mitch migration out of the most severely affected areas increased substantially both nationally and internationally (e.g. from Nicaragua to Costa Rica, and from Guatemala to Belize). In the case of richer states such as Cayman Islands, international immigration increases at the aftermath of the disaster owing to the increase in the demand of labor for the reconstruction. Regarding the effects on poverty, it was generally observed that Hurricanes caused significant economic setbacks within the activities practiced by the poorest people (e.g. artisan fishing, subsistence agriculture, employment in larger farms). Poverty was also exacerbated in urban areas due to the increased health risks associated with worsened sanitary conditions of affected populations.

Institutional and democratic weakness (b) also contributes to increasing population affected by disasters (g) both directly and through its influence on unregulated and unplanned urbanization (c). Table 2 includes an index of governance effectiveness in the region. Institutional weakness diminishes the efficiency and legitimacy of public policies to deal with emergency situations. Vulnerability is also increased by democratic failures leading to scarce possibilities of participation in public politics. In rural settings, weak institutions lead to high degrees of isolation, and lack of planning, and infrastructure. In most of Central America, the Hispaniola, Grenada, and Jamaica's rural areas, building codes are not adhered to as poor people build wood, thatched, and zinc roof structures without technical approval. Timber blockhouses are also common. Haiti is probably one of the best examples of this causal relation. Gonaives was the location most affected by Tropical Storm Jeanne. This city has been the main focus of political tensions and military confrontations since the emergence of the rebellion against the government of J.B. Aristide. In addition to specific geographic circumstances, the main observed factors explaining the catastrophe occurred in Gonaives were the combination of urban expansion and poverty. Between 1985 and 1996 the urban area of Gonaives had tripled. Unregulated development implied inadequate soil occupation, including irrigated agriculture lands. The absence of urban planning encouraged the occupation of peripheral wetlands and slopes. This anarchic form of development also leaded to the lack of water drainage systems which further aggravated this tragedy. On the opposite extreme, Cayman Islands and Bahamas count with relatively strong and democratic institutional structures and therefore this part of the syndrome is not manifested. However, it was observed that these countries should put stronger emphasis on the cross-cutting theme of disaster and risk management, in the face of increasing exposure and vulnerability. This observation indicates that it is not sufficient to have strong institutions but vulnerability management must also become a national priority. This is well illustrated by the case of Cuba, in which reducing mortality due to natural disasters is a top priority for the national government.

In many countries, disaster prevention has largely been absent from the public discourse of political leaders as well as from the electoral process. Local communities, already stressed by their daily struggle for better living conditions, have not pressured their political leaders to do more to reduce vulnerability to disaster. In addition, there is a marked inability by the scientific community to adequately convey the results of their research (l) to communities, governments, and the private sector, which consequently remain poorly equipped to interact with decision makers to address vulnerability. Resilience, when related to disaster

Table 2
National indicators related to vulnerability symptoms in the assessed countries

Country	Percentage living in slums 2001 (A)	Fertility rate (births per woman) 2002 (B)	Governance index (2002) (range −2.5 to 2.5) (C)	Annual growth rate of urban population (1995–2000) (D)	Change in forest area between 1990 and 2000 (%) (E)
Bahamas	2	2	1.38	2.2	0
Belize	63	3	−0.04	3.9	−21
Cayman Islands	—	—	1.95	3.6	—
Costa Rica	12	2	0.45	2.9	−7
Dominican Rep.	38	3	−0.42	2.7	0
El Salvador	34	3	−0.5	2.7	−37
Grenada	8	3	0.36	1.5	—
Guatemala	62	4	−0.58	3.2	−16
Haiti	85	4	−1.56	3.5	−44
Honduras	18	4	−0.73	4.8	−10
Jamaica	35	2	−0.04	1.7	–
Nicaragua	80	3	−0.85	3.3	−26

Sources: UN-Habitat Human Settlements Statistical Database (A,D), World Bank Development Indicators (B), Kaufmann et al. (2003) (C); Earth Trends-World Resources Institute (E).

preparedness, is linked to the capacity to predict, prepare for, and recover from damaging agents. But it also means the capacity to identify the thresholds which constitute the limit of a system's capacity to absorb extreme hydrometeorological events (Girot, 2002). A general recommendation coming from ECLAC's assessments is the need for the countries to improve the quality of information for disaster management and to provide training in damage assessment. In the longer term, a goal should be the development of appropriate risk reduction and transfer mechanisms in the framework of a national disaster management policy.

As mentioned above, institutional and democratic weakness (b) also promotes rapid, unregulated, and unplanned urbanization (c) characterized by inadequate land use and infrastructure development deficits. This, in turn, influences the formation of slums and the occupation of hazardous areas (d). Land-use planning and building codes are still generally inadequate or poorly enforced in most of the hazard-prone areas of the region. Land-use controls have been largely unsuccessful in preventing the proliferation of precarious settlement patterns. In some municipalities, regulations adopted to ensure better standards for residential development have even had adverse effects because they have excluded the poor from the legal land markets (Martine and Guzman, 2002). In general, ECLAC's assessments agree on the observation that the most affected areas show a development pattern characterized by an inadequate occupation of the territory and lack of urban planning and building regulations. For instance, in Guatemala 20% of the houses affected by Stan required relocation given that they were settled in particularly high-risk areas. In fast-growing tourist areas, policy failures might also relate to corrupt construction practices resulting from the non-compliance with, or non-existence of, building standards. The continuing policy of granting permission for the construction of hotels and residences in obviously high-risk areas is to be construed as an important policy failure in countries such as Belize and the Dominican Republic.

4.3. *Disasters and environmental degradation*

Another causal pattern ultimately leading to increasing population severely affected by disasters (g) has its main driver (or root-cause) in the degradation and conversion of ecosystems (h). The expansion of agriculture (m), population growth (e), and poverty and socio-economic marginalization in rural areas (a) are the main causes of land-use changes and ecosystems conversion (h). At the national and global scale, socioeconomic pressures related to international market trends, technological innovations, and institutional dynamics promote the expansion of the agriculture frontier. At the local level, lack of development opportunities compels small farmers and poor migrants to clear marginal forestlands for subsistence.

Ecosystem degradation and conversion manifests in various forms, including deforestation, overgrazing, river bank alterations, and inappropriate hillside agriculture. In coastal areas, mangrove forests, which provide natural protection against high winds and sea swells, are disappearing from hurricane-prone coastal regions (IDB, 2000). Scientific literature supports a direct linkage between deforestation and local flooding (within relatively small watersheds). However, there is no scientific evidence of a relationship between deforestation and massive flooding (Chomitz and Kumari, 1998; Kaimowitz, 2004). Ecosystems' unsustainable uses and conversion (h) also accelerate processes of erosion (i). Continuing soil erosion and the loss of vegetative cover diminishes the land's capacity to absorb heavy rainfall and leads to significant terrestrial run-off changes and the increase of river baseflows.

ECLAC assessments indicate that Haiti and El Salvador are the most likely candidates to present a causal relation between deforestation and local flooding impacts, and thus between ecosystem conversion (h) and increasing intensity of hydrometeorological events causing disasters (j) (see also Table 2 (F)). In Haiti, 25 out of the 30 watersheds in the country are completely deforested. In addition to agriculture expansion, deforestation is caused in Haiti by logging for meeting the energetic needs of the poor population. Logging for fuelwood was a main factor of deforestation around the city of Gonaives, but there is no evidence on how much this denudation of vegetation influenced the massive flooding associated to the pass of Hurricane Jeanne. In El Salvador, high population density is causing constant expansion of the agriculture frontier. Deforestation, unplanned urban development, and infrastructure construction have caused soil degradation, and the alteration of hydrological regimes. Almost a half of the Salvadorian territory has slopes of more than 15% which together with low vegetation cover and agriculture without soil conservation practices lead to high erosion rates (59 million tons of soil per year). As in Haiti, the most important watersheds are severely deforested. In both countries, the areas of underground water recharge are altered and present decreasing infiltration rates due to land-use changes.

The linkage between ecosystem degradation and disasters intensity was also presumed in the case of relatively big islands such as Jamaica, where land-use changes, including inadequate settlement patterns, have greatly altered the rainfall–runoff relationships so that hydrographs tend to rise more quickly and flood flows are more frequent. In Belize and some Caribbean countries, the degradation of important coastal ecosystems have significantly aggravated the vulnerability of coastal infrastructure to high-energy wave action and storm surge because natural barriers such as mangroves, sand dunes, or coral reefs have lost much of their protective functions.

Both ecosystem conversion and erosion make the soil more susceptible to the destructive capacity of landslides and floods and, therefore, augment the intensity of hydrometeorological events causing disasters (j). In El Salvador the increase of sediments due to high erosion rates dramatically reduced riverbeds and obstructed natural drainage systems. Flash floods were the leading cause of death and destruction during Hurricane Mitch (Girot, 2002). Both in Mitch and Stan, landslides and mudflows hit hillside small farmer areas the hardest, while floods were most prevalent in the lowlands and floodplains where most of the large-scale farming takes place. Both in El Salvador and Guatemala, slope failure and mudflows caused major damage to farms, housing, roads, infrastructure, and housing. Landslides also blocked roads, and disrupted access to entire communities.

The increasing number and intensity of hydrometeorological events causing disasters (j), in turn, both influences the buffer capacity of ecological systems (h), and increases the rates of erosion (i). For instance, environmental degradation caused by prior hydrometeorological extreme events contributed to aggravate the effects of Hurricane Mitch. More specifically, the 1997 ENSO had caused droughts and forest fires, with the loss of 1.5 million hectares of forest in Central America. Thus, extreme droughts and fires heightened the subsequent devastation of Mitch by exposing the soil to erosion, reducing infiltration capacity, and incrementing the amount of forest debris blocking natural drainage channels. Mitch, in turn, further weakened the environment's capacity to mitigate the effects of subsequent extreme natural events due to both direct effects on soil erosion, and indirectly by displacing population groups and thus increasing poverty. In the case of the Hurricane Stan in Guatemala the estimated soil erosion was 9,027,483 tons, which corresponds to 12.7% of the annual erosion.

Accumulative impact from previous disasters has been also observed in the case of coastal ecosystems in the Caribbean, where free standing corals, coral branching forms, and mangroves are often tossed out, broken, or seriously damaged. For instance, in Belize severe coastal erosion was reported after Hurricane Keith as well as damages from silting and wave action to reef barriers and seagrass beds.

4.4. Economic dimension

Increasing intensity of hydrometeorological events causing disasters (j) leads to increasing economic damage due to disasters (k). Housing is often the most affected sector in Central America and the Caribbean, followed by the infrastructure sector. However, significant losses are always produced in agriculture, tourism, other productive sectors, and ecological services. Table 3 provides an idea of the magnitude of the economic damage associated to hydrometeorological disasters in the region. In turn, economic damage (k) affects poverty and socio-economic marginalization (a). In fact, the impacts of hydrometeorological disasters on the productive capacity of already debt-ridden, impoverished nations foster secondary catastrophes for public health, unemployment, and the general living conditions of poor people.

The formation of slums and occupation of hazardous areas (d) also increases economic damage due to disasters (k). For instance, through the obstruction of riverbeds by the debris from removed slums' constructions and dumped rubbish, which subsequently block drainage channels that might evacuate the excess of rain. In the Caribbean countries and Belize, the concentration of tourism-related infrastructures in coastal areas is increasing the economic damage caused by storm surge, wave inundation, and strong winds. Tourist facilities are often located in low-lying areas due to the lack of both well-informed zoning and rigid enforcement of planning recommendations by government authorities.

Table 3
Economic impacts of hydrometeorological disasters assessed by the United Nations Economic Commission for Latin America and the Caribbean

Event	Assessed country	Total economic damage in million US$	Total economic damage as percentage of GDP	Intensity when hit or approached the country	Decrease of estimated GDP growth after disaster (−%)
Stan (2005)	El Salvador	355	2.2	Tropical storm	~0
	Guatemala	988	3.4	Tropical storm	~0
Frances and Jeanne (2004)	Bahamas	551	10.5	Category 4	1.7
Jeanne (2004)	Dominican Rep.	296	1.9	Tropical storm	~0
	Haiti	265	7	Tropical storm	1.1
Ivan (2004)	Cayman Islands	3,432	183	Category 4	4.3
	Grenada	889	212	Category 3	1.4
	Jamaica	595	8	Category 4	0.7
Keith (2001)	Belize	280	45	Category 4	1
Mitch (1998)	Costa Rica	92	1	Tropical storm	~0
	El Salvador	398	3.6	Tropical storm	0.2
	Guatemala	748	4.2	Tropical storm	1.3
	Honduras	3794	82	Category 5	2.4
	Nicaragua	988	49	Tropical storm	0.6

Sources: ECLAC (1999, 2000, 2004a–d, 2005a–c), OECS (2004).

5. Causal loops, combination with other syndromes, and degree of generality across places

Our syndrome proposal suggests the existence of three vicious circles or causal loops increasing vulnerability to hydrometeorological disasters in the region.

Two of these causal loops are focused on the dynamics occurring within urban poor areas ($a \rightarrow d \rightarrow g \rightarrow a$), and ($a \rightarrow d \rightarrow k \rightarrow a$). They point to the importance of breaking urbanization cycles marked by the absence of effective land-use planning which lead to the occupation of hazardous areas by poor people. The second loop is not as relevant as the first one due to the weak relationship that might exist between the formation of slums and the increasing economic damage due to disasters ($d \rightarrow k$). Poverty and socioeconomic marginalization is a central symptom closing these loops, which reinforces the generally accepted idea that poverty is a central driving force of vulnerability. This diagnosis is consistent with Martine and Guzman's scrutiny of the limitations of market mechanisms for steering urban developments which reduce vulnerability. As aptly stated by these authors: "[C]urrent mechanisms that organize land markets, land speculation and serendipity, cannot be trusted to provide social and environmental solutions. Should they continue to prevail, the next disasters will have progressively more serious consequences than Mitch did" (Martine and Guzman 2002, p. 59). Breaking these vicious circles might need to reconsider the economic incentives and planning tools which have proven to be ineffective for avoiding that a large part of the population settles in hazardous areas.

The third causal loop goes far beyond the urban context and establishes ecosystem degradation and conversion as its main driving force ($h \rightarrow j \& (h \rightarrow i \rightarrow j) \rightarrow k \rightarrow a \rightarrow h$). This vicious circle supports the notion that vulnerability should be understood in the context of human–environmental interactions. In this particular case, biospheric, pedospheric, and hydrospheric factors are found to be causally related with the economic, social organization and population spheres. Addressing this kind of vicious circle requires the integration of research, policies and institutions which often operate within separate domains in an uncoordinated manner. This causal loop indicates that vulnerability mitigation strategies need to address whole causal clusters rather than focusing on single symptoms. Breaking this vicious circle is fundamental for stopping the cumulative impacts of environmental degradation leading to social and economic vulnerability increase.

A more thorough comprehension of these three vicious circles can be achieved by looking at some of the causal complexes described within ECLAC's national reports on SSD, the WBGU's SGC, and the NCCR North–South pre-synthesis project report.

The two causal loops embedded in urban areas are closely related to: (1) the "Metropolization" causal complex described for Colombia by Escobar-Ramírez (2004), (2) the "Favela" SGC (Kropp et al., 2001), and (3) the core problem of the urban syndrome context described by Barrera et al. (2003). These syndrome-oriented studies explore in detail the root causes of the informal processes of land occupation, housing construction, job creation, and service and infrastructure provision that absorb the avalanches of migrants flowing to urban areas in Latin America. They show the multiple dimensions of urbanization including its connection to the rural realities and the historical processes of socio-economic exclusion which shape the growth of cities in Latin American countries.

The details of the third causal loop of the vulnerability causal complex are further developed by: (1) the over-exploitation SGC (Cassel-Gintz and Petschel-Held, 2000), (2) the core problems detected in the highland–lowland syndrome context in Central America (Barrera et al., 2003), and (3) the "vegetation-cover change" causal complex described for Mexico by Tudela (2004). For instance, these syndrome-oriented studies illustrate how the root and proximate causes of ecosystem degradation and conversion are related to the combination of: (1) the expansion of agriculture and cattle ranching, (2) biodiversity loss, (3) soil degradation which leads to the deforestation of new areas for cultivation, and thus constituting a vicious circle of environmental degradation, (4) conflicts over land tenure and land titling, (5) intensification, (6) dismantlement of traditional social networks and loss of cultural identity, (7) population growth, (8) land abandonment, and (9) hydrological regime changes, among others. As a corollary, (10) impoverished peasants choose to migrate to cities where they may survive in precarious conditions.

The causal complex in Fig. 1 is still a preliminary candidate of a SSD of vulnerability to hydrometeorological disasters for Central America and the Caribbean. Its consolidation will require further evidence through interdisciplinary workshops with regional experts and further literature review. This type of consolidation was carried out in the case of the Argentine Pampas region (Manuel-Navarrete et al., 2005). We hypothesize that such process would lead to a similar version of the causal complex described here that could be generalized to most Central American countries as well as some Caribbean countries such as Haiti, Dominican Republic, and Jamaica. However, significant symptoms of this syndrome do not manifest in the case of smaller Caribbean islands and Cuba. For instance, in the case of Cuba strong institutions backed by sound scientific knowledge (which permit effective early warning and evacuation systems) are dramatically reducing the mortality rates caused by disasters. In the case of some small Caribbean islands, poverty and migration are not main driving forces of vulnerability, but isolation, the size of the economy, and greater exposure to the effects of global warming (e.g. sea-level rise) play important roles.

6. Recommendations for policy and future research

We explored the roles that the SSD approach can play to insert vulnerability reduction as part of a systemic and comprehensive vision of sustainable development. The identification of a SSD of vulnerability contributes to understanding the causes of disasters in an integrated and coherent manner. The vulnerability SSD proposed in this paper needs to be considerably reviewed and refined in order to check the relevance of its symptoms and interrelations and its actual degree of generality across places. However, this first account provides a synthesis for envisioning the crucial interrelations underlying vulnerability to hydrometeorological disasters in Central America and the Caribbean.

One of the main advantages of SSD representations is to provide an easily communicable and eventually generalizable account of the relationships between patterns of development and vulnerability to environmental changes. Even if some degree of contextualization (i.e. adaptation to specific circumstances of place) will always be required, SSD provide general recommendations for integrated policy to reduce vulnerability across places dealing with the same syndrome.

This paper illustrates how the identification of vicious circles (or socio-ecological traps) that increase vulnerability to disasters can help to design integrated actions and solutions addressing clusters of symptoms rather than isolated problems. For instance, the first vicious circle identified in Fig. 1 ($a \rightarrow d \rightarrow g \rightarrow a$) shows the need to combine urban planning regulations with policies for reducing poverty and socio-economic marginalization. In addition, it calls attention to how this vicious circle is affected by: institutional weakness (both before and during the emergency situation), ineffective communication between science and government institutions, and migration. We argue that efforts directed to just one of these symptoms will be less effective than more integrated strategies. Depending on the circumstances, mono-symptomatic policies may fail completely due to the pervasiveness of the rest of symptoms sustaining the syndrome.

Syndrome diagrams can also show closed loops that can be positive (virtuous circles, or sustainable developments). For instance, in some Caribbean countries the effective implementation of early warning and evacuation systems has drastically reduced mortality due to disasters. These early warning systems are backed by government and scientific effective institutions, and often go together with policies for reducing socio-economic marginalization and promoting well-organized urban growth.

The actors caught on, or promoting, these closed loops can be identified and policies oriented to either make them assume responsibility, free them from the vicious circle, or support them in reproducing the positive aspects of the virtuous circle can be formulated. For instance, the syndrome may help to shed light on the relationship between particular acts of corruption in urban areas and the loss of human lives. Political and economic settings or conditions promoting or hindering sustainable development can also be identified through syndrome analysis and policies can be designed for reducing a region's vulnerability.

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