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Full-cost accounting of coastal disasters in the United States: Implications for planning and preparedness

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ABSTRACT

As coastal disasters become more frequent and costly, a full assessment of costs becomes more important. This paper aims to identify costs of coastal disasters to human, social, built and natural capital and their associated services at the local site of a disaster and in the regions and nations that respond for relief and recovery. The spatial and temporal magnitude and scale of costs is captured differently in typical cost accounting and a more comprehensive approach, full-cost accounting. The difference between these approaches will be demonstrated using Hurricane Katrina (2005) as a case study, though we do not attempt to perform a full-cost accounting of this actual event. We examine how disaster planning and preparedness becomes more cost effective when the full cost of disasters is calculated. A full-cost accounting of coastal disasters sets the stage for rigorous comparisons of strategies for post-disaster development. The rudimentary analysis of this paper indicates that continued population development as well as the maintenance of current settlements in particular regions along the coasts may not be in the national interest. In this way, full-cost accounting could help reduce vulnerability to future disasters.

1. Introduction

Coastal disasters are affecting more people and communities every year. This is due to the increased frequency in natural disasters along the coast confounded by the migration of people from in-land areas to coastal regions around the world (Martinez and Intralawan, 2007-this issue). Local government and business officials must balance costs for planning and preparing for disasters with more immediate demands on resources. The cost of disasters has been widely reported based on the costs to human capital (lives lost) and built capital (public and private infrastructure) at the local level (Boswell et al., 1999), although some efforts have been made to estimate local public costs for recovery and response during hurricanes (Boswell et al., 1999). In many cases, these costs have not proven high enough to lead local or federal decision makers to implement sufficient mitigation actions in order to reduce vulnerability and damage. Furthermore, in the United States policies at the federal level encourage resettlement in particularly vulnerable coastal areas rather than migration inland (Bagstad et al., 2007-this issue).

In this paper, we examine the *full costs* related to coastal disasters including losses to natural, social, human and built capital and the often uncounted or immeasurable costs of services provided by all four capitals in disaster relief and recovery. The specific objectives of this paper are as follows: (1) identify salient costs to built, human, natural and social capital resulting from coastal disasters; (2) identify salient costs of services provided by each capital in disaster relief and recovery; (3) examine the importance of spatial and

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temporal scale in disaster accounting; (4) differentiate costs captured by typical and full-cost accounting; and (5) examine policy implications of performing a full-cost accounting of disasters including pre-disaster planning, demographic policy and allocation of funds during recovery.

Although we have not attempted to conduct an actual full-cost accounting for any one disaster, this paper is clearly framed by the recent hurricane activity on the Gulf Coast. Where possible, we have included values for Hurricane Katrina in our discussion.

2. Disaster cost accounting methodologies

Cost accounting typically selects as its object a particular product or process, a business or organization or the activities of an entire country or industry (Bebbington et al., 2001). It is typically applied to human activities for which both benefits and costs can be assessed, and for which externalities are often ignored. Application of this method to disasters is unique in that the 'offender' is a natural phenomenon, although human disturbance and policy may accentuate resulting losses. It is important to keep in mind that the ultimate purpose of accounting is to be informative; thus, we argue that decisions made in disaster cost accounting must keep in mind how the analysis will be used in policy decisions.

2.1. *Typical disaster cost accounting*

Although there is no well defined, accepted method for disaster cost accounting in the literature, the methods typically used to predict costs including those developed and implemented by the National Institute of Building Sciences (NIBS), and the Federal Emergency Management Agency (FEMA) focus on property loss, public and private infrastructure loss, agricultural losses, casualties and economic losses due to unemployment. Insured losses are often estimated separately by insurance companies (Boswell et al., 1999). A model developed by Boswell et al. (1999) aims to predict public costs of response and recovery including debris removal, protective measures, as well as repair of public infrastructure (roads, signs, parks, buildings, utilities, etc.) which despite accounting for 75% of total public expenditures resulting from hurricanes are not typically included in the FEMA or NIBS models (Boswell et al., 1999). We refer to all of these accounting methods as 'Typical Cost Accounting' to distinguish what is typically done, from what might be encouraged under a full-cost accounting or social cost accounting framework.

2.2. *Expanding the analysis: full-cost accounting*

Just as there is no clear definition of traditional or typical cost accounting in the literature, it is difficult to find a clear definition in the ecological economics literature for 'full-cost accounting,' which also has been described as social cost accounting or true cost accounting. Social cost benefit analysis sums the total benefits and the total costs to a society of a particular event, policy, or action (Harberger, 1984). In describing a full-cost accounting approach for disasters we clearly aim to expand what is typically accounted for, however, the guidelines to do so appear to be vague and problem specific. We draw significant insights from the Cost–Benefit Accounting (CBA) literature which aims to account for all the effects of a project on society, regardless of who is affected and whether the impacts can be captured in monetary units (Sugden and Williams, 1978). Indeed, the framework laid out by CBA provides for a full social cost accounting that incorporates all of the impacts to society of an event or proposed project including those captured by markets and those that are clearly non-market costs and benefits. The framework of CBA incorporates the challenges of uncertainty, impacts over time, impacts of different types and units and effects on various groups of people (Sugden and Williams, 1978). In practice, however, CBA is often criticized as being too limited in scope particularly with respect to intergenerational accounting, distribution impacts, indirect effects and non-market goods and services.

Despite the lack of clear definitions for typical and full-cost accounting, we must differentiate and justify the type of exercise proposed in this paper from that which is typically done following a disaster. Again, drawing from the CBA literature we are presented with three distinctions that must be considered when deciding how to identify and classify impacts in a cost accounting exercise. First, we must distinguish between real and pecuniary effects. The former refers to effects that result in the actual loss or gain of valued resources, whereas the latter refers to transfers resulting from price changes that increase revenues for some people but harm others (Campen, 1986). For example, the loss of buildings is measured as a real loss whereas the change in property values of remaining structures, due to their proximity to the disaster, is measured as a pecuniary value. In the case of disasters, typical cost accounting focuses on real impacts and ignores pecuniary effects. In the context of ecological economics, which recognizes distribution as a core issue of concern, we must include pecuniary effects in a full-cost accounting. Attempts to incorporate distributional aspects of a social cost benefit analysis have been incorporated into elaborate distribution weighting methods (Harberger, 1984). Since we do not attempt to place monetary values on any of the costs or benefits discussed in this paper, we avoid this problem. Nonetheless, there are excellent examples of pecuniary benefits especially in the region surrounding a local disaster zone. However, it is important that the relatively higher impact of disasters on the poor be well recognized (Masozera et al., 2007-this issue).

The second distinction in cost accounting requires attention to direct versus indirect effects (Campen, 1986). Direct effects are much easier to account for and in the case of disasters focus on local damage and costs of rebuilding in the near-term. Indirect effects, many of which occur at the regional, national or even international scale and may extend far into the future, must be incorporated in a full-cost accounting of a disaster. As with any accounting of indirect effects, a boundary must be set in order not to include the exponentially increasing list of indirect impacts which are often poorly documented, difficult to assess and may have negligible costs. Drawing these boundaries can be quite difficult, though we could gain insight from the Life Cycle Assessment (LCA) literature in particular when rebuilding costs are calculated. Life cycle assessment (LCA) is a multi-parameter tool that was developed under ISO 14000. It provides an evaluation of the direct and indirect environmental, economic and technological costs of a product or service throughout its lifetime from ‘cradle to grave’ (Lindfors et al., 1995).

Finally, decisions must be made about whether to include intangible effects in addition to tangible effects. The former are goods and services which are not traded in markets compared to the latter for which market prices exist (Campen, 1986). Typical cost accounting focuses primarily on tangible effects although some intangible effects, such as human casualties, are also incorporated. A full-cost accounting must attempt to value all capital losses including social, human and natural capital and their associated non-market goods and services.

There are multiple challenges posed by any cost accounting exercise, and we do not pretend to ignore the assumptions, uncertainties and methodological challenges. Among these are assumptions about where to limit the analysis, acceptance and reporting of uncertainty and precision, data availability, incompatible units of reporting and limited precedent for conducting full-cost accounting of disasters in the literature. However, we remind the reader that disaster cost accounting should foremost be used to inform decision makers and resulting policies related to disaster recovery and future mitigation. Thus, despite these challenges, every attempt must be made to quantify the true impacts of disasters on society such that better decisions can be made.

2.3. *The ecological economics approach to capital stocks and services*

In economic terms, capital refers to a stock that yields an economic output over time (Goudy, 2000). Traditional economics primarily uses capital to refer to manufactured or built capital, meaning a manufactured means of production, including built infrastructure, machinery, land, etc. (Prugh et al., 1999). Human capital is considered to be the stock of knowledge, labor and skill embodied in the labor force. The focus on built and human capital is reflected in typical disaster cost accounting that focuses primarily on losses to built infrastructure and human lives.

Ecological economics extends the definition of capital to include other stocks that yield beneficial flows to society over time including social capital, natural capital and other dimensions of human capital (Fig. 1). Social capital can be described as “…the everyday networks, including many of the social customs and bonds that define them and keep them together…” (Halpern, 2005). Natural capital includes natural resources, renewable and non-renewable, that provide ecosystem services over time (Goudy, 2000; Costanza et al., 1997). Ecological economists include as a form of human capital not only the knowledge and skills embodied in the labor force, but in the entire population recognizing that much of the work conducted by society is not captured by the labor force in terms of GDP (Anielski and Rowe, 1999).

Neo-classical economics assumes that capital stocks are substitutable. Ecological economics rejects this idea by recognizing the profoundly different services provided by each type of capital to society. Indeed, the concept of strong (vs. weak) sustainability is built upon the assumption that we must learn to identify critical types and thresholds of each of the four capitals (Pearce and Atkinson, 1993; Daly and Farley, 2004; Ekins et al., 2003). The yields derived from these four forms of capital are many and cannot all be included here. However, they include material flows for consumers derived from built capital, ecosystem goods and services provided by natural capital that sustain life (Costanza et al., 1997), labor (paid and volunteer), knowledge and skills provided by human capital (Davenport, 1999) and resilience to disturbance and community actions delivered through social capital (Halpern, 2005; Fig. 1).

Disasters clearly lead to the direct loss of all four types of capital, especially at the local scale. Most disaster cost estimates focus on losses to built capital, human losses (deaths) and paid

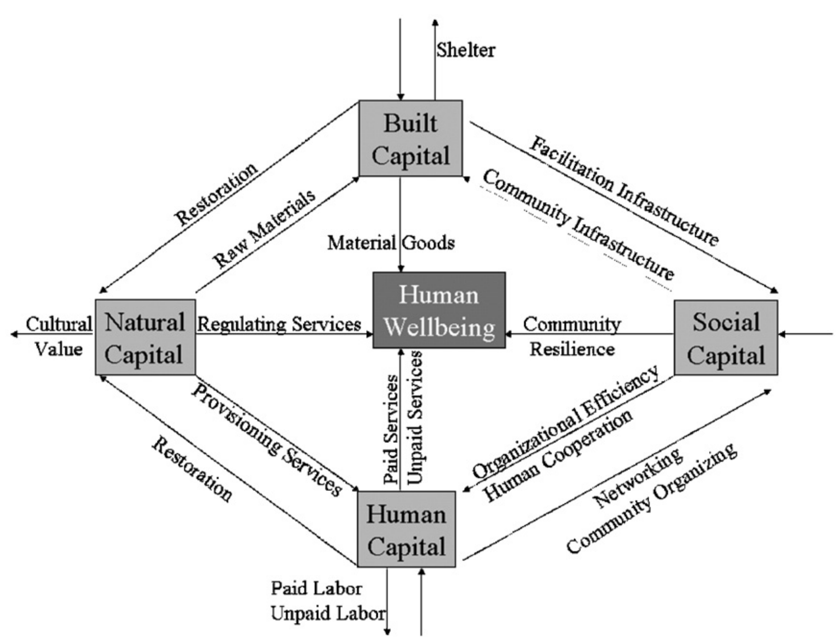

Fig. 1 – Capital stocks and flows to human well-being.

labor costs of relief and rebuilding (a flow from human capital). A full accounting of the loss of all four forms of capital will illustrate the devastation of disasters at a scale not currently captured by typical cost accounting. The approach taken in this paper is to examine all of the losses to built, social, human and natural capital as well as the costs of drawing on services provided by these stocks that serve in coastal disaster relief, recovery and rebuilding.

2.4. The monetary valuation debate

Within the field of ecological economics, a lively debate is ensuing around the methods of valuation used to account for each of the four types of capital. Many researchers are in favor of monetary valuation, primarily because it provides a convenient and universal unit of measure that helps us to compare the relative importance of different capital stocks, or in the case of disasters the value of their loss. Others argue that certain types of capital stock do not belong in the realm of monetary valuation. For example, in accounting for human capital, data are typically reported in terms of number of people killed, injured or otherwise impacted. Attempts to place monetary value on these losses conflict with the ethics of society to regard human life as invaluable. Similarly social capital rarely is reported in terms of monetary valuation, in part because the methods to do so require so many assumptions but also because the value of these stocks may go beyond monetary values and may simply be immeasurable. Valuing natural capital presents similar challenges, although some researches argue that at least the tangible, quantifiable and substitutable goods and services provided by ecosystems can indeed be valued either by asking people how much they are willing to pay for such services (contingent valuation), or by estimating the cost to provide the same services with built capital (replacement cost). A good example of this might be valuing storm protection provided by wetlands by calculating the cost of a storm protection wall or levee designed to provide the same protection. This method of damage cost or replacement cost often does not capture the full value of natural capital since any one source of natural capital (i.e. a wetland) yields many goods and services simultaneously, only one of which is captured using replacement cost. Many of these services do not have replacement costs or built capital substitutes, putting them again into the realm of the immeasurable. In addition, damage costs measured in absolute dollars do not capture the relative losses which are often much higher for the poor (Masozera et al., 2007-this issue). Moreover, monetary valuation perpetuates the concept of universal substitutability and notions of weak sustainability.

For the purposes of this paper, we will report all values in terms of the units actually reported in the literature. In this way, we leave open the possibility for others to place monetary values on the capital stocks and services we have identified, but still provide full transparency as to the actual quantifiable losses in the four stocks reported at the time of this writing for Hurricane Katrina.

3. Costs associated with coastal disasters

3.1. Spatial scale and distribution of disaster costs across capital stocks and flows

A full-cost accounting of disasters requires us to look beyond the local impacts of a disaster to the regional, national and often international scale. In so doing, we must include not only losses to capital stocks, but also relief costs which typically come as a flow from one or more of the four capital stocks. Although the direct costs of coastal disasters are highly localized in the disaster zone itself, relief costs are usually borne by communities not directly affected by the disaster (Fig. 2).

In our analysis, we have divided the costs of a disaster into those direct losses to the four capital stocks (Table 1), that typically take place at the local scale and draw on services provided by the four capitals often from outside the disaster

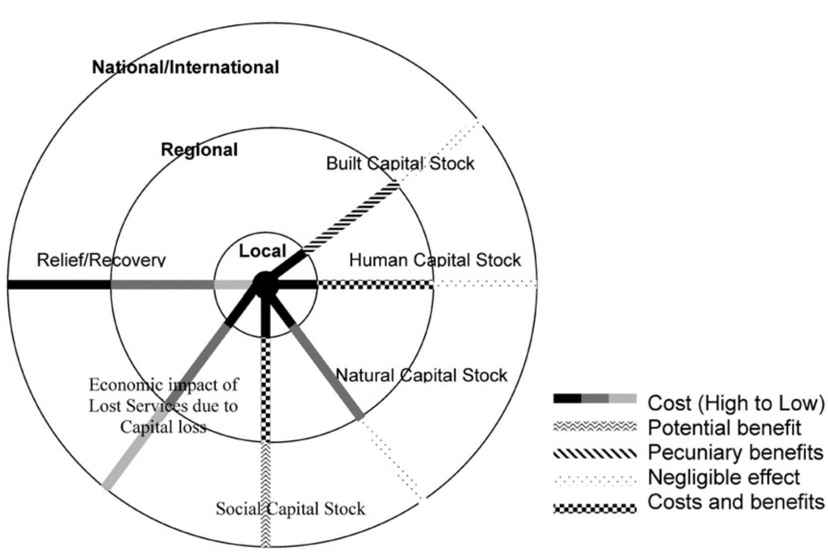

Fig. 2 – Spatial scale and distribution of disaster costs and benefit.

Table 1 – Summary of losses to capital following a coastal disaster

	Local	Regional	National – International	Hurricane Katrina
Built Capital				
Agricultural infrastructure & property	-			$200 billion estimated total damages (King 2005)
				$40-$60 billion insured losses (King 2005)
Residential property	-			$15-$29 billion: personal (Insurance Journal 2005)
Commercial property	-	0 (+)		$19-$25 billion: commercial (Insurance Journal 2005)
Public infrastructure	-			$4-$6 billion: marine and energy (Insurance Journal 2005)
Industrial property and infrastructure	-	0 (+)		$18 billion requested in S.1765 for port rebuilding
Human Capital				
Deaths	-			1,383 people (Knabb et al. 2005)
Injuries	-			
Loss of school time	-	-		17 universities and colleges closed (CampusRelief.org)
Reduced school performance	-			
Resettlement of	-	+/-	+/-	
Loss of public health services	-	-	-	100 health centers affected $1 billion requested í05 in S.1765
Reduced individual ability (mental health)	-	-	-	
Natural Capital				
Wetlands	-	-		
Barrier Islands				
Forests	-	-		5.8 billion board meters damaged (19 billon board
Land loss (sheared marsh)	-	-		
Habitat loss for oysters				99% oyster mortality (LDFW 2005)
Fisheries	-	-		Estimated $1.1 billion in losses for 2006 (LDFW
Wildlife	-			16 federal wildlife refuges were damaged (aprx.
Crop losses	-			$1 billion in total losses (Schnepf and Chite 2005)
Livestock losses				$102 million in poultry industry (Schepf and Chite 2005)
Toxic contamination	-	-		24.6 million liters (6.5 million gallons) of oil spilled (EPA 2005)
Social Capital				
Social support	-/+	+	0	$1 billion requested for community loans in S. 1765
Linking social capital	-	-	-	$50 billion requested for community development
Bridging social capital	-			LA FY05 Cut $2,177,521 Vocational Rehab Services
Displaced social networks	-			LA FY05 Cut $6,868,222 to Office of Urban Affairs
Funds lost to general recovery	-	-	-	LA FY05 cut $4,134,788 to Office of Rural Development

The symbols '–', '0' and '+' indicate costs, no impact or benefit, respectively. Increases in pecuniary value, rather than physical stock, are captured in parentheses. Note that although data exist for many forms of capital, only those grayed are accounted for in aggregated typical disaster cost accounting.

zone (Table 2). Furthermore, in some cases, regional communities may actually benefit from a disaster as evacuees and relief funds are funneled into a region, benefiting surrounding communities (Fig. 2). Pecuniary values such as real estate values grew dramatically in the counties surrounding New Orleans following Hurricane Katrina (CNN, Sept 11 2005). Certain industries may also benefit from a disaster, such as the oil industry whose prices went up dramatically after Hurricane Katrina (Schnepf and Chite, 2005). This is a perverse reaction by the market at a time when housing, food and energy are in greatest need by people afflicted by disaster.

3.2. Temporal scale of disaster recovery: importance of discount rate

It is also important to consider the time scale of capital losses in calculating damage costs. Recovery of the four capital stocks will occur at different rates, depending upon the scale of loss, investment in rebuilding and the nature of the capital itself. Whereas built capital recovery is typically limited solely by available human labor and construction materials, natural capital recovery may be limited by natural processes some of which can not be enhanced by investment. Typical cost accounting ignores long-term costs to the region, reflecting the relatively short time period required to replace built capital. Incorporating residual or long-term costs is especially important when examining natural capital. For example, one impact on natural capital after Hurricane Katrina was the release of many toxic contaminants into Lake Pontchatrain and the nearby estuary. Although there have not yet been any documented effects on aquatic life (USEPA, 2005a), the costs to fisheries and ecosystem health could extend far into the future. Furthermore, impacts on agricultural production may also extend into the future.

Accounting for losses that extend into the future requires us to consider whether the cost of delayed recovery should be discounted, when compared to present costs of recovery. Intertemporal discounting, applied to individuals and market

Table 2 – Services provided, primarily from outside the disaster region, in response to coastal disasters

	Local	Regional	National – International	Hurricane Katrina
Built Capital				
Buildings used for shelters		-		1,100 shelters used (ARC 2005)
Trucks and machinery	-	-		
Material supplies for clean up		-	-	
Disruption of trading in coastal ports	-	-	-	
Disruption of energy supply from Gulf of Mexico	-	-	-	
Human Capital				
Loss of productive work due to built capital losses	-			106,547 unemployment claims (BLS 2005)
Loss of productive work in other sectors due to volunteerism	-	-	-	213,630 volunteers responded to Katrina for 2-3 weeks each (ARC 2005)
Cost of paid work for clean-up, relief, recovery	-	-	-	
Natural Capital				
Waste disposal of damaged property		-		19.96 million metric tons of debris (22 million short tons) (LDEQ 2005)
Food		-	-	26.7 million hot meals and 23.8 million snacks (ARC 2005)
Water		-		
Clothing		-	-	
Social Capital				
Funds donated for clean-up				
Volunteer time donated				213,630 volunteers responded for 2-3 weeks each (ARC 2005)

The symbols '–', '0' and '+' indicate costs, no impact or benefit, respectively. Note that although data exist for many forms of capital, only those grayed are accounted for in aggregated typical disaster cost accounting.

goods is typically justified for three reasons: (1) the pure time rate of preference which accounts for uncertainty and impatience in valuing the present over the future; (2) the opportunity cost of a lost investment opportunity; and (3) the expectation of being wealthier in the future (Daly and Farley, 2004). However, discounting for individuals cannot be applied to society and discounting of market goods should not be applied to non-market goods (Daly and Farley, 2004). Therefore, whereas a standard discount rate may be appropriate for build capital stocks, which depreciate with time, it is inappropriate for social, human and natural capital stocks which accumulate value with use rather than depreciate.

In such cases, a social discount rate must be included which "is a rate of conversion of future value to present value that reflects society's collective ethical judgment, as opposed to an individualistic judgment, such as the market rate of interest" (Daly and Farley, 2004). In cases where natural capital in particular is not substitutable and has become the limiting factor to human well-being, a negative discount rate may be most appropriate (Daly and Farley, 2004).

In cases where a positive discount rate is selected, several researchers have proposed alternatives to the typical exponential discounting curves. These alternative functions, logarithmic, hyperbolic or linear more accurately represents personal time rate of preference (PTRP) than exponential discounting because empirical studies suggest that people do discount the near future with the present but that discounting at different times in the distant future does not follow an exponential curve (Daly and Farley, 2004; Sumaila and Walters, 2005; Weitzman, 1998).

3.3. *Built capital*

Estimating built capital losses as a direct result of a disaster may appear to be straightforward in that they tend to be well reported and accounted for in typical disaster accounting (Boswell et al., 1999), although attempts to clearly define all of these costs can become quite convoluted. They include losses to public, commercial, industrial, agricultural and residential infrastructure. Determining a monetary value of these losses is often complicated by discrepancies between insurance estimates of replacement cost and actual costs of rebuilding (Tobin and Montz, 1997), unaccounted for or uninsured losses (Changnon et al., 2000) and estimating market value of properties not restored (Ward, 1978). Furthermore, this ignores inequities and distributional impacts of capital losses (Masozera et al., 2007-this issue).

Private insurer losses from Hurricane Katrina for damaged, destroyed or flooded homes and businesses, and for offshore oil and gas platforms that were damaged, lost or missing and presumed sunk in the Gulf of Mexico, are estimated to be in the range of $40 to $60 billion (King, 2005; 2005 U.S. Dollars). Insured property losses are estimated by the American Insurance Services Group (AISG) to be $38.1 billion (Knabb et al., 2005). Total economic losses, including insured and uninsured property, and flood damages are expected to exceed $200 billion (King, 2005).

Although it has been particularly difficult to gather statistics on the number of homes, businesses and infrastructure represented by these monetary loss estimates, one source does separate insured losses as follows: personal lines, $15.2

to $19.3 billion; commercial lines, $19.7 to $25.3 billion; marine and energy, $4 to $6 billion; liability, $1 to $3 billion; other, up to $1 billion (Insurance Journal, 2005).

One issue that is not typically included in disaster accounting is the value added to built capital in the region due to increased demand for housing, office space and public utilities. This results in a rise in market values at least temporarily due to increased demand resulting from a lack of supply in the disaster zone, and thus often an actual increase in investment to the built capital stock in the region (CNN, September 11, 2005).

Built capital losses can also have impacts beyond the local disaster zone with implications far into the future. For example, The Port of New Orleans traffics 64% of corn, 67% of soybean and 41% of rice exports annually. As of September 7, 2005, the capacity of the port had been reduced to 65% normal capacity (Schnepf and Chite, 2005). The high energy prices sparked by Katrina could lead to significant shifts in agricultural activities throughout the country, in particularly impacting the cost efficiency of producing nitrogen fertilizers which are highly dependent on natural gas (Schnepf and Chite, 2005). These costs should be incorporated into a full-cost accounting. $18 billion dollars has been requested by the Louisiana delegation to rebuild the Port of New Orleans (S. 1765).

Disasters draw on many services provided by built capital. These services are typically provided by built capital beyond the disaster region including transportation, energy and sheltering. Obviously all built capital services are originally derived from natural capital stocks, but these are not included here. As of November 10, 2005, the American Red Cross estimates that 1100 shelters have provided 3.41 million overnight stays for evacuees of Hurricane Katrina (ARC, 2005).

3.4. *Human capital*

In traditional disaster cost accounting, the human toll is often quantified in terms of human lives and represents a direct loss to the human capital stock. The death toll for Hurricane Katrina, as of December 2005, is estimated to be 1383 although uncertainty remains about the true death toll due to thousands of people that remain missing as of December 2005 (Knabb et al., 2005).

In full-cost accounting, we must also quantify depletions to human capital stock that may arise due to reduced capacity of individual output resulting from losses in public health, education or social services. Due to losses in built capital, seventeen universities and college campuses have been closed due to impacts from Hurricane Katrina (Campusrelief.org, 2005). Similarly, in North Carolina, Hurricane Floyd led to students failing to meet state-level standards that would have otherwise been attained (Homes, 2002). Due to Hurricane Katrina, emergency care and hospitals have been destroyed and primary care providers to low income populations have been reduced or eliminated. The National Association of Community Health Centers estimates that over 100 health centers sites have been affected (NACHC, 2005). Other threats to public health include damage to drinking water and sanitation systems, loss of medical and prescription records and lack of adequate care available for disabled and elderly patients with chronic conditions.

Disasters may also lead to a shift in human capital from the disaster zone to other parts of a region or nation, due to the resettlement of people including professionals, families and skilled workers. During Hurricane Katrina, 1.2 million people were under evacuation orders, many of which complied and some of which remain semi-permanently displaced (Knabb et al., 2005). Thus, in conducting a full-cost accounting, it is important to recognize the accumulation of capital stocks that may take place outside the disaster zone. For example, within 2 weeks of Hurricane Katrina many branches of nation-wide businesses were re-established in nearby Lafayette or Baton Rouge, LA. East Baton Rouge grew from 425,000 people to 850,000 people in one week following Hurricane Katrina. A full accounting of both the costs and benefits to communities receiving evacuees for resettlement must also be incorporated into a full analysis.

Losses in human labor due to destruction of businesses and infrastructure are a major cost to human capital flows. The Bureau of Labor Statistics, Mass Layoff Statistics, received 106,547 individual claims resulting from mass layoffs in Mississippi and Louisiana (BLS, 2005). Unemployment in affected areas of Louisiana was 12.4%; however, individual unemployment rates for the most damaged parishes are not available because data collection itself has been hindered by the hurricane. In September 2005, the areas most affected by Hurricanes Katrina and Rita had an unemployment rate 5.3 percentage points above the 4.8% national average (BLS, 2005).

Disasters draw on human capital from outside the local disaster zone in the form of labor required for disaster relief and recovery. While paid labor for recovery and relief is typically captured in disaster accounting, the value of volunteer labor often is not. Clearly the labor of volunteers results in a loss in productive work (paid or otherwise) in other parts of society. In the case of a large disaster, such as Hurricane Katrina, many of the unpaid volunteers who responded to the disaster came from outside the region of the disaster zone thus having at least temporary impacts on the economic productivity of other sectors in other parts of the country. As of November 10, 2005, the American Red Cross estimates that 213,630 volunteers responded to Hurricane Katrina (ARC, 2005). Most were deployed for 2–3 weeks. This value is not considered in most accounting methods.

There is also at least a temporary shift in services from local human capital from pre-disaster labor tasks to post-disaster labor clean up. In terms of total labor, we must also account for the costs to local businesses of missed work by people rebuilding their own private properties.

3.5. *Natural capital*

Agricultural losses are typically the only form of natural capital assessed in typical disaster cost accounting. Direct farm production losses caused by Hurricane Katrina could be $1 billion. They project an additional $1 billion in indirect costs to agriculture, primarily caused by waterway transportation problems and rising fuels costs. For some crops, particularly sugar cane, the extent of losses will not be known until harvest (Schnepf and Chite, 2005). Hurricane Katrina is also blamed for damage to 5.8 billion board meters (19 billion board feet) of timber covering 30% of the affected region (USFS, 2005).

Losses to other natural capital stocks are rarely included in disaster damage assessments even though they can be quite large. A reason for this lack in acknowledgment may be due to the inability to fully capture the scale and interconnectedness of the affected natural capital. For example, it is relatively easy to estimate that 99% of oyster resources were lost during Hurricane Katrina (LDFW, 2005), which represents a $206 million loss. Combined fisheries losses are estimated to be as high as $1.1 billion over the coming year. However, it is more difficult to capture are the indirect effects on natural habitats or the extended costs of these losses into the future. Oysters provide a nursery space for fish to spawn therefore the loss of oysters creates a significant impact on the stock of fish (Costanza et al., 1997). This type of interdependency must be included when assessing damage to natural capital in order to receive a full-cost analysis.

Release of waste during a disaster requires natural capital for assimilation. During Hurricane Katrina, a 250,000 barrel storage tank was dislodged and damaged in flooding, releasing 25,110 barrels of oil. The contamination of polyaromatic hydrocarbons, diesel and arsenic has impacted 1,700 homes in adjacent neighborhoods and several canals (USEPA, 2005b). At least 19.96 million metric tons (22 million short tons) of debris is being disposed of in regional landfills from coastal Louisiana parishes alone (LDEQ 2005). The U.S. EPA and Louisiana Department of Environmental Quality have collected over one million pounds of household hazardous waste. Damage to offshore oil infrastructure has led to several million gallons of spilled oil scattered throughout southeastern Louisiana (Knabb et al., 2005). As mentioned earlier, the affect of this waste is difficult to measure but should be considered in a full-cost damage assessment.

It is important to note that losses to natural capital may be accentuated by previous perturbations to natural systems, placing such losses at the intersection of natural disasters and human induced vulnerability. For example, Hurricane Katrina itself would not have led to contamination of water bodies and fish stocks with metals and organics. Rather these aquatic systems were made more vulnerable due to their proximity to 26 superfund sites in the path of Hurricane Katrina (http://www.epa.gov/katrina/superfund.html). More importantly, some may argue that Hurricane Katrina would not have damaged New Orleans' four capitals to the extent that it did if it was not for the ongoing human induced deterioration of the wetlands, which provide crucial ecosystem service, such as flood protection and hurricane buffering (Coast 2050).

Losses to natural capital often extend far into the future and beyond the localized disaster zones. This longevity only exacerbates the difficulty of assessing loss because of the inability to fully understand how natural capital socks will be affected in the future and to what extent. For example, there is no effective way to measure how fish stocks will continuously be damaged due to potentially long lasting toxins in the water. Major beach erosion has occurred along the coasts of Mississippi and Alabama, the economies of which are highly dependent on coastal tourism (Knabb et al., 2005). Without beach restoration, this impact may have economic consequences far into the future.

3.6. *Social capital*

Social capital is embodied in the web of relations among people living in particular spatiotemporal contexts such as a town, a nation or an Internet-based virtual community. Social capital has been classified into three major categories: bridging, bonding and linking (Putnam, 2000; Pelling, 2003). Bridging social capital is inclusive and outward looking (e.g. the environmental movement); bonding social capital is exclusive and inward looking (e.g. garden clubs). While bridging capital is constituted horizontally among peers, linking capital refers to the vertical relationships between organizations of different scales such as the link between neighborhood groups and the federal government through community development block grants (Pelling, 2003).

Of particular interest to cost accounting of coastal disasters is social capital's simultaneously private and public nature (Putnam, 2000). Social capital is a private good insofar as certain benefits, for example belonging to a fraternal organization, are only accrued by members of the organization. However, once an organization is established, there is the potential for positive externalities to those outside the group, in the form of extended trust or charitable activities. Assessing the costs associated with the loss of these public goods due to disaster is exacerbated insofar as these public goods are non-rival and non-excludable. How much is one willing to pay for being able to trust that their neighbor will not steal their porch furniture, let alone can be trusted to watch one's children so that they can attend a job interview?

Disasters do not directly result in the loss of social capital. As an emergent feature of the intersection of natural, human and built capital, social capital will suffer whenever any of these underlying stocks is diminished. These losses are as varied as are the relationships between the three primary capitals that give rise to social capital. The physical forces of disasters cause death and injury to people. When the life support funds and services provided by natural and built capitals are hampered, people die or survive in a state of lower prosperity. Taken in sum, distressed people living in distressed places will yield less social capital.

Thus, recovery of social capital is partly dependent on the recovery of natural, human and built capital. However, given that social capital (uniquely among the more concrete forms of capital) grows through use and considering the many social transactions that occur during disaster response and recovery, there is the potential for immediate, albeit short-term, increases to social capital in the midst of disasters. Above all, recovery from disasters entails some degree of social reorganization—both short and long term. This reorganization can result in a loss of social capital in some sectors, but it can also provide opportunities for the improvement and formation of social capital in others.

Losses to social capital, damaging as they are to everyday quality of life, can hinder disaster recovery at the community as well as the individual level. At the individual level, recovery entails overcoming psychological and emotional responses including anxiety, depression and grief. Social support networks play a key role in overcoming these disaster effects (Lindell and Prater, 2003). When social networks are degraded or destroyed due to displacement, psychological and emotional problems are more likely to go unchecked making personal recovery more difficult (e.g. hampering job search). Additionally, the effects of these problems may cascade beyond the individual or family causing secondary damage to social structures. In the case of

Hurricanes Katrina, the increase in unemployment brought on in the immediate aftermath of the storm (BLS, 2006) had costs borne directly by those out of work (e.g. loss of wages, loss of workplace social relationships) and may degrade the stock of social capital in the community at-large in the form of mutual support and trust.

As already mentioned, social capital can see losses as well as gains in the immediate aftermath of disasters. The devastation of losing one's family members, friends, home and neighborhood and their concomitant social ties results in a great loss of bonding social capital. However, bridging and linking social capital may, if only temporarily, grow in the face of effective disaster relief (Pelling, 2003). This may happen when public safety, aid organizations (governmental and non-governmental) and volunteers – all of which are likely to be outsiders in the case of large-scale disasters – are able to respond promptly to fairly administer adequate aid to save and begin rebuilding lives. Fellow feeling may be increased; trust networks may be established and extended to groups outside of pre-disaster social networks (Putnam, 2000). High levels of linking social capital imply that trust exists between one or more vertical groups. This trust contributes to cooperation between groups—cooperation critical to disaster response (Pelling, 2003). Uncoordinated, inequitable and insufficient disaster relief is likely to decrease trust and degrade both linking and bridging social capital thus increasing the potential for inter-group animosity and degrading bonding social capital (Putnam, 2000).

Second-order costs of disasters on social capital arise from the opportunity costs of recovery. Funds dedicated to disaster recovery (e.g. clean-up, rebuilding, prevention) are funds that will not be spent to address problems that existed before the disaster (Table 2). Some pre-disaster problems may be addressed through recovery spending (e.g. aging infrastructure). However, it is unclear that problems correlated to social capital deficiencies (e.g. education performance, violent crime) will be ameliorated by the often-harried application of disaster relief funds (Putnam, 2000). Worse still, the degradation of social capital directly caused by the disaster is likely to make these problems grow.

The reorganization of social networks brought on by disasters may open opportunities for new interactions within social systems as well as between social and politico-economic systems (Pelling, 2003). Traditionally marginalized groups may be able to improve their lot. For example on-going inequalities may be exposed through the heightened visibility of marginalized peoples during disaster coverage in the media (e.g. the plight of poor residents of New Orleans during Katrina). However, pre-existing power hierarchies may be consolidated, resulting in post-disaster social structures that continue past patterns of unjust distribution (Farley et al., 2007-this issue).

3.7. *Interconnected costs*

Many relief services provided during a disaster result from a combination of natural, human, social and built capital. Many of these interconnections are discussed in previous sections, and we acknowledge that accounting for the indirect effects of a disaster as they ripple through each of the capitals is difficult to quantify in a full-cost accounting exercise. As an example, the loss of a school building (built capital) may result in underutilization of the human capital imbedded in the teacher's knowledge thus resulting in reduced social and human capital that would have otherwise resulted from the education of students in the building. Other examples are the raw materials for food, clothing, energy and clean water. All of these come from natural capital, whereas the delivery of these services requires services from built capital (transportation and machinery), human capital (labor) and social capital (donations and willingness to volunteer).

4. Policy implications

Full-cost accounting of disasters is a difficult task requiring considerable commitment, funding and data. However, it could have several important policy implications, which justify such efforts. First, a close examination of the full costs of coastal disasters should encourage decision makers to proactively restore natural and built capital in order to mitigate impacts as well as more efficient and effective disaster plans. Second, the rising cost of coastal disasters argues for national level planning aimed at moving populations from vulnerable parts of the coast to inland areas where populations are currently decreasing (Mitchell, 2004). Finally, in the rebuilding following a disaster, a full-cost accounting of all capital losses will guide decisions as to how to rebuild a community with the optimal levels of each of the four capitals, including those that are currently underinvested. Political barriers to implementing a full-cost accounting into decisions are discussed by Bagstad et al. (2007-this issue).

4.1. *Coastal disaster planning*

The environmental hazards endemic to coastal areas are exacerbated by anthropogenic local and global environmental change (Intralawan et al., 2007-this issue). Beach erosion (due to coastal development), wetland loss (due to development and natural as well as mineral extraction-based subsidence) combined with rising sea levels and increased sea surface temperatures create more powerful storms (Webster et al., 2005) whose storm surges are less dampened by diminishing natural buffers (e.g. wetlands, barrier islands and mangrove forests).

A full-cost accounting is an important consideration in terms of planning and preparing for disaster. Investment in all four forms of capital is required to prepare a community for disaster. Godschalk et al. (1999) outline four components of natural disaster mitigation that are important to building communities resilient to natural disasters including resilient life-line infrastructure such as roads and utilities (built capital), locating public safety centers in safe areas (human capital), ensuring that natural environmental defenses including dunes and wetlands are protected (natural capital) and community development (social capital).

Failure to account for the true costs of a disaster, and thus the risk associated with such a possibility, may lead to poor decisions about where to invest local and federal funds. For example, it was deemed too expensive to restore the coastal wetlands in the Gulf Coast. At an estimated cost of $14 billion (LCWCRTF, 1998), investment in this form of natural capital could have led to significant savings in built, human, natural and social capital losses resulting from Hurricane Katrina. The storm surge produced by Katrina was as high as 8 m (27 feet) at Hancock, Mississippi, and penetrated 9.66 km (six miles) inland. Precise storm surge estimates in Louisiana are not available, although storm surge was significant enough to cause the rise in Lake Pontchatrain that ultimately resulted in levee breeches and overtopped floodwalls (Knabb et al., 2005). Each 4.8–6.4 km (3–4 miles) of wetland would have reduced the storm surge by 0.3 m (one foot), thus reducing the impact on the city of New Orleans and other coastal communities (U.S. ACOE, personal communication, 2005). In the past century, over 400,000 hectares (one million acres) of coastal wetlands of Louisiana have been lost (LCWCRTF, 1998), reducing the coastline by dozens of kilometers. Clearly, this investment would have been worthwhile considering the high costs of Hurricane Katrina. Likewise, investment in improving the levee system in New Orleans would have similarly resulted in significantly fewer losses to capital following Hurricane Katrina. There is some evidence that renewed attention to disaster preparation in other parts of the country is already taking place (Murphy, 2005).

4.2. *Investment in capital stocks during disaster recovery*

During disaster recovery, decisions as to how much to invest in each of the four capitals should be based on a full-cost accounting in order to appropriately decide what the 'optimal' levels of investment are in order to maximize human well-being in the future. Without full-cost accounting, some stocks may be under measured and thus receive little investment during recovery.

For example, damage costs calculated by typical cost accounting are estimated to be $200 billion for Hurricane Katrina (of which $100 billion is estimated to come from the federal government), but these represent primarily costs for labor recovery and built capital reconstruction (King, 2005). However, the 'Blue Print for Rebuilding' after Hurricane Katrina, proposed by the Louisiana Delegation asks for an estimated $250 billion from the federal government alone and reflects many of the other losses not directly quantified in damage assessments including losses to natural, human and social capital (S. 1765). This bill is controversial and does include a number of non-hurricane related costs; however, Tables 1 and 2 indicate that the costs accounted for in typical cost accounting ignore significant costs that should be addressed by society during recovery.

Life cycle assessment, a type of full-cost accounting, should be used when comparing alternative rebuilding strategies in order to select a cost-minimizing mix of solutions (Curran, 2002) to address disaster vulnerability and rebuild more sustainable communities (Dickinson et al., 2007). For example, knowing the full life-cycle costs of levee construction, maintenance and operation (where up-front costs may be lower than long-term) as well as those for wetland rehabilitation (where up-front costs are relatively much higher than long term costs if the rehabilitation is successful in restoring a self-sustaining "natural" system) will allow for the development of an integrated storm surge protection system. Such an integrated system can maximize protection capabilities while minimizing costs by selecting optimal amounts of levee and wetland investment.

4.3. *National demographic policy*

People choose to live near coastal areas because of economic opportunities and the quality of life offered by coastal amenities. Perhaps as much as 25% of global primary productivity is accounted for by the 8% of global surface area defined as the coastal zone (Martinez and Intralawan, 2007-this issue). Additionally, coastal populations have increased due to urbanization (Turner et al., 1996). However, there are many environmental hazards associated with living in coastal regions including rainfall, storm surge, wind, saltwater infiltration and toxic algal blooms (Davidson and Lambert, 2001; Turner et al., 1996).

Over 25% of the U.S. population resides in coastal counties, with migration to the coast increasing every year. Increases in coastal populations, combined with increased hurricane intensity suggest that costs from coastal disasters are likely to continue to rise. The migration to the coast in the past half century is coupled by negative population growth in much of the heartland, great plain, counties (U.S. Census Bureau, 2000). Full-cost accounting may lead us to reassess appropriate concentrations of people on the coast and develop incentives discouraging population and infrastructure growth along the coast and encouraging repopulation of rural counties in the Great Plain states, many of which have a negative population growth, but supply over half of the nations wheat and beef (Mitchell, 2004). Incentives may emerge on their own if energy prices increase significantly. The current practice of industrial agriculture may give way to more traditional, and labor intensive, practices that coincidentally have lower impact on natural systems. In the meantime, the subsidies, often perverse and conflicting, to coastal development and rebuilding in vulnerable locations should be reconsidered (Bagstad et al., 2007-this issue). More starkly, Farley et al. (2007-this issue) make the case for considering a strategic withdrawal, "redraw[ing] the map of Louisiana," in the face of the argued impossibility of restoring lost wetlands.

5. Conclusions

We have found that a solid methodology for conducting full-cost accounting for disasters is not well described in the ecological economics literature. We propose an initial framework to conduct such an exercise based on losses to built, human, natural and social capital stocks and services provided from each during disaster relief and recovery. Although data regarding most of these capitals are generally available, only losses to built capital and paid recovery efforts are included in typical disaster cost accounting. Full-cost accounting requires careful analysis of intangible, pecuniary and indirect effects and close attention to spatial and temporal scale.

A full-cost accounting of coastal disasters could inform local and national policy in three important ways. First, examination of the full-costs of coastal disasters demands a more proactive approach to disaster mitigation through investment in natural capital (coastal wetlands) and built capital (strong infrastructure) as well as better disaster preparedness achieved through community development (social capital) and disaster planning (human capital). Second, we argue that current policies that encourages settlement in vulnerable parts of the coast should be replaced with policies that provide incentives to repopulate the interior of the country, much of which is currently experiencing negative population growth. Finally, and perhaps most importantly, a full-cost accounting is required in order to made appropriate decisions about the optimal investment during recovery in built, human, natural and social capital.

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